A47/A11 Thickthorn Junction

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6.3 Environmental Statement Appendices
Appendix 13.1 – Flood Risk Assessment

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ENVIRONMENTAL STATEMENT APPENDICES
Appendix 13.1 – Flood Risk Assessment

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1. Executive summary

1.1.1. This Flood Risk Assessment (FRA) is a requirement of the National Planning Policy Framework (NPPF) and the National Policy Statement for National Networks (NPS NN). The FRA informs the environmental assessment presented in ES Chapter 13 (road drainage and water environment **(TR010037/APP/6.1)**) for the Proposed Scheme at the A47/A11 Thickthorn Junction (which is referred herein as the 'Proposed Scheme'). This report investigates all potential flood mechanisms relevant to the Proposed Scheme in accordance with the NPPF.

1.1.2. Consultation with the Environment Agency and Norfolk County Council was undertaken in 2018, 2020 and 2021 as part of this assessment and is ongoing.

1.1.3. The Environment Agency's historic flood map (Environment Agency, 2020c) does not indicate any areas of previous flooding within the area of the Proposed Scheme. Norfolk County Council Highways team confirmed that there has been no flooding on County road approaches to the roundabout; however, there has been flooding on the A47 / A11 Thickthorn Junction itself.

1.1.4. The Environment Agency's flood map for planning and the Greater Norwich Strategic Flood Risk Assessment identifies the majority of the Proposed Scheme lies within Flood Zone 1. There are areas identified within Flood Zones 2, 3a and the indicative extent of Flood Zone 3b. These areas are associated with Cantley Stream and its floodplain.

1.1.5. A detailed hydraulic modelling assessment of Cantley Stream predicted flooding for the 100-year event upstream of the A11 and throughout the Cantley Stream floodplain around Cantley Lane South and the A47. The model predicts the existing Cantley Lane South culvert to surcharge during the 100-year event causing out of bank flooding and flooding to Cantley Lane South. Under the existing scenario, out of bank flow is predicted to overtop Intwood Road near the downstream extent of the model and flooding of a residential receptor adjacent and upstream of Intwood Road was also predicted. Climate change impacts increase the predicted flood depths. The Proposed Scheme is considered to be at high risk of fluvial flooding.

1.1.6. The Environment Agency's flood risk from surface water map indicates that most of the Proposed Scheme is at very low risk from surface water flooding. The Proposed Scheme intercepts surface water flood flow pathways and as such is considered to be at high risk of surface water flooding. Hydraulic modelling was carried out, with an allowance for climate change, to assess the existing surface water flood risk on local receptors to Cantley Stream and north of the proposed new Cantley Lane link road. The model predicts the receptors are currently at risk of surface water flooding to a depth of 0.3m where depths do not pass the estimated doorstep threshold.

1.1.7. The BGS groundwater flooding susceptibility maps show the majority of the Proposed Scheme area has limited potential for groundwater flooding to occur. There are areas of potential for groundwater flooding associated with Cantley Stream. There are no historical records of groundwater flooding within the vicinity of the Proposed Scheme but findings from the ground investigation suggest that groundwater flooding is a potential risk in the vicinity of Cantley Stream.

1.1.8. The Proposed Scheme is at low risk of flooding from water, sewerage and highway infrastructure failure. The Proposed Scheme is not at risk of flooding from canals, reservoir failure or tidal sources.

1.1.9. The removal of the throttle at the Cantley Lane South culvert, extension of the A11 culvert and Cantley Lane stream realignment have the potential to displace fluvial flood waters which may in turn increase flood risk to others. The Proposed Scheme is predicted to increase flood depths at a residential receptor adjacent to Intwood Road and property level protection is proposed as mitigation. Confirmation of the impact at the property near Intwood Road and, therefore the required mitigation, is subject to additional survey and modelling to better predict the impacts in this location. No other 'more vulnerable' receptors are affected by the Proposed Scheme. There are also changes to the patterns of fluvial flood risk within the Cantley Stream floodplain, with predicted increases and decreases in flood depth depending on the location. The removal of the existing Cantley Lane south culvert removes the throttle to flood flows, reducing flood depths immediately upstream and changing the pattern of flood risk downstream (along with the stream realignment). The differences in flood depths affect agricultural (pasture) land and areas of amenity use which are classed as 'less vulnerable' and 'water-compatible' under the NPPF flood risk vulnerability classification.

1.1.10. The proposed drainage system must discharge at greenfield runoff rates and provide sufficient attenuation for the 100-year plus 40% climate change rainfall event. The proposed drainage design will use a combination of surface water channels, kerb and gullies and combined surface water drainage systems. The proposed SuDS features included within the drainage design include, vegetated detention basins, filter drains and grassed ditches. Runoff from existing drainage areas will either remain as existing or reduce. Discharge from the proposed drainage system to Cantley Stream will have negligible impacts on flood risk at Cantley Stream and on freeboard at the new Cantley Lane South culvert.

1.1.11. Natural drainage will be managed by a combination of carrier drains and pre-earthworks drainage which will be conveyed to outfall to Cantley Stream. Where the Proposed Scheme intercepts surface water flood flow pathways, pre-earthworks drains, cross drains or 'dry culverts' conveying natural catchment drainage / overland flood flow pathways must be designed to accommodate a 1 in 100-year storm event including a 40% climate change allowance to mitigate impacts to the Proposed Scheme and to others. The exact location and sizing of the cross drains shall be confirmed at detailed design once a detailed local topographic survey has been undertaken.

1.1.12. It is considered that the Proposed Scheme will not result in additional fluvial or surface water flood risk.

1.1.13. There is potential the Proposed Scheme could intercept the Chalk aquifer during construction of the A11-A47 connector road. A pumped solution is necessary as a gravity outfall cannot be achieved. Any groundwater ingress to this area is managed by the proposed drainage which would convey the groundwater drainage to a pumping station where it would be pumped to a detention basin. The magnitude of the groundwater ingress would be informed by the supplementary ground investigation which is to commence in March 2021. Where possible, below ground structure design including piling shall ensure there is no barrier to groundwater flow which may cause groundwater mounding.

1.1.14. Potential impacts on flood risk during construction will be mitigated by the implementation of appropriate temporary drainage measures which will be outlined in temporary works drainage strategy and implemented through the EMP (**TR010037/APP/7.4**). The construction of the structures within the Cantley Stream floodplain must be constructed in a phased manner to avoid additional flood risk, over and above that stated for the operational Proposed Scheme.

1.1.15. Residual risk from the blockage of the proposed Cantley Lane South culvert, exceedance of the proposed drainage design and groundwater flooding is considered to be low.

1.1.16. This FRA has considered the risk to the Proposed Scheme and the risk posed by the Proposed Scheme on flooding from all sources. With mitigation as part of the Proposed Scheme will be safe for its lifetime and will not cause any increase in surface water and groundwater flood risk elsewhere. The Proposed Scheme will not increase fluvial flood risk, with mitigation, to 'more vulnerable' receptors. There are changes to the patterns of flood risk resulting from the removal of the existing Cantley Lane South culvert throttle and the stream realignment to downstream farm land and amenity areas. However, the development is considered appropriate under the requirements of the NPPF and NPS NN.

2. Introduction

2.1. Scope of works

Aims and objectives

2.1.1. This appendix supports the environmental assessment presented in ES Chapter 13 Road drainage and water environment (**TR010040/APP/6.1**).

2.1.2. 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
- mitigation measures required

Methodology

2.1.3. The FRA has been completed in accordance with the current guidance contained in the National Planning Policy Framework (NPPF) (MHCLG, 2019) and the supporting online Planning Practice Guidance (PPG) for Flood Risk and Coastal Change (MHCLG, 2016). The assessment has been undertaken in accordance with Highways England's technical guidance provided in Design Manual for Roads and Bridges (DMRB) LA113 Road Drainage and the Water Environment, revision 1 (Highways England, 2019a), hereafter referred to as DMRB LA113.

2.1.4. 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.

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

Data sources

- The online NPPF and supporting PPG (MHCLG, 2019; 2016)
- Environment Agency Flood Map for Planning (Environment Agency, 2020a), Surface Water, Reservoir, River and Tidal Flood Risk (Environment Agency, 2020b)
- Historic Flood Map (Environment Agency, 2020c)
- A47/A11 Thickthorn Junction Drainage Strategy Report- HE551492-GTY-HDG-000-RP-CD-30003 (Appendix 13.2) (**TR010037/APP/6.3**)
- Environmental Scoping Report (Highways England, 2018) (**TR010037/APP/6.5**)

- British Geological Survey's GeoIndex (British Geological Survey, 2020)
- 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)
  - Norwich Local Area Surface Water Management Plan (SWMP) Norfolk County Council (2011b)
  - Norfolk Local Flood Risk Management Strategy (LFRMS) Norfolk County Council (2015)
  - Greater Norwich Area Strategic Flood Risk Assessment (SFRA) (JBA, 2017)

3. Legislative, policy framework and climate change

3.1. National Policy Statement for National Networks

3.1.1. The National Policy Statement for National Networks (NPS NN) (Department for Transport, 2014), 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. The National Planning Policy Framework

3.2.1. The NPPF (Ministry of Housing, Communities and Local Government, 2019) and associated PPG (Ministry of Housing, Communities and Local Government, 2016) 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.

3.2.3. In addition, 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.

3.2.4. 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

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

3.2.6. 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.

3.2.7. 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 1 in 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.

3.2.8. Depending upon the NPPF classification of the proposed development vulnerability to flooding 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.

3.3. Local planning policy

3.3.1. 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. Development should be located to minimise flood risk and mitigate any such risk through design and the implementation of sustainable drainage. Development should minimise water use and protect groundwater sources.
- South Norfolk Local Plan Development Management Policies Document (DPD) (South Norfolk Council, 2015), contains the following policies relevant to flood risk:

- Policy DM 4.2 Sustainable drainage and water management. Sustainable drainage measures must be fully integrated within design to manage any surface water arising from development proposals, and to minimise the risk of flooding on the development site and in the surrounding area. All developments:
  - should include a sewerage capacity assessment
  - should include drainage features that will slow the movement of water through the drainage system
  - must not cause any deterioration in water quality and measures to treat surface water runoff must be included within the design of the drainage system

3.3.2. Norfolk County Council also provide guidance to developers on their role as Lead Local Flood Authority (Norfolk County Council, 2020)

3.4. Climate change

3.4.1. 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."*

3.4.2. 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."

3.4.3. 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 proposal, it is considered appropriate to class the Proposed Scheme as "essential infrastructure". It is considered that the lifetime of the development for the purposes of the flood risk assessment is 100 years.

3.4.4. Although the majority of the Scheme is located within Flood Zone 1 it does pass through areas of 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%. 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.

3.4.5. The PPG climate change allowance guidance (Environment Agency, 2020d) also states that Nationally Significant Infrastructure Projects should consider applying the H++ allowances for high impact climate change allowances. The relevant allowance for the Proposed Scheme would be 80% on peak river flows.

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. It plays a key role in the delivery of goods from the A1 into East Anglia. The A11 is a trunk road that runs from Norwich to London and crosses the A47 at A47/A11 Thickthorn Junction.

4.1.2. A47/A11 Thickthorn Junction is located approximately 6km to the southwest of Norwich. The existing junction comprises of five exits: A47 northbound and southbound, A11 eastbound and westbound, and the B1172 Norwich Road.

4.1.3. The land immediately to the northeast, southeast, and southwest quadrants of the existing A47/A11 Thickthorn Junction is currently predominantly agricultural land, although some parcels of land to the northeast and southeast have the benefit of planning permission for housing developments. The land in the northwest quadrant accommodates Thickthorn Park and Ride and Thickthorn Services comprising a hotel, a restaurant, an electricity substation and a petrol filling station.

4.1.4. There are several residential properties located to the northwest of the junction on the B1172 Norwich Road, and to the northeast along the Old Newmarket Road. The Cringleford residential area is located less than 500m to the north and east of the existing junction.

4.2. Existing drainage

4.2.1. The Highways Agency Drainage Data Management System (HA DDMS) (Highways England, 2020a) provides details on the existing drainage network which is summarised below:

- The catchment draining the south west of the Proposed Scheme which discharges runoff from the A11 south of Cantley Stream, is drained via a cluster of three outfalls currently classified as low pollution risk according to HA DDMS (2020b).
- The catchment draining the A11 north of Cantley Stream and A47 / A11 Thickthorn Junction is drained via a cluster of nine outfalls currently classified as low pollution risk.
- The catchment draining the south east of the Proposed Scheme discharges runoff from the A47 to Cantley Stream. It is drained via a cluster of 13 outfalls currently classified as low pollution risk.

- HA DDMS also identified 19 soakaways all currently classified as low pollution risk within the study area, these receive runoff from the A47 / A11 Thickthorn Junction and the A47 between the junction and Cantley Stream.

4.2.2. The location of these are given in ES Figure 13.5 (Groundwater abstractions, discharges, and source protection zones) **(TR010037/APP/6.2)** and in ES Figure 13.6 (Surface water flood risk) **(TR010037/APP/6.2)**.

4.2.3. The low pollution risk from the existing outfalls and soakaways identified within the Proposed Scheme DCO boundary indicates there is no existing pollution risk (this assumes road runoff from the total existing drainage area to a single cumulative outfall to Cantley Stream at the A11 and A47 crossing).

4.2.4. All of the outfalls identified appear to discharge to Cantley Stream. The existing drainage network, including the outfalls and soakaways identified above, require verification through additional drainage survey after a recent drainage survey was unable to identify the locations of the outfalls and soakaways.

4.2.5. A number of catchpits were identified on HA DDMS across the Proposed Scheme, within the DCO boundary. No other surface water outfalls, soakaways or attenuation features were identified within the Proposed Scheme area. Furthermore, HA DDMS did not indicate the presence of any additional pollution control devices or oil / petrol interceptors within the Proposed Scheme.

4.2.6. The Proposed Scheme lies within a partly urbanised catchment, particularly to the east of the A47 where surface water drainage is governed by local authority (Norfolk County Council) highways drainage and Anglian Water's sewerage drainage network. Subject to the outcome of additional drainage survey, the Proposed Scheme drainage does not appear to connect to the local network.

4.3. Description of the Proposed Scheme

4.3.1. The Proposed Scheme comprises one new 1.65km long free-flowing slip road that will connect the A11 with the A47. The new slip road will re-route traffic away from the existing Thickthorn Junction and divert it under new underpasses. There will be changes to the Thickthorn roundabout such as providing additional lanes for traffic, and improvements will be made to traffic signals and pedestrian crossings within the vicinity. In addition, a new 0.95km link road between Cantley Lane South and the B1172 Norwich Road will be constructed to allow continued access to the Thickthorn Junction.

4.3.2. One 1.65km connector road will be constructed between the A11 eastbound to A47 eastbound, directing traffic away from Thickthorn Junction. Once travellers have left the main A11 eastbound carriageway, the connector road will allow travellers to merge to the A47 eastbound without the need to stop.

4.3.3. The A11-A47 connector road will include provision of a maintenance layby and require the construction of two new underpasses and two new overbridges.

4.3.4. The new link road between Cantley Lane South and the B1172 Norwich Road will be constructed on embankment at the Cantley Lane South end adjacent to Cantley Stream. This embankment encroaches on the existing Flood Zones (2 and 3) associated with Cantley Stream as confirmed by Environment Agency maps and site-specific modelling carried out as part of this assessment (see Section 5).

4.4. Summary of consultation

4.4.1. The Environment Agency, Anglian Water and Norfolk County Council responded to the EIA Scoping Report (Highways England, 2018) via the Planning Inspectorate. The responses relevant to flood risk which were documented in the Scoping Opinion (Planning Inspectorate, 2018) (**TR010037/APP/6.6**) are summarised below:

- Acknowledgment and reference to the Greater Norwich Area Strategic Flood Risk Assessment; Final Report: Level 1 must be made
- A full assessment of groundwater flood risk is necessary with a consideration of climate change and any necessary mitigation
- There are existing water mains and foul sewers in Anglian Water's ownership within the boundary of the site that could potentially be affected by the development. The Environmental Statement should make reference to existing water mains and foul sewers in Anglian Water's ownership.
- Any improvements to the Cantley Lane or connection to Roundhouse Roundabout must consider the recent flooding and improvements to highways drainage proposed, where possible.
- All watercourses, including tributaries, be included within any hydraulic model, to ensure that flood risk is not increased
- Mitigation, through the form of 'dry culverts' must be provided to maintain continuity of any surface water flooding flow paths that may be interrupted by the Proposed Scheme
- Any new hydraulic structures, including 'dry culverts', must be designed to convey flows during a 1 in 100-year event including an allowance for future climate change
- Drainage mitigation should provide sufficient attenuation for a 1 in 100-year event including an allowance for future climate change
- Any works in or near to ordinary watercourses would require consent from the LLFA

4.4.2. A meeting was held with the Environment Agency and Norfolk County Council to discuss the flood risk aspects of the Proposed Scheme in May 2018. Two follow up combined meetings with both the Environment Agency and Norfolk County Council took place in August 2020 and November 2020. The key points from these meetings are summarised below:

- Agreement that the proposed new larger culvert beneath Cantley Lane removes the throttling effect on flows / levels and, due to the negligible changes in downstream flood risk, removes the requirement to provide any compensatory flood storage
- Discussions and agreement on the proposed layout and gradient of the realigned section of Cantley Stream
- Discussions on the proposed culvert design and minimum level of freeboard required. A requirement for freeboard of 600mm above the 1 in 100 year plus 65% flood level was initially agreed.
- Discussions on the requirement to provide suitable habitat in the realigned section for water voles and for the provision of mammal passage through the culvert.

4.4.3. Given the various constraints on the proposed stream realignment and culvert, namely flood risk, habitat for water voles, vertical road levels and tie-ins, agreement was sought for a reduced level of freeboard at the Cantley Lane South culvert. A technical note summarising the proposed freeboard was provided to Norfolk County Council in January 2021. A copy of this note is provided in Annex A. Norfolk County Council has accepted the proposal for a reduced freeboard given the constraints.

4.4.4. The Environment Agency and Norfolk County Council were provided with baseline flood modelling information for technical review and comment in June 2020. The outcomes of this review were addressed as part of the subsequent modelling of the Proposed Scheme. The updated modelling information (including modelling of the Proposed Scheme) was provided to the Environment Agency for additional review in January 2021. Comments on the updated modelling information were provided by the Environment Agency in March 2021 and these are currently being addressed.

4.4.5. The Norfolk Rivers Internal Drainage Board (IDB) were consulted on the Proposed Scheme in May 2018 and January 2021. The IDB confirmed that no consent would be required for the Proposed Scheme but requested that any surface water flow is discharged in accordance with the non-statutory technical standards for sustainable drainage systems (DEFRA, 2015), particularly Sections 2 and 4 of the standards.

4.4.6. This Flood Risk Assessment has been issued to the Environment Agency and Norfolk County Council for comment.

4.5. Existing hydrology and hydrogeology

Hydrology

4.5.1. Cantley Stream, an ordinary watercourse, flows beneath both the A11 and A47 in an easterly direction where it joins Intwood Stream. Intwood Stream is an Environment Agency designated main river which is located approximately 0.9km from the Proposed Scheme.

4.5.2. Two ponds are located between the A11 and A47 on the north bank of Cantley Stream. These lie outside of the DCO boundary; however, they are located within Cantley Stream floodplain.

4.5.3. The Proposed Scheme is not within an area that benefits from flood defences.

Hydrogeology

4.5.4. The geology of the area can be an important influencing factor on the way the water runs off the ground surface causing adverse flood risk affects elsewhere. This is largely due to variations of hydraulic properties in the superficial (permeable, unconsolidated deposits) and bedrock (solid permeable) aquifers. The Environment Agency classifies these as follows:

- Principal: layers of rock or drift deposits with high permeability which, therefore, provide a high level of water storage
- Secondary A: rock layers or drift deposits capable of supporting water supplies at a local level and, in some cases, forming an important source of base flow to rivers
- Secondary B: lower permeability layers of rock or drift deposits which may store and yield limited amounts of groundwater
- Secondary undifferentiated: rock types where it is not possible to attribute either category a or b
- Unproductive Strata: rock layers and drift deposits with low permeability and therefore have negligible significance for water supply or river base flow.

4.5.5. The superficial geology mainly comprises Lowestoft Formation (Diamicton), classified as a Secondary (Undifferentiated) aquifer. The Sheringham Cliffs Formation Sand and Gravels and Alluvium superficial deposits are also present and are classified as Secondary A aquifers.

4.5.6. The Sheringham Cliffs Formation Sand and Gravel is overlain by the Lowestoft Formation (Diamicton) across the majority of the Proposed Scheme. The Sheringham Cliffs Formation outcrop in the southern half of the site where the ground falls towards Cantley Stream.

4.5.7. The bedrock geology underlying the superficial geology comprises undifferentiated formations within the White Chalk Subgroup, a Principal Aquifer. This aquifer has a Major Aquifer Intermediate vulnerability classification. This means the overlying superficial deposits provide some protection but there is still the potential for leaching to groundwater. The Chalk is present under the Proposed Scheme at an elevation of approximately 18mAOD (14mbgl).

4.5.8. The groundwater levels within the Proposed Scheme area are driven by the Chalk. Groundwater monitoring from the 2018 ground investigation has shown that the Chalk has a groundwater level range of 12 to 16mAOD or (20 to 0.05mBGL) in BH26_P1 and BH33 respectively (Figure 13.8 (Ground investigation boreholes) (**TR010037/APP/6.3**), and is occasionally sub-artesian (recorded in overlying permeable superficial deposits of the Sheringham Cliffs Formation), indicating a degree of hydraulic continuity between the units. The chalk groundwater levels are close to surface adjacent to Cantley Stream, indicating a component of baseflow to the stream from the Chalk aquifer.

4.5.9. The Lowestoft Formation is impermeable and semi-confines the underlying Sheringham Cliffs Formation and the Chalk. Monitoring has shown the Lowestoft Formation is dry within the Proposed Scheme area.

4.5.10. Groundwater monitoring from the 2018 ground investigation has shown that groundwater flow within the Sheringham Cliffs Formation and the Chalk is predominantly towards the south and Cantley Stream.

4.5.11. The Proposed Scheme is within a groundwater Nitrate Vulnerable Zone (NVZ) where directly underlain by Sheringham Cliffs Formation Sand and Gravels superficial deposits.

4.5.12. The Proposed Scheme is within a source protection zone (SPZ) 3 (Total Catchment) associated with groundwater abstractions for public water supply in Norwich, 5km to the east and 2.5km to the north.

4.5.13. Further details of the hydrogeology of the study area are contained in of the ES Chapter 13 (Road drainage and water environment) (**TR010037/APP/6.1**) and in Appendix 13.3 Groundwater assessment (**TR010037/APP/6.3**).

5. Sources of potential flooding

5.1. Overview

5.1.1. Existing sources of flood risk affecting the Proposed Scheme have been assessed and any potential impacts arising from the development have been evaluated. This process has utilised existing flood information and recommends mitigation strategies where required. Flooding in the area of the Proposed Scheme may arise from the following sources:

- fluvial (rivers)
- pluvial (surface water)
- infrastructure failure including sewerage, highway drainage and water mains
- groundwater

5.1.2. The Proposed Scheme is not presently at risk of flooding from canals, reservoir failure or tidal sources and therefore this has not been considered in the assessment.

5.2. Historical flooding

5.2.1. The Greater Norwich SFRA (JBA, 2017) provides details on a number of flood events known to have affected the Greater Norwich area between 1273 and 2017. Coastal flooding events affected the Yare and Bure catchments in 1608, 1897, 1953, 1976, 1981, 1983, 1993, 2007 and 2013. A rainfall and snowmelt flood occurred in 1878. A number of these floods resulted in fatalities and damage to hundreds or thousands of properties.

5.2.2. A 1 in 1000-year rainfall event in 1968 caused fluvial flooding which affected the Yare catchment. Rainfall caused widespread inundation of the fluvial floodplains on the Yare river in 1981. In 1993, a rainfall event caused flooding in Norwich and part of the Broads and affected 33 properties. The River Yare was affected with some flooding due to surface water.

5.2.3. The Environment Agency's Historic Flood Map (Environment Agency, 2020c) does not indicate any areas of previous flooding within the area of the Proposed Scheme.

5.2.4. Norfolk County Council Highways team confirmed that there has been no flooding on County road approaches to the roundabout. However, there has been flooding on the A47 / A11 Thickthorn Junction itself. Highways England are addressing existing highway flooding issues on the junction as part of a drainage renewal project separate to the Proposed Scheme.

5.2.5. HADDMS (Highways England, 2020a) identified a number of instances of historic carriageway flooding on the A47 within the Proposed Scheme. 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, 2020a):

- One low severity (0-2) incident of carriageway flooding on the A47 north of the Proposed Scheme in 2014
- Four low severity (0-2) incidents of flooding on the carriageway at the A47/A11 Thickthorn Junction in 2012 and 2016-2018
- Three low severity (0-2) incidents of flooding on the carriageway southeast of the Proposed Scheme due to blocked gullies in 2018
- Eight low severity (3-4) incidents of flooding on the carriageway at the A47/A11 Thickthorn Junction between 2011 to 2018 due to blocked gullies and heavy rainfall
- Three low severity (3-4) incidents of flooding on the A47 carriageway southeast of the Proposed Scheme in 2009, 2014 and 2019
- One medium severity (5-6) incident of flooding on the A47 north of the Proposed Scheme in 2016
- Two medium severity (5-6) incidents of flooding on the A47/A11 Thickthorn Junction roundabout in 2016
- One medium severity (5-6) incident of flooding on the A47 by Intwood Stream in 2013

5.2.6. The continued flooding at the existing A47/A11 Thickthorn Junction has been identified by Highways England as a flooding hotspot on HA DDMS (Highways England, 2020a).

5.2.7. Norfolk County Council Highways team confirmed that there has been no flooding on county road approaches to the roundabout.

5.3. Fluvial flood risk

5.3.1. Fluvial flooding occurs from an increase in water level from a watercourse, causing it to breach its banks and flood the surrounding area.

According to the Environment Agency’s flood map for planning (Environment Agency, 2020a), the majority of the Proposed Scheme is located within Flood Zone 1. This can be seen in Figure 5-1. Flood Zone 1 is associated with a low risk of flooding from fluvial sources (an annual probability of less than 1 in 1,000 (0.1%) of river flooding).

5.3.2. There are localised areas of Flood Zone 2 (between 1% and 0.1% chance of flooding in any year) and Flood Zone 3 (1% or greater chance of flooding in any year) associated with Cantley Stream where the Proposed Scheme crosses or is located adjacent to the watercourse.

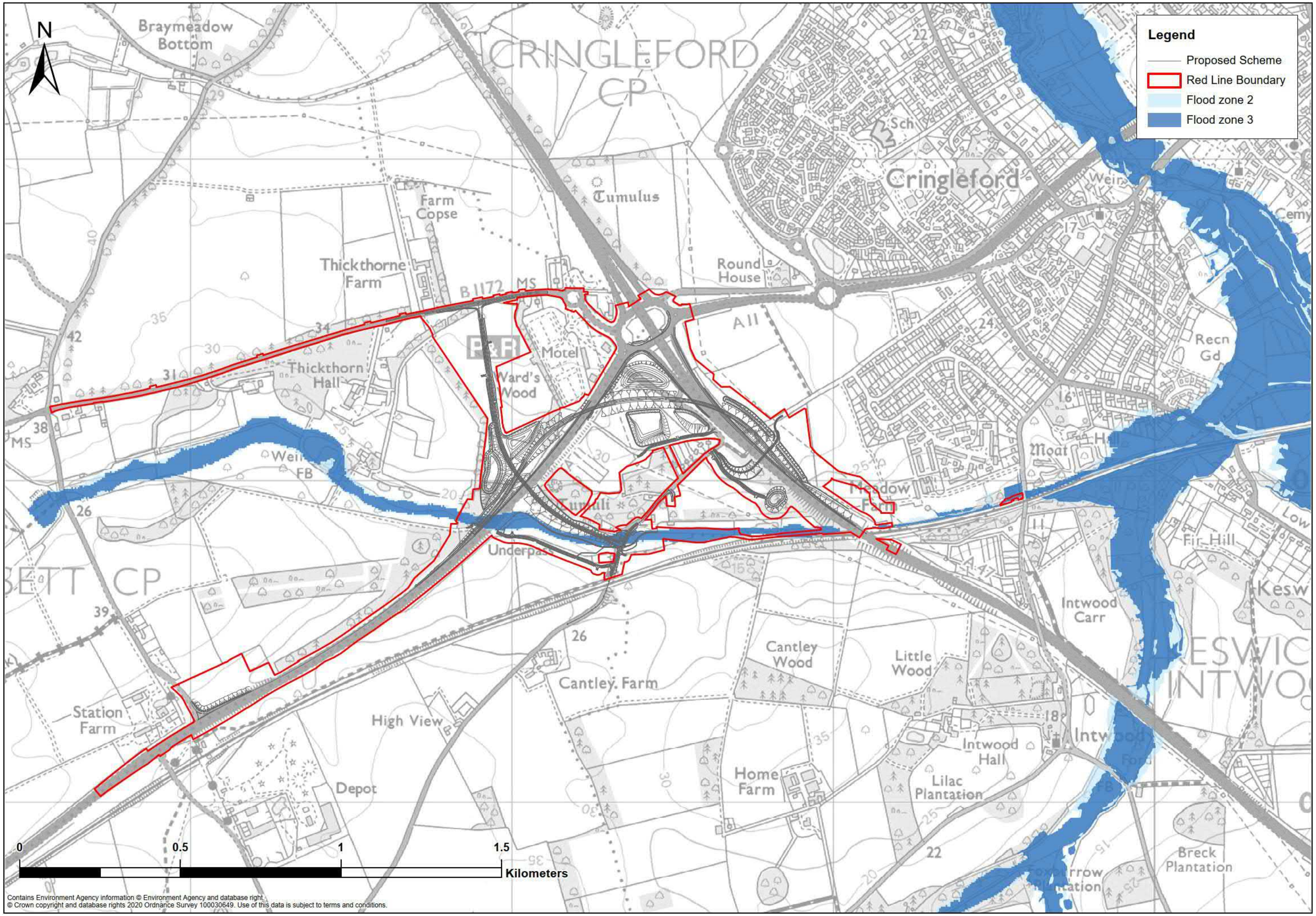
5.3.3. The SFRA (JBA Consulting, 2017) identifies areas of Flood Zone 3 as being Flood Zone 3a and indicative 3b:

- Flood Zone 3a comprises of land assessed as having a 1 in 100 or greater annual probability of river flooding;
- Flood Zone 3b comprises as land where water has to flow or be stored in times of flood.

5.3.4. The SFRA (JBA Consulting, 2017) states the term ‘indicative extent of Flood Zone 3b’ is a precautionary approach.

5.3.5. According to the Environment Agency’s flood map for planning (Environment Agency, 2020a) there are no flood defences, areas benefitting from defences or flood storage areas within the Proposed Scheme area.

Figure 5-1: The Proposed Scheme and the Environment Agency Flood Zones



5.3.6. Hydraulic modelling has been undertaken to characterise both the existing and proposed development flooding conditions of Cantley Stream and the respective floodplain. The combined 1D/2D model was built using InfoWorks Integrated Catchment Modelling (ICM, Version 9). Detailed model results can be found in Annex B, Thickthorn Hydraulic Model Technical Note.

5.3.7. The Environment Agency's Flood Zones and the site-specific hydraulic modelling confirmed that the embankment for the proposed Cantley Lane South to B1172 Norwich Road link road encroaches onto the existing Flood Zones 2 and 3.

5.3.8. The baseline model was run for the following event scenarios:

- 100-year event
- 100-year event plus 35% climate change
- 100-year event plus 65% climate change
- 100-year event plus 80% climate change
- 1000-year event

5.3.9. For the 100-year event, flooding is predicted upstream of the A11 culvert causing water to pond along the toe of the A11 embankment up to a maximum depth of 0.87m without climate change and up to a maximum depth of 1.21m with a 65% allowance for climate change (Figure 5-2 and Figure 5-3). The model predicts the Cantley Lane South culvert to surcharge during the 100-year event causing out of bank flooding to a maximum depth of 0.93m without climate change and up to a maximum depth of 1.08m with a 65% allowance for climate change. The Cantley Lane South carriageway is predicted to flood to a depth of up to 0.1m without climate change and up to a maximum depth of 0.2m with a 65% allowance for climate change The model predicts properties in the vicinity of Cantley Lane South culvert to be unaffected by flooding with or without climate change.

5.3.10. Out of bank flooding is predicted between the culvert and A47 reaching maximum flood depths of 0.68m without climate change and up to a maximum depth of 0.79m with a 65% allowance for climate change. Flooding is predicted up to a maximum depth of 0.82m without climate change and up to a maximum depth of 1.03m with a 65% allowance for climate change downstream of the A47 on the north bank of Cantley Stream. Out of bank flow is predicted to overtop Intwood Road (less than 0.2m in both scenarios), just north of the culvert near the downstream extent of the model. Flooding of a residential receptor adjacent to Intwood Road (close to the downstream extent of the model) was also predicted during the 100-year event. There is some degree of uncertainty around the precise depth and nature of flooding at this residential receptor given its proximity to the downstream model extent. Additional survey is currently being undertaken at this location in order to reduce model uncertainty.

5.3.11. Baseline flood extent maps throughout the modelled reach for all scenarios can be found in Annex B.

Figure 5-2: Baseline model flood depths for the 100-year event along the proposed stream realignment

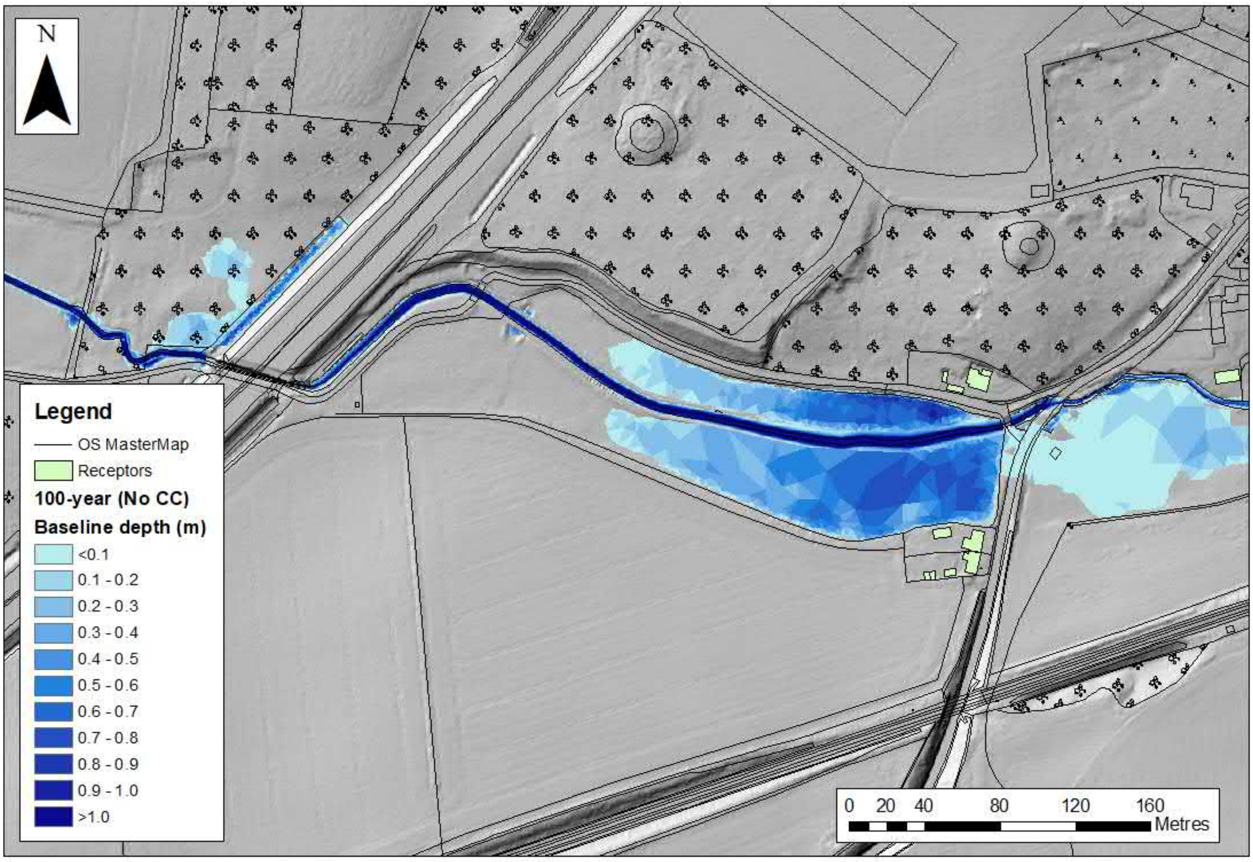
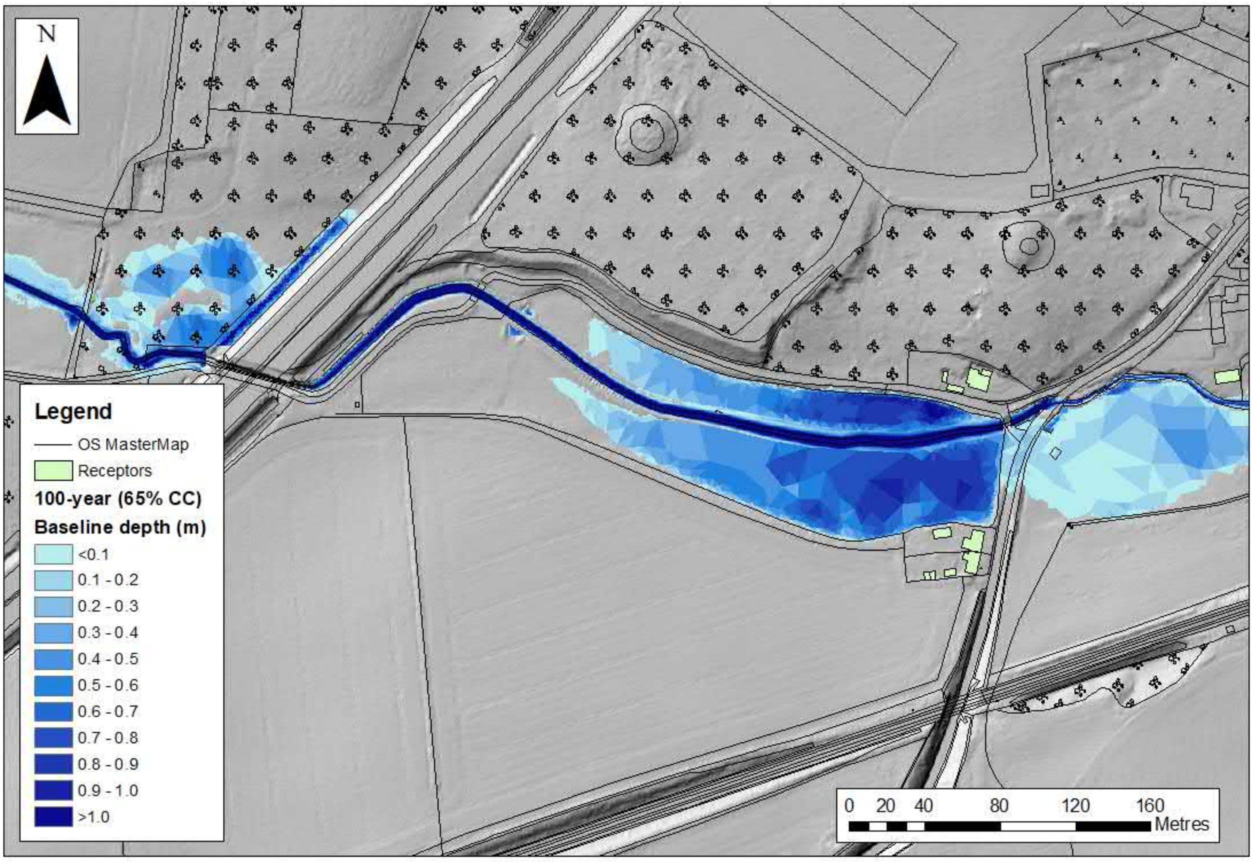


Figure 5-3: Baseline model flood depths for the 100-year plus 65% climate change event along the proposed stream realignment



5.4. Pluvial (surface water) flood risk

5.4.1. The Greater Norwich Area SFRA (JBA Consulting, 2017) states flooding from surface water runoff (or 'pluvial' flooding) is usually caused by intense rainfall that may only last a few hours, occurring often where the natural (or artificial) drainage system is unable to cope with the volume of water. Surface water flooding problems are inextricably linked to issues of poor drainage, or drainage blockage by debris, and sewer flooding.

5.4.2. The Environment Agency's indicative long-term flood risk map (Environment Agency, 2020b) indicates a large area of the Proposed Scheme is at very low risk of surface water flooding. The Environment Agency classify very low flood risk as less than 1 in 1000 (0.1%) chance of flooding in any given year.

5.4.3. However, there are areas of low to high risk of surface water flooding which are predominantly associated with the Cantley Stream and surface water flood flow pathways draining to the stream. These areas are identified along the A11 and A47 carriageway. Surface water flood flow pathways associated with Cantley Stream are also observed crossing the A11 carriageway. There are isolated areas of ponding not linked to watercourses identified at the existing A47 / A11 Thickthorn Junction and north of the B1172 Norwich Road. Figure 5-4 shows the location of surface water flood risk at the Proposed Scheme.

5.4.4. The Environment Agency classify the low to high risk of surface water flooding as:

- Low - the area has between 1 in 1000 (0.1%) and 1 in 100 (1%) chance of pluvial flooding in any given year
- Medium - the area between 1 in 100 (1%) and 1 in 30 (3.3%) chance of pluvial flooding in any given year
- High - the area has greater than 1 in 30 (3.3%) chance of pluvial flooding in any given year

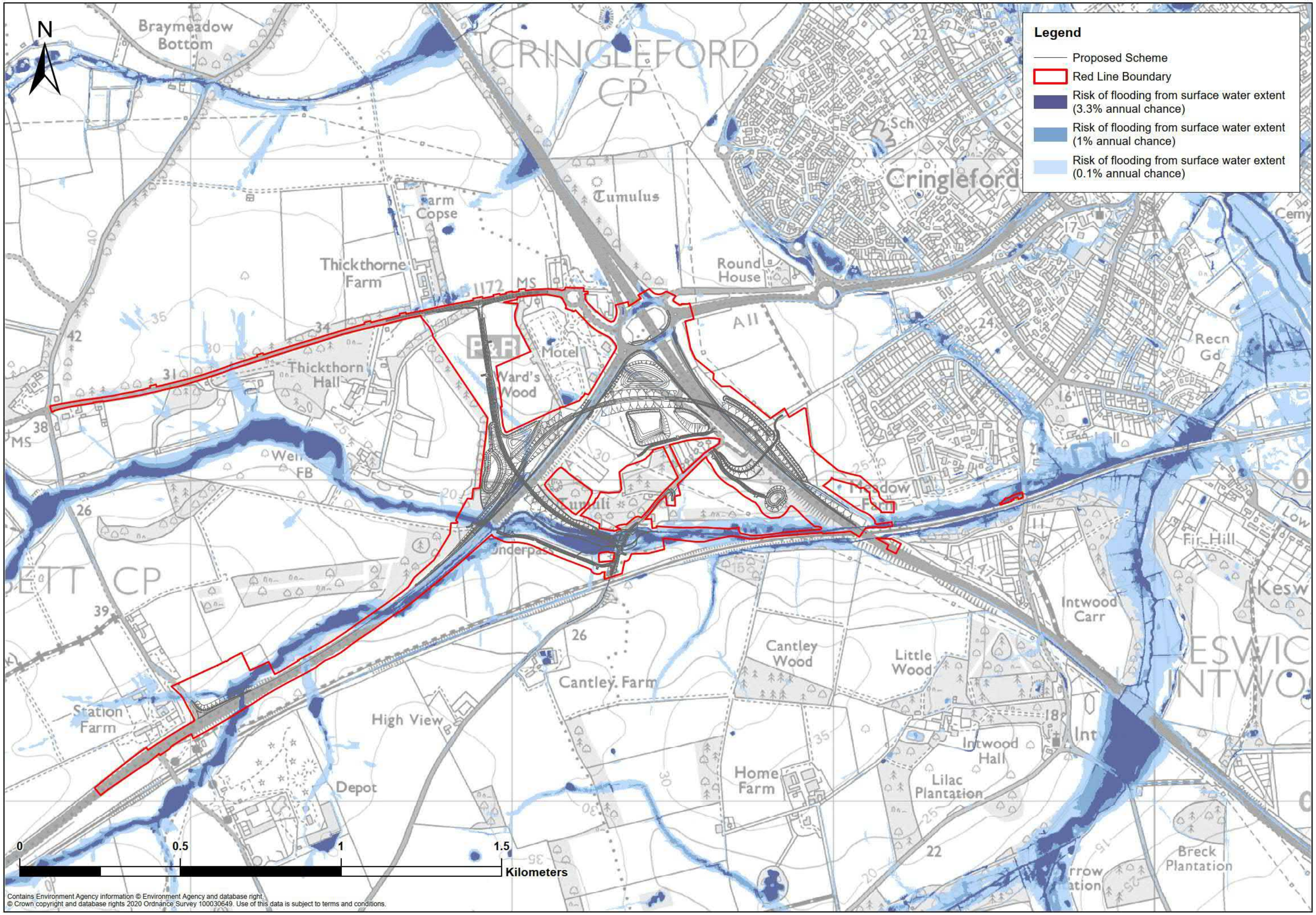
5.4.5. The Environment Agency long-term flood risk map is based on coarse scale mapping.

5.4.6. The impacts of climate change on existing surface water flood risk are considered in the Greater Norwich Area SFRA (JBA Consulting, 2017). The surface water flood risk map for the 1 in 100-year storm event, with a 40% climate change allowance, is provided in the SFRA and shows the extent of flooding is marginally less that the 1 in 1000-year extent shown in Figure 5-4.

5.4.7. The existing drainage catchment plan (Annex D) shows the Proposed Scheme crosses five natural drainage catchments. Contributing surface water flow pathways, based on LiDAR data, are also shown on the plan. There are no known permanent watercourses or ditches associated with these catchments. These are defined as:

- Catchment A - Land west of the A11 and south of B1172. The catchment drains to Cantley Stream upstream of the A11 culvert.
- Catchment B - Land bounded by the A11 to the west, Cantley Stream to the south and part of Cantley Lane South to the east. The catchment drains to Cantley Stream upstream of the Cantley Lane culvert.
- Catchment B1- The land bound by the A11 to the west, Cantley Stream to the north and Cantley Lane South to the east. The catchment drains to Cantley Stream upstream of the Cantley Lane culvert.
- Catchment C - The east portion of the land contained by the A11, the railway and the A47. The catchment is partly bound to the west by Cantley Lane South and outfalls to Cantley Stream upstream of the A47 culvert.
- Catchment D - The land containing the fields east of the A47, bound by Cantley Lane to the north and Cringleford residential area to the east. The catchment outfalls to Cantley Stream, downstream of the A47 culvert.

Figure 5-4: The Proposed Scheme and the surface water flood risk extent.



5.4.8. A detailed assessment of the surface water flood risk to the Proposed Scheme was carried out using the hydraulic model. The model assessed the impact of surface water on receptors local to Cantley Stream using a direct rainfall runoff model. The area of interest were the buildings located north of the junction between the new link road and Cantley Lane South. The model simulation was run for the 100-year plus 40% climate change event with a critical storm duration of 0.5 hours.

5.4.9. The model predicts peak surface water depths of 0.3m in the vicinity of the receptors to the north of the proposed Cantley Lane link road. Estimated water levels at these receptors do not pass the estimated doorstep threshold level. The flooding occurs as a direct result of rainfall runoff collected at the receptors from rainfall directly at or uphill of their location. Further details can be found in Annex B.

5.5. Risk of flooding from water and highways infrastructure failure

5.5.1. Sewer flooding occurs when intense rainfall overloads the sewer system capacity (surface water, foul or combined), and / or when sewers cannot discharge properly to watercourses due to high water levels. The SFRA (JBA Consulting, 2017) indicates that there have been 11 incidents of flooding from the ‘properties at risk of flooding’ (known as ‘DG5’) register in the Norwich and Cringleford area. It is unknown if these events affected the area of the Proposed Scheme as no further detail on the precise locations, dates or extents of these flood events was available. The LFRMS (Norfolk County Council, 2015) indicated that 20 residential properties in Hethersett to the west of the Proposed Scheme are at risk of surface water flooding. However, HADDMS does not indicate any historical flooding events that were due to sewerage infrastructure failure.

5.5.2. Construction of the Proposed Scheme would require the diversion of a number of water infrastructure pipes and sewers. Namely a foul gravity sewer at Cantley Stream, a water main at Cantley Lane and a surface water sewer adjacent to the A11. A further foul rising main that passes beneath Thickthorn Junction would not be diverted as a result of the Proposed Scheme.

5.5.3. A total of 19 low severity and four medium severity highways infrastructure flood events were recorded by HA DDMS (Highways England, 2020a) between 2009 and 2019. Furthermore, Highways England have identified the continued flooding at the existing A47/A11 Thickthorn Junction as a flooding hotspot on HA DDMS (Highways England, 2020a). Historic flooding issues at the existing A47/A11 Thickthorn Junction will be addressed by a separate Highways England scheme.

5.5.4. The above incidents of sewer flooding are highly localised and unlikely to directly affect the Proposed Scheme. Although there is likely to be a lack of information regarding historical water and sewer infrastructure failure flooding incidents, the existing risk of flooding from this source is considered to be low.

5.6. Groundwater flood risk

5.6.1. Figure 5-5 shows the British Geological Survey (BGS; British Geological Survey, 2020) groundwater flooding susceptibility for the area encompassing the Proposed Scheme. The majority of the Proposed Scheme area has limited potential for groundwater flooding to occur. There are areas of potential for groundwater flooding of property situated below ground level and at surface to occur which is associated with Cantley Stream and the A11. The groundwater susceptibility dataset is only available for a 500m corridor around the existing road, and as such there is no information available for the areas to the west of the A47/A11 Thickthorn Junction.

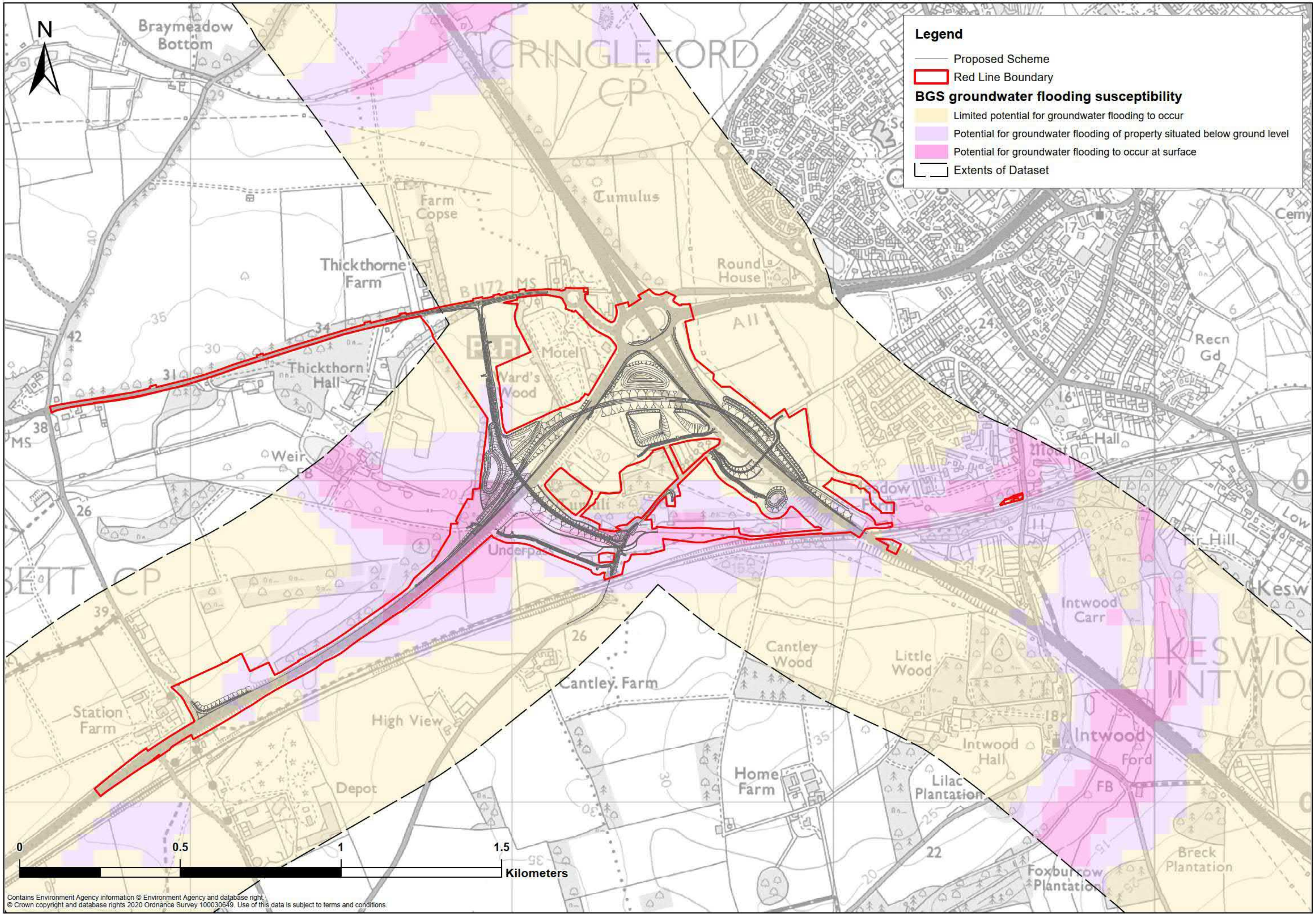
5.6.2. This is consistent with the Areas Susceptible to Groundwater Flooding map which shows groundwater flood areas on a 1km square grid produced as part of the SFRA (JBA Consulting, 2017).

5.6.3. This is confirmed by the geology surrounding the Proposed Scheme. There is potential for groundwater flooding to occur in the southwest and southeast of the Proposed Scheme area, generally along the line of Cantley Stream. Chalk is found close to surface in this area and is thought to outcrop in the riverbed. Sub artesian groundwater conditions have been noted in boreholes closest to Cantley Stream.

5.6.4. Groundwater monitoring as part of the 2018 ground investigation collected groundwater levels over a 21-month monitoring period between April 2018 and January 2020. Minimum groundwater depths below ground level (m bGL) range from 0.05 bGL at BH33 and 20.20m bGL at BH26_P1. A location plan of the monitoring boreholes is found in ES Figure 13.8 (Ground investigation boreholes) **(TR010037/APP/6.2)**. BH33 is located adjacent to Cantley Stream and BH26_P1 is located at the eastern end of the Proposed Scheme, near the A47 carriageway.

5.6.5. Findings from the ground investigation detailed above confirm that there is a risk of groundwater flooding occurring at the surface within the vicinity of Cantley Stream, where Chalk groundwater levels are shallow and likely provide baseflow to the stream. There is limited potential for groundwater flooding to occur across the rest of the Proposed Scheme, where groundwater levels are generally deeper below ground level.

Figure 5-5: The Proposed Scheme and the groundwater flood risk extent.



5.6.6. 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

5.7.1. The Environment Agency flood map for planning and the SFRA identifies sections of the Proposed Scheme as being located within the indicative extent of Flood Zone 3b. However, the majority of the Proposed Scheme is within Flood Zone 1. In addition to this, there have been no reported incidents of fluvial flooding affecting the Proposed Scheme.

5.7.2. A detailed hydraulic modelling assessment of Cantley Stream predicted flooding for the 100-year event upstream of the A11 culvert. The model predicts the Cantley Lane South culvert to surcharge during the 100-year event causing out of bank flooding to a maximum depth of 0.93m. The model predicts residential properties in the vicinity of Cantley Lane South culvert to be unaffected by flooding. Out of bank flooding is predicted between the culvert and A47 reaching maximum flood depths of 0.68m. Climate change increases the predicted flood depths along the areas identified above. The model also predicts out of bank flooding downstream of the A47 which affects a residential property adjacent to Intwood Road. Therefore, the risk of fluvial flooding is considered to be high.

5.7.3. The Environment Agency flood risk from surface water map indicates that most of the Proposed Scheme is at very low risk from surface water flooding. There are areas where the risk of surface water flooding is identified as being low to high where the topography of the land has the potential to allow flood flow pathways to form. Therefore, the risk of surface water flooding is considered to be medium to high where areas of ponding or surface water flow pathways cross the Proposed Scheme. Hydraulic modelling was carried out to assess the impacts of surface water flood risk on a residential receptor to the north of Cantley Stream and west of Cantley Lane South. The model predicts the receptors are at risk of surface water flooding to a depth of 0.3m where levels do not pass the estimated doorstep threshold.

5.7.4. The SFRA (JBA Consulting, 2017) indicates that there have been 11 incidents of flooding from the 'properties at risk of flooding' (known as 'DG5') register in the Norwich and Cringleford area. The LFRMS (Norfolk County Council, 2015) indicated that 20 residential properties in Hethersett to the west of the Proposed Scheme are at risk of surface water flooding. Although there is likely to be a lack of information regarding historical water and sewer infrastructure failure flooding incidents, the existing risk of flooding from this source is considered to be low. A total of 19 low severity and four medium severity highways infrastructure flood events were recorded by HA DDMS (Highways England, 2020a) between 2009 and 2019. Furthermore, Highways England have identified the continued flooding at the existing A47/A11 Thickthorn Junction as a flooding hotspot on HA DDMS (Highways England, 2020a). Historic flooding issues at the existing A47/A11 Thickthorn Junction will be addressed by a separate Highways England drainage renewal scheme. In addition, Norfolk County Council Highways team confirmed that there has been no flooding on county road approaches to the roundabout. Therefore, the risk of flooding from highway drainage infrastructure is considered to be low.

5.7.5. The BGS groundwater flooding susceptibility maps show the majority of the Proposed Scheme area has limited potential for groundwater flooding to occur. There are areas of potential for groundwater flooding of property situated below ground level and at surface to occur which is associated with Cantley Stream and the A11. There are no historical records of groundwater flooding within the vicinity of the Proposed Scheme, however findings from the ground investigation suggest that groundwater flooding is a potential risk in the vicinity of Cantley Stream.

6. NPPF guidance

6.1.1. The Proposed Scheme is considered to be essential transport infrastructure and it is therefore classified as “Essential Infrastructure”. Section 5.2.6 indicated that the Proposed Scheme lies partly within Flood Zones 1, 2 and 3.

6.1.2. NPPF guidance states that a Sequential Test is required for development in Flood Zone 2 or 3 in order to assess other available sites to find out which has the lowest flood risk. Alternative options for the junction improvements were considered at Stage 2 (Option Selection) and the preferred route announcement was made in 2017. As such, the Proposed Scheme meets the requirements of the Sequential Test.

6.1.3. According to Table 3 (flood risk vulnerability and ‘flood zone’ compatibility) of the flood risk and coastal change PPG for the NPPF, reproduced in Table 6-1, the

Table 6-1: NPPF Planning Practice Guidance - Table 3 (flood risk vulnerability and ‘flood zone’ compatibility)

Flood Risk Vulnerability Classification	Flood Risk Vulnerability Classification				
	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.

Site is considered appropriate for development in Flood Zone 3a providing it passes the requirements of the Exception Test.

6.1.4. In addition to passing the Exception Test, the PPG and Section 5.94 of the NPS NN notes, that permitted essential infrastructure in Flood Zone 3a must remain operational and safe in times of flood. According to paragraph 160 of the NPPF, for an Exception Test that is informed by a site-specific Flood Risk Assessment to be passed, the following criteria must be met (MHCLG 2016, 2019):

- The wider sustainability benefits to the community provided by the Proposed Scheme outweigh the flood risk.
- The development will be safe for its lifetime, taking into account the vulnerability of its users, without increasing flood risk elsewhere, and, where possible, will reduce flood risk overall.

6.1.5. The first criteria imposed by the NPPF is met by the Proposed Scheme delivering wider benefits to the strategic road network. The development of the A47/A11 Thickthorn Junction would alleviate traffic as the A47 meets the A11 making journey times more reliable and increase capacity for future traffic growth. The Proposed Scheme would also help support regional housing and economic growth in Norwich and the surrounding areas. The Proposed Scheme would provide a safer route between communities for cyclists, walkers, horse riders and other non-motorist groups.

6.1.6. The A47 is a trunk road linking Peterborough with Lowestoft on the east coast of England. It plays a key role in the delivery of goods from the A1 into the Norfolk and north Suffolk regions. Its other main function is serving as a ‘holiday road’, connecting the Midlands with tourist destinations on the Norfolk coast. Maintaining connectivity, increasing capacity and reducing delays on the A47 are imperative to the livelihoods of these two vital industries.

6.1.7. The second criteria are considered in Sections 7 to 10 of this FRA.

7. Flood risk to others

7.1.1. The potential impacts of the development on flood risk to others is a key consideration. The Proposed Scheme would not result in an increase in tidal, infrastructure failure and reservoir failure flood risk.

7.2. Fluvial flood risk

7.2.1. Construction works within Cantley Stream and its floodplain have the potential to displace fluvial flood waters which may in turn increase flood risk to others. Construction in these areas include the extension to the A11 Cantley Stream underpass, the embankments and carriageways of the new Cantley Lane link road and Cantley Lane South road, the proposed new Cantley Lane South culvert and the Cantley Stream realignment.

7.2.2. Construction works within Cantley Stream have the potential in increase fluvial flood depths and velocities in the section of watercourse adjacent to the Network Rail embankment.

7.3. Surface water flood risk

7.3.1. There is a potential for an increase in surface water runoff rate and volume from the Proposed Scheme due to the increase in areas of hardstanding, alterations to ground levels and the provision of a pumping station to provide drainage to the Ward's Wood underpass. An increase in the rate of surface water runoff could exacerbate downstream flood risk by, for example, overloading sewers or gullies, exceeding the capacity of watercourses, culverts and other associated drainage infrastructure.

7.3.2. The majority of the Proposed Scheme area is agricultural land which can be expected to generate runoff at typical greenfield rates. An increase in areas of hardstanding as part of the Proposed Scheme would, without mitigation, alter and increase rates and volumes of runoff when compared to greenfield conditions.

7.3.3. Any interception of surface water flood flow pathways made by the Proposed Scheme could cause localised flooding by diverting flood risk on to others or to the Proposed Scheme itself. The Proposed Scheme would intercept the following natural drainage catchments identified in Section 5.4.5 and shown in Annex D - Drainage Outfall Catchments Scheme Layout Plan.

- Catchment A - The proposed new Cantley Lane link road and proposed attenuation basin will split the catchment east to west, creating a new catchment A2. If not mitigated, drainage from the original catchment A will cause ponding behind (north) of the new A11-A47 connector road.

- Catchment B - The proposed Cantley Lane link road will split the catchment north west to south east. Without mitigation, this would cause ponding behind the northern toe of the Cantley Lane link road embankment.
- Catchment B1 - The proposed access track will split the catchment north west to south east. Without mitigation, this would cause ponding on the southern side of the new farm access track. Catchment B1 also includes a surface water flow pathway which discharges, via existing highway catchment E, to Cantley Stream immediately upstream of the Cantley Lane South culvert. Without mitigation, the overland flood flow pathway could result in flooding to nearby properties.
- Catchment C - The proposed A47 access track, earth bunds and access bridge will split the natural catchment C into a further two catchments collectively named C2. Without mitigation, this will cause ponding behind the A47 access track and at the toe of the access bridge embankment.
- Catchment D - The proposed earth bund and embankment of the A11- A47 connector road encroaches into Catchment D and reduce the catchment area. Without mitigation, this would potentially result in higher runoff rates to outfall at Cantley Stream.

7.4. Groundwater flood risk

7.4.1. Construction of the Proposed Scheme has potential to intercept the underlying Chalk aquifer beneath the proposed A11-A47 connector road. There is a risk that groundwater levels within the Chalk aquifer may be intercepted and cause groundwater flooding into the link road and Ward’s Wood underpass. The levels within the chalk aquifer are currently unknown, however. These are due to be confirmed by a supplementary ground investigation.

7.4.2. Any below ground structures adjacent to Cantley Stream and in areas identified as having a potential for groundwater flooding at or below surface, may result in groundwater flooding if they create a barrier to groundwater flow.

8. Flood risk mitigation

8.1.1. Mitigation measures as a result of a potential increase in fluvial, surface water and groundwater flood risk to others have been assessed.

8.2. Fluvial flood risk

8.2.1. Post-development modelling of Cantley Stream was used to inform the design of the realigned stream channel and a new culvert beneath Cantley Lane South. The modelling highlighted competing interests between the need to provide average minimum swimming depths of 0.30m in water vole habitat and maintaining at least 0.60m freeboard through the culvert during the 100-year event plus 65% climate change allowance. Furthermore, there are significant constraints on road levels and alignment at Cantley Lane South due to the need to tie into existing property accesses. The proposed channel width of 3m (up to a maximum reduction of 1m from the existing) allowed for suitable average depths for water vole swimming (with the provision of additional riffle and pool features) whilst meeting the limits on proposed levels and alignment. However, meeting these requirements reduced the minimum freeboard through the culvert to 0.428m during the 100-year plus 65% climate change event. Norfolk County Council has confirmed that whilst they would prefer a freeboard of 0.60m, they accept the reduced freeboard given the site constraints. A technical note describing in more detail the various constraints on the culvert freeboard is provided in Annex A.

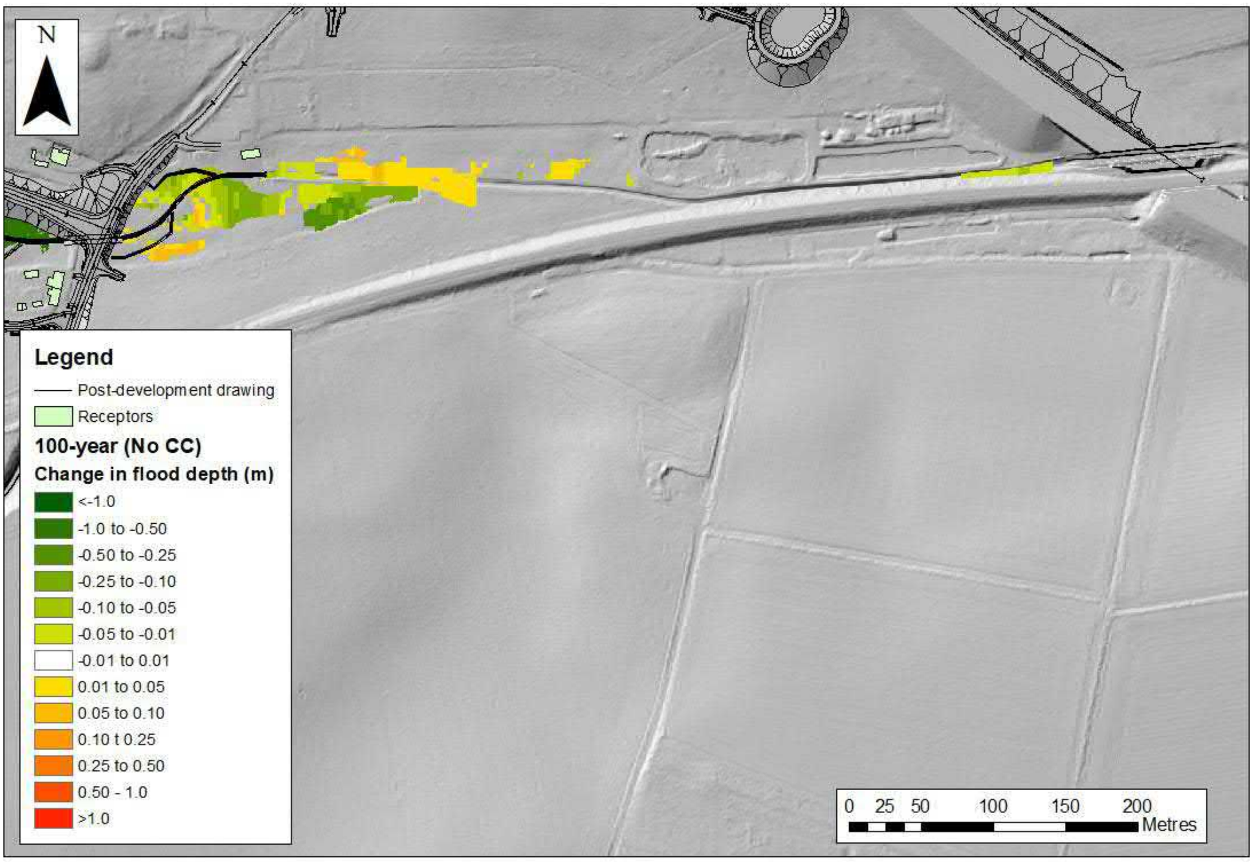
8.2.2. Annex C provides the complete set of maps showing difference in the maximum flood depth between baseline and proposed conditions. It should be noted that all flood depth difference maps reflect changes between the baseline and post development ground elevation models and do not always reflect the true differences in flood depths, for example, in the direct areas of channel realignment. Also, where the flood maps are based on LiDAR the depth difference maps are subject to the accuracy and resolution of this data. Therefore, conclusions on the impacts are based on the broad patterns of changes shown in the flood depth difference maps.

8.2.3. For the 100-year event, extension of the existing A11 culvert reduced water depths at the toe of the A11 embankment by up to 0.1m (see Figure 8-1). Furthermore, the model predicted a reduction in floodplain depths in the area of stream realignment up to 0.93m.

Figure 8-1: Flood depth difference for the 100-year event between the baseline and post-development model of the realigned Cantley Stream

8.2.4. For the 100-year event, the model predicted a maximum flood depth reduction of up to 0.5m downstream of the Cantley Lane South culvert. The model did, however, predict maximum flood depth increases of up to 0.1m within the same area. The changes in flood risk in this area is primarily a reflection of the stream realignment which results in a different pattern of flood risk; although discrepancies in the LiDAR are also a factor. Furthermore, the model predicted a reduction of flood depths upstream of the A47 culvert by up to 0.1m (Figure 8-2).

Figure 8-2: Flood depth difference for the 100-year event between the baseline and post-development model between Cantley Lane South culvert and A47



8.2.5. Figure 8-3); although the increase in the water channel is predicted to increase by 0.008m. A residential receptor (Crossing Cottage) is located upstream of Intwood Road and would be impacted by the increase in flood risk without mitigation. As such, property level protection is proposed as mitigation for this increase in flood risk.

8.2.6. There is some degree of uncertainty around the precise depth and nature of flooding at Crossing Cottage due to its location close to the downstream extent of the model. As such, further survey data is currently being collected in this area to allow the model to be updated so that a more accurate assessment of flood risk impacts can be made. Following completion of the additional modelling assessment, the requirements for flood mitigation would be reconsidered.

Figure 8-3: Flood depth difference for the 100-year event between the baseline and post-development model between A47 and outfall to the model

8.2.7. For the 100-year plus 65% climate change event, increasing the width of the culvert beneath Cantley Lane South removed the existing throttle and significantly reduced average flood depths by up to 1.0m along the realigned reach upstream of the culvert (Figure 8-4). Furthermore, extension of the A11 culvert reduced water depths at the toe of the A11 embankment by up to 0.1m although there are isolated areas (up to 0.5m increase) associated with changes to the farm access track and drainage ditch ground levels, however, these are likely, at least in part, to be due to uncertainty in the ground levels in the area.

Figure 8-4: Flood depth difference for the 100-year plus 65% climate change event between the baseline and post-development modelling of the realigned Cantley Stream

8.2.8. For the 100-year plus 65% climate change event the model predicted maximum flood depth decreases downstream of Cantley Lane South culvert of up to 0.25m (generally about 0.13m). The model also predicted maximum flood depth increases of up to 0.1m (generally about 0.06m). As noted previously, this is principally due to the stream realignment and discrepancies in the LiDAR (Figure 8-5).

Figure 8-5: Flood depth difference for the 100-year plus 65% climate change event between the baseline and post-development model between Cantley Lane South culvert and A47

8.2.9. For the 100-year plus 65% climate change event the Proposed Scheme generally increases flood depths in the floodplain at the Intwood Road and railway line crossing by approximately 0.015m (Figure 8-6). Proposed mitigation, in the form of property level protection is proposed for Crossing Cottage subject to further assessments as described in paragraph 8.2.11.

Figure 8-6: Flood depth difference for the 100-year plus 65% climate change event between the baseline and post-development model between A47

8.2.10. Flood depth differences for the 100-year plus 80% climate change (H++) event are given in Annex C. It is considered that no safety critical issues arise when considering this scenario; there is no additional flooding of the new or existing road network. Minimal depth differences are observed between the 65% and 80% climate change events.

8.2.11. The removal of the throttle at the existing Cantley Lane South culvert has significantly reduced flood depths upstream. There are no downstream flood risk impacts to 'more vulnerable', that is residential, receptors apart from a property adjacent to Intwood Road where a small increase in flood risk is predicted (up to 0.015m) and property level protection is proposed. Confirmation of the impact and, therefore the mitigation, is subject to additional survey and modelling to better predict the impacts in this location.

8.2.12. Due to the proposed removal of the existing Cantley Lane South culvert and the realigned stream there are changes in the patterns of flood risk within the floodplain affecting agricultural land and amenity areas (classed as 'less vulnerable' and 'water compatible' under the NPPF). Following the initial impact assessment of removing the existing Cantley Lane South culvert throttle, it was agreed with Norfolk County Council and the Environment Agency in August 2020 that there is no requirement to provide compensatory flood storage upstream of Cantley Lane South culvert.

8.2.13. Increasing the aperture of the Cantley Lane South culvert also provides benefits for the water environment including improved habitat connectivity with low flow channel, natural sediment bed and mammal ledges elevated above the design flood level. The larger culvert, with improved freeboard compared to baseline conditions, also reduces the risk of blockage by debris.

8.2.14. The changes in flood depths within the Cantley Stream channel and floodplain adjacent to the Network Rail embankment (both upstream and downstream of the A47) are negligible (up to 0.015m during the 100 year plus 65% climate change event). Furthermore, the maximum increase in flow velocity as a result of the Proposed Scheme is 0.05m/s during the 100 year plus 65% climate change event. For large proportions of this section of Cantley Stream, both flow velocities and flood depths are decreased as a result of the Proposed Scheme. As such, it is considered there is no increased risk of erosion to the Network Rail embankment or of flooding to the railway line.

8.3. Surface water flood risk

Proposed drainage strategy

8.3.1. Without mitigation, the increase in impermeable area due to the Proposed Scheme would result in an increase of peak flow rate and volume of surface water discharged from the drainage network and entering Cantley Stream.

8.3.2. The proposed drainage design would use a combination of surface water channels, kerb and gullies and combined surface water drainage systems. For proposed carriageways and junctions, the selection of drainage collection systems considered for the surface water removal from carriageways on embankments includes; kerb and gullies with hard strip, kerb and gullies, combined drainage and kerb systems, and surface water channels. These systems are typical solutions and align with DMRB standards.

8.3.3. Highway drainage will utilise all three existing outfalls plus an additional five new outfalls. There are also two additional outfalls into the Cantley Stream to re-establish natural runoff cut-off by the proposed Cantley Lane link road embankment. The proposed new drainage system has been designed to provide sufficient attenuation volume to accommodate the 100-year plus 40% climate change event and discharge to Cantley Stream at greenfield runoff rates. Proposed highway drainage catchments and drainage layout drawings are provided in Annex D.

8.3.4. The proposed SuDS features included within the drainage design include, vegetated detention basins, filter drains, attenuation pipes and grassed ditches (swales). The inclusion of filter drains is subject to further assessment following supplementary ground investigation which is due to commence in Spring 2021.

8.3.5. The detention basins promote the four pillars of SuDS (quantity, quality, biodiversity and amenity). The basins provide storage to restrict discharge rates to greenfield runoff rates, provide vegetated surface for water to flow over to settle, filtrate and biodegrade hydrocarbons and pollutants (including sediment and dissolved sediment-bound and soluble heavy metals). The detentions basins also promote biodiversity as these will include a suitably diverse range of local species.

8.3.6. Grassed ditches or swales provide a vegetated surface for water to flow over to settle and filtrate hydrocarbons and highway pollutants. Grassed ditches also promote biodiversity as these include a suitably diverse range of local species.

8.3.7. Filter drains at the edge of road carriageways, if included, provide a degree of filtration and contribute to attenuating carriageway runoff. Gravel media can also host microorganisms and provide a breeding ground for insects.

8.3.8. Oversized pipes with hydrobrake flow control devices are provided to attenuate highway runoff to greenfield runoff rates. Attenuation pipes will include catch pits to settle and capture sediment within the surface water runoff.

8.3.9. On the A11-A47 connector road and Ward's Wood underpass, the highway drainage cannot discharge to the ground or by gravity to a surface water outfall. Therefore, a rising main and pumping station would discharge to Cantley Stream via an attenuation basin designed to provide sufficient attenuation volume for the 100-year plus 40% climate change event.

8.3.10. The following design standards have been adopted as part of the proposed drainage design strategy to avoid flooding on the highway:

- 1 in 1-year storm event – designed for no surcharge of pipe network
- 1 in 5-year storm event – designed for no flooding of the carriageway
- 1 in 10-year storm event – designed for no flooding of critical areas
- 1 in 50-year storm event – designed for no flooding at sags, adjacent to structures or at road crossings. Design ensures flood flow pathways exist for any local flooding in these areas
- 1 in 100-year storm event – designed for no flooding of third-party land.

8.3.11. All new highway drainage will be designed to attenuate to greenfield runoff rates from a 1 in 100-year rainfall event plus a 40% allowance for climate change.

8.3.12. Existing highway drainage areas are either reduced, or remain as existing, as part of the Proposed Scheme. Runoff rates from drainage catchments F2 and J are reduced or remain as existing for catchments A, H, I and K.

8.3.13. The Proposed Scheme drainage shall be designed in accordance with relevant standards in the Design Manual for Roads and Bridges (Highways England, 2019b; 2020b). Further details can be found in Appendix 13.2 (Drainage Strategy Report) **(TR010037/APP/6.3)**.

8.3.14. The flood risk impacts of the proposed drainage discharges were assessed using the hydraulic model of Cantley Stream (see Annex B). Additional inflow hydrographs from the proposed surface water drainage outfalls were included in the hydraulic model to assess the impact of the proposed drainage systems on structures and downstream flood risk within Cantley Stream. The drainage inflow hydrographs were for the 1 in 100-year plus 40% climate change event and the fluvial hydrographs for the 1 in 100-year plus 65% climate change event. Since the drainage system routes the same rainfall runoff that is already applied as a fluvial inflow to the upstream boundary to the model, adding the drainage inflows effectively doubles the contributing catchment flow and constituted a conservative approach.

8.3.15. The model assessed the impact of the runoff from the proposed drainage system on freeboard at the A11 bridge and new culvert at Cantley Lane South. The model predicts that minimum freeboard through the A11 culvert reduces by 4mm (Table 8-1). It also predicts the proposed drainage runoff would have minimal impact (reduction by 2mm) on the freeboard through the new Cantley Lane South culvert. As such, the impact of additional carriageway drainage inflows on flood risk in Cantley Stream is considered to be minimal.

8.3.16. The impacts on additional carriageway drainage inflows throughout the rest of the modelled Cantley Stream reach were negligible and within the margin of error of the model.

Table 8-1: Influence of the drainage network on freeboard in the post-development model for the 100-year plus 65% climate change event

A11 Cantley Stream underpass			Cantley Lane South culvert		
Baseline minimum freeboard (m)	Post development minimum freeboard: Sim 1 (m)	Post development minimum freeboard: Sim 2 (m)	Baseline minimum freeboard (m)	Post development minimum freeboard: Sim 1 (m)	Post development minimum freeboard: Sim 2 (m)
1.839	1.772	1.768	0.00	0.428	0.426

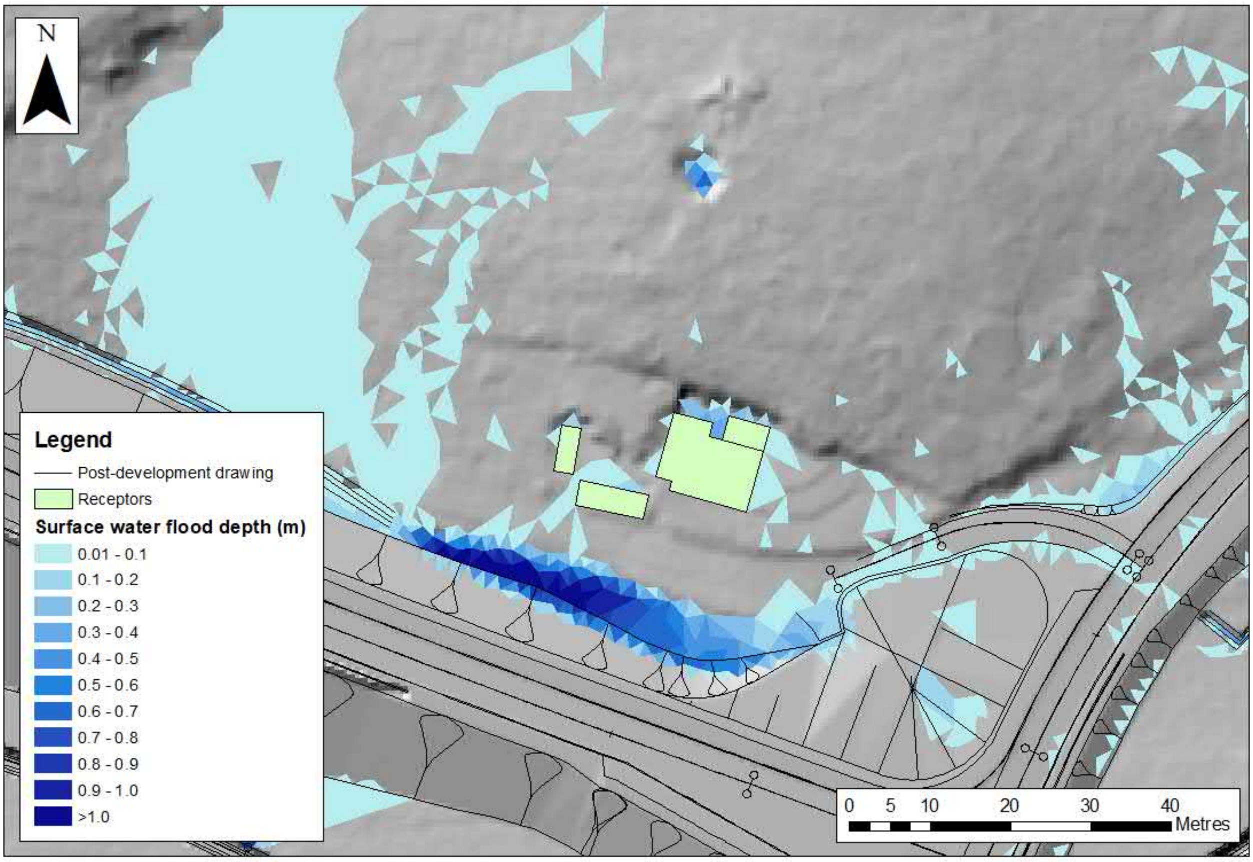
8.3.17. It is imperative the Proposed Scheme and the proposed drainage network do not increase surface water flood impacts to downstream flood-sensitive receptors.

The model was used to assess the risk of the proposed drainage on Meadow Farm Cottage north west of the proposed junction of Cantley Lane link road with Cantley Lane South (Figure 8-7). The link road intercepts an existing surface water flow pathway and it is proposed to mitigate this through the use of a cross drain conveying flows beneath the embankment in order to maintain continuity of this pathway.

8.3.18. The model was used to assess the impact of a 1 in 100-year plus 40% climate change direct rainfall event applied in the vicinity of the receptor. This was applied in conjunction with a 1 in 100-year plus 65% climate change fluvial event in Cantley Stream. Surcharging occurred within pipes and one manhole was surcharged with a flood depth of 0.09m. The surcharging; however, was found to be inconsequential and did not result in an increased flood risk to the receptor.

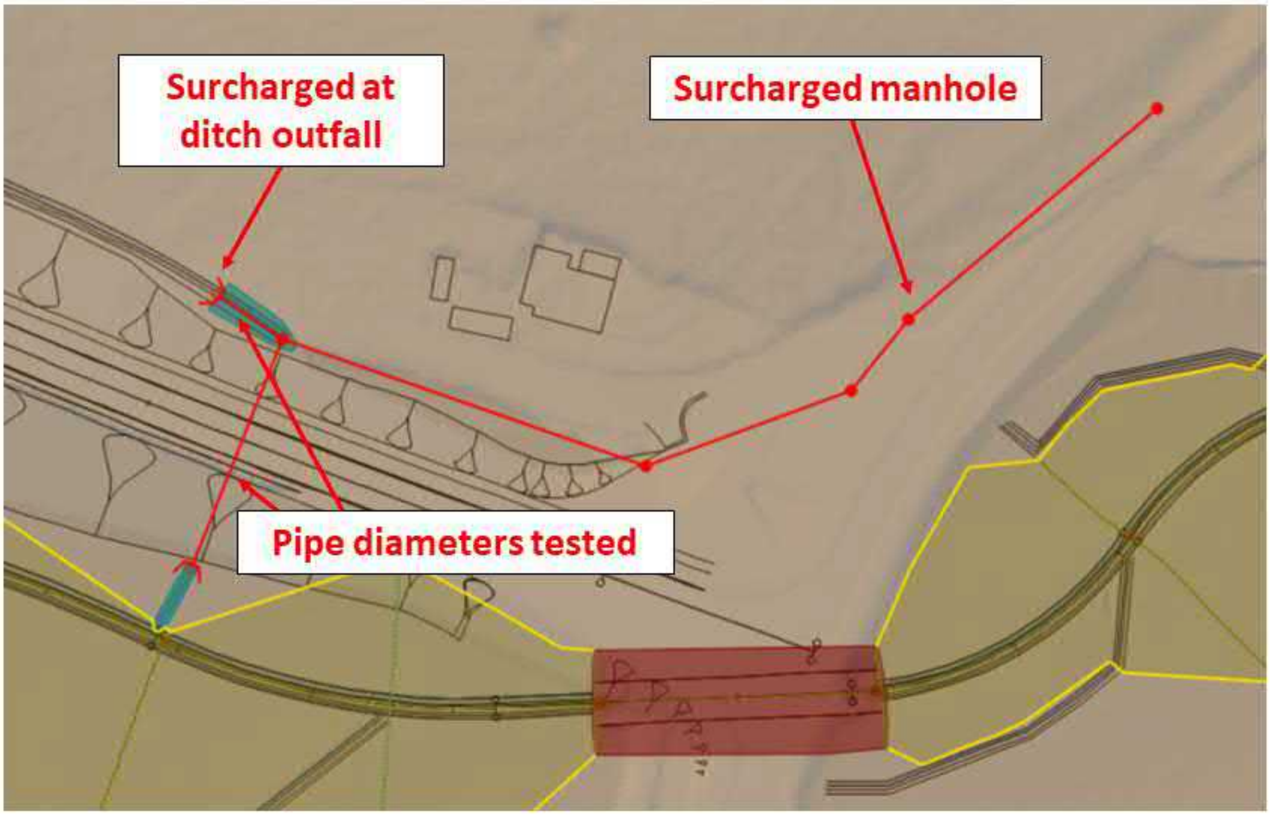
8.3.19. The model showed that, although flooding was predicted adjacent to Meadow Farm Cottage, the flooding occurred as a result of pre-existing surface water flow pathways to the north and not due to the proposed embankment and associated drainage.

Figure 8-7: Extent of surface water flooding as a result of the drainage network



8.3.20. The model was used to assess the impact of changes in drainage pipe diameter on backup at the ditch outfall shown in Figure 8-8. The diameter of the pipes connected to the ditch outfall and that of the cross drain under the road (originally 375mm and 525mm, respectively), were increased to 600mm. While the change removed surcharging in the ditch outfall pipe, flooding in the area of receptors was unchanged. Furthermore, while the flood depths along the property access road were somewhat reduced, the extent of flooding in this area remained mostly unchanged.

Figure 8-8: Locations in the model where alternative pipe diameters were assessed



Overland flow pathways

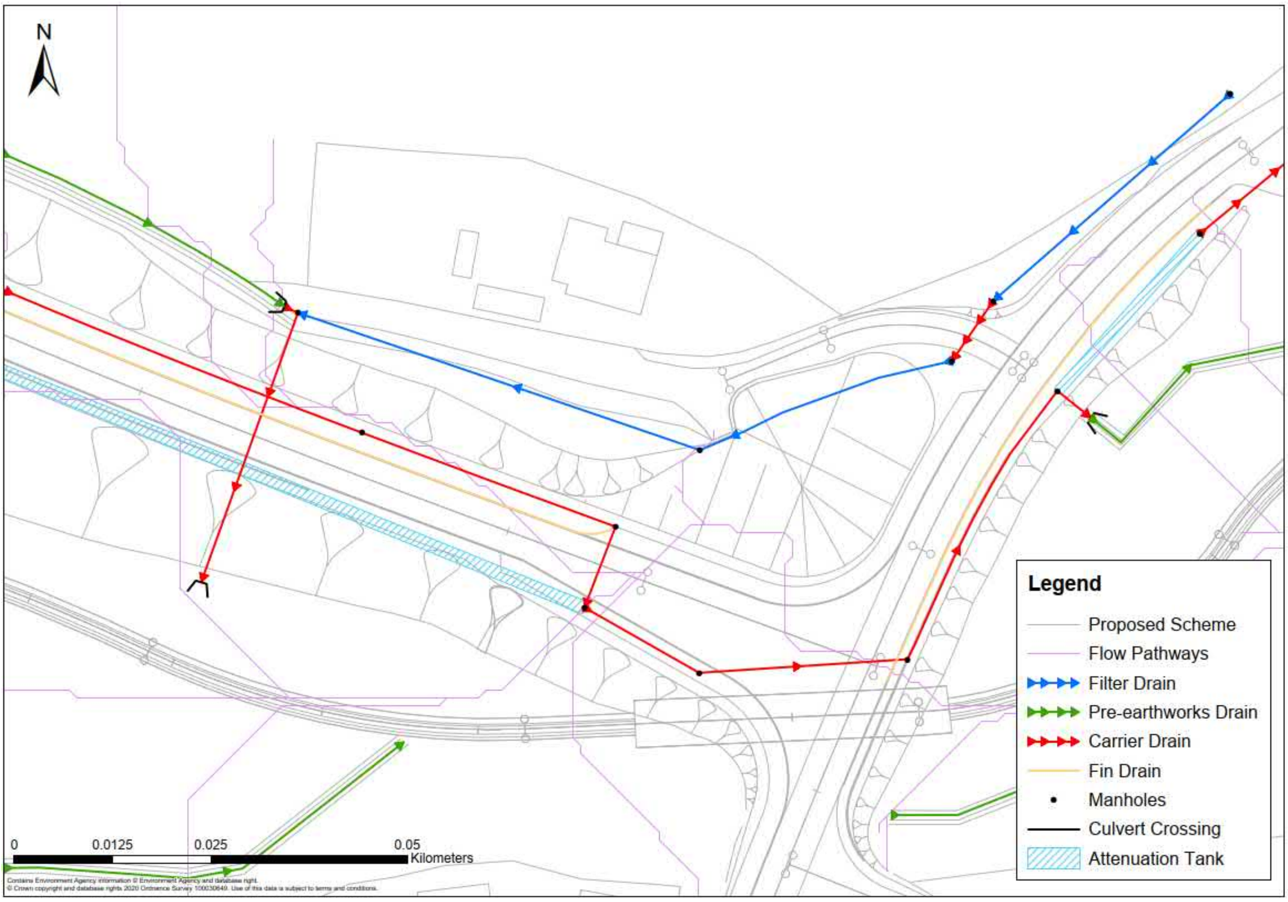
8.3.21. The Proposed Scheme could cause localised flooding by diverting surface water overland flow pathways resulting in increased flood risk to others or to the Proposed Scheme itself. The overland flow route map provided by Norfolk County Council in the Scoping Opinion (Highways England, 2018) alongside an analysis of contributing surface water catchments, based on LiDAR data, was used to determine the appropriate mitigation. Details of the proposed drainage network and overland flow routes are found Appendix 13.2 (Drainage strategy report) **(TR010037/APP/6.3)**. Drainage layout drawings with surface water flow pathways are also presented in Annex D.

8.3.22. Natural catchment runoff collected in catchment A will be collected via two carrier drains and routed south, bypassing attenuation Basin 1 to join with a preearthwork drain before discharging to Cantley Stream upstream of the A11 culvert.

8.3.23. Drainage from catchment A2 would be collected by pre-earthworks drains at the toe of the A47-A11 embankments and joins with catchment A drainage before outfall to Cantley Stream. The flow pathways from natural catchments A and A2 would discharge at the same location as the existing catchment.

8.3.24. Drainage from catchment B would be collected by a drainage ditch located at the toe of the new link road embankment and passes below the new link road and discharges to the realigned Cantley Lane stream section. Pre-earthworks and filter drains would collect water ponding on the north side of the new link road embankment, south of Meadow Farm Cottage, before connecting with the drainage ditch at the toe of the embankment (see Figure 8-9). It is assumed that overland flow from the intercepted catchment B south of the new link road discharges to the realigned Cantley Stream floodplain.

Figure 8-9: Meadow Farm Cottage drainage arrangements for natural Catchment B



8.3.25. Surface water runoff from catchment B1 would be collected by pre-earthworks drains along the southern toe of the access track and split in two directions. Drainage would be culverted beneath the access track and outfalls to Cantley Stream at two locations. Part of the surface water flood flow pathway in natural catchment B1 drains to highway catchment E2 where it would be contained within the drainage system. There is no alteration in the natural catchment upstream of catchment E2. The design of the proposed highway drainage would ensure any exceedance would be diverted eastwards and downstream towards the realigned Cantley Stream.

8.3.26. Earth bunds and the Cantley Lane Footbridge enclose two small natural catchments south east of A47 / A11 Thickthorn Junction, collectively named catchment C2. Drainage in this area would be collected by pre-earthworks drains which bypass attenuation Basin 2 and connects to the proposed pipe conveying catchment C drainage (Figure 8-10 and Figure 8-11). Drainage from this pipe discharges via a new outfall to the Cantley Stream watercourse in the same location as indicated by the surface water flow pathway. The remainder of natural catchment C is unaffected by the Proposed Scheme.

Figure 8-10: Proposed earth bund drainage arrangements

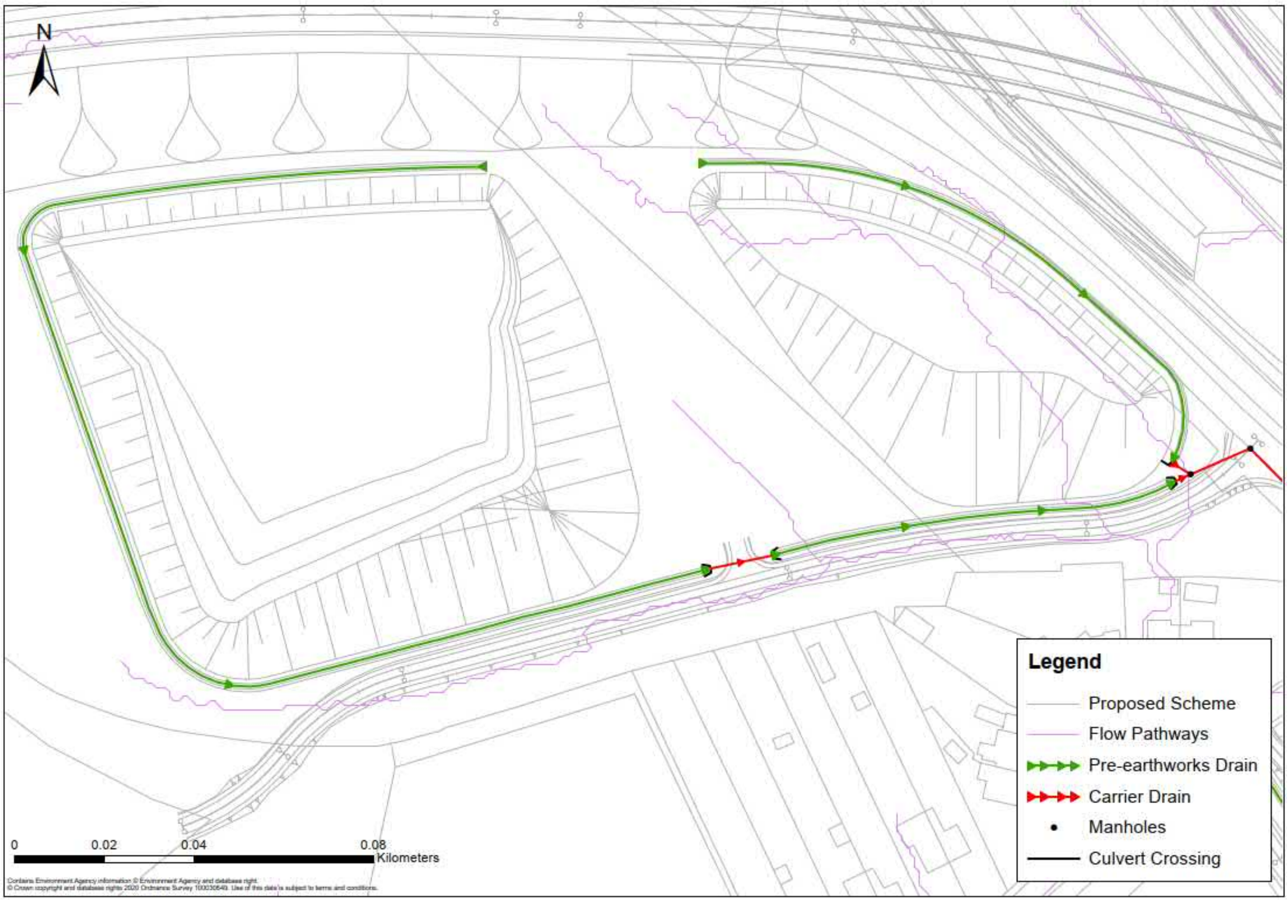
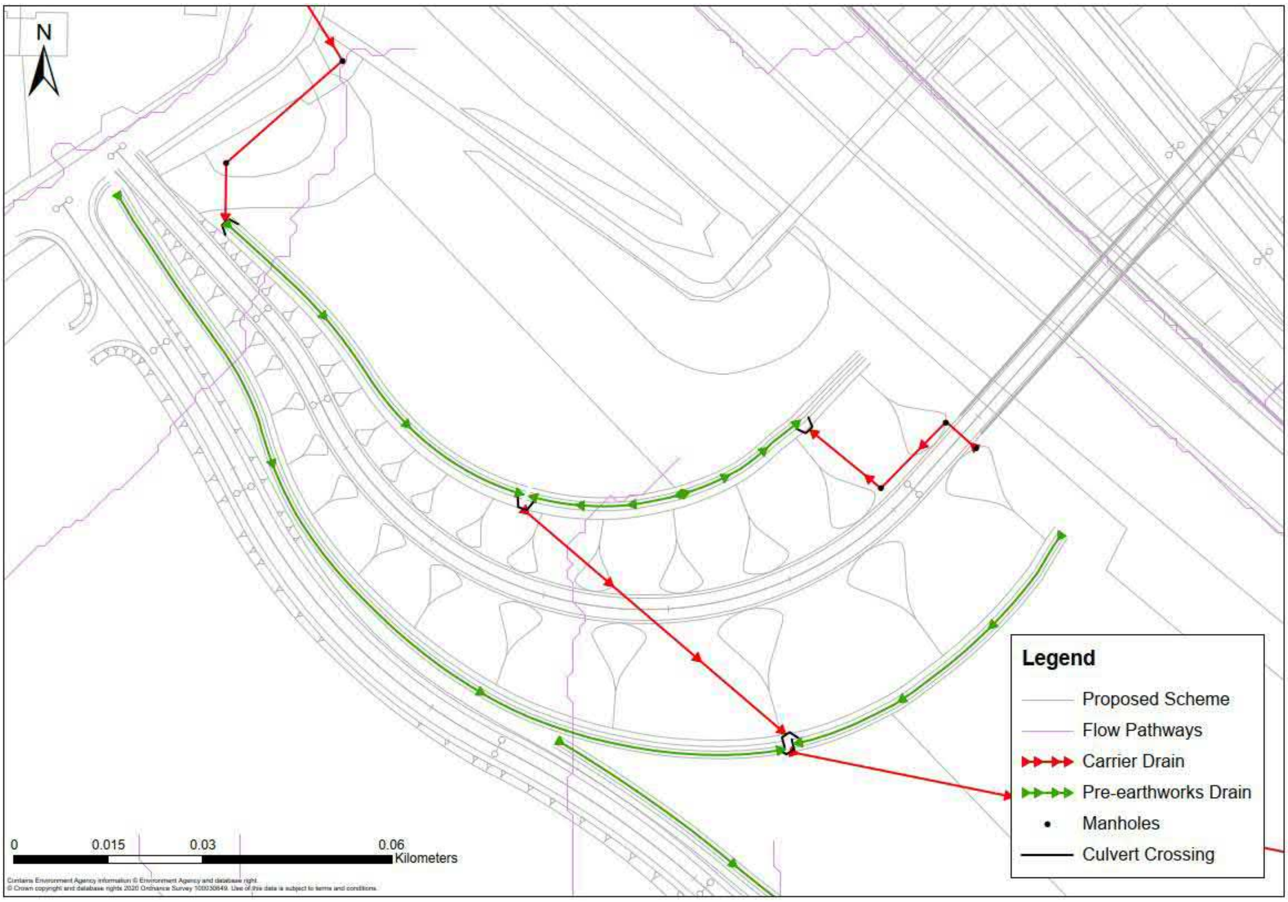


Figure 8-11: Proposed footbridge drainage arrangements



8.3.27. Drainage from natural catchment D is collected by pre-earthworks drains at the toe of the A47 which is piped to outfall to Cantley Stream in a similar manner to the existing situation. As a result of the Proposed Scheme, the existing natural catchment area D is reduced is part of the catchment is routed through the Basin 2 as part of proposed catchment F2.

8.3.28. Proposed cross drains or 'dry culverts' conveying natural catchment drainage / overland flood flow pathways must be designed to accommodate a 1 in 100-year storm event including a 40% climate change allowance to mitigate impacts to the Proposed Scheme and to others. The exact location and sizing of the cross drains shall be confirmed at detailed design once a detailed local topographic survey has been undertaken.

8.4. Groundwater flood risk

8.4.1. The proposed drainage design discharges to groundwater via filter drains (subject to further supplementary ground investigation) and surface water via detention basins and largely reflects the existing drainage network.

8.4.2. There is potential the Proposed Scheme could intercept the Chalk aquifer during construction of the A11-A47 connector road. A pumped solution is necessary as a gravity outfall cannot be achieved. Any groundwater ingress to this area is managed by the proposed drainage which would convey the groundwater drainage to a pumping station where it would be pumped to a detention basin prior to discharge to Cantley Stream. The magnitude of the groundwater ingress would be informed by the supplementary ground investigation. The design of a pump solution will be developed at the detailed design stage and would be subject to further discussions, risk assessments and agreement with relevant consenting authorities.

8.4.3. Where possible, below ground structure design including piling shall ensure there is no barrier to groundwater flow which may cause groundwater mounding.

9. Construction related flood risk and mitigation

9.1. Construction related flood risk

9.1.1. This section details the potential impacts on flood risk to the Proposed Scheme and elsewhere during the construction phase. Further details of the construction approach are available in the ES Chapter 2 (The proposed scheme) **(TR010037/APP/6.1)**.

9.1.2. During construction there will be an increase in new hardstanding areas, including the main site and satellite compounds, which, if not mitigated, would increase the flow rate and volume of runoff from the construction areas. The proposed locations of construction compounds are given in the General Arrangement Plans **(TR010037/APP/2.2)**. This could result in the increased localised flooding to the Proposed Scheme and other flood-sensitive downstream receptors within the Cantley Stream floodplain.

9.1.3. 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. Works may lead to temporary changes in the surface water runoff regime by the alteration of ground elevations and the 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.

9.1.4. There is also potential for an increase in fluvial flood risk downstream associated the construction of the extension to the A11 Cantley Stream underpass, the embankments and carriageways of the new Cantley Lane link road and Cantley Lane South road, the proposed new Cantley Lane South culvert and the Cantley Stream realignment.

9.1.5. 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. Cantley Stream is sensitive to sediment input and any temporary sediment pollution incidents are likely to have a long-term impact on the river (Appendix 13.5 Geomorphological assessment) **(TR010037/APP/6.3)**.

9.2. Mitigation of construction related flood risk

9.2.1. 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.

9.2.2. Any temporary and permanent drainage arrangements would be implemented before construction. During construction, best practice methods for mitigation of temporary flood risk to and from the Proposed Scheme would be implemented as part of the wider Environmental Management Plan (EMP **(TR010037/APP/7.4)**). There are construction activities planned immediately adjacent to Cantley Stream. As such, consent for these activities will be required from Norfolk County Council.

9.2.3. A temporary works drainage strategy must be specified within the EMP **(TR010037/APP/7.4)** 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 (Appendix 13.2) (**TR010037/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.

9.2.4. 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.

9.2.5. 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.

9.2.6. The construction of the structures within the Cantley Stream floodplain must be constructed in a phased manner to avoid additional flood risk, over and above that stated in section 8.2. The construction of Cantley Lane South culvert and the stream realignment, prior to Cantley Lane link road would mitigate against potential impacts to nearby receptors including construction workers.

9.2.7. 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 areas as defined in this assessment.

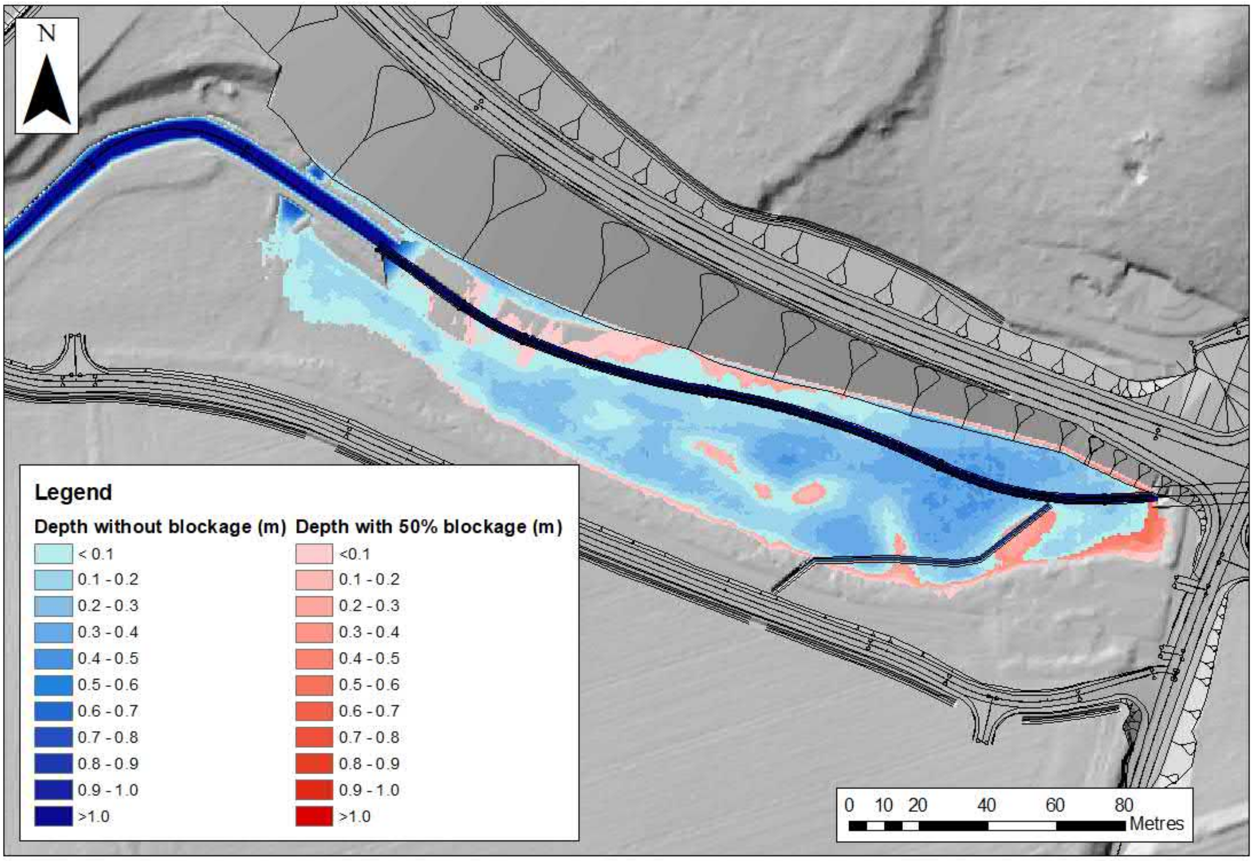
9.2.8. A flood emergency response plan will be developed as part of the temporary works drainage strategy within the EMP **(TR010037/APP/7.4)** to manage the flood risk impacts during construction and to ensure construction workers are not exposed to increased flood risk.

9.2.9. Given the above mitigation, it is anticipated that during construction the Proposed Scheme will not result in an increase in flood risk elsewhere, over and above what is described in section 8.2.

10. Residual risk

10.1.1. A sensitivity assessment was undertaken to determine the flood risk impacts if the Cantley Lane South culvert was blocked by 50%. The model found that for the 100-year plus 65% climate change event, throttling re-occurred upstream of the Cantley Lane South culvert, as it did in the baseline scenario. The blockage increased flooding in the Cantley Stream floodplain and along the toe of the link road south embankment (see Figure 10-1). There is no residual risk associated with the culvert under the proposed Cantley Lane link road.

Figure 10-1: Maximum flood extent for the 100-year plus 65% event due to a 50% blockage in the Cantley Lane South culvert



10.1.2. Storms in exceedance of the proposed drainage design storm (1 in 100 year with 40% rainfall climate change allowance) should be retained within the highway boundaries and eventually routed back into the drainage networks once the extreme event has receded. Should exceedance events extend beyond the highway boundary overland flows would follow existing surface water flow paths towards Cantley Stream; there are no flood-sensitive downstream receptors between the proposed highway drainage system and the stream. Surface water exceedance events for Cantley Lane link road and Cantley Lane South (catchments E and E2 in Annex D) would be retained within the carriageway and where exceeded would flow eastwards towards Cantley Stream.

10.1.3. Therefore, the residual flood risk to others is considered to be low and would be reduced compared to the existing drainage.

10.1.4. Residual risk from groundwater flooding is considered to be low.

10.1.5. Paragraph 160 of the NPPF (MHCLG 2016, 2019) states that for an Exception Test that is informed by a site-specific Flood Risk Assessment to be passed, the development will not increase flood risk elsewhere and where possible, will reduce flood risk overall. Section 5.94 of the NPS NN (Department for Transport, 2014) states that if a FRA is required, the applicant should include the assessment of the residual risk after risk reduction measures have been considered.

10.1.6. With mitigation in place, the Proposed Scheme will not increase flood risk to any 'more vulnerable' (i.e. residential) receptors. There are changes to the patterns of flood risk resulting from the removal of the existing Cantley Lane South culvert throttle and the stream realignment to downstream farmland and amenity areas. Furthermore, the carriageway itself, including Cantley Lane south, is not at risk of flooding during the design event.

10.1.7. Considering the above, it is considered the Proposed Scheme passes the Exception Test and meets the requirements of both the NPPF and NPS NN.

11. Conclusion

11.1.1. This Flood Risk Assessment (FRA) is a requirement of the National Planning Policy Framework (NPPF) and the National Policy Statement for National Networks (NPS NN). This report investigated all potential flood mechanisms relevant to the Proposed Scheme in accordance with the NPPF.

11.1.2. Consultation with the Environment Agency and Norfolk County Council was undertaken in 2018, 2020 and 2021 as part of this assessment and is ongoing.

11.1.3. The Environment Agency's historic flood map (Environment Agency, 2020c) does not indicate any areas of previous flooding within the area of the Proposed Scheme. Historic flooding issues at the existing A47 / A11 Thickthorn Junction will be addressed by a separate Highways England scheme.

11.1.4. The Environment Agency's flood map for planning and the Greater Norwich Strategic Flood Risk Assessment identifies the majority of the Proposed Scheme within Flood Zone 1. There are areas identified within Flood Zones 2, 3 and the indicative extent of the existing Flood Zone 3b such as the embankment for the proposed Cantley Lane link road. These areas are associated with Cantley Stream and the floodplain.

11.1.5. A detailed hydraulic modelling assessment of Cantley Stream predicted flooding for the 100-year event upstream of the A11 and throughout the Cantley Stream floodplain around Cantley Lane South and the A47. Climate change impacts increase the predicted flood depths. The Proposed Scheme is considered to be at high risk of fluvial flooding.

11.1.6. The Environment Agency' flood risk from surface water map indicates that most of the Proposed Scheme is at very low risk from surface water flooding. The Proposed Scheme intercepts surface water flood flow pathways and as such is considered to be at high risk of surface water flooding.

11.1.7. The BGS groundwater flooding susceptibility maps show the majority of the Proposed Scheme area has limited potential for groundwater flooding to occur. There are areas of potential for groundwater flooding associated with Cantley Stream. There are no historical records of groundwater flooding within the vicinity of the Proposed Scheme but findings from the ground investigation suggest that groundwater flooding is a potential risk in the vicinity of Cantley Stream.

11.1.8. The Proposed Scheme is at low risk of flooding from water, sewerage and highway infrastructure failure. The Proposed Scheme is not at risk of flooding from canals, reservoir failure or tidal sources.

11.1.9. The removal of the throttle at the Cantley Lane South culvert, extension of the A11 culvert and Cantley Lane stream realignment have the potential to displace fluvial flood waters which may in turn increase flood risk to others. The Proposed Scheme is predicted to increase flood depths at a residential receptor adjacent to Intwood Road and property level protection is proposed as mitigation. Confirmation of the impact at the property near Intwood Road and, therefore the required mitigation, is subject to additional survey and modelling to better predict the impacts in this location. No other 'more vulnerable' receptors are affected by the Proposed Scheme. There are also changes to the patterns of fluvial flood risk within the Cantley Stream floodplain, with predicted increases and decreases in flood depth depending on the location. The removal of the existing Cantley Lane south culvert removes the throttle to flood flows, reducing flood depths immediately upstream and changing the pattern of flood risk downstream (along with the stream realignment). The differences in flood depths affect agricultural (pasture) land and areas of amenity use which are classed as 'less vulnerable' and 'water-compatible' under the NPPF flood risk vulnerability classification.

11.1.10. The proposed drainage system will discharge at greenfield runoff rates and provide sufficient attenuation for the 100-year plus 40% climate change rainfall event. The proposed drainage design will use a combination of surface water channels, kerb and gullies and combined surface water drainage systems. The proposed SuDS features included within the drainage design include, vegetated detention basins, filter drains and grassed ditches. Runoff from existing drainage areas will either remain as existing or reduce. Discharge from the proposed drainage system to Cantley Stream will have negligible impacts on flood risk at Cantley Stream and on freeboard at the new Cantley Lane South culvert.

11.1.11. Where the Proposed Scheme intercepts surface water flood flow pathways, pre-earthworks drains, cross drains or 'dry culverts' conveying natural catchment drainage / overland flood flow pathways must be designed to accommodate a 1 in 100-year storm event including a 40% climate change allowance to mitigate impacts to the Proposed Scheme and to others. The exact location and sizing of the cross drains shall be confirmed at detailed design once a detailed local topographic survey has been undertaken.

11.1.12. Based on the above, it is considered that the Proposed Scheme will not result in additional fluvial or surface water flood risk.

11.1.13. There is potential the Proposed Scheme could intercept the Chalk aquifer during construction of the A11-A47 connector road. A pumped solution is necessary as a gravity outfall cannot be achieved. Any groundwater ingress to this area is managed by the proposed drainage which would convey the groundwater drainage to a pumping station where it would be pumped to a detention basin.

The magnitude of the groundwater ingress would be informed by the supplementary ground investigation. Where possible, below ground structure design including piling shall ensure there is no barrier to groundwater flow which may cause groundwater mounding.

11.1.14. Potential impacts on flood risk during construction will be mitigated by the implementation of appropriate temporary drainage measures defined in the temporary works drainage strategy which will be included in the EMP (**TR010037/APP/7.4**). The construction of the structures within the Cantley Stream floodplain must be constructed in a phased manner to avoid additional flood risk, over and above that stated in section 8.2. The construction of Cantley Lane South culvert and the stream realignment, prior to Cantley Lane link road would mitigate against potential impacts to nearby receptors including construction workers.

11.1.15. Residual risk from the blockage of the proposed Cantley Lane South culvert, exceedance of the proposed drainage design and groundwater flooding is considered to be low.

11.1.16. This FRA has considered the risk to the Proposed Scheme and the risk posed by the Proposed Scheme on flooding from all sources. With mitigation as part of the Proposed Scheme will be safe for its lifetime and will not cause any increase in surface water and groundwater flood risk elsewhere. The Proposed Scheme will not increase fluvial flood risk, with mitigation, to ‘more vulnerable’ receptors. There are changes to the patterns of flood risk resulting from the removal of the existing Cantley Lane South culvert throttle and the stream realignment to downstream farm land and amenity areas. However, the development is considered appropriate under the requirements of the NPPF and NPS NN.

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Annex A. Freeboard and flood risk at Cantley Lane South technical note

A47/A11 THICKTHORN JUNCTION

Appendix 13.1 Annex A Freeboard and Flood Risk at Cantley Lane South Culvert

PCF STAGE 3
AUTHORISED AS STAGE 3 COMPLETED | A3
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1. Introduction

1.1.1. The Proposed Scheme at A47 Thickthorn Junction includes relocation of access roads to Cantley Lane South between the A11 and A47 in Norfolk. These works require the realignment of Cantley Stream – an ordinary watercourse tributary of the River Yare – and the replacement of an existing culvert beneath Cantley Lane South.

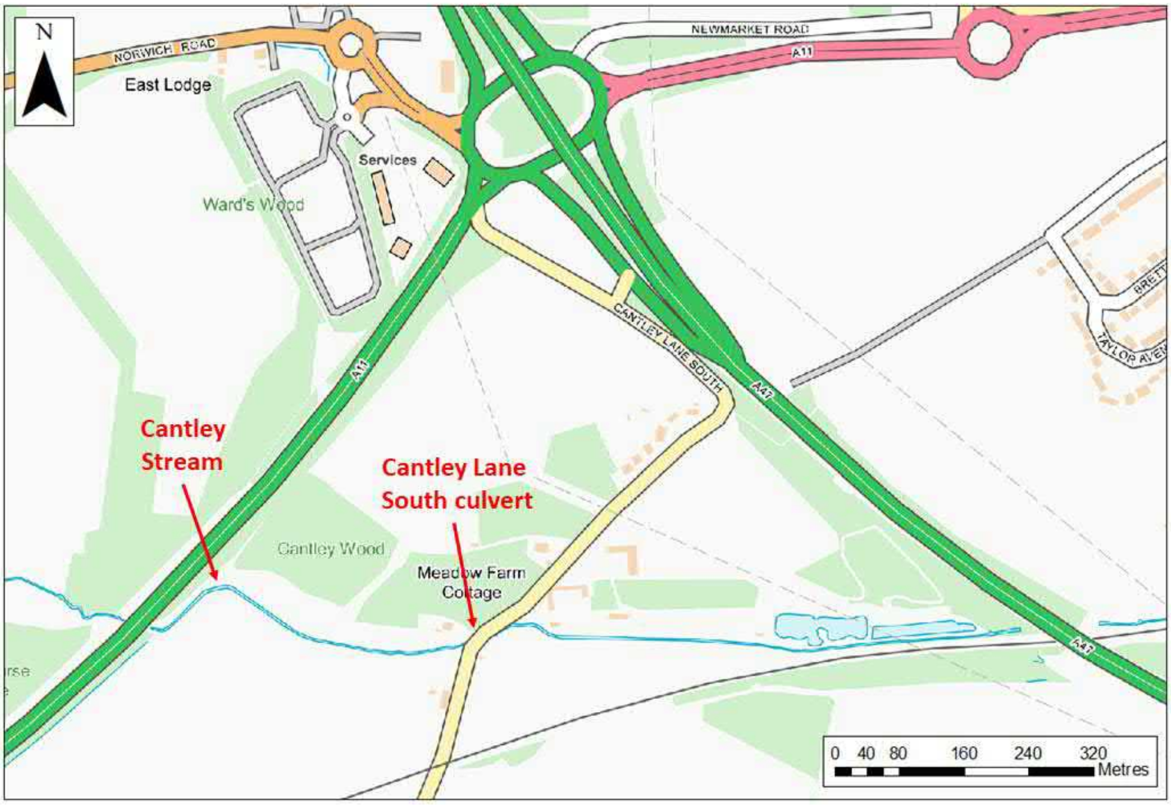
1.1.2. The proposed culvert at Cantley Lane South provides a significant improvement in terms of flow compared to the existing culvert. However, the replacement culvert does not allow for the level of freeboard originally requested by the Lead Local Flood Authority (LLFA). Additionally, the Design Manual for Roads and Bridges (DMRB) requires that structures with freeboard below the threshold requested by the LLFA be designed for impact from debris.

1.1.3. This note has been compiled to summarise decisions taken with respect to the realigned stream and new culvert. The discussion includes an overview of the existing watercourse and culvert at Cantley Lane South, a summary of the various constraints on culvert and channel design, a summary of the analysis carried out through modelling and the conclusions reached with respect to design.

2. Existing culvert at Cantley Lane South

2.1.1. The Thickthorn Junction is located at the intersection of the A11 and A47 southwest of Norwich in Norfolk. The A11 and A47 run northwest-southeast and northeast-southwest, respectively. Cantley Stream is located south of the junction, flowing west to east and crossing beneath both A-roads. The existing culvert is located beneath Cantley Lane South, which is situated between the A-roads and provides access to farms and other properties. A map of Thickthorn Junction is provided in Figure 2-1.

Figure 2-1 : Map of Thickthorn Junction



* Contains OS data © Crown copyright and database right 2020.

2.1.2. The existing culvert at Cantley Lane South is an arch sprung-shaped concrete culvert that crosses beneath a bend in the road. The opening to the culvert is approximately 1.6m across and 0.9m high. The length of the culvert is approximately 10m. The stream appears to briefly run parallel to the headwall before entering the culvert at approximately a 90-degree angle (Figure 2-2).

Figure 2-2: Photographs upstream (left) and downstream (right) of existing Cantley Lane South culvert

2.2. Throttling behaviour

2.2.1. The existing culvert is shaped and positioned such that baseline modelling predicts significant throttling of flood water at the upstream end of the culvert. Modelling of high flow events predicts flooding to a depth of 1.08m upstream of the culvert where water collects in the floodplain between two ridges (Figure A.5 in Appendix A).

2.2.2. The existing culvert was also found to act as a throttle during low flows. Whilst water remained in bank, water depths are predicted to be elevated compared to nearby reaches. The Low Flows 2 software was used to estimate the streamflow that is exceeded 95% of the time (Q95) for Cantley Stream. Figure 2-3 shows stream depths upstream and downstream of the existing culvert when running the baseline model with a steady Q95 flow.

2.2.3. The throttling of the culvert means that for a distance of approximately 160m upstream of Cantley Lane South, depths will exceed 0.37m for at least 347 days per year under baseline conditions. Depths further upstream and closer to the A11 culvert are lower as the effect of throttling is reduced upstream. These depths are important for the suitability of habitat for water voles in Cantley Stream (see Section 3.4).

Figure 2-3 : Predicted baseline stream depths near Cantley Lane South for Q95 low streamflow

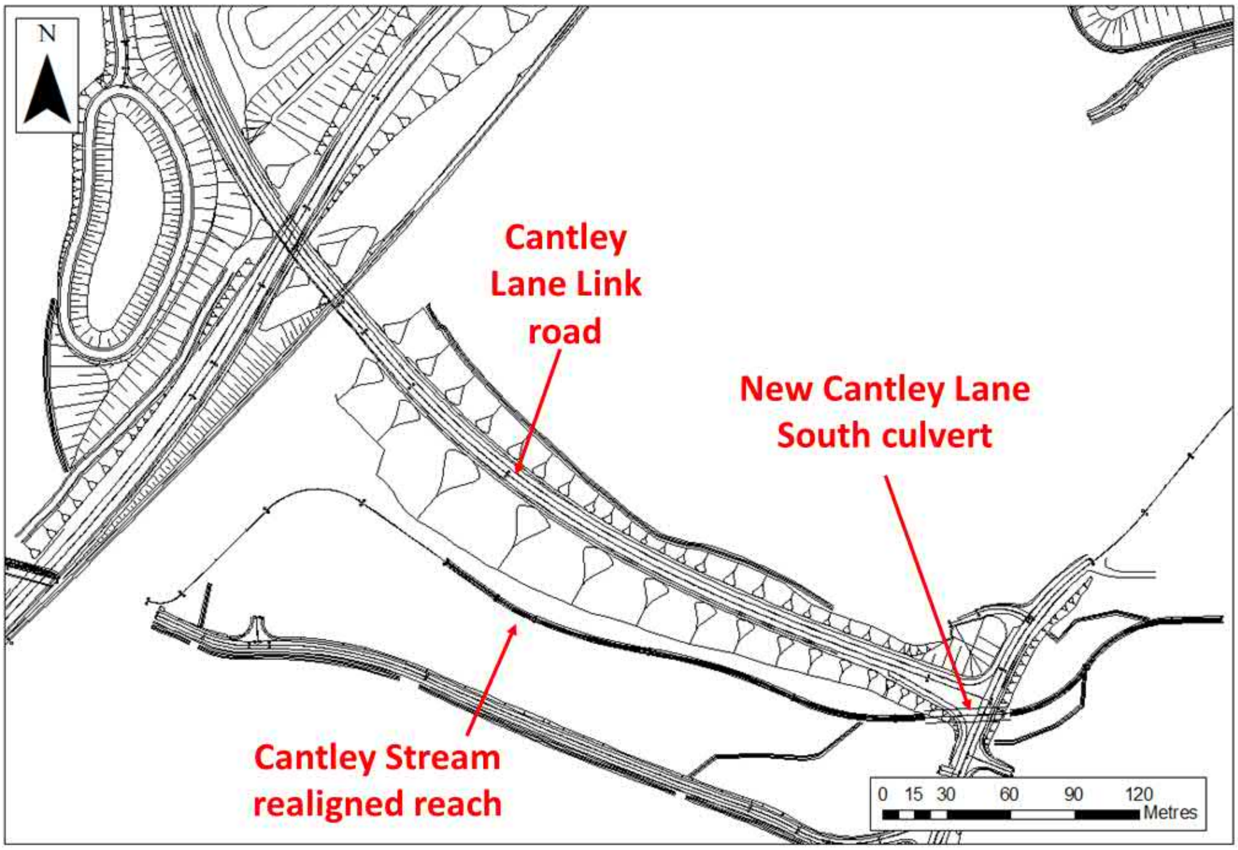
* Contains OS data © Crown copyright and database right 2020.

2.2.4. As discussed in the following section, the existing throttle at Cantley Lane South in the area of realignment has had implications for redesign of the channel and culvert for the Proposed Scheme at Thickthorn Junction.

2.3. Proposed replacement

2.3.1. A drawing of proposed structures in the area of realignment is shown in Figure 2-4. The location of the replacement culvert is indicated.

Figure 2-4 : Proposed new structures upstream of Cantley Lane South



3. Constraints

3.1.1. Several interests and constraints with respect to the new channel and culvert design were identified. These include constraints to the road and culvert design, geomorphological interests, ecological requirements and the prevention of new flood risk.

3.2. Road design constraints

3.2.1. The road design and elevation were constrained by several factors, including:

- An unobstructed visibility splay is required at the junction of Cantley Lane South and the proposed Cantley Lane Link road between the A11 and Cantley Lane South.
- The proposed road must tie into the existing carriageway prior to the Cantley Lane South Breckland Railway structure and prior to the Meadow Farm Cottages property access.
- The access to the properties at Bridge Cottages must be retained.
- The access to the property at 128 Cantley Lane South must be retained.
- The proposed road must tie in with the levels of the proposed Cantley Lane Link at the proposed junction location.

3.2.2. In terms of vertical alignment, for a design speed of 70kph as applied to Cantley Lane South, a desirable minimum sag curvature K-value of 20 and a desirable minimum crest curvature K-value of 30 is required by CD 109 Table 2.10 in the Design Manual for Roads and Bridges (DMRB). The K-value is an expression of the degree curvature of the vertical alignment based on the length of curve required for a change in 1% gradient. The proposed design utilises sag curvature K-values of 9 and a desirable minimum crest curvature K-value of 17, which is considered a two-step relaxation and one-step relaxation from the standard, respectively, in order to meet the constraints outlined above. As these relaxations are on the approach to the junction between Cantley Lane Link and Cantley Lane South, this constitutes a departure from DMRB standard. All proposed departures have been agreed with the local authority.

3.2.3. The road elevation at Cantley Lane has been maximised, within the constraints listed, to provide the most space for the culvert and associated freeboard. Raising the road from its present elevation would require a further reduction in vertical curvature in order to ensure that access is retained to the properties along Cantley Lane South. Further reducing the vertical geometry is not considered appropriate due to potential safety implications to road users.

3.3. Culvert design constraints

3.3.1. The dimensions of the culvert are informed by modelling streamflow through the culvert (see 4.2.2) under various conditions. As discussed in the preceding section, the road level cannot be raised, and the height of the culvert is therefore constrained by the existing road level. It is further constrained by a minimum thickness of surfacing materials of 120mm as defined in CD 358 Section 8.2 of the DMRB. This is considered a minimum thickness and cannot be reduced. Overall culvert dimensions are also constrained by the sizing of pre-cast units and structural integrity.

3.3.2. Additional considerations include environmental impact and depositional issues related to hydraulic effects of the culvert. For example, if stream velocities are slowed too suddenly through the culvert, an obstructive build-up of sediment could result from deposition. Environmental considerations related to stream depths are discussed in the following section.

3.4. Water vole habitat

3.4.1. Cantley Stream is home to a population of water voles, which are protected under Schedule 5 of the Wildlife and Countryside Act 1981 (as amended). Water voles require a habitat in which the stream is sufficiently deep for swimming and an ideal water depth is approximately 30cm. Although the water voles are present at some other locations along the stream, the reach requiring realignment upstream of Cantley Lane South has been an especially favourable habitat where they are present in high numbers.

3.4.2. As discussed in Section 2.2, current water depths along parts of this reach are higher than elsewhere in the stream on account of a throttle at the existing culvert and the higher depths have allowed a relative medium to high number of water voles to thrive along both banks between the A11 and Cantley Lane South. As the water voles' habitat is protected, this constraint has dominated over other aspirations such as improving the geomorphological state of the stream.

3.5. Geomorphology

3.5.1. Cantley Stream is a chalk stream that has been heavily modified. As a result of these modifications, the stream no longer has features typical of natural chalk streams, which offer rare habitats in the UK. An ideal realignment of the stream would attempt to re-create a more natural planform and channel dimensions in the hope of restoring some of the stream's natural chalk features. The ideal chalk stream has a minimum 1:10 depth to width ratio, meaning that the realigned channel would have be widened significantly from its current state in order to achieve this level of restoration.

3.5.2. The behaviour of a stream is partially governed by the available energy to move sediments. In general, it is better to not change the existing gradient in a realigned river as the extra momentum may trigger geomorphological change. At Cantley Lane the realigned reach, upstream of the culvert, has been slightly steepened to so that the river is as low as possible at the culvert. Downstream of the culvert the realigned watercourse is slightly less steep so that it ties into the continuation. This steepening is subtle and was agreed in principle with Norfolk County Council during a previous consultation meeting on 6 August 2020.

3.6. Downstream flood risk

3.6.1. The existing culvert at Cantley Lane South throttles streamflow such that water backs up at the upstream end. Therefore, consideration must be given to whether changes to this throttling behaviour, especially a removal or reduction in throttling, introduce any new flood risk downstream of the culvert.

4. Decisions and modelling

4.1.1. The roads and structures teams considered the constraints outlined in Section 3 as part of their design of the realigned Cantley Stream and new culvert. These design decisions were further informed by fluvial modelling to simulate streamflow in Cantley Stream under varying post-development scenarios.

4.2. Preliminary design

4.2.1. As discussed previously with the LLFA, the gradient of the stream was increased from its original design to allow the proposed roads to be as compliant as possible with DMRB standards. This also had the effect of creating more space for the culvert.

4.2.2. Preliminary modelling using an ideal channel and varying culvert widths based on pre-cast units showed that a 6m-wide culvert eliminated surcharging in the culvert. The stream width was initially designed to be consistent with the geomorphology interests summarised in Section 3.5. This channel width was predicted to allow for the LLFA's requested 600mm of freeboard above flood levels for a 100-year fluvial event with 65% climate change. Freeboard was further maximised in the culvert design by using a minimum thickness for cover to the road.

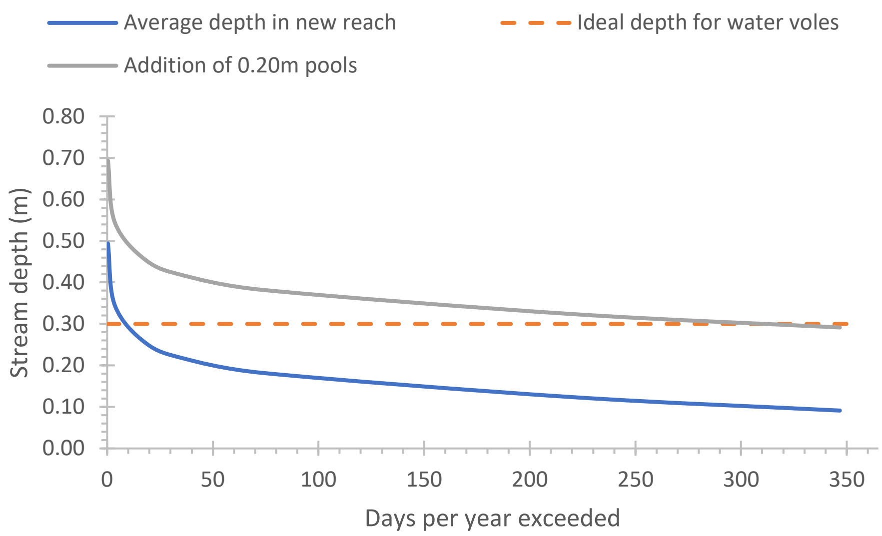
4.2.3. The model showed that the consequence of allowing for freeboard by eliminating surcharging was the removal of the throttling behaviour at Cantley Lane South. Modelling predicted that the removal of throttling would not significantly increase downstream flood risk (Section 5.4).

4.3. Channel width and water vole habitat

4.3.1. Simulations carried out with low flows in the preliminary wider channel design suggested that the combination of river widening and removal of the culvert throttle reduced low flow water depths compared to the existing arrangement. Rather than the higher depths at the culvert illustrated in Figure 2-3, the removal of the throttle led to more uniform depths along the stream. Depths throughout the new wider stream were predicted to be unsuitable for water voles.

4.3.2. The proposed channel design was narrowed to increase channel depths and allow for a more adequate water vole habitat, which entailed reducing the scope of geomorphological benefits and reducing freeboard below the LLFA's requested level (600mm). While mean flow depths in the narrowed channel (approximately 16cm) are more consistent with those along much of the existing stream, it will still be necessary to implement measures to provide the ideal water depth of 30cm for the water voles. Figure 4-1 shows a prediction of average stream depth in the realigned reach versus the number of days per year the stream is at that depth. Given that the 30cm target cannot be achieved in the new reach for more than approximately 11 days per year, riffles and pools with an additional depth of 20cm have been introduced to the proposed design to maintain 30cm water depth during low flows throughout the full length of the diverted reach upstream of Cantley Lane South.

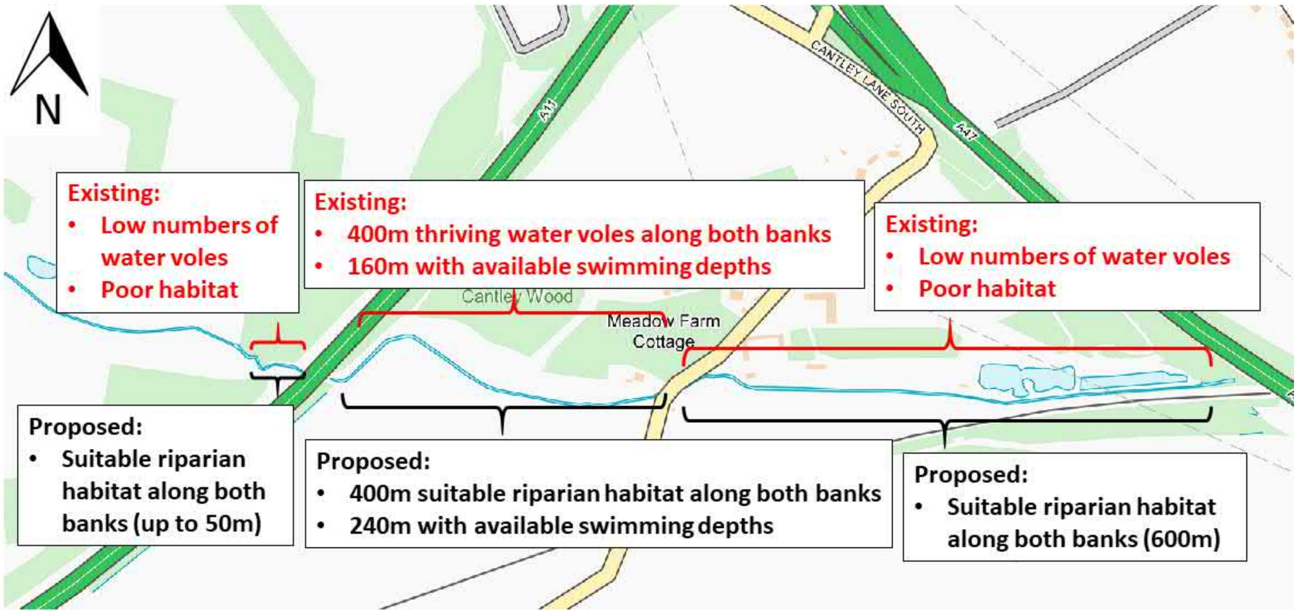
Figure 4-1 : Average stream depth in realigned reach vs. number of days on which depth is exceeded



4.3.3. The nature of riffles and pools mean that the water depth along the realigned reach will not be uniform. There will be areas where water depths are still sometimes below 30cm. However, providing riffle and pool features along the this reach (approximately 240m from the realignment upstream tie-in point to the Cantley Lane culvert inlet) will provide an improvement in terms of the reach length with suitable swimming depths for water voles in this section of the stream. Currently, the higher stream depths are in the 160m section immediately upstream of Cantley Lane South (see Section 2.2). Figure 4-1 shows that with 20cm deep pool features and 10cm, then sufficient depths for water voles would be achieved for approximately 310 to 320 days per year. This is a slight reduction in the number of days compared to baseline conditions (see Section 2.2). However, this would be offset by the greater length of the reach achieving minimum depths of 0.30m and the additional improvements summarised in paragraph 4.3.4.

4.3.4. In addition to the riffles and pools along the realigned reach, it is proposed to improve riparian planting along both banks where current conditions are sub-optimal for water voles. The improvements are proposed for 600m directly downstream of Cantley Lane South and up to 50m upstream of the A11 bridge extension. The enhancements to these reaches, in addition to the riffles and pools of the realigned reach, are expected to increase the length of water voles' habitat to approximately 1km along both banks. Figure 4-2 illustrates existing and proposed habitat for water voles. Based on these values, a total of 2100mm of suitable water vole bank habitat (i.e. both banks along a 1050m reach) will be provided. Furthermore, suitable swimming habitat will be provided along a 240m reach compared to 160m under baseline conditions. This provides a substantial net benefit compared to existing conditions.

Figure 4-2 : Comparison of water vole habitat pre-works and post-works

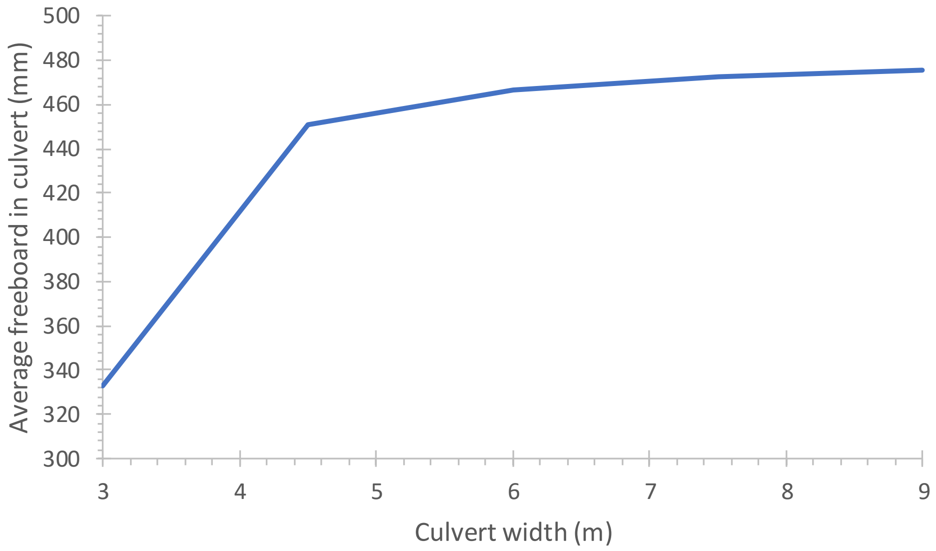


Additional considerations

4.3.5. Further considerations for the narrower channel include the guidance published by The Mammal Society (Dean *et al.*, 2016) for water vole mitigation. This guidance recommends bank gradients approaching 1:1 that extend above flood levels. The current channel geometry used for modelling and assessment is preliminary, but includes bank slopes near 1:1 or steeper from the bank tops to the edge of the bed. While some post-development overbank flooding is predicted to occur for a 1 in 100-year event, flows are predicted to be more contained than under baseline circumstances. A more refined channel geometry will be defined at detailed design stage and will ensure the bank profiles and riffle-pool features are designed to maximise benefit for water voles in line with the guidance outlined above.

4.3.6. With respect to freeboard, the width of the culvert was already set at the widest available pre-cast unit and diminishing gains were found in widening the culvert beyond 6m (Figure 4-3), which was already considered the maximum reasonable width for the final narrower channel design.

Figure 4-3 : Average freeboard between upstream and downstream ends for different culvert widths



5. Final design

5.1.1. As summarised in Section 3, the numerous constraints on the design of the Cantley Lane South culvert and the realigned Cantley Stream channel have led to a set of compromises between the parties and interests involved. This section summarises the final results with respect to the interests of the LLFA. The final design of the river channel and realignment, including the riffle pool sequence, will be undertaken at detailed design stage.

5.2. Summary of proposed design

5.2.1. Table 5-1 summarises the final design decisions specifically for the realigned reach of Cantley Stream with respect to the items discussed in this note.

Table 5-1 : Existing and final design values for realigned reach of Cantley Stream

Item	Existing	Final value (no riffle/pool features)	Final value (with riffle/pool features)
Channel width (bed)	Approx. 3-4m	Approx. 3m	Approx. 3m
Channel length	388m (incl. culvert)	394m (incl. culvert)	394m (incl. culvert)
Stream gradient	1:326	1:333 US of culvert; 1:454 DS of culvert	1:333 US of culvert; 1:454 DS of culvert
Minimum freeboard through Cantley Lane culvert (100-year event with 65% climate change allowance)	Surcharged	428mm	428mm
Days/year at 30cm or greater water depth	>347 days per year across 160m of the reach	~11 days per year across the whole 394m reach	~310 to 320 days per year across the whole 394m reach

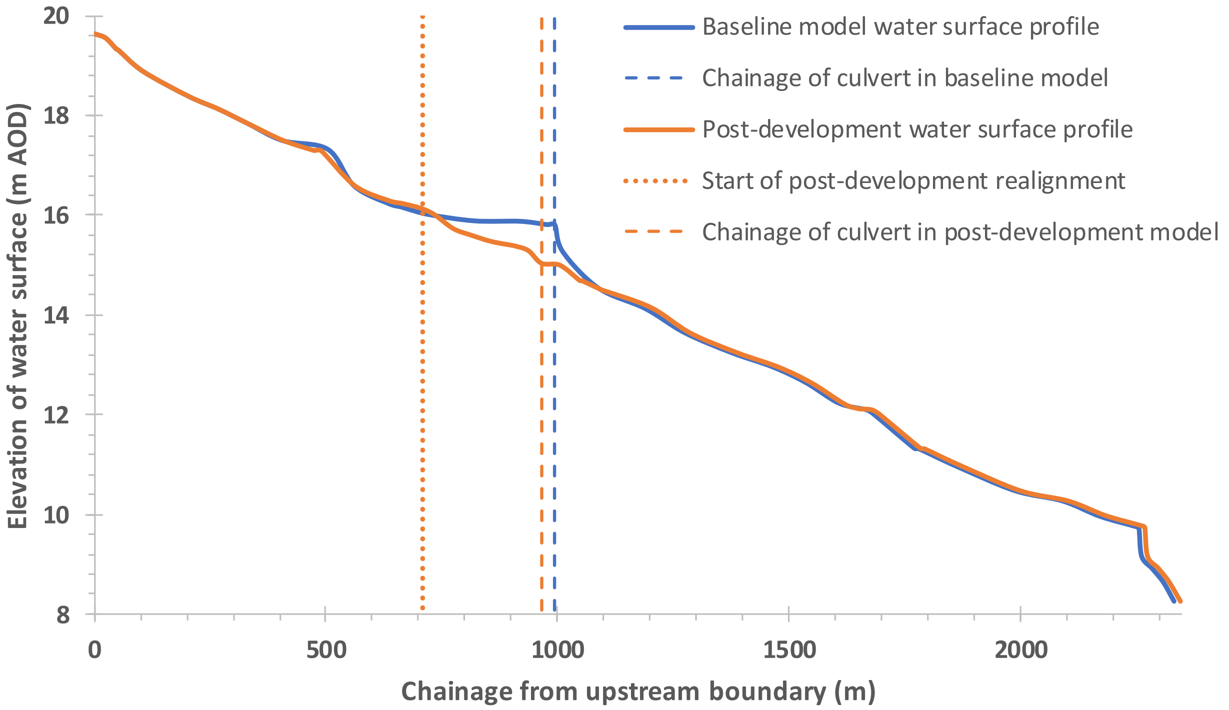
5.3. Freeboard

5.3.1. Although the LLFA has requested that the Cantley Lane South culvert allow for 600mm of freeboard above flood levels for a 100-year event with 65% climate change, modelling of this event determined that this was not possible under the constraints of the design. Modelling of this event using the chosen design predicts a **minimum freeboard of 428mm**. The LLFA has agreed to accept this minimum freeboard under the constraints presented.

5.4. Downstream flood risk

5.4.1. Figure 5-1 illustrates the removal of throttling and minimal change to downstream flood risk by comparing the longitudinal water surface profile for peak levels in the stream for the baseline and post-development models.

Figure 5-1 : Longitudinal water surface profile (peak levels) for baseline and post-development model



5.4.2. The figure shows that flood levels upstream of the realignment are at or below those in the baseline scenario, as the removal of the throttle prevents backup of water in these sections. Furthermore, removal of the throttle leads to only minor changes downstream of the culvert.

5.4.3. Predicted stream levels in cross sections upstream and downstream of the realignment are presented in Table 5-2. The table highlights that the average increase in water levels predicted upstream and downstream of the realignment following development is less than 0.10m. The greatest increase (0.084m) is found at a location where the existing farm access track bridge was removed along with associated head loss.

5.4.4. At the far downstream extent of the model, impact is predicted upstream of the culvert at Intwood Road in the vicinity of a residential receptor. The predicted increase in maximum flood depth was 0.014m compared to baseline conditions. Model uncertainty near the downstream boundary is high and work to quantify the impact to the receptor is under way at the time of writing.

5.4.5. To compare the extent of flooding in the baseline and post-development models, maps of results from each model are provided in Appendix A.

Table 5-2 : Stream levels at cross sections downstream of realignment (baseline and post development)

Cross section name (upstream to downstream)	Baseline water level (m AOD)	Post-development – Simulation 1	
		Water level (m AOD)	Change (m)
_02224	19.636	19.636	0.000
Interpolate 1	19.555	19.554	-0.001
Culvert Cantley Pond US	19.336	19.334	-0.002
_02172	19.301	19.299	-0.002
_02120	18.884	18.884	0.000
_02023	18.381	18.381	0.000
Interpolate 2	18.127	18.127	0.000
_01895	17.83	17.831	0.001
_01824	17.494	17.500	0.006
_01681	16.581	16.587	0.006
_01606	16.227	16.287	0.060
Bridge Cantley Wood contraction*	16.162	16.238	0.076
Bridge Cantley Wood expansion*	16.123	16.207	0.084
Realigned reach			
01072	14.124	14.145	0.021
00986	13.636	13.631	-0.005
00885	13.238	13.237	-0.001
00796	12.948	12.946	-0.002
Interpolate 4	12.635	12.630	-0.005
00654	12.225	12.202	-0.023
00594	12.093	12.092	-0.001
00579	12.007	12.006	-0.001
00484	11.321	11.32	-0.001
00475	11.309	11.308	-0.001
00398	10.972	10.971	-0.001
00268	10.47	10.467	-0.003
00165	10.264	10.26	-0.004
00083**	9.952	9.966	0.014
00007**	9.751	9.765	0.014
00000**	9.711	9.726	0.015
Culvert Intwood Rd DS**	9.149	9.150	0.001
Interpolate 5**	8.902	8.902	0.000
Interpolate 6**	8.628	8.629	0.001
Outfall XS**	8.248	8.249	0.001
Average increase in level baseline to post-development (m):			**0.009**
Average decrease in level baseline to post-development (m):			**-0.002**

*Name changed in post-development model to reflect removal of bridge

**Levels at these sections are affected by the downstream boundary of the model and interpolation of the geometry

6. References

Dean, M., Strachan, R., Gow, D. and Andrews, R. (2016). The Water Vole Mitigation Handbook (The Mammal Society Mitigation Guidance Series). Eds Fiona Mathews and Paul Chanin. The Mammal Society, London.

Appendix A. Baseline and Post-development flood extent maps

Baseline and post-development flood extent maps have been compiled in this appendix for the purposes of comparison. All figures show predicted depths for the 100-year event with 65% climate change. Post-development maps also include the simulated inflows expected from the new drainage network.

The flood extents for the baseline and post-development models are shown against a hillshade view of the rasters representing the baseline and post-development ground, respectively. These rasters are derived from LiDAR imagery of the existing ground and 3D elevation data for the post-development road design. The post-development flood maps also include an overlay of the road design drawing.

Figure A.1 Maximum predicted depths over entire reach for baseline scenario

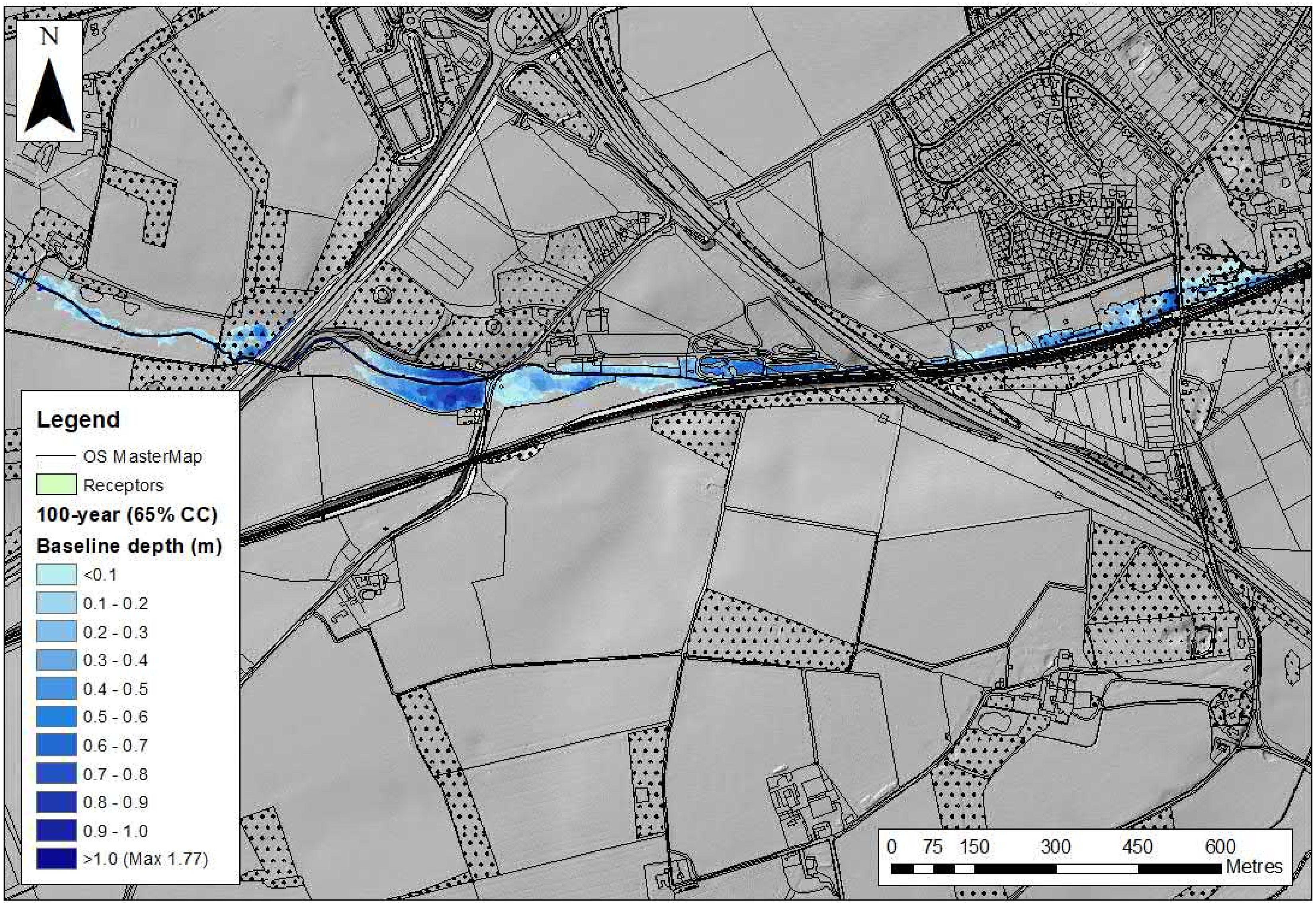


Figure A.2 Maximum predicted depths over entire reach for post-development scenario

Figure A.3 Maximum predicted depths between upstream boundary and A11 for baseline scenario

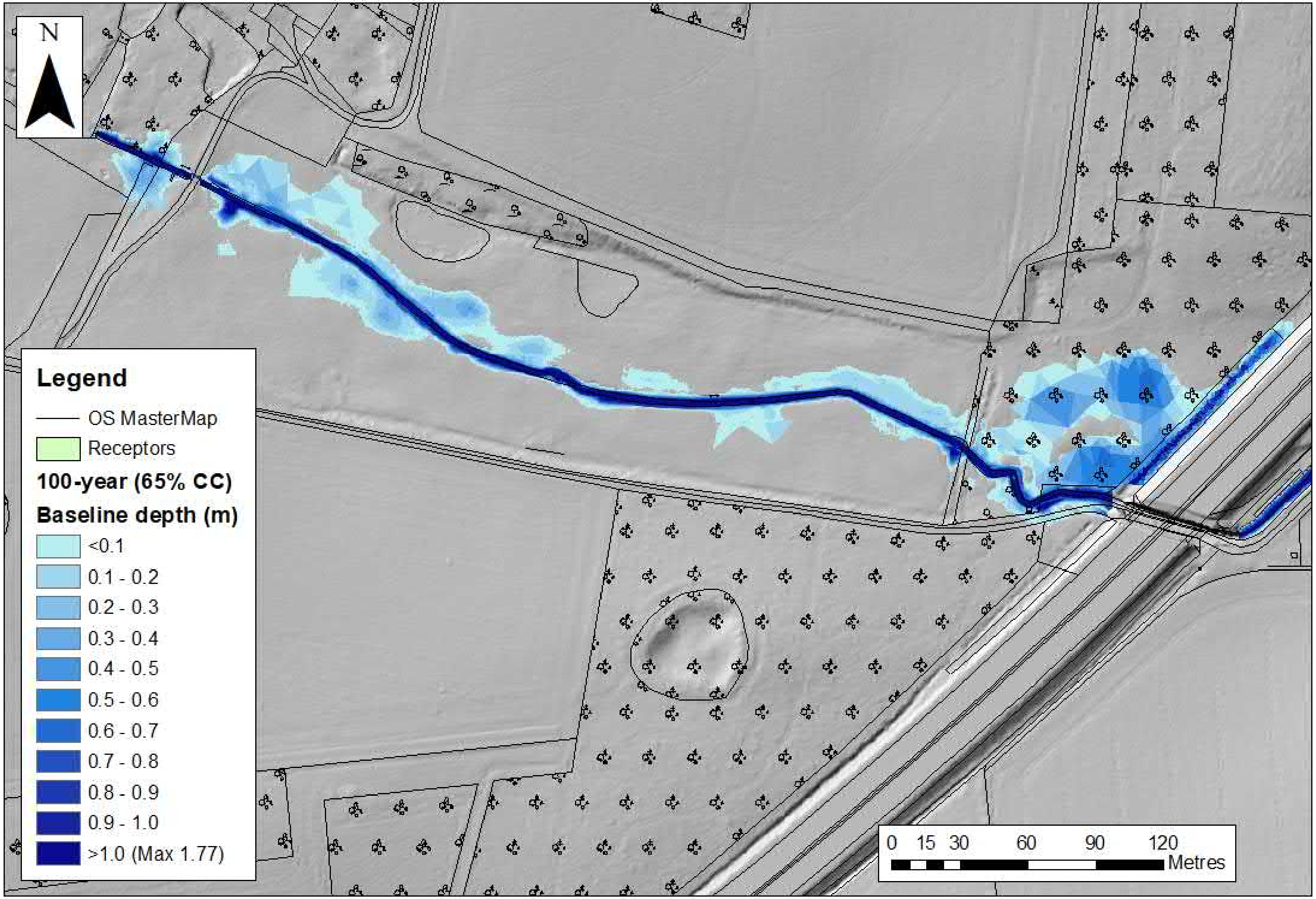


Figure A.4 Maximum predicted depths between upstream boundary and A11 for post-development scenario

Figure A.5 Maximum predicted depths between A11 and Cantley Lane South for baseline scenario

Figure A.6 Maximum predicted depths between A11 and Cantley Lane South for post-devepment scenario

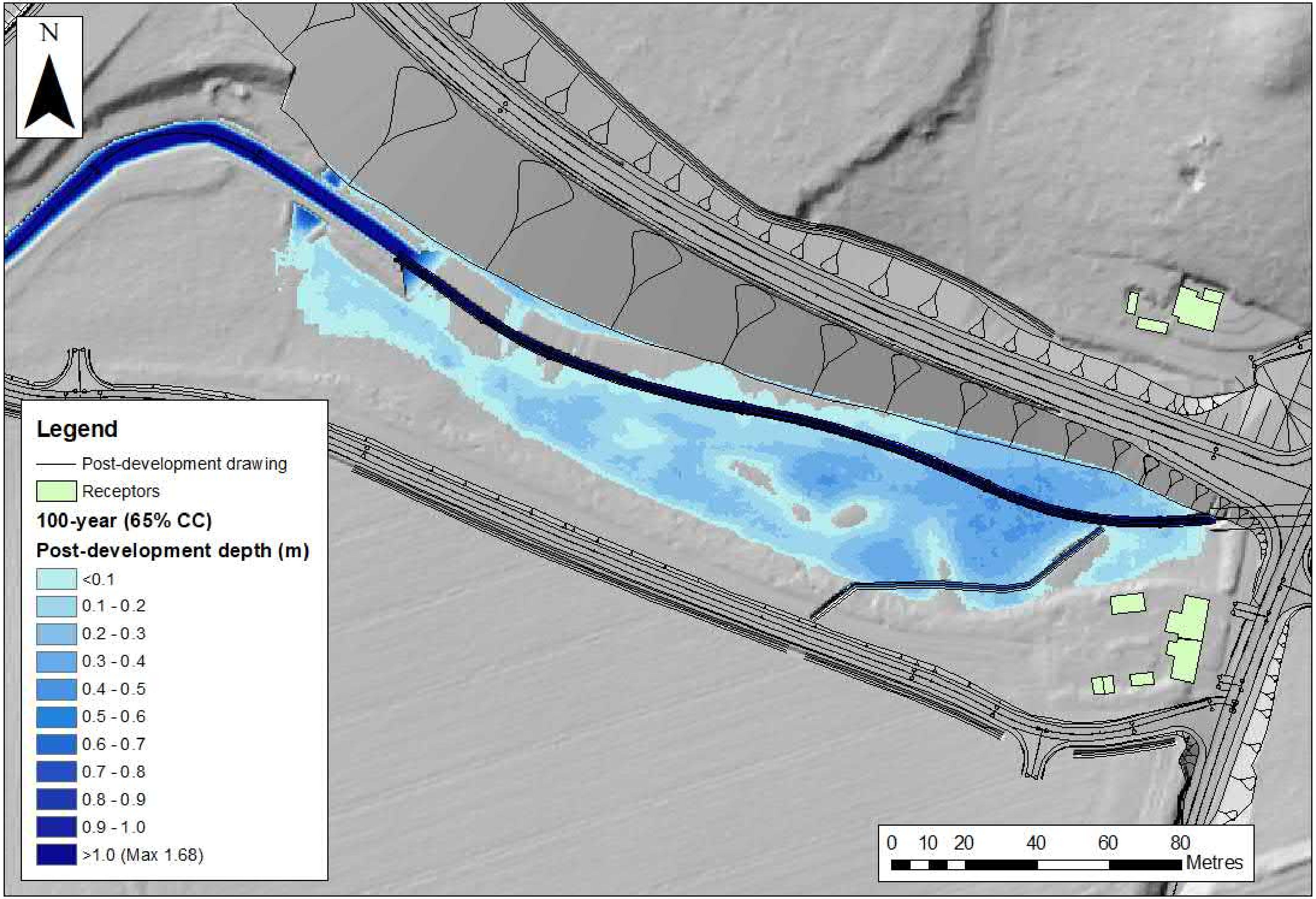


Figure A.7 Maximum predicted depths east of Cantley Lane South for baseline scenario

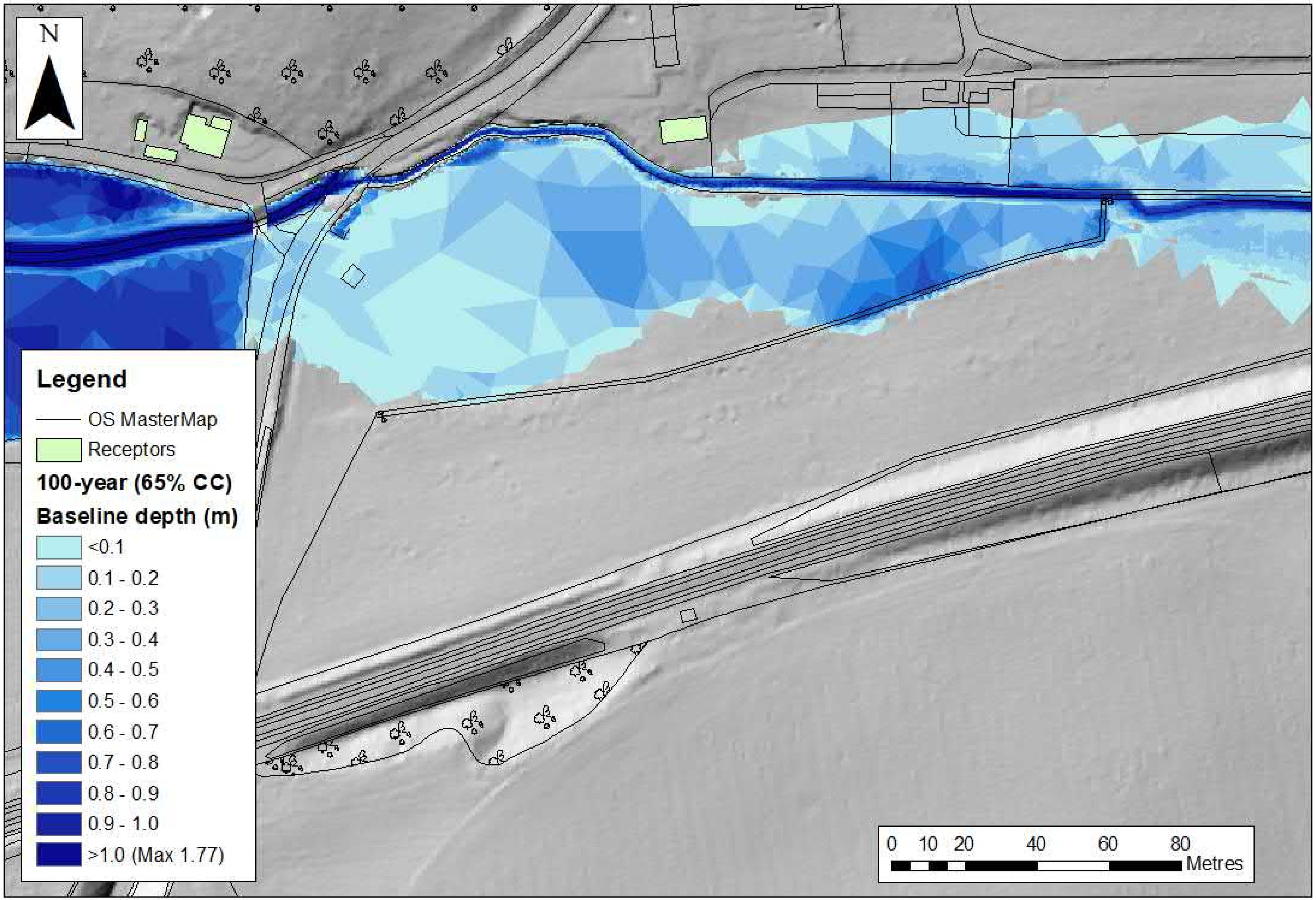


Figure A.8 Maximum predicted depths east of Cantley Lane South for post-development scenario

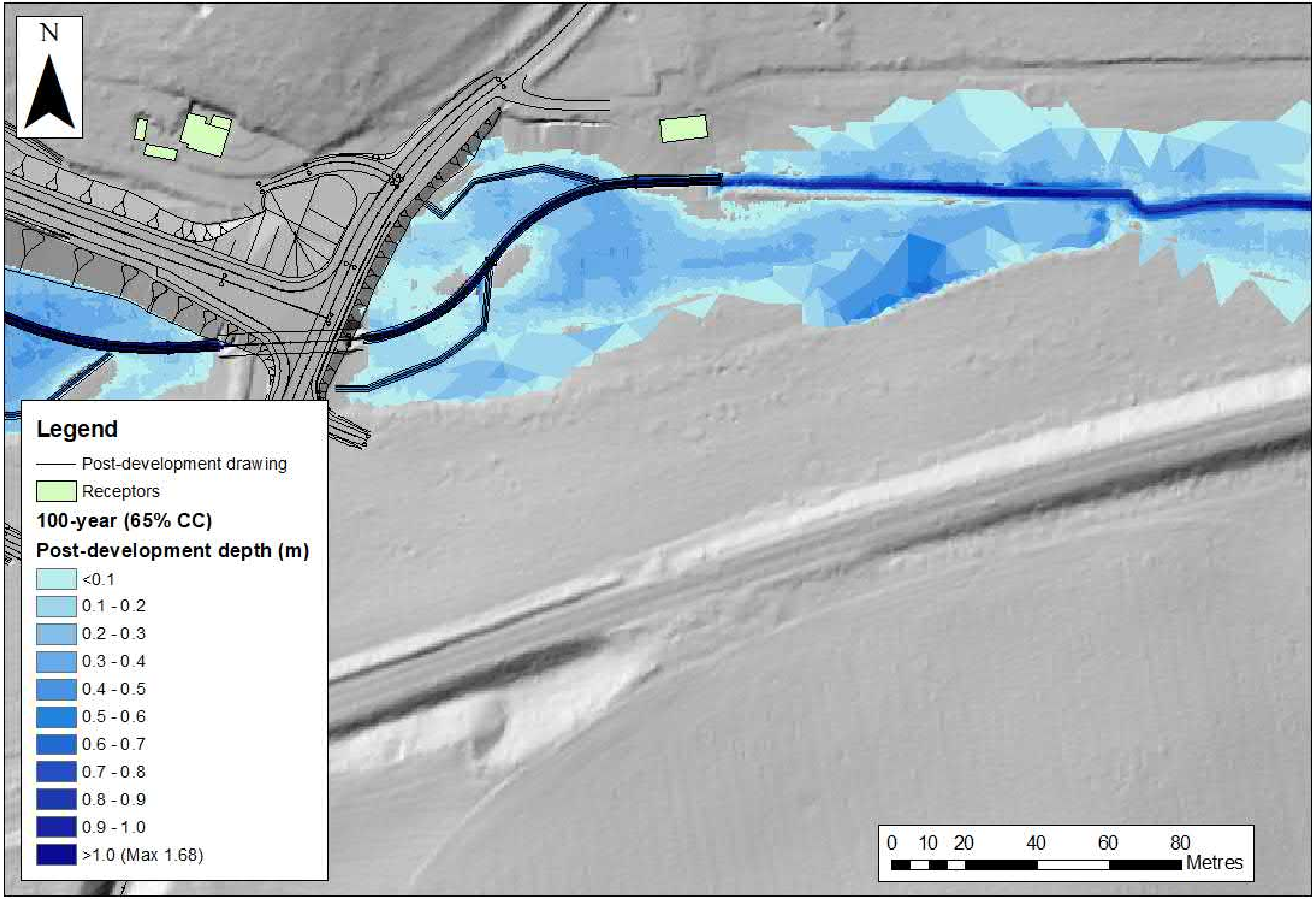


Figure A.9 Maximum predicted depths west of A47 for baseline scenario

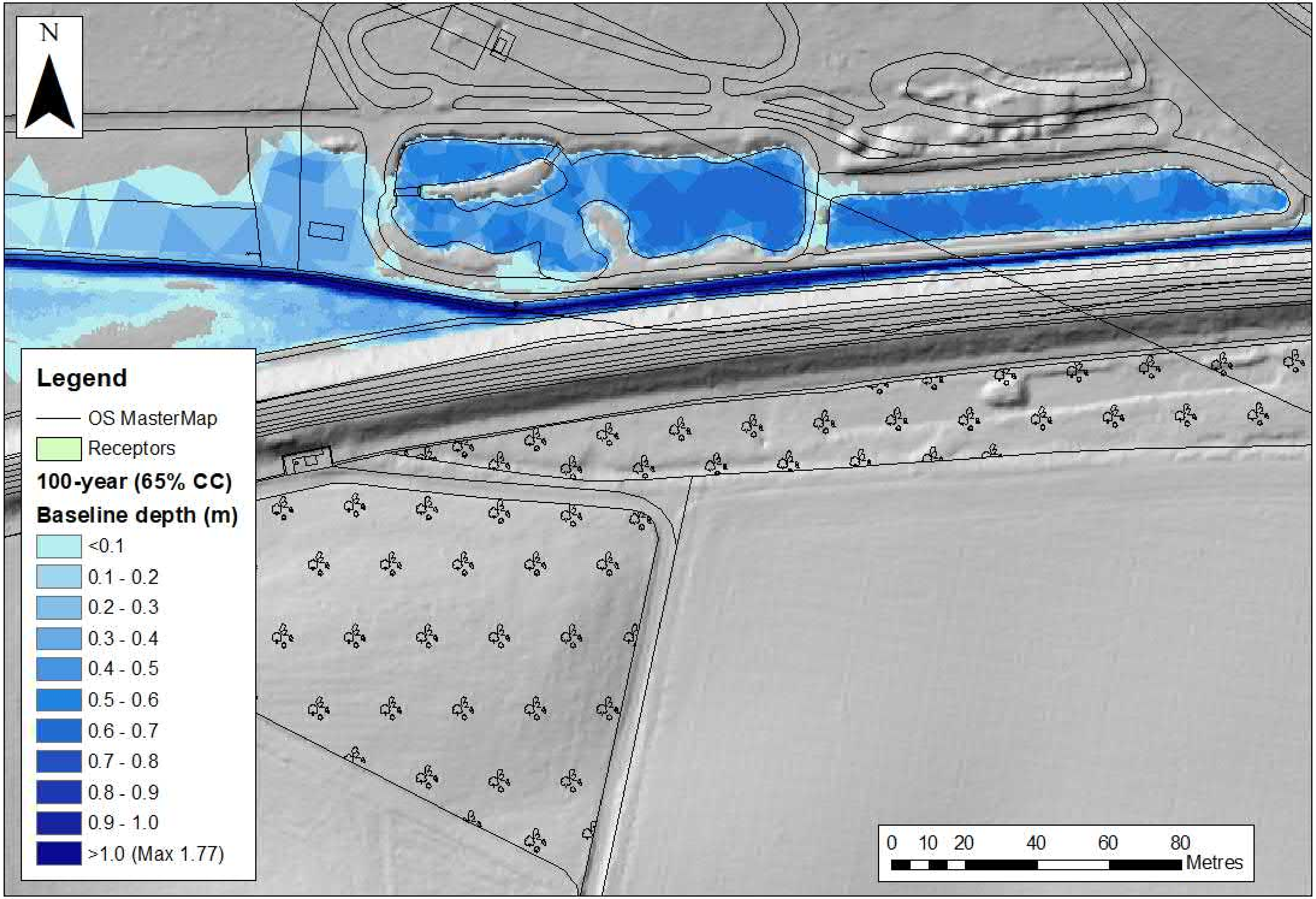


Figure A.10 Maximum predicted depths west of A47 for post-development scenario

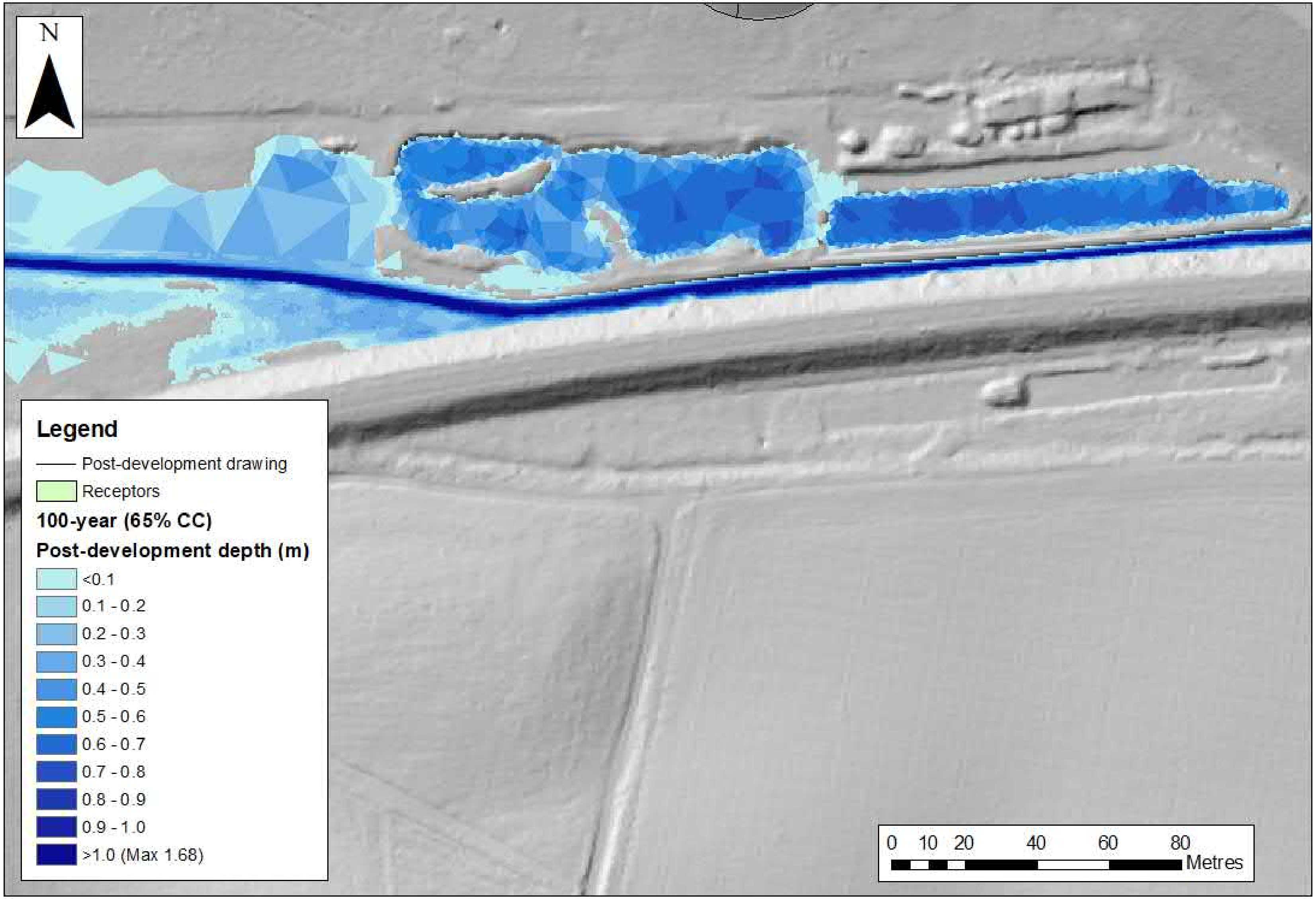


Figure A.11 Maximum predicted depths east of A47 for baseline scenario

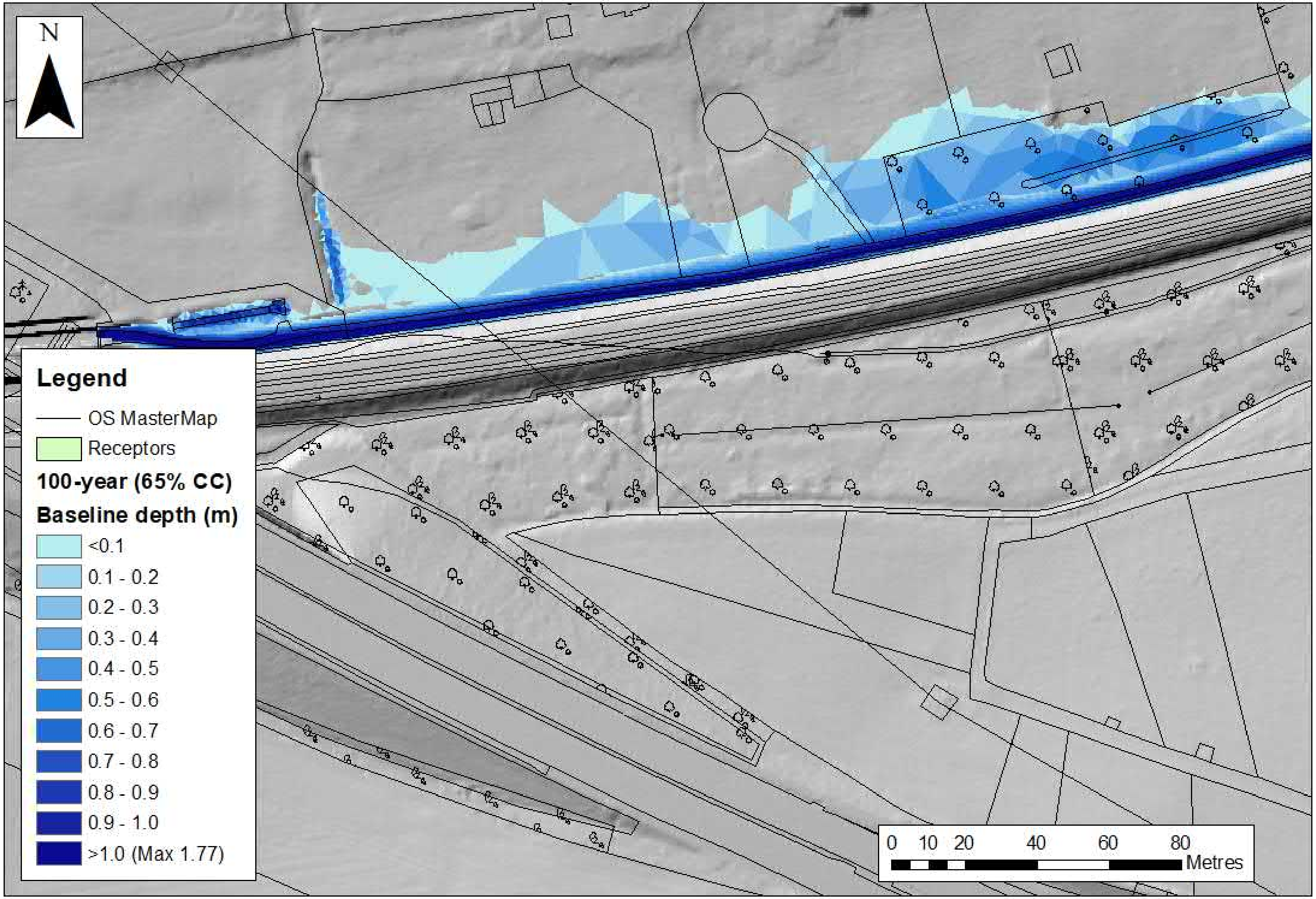


Figure A.12 Maximum predicted depths east of A47 for post-development scenario

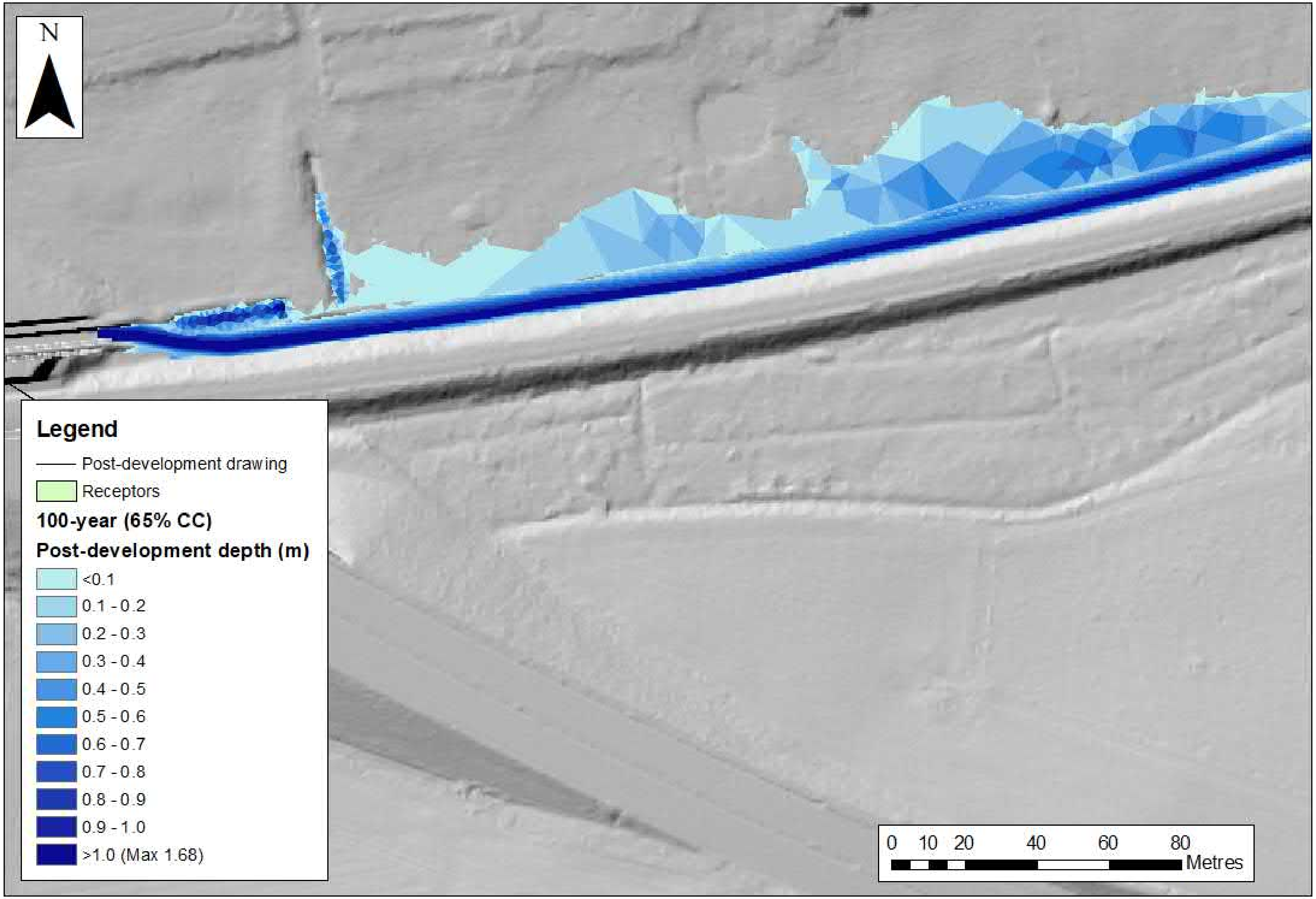


Figure A.13 Maximum predicted depths west of Intwood Road for baseline scenario

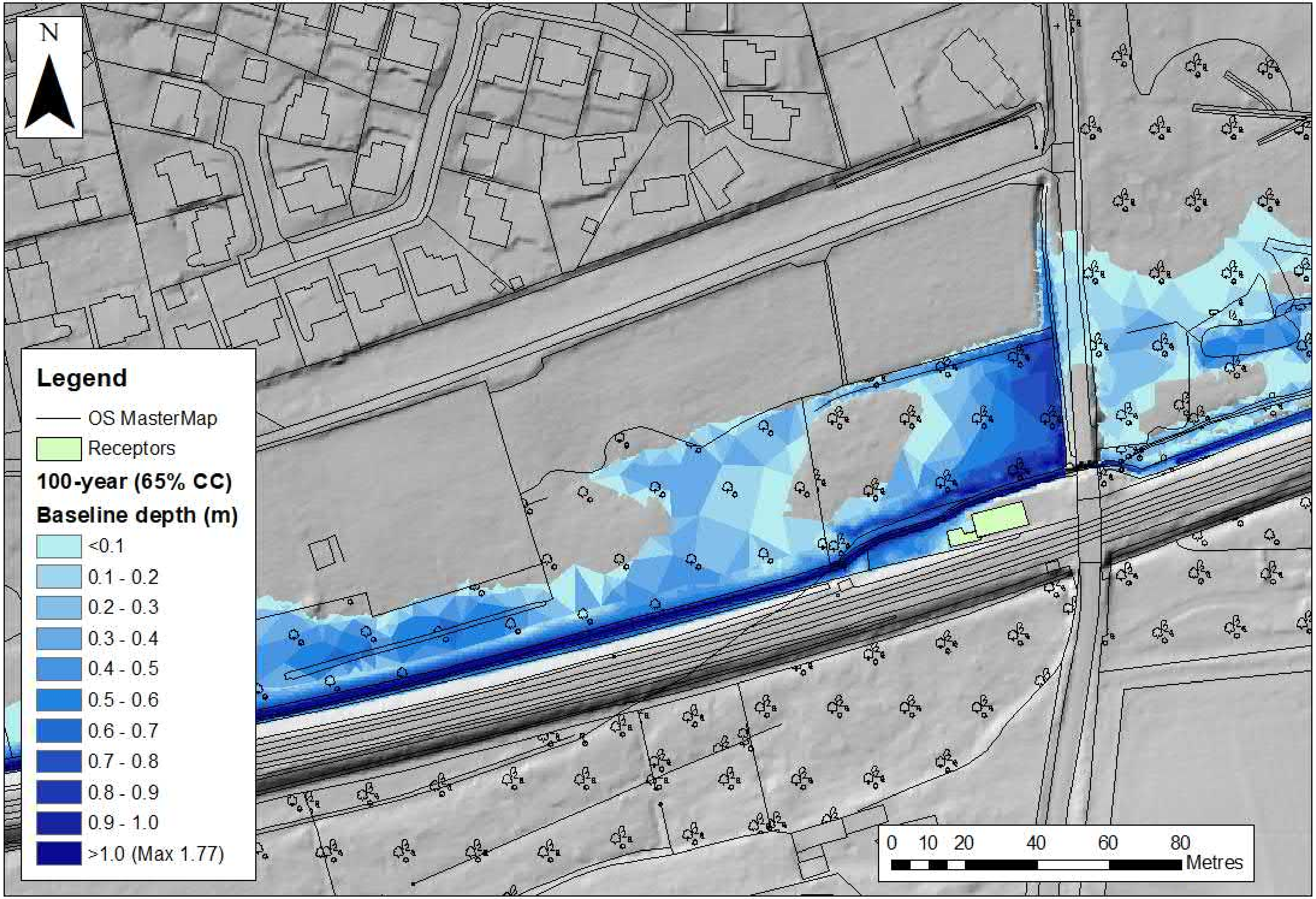


Figure A.14 Maximum predicted depths west of Intwood Road for post-development scenario

Figure A.15 Maximum predicted depths between Intwood Road and downstream boundary for baseline scenario

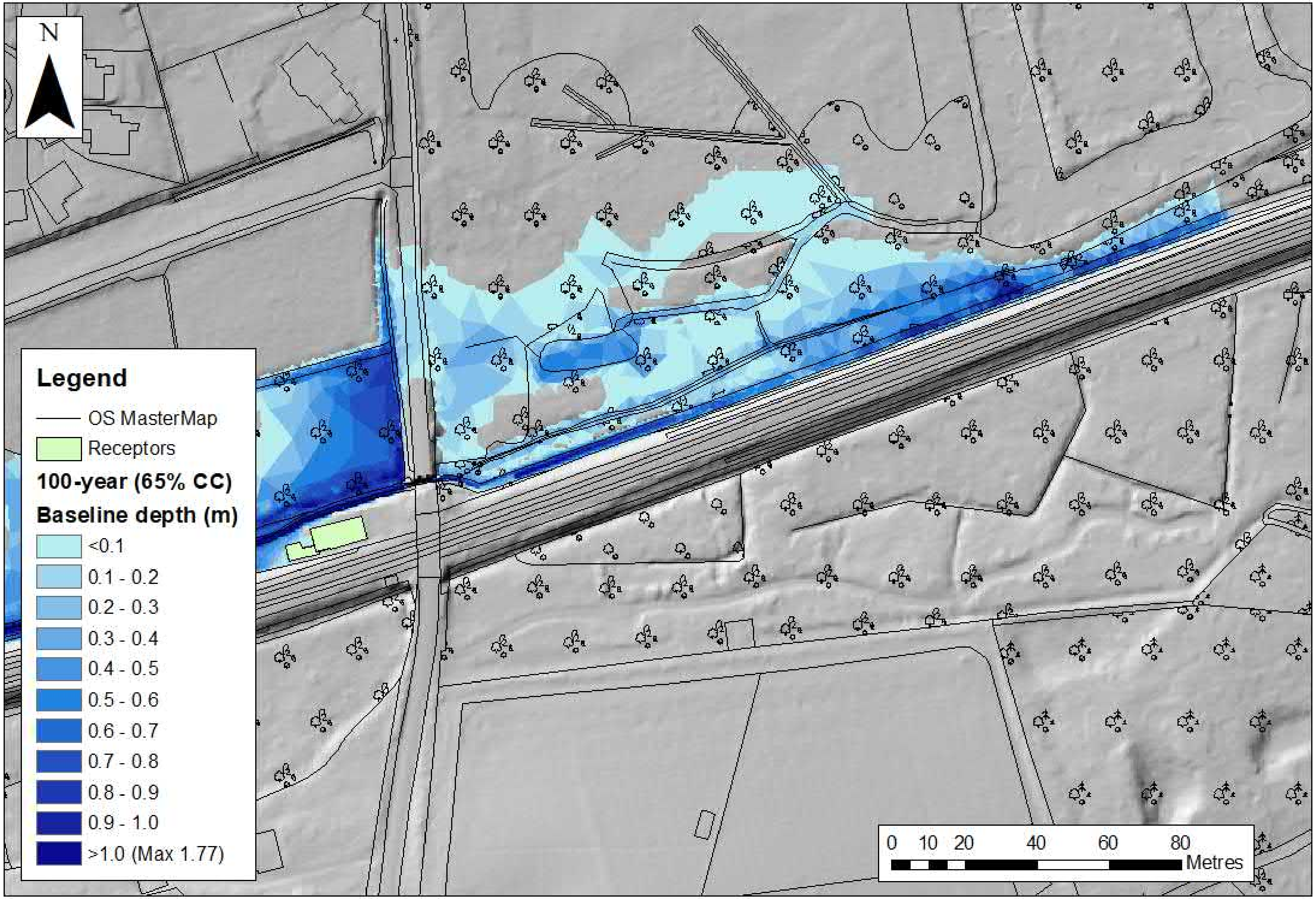


Figure A.16 Maximum predicted depths between Intwood Road and downstream boundary for post-development scenario

Annex B. Hydraulic model technical note

A47/A11 THICKTHORN JUNCTION

Appendix 13.1
Annex B
Hydraulic Model Technical Note

PCF STAGE 3
AUTHORISED AS STAGE 3 COMPLETED | A3
HE551492-GTY-EWE-000-RP-LE-30003 | C01
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1. Introduction

1.1.1. As part of the Proposed Scheme at A47/A11 Thickthorn Junction, a hydraulic model of Cantley Stream was developed to characterise the existing flooding conditions of the stream and to evaluate the impacts of the Proposed Scheme on the flooding conditions. These works also propose the realignment of Cantley Stream, an ordinary watercourse tributary of the River Yare. The model was used to inform design decisions and assess water levels in the realigned stream under low-flow conditions for the purpose of addressing ecological constraints and geomorphology interests.

1.1.2. The model was developed in two stages. The first ‘baseline’ stage was used to model existing fluvial flooding under a critical high-flow storm event in Cantley Stream. The second ‘post development’ stage involved a revision of the baseline model to incorporate the Proposed Scheme development and realigned stream. The post development model was also expanded upon to include a direct rainfall simulation for the purpose of evaluating potential surface water risk to receptors following development of the Proposed Scheme.

1.1.3. This technical note summarises the modelling procedures, results, and analysis for each of the modelling stages. It also includes additional discussion of how post development modelling was used to inform design decisions under various constraints.

2. Baseline hydraulic model

2.1.1. A model was developed to assess baseline flooding conditions along Cantley Stream, particularly in the area of proposed stream realignment. This section summarises model development and results.

2.2. Data sources

2.2.1. The following sources of data were used to inform the baseline hydraulic modelling:

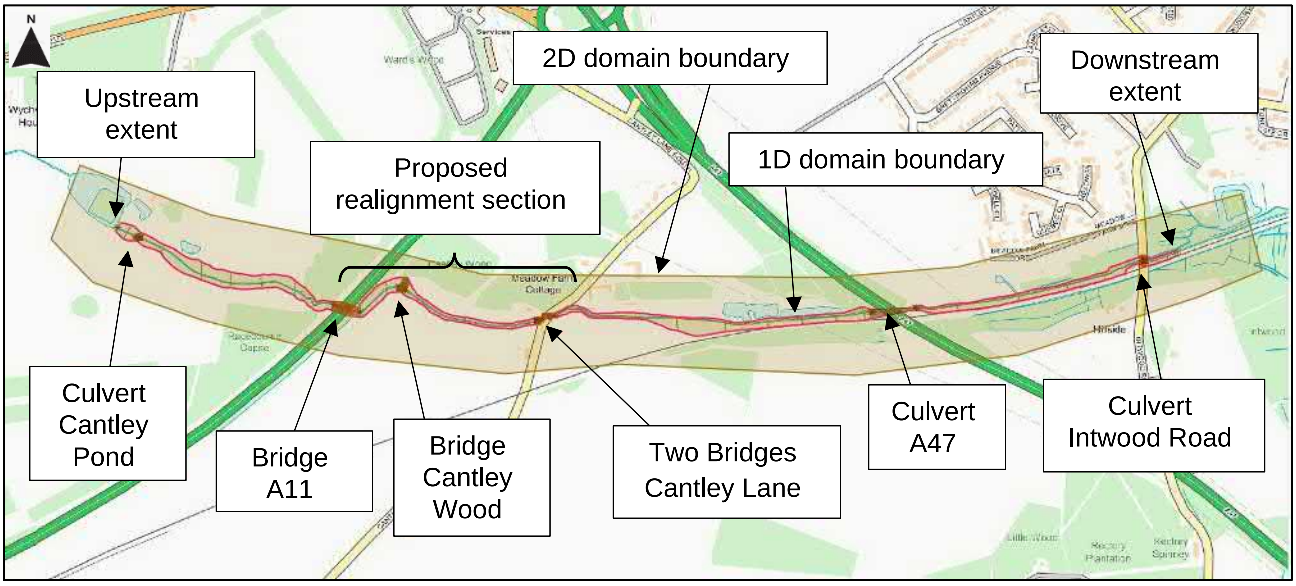
- Cross section survey undertaken by Landscope in 2018 and associated drawings and photographs
- River reconnaissance survey, field measurements and photographs undertaken by Sweco in 2018 and 2020
- 0.5 m resolution LiDAR (2017) available from Defra (Defra, 2020)
- Ordnance Survey (OS) MasterMap data (Ordnance Survey, 2020)
- The Environment Agency's flood maps (Environment Agency, 2020a)
- Manning's n roughness table based on Chow, 1959 (Oregon State University, 2006)

2.3. Model build

2.3.1. A hydraulic model of Cantley Stream was developed using Infoworks Integrated Catchment Model (ICM, Version 9). The software allows for integration of 1D and 2D modelling and is therefore well suited to represent both in-channel and floodplain processes.

2.3.2. The model was based on data collected from a survey carried out in 2018 by Landscope Engineering as part of this assessment. Additional resources were used to supplement the survey including Google satellite imagery and street level photographs; digital terrain model (DTM) LiDAR data publicly available through the Department for Environment, Food and Rural Affairs (Defra); and additional geomorphological measurements carried out by Sweco. Figure 2-1 shows an overview of the ICM model of Cantley Stream with notable model features highlighted.

Figure 2-1 : Overview of Infoworks ICM model of the Cantley Stream



1D domain

2.3.3. The model covers approximately 2.3km of Cantley Stream and includes 51 cross sections, 32 of which were provided by the survey. Additional cross sections were added by interpolation where the modelling of structures required more sections than provided by the survey. Interpolates were also added between sections separated by larger distances (approximately 50-100m) to improve spatial resolution of 1D calculations. Surveyed cross sections are numbered in the model, whereas interpolated cross sections are identified by their associated structure name or simply by the name “Interpolate”.

2.3.4. The ‘panelling’, to attribute changes in bank roughness, was conducted by inspection of the cross-section survey and photographs. A summary of channel roughness values used in the model is included in Table A.1 in Appendix A.

2.3.5. All bridges and culverts along the modelled reach were included in the model and were based on site dimensions. Three of these structures were modelled as bridges with expansion and contraction sections; two were modelled as culverts with inlet and outlet head losses; and two were modelled as conduits without inlet and outlet losses. Key structure parameters were based on appropriate values for each structure.

2.3.6. The upstream extent of the 1D domain is placed at the uppermost survey section (_02224), which is just downstream of the outlet from Cantley Stream Pond (TG 17447 05027). The downstream extent of the model was placed approximately 70m downstream of Intwood Road (TG 19593 04955).

2D domain

2.3.7. The 2D domain was arranged to cover all areas where out-of-bank flow is predicted to occur within the area of interest. Modelled flow does leave the 2D zone domain east of the outfall, but this area of the 2D zone is beyond the portion of the stream being considered for realignment. The boundary of the 2D zone was set to a 'normal depth' condition, which assumes uniform flow out of the boundary.

2.3.8. Infoworks ICM uses a flexible mesh of irregular triangular elements for the 2D domain. The 2D mesh was based on 2017 0.5m Composite DTM LiDAR available from Defra. In June 2020, more recent Composite DTM LiDAR was made available; however, this became available following completion of the baseline stage of modelling, so the 2017 LiDAR was used in both the baseline and post development model for consistency. Terrain-sensitive meshing was applied to improve resolution in areas with steep elevation changes. The primary area of flooding was determined by satellite imagery to consist mainly of pasture with medium grass during summer periods. Since summer events were modelled, a Manning's roughness consistent with medium grass pasture was applied. Key parameters used for the meshed 2D domain are summarised in Table A.2 of Appendix A.

2.3.9. No separate roughness or mesh zones were added to the 2D portion of the model. Although there are wooded areas in the model domain, the floodplain appeared to be limited to grass pasture, particularly in the area of interest. Two structures identified from OS MasterMap data within flooded areas were viewed using Google satellite imagery and Street View and appeared to be sheds. One shed, within the area of redevelopment and stream realignment, was very small and the other, which was somewhat larger, was not within an area of redevelopment. As such, these sheds were not represented explicitly within the 2D domain. A residential receptor identified near Intwood Road (at the downstream model extent) was predicted to experience flooding, but was not represented as a separate mesh object in the model as it was outside the boundary of the Proposed Scheme and more than 1200m from the stream realignment area. (See paragraph 2.4.2 and 3.9.4 for further details on this receptor).

1D-2D connections

2.3.10. The computational boundary between the 1D and 2D domains is defined by bank lines. Bank lines were drawn between cross-section endpoints and points between the section ends were updated directly from the ground model based on LiDAR. In some instances, cross sections were extended, and the relevant parts of these sections were also updated from the LiDAR. The section ends and banks were defined with a view to containing 1D flow patterns within the 1D zone, but also keeping distinct topographical or structural features in the floodplain within the 2D portion of the model. Most banks were given a default discharge coefficient of 0.8 and a modular limit of 0.6. The results of sensitivity analyses on these parameters is shown in Table 2-2 and Table 2-3.

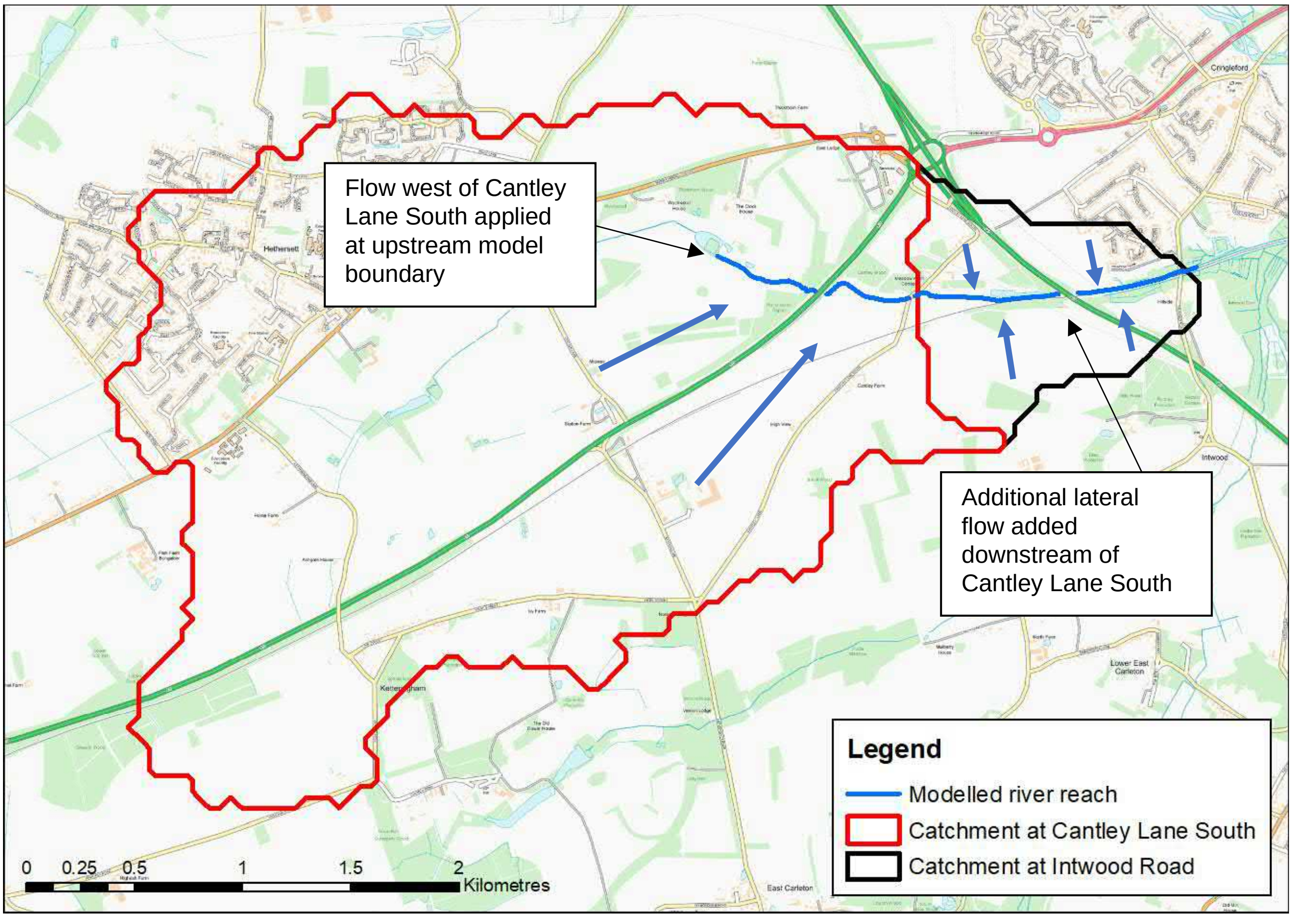
2.3.11. The floodplain, especially between the A11 and Cantley Lane South, sits between two ridges. Modelled floodwaters tend to pool between the ridges. This build-up of water within the floodplain may contribute to instability and flow reversals between the 1D and 2D domains at the banks. Bank lines in this section were given a lower modular limit of 0.5 to minimise instability.

Boundary conditions

2.3.12. The generation of hydrographs used for this model are described in the report A47/A11 Thickthorn Junction FEH (Flood Estimation Handbook) Hydrological Assessment (Appendix E of this report). Three hydrographs were provided at points along the model extents, each representing the total catchment up to those points. Flow at Cantley Lane South is likely to be determined by two main contributing catchment areas, one on each side of the A11. A conservative approach was taken when applying flows to the model, whereby the hydrograph for Cantley Lane South was applied to the upstream boundary of the model (upstream of the A11) so that the entire reach from the upstream boundary to Cantley Lane South receives flow from both contributing areas. See Figure 2-2 for an illustration of how the hydrology was incorporated into the model.

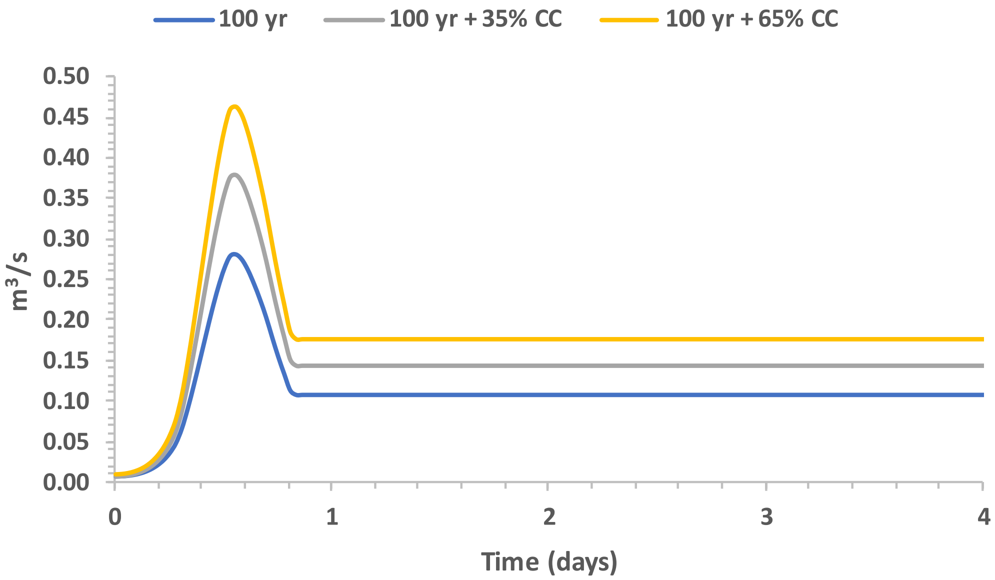
2.3.13. An additional lateral flow contribution for the catchment area downstream of Cantley Lane South was estimated by subtracting the Cantley Lane South hydrograph from the hydrograph representing the full downstream extent at the outfall. Two-thirds of this difference hydrograph was applied upstream of the A47 and one-third applied downstream of the A47. Applicable catchment descriptors for this region are those for the downstream extent catchment and are described in Table 2-1 of the A47/A11 Thickthorn Junction FEH Hydrological Assessment (Appendix E of this report).

Figure 2-2 : Illustration of how catchment hydrology is incorporated into the hydraulic model



2.3.14. Variations in the trailing limb of the hydrographs used to create the difference hydrograph led to some instances of negative flow. It can be seen in Figure 2-3 that this was corrected by enforcing a conservative minimum value for the trailing limb.

Figure 2-3: Hydrographs for lateral flow downstream of Cantley Lane South by modelled event



2.3.15. Climate change allowances were implemented by scaling hydrographs by the relevant factors, which were based on the most recent guidance for the Anglian region (Environment Agency, 2020b). These were based on ‘Essential infrastructure’ in Flood Zone 3 which requires the use of the ‘Higher central’ and ‘Upper end’ allowances which are 35% and 65% respectively for the ‘2080s’ time horizon. The ‘H++’ allowance for peak river flow in this region for the ‘2080s’ time horizon is 80% and is considered where the Proposed Scheme may pose safety critical issues.

2.3.16. The following events were modelled:

- 100-year event without an allowance for climate change
- 100-year event with a 35% allowance for climate change
- 100-year event with a 65% allowance for climate change
- 100-year event with a 80% allowance for climate change
- 1000-year event without an allowance for climate change

Run parameters

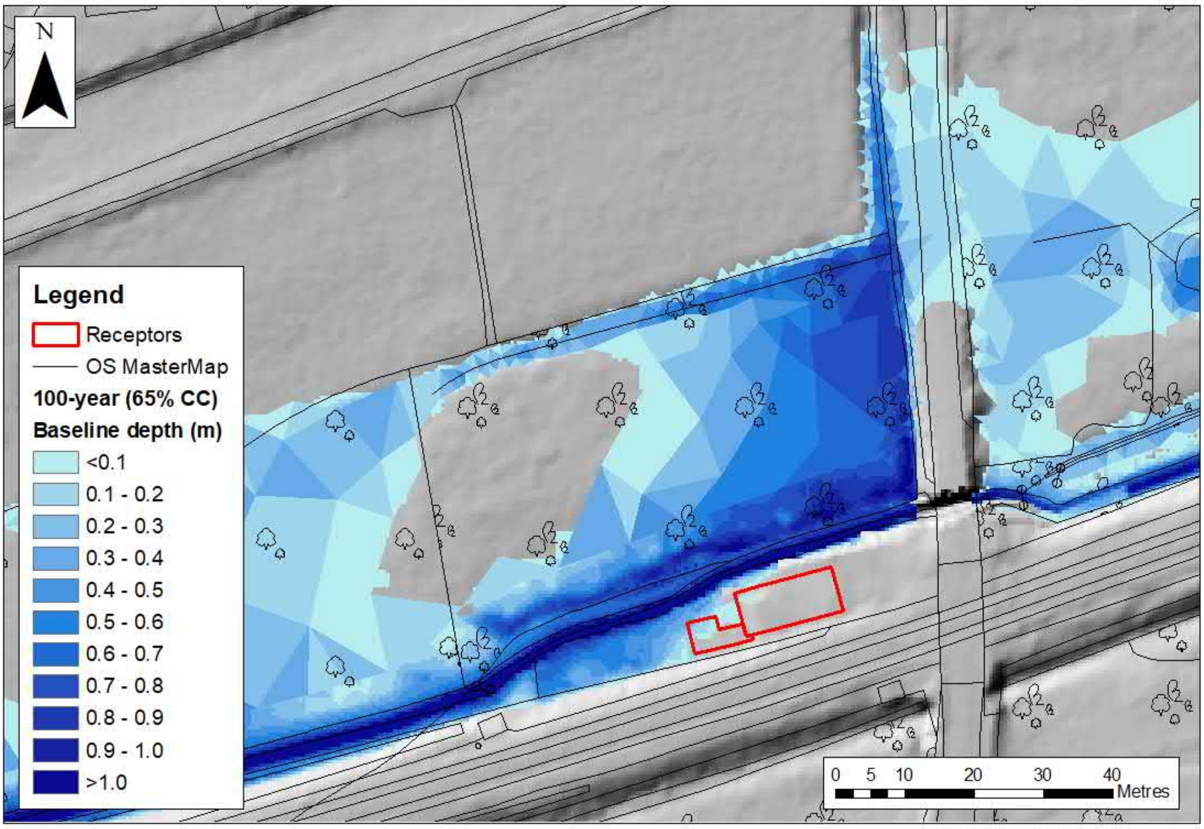
2.3.17. The model was run for a 48-hour hydrograph duration with a 1 second timestep and output every 5 minutes. The option to link 1D and 2D calculations at the minor timestep was selected, and all other run parameters were defaults. The volume balance error for all events was less than 5m^3 and less than or equal to 0.001% of inflows.

2.4. Baseline model results

2.4.1. Maps of predicted flooding along the Cantley Stream floodplain have been provided in Appendix B. The highest peak floodplain depths occur upstream of the A11 bridge where water collects in a ditch parallel to the A11 and in the flooded area just upstream of Cantley Lane South, where throttling occurs at the culvert under the road. Peak depth in the 2D floodplain in this area for a 100-year event with 65% climate change is 1.08m.

2.4.2. The two buildings discussed in paragraph 2.3.9, which are assumed to be sheds, are flooded for all events (to a maximum depth of 0.34m at the larger shed for the 100 year plus 65% climate change event). The model also predicts that the Cantley Lane South road is overtopped where flow is throttled by the road culvert. Out of bank flow is predicted to overtop Intwood Road, just north of the culvert near the downstream extent of the model, in the vicinity of the residential receptor mentioned in paragraph 2.3.9. Flooding at Intwood Road for the 100-year events with 65% climate change is shown in Figure 2-4, which shows flood depths up to 0.6m near the property and up to 0.4m near the building.

Figure 2-4 : Baseline flooding at Intwood Road near model boundary (100-year event with 65% climate change)



2.4.3. Flooding is notable along the portion of the reach where realignment is proposed, upstream of the bridge where throttling occurs at Cantley Lane South. This portion of the floodplain lies between steep topographical ridges which, along with Cantley Lane itself, form boundaries within which floodwaters build to higher depths.

2.4.4. Figure 2-5 and Figure 2-6 show depths in two locations in the floodplain upstream of Cantley Lane South for the 100-year event with 65% climate change. The plot in Figure 2-6 illustrates the accumulation of floodwater in this region before it equilibrates at a lower depth after returning to the stream or overtopping Cantley Lane South.

Figure 2-5 : Locations of depths plotted in Figure 2-6

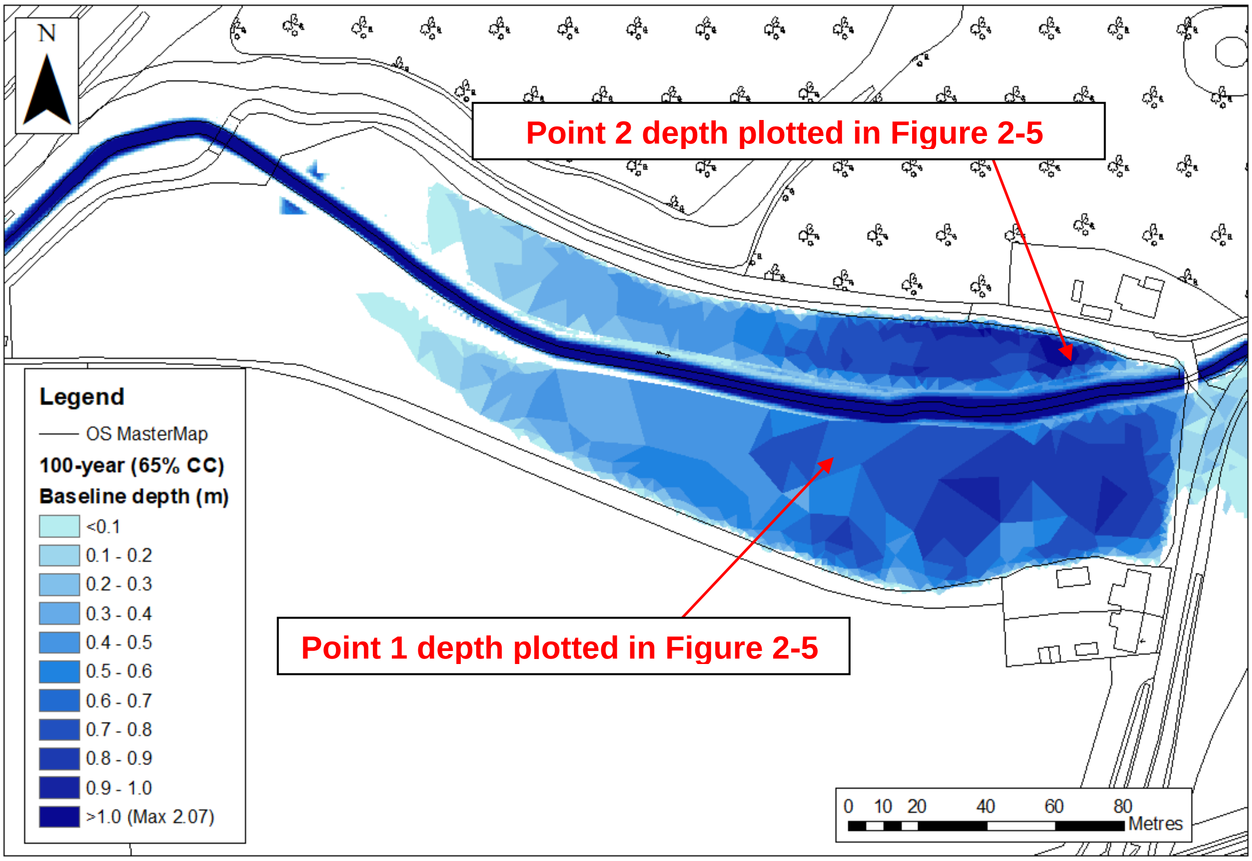
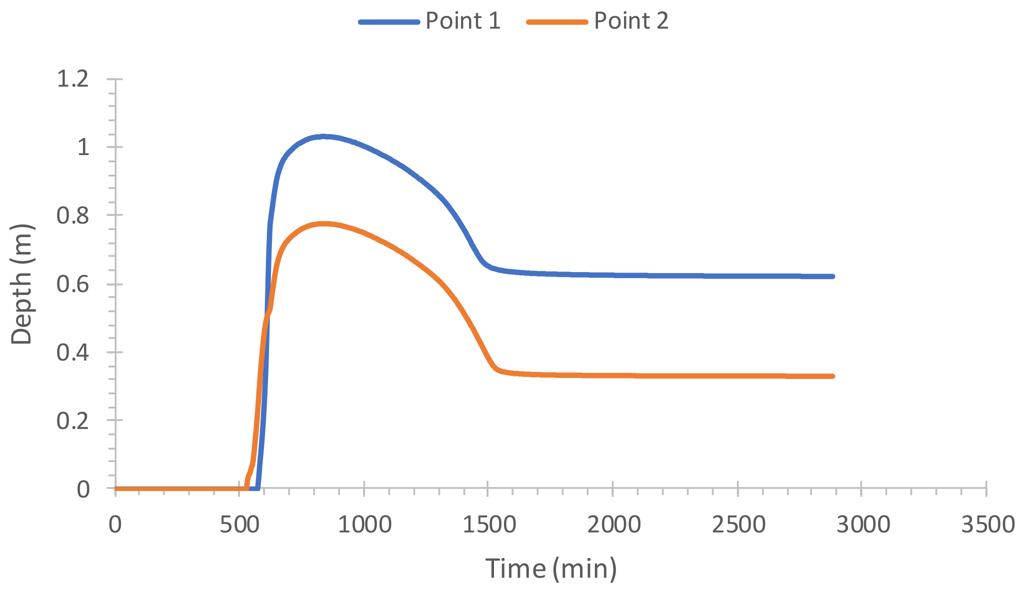


Figure 2-6 : Depth over simulation time in the 2D domain at two points upstream of Cantley Lane South (65% climate change scenario)



2.4.5. Figure 2-7 shows a close-up map of flood depths when water in the floodplain overtops Cantley Lane South during the 1 in 100 year plus 65% climate change scenario. Figure 2-8 is a plot of the depth of water above Cantley Lane at the point indicated in Figure 2-7 over the simulation period for the same event. Cantley Lane South is predicted to experience water depths of approximately 0.2m for several hours during a large flood event.

Figure 2-7 : Flow over Cantley Lane South for 100-year event with 65% climate change

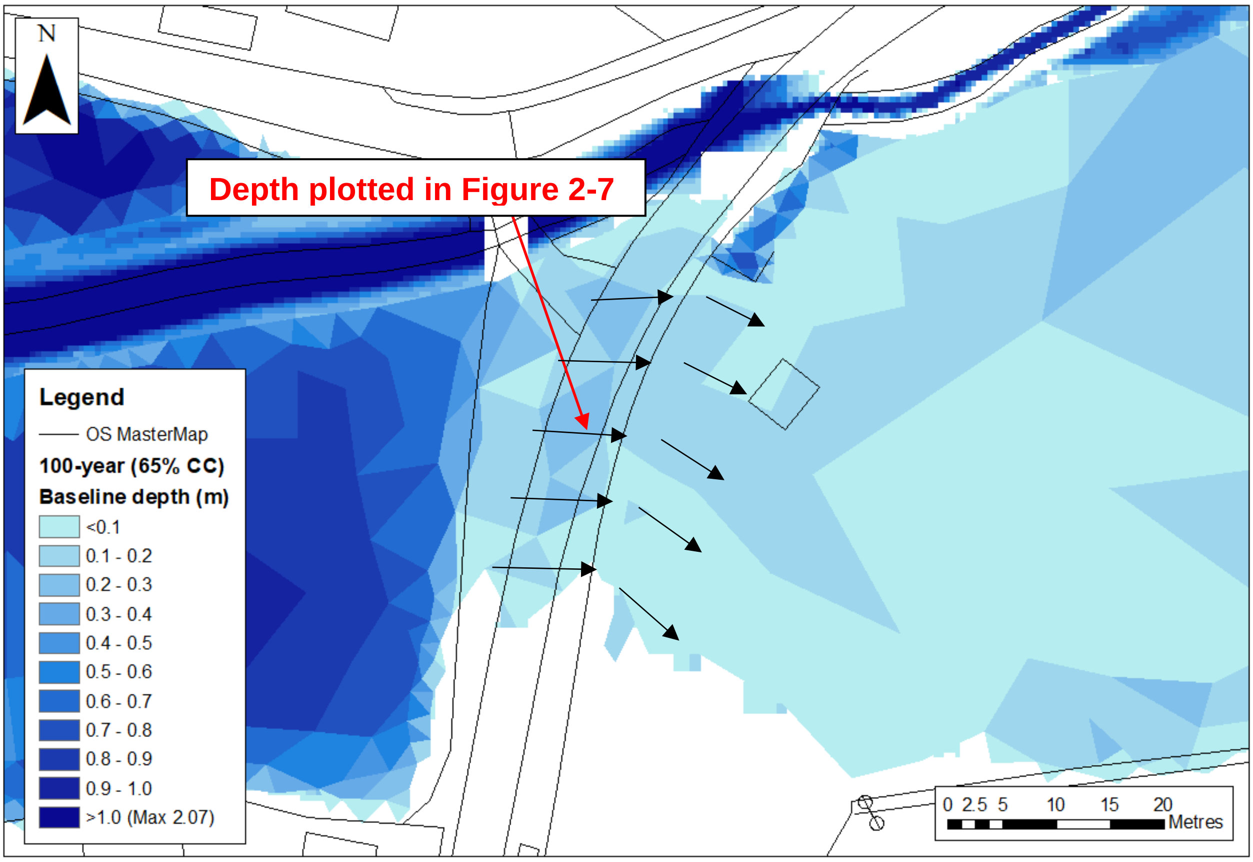
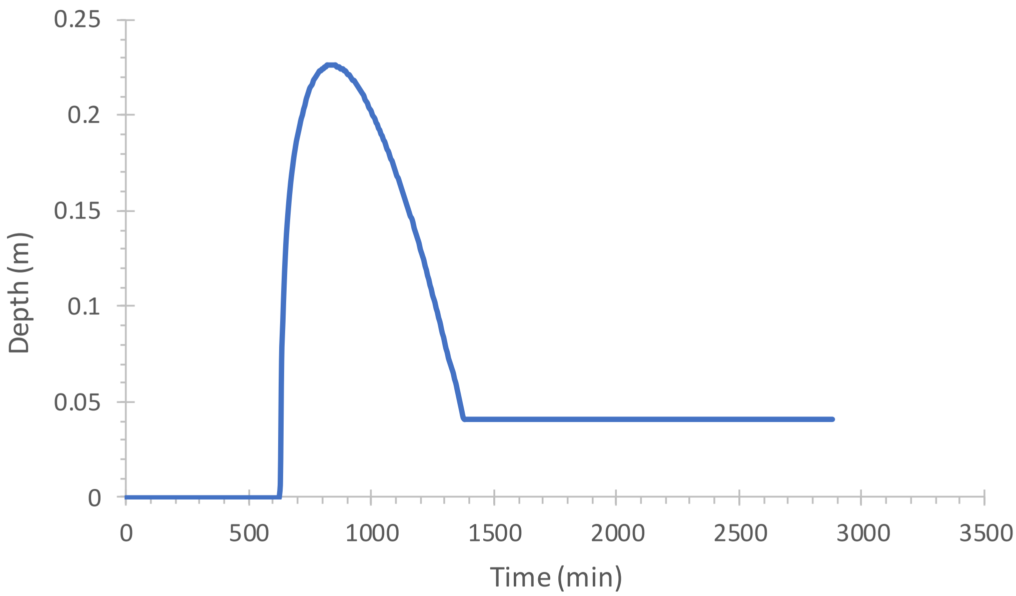


Figure 2-8 : Water depth at point along Cantley Lane over duration of simulation



Sensitivity analysis

2.4.6. Additional simulations were run to test the model's sensitivity to variation in key parameters and boundary conditions. The following sensitivity tests were carried out using the 100-year event flow:

- Altering channel (1D domain) roughness values by +/- 20%
- Altering the inflow hydrographs by +/- 20%
- Adding a constant water level of approximately the bank full level at the model downstream extent
- Creating a 50% blockage at Bridge 2 Cantley Lane (under Cantley Lane South)
- Altering floodplain (2D domain) roughness by +/- 20%
- Altering bank discharge coefficients by +/- 20%
- Altering bank modular limits by +/- 20%

2.4.7. The results in Table 2-1 show that the model is minimally sensitive to changes in roughness and flow. For the main reaches of interest (those between the A11 and A47), 20% changes in roughness led to corresponding changes in output of less than 10%. For those same reaches, 20% changes in flow led to changes in output of less than 15%. There was no change in depths or levels in this area when the downstream boundary was set to bank-full; this condition only had a minor effect on cross-sections directly upstream of the outfall. A 50% blockage at the bridge beneath Cantley Lane was also associated with minor changes (less than 6%) in levels and depths.

Table 2-1 : River channel sensitivity to channel roughness, flow, downstream level and blockage in reaches of interest

Scenario	Maximum change in peak 1D level (m)	Average change in peak 1D level (m)	Maximum change in peak 1D depth (%)	Average change in peak 1D depth (%)
+20% 1D Roughness	0.10	0.04	8.1	3.46
-20% 1D Roughness	-0.13	-0.05	-9.5	-4.35
+20% flows	0.14	0.08	11.8	6.1
-20% flows	-0.19	-0.13	-13.8	-10.5
Downstream boundary approx. bank full	0.00	0.00	0.0	0.0
50% Blockage at Bridge 2 Cantley Lane	0.08	0.02	5.9	1.4

*Reaches of interest are those between the A11 and the A47

2.4.8. Table 2-2 and Table 2-3 indicate that model results in the 2D domain were insensitive to changes in 2D roughness and bank parameters.

Table 2-2 : Floodplain depth sensitivity to floodplain roughness, bank discharge coefficients and bank modular limit in regions of interest

Scenario	Maximum change in peak 2D depth (m)	Maximum change in peak 2D depth (%)
+20% 2D Roughness	0.012	1.75
-20% 2D Roughness	-0.014	-2.00
+20% Discharge coeff.	0.003	0.41
-20% Discharge coeff.	-0.003	-0.41
+20% Modular limit	0.000	0.02
-20% Modular limit	0.001	0.11

*Regions of interest are those between the A11 and the A47

Table 2-3 : Floodplain volume sensitivity to floodplain roughness, bank discharge coefficients and bank modular limit in regions of interest

Scenario	Maximum change in peak 2D volume (m^3)	Maximum change in peak 2D volume (%)
+20% 2D Roughness	68.923	4.66
-20% 2D Roughness	-74.384	-5.03
+20% Discharge coeff	11.775	0.80
-20% Discharge coeff	-13.447	-0.91
+20% Modular limit	-1.951	-0.13
-20% Modular limit	4.283	0.29

*Regions of interest are those between the A11 and the A47

3. Post development model

3.1.1. In the post development modelling stage, the baseline model was adapted to incorporate changes from the Proposed Scheme. This stage of modelling served several purposes:

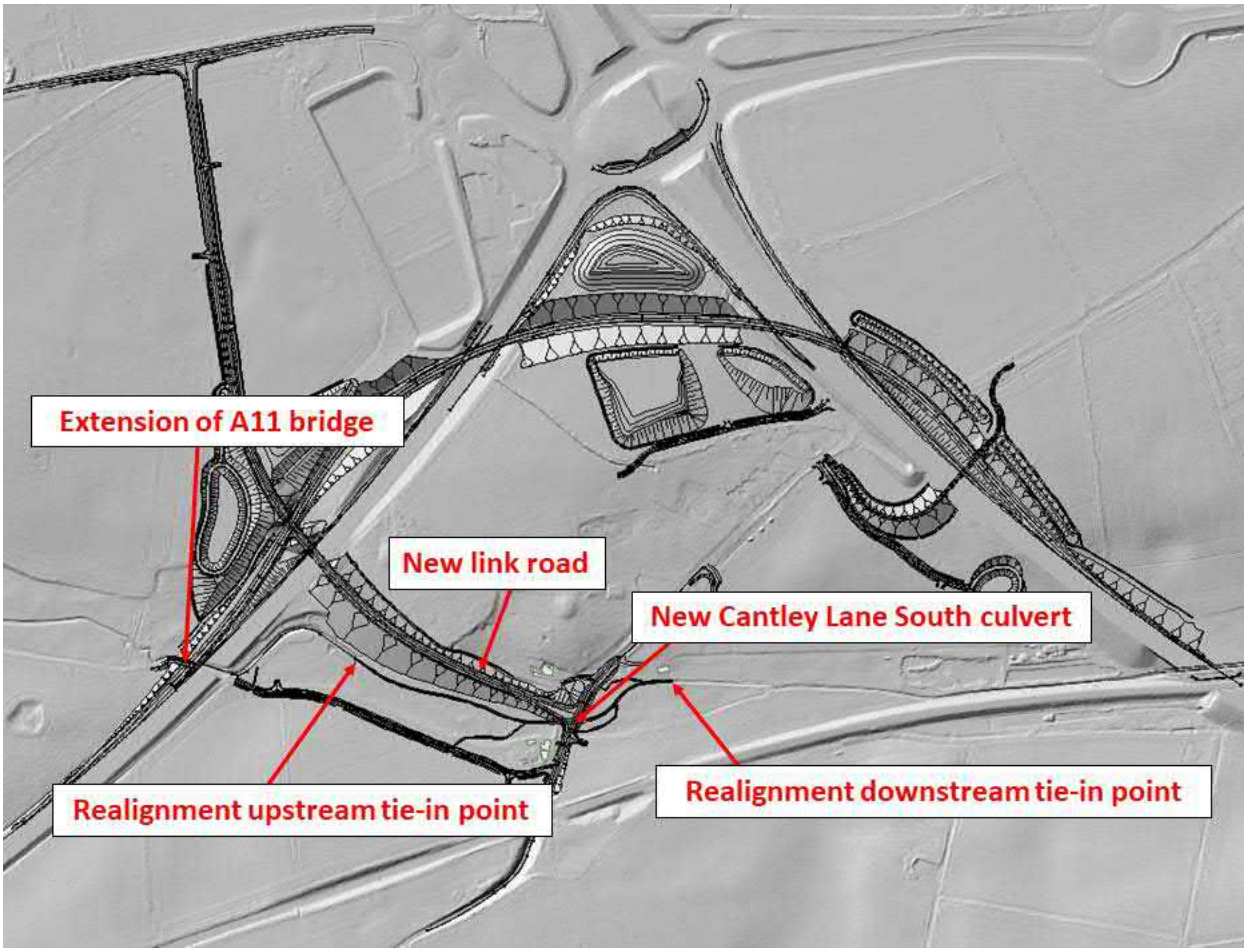
- to assist with design decision-making through the modelling of different scenarios
- to compare post development fluvial flood depths and extent to the baseline model
- to look at any possible surface water flood risk to receptors introduced by the Proposed Scheme
- to examine options for optimising flows and depths in the realigned watercourse for water vole habitat

3.2. Summary of proposed scheme

3.2.1. The Proposed Scheme involves upgrades to the existing roads at A47 Thickthorn Junction as well as creation of a new local access 'link' road between Cantley Lane South and the B1172 Norwich Road. This will involve a diversion of Cantley Stream, an ordinary watercourse, as well as the construction of a new culvert at Cantley Lane South and an extension of the existing A11 bridge.

3.2.2. A drawing of the road design at Thickthorn Junction is shown in Figure 3-1 with key features indicated.

Figure 3-1 : Drawing of new road and stream design for A47 Thickthorn Junction Scheme



3.3. Model build

3.3.1. A copy of the baseline model was used as a starting point for modelling the post development scenario under the Proposed Scheme at Thickthorn Junction. The ground model, 1D and 2D parts of the model required updates to represent the post development design.

3.4. Ground model update

3.4.1. The baseline ground model was updated to incorporate the post development changes. Added features include new roads, embankments, sustainable urban drainage system (SuDS) ponds, the realigned stream channel and other ground features such as drainage ditches that have been designed as part of the Proposed Scheme.

3.5. 1D zone changes

3.5.1. The development plan for Thickthorn Junction involves the realignment of Cantley Stream between the A11 and Cantley Lane South. The 1D river reach was edited to follow the new channel alignment, and cross sections were added along this new portion with elevation points updated from the ground model. The introduction of the road embankment next to the stream entailed extending the width of cross sections to capture 1D flow within the wider floodplain and improve model stability. Roughness of banks was reduced by 0.01 to account for landscaping during realignment.

3.5.2. Changes to structures along the reach included the extension of the underpass beneath the A11 and the revision of the culvert beneath Cantley Lane South. Modelling of the extension of the underpass was informed by design drawings and achieved by extending the length of the existing bridge opening to the updated entry location. A new contraction cross section was added upstream of the opening with an invert level estimated based on the bed level slope through the opening.

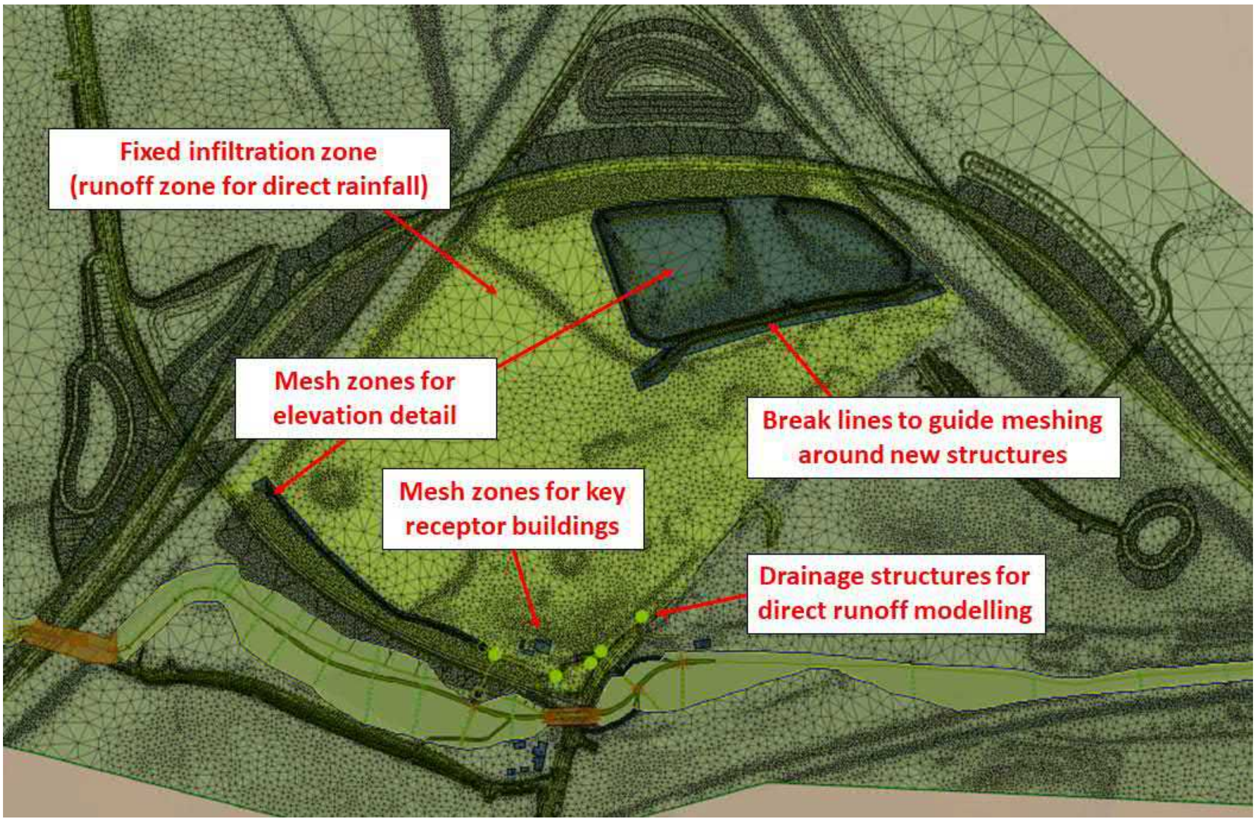
3.5.3. The proposed culvert design at Cantley Lane South was a box culvert with mammal ledges and wingwalls and was modelled using a culvert object with a custom opening shape and appropriate parameters in ICM (see paragraph 3.7.4 for further details on the culvert sizing and design).

3.6. 2D zone changes

3.6.1. In addition to the revised ground model, other 2D objects were added so that modelling could more adequately inform the post development design and assess the impact on the landscape and possible receptors (Figure 3-2). These 2D objects included:

- Mesh zones allowing for a finer mesh in areas with detailed ground features
- Mesh zones raised above ground level to represent building receptors in the area of interest
- Break lines to guide meshing around structures in the area of interest
- Additional features to be used in a direct rainfall simulation:
    - An infiltration zone to represent a runoff surface
    - Mesh level zone to represent a drainage ditch not included in the ground model
    - Select 1D-2D drainage structures adapted from MicroDrainage design files

Figure 3-2 : 2D elements added to the post development model



* Screen capture from model

3.7. Modelling to inform design

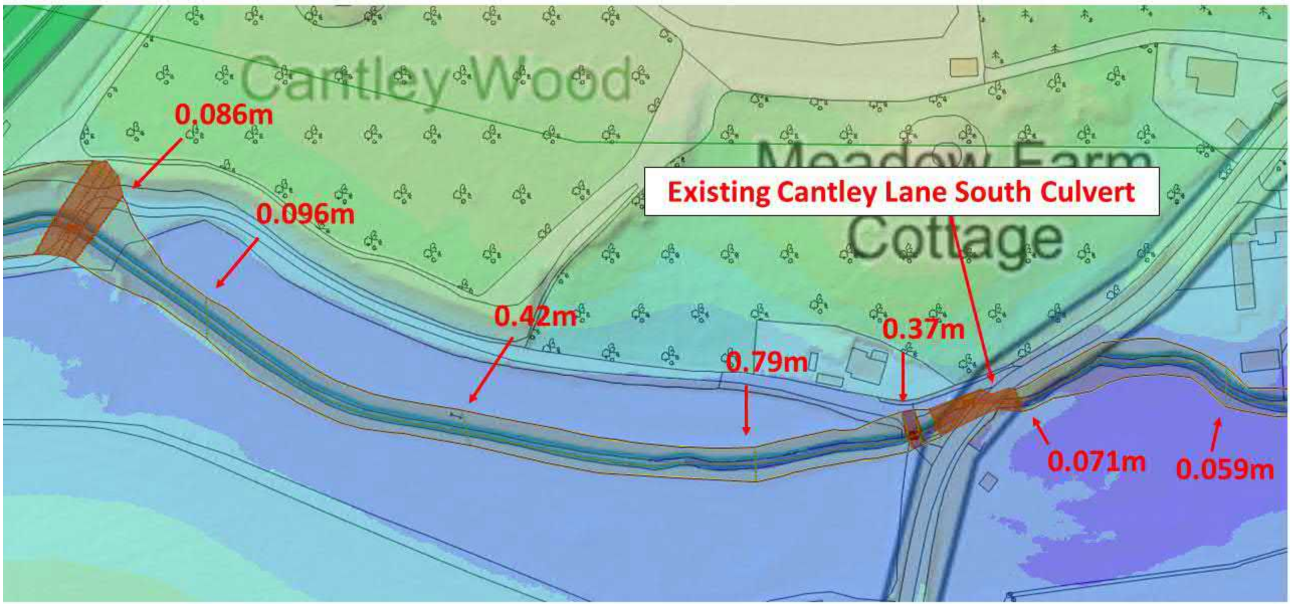
3.7.1. In addition to looking at flood risk, post development modelling was used to inform the design of the realigned stream channel and a new culvert beneath Cantley Lane South. This modelling highlighted some of the competing interests and regulatory constraints inherent to the stream realignment. This section provides background on these constraints and the resulting design decisions.

Background on throttle at existing culvert

3.7.2. The existing culvert at Cantley Lane South is shaped and positioned such that baseline modelling predicted significant throttling of stream flow and overtopping of Cantley Lane South. Modelling of high flow events (100-year storm with 65% climate change allowance) predicted flooding to a depth of 1.08m upstream of the culvert where water collects in the floodplain between two ridges (see discussion in paragraph 2.4.3 and Figure B.3 in Appendix B). The existing culvert was also found to act as a throttle during low flows, which were simulated to examine habitat suitability for water voles (paragraph 3.7.6). Whilst water remained in bank, water depths were predicted to be elevated compared to nearby reaches.

3.7.3. The Low Flows 2 software was used to predict the streamflow exceeded 95% of the time (Q95) for Cantley Stream. Figure 3-3 shows stream depths upstream and downstream of the existing culvert when running the baseline model with a steady Q95 flow. The throttling of the culvert means that for a distance of approximately 160m upstream of Cantley Lane South, depths will exceed 0.37m for at least 347 days per year under baseline conditions. Depths further upstream and closer to the A11 culvert are lower as the effect of throttling is reduced upstream.

Figure 3-3 : Predicted baseline stream depths near Cantley Lane South for Q95 flows



* Screen capture from model

Culvert and road constraints

3.7.4. Constraints on the new road design meant that the level of the road at Cantley Lane South could not be raised. Norfolk County Council, the Lead Local Flood Authority (LLFA), had requested 600mm of freeboard above flood levels for a 100-year event with 65% climate change allowance for any new culvert. Modelling determined that a 6m width of pre-cast culvert units was the optimal width for maximising freeboard through the culvert.

3.7.5. Given the constraint on road level at Cantley Lane South and the need to design a wider culvert to maximise freeboard, the existing throttle at Cantley Lane South was eliminated in the post development design. An analysis of the water surface profile in the post development model showed that the removal of throttling did not lead to a significant increase in the predicted stream levels downstream of the culvert.

Water vole habitat

3.7.6. Cantley Stream is home to a population of water voles, which are protected under Schedule 5 of the Wildlife and Countryside Act 1981 (as amended). Water voles require a habitat in which the stream is sufficiently deep for swimming and an ideal water depth is approximately 0.30m. Although the water voles are present along the length of the stream, the reach requiring realignment upstream of Cantley Lane South has been an especially favourable habitat where they are present in high numbers. As discussed in paragraph 3.7.2, current water depths along parts of this reach are higher than elsewhere in the stream on account of a throttle at the existing culvert. Post development modelling showed that removing this throttle in order to maximise freeboard (paragraph 3.7.5) led to more uniform and reduced predicted depths along the entire stream rather than an area of higher depth at the culvert. As the water voles' habitat is protected, this constraint has dominated over other aspirations such as improving the geomorphological state of the stream. Further details on the water voles at Thickthorn Junction are found in Environmental Statement (ES) Chapter 8 (Biodiversity) **(TR010037/APP/6.1)** and in ES Appendix 8.9 **(TR010037/APP/6.3)**.

Geomorphology

3.7.7. Cantley Stream is a chalk stream that has been heavily modified. As a result of these modifications, the stream no longer has features typical of natural chalk streams, which offer rare habitats in the UK. An ideal realignment of the stream would attempt to re-create a more natural planform and channel dimensions in the hope of restoring some of the stream's natural chalk features. The ideal chalk stream has a minimum 1:10 depth to width ratio, meaning that the realigned channel would have to be widened significantly from its current state in order to achieve this level of restoration.

3.7.8. The behaviour of a stream is partially governed by the available energy to move sediments. In general, it is better to not change the existing gradient in a realigned river as the extra momentum may trigger geomorphological change. At Cantley Lane, the realigned reach upstream of the culvert has been slightly steepened so that the river is as low as possible at the culvert (in order to maximise freeboard). Downstream of the culvert the realigned watercourse is slightly less steep so that it ties into the continuation. This steepening is subtle and was agreed in principle with the LLFA during a previous consultation meeting on 6 August 2020.

Decision on channel width

3.7.9. Simulations carried out with low flows in a preliminary wider channel design suggested that the combination of river widening for chalk stream restoration and removal of the culvert throttle reduced low flow water depths compared to the existing arrangement. Rather than the higher depths at the culvert illustrated in Figure 3-3, the removal of the throttle led to more uniform depths along the stream. Depths throughout the new wider stream were predicted to be unsuitable for water voles.

3.7.10. The adopted channel design was narrowed to increase channel depths and allow for a more adequate water vole habitat, which entailed reducing the scope of geomorphological benefits and reducing freeboard below the LLFA's requested level (600mm). Table 3-1 summarises the final minimum freeboard and stream depths predicted in the narrower channel.

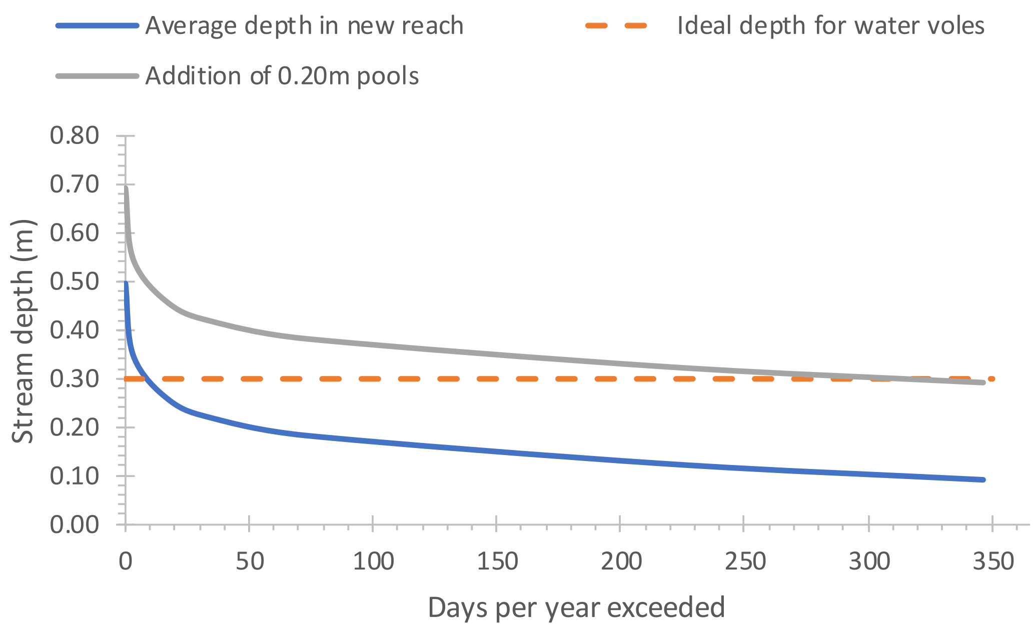
Table 3-1 : Final minimum freeboard and stream depths in final channel design

Approx. channel width (bed)	Minimum freeboard in culvert (100-year with 65% climate change)	Average stream depth along realigned reach (Q95)	Average stream depth along realigned reach (Qmean*)
3m	0.428m	0.091m	0.16m

* Using average annual streamflow as predicted by Low Flows 2.

3.7.11. While mean flow depths in the narrowed channel (approximately 16cm) are more consistent with those along much of the existing stream, it will still be necessary to implement measures to provide the ideal water depth of 0.30m for the water voles. Figure 3-4 shows a prediction of average stream depth in the realigned reach versus the number of days per year the stream is at that depth. Given that the 0.30m goal cannot be achieved in the new reach for more than approximately 11 days per year, riffles and pools with an additional depth of 0.20m have been introduced to the design to maintain 0.30m water depth during low flows throughout the length of the diverted reach of Cantley Stream upstream of the culvert.

Figure 3-4 : Average stream depth in realigned reach vs. number of days on which depth is exceeded



3.7.12. The nature of riffles and pools mean that the water depth along the reach will not be uniform. There will be areas where water depths are still sometimes below 0.30m. However, providing riffle and pool features along the realigned reach in addition to proposed riparian planting along other parts of the stream will provide an improvement in terms of available habitat for water voles. Further details of the channel and riparian mitigation for water vole are discussed in Annex A to the A47/A11 Thickthorn Junction Flood Risk Assessment (ES Appendix 13.1 **(TR010037/APP/6.3)**).

3.8. Model variations

3.8.1. Three model simulations were used for the purposes of flood risk assessment. The first was a fluvial model to be used for comparison with the baseline. The others were used to assess the impact of proposed drainage systems and other structures on fluvial and surface water flooding. A summary of these three simulations is discussed below.

Simulation 1

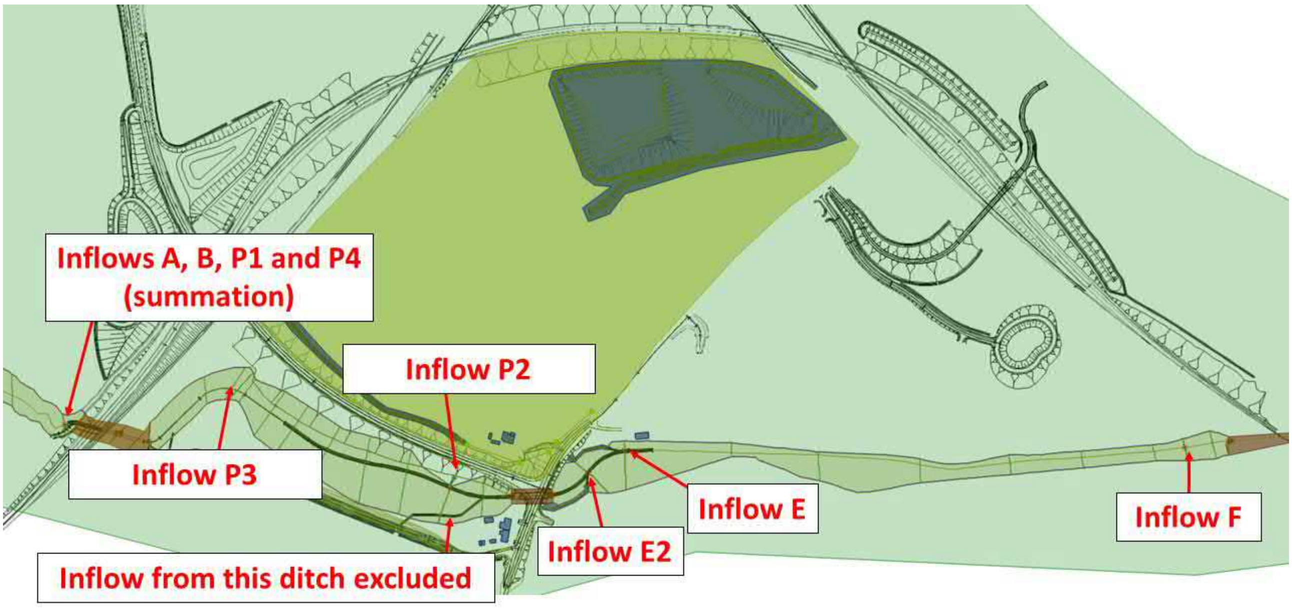
3.8.2. In the first simulation, the same inflows applied in the baseline model for a 100-year event with 65% climate change (14-hour summer storm) were applied to the post development model. This simulation was intended as a direct comparison with the baseline model for the purposes of assessing changes to flood risk.

Simulation 2

3.8.3. In the second simulation, additional inflow profiles from proposed surface water drainage outfalls were incorporated into the model in order to look at the impact of new drainage systems on structures and flooding. Since the drainage system routes the same rainfall runoff that is already applied as inflow to the upstream boundary, adding the drainage inflows is a double counting of catchment flow. This was considered a conservative approach that would allow for examining the hydraulic effects of inflows at specific points. Only drainage outfalls at locations near or within the watercourse were added and the values of the inflow rates were based on MicroDrainage modelling of the Proposed Scheme drainage system. Figure 3-5 shows the location of these inflow points. One drainage ditch south of the stream and west of Cantley Lane South was excluded, as the upstream catchment is unaffected by the Proposed Scheme.

3.8.4. Simulation 2 was also used to look at the influence on freeboard in the extended A11 bridge and the new culvert at Cantley Lane South; the two structures updated in the post development model.

Figure 3-5 : Location of drainage inflows



* Screen capture from model

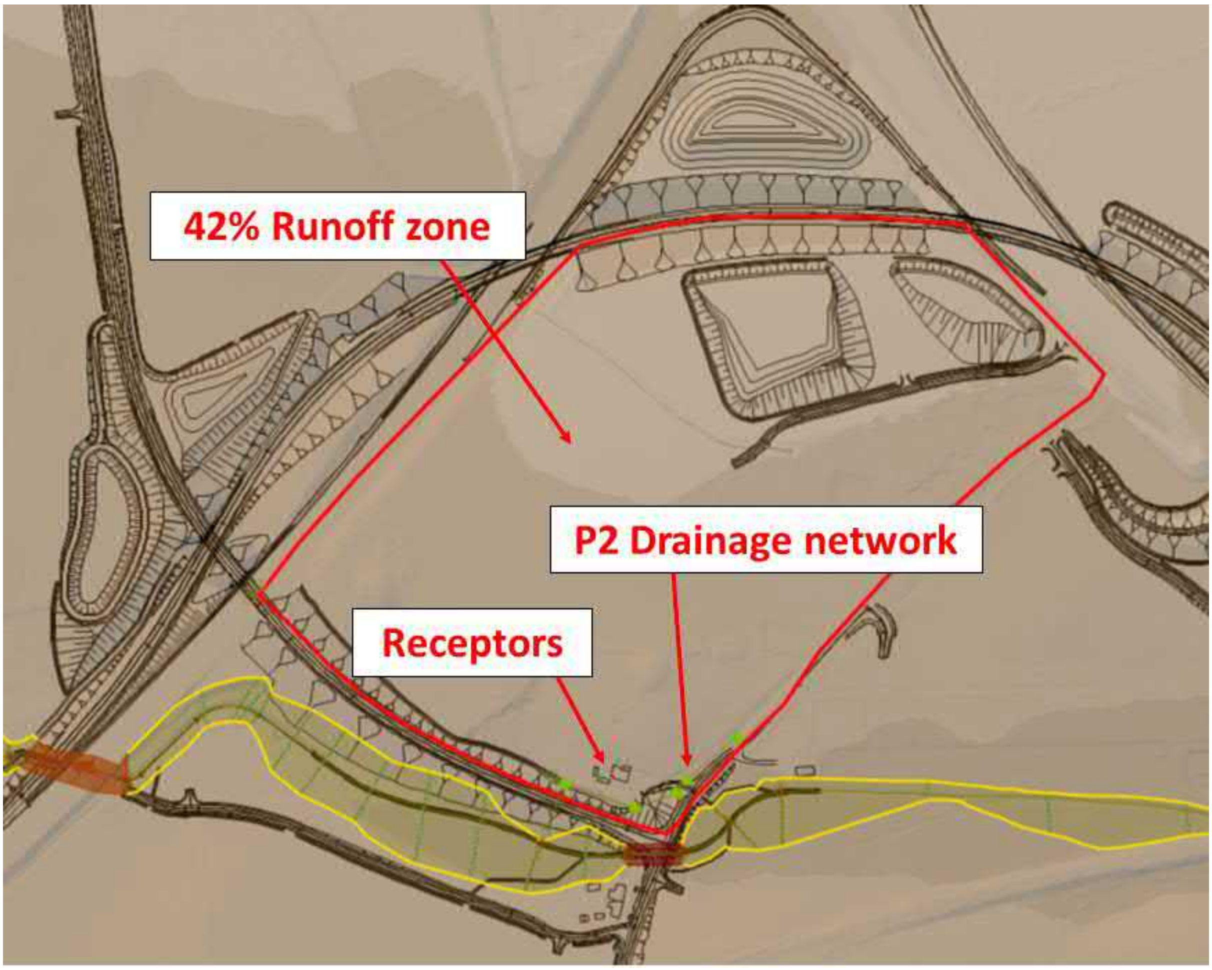
3.8.5. Inflow profiles representing the 1 in 100 year plus 40% climate change outfall flow from the drainage system to the river were applied. The design flows were throttled to a greenfield rate calculated using IH124.

Simulation 3

3.8.6. In Simulation 2, point-source inflows were directly applied to the stream at P2 and P3 (Figure 3-5) to represent drainage inputs. This application of drainage flows to the model does not allow the performance of the drainage network, and in particular the culvert at P2, to be assessed. Since this network is in the vicinity of receptors, a third simulation (Simulation 3) was carried out where flows in this vicinity were modelled directly by representing the drainage system and applying direct rainfall.

3.8.7. The direct rainfall in Simulation 3 was for a 100-year event with 40% climate change allowance. Testing indicated that the critical duration for rainfall draining to the area directly around the receptors was approximately 0.5 hours. The 0.5-hour rainfall event was applied to a subregion (runoff zone) draining to the area of interest (Figure 3-6). The runoff zone used a fixed runoff coefficient of 42% which was a weighted average of the surface percentage runoff coefficient (SPRHOST; 35%) to represent the natural unchanged ground and a fixed runoff of 70% from the developed areas.

Figure 3-6 : Subregion of 2D zone with applied rainfall runoff in Simulation 2

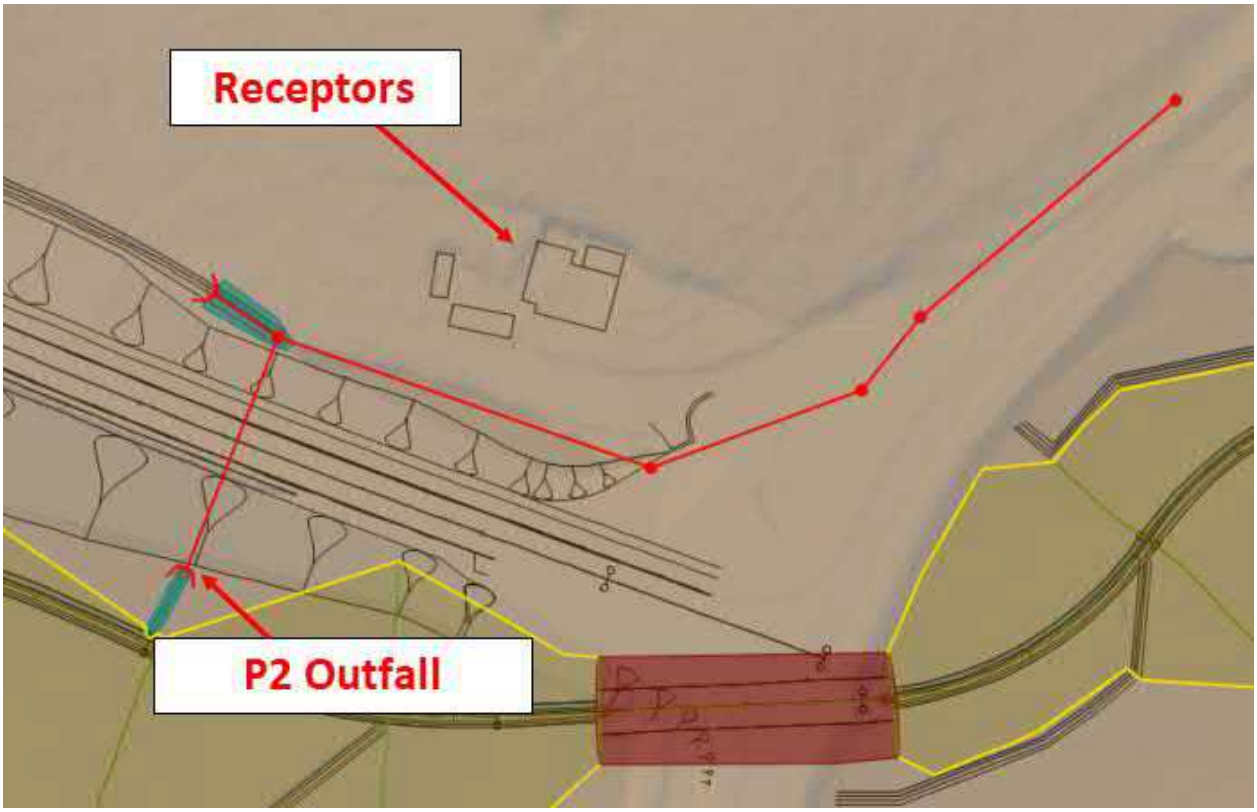


* Screen capture from model

3.8.8. The fluvial hydrology applied to the Cantley Stream part of the model network was amended to a 0.5-hour storm with 65% climate change allowance and was applied as described in paragraph 2.3.14. Drainage inflow profiles other than those at P2 and P3 (locations in Figure 3-5) for a 0.5-hour storm were applied to this third model variation. As with Simulation 2, it is acknowledged that drainage flows to Cantley Stream, either via the point-source inflows or the direct rainfall, is a double-counting of inflows from the catchment (see paragraph 3.8.3).

3.8.9. The drainage network linked to the P2 inflow point was provided as MicroDrainage network files, which were imported into ICM and adapted to a direct rainfall model (Figure 3-7). The drainage network for P3 was not included, since flows to P3 are otherwise directed to P2, and this was thought to be conservative for the purpose of looking at the performance of the drainage near receptors. Most conduits are expected to be filter drains in the final design but were modelled in MicroDrainage using nodes to collect runoff from subcatchments. In the ICM model, the nodes that were connected to subcatchments were converted to 2D manholes to collect runoff from the 2D runoff zone. The 2D manholes drain water from the mesh element immediately surrounding the manhole. The capture area of the manholes can be adjusted to account for the fact that water would drain to the filter drainpipes along the pipe length rather than at the manhole point. However, the manhole capture areas (without adjustment) were considered sufficient as a conservative approach to looking at surface water flood risk since the amount of runoff captured by manholes in the model is likely to be slightly underpredicted.

Figure 3-7 : Drainage network at P2 and nearby receptors



* Screen capture from model

3.8.10. The receptors shown in Figure 3-7 were modelled as mesh zones raised to doorstep threshold level. This threshold level was calculated using the method employed by the EA in its national mapping exercise. This method sets the threshold level as the smaller of either (a) 300mm above maximum ground level within the area of the building, or (b) 300mm plus two standard deviations above mean ground level within the area of the building.

3.8.11. Simulation 3 is carried out using a separate scenario in the ICM model network. This is because, while the bank lines were set very wide in the 14-hour storm simulations to allow for 1D stability, this was not necessary for the 0.5-hour storm in which stream levels are lower. Therefore, the banks for this simulation were modified in one location to allow for the inclusion of a ditch at the P2 outfall that routes flow to the stream.

Simulation summary

3.8.12. Table 3-2 summarises the details of the three simulations carried out.

Table 3-2 : Summary of three post development model simulations

Simulation Details	Simulation 1	Simulation 2	Simulation 3
Fluvial hydrograph (ReFH2) storm duration and season	14-hour summer	14-hour summer	0.5-hour summer
Fluvial hydrograph climate change allowance	65%	65%	65%
Drainage inflows storm duration	N/A	14-hour	0.5-hour
Drainage inflows climate change allowance	N/A	40%	40%
Number of drainage inflows applied	0	6	4 (P2/P3 removed)
Direct rainfall applied?	No	No	Yes
Direct rainfall climate change allowance	N/A	N/A	40%

3.9. Post development model results

3.9.1. This section provides a summary and analysis of output from post development model for the three different simulations carried out.

Simulation 1

3.9.2. Simulation 1 was used to compare stream levels and flood extent with those of the baseline model. Maps of predicted fluvial post development flooding for a 14-hour summer storm fluvial event (100-year event with and without 35%, 65%, and 80% climate change allowance, and 1000-year event) have been provided in Appendix C. Figure C.3 illustrates that, for the 65% climate change scenario, maximum floodplain depths along the realigned reach do not exceed 0.5m outside of the main channel or other low-lying features. This indicates a reduction in maximum flood depth from the baseline scenario between the A11 and Cantley Lane South (see paragraph 2.4.1) where flooding is currently affected by throttling of streamflow at the Cantley Lane culvert.

Downstream flood risk

3.9.3. Minimum freeboard at peak stream depth in the Cantley Lane South culvert is 428mm. As discussed in paragraphs 3.7.4 and 3.7.5, the new culvert is designed to maximise freeboard such that the throttling behaviour found at the existing culvert is removed. A comparison of the water surface profiles from the baseline and post development models (Simulation 1) is shown in Figure 3-9. The figure illustrates that the removal of the throttle has not significantly changed the water surface profile elsewhere. Further comparisons of flood extent can be seen in the maps provided in Appendix B and Appendix C.

3.9.4. A potential 14mm increase in water level near the residential receptor at Intwood Road, near the model outfall (paragraphs 2.3.9 and 2.4.2), has been identified. Modelling uncertainty exists due to its proximity to the downstream boundary and interpolated geometry. Work to better quantify the impact to the receptor is under way at the time of writing. Predicted post-development depths at this receptor are shown in Figure 3-8 with flood depths up to 0.6m near the property and 0.4m near the building.

Figure 3-8 : Post-development flooding at Intwood Road near model boundary (100-year event with 65% climate change)

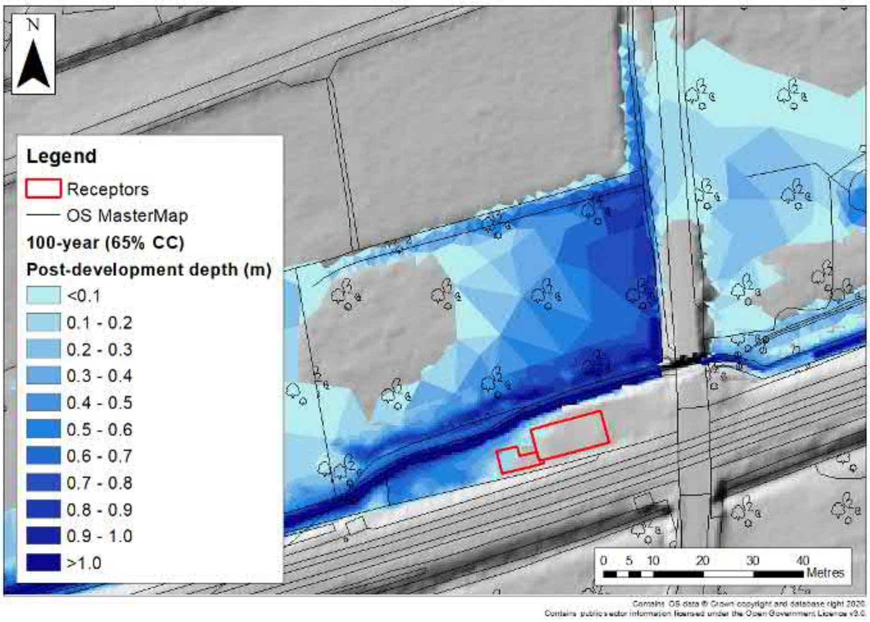
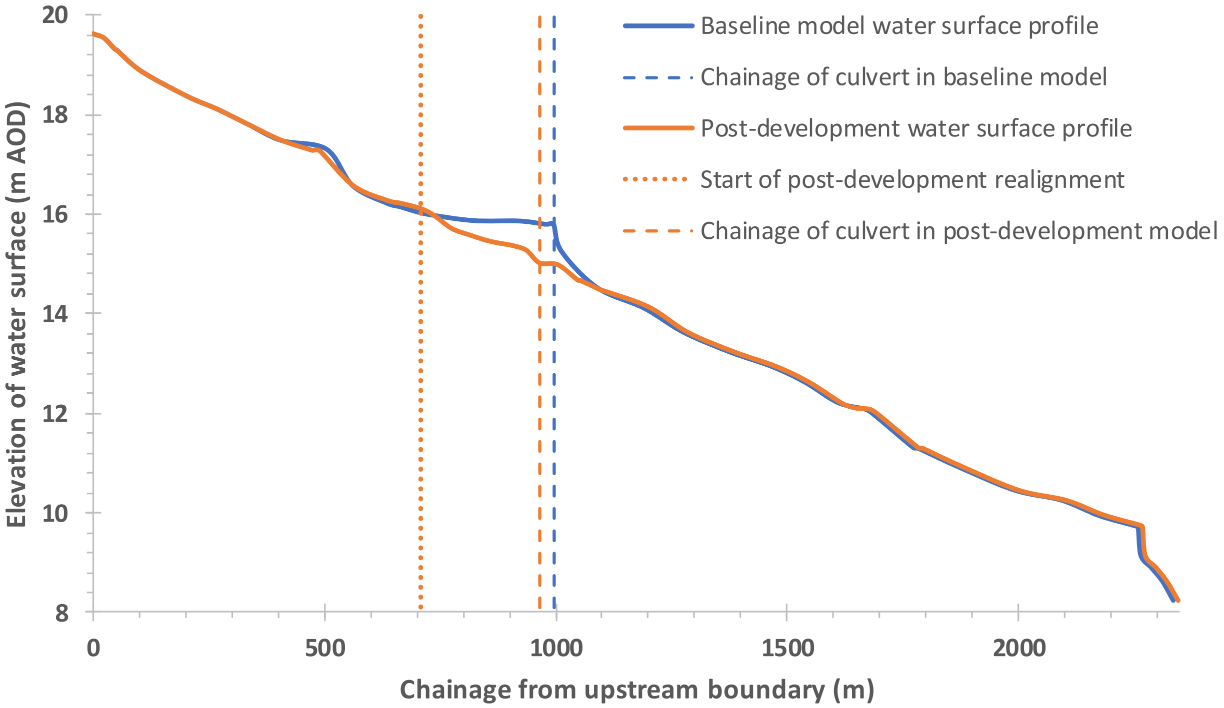


Figure 3-9 : Comparison of Cantley Stream water surface profile in baseline and post development model



3.9.5. Predicted stream levels in cross sections upstream and downstream of the realignment are presented in Table 3-3. The table highlights that the average increase in stream levels predicted upstream and downstream of the realignment following development is less than 10mm. The greatest increase (84mm) is found at the location of where a structure in the baseline model (Bridge Cantley Wood) has been removed, possibly on account of removal (assumed) of head losses caused by the existing farm access track bridge.

Table 3-3 : Stream levels upstream and downstream of realignment (baseline and post development) for 100-year event with 65% climate change allowance

Cross section name (upstream to downstream)	Baseline water level (m AOD)	Post development – Simulation 1	
		Water level (m AOD)	Change (m)
_02224	19.636	19.636	0.000
Interpolate 1	19.555	19.554	-0.001
Culvert Cantley Pond US	19.336	19.334	-0.002
_02172	19.301	19.299	-0.002
_02120	18.884	18.884	0.000
_02023	18.381	18.381	0.000
Interpolate 2	18.127	18.127	0.000
_01895	17.83	17.831	0.001
_01824	17.494	17.500	0.006
_01681	16.581	16.587	0.006
_01606	16.227	16.287	0.060
Bridge Cantley Wood contraction*	16.162	16.238	0.076
Bridge Cantley Wood expansion*	16.123	16.207	0.084
Realigned reach			
01072	14.124	14.145	0.021
00986	13.636	13.631	-0.005
00885	13.238	13.237	-0.001
00796	12.948	12.946	-0.002
Interpolate 4	12.635	12.630	-0.005
00654	12.225	12.201	-0.023
00594	12.093	12.092	-0.001
00579	12.007	12.006	-0.001
00484	11.321	11.32	-0.001
00475	11.309	11.308	-0.001
00398	10.972	10.971	-0.001
00268	10.47	10.467	-0.003
00165	10.264	10.26	-0.004
00083**	9.952	9.966	0.014
00007**	9.751	9.765	0.014
00000**	9.711	9.726	0.015
Culvert Intwood Rd DS**	9.149	9.150	0.001
Interpolate 5**	8.902	8.902	0.000
Interpolate 6**	8.628	8.629	0.001
Outfall XS**	8.248	8.249	0.001
Average increase in level baseline to post development (m):			**0.009**
Average decrease in level baseline to post development (m):			**-0.002**

*Name changed in post development model to reflect removal of bridge
**Levels at these sections are affected by the downstream boundary of the model and interpolation of the geometry

Simulation 2

3.9.6. Simulation 2 was used to look at possible influences on freeboard at the extended A11 bridge and new culvert at Cantley Lane South. This was of interest to the LLFA as discussed in paragraph 3.7.4. Table 3-4 summarises the differences in freeboard between the baseline and post development models in the A11 bridge and Cantley Lane South culvert for the 1 in 100-year plus 65% climate change scenario.

Table 3-4 : Differences in minimum freeboard between baseline and post development model for 1in 100-year plus 65% climate change

A11 Bridge			Cantley Lane South culvert		
Baseline minimum freeboard (m)	Post development minimum freeboard: Sim 1 (m)	Post development minimum freeboard: Sim 2 (m)	Baseline minimum freeboard (m)	Post development minimum freeboard: Sim 1 (m)	Post development minimum freeboard: Sim 2 (m)
1.839	1.772	1.768	0.00	0.428	0.426

3.9.7. As the table highlights, the minimum freeboard through the A11 bridge is reduced by approximately 0.07m from its baseline value and by an additional 0.004m by the addition of drainage inflows near the upstream end. As discussed in paragraph 3.7.2, the throttle at the existing Cantley Lane South culvert causes the culvert to surcharge, leaving no freeboard. In the post development model, the addition of drainage inflows had minimal impact (0.002m) on the post-development freeboard in the new Cantley Lane South culvert.

Alternative scenarios

3.9.8. A scenario was tested using the Simulation 2 inflows in which Cantley Lane South culvert was blocked by 50%. The modelling of this was done by adding a sediment depth to the conduit equal to one-half of the conduit height. In this scenario, throttling occurred upstream of the culvert as it does in the existing culvert, leading to a water surface profile comparable to that of the baseline model. Figure 3-10 shows the local flood extent with and without the 50% blockage (includes Simulation 2 drainage inflows), and Figure 3-11 shows the water surface profile in the area of the culvert with and without the 50% blockage.

Figure 3-10 : Post development flood extent (including additional inflow from drainage) at Cantley Lane South with and without culvert blockage

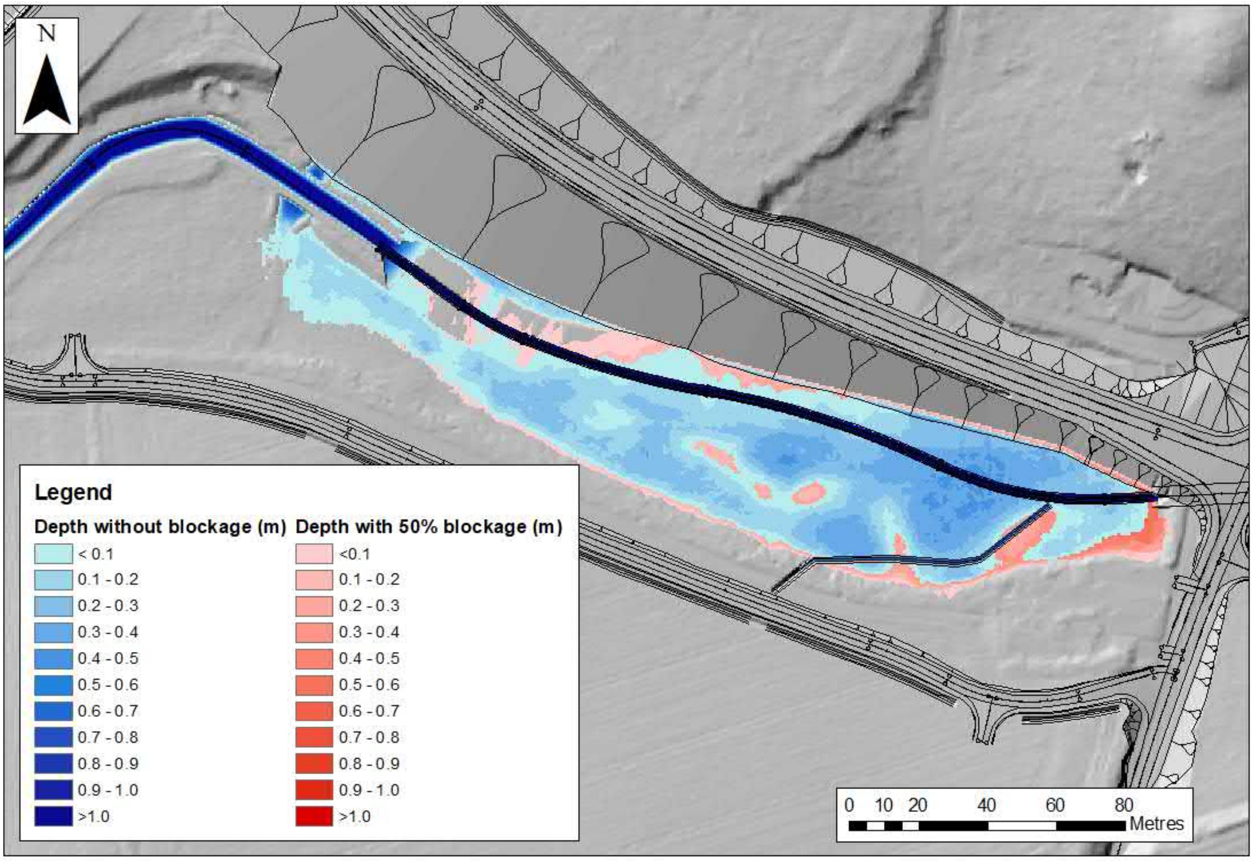
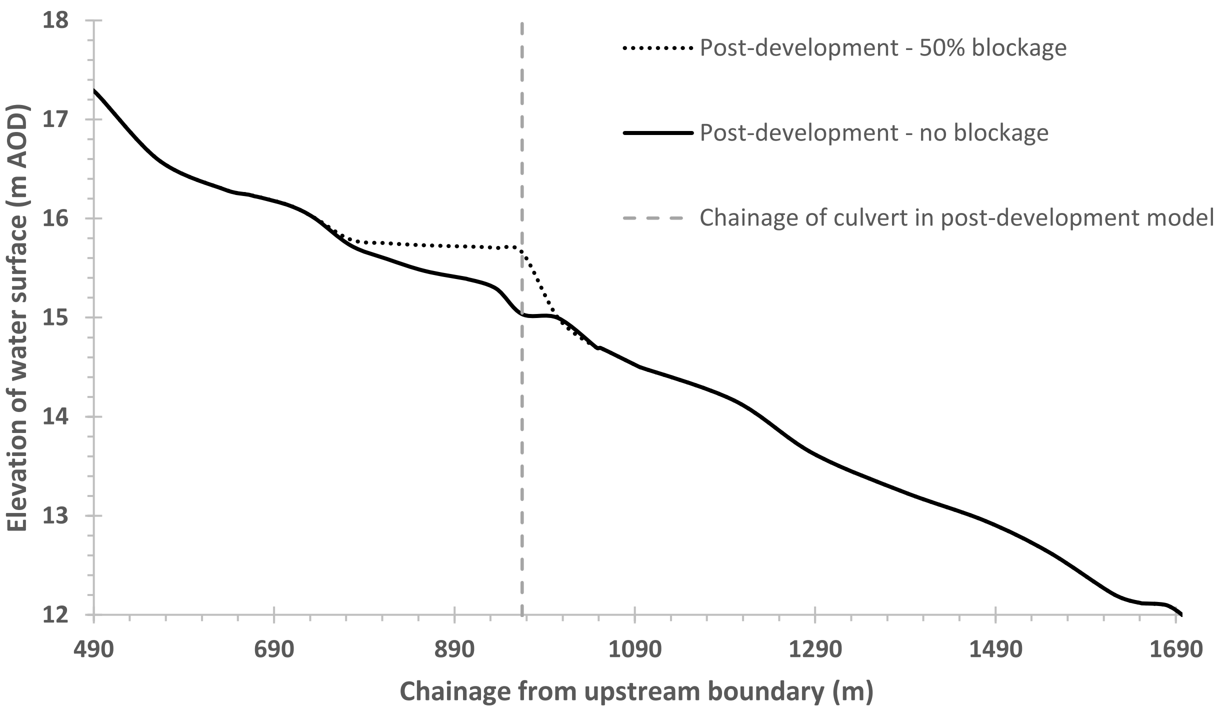


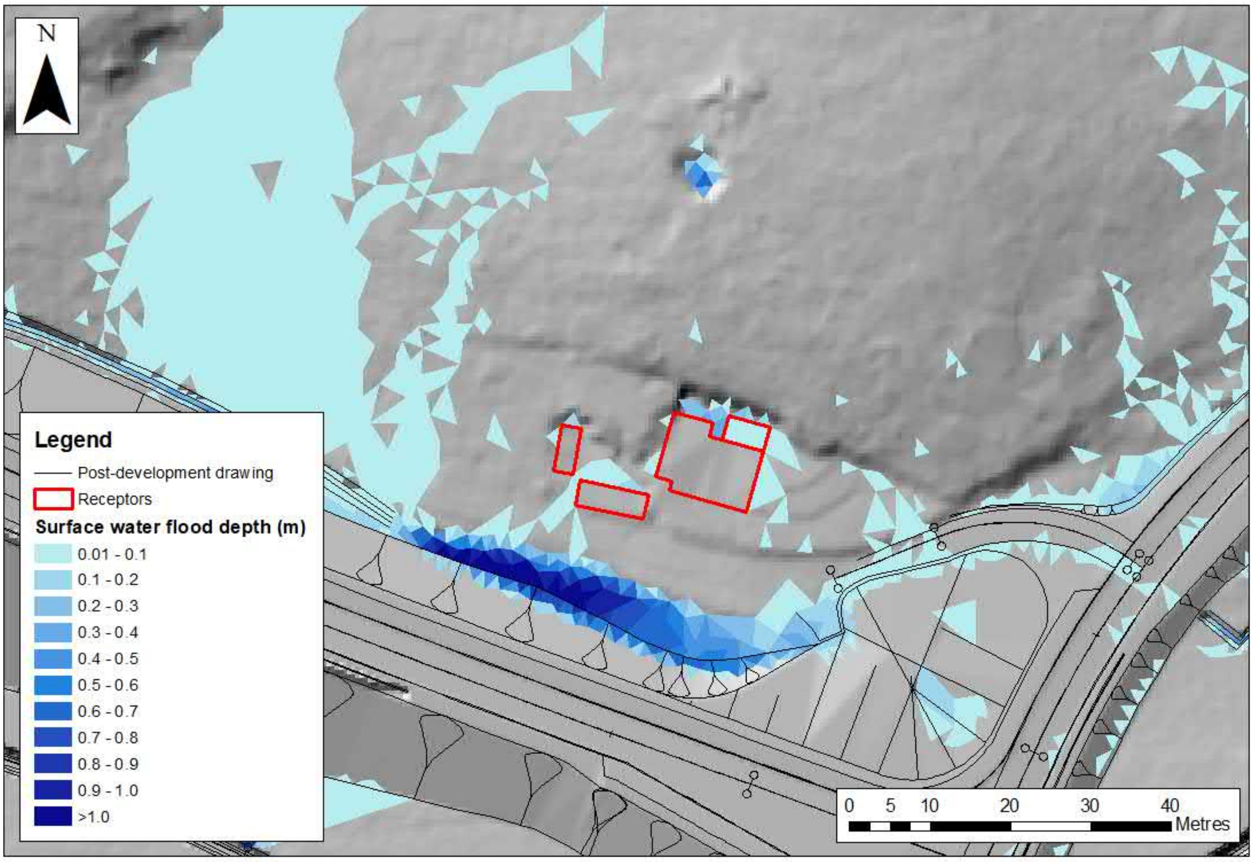
Figure 3-11 : Post development water surface profile near Cantley Lane culvert with and without blockage



Simulation 3

3.9.9. Simulation 3 was aimed at testing the performance of a culvert under the new link road. Under sizing of this culvert could lead to additional flood risk to nearby receptors. Figure 3-12 shows the peak surface water depths in the area of interest. These results correspond to inputs for Simulation 3 summarised in Table 3-2.

Figure 3-12 : Surface water flooding around receptors in the area of interest

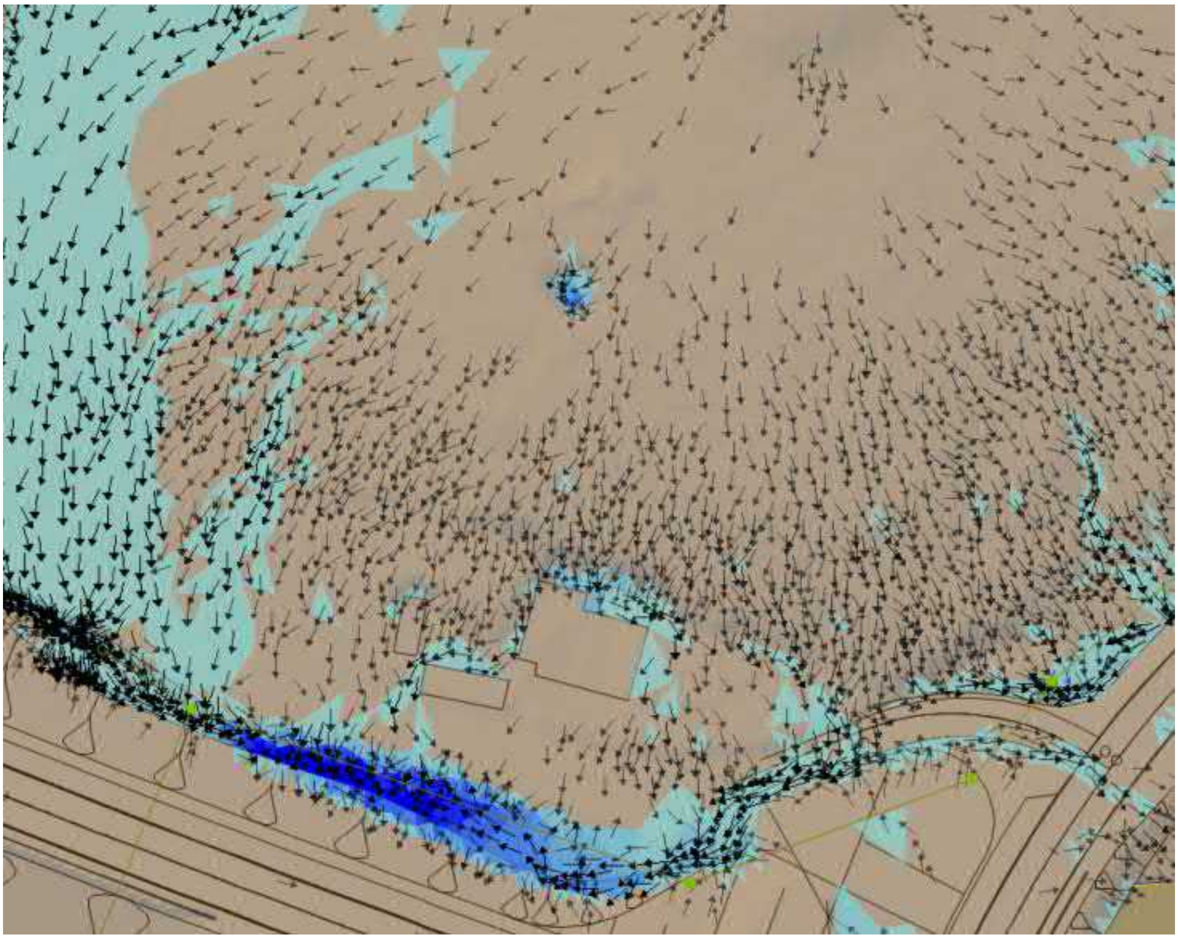


* 0.5-hour 100-year pluvial event with 40% climate change

Runoff patterns

3.9.10. Figure 3-13 shows flow paths predicted by the model within 2D mesh elements. This visualisation of flow paths underscores that no flooding is predicted to occur at receptors as a result of backup from the newly developed drainage system. From a qualitative view of flow paths in the runoff zone, it can be said that runoff arriving at the receptors is primarily from pre-existing terrain. It should be noted that the model is not intended as a full drainage model and excludes any representation of drainage networks that route runoff from structures at the northern side of the runoff zone (Figure 3-6).

Figure 3-13 : Surface water flooding flow paths around receptors in post-development modelling



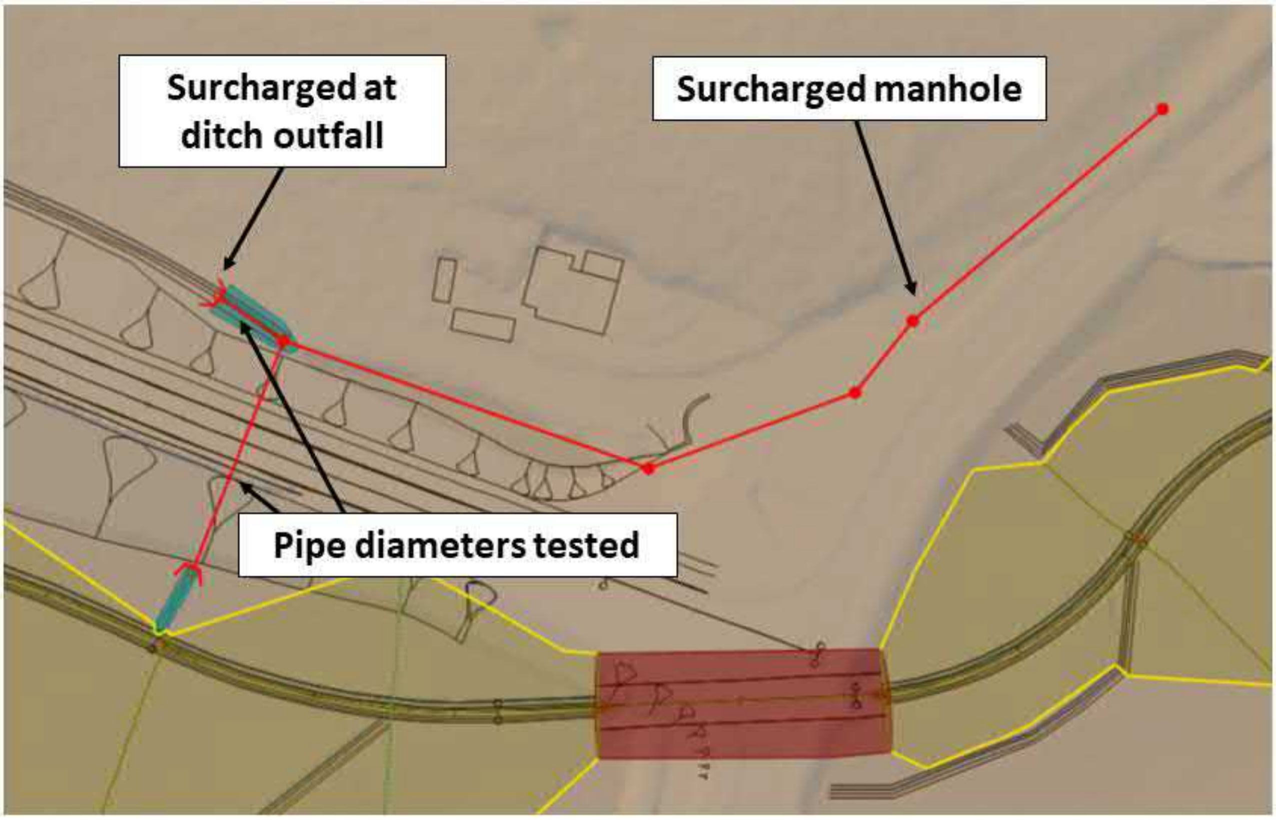
Surcharging in pipes and manholes

3.9.11. Surcharging occurred within pipes and one manhole was surcharged with a flood depth of 0.09m. This surcharging was found to be inconsequential with respect to flood risk at receptors. Backup of surface water was found at the ditch outfall identified in Figure 3-14.

Alternative scenarios

3.9.12. A scenario was tested to assess the impact of changes in drainage pipe diameter on backup at the ditch outfall. The diameter of the pipe connected to the ditch outfall and that of the cross drain under the link road near receptors (originally 375mm and 525mm, respectively), were increased to 600mm (locations identified in Figure 3-14). While the change removed surcharging in the ditch outfall pipe, flooding in the area of receptors was unchanged. Furthermore, while the flood depths along the link road were somewhat reduced, the extent of flooding in this area remained mostly unchanged.

Figure 3-14 : Locations where alternative pipe diameters were tested



3.9.13. A further test was carried out to assess sensitivity with respect to the ditch roughness, since it was initially unchanged from the overall 2D-zone roughness (Manning's n set to 0.04) in the model. A roughness zone was applied to the ditch and Manning's n was reduced to 0.025. This was found to have almost no impact on flood extent or depth.

3.9.14. As discussed in paragraph 3.8.9, drainage structures at point P3 were not included in Simulation 3. For this reason, the model is considered to be an overprediction of the amount of water overflowing from the ditch and collecting along the road. Furthermore, as discussed in paragraph 3.8.9, conservative choices were made with respect to the use of 2D manholes and their chosen parameters as points of surface water collection to the drainage network.

4. Conclusion

4.1.1. This report was prepared to summarise the hydraulic modelling undertaken to estimate baseline and post development flooding conditions along Cantley Stream in support of design decisions and to assess flood risk impacts for the Proposed Scheme at A47/A11 Thickthorn Junction. The Proposed Scheme involves realignment of the modelled stream and the construction of a new culvert.

4.1.2. Baseline flood depths and maps are presented for the 100-year event with and without climate change (35%, 65%, and 80%), and for the 1000-year event. In all baseline scenarios, notable flooding is predicted in the area of interest for stream realignment and culvert construction and appears to be largely influenced by the existing culvert beneath Cantley Lane South and the topography of the floodplain in this area.

4.1.3. Modifications to the model to simulate the stream realignment and new development of roads and structures are described in detail. Three simulations were carried out for post development modelling.

4.1.4. The first primary simulation served as a direct comparison with the baseline model, while the others included additional features to look at the impact of new drainage flows and surface water flood risk associated with the Proposed Scheme. The model was utilised throughout the design process to inform decisions on the realigned stream channel geometry and the design of the new culvert at Cantley Lane South under competing constraints and interests.

4.1.5. Results for all three post development simulations are discussed. Flood maps and stream depths for the primary simulation are provided for comparison with the baseline model. Comparisons show that the realigned reach, new road structures, and new culvert under the Proposed Scheme will remove the throttling behaviour of the stream upstream of Cantley Lane South, reducing the volume of flooding in the area. Work is under way to better quantify potential impact to a receptor downstream near Intwood Lane; this includes further survey and an update to the flood model.

4.1.6. It was found that drainage inflow points added to the model resulted in minimal change to flood levels in Cantley Stream and also to freeboard through modified structures at the A11 and Cantley Lane South. It was also found that, although throttling of the stream at Cantley Lane South is removed under post development conditions, it is likely to re-occur in the event of a blockage at the new Cantley Lane South culvert.

4.1.7. The performance of a proposed surface water system in the vicinity of a resident receptor was tested in scenario 3. The scenario was driven by a 100-year 0.5-hour rainfall event with a 40% allowance for climate change, rainfall was applied directly to the model mesh. The model predicts that the culvert is not undersized and the receptor is not at greater risk of flooding. The receptor is affected by surface water from the existing upper catchment, this risk is not expected to be exacerbated by the Proposed Scheme. Simulations of alternative scenarios showed that some changes to parameters and geometry in an area of surcharging does not affect flood extent or the nature of flooding at receptors.

Appendix A. **Model Parameters**

Table A.1 Key model parameters in the 1D domain

Model object	Parameter	Value (Baseline)	Value (Post development realigned reach)
River reaches	Panel roughness in main channel (Manning's n)	0.04	0.04
River reaches	Panel roughness on banks (Manning's n)	0.06	0.05
River banks	Discharge coefficient	0.8	0.8
River banks *(all except below)*	Modular limit	0.6	0.6
River banks between *Bridge Cantley Wood* and *Bridge 1 Cantley Ln* (Baseline only)	Modular limit	0.5	N/A
Left bank between *Bridge 2 Cantley Ln* and *Culvert A47* (Baseline only)	Modular limit	0.5	N/A

Table A.2 Key model parameters in the 2D domain

Model object	Parameter	Value
2D zone	Maximum triangle size	500 m^2
2D zone	Minimum triangle size	1 m^2
2D zone	Maximum height variation	0.5 m
2D zone	Manning's n	0.04

Appendix B. **Baseline flood maps**

Figure B.1 : Maximum baseline flood depths between upstream boundary and Cantley Lane South (100-year event with no climate change)

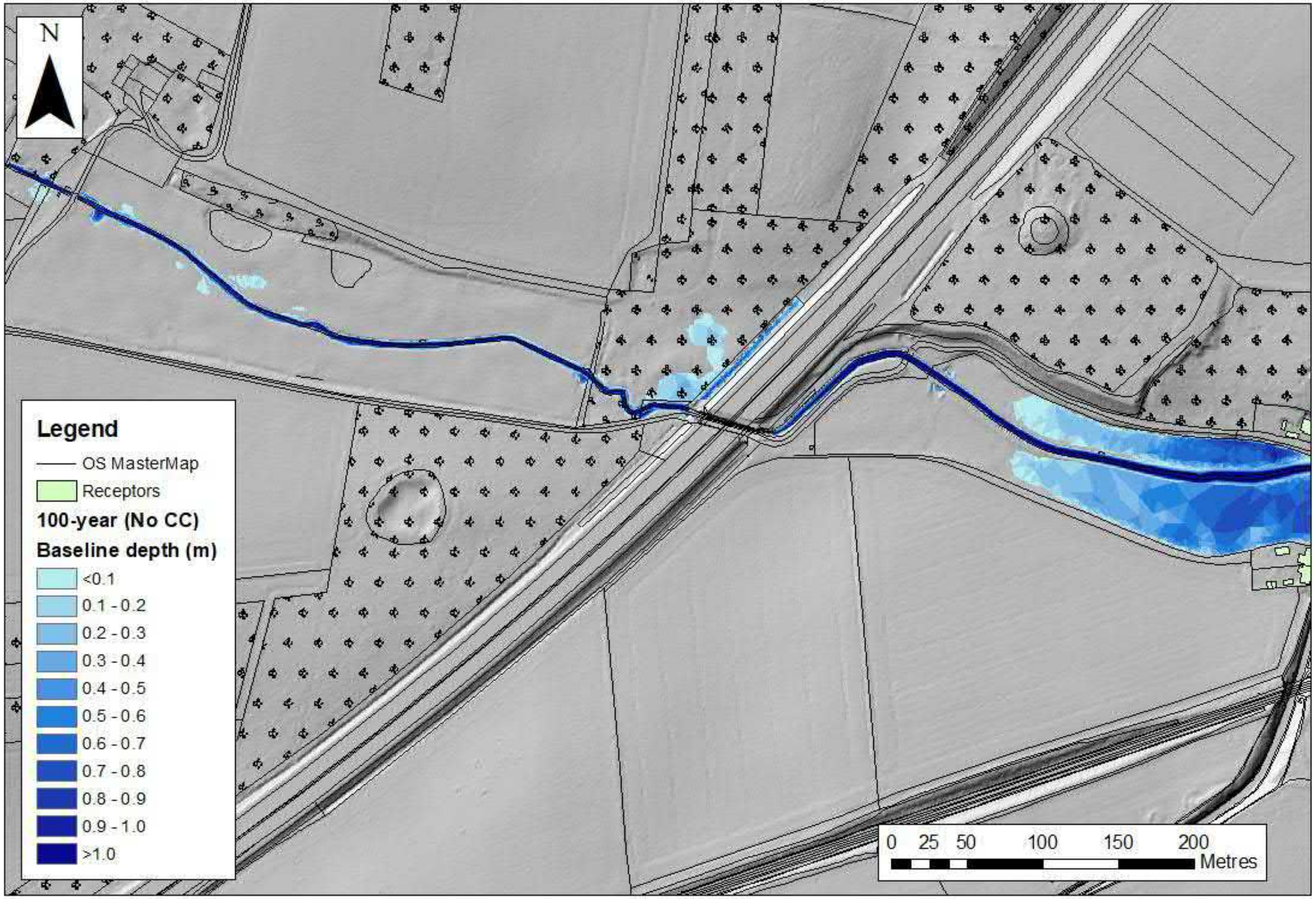


Figure B.2 : Maximum baseline flood depths between upstream boundary and Cantley Lane South (100-year event with 35% climate change)

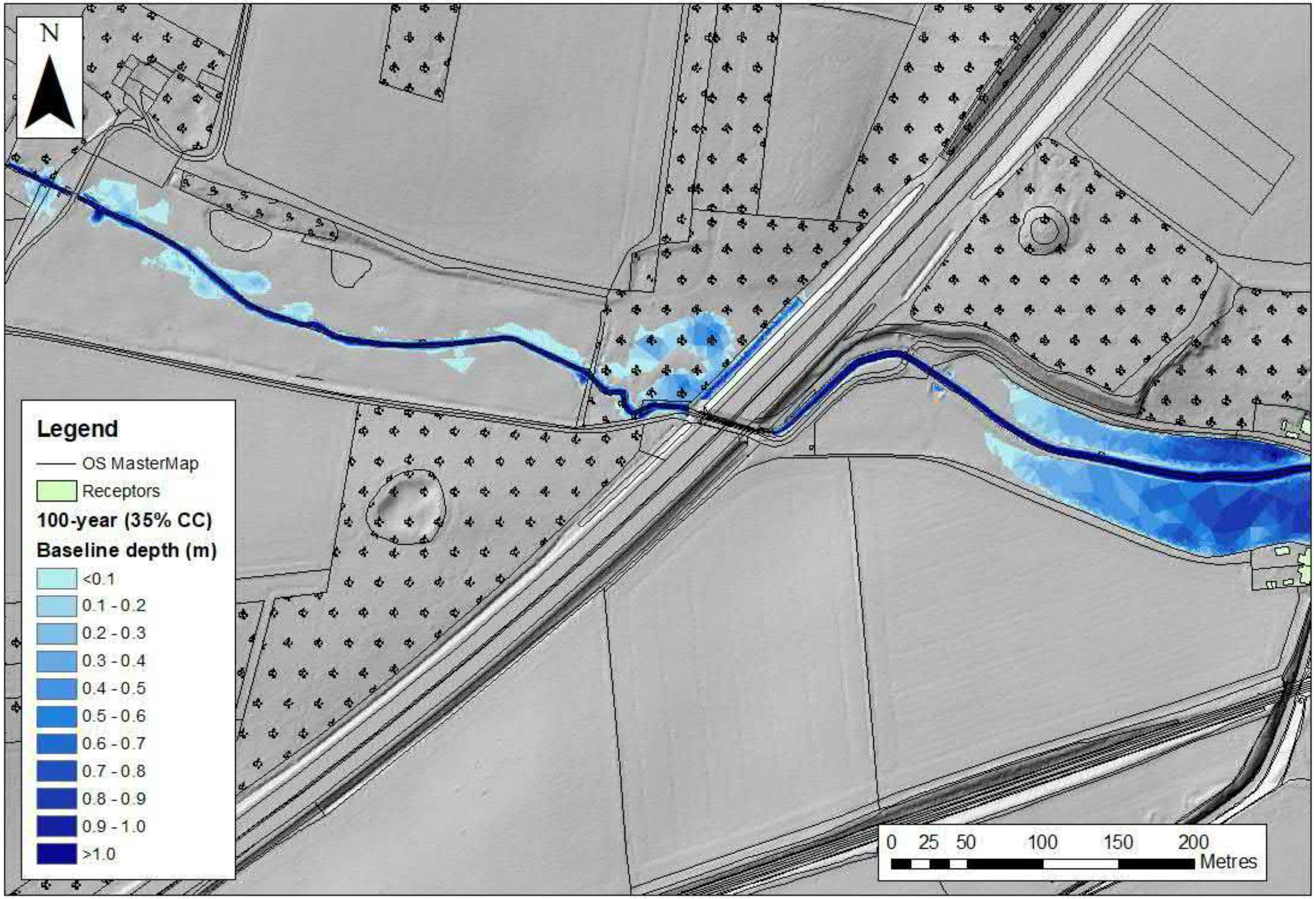


Figure B.3 : Maximum baseline flood depths between upstream boundary and Cantley Lane South (100-year event with 65% climate change)

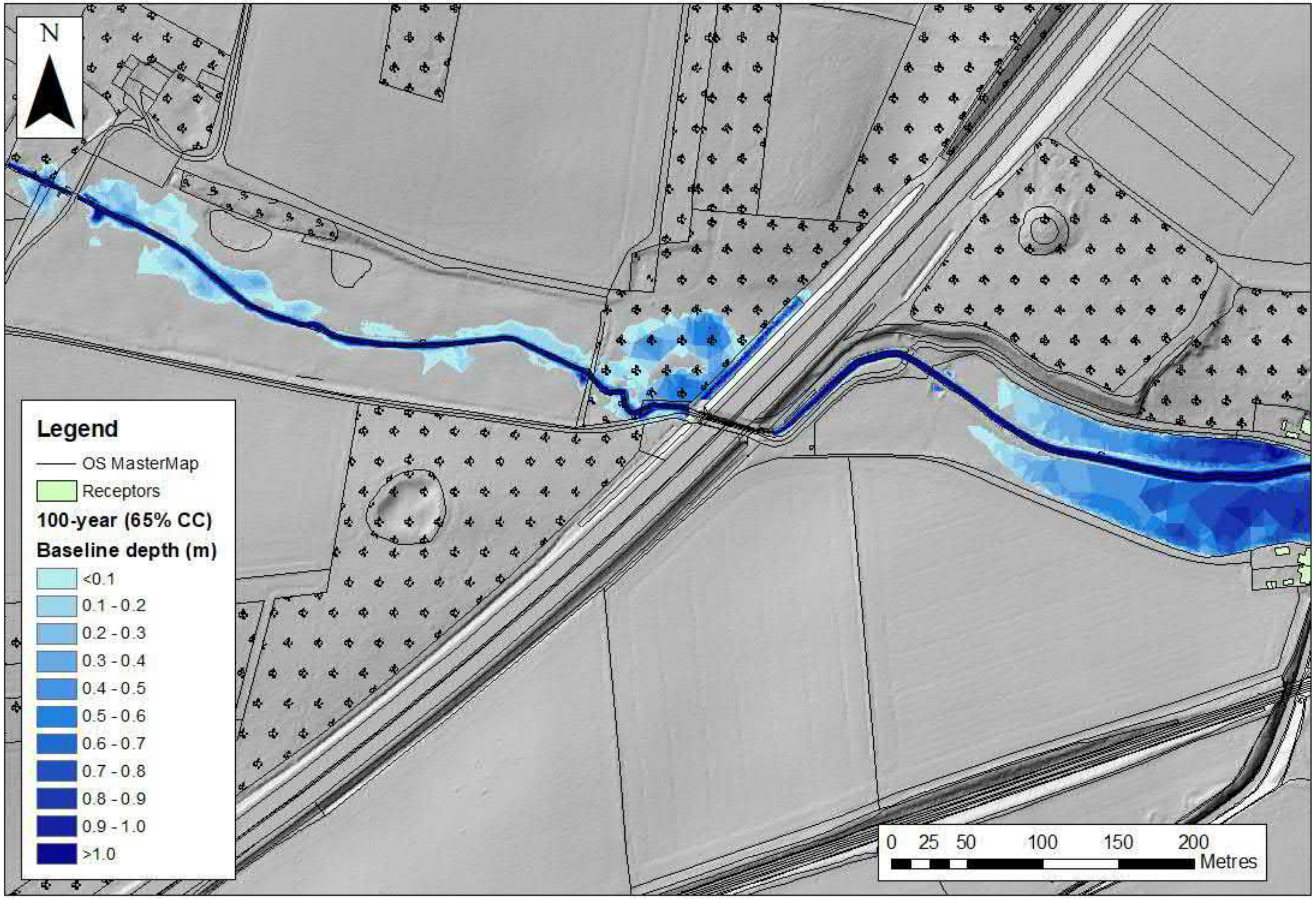


Figure B.4 : Maximum baseline flood depths between upstream boundary and Cantley Lane South (100-year event with 80% climate change)

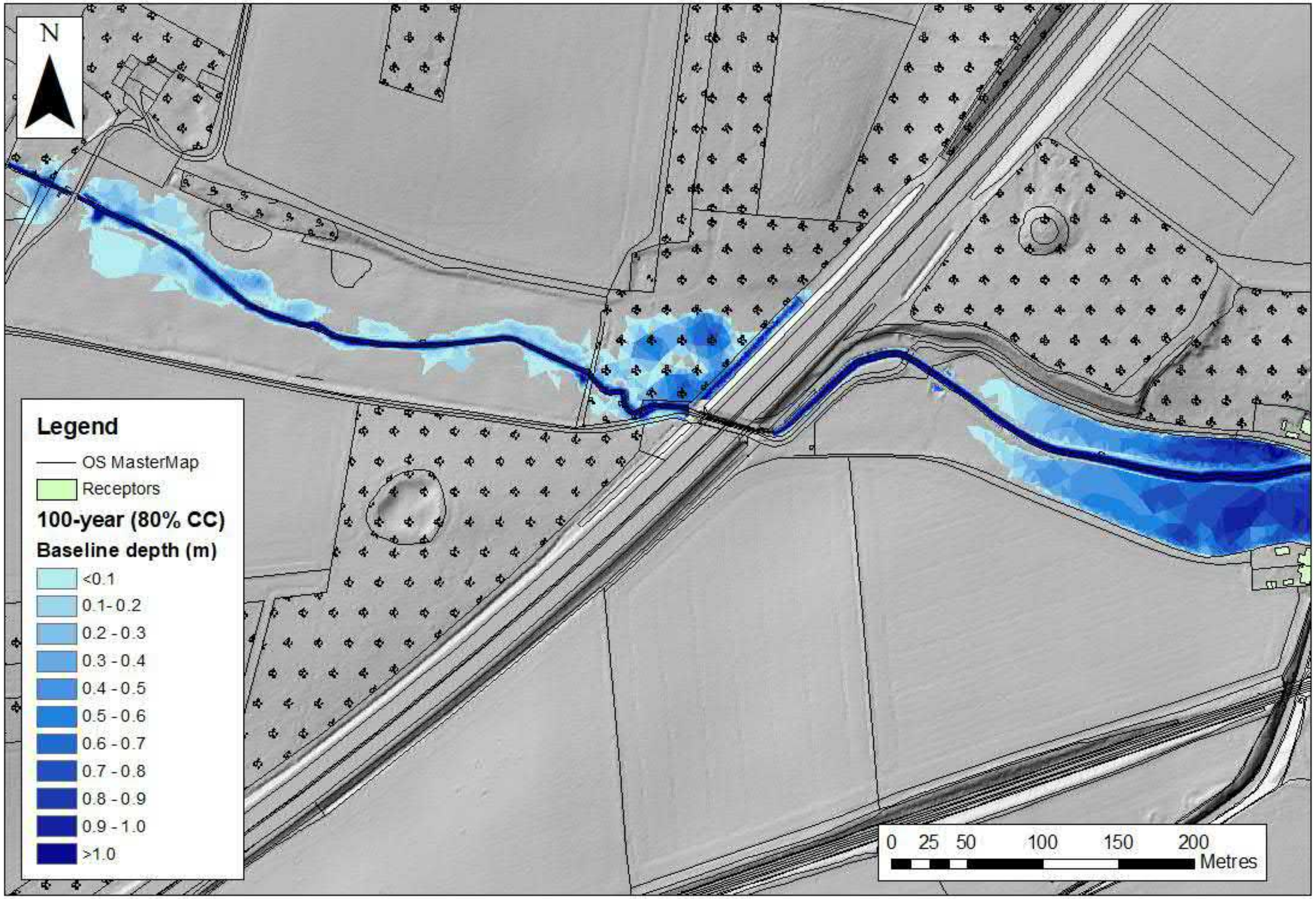


Figure B.5 : Maximum baseline flood depths between upstream boundary and Cantley Lane South (1000-year event with no climate change)

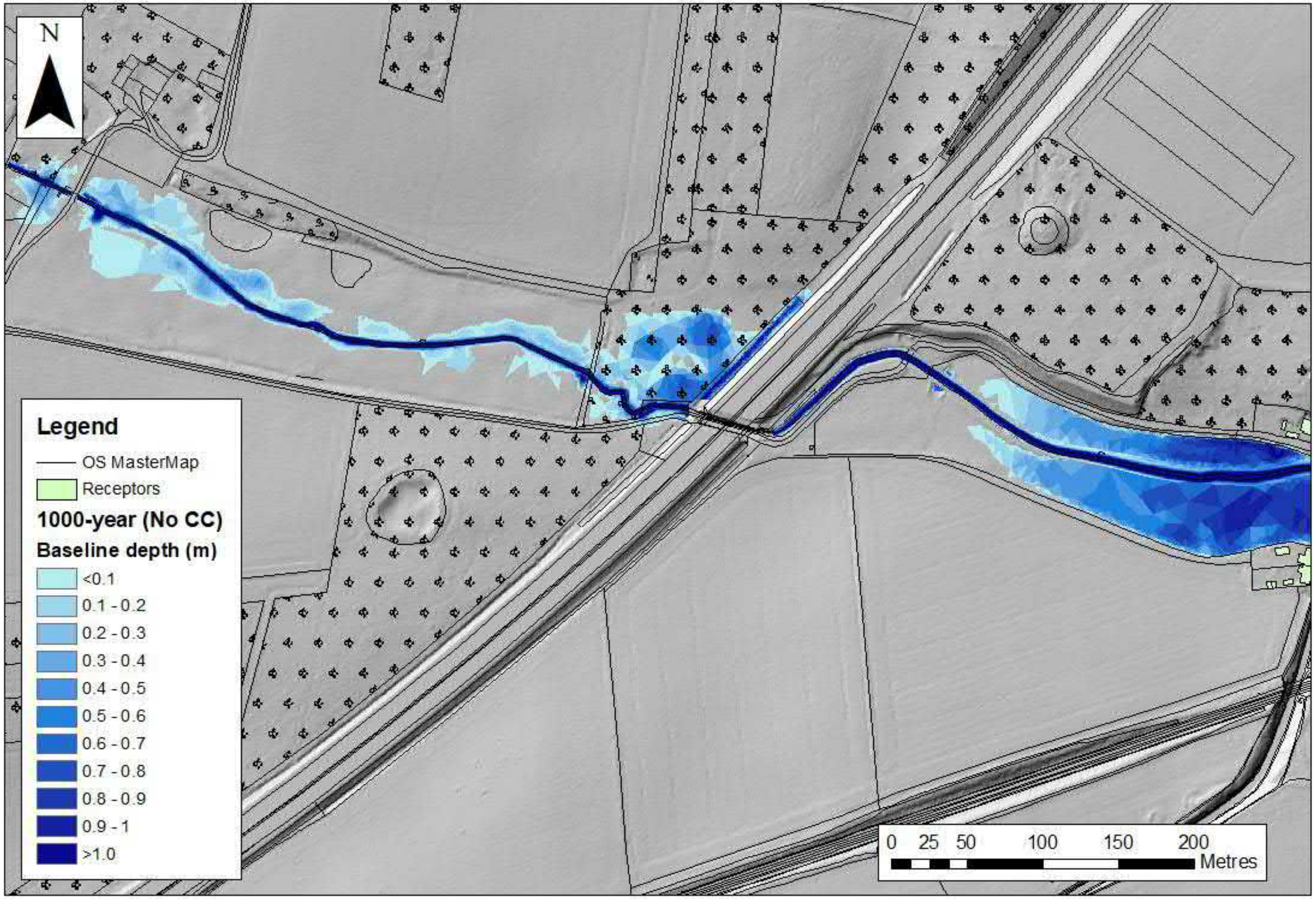


Figure B.6 : Maximum baseline flood depths between Cantley Lane South and the A47 (100-year event with no climate change)

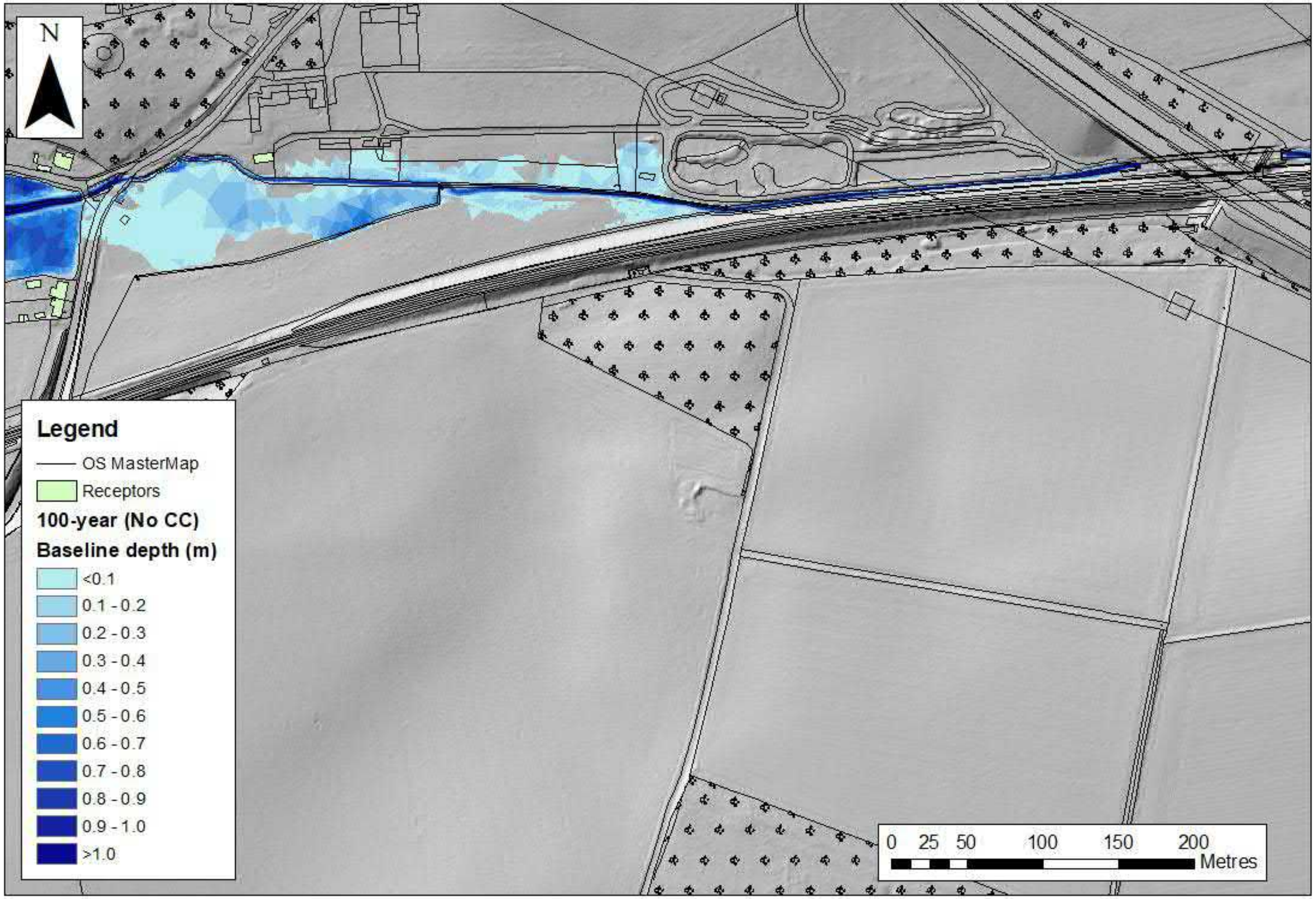


Figure B.7 : Maximum baseline flood depths between Cantley Lane South and the A47 (100-year event with 35% climate change)

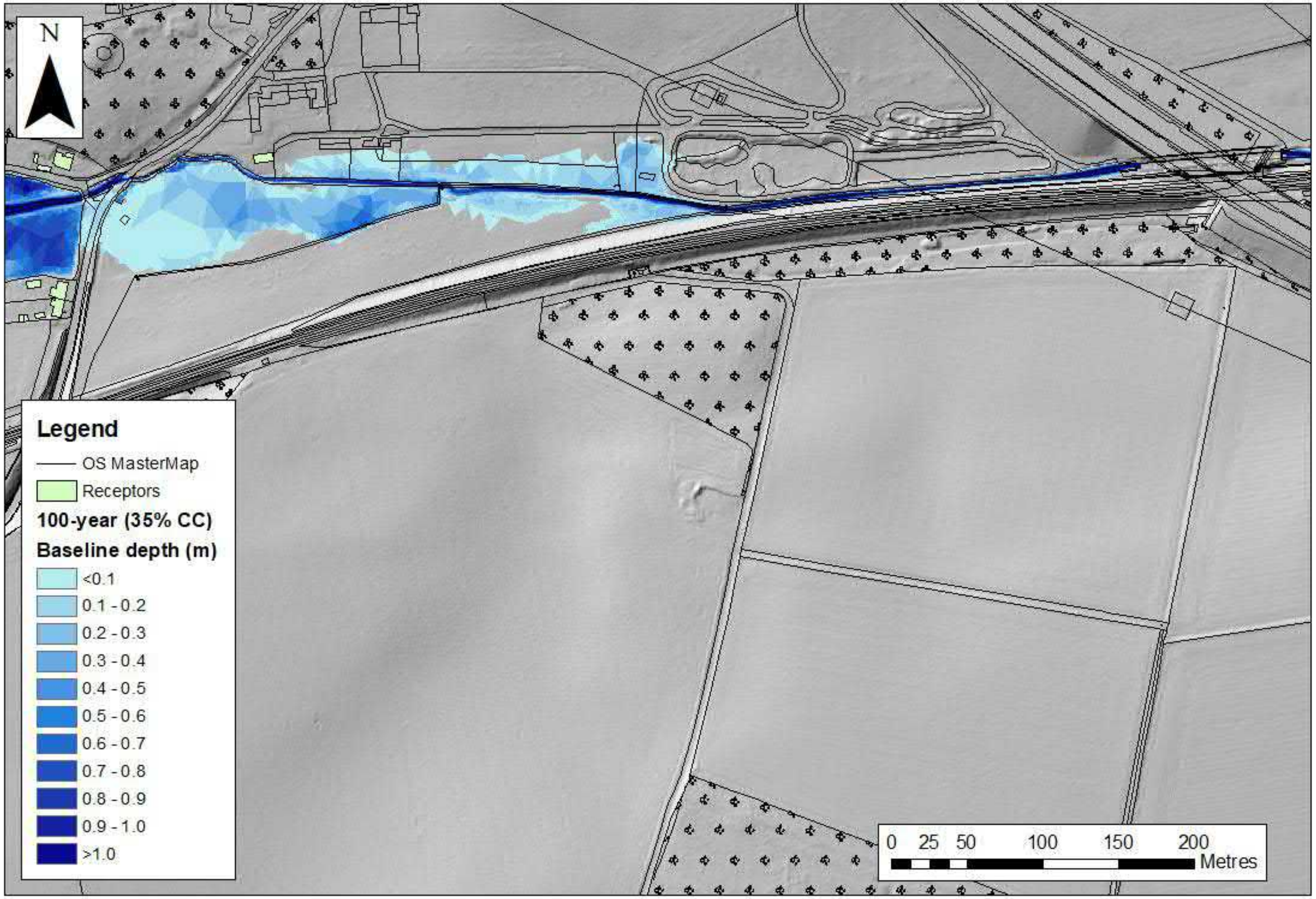


Figure B.8 : Maximum baseline flood depths between Cantley Lane South and the A47 (100-year event with 65% climate change)

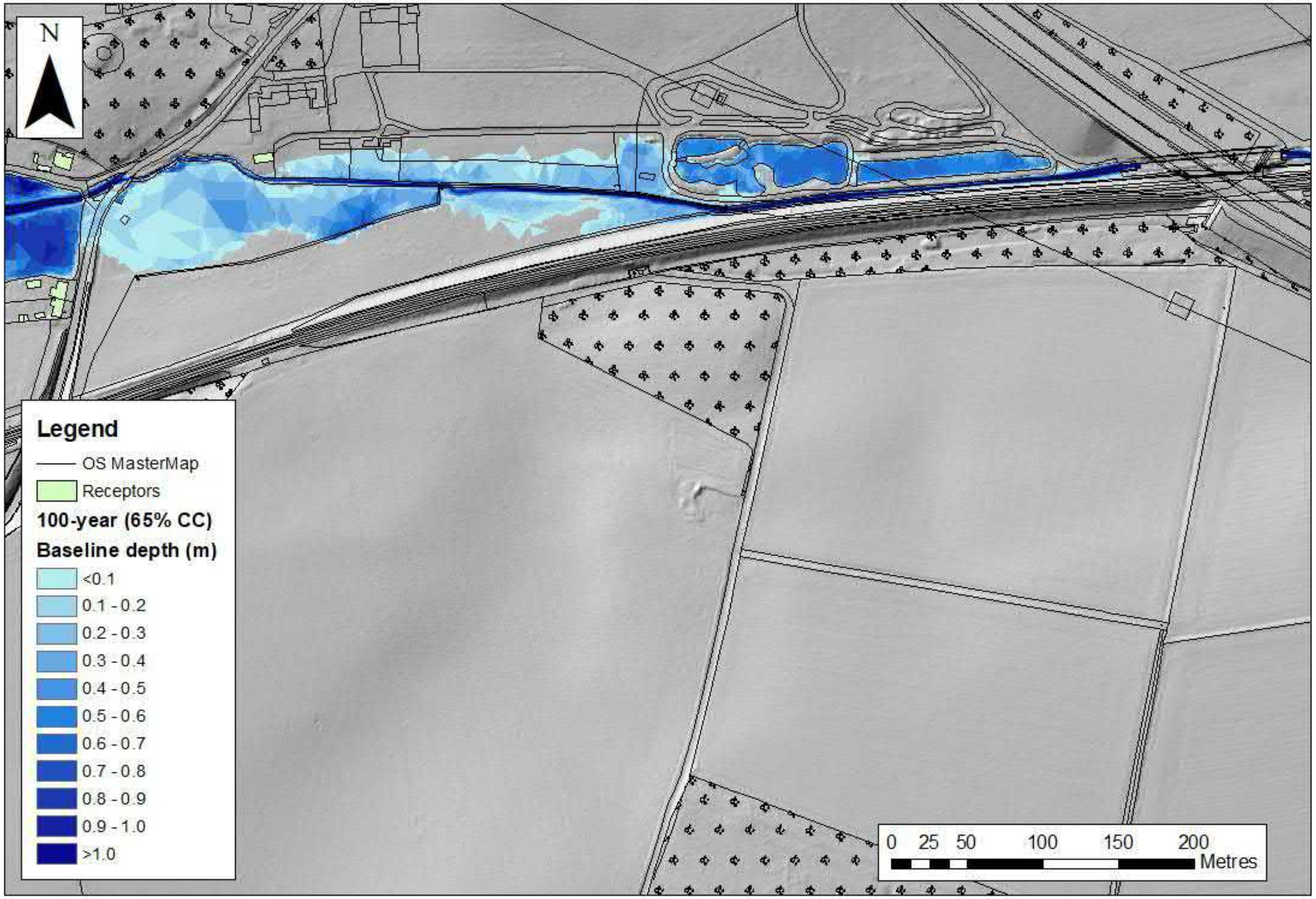


Figure B.9 : Maximum baseline flood depths between Cantley Lane South and the A47 (100-year event with 80% climate change)

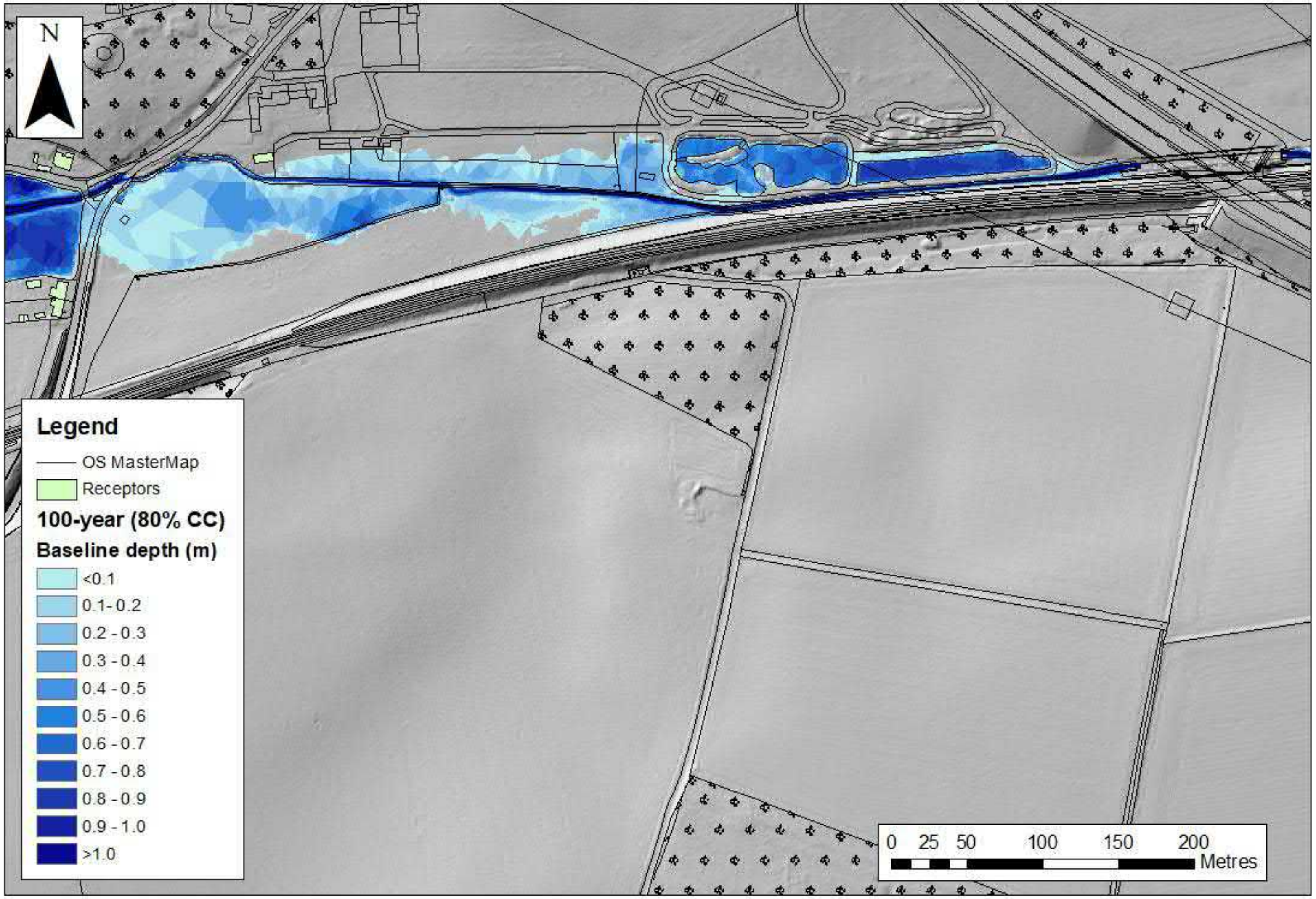


Figure B.10 : Maximum baseline flood depths between Cantley Lane South and the A47 (1000-year event with no climate change)

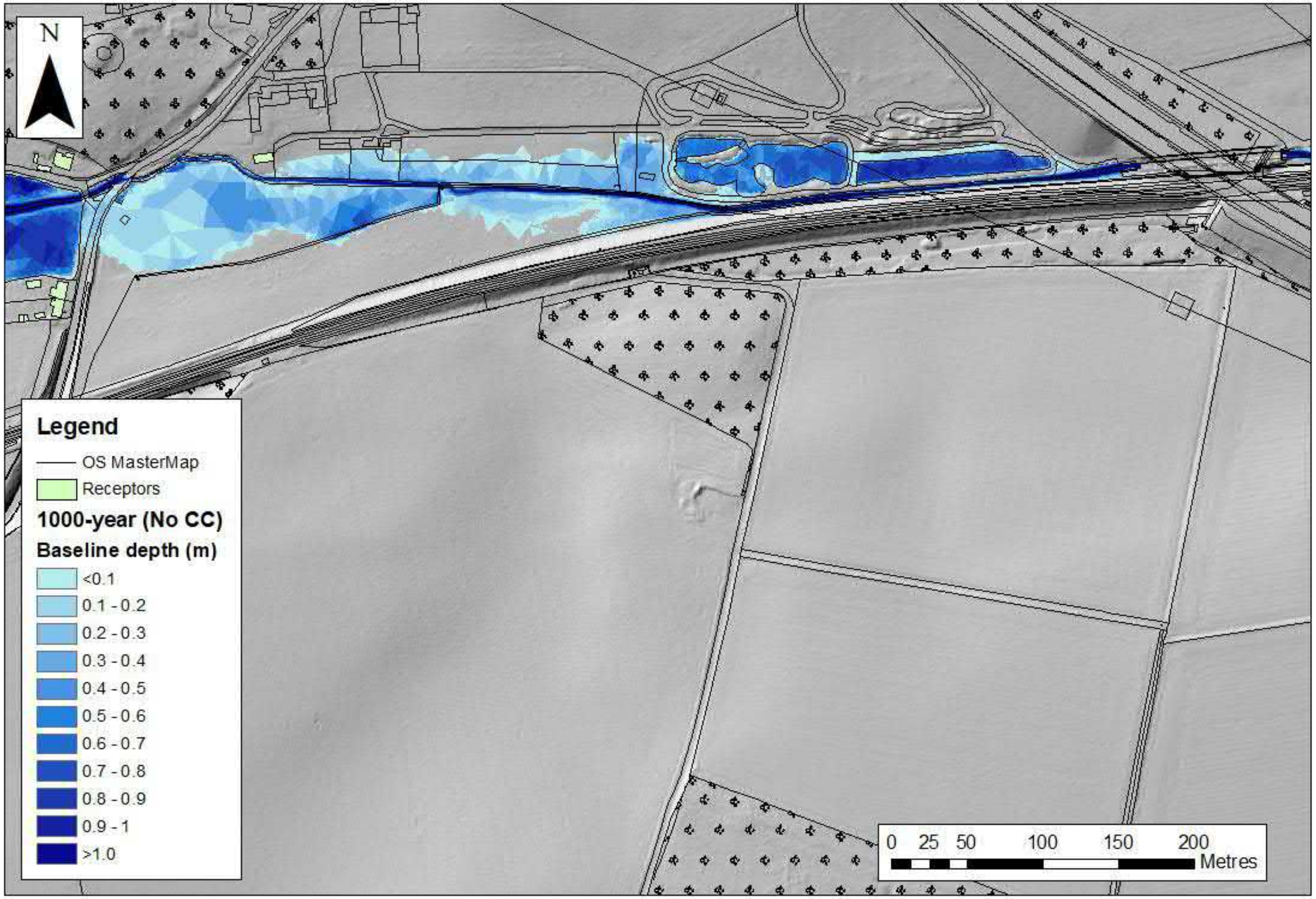


Figure B.11 : Maximum baseline flood depths between the A47 and the model outfall (100-year event with no climate change)

Figure B.12 : Maximum baseline flood depths between the A47 and the model outfall (100-year event with 35% climate change)

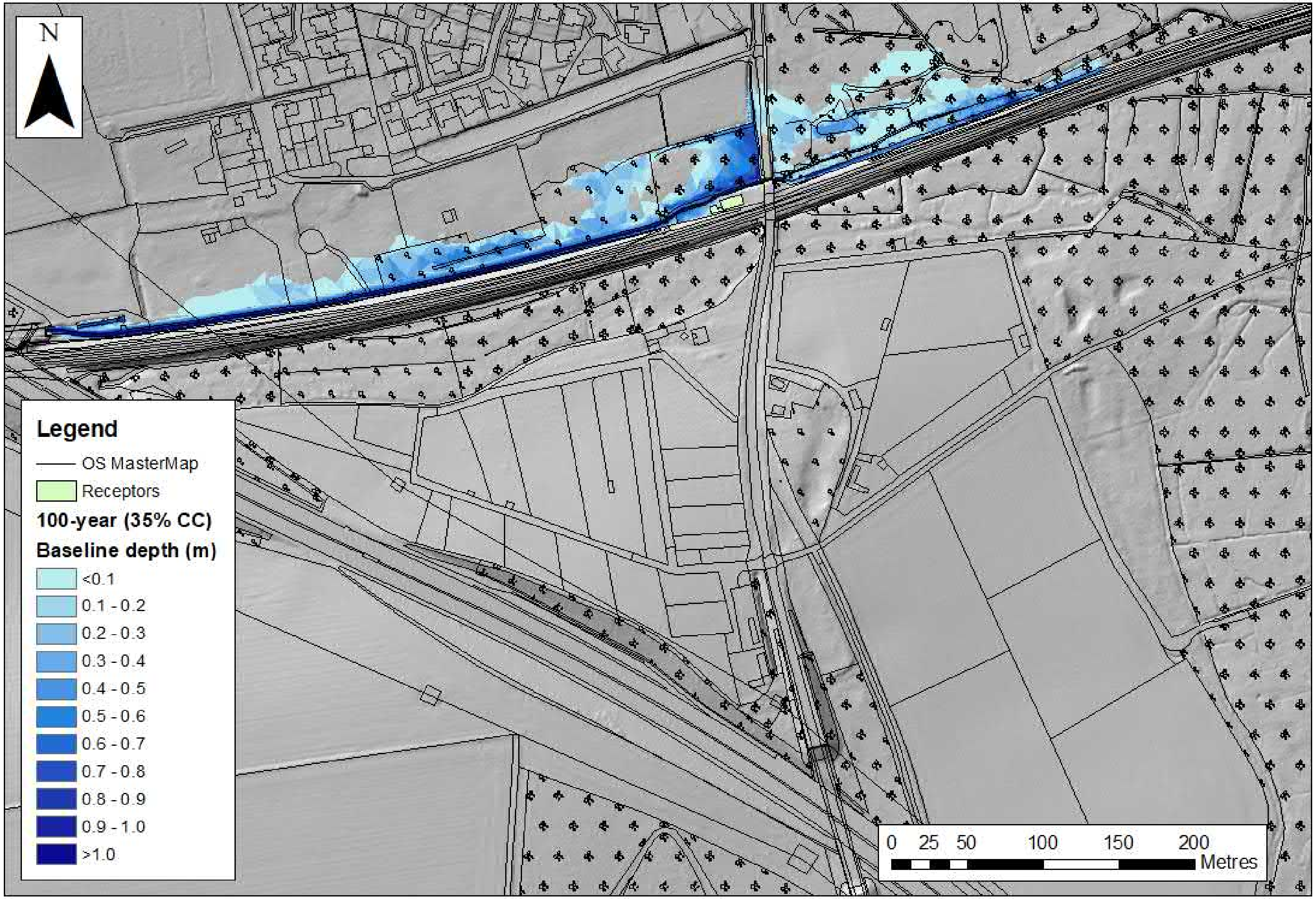


Figure B.13 : Maximum baseline flood depths between the A47 and the model outfall (100-year event with 65% climate change)

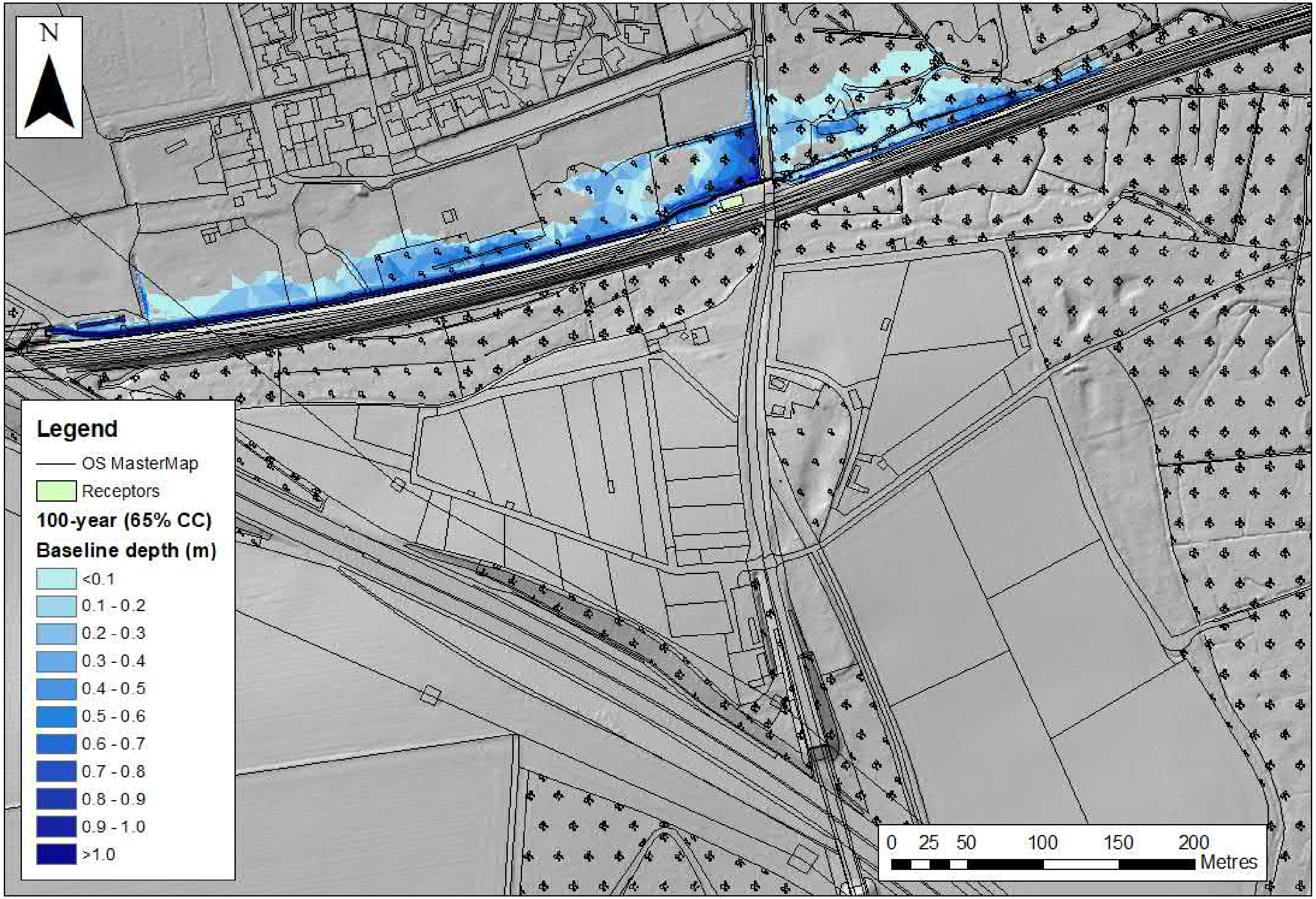


Figure B.14 : Maximum baseline flood depths between the A47 and the model outfall (100-year event with 80% climate change)

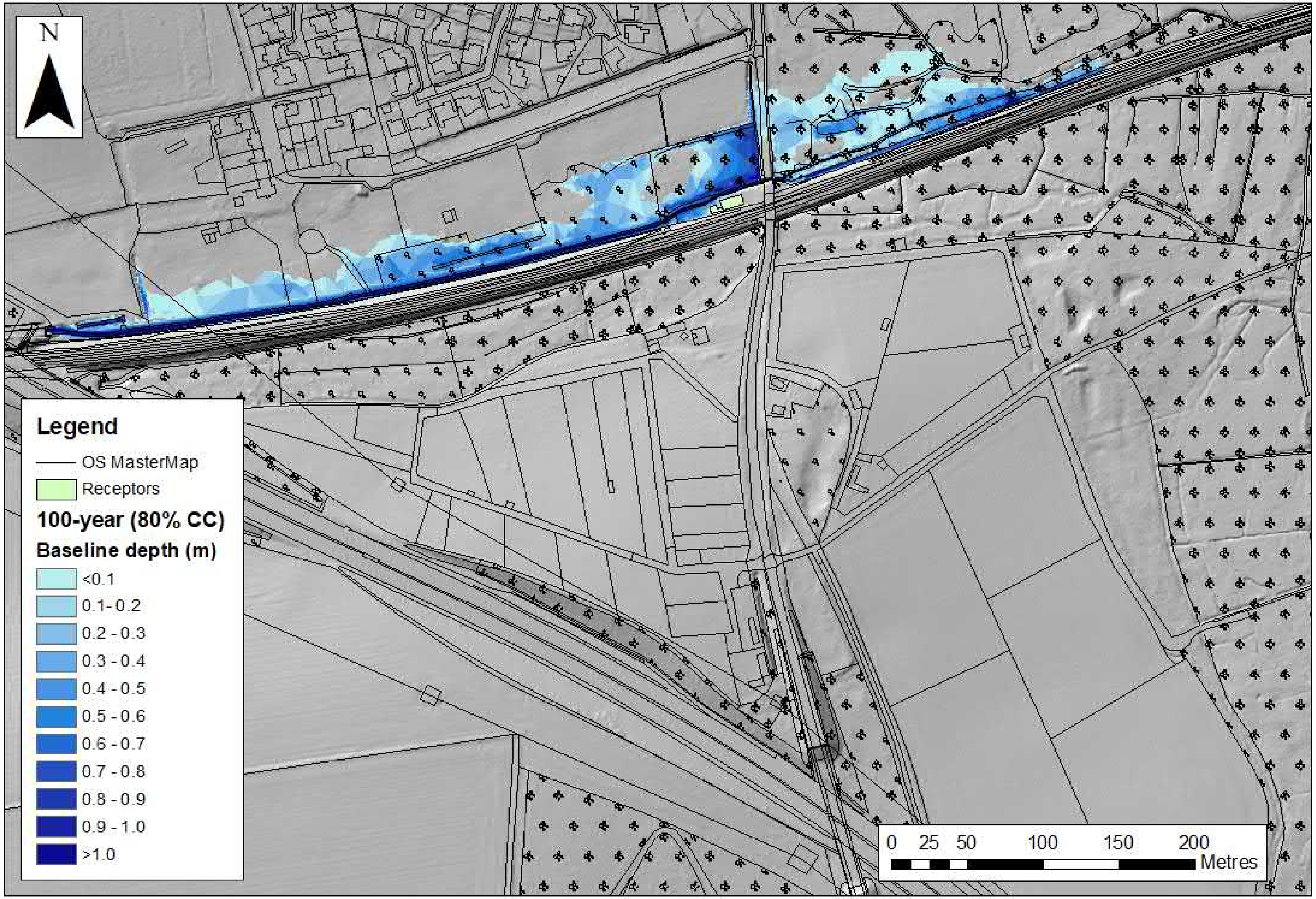
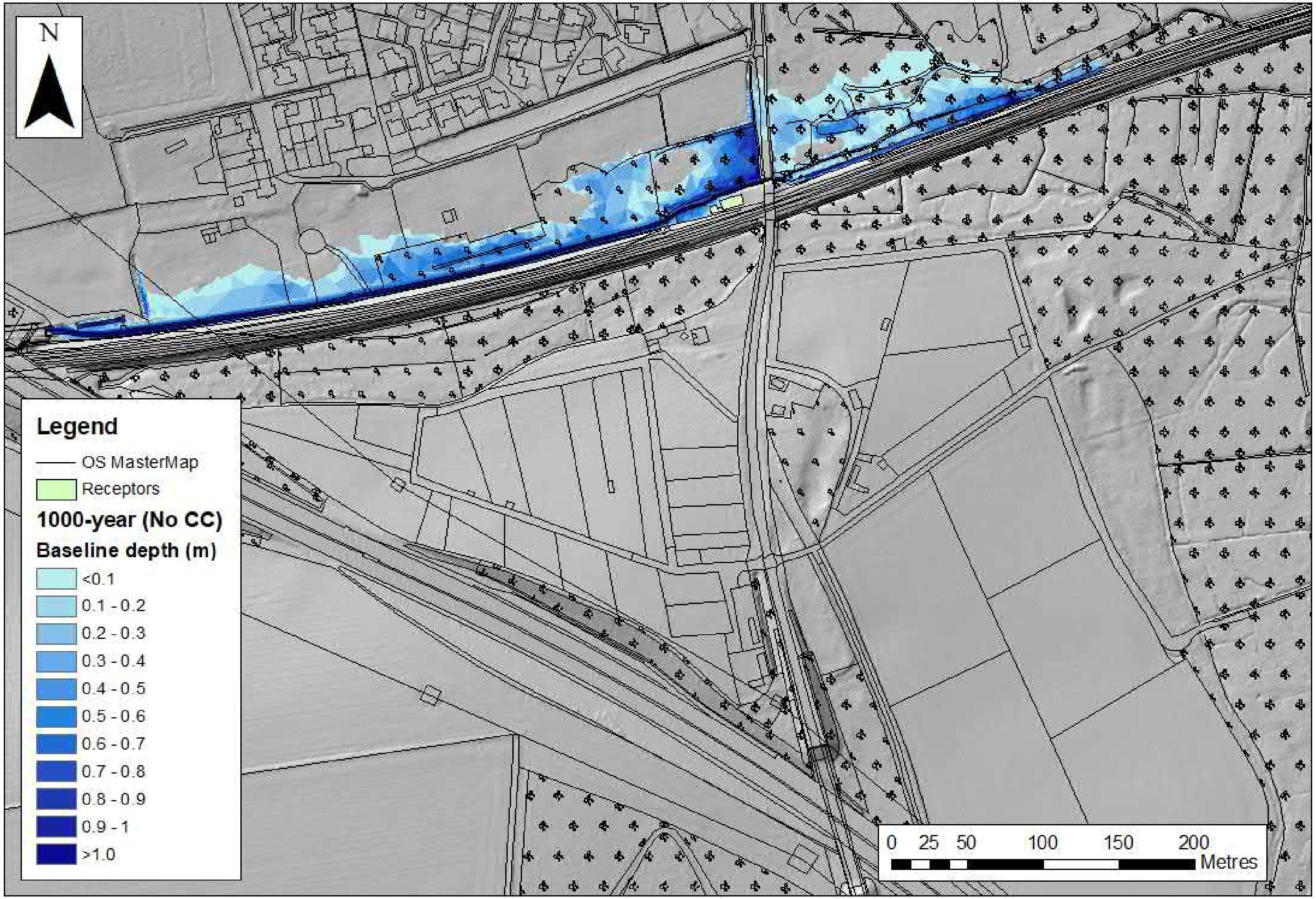


Figure B.15 : Maximum baseline flood depths between the A47 and the model outfall (1000-year event with no climate change)



Appendix C. Post development flood maps

Figure C.1 : Maximum post development flood depths between upstream boundary and Cantley Lane South (100-year event with no climate change)

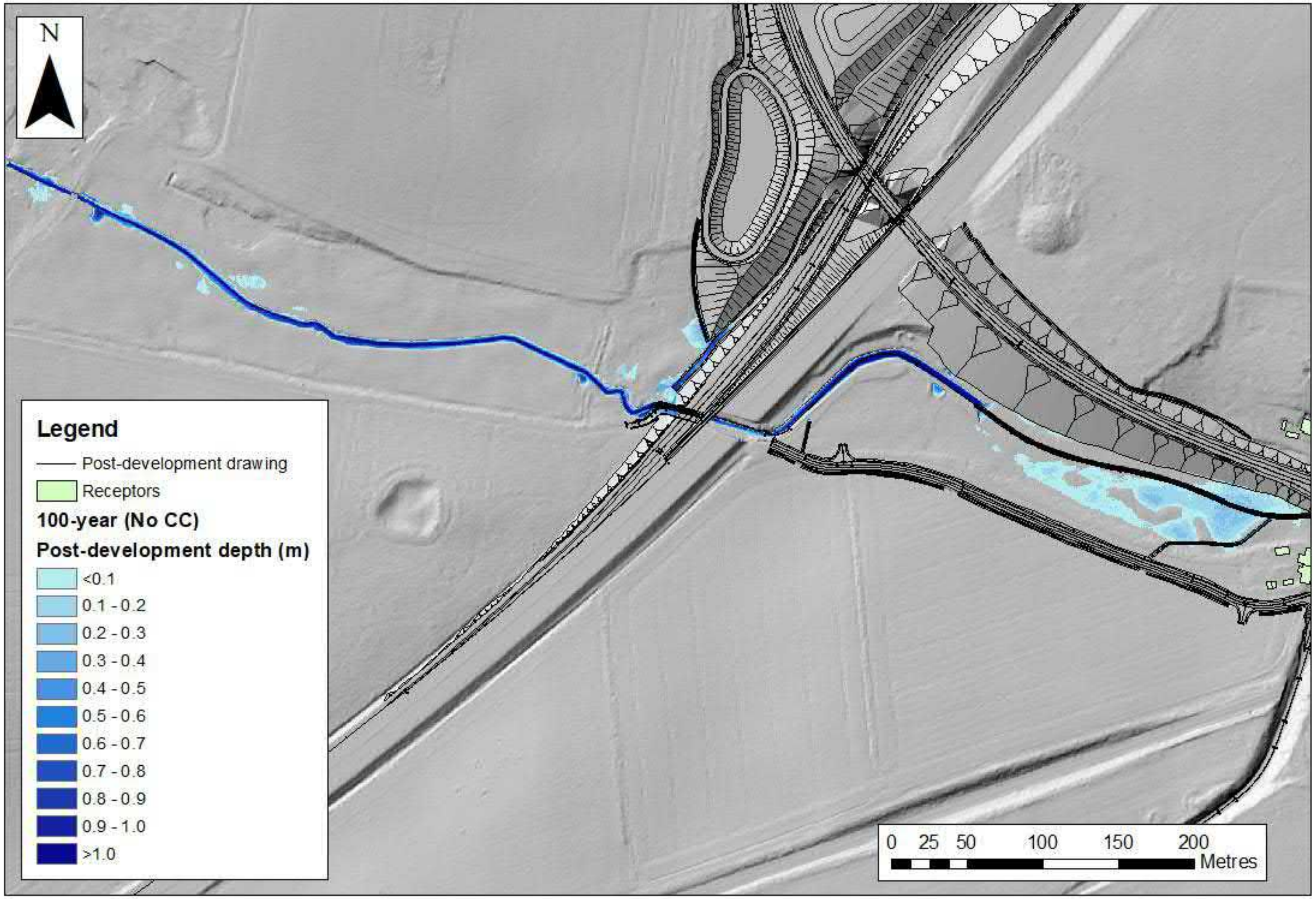


Figure C.2 : Maximum post development flood depths between upstream boundary and Cantley Lane South (100-year event with 35% climate change)

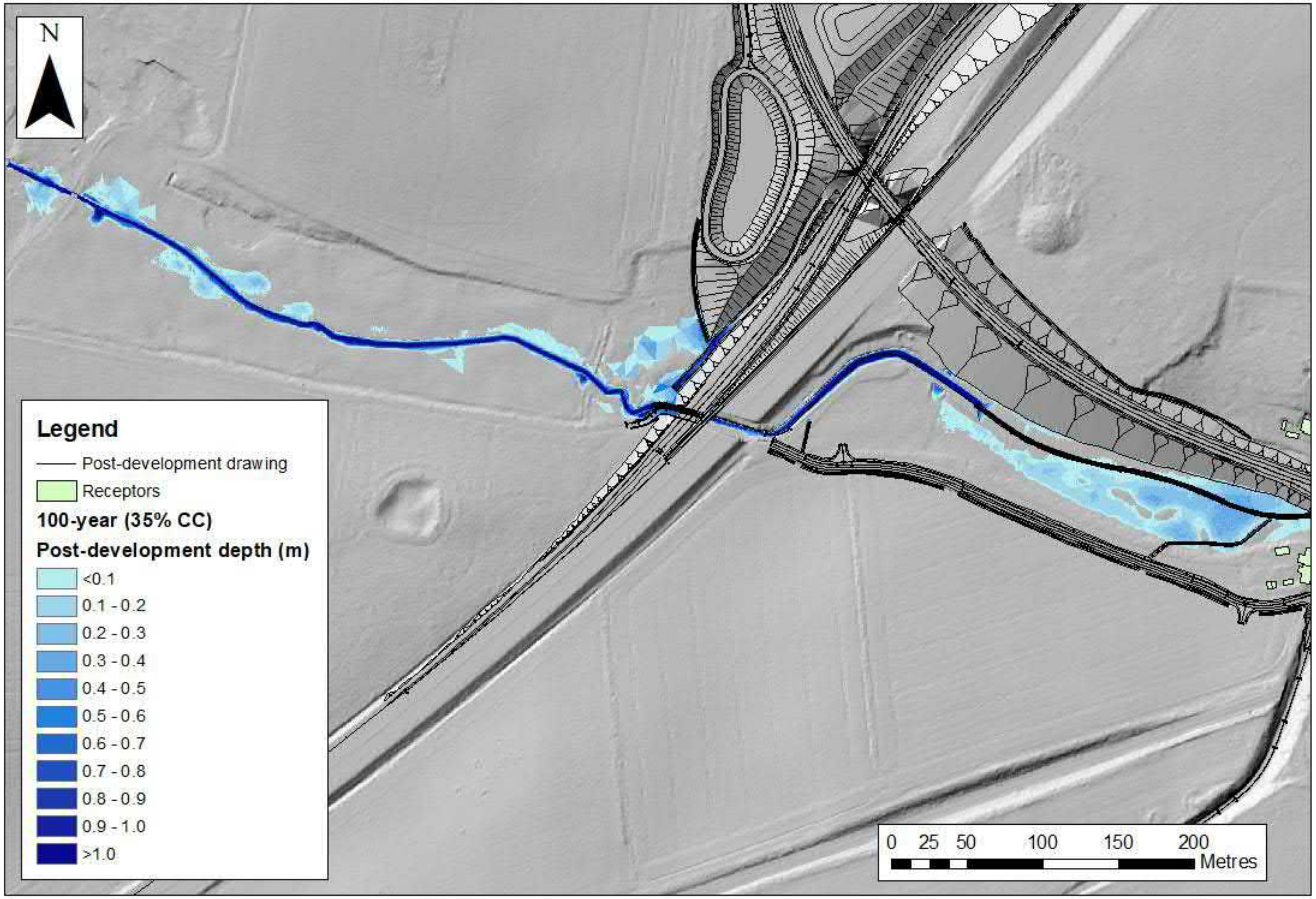


Figure C.3 : Maximum post development flood depths between upstream boundary and Cantley Lane South (100-year event with 65% climate change)

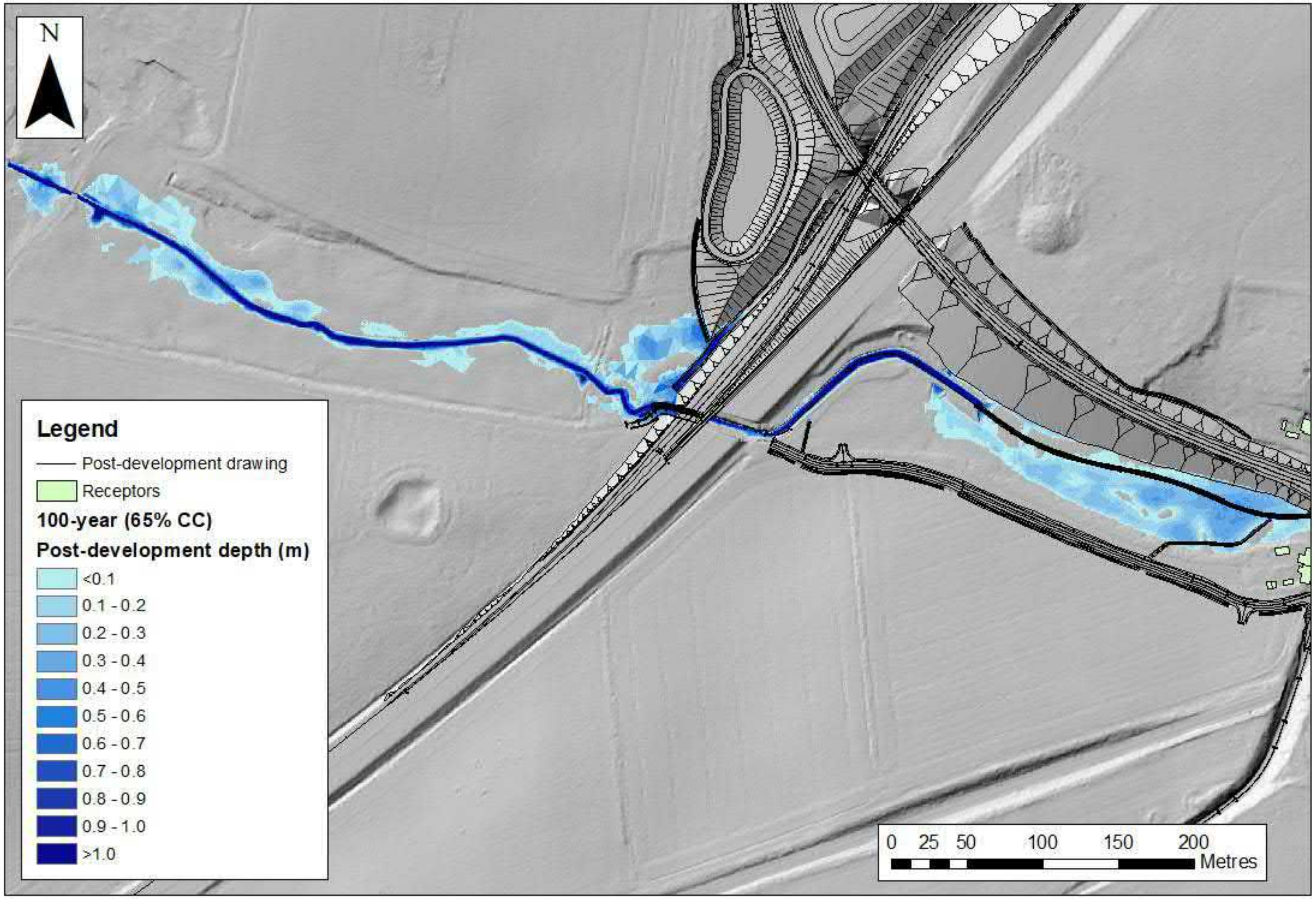


Figure C.4 : Maximum post development flood depths between upstream boundary and Cantley Lane South (100-year event with 80% climate change)

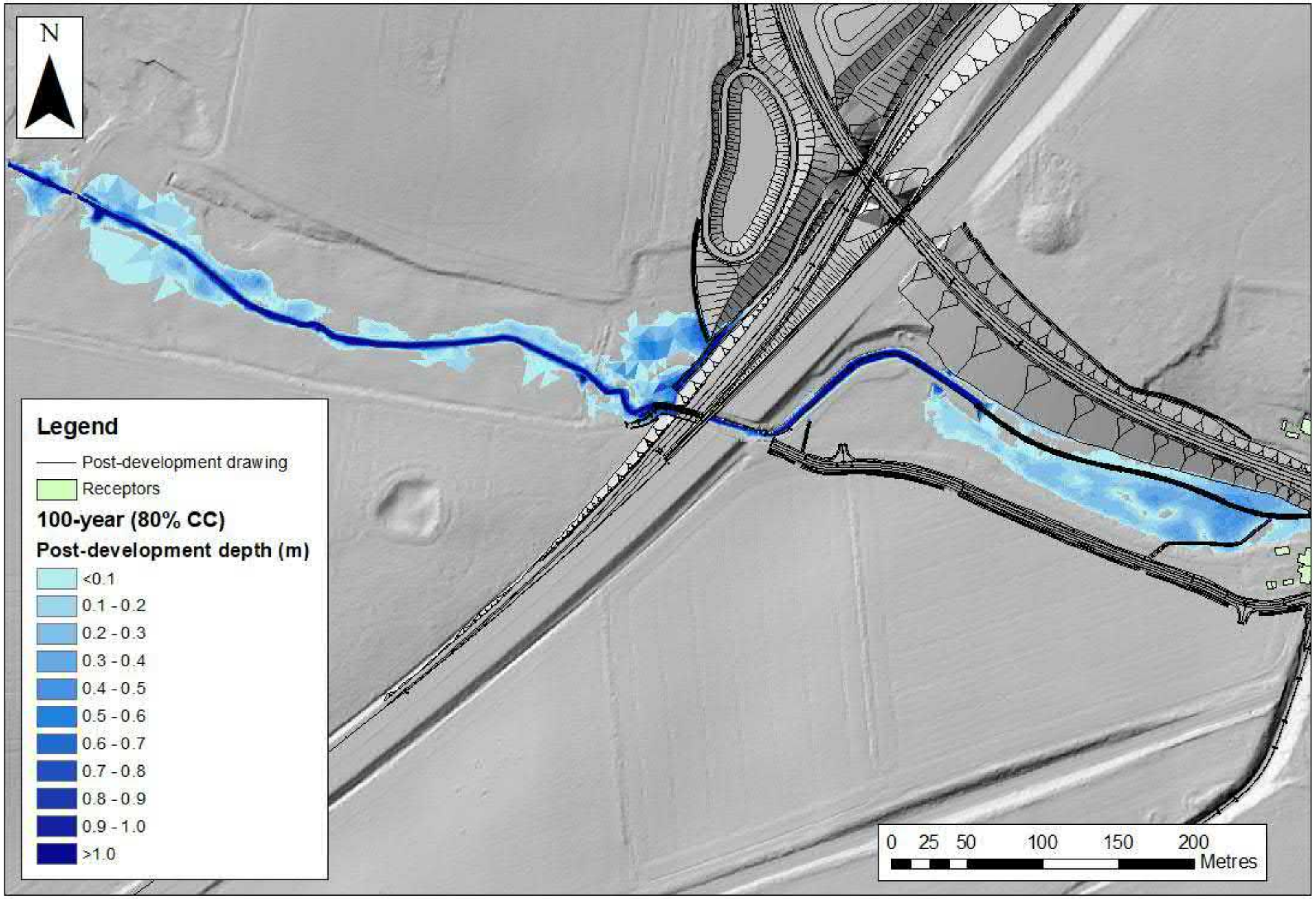


Figure C.5 : Maximum post development flood depths between upstream boundary and Cantley Lane South (1000-year event with no climate change)

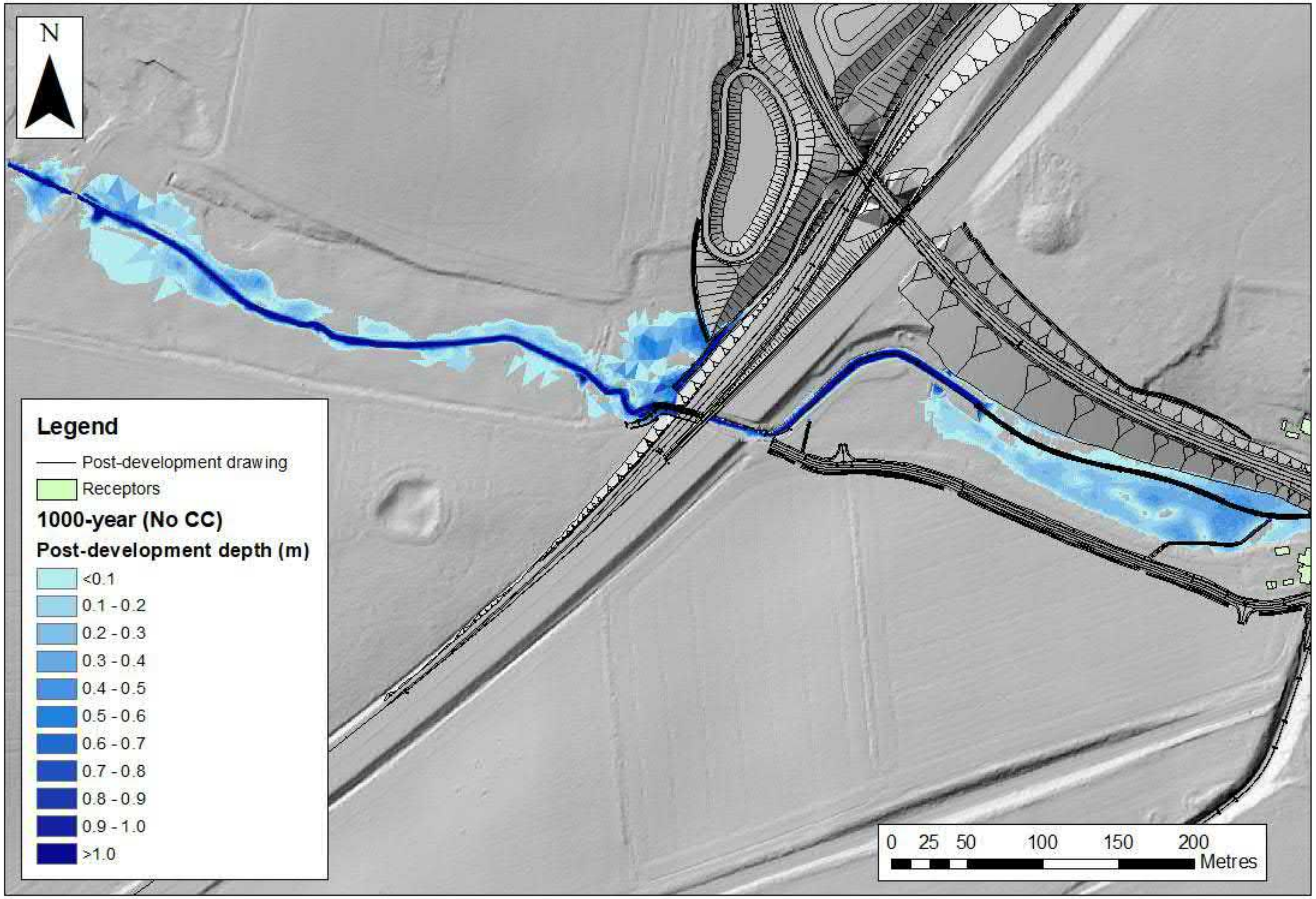


Figure C.6 : Maximum post development flood depths between Cantley Lane South and the A47 (100-year event with no climate change)

Figure C.7 : Maximum post development flood depths between Cantley Lane South and the A47 (100-year event with 35% climate change)

Figure C.8 : Maximum post development flood depths between Cantley Lane South and the A47 (100-year event with 65% climate change)

Figure C.9 : Maximum post development flood depths between Cantley Lane South and the A47 (100-year event with 80% climate change)

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Figure C.10 : Maximum post development flood depths between Cantley Lane South and the A47 (1000-year event with no climate change)

Figure C.11 : Maximum post development flood depths between the A47 and the model outfall (100-year event with no climate change)

Figure C.12 : Maximum post development flood depths between the A47 and the model outfall (100-year event with 35% climate change)

Figure C.13 : Maximum post development flood depths between the A47 and the model outfall (100-year event with 65% climate change)

Figure C.14 : Maximum post development flood depths between the A47 and the model outfall (100-year event with 80% climate change)

Figure C.15 : Maximum post development flood depths between the A47 and the model outfall (1000-year event with no climate change)

Appendix D. References

Department for Environment and Rural Affairs. (2020). *Defra Survey Data Download*. [Online]. Available at: https://environment.data.gov.uk/DefraDataDownload/?Mode=survey [Accessed 3 March 2020].

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Appendix E. A47/A11 Thickthorn Junction FEH Hydrological Assessment

A47/A11 THICKTHORN JUNCTION

FEH Hydrological Assessment

PCF STAGE 3
SUITABLE FOR REVIEW & COMMENT | S3
HE551492-GTY-EWE-000-RP-LE-30007 | P02
17/01/21

Notice

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1. Introduction

1.1.1. As part of the works to the A47/A11 Thickthorn Junction ('the Proposed Scheme'), a hydrological assessment of Cantley Stream is required in order to inform the Flood Risk Assessment and associated detailed hydraulic modelling.

1.1.2. The Proposed Scheme involves upgrades to the existing A47/A11 Thickthorn Junction as well as creation of a new local access link road at Cantley Lane South. This will involve a diversion of Cantley Stream, an ordinary watercourse, as well as the construction of a new culvert conveying Cantley Lane South over the diverted watercourse. Detailed hydraulic modelling is required to inform the design and assessment of the watercourse diversion and culvert, and ultimately the Flood Risk Assessment.

1.1.3. No previous hydrological assessments were available for Cantley Stream, as such, this document outlines the hydrological calculations undertaken in order to inform the hydraulic modelling and Flood Risk Assessment.

1.2. Guidance and data sources

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

- Estimating flood peaks and hydrographs for small catchments: Phase 1 (SC090031), Environment Agency, 2012.
- Flood Estimation Guidelines LIT 11832 (version 2.0), Environment Agency 2020.
- 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.

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

- National River Flow Archive peak flow dataset Version 8.
- The Chronology of British Hydrological Events.

1.2.3. The hydrological assessment of Cantley Stream has been based on the Flood Estimation Handbook (FEH) techniques. The flow estimations have been carried out in accordance with the above guidance from the Environment Agency.

1.3. Scope of the assessment

1.3.1. As part of the assessment, estimates of peak flood flows as well as design hydrographs are required at various locations throughout the Cantley Stream catchment. These design flood hydrographs will then be incorporated into a hydrodynamic model representing the Cantley Stream watercourse and its floodplain in order to assess the impact of the Proposed Scheme on flood risk.

1.3.2. Design hydrographs are required for the following flood return periods:

- 1 in 2 years
- 1 in 25 years
- 1 in 50 years
- 1 in 100 years
- 1 in 1000 years
- 1 in 100 years plus an allowance for climate change.

2. Catchment description

2.1.1. Cantley Stream is an ordinary watercourse running in a generally west to east direction to the south-west of Norwich. The watercourse joins the River Yare to the east of the A47. The catchment is largely rural although the upstream northern part of the catchment includes the village of Hethersett. There are sporadic patches of mixed woodland through the catchment although the majority of the land use is arable and pastureland. The major highways of the A11 and A47 both pass through the catchment as well as a number of smaller local roads. The stream, in the area of the Proposed Scheme, is lined on both banks by small informal flood embankments which are subject to overtopping during peak flows.

2.1.2. Cranfield Soil and Agrifood Institute (2020) soil maps indicate the catchment soils are slightly acid loamy and clayey soils with impeded drainage (Soilscape 8) although parts of the upstream catchment (around Ketteringham) include slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils (Soilscape 18). Soils at the very downstream portion of the catchment are loamy and sandy soils with naturally high groundwater and a peaty surface (Soilscape 23).

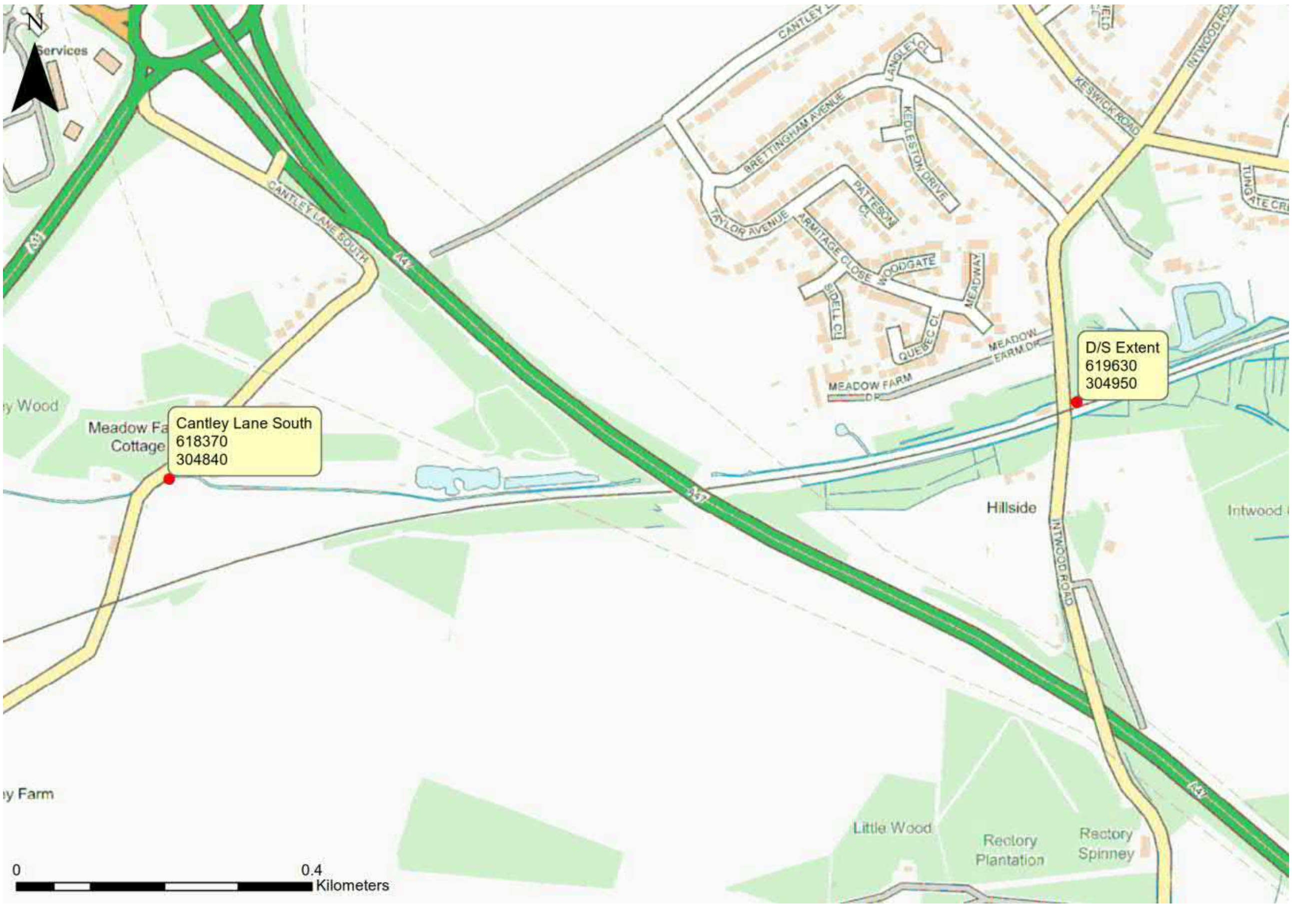
2.1.3. British Geological Survey (2020) maps indicate superficial geology for the catchment is mainly Lowestoft Formation – Diamicton in the upper catchment and Sheringham Cliffs Formation - Sand and Gravel in the lower catchment.

2.2. Location of flow estimates

2.2.1. Two flow estimate locations are required to inform the hydraulic modelling. These are given below and in Figure 2.1.

- Cantley Lane South at Ordnance Survey (OS) National Grid Reference (NGR) 618370 304840
- Downstream model extent at OS NGR 619630 304950.

Figure 2.1 : Cantley Stream Flow Estimation Locations



2.3. Catchment descriptors

2.3.1. Catchment descriptors and catchment boundaries for Cantley Stream were extracted from the FEH Web Service (2020). The boundaries were checked against DSM 2m spatial resolution LIDAR flown in 2017 and obtained from the DEFRA (2020) Survey Data Download portal. The catchment boundaries are shown in Figure 2.2 and the relevant descriptors are detailed in Table 2-1. Full catchment descriptors are given in Appendix A.

Figure 2.2 : Cantley Stream FEH Catchment Boundaries

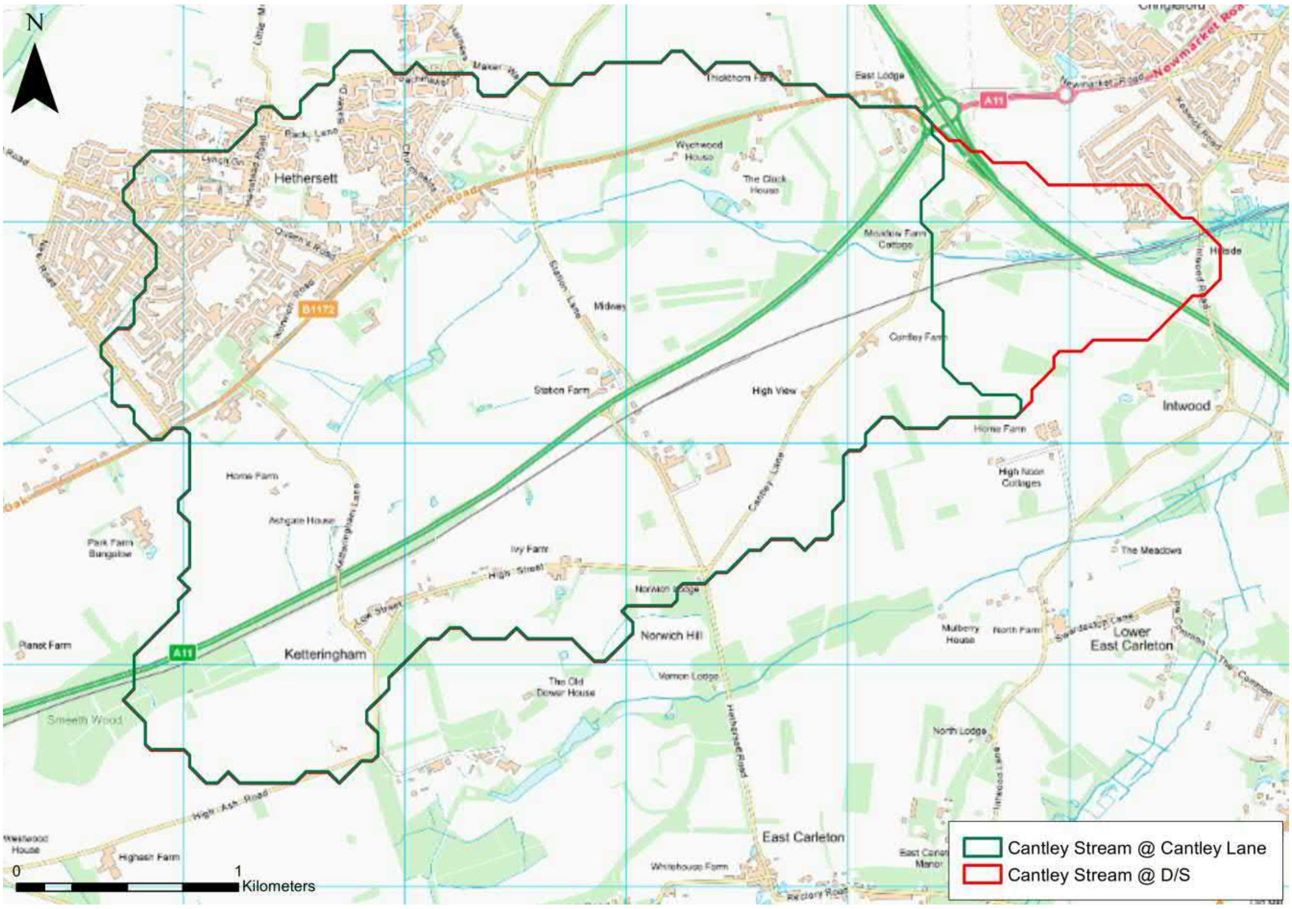


Table 2-1 : FEH Catchment Descriptors

Descriptor	Cantley Lane	Downstream Extent
AREA (km²)	8.773	9.678
BFIHOST (-)	0.607	0.614
FARL (-)	0.977	0.980
SAAR (mm)	623.0	623.0
SPRHOST (-)	35.670	35.490
$URBEXT_{2000}$ (-)	0.057	0.057

2.3.2. The catchment descriptors indicate the catchments are sparsely urbanised and with relatively permeable soils. There is some evidence of attenuation from lakes within the catchment although this is minor and most likely due to the presence of a number of agricultural ponds. The descriptors suggest the catchments would be suitable for routine FEH hydrological analyses and no adjustments to the catchment parameters would be required. The BFIHOST values are close to the 0.60 threshold for 'permeable' catchments and as such, the ReFH2 method should be used with caution. For this assessment, both the ReFH2 and FEH Statistical methods were used.

2.4. Historical flood information for Cantley Stream

2.4.1. A review was undertaken using the Chronology of British Hydrological Events (2020). However, no records of flooding at Cantley Stream were found. Furthermore, the Environment Agency's Historic Flood Map does not indicate any previous reported flooding at the area of the Proposed Scheme.

2.4.2. There were reports of flooding of Thickthorn roundabout by a local newspaper in 2017 which caused long delays, however, the flooding here is likely to be related to the highways drainage network and is unlikely to be as a result of bank overtopping from Cantley Stream (Eastern Daily Press, 2017).

3. Peak flow estimation

3.1.1. The estimates of peak flood flows for Cantley Stream were based on the FEH Statistical method incorporating observed data from gauged 'donor' catchments, where applicable. Flow estimations have been carried out in accordance with relevant guidance.

3.2. Estimation of the median annual flood (QMED)

3.2.1. All hydrological analysis for QMED and the subsequent pooled analyses was carried out using WINFAP v4 (Wallingford Hydrosolutions, 2020a). Several methods for calculating QMED are available from the FEH, including the following:

- QMED from Peaks-Over-Threshold (POT) data series
- QMED from Annual Maxima (AMAX) data series
- QMED from FEH Web Service catchment descriptors, with or without adjustment from a gauged 'donor' catchment.

3.2.2. Cantley Stream is a relatively small catchment with no gauged data available for watercourse flow or level. As such, the only available approach was to estimate QMED from catchment descriptors and to find a suitable gauged 'donor' catchment with which to adjust the QMED estimate, if appropriate.

3.2.3. A donor catchment was identified in WINFAP as 34001 Yare at Colney although this was discounted due to the large size differential between it and the subject catchment (229km^2 versus 10km^2). Furthermore, exclusion of this donor catchment yielded a more conservative estimate of QMED which was deemed appropriate for the purposes of this study. Therefore, QMED was estimated from catchment descriptors only, with no adjustment using a donor gauge.

3.2.4. Table 3-1 below shows QMED estimates for the Cantley Stream catchments.

Table 3-1 : Cantley Stream catchment QMED estimates

Catchment	QMED (unadjusted) ($m^3 s^{-1}$)
Cantley Lane South	0.838
Downstream Extent	0.907

3.3. Pooled analysis

3.3.1. Estimates of QMED were scaled to higher return period flood flow estimates using pooled analysis in WINFAP v4. The default pooling group was reviewed in detail to ensure all constituent stations were appropriate in relation to the Cantley Stream catchment.

3.3.2. A review of the pooling group was made including parameters such as catchment area, SAAR and BFIHOST. Catchments within the pooling group with BFIHOST>0.75 (highly permeable) were identified. The pooling group was adjusted for permeable catchments using the Wallingford Hydrosolutions permeable adjustment worksheet, following Environment Agency Flood Estimation guidelines.

3.3.3. An Urban Expansion factor (UEF) was used to update the catchment value of URBEXT2000 to the current year (2020). The following equation was used to calculate a value of UEF equal to 1.04 and applied to the value of URBEXT2000 (DEFRA, 2006)

$$UEF = 0.7851 + 0.2124\, tan^{-1}\left(\frac{Year - 1967.5}{20.32}\right)$$

(The term within the parentheses is in radians)

3.3.4. An Urban Adjustment Factor (UAF) was applied to the pooling group, given the catchments have an urbanised area of greater than 3% (URBEXT2000>0.03) (Wallingford Hydrosolutions, 2016a). The final pooling group is given in Table 3-2 below.

Table 3-2 : Final FEH pooling group

Pooling group station	Record length (years)
26802 Gypsey Race @ Kirkby Grindalythe	22
27051 Crimple @ Burn Bridge	46
25019 Leven @ Easby	40
49005 Bolingey Stream @ Bolingey Cocks Bridge	8
27010 Hodge Beck @ Bransdale	41
45816 Haddeo @ Upton	25
28033 Dove @ Hollinsclough	43
47022 Tory Brook @ Newnham	25
41020 Bevern Stream	49

Pooling group station	Record length (years)
72014 Conder @ Galgate	50
25011 Langdon Beck @ Langdon	32
26014 Water Forlornes @ Driffield	20
73015 Keer @ High Keer Weir	27
27032 Hebden Beck @ Hebden Bridge	52
49003 (de Lank @ de Lank)	53
	Total record length: 533

3.3.5. The FEH recommends the use of the generalised logistic growth curve over other fitting methods available in WINFAP. Figure 3.1 shows that the generalised logistic growth curve provides a more conservative estimate of flow at higher return periods. This was deemed appropriate for the purposes of this assessment. The generalised logistic growth curve was used which provided the following flood frequency curve (Figure 3.1) and peak flow estimates (Table 3-3). The pooling group produced a Z value of 1.09 which was within the acceptable limits (absolute Z value<1.645) of the generalised logistic growth curve fitting.

Figure 3.1 : Cantley Stream flood frequency curve

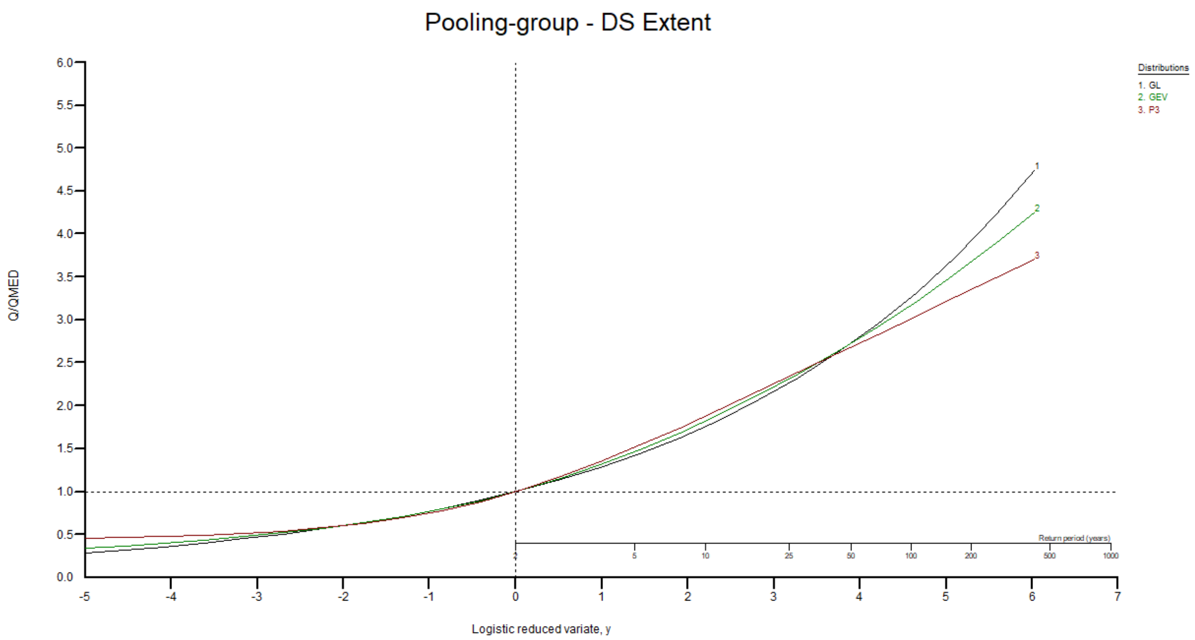


Table 3-3 : Design flow estimates for Cantley Stream

Return period (years)	Growth factor	Peak flow estimate ($m^3 s^{-1}$)	
		Cantley Lane South	Downstream Extent
2	1.000	0.838	0.907
25	2.052	1.719	1.861
50	2.176	1.823	1.973
100	2.604	2.182	2.361
1000	5.630	4.718	5.105
100 + 35% CC	-	2.946	3.188
100 + 65% CC	-	3.600	3.896

3.4. Consideration of climate change

3.4.1. The Proposed Scheme is classified as 'essential infrastructure' under the guidance to the Ministry of Housing, Community and Local Government (MHCLG) (2019) National Planning Policy Framework. According to the Environment Agency's Flood Map for Planning (2020b), the Proposed Scheme is located partly in Flood Zones 2 and 3. Environment Agency guidance on climate change allowances for peak river flows for flood risk assessments recommends using the upper end allowance (90th percentile) for such a development.

3.4.2. For the Proposed Scheme, the climate change allowance for peak river flow anticipated for the '2080s' (2070 to 2115) is most appropriate.

3.4.3. The Proposed Scheme is located in the Anglian River Basin District. Table 3-4 outlines the relevant Environment Agency (2020c) climate change allowances for this district with the final allowance used as part of this assessment highlighted in red.

Table 3-4 : Peak river flow climate change allowances for the Anglian River Basin District

River Basin District	Allowance category	Total potential change anticipated for the '2020s' (2015 to 2039)	Total potential change anticipated for the '2050s' (2040 to 2069)	Total potential change anticipated for the '2080s' (2070 to 2115)
Anglian	H++	25%	40%	**80%**
	Upper end (90th percentile)	25%	35%	**65%**
	Higher central (70th percentile)	15%	20%	**35%**
	Central (50th percentile)	10%	15%	25%

3.4.4. Based on the above, in order to account for the future effects of climate change on peak river flow at Cantley Stream, the 1 in 100-year return period peak flow estimate will be increased by 65%. For any consideration of compensatory flood storage, the 1 in 100-year return period peak flow will be increased by 35%.

3.4.5. The H++ allowances for an extreme climate change scenario in the Anglian River Basin District would be 80%.

UKCP18 Climate Change Allowances

3.4.6. The above guidance was last updated in December 2019. However, the Met Office (2018) UKCP18 climate change projections may influence peak river flows. At the time of writing, no guidance was available on the impacts of UKCP18 data on peak river flow allowances.

4. Design hydrographs

4.1.1. Given the absence of any gauged river flow or level information for Cantley Stream, the approach adopted for creating design hydrographs was to utilise Wallingford Hydrosolutions (2020b) ReFH2 software version 2.3.

4.1.2. Rainfall event duration (and subsequent flow hydrograph duration) and all other ReFH2 model parameters were based on the default catchment-based equations outlined in the ReFH2 Technical Report. The hydrographs were generated using the ReFH2 software. An example of the ReFH2 hydrographs is given in Figure 4.1 below. Full hydrograph data tables and ReFH2 parameters are given in Appendix B for reference.

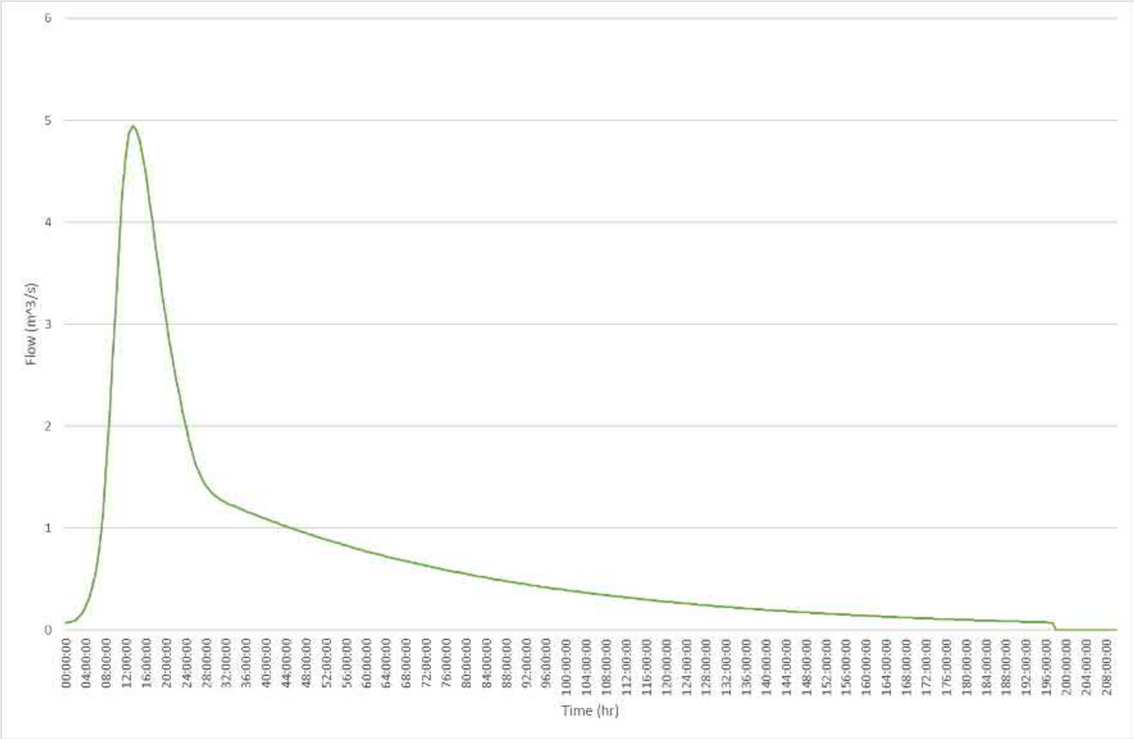
4.1.3. Various storm durations were tested for the catchment to determine the most conservative event (that is, the critical storm duration). Peak flow values are given in Table 4-1 below; these values are for namely a 14 hour duration, urban adjusted, summer storm profile event. The growth factor for each storm event has been calculated for comparison with the FEH Statistical method and completeness. The growth factor for the ReFH2 method is within the typical range.

4.1.4. Table 4-1 shows that the ReFH2 method provides the most conservative estimates of peak flow and as such was the adopted method used in the hydraulic modelling for the Flood Risk Assessment.

Table 4-1 : ReFH2 design flow estimates for Cantley Stream (point inflows)

Return period (years)	Cantley Lane South Growth Factor	Peak flow estimate ($m^3 s^{-1}$)	
		Cantley Lane South	Downstream Extent
2	1.00	1.03	1.10
25	2.64	2.80	2.96
50	3.43	3.66	3.88
100	4.34	4.66	4.94
1000	7.93	8.62	9.14
100 + 35% CC	5.87	6.30	6.67
100 + 65% CC	7.17	7.70	8.15

Figure 4.1 : ReFH2 design hydrograph for Cantley Stream for a 1 in 100-year return period flood event



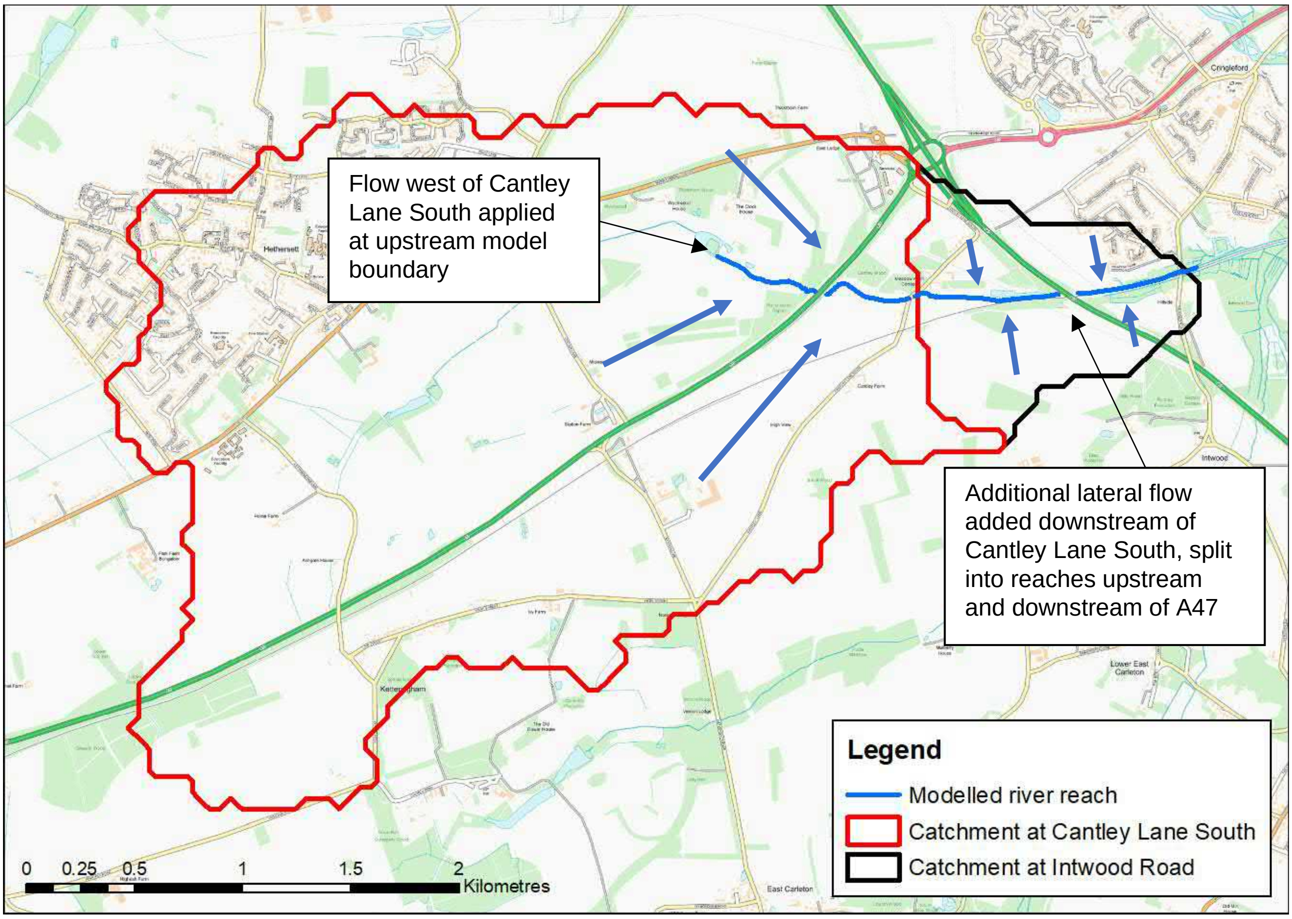
4.2. Implementation of design hydrographs in hydraulic model

4.2.1. Flow at Cantley Lane South is likely to be determined by two main contributing catchment areas, one on each side of the A11. It was decided that applying the hydrograph for Cantley Lane South to the upstream boundary of the model (upstream of the A11 at OS NGR 617475 305020) would constitute a conservative approach in which the entire reach from the upstream boundary to Cantley Lane South receives flow from both contributing catchment areas.

4.2.2. An additional lateral flow contribution for the intervening catchment area between Cantley Lane South and the downstream model extent (at OS NGR 619630 304950) was estimated by subtracting the Cantley Lane South hydrograph from the hydrograph for the catchment at the downstream extent. Two-thirds of this difference was applied upstream of the A47 culvert and one-third applied downstream of the A47 culvert in order to account for an approximate split of the lateral inflows into the reaches of the model upstream and downstream of the A47. Applicable catchment descriptors for this region are those for the downstream extent catchment (Table 2-1).

4.2.3. Figure 4.2 shows an extract from the A47 Thickthorn Junction Baseline Hydraulic Model Report (HE551492-GTY-EWE-000-RP-LE-30003) which illustrates how the hydrology was incorporated into the hydraulic model. Further explanation of the hydrograph shape of the lateral inflows applied in the model can also be found in the model report.

Figure 4.2: Illustration of how catchment hydrology is incorporated into the hydraulic model



4.3. Assumptions, limitations and uncertainty

4.3.1. It is assumed that the catchment descriptors are an accurate reflection of catchment urbanisation. However, using only catchment descriptor data to estimate flood flows creates uncertainty in the flow estimates. In order to improve the uncertainty of the methods, peak flow data could be collected directly from the stream, ideally for a minimum period of two years. Given the time constraints of the Proposed Scheme, collection of flow data would not be applicable for this analysis.

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- Wallingford Hydrosolutions (2016b) *The Revitalised Flood Hydrograph Model, ReFH 2.2: Technical Guidance*

Appendix A. FEH catchment descriptors

Table A-1 : FEH catchment descriptors

Descriptor	Cantley Lane	Downstream Extent
CATCHMENT	TG 18350 04800	TG 19600 04950
CENTROID	TG 16455 04335	TG 16705 04383
AREA	8.7725	9.7675
ALTBAR	39	37
ASPBAR	59	58
ASPVAR	0.4	0.37
BFIHOST	0.607	0.614
DPLBAR	2.79	3.79
DPSBAR	19.6	22.2
FARL	0.977	0.98
FPEXT	0.1106	0.1065
FPDBAR	0.549	0.567
FPLOC	1.117	1.099
LDP	5.9	7.23
PROPWET	0.31	0.31
RMED-1H	11.3	11.3
RMED-1D	27.9	27.8
RMED-2D	34.1	34
SAAR	623	623
SAAR4170	610	609
SPRHOST	35.76	35.49
URBCONC1990	0.767	0.771
URBEXT1990	0.0493	0.048
URBLOC1990	1.483	1.34
URBCONC2000	0.825	0.827
URBEXT2000	0.057	0.0569
URBLOC2000	1.438	1.281
C	-0.02186	-0.02197
D1	0.28608	0.28594
D2	0.32331	0.32439
D3	0.23581	0.23651
E	0.31192	0.312
F	2.47695	2.47685
C(1 km)	-0.022	-0.024
D1(1 km)	0.293	0.286
D2(1 km)	0.323	0.359

Descriptor	Cantley Lane	Downstream Extent
D3(1 km)	0.235	0.24
E(1 km)	0.312	0.311
F(1 km)	2.473	2.472

Appendix B. ReFH2 analysis and hydrographs

Table B-2: Key ReFH2 parameters

Descriptor	Cantley Lane	Downstream Extent
Duration	14 hr Summer	14 hr Summer
Timestep	40 Minutes	40 Minutes
Cini	51.68 mm	50.95 mm
Cmax	564.42 mm	573.29 mm
BR	2.35	2.35
BL	49.43	58.8
Tp	5.09 hr	5.15 hr

Table B-3: Design hydrograph for Cantley Lane 14hr Summer Storm

Time	2 yr	25 yr	50 yr	100 yr	1000 yr	100+1.65 yr
00:00:00	0.069	0.069	0.069	0.069	0.069	0.113
00:40:00	0.069	0.070	0.070	0.071	0.072	0.116
01:20:00	0.070	0.075	0.077	0.079	0.086	0.130
02:00:00	0.075	0.086	0.091	0.096	0.112	0.158
02:40:00	0.082	0.104	0.113	0.123	0.154	0.202
03:20:00	0.093	0.131	0.147	0.163	0.218	0.269
04:00:00	0.109	0.170	0.195	0.221	0.310	0.365
04:40:00	0.130	0.222	0.260	0.300	0.435	0.495
05:20:00	0.159	0.292	0.346	0.406	0.607	0.669
06:00:00	0.196	0.383	0.462	0.547	0.840	0.902
06:40:00	0.246	0.509	0.622	0.744	1.173	1.228
07:20:00	0.320	0.701	0.867	1.051	1.708	1.734
08:00:00	0.418	0.962	1.204	1.476	2.466	2.435
08:40:00	0.528	1.262	1.595	1.971	3.366	3.253
09:20:00	0.643	1.583	2.016	2.507	4.353	4.137
10:00:00	0.757	1.908	2.443	3.056	5.379	5.042
10:40:00	0.862	2.215	2.852	3.584	6.384	5.913
11:20:00	0.947	2.475	3.202	4.041	7.278	6.668
12:00:00	1.007	2.671	3.470	4.398	8.001	7.257
12:40:00	1.032	2.771	3.614	4.595	8.428	7.582
13:20:00	1.031	2.797	3.658	4.664	8.611	7.695
14:00:00	1.014	2.772	3.635	4.645	8.622	7.663
14:40:00	0.985	2.710	3.560	4.558	8.499	7.521
15:20:00	0.948	2.621	3.448	4.421	8.271	7.294
16:00:00	0.905	2.509	3.306	4.243	7.959	7.001
16:40:00	0.857	2.382	3.141	4.036	7.586	6.659
17:20:00	0.808	2.249	2.968	3.816	7.183	6.296

18:00:00	0.760	2.118	2.797	3.598	6.782	5.937
18:40:00	0.713	1.988	2.627	3.381	6.380	5.579
19:20:00	0.667	1.859	2.458	3.165	5.978	5.223
20:00:00	0.623	1.737	2.297	2.959	5.593	4.883
20:40:00	0.582	1.623	2.147	2.767	5.232	4.565
21:20:00	0.545	1.518	2.009	2.589	4.899	4.273
22:00:00	0.511	1.422	1.881	2.424	4.586	4.000
22:40:00	0.480	1.330	1.759	2.268	4.288	3.742
23:20:00	0.449	1.243	1.644	2.118	4.003	3.495
24:00:00	0.421	1.161	1.535	1.977	3.732	3.263
24:40:00	0.396	1.085	1.433	1.846	3.478	3.046
25:20:00	0.373	1.018	1.344	1.729	3.250	2.852
26:00:00	0.356	0.966	1.273	1.637	3.069	2.700
26:40:00	0.342	0.924	1.217	1.563	2.925	2.579
27:20:00	0.331	0.890	1.171	1.503	2.807	2.480
28:00:00	0.321	0.862	1.133	1.453	2.709	2.398
28:40:00	0.313	0.838	1.101	1.412	2.628	2.329
29:20:00	0.306	0.818	1.074	1.376	2.558	2.270
30:00:00	0.300	0.800	1.050	1.345	2.499	2.220
30:40:00	0.295	0.785	1.030	1.319	2.449	2.176
31:20:00	0.290	0.772	1.012	1.296	2.406	2.139
32:00:00	0.286	0.760	0.997	1.277	2.369	2.107
32:40:00	0.282	0.750	0.984	1.259	2.337	2.078
33:20:00	0.278	0.740	0.970	1.242	2.306	2.050
34:00:00	0.274	0.730	0.957	1.226	2.275	2.023
34:40:00	0.271	0.720	0.945	1.209	2.244	1.996
35:20:00	0.267	0.710	0.932	1.193	2.214	1.969
36:00:00	0.263	0.701	0.919	1.177	2.184	1.942
36:40:00	0.260	0.692	0.907	1.161	2.155	1.916
37:20:00	0.256	0.682	0.895	1.146	2.126	1.891
38:00:00	0.253	0.673	0.883	1.131	2.098	1.865
38:40:00	0.249	0.664	0.871	1.115	2.070	1.840
39:20:00	0.246	0.655	0.860	1.100	2.042	1.816
40:00:00	0.243	0.646	0.848	1.086	2.015	1.791
40:40:00	0.240	0.638	0.837	1.071	1.988	1.767
41:20:00	0.236	0.629	0.825	1.057	1.961	1.744
42:00:00	0.233	0.621	0.814	1.043	1.935	1.720
42:40:00	0.230	0.613	0.803	1.029	1.909	1.697
43:20:00	0.227	0.604	0.793	1.015	1.883	1.675
44:00:00	0.224	0.596	0.782	1.001	1.858	1.652
44:40:00	0.221	0.588	0.772	0.988	1.833	1.630
45:20:00	0.218	0.580	0.761	0.975	1.809	1.608
46:00:00	0.215	0.573	0.751	0.962	1.784	1.587

46:40:00	0.212	0.565	0.741	0.949	1.760	1.565
47:20:00	0.209	0.557	0.731	0.936	1.737	1.544
48:00:00	0.207	0.550	0.721	0.923	1.714	1.524
48:40:00	0.204	0.542	0.712	0.911	1.691	1.503
49:20:00	0.201	0.535	0.702	0.899	1.668	1.483
50:00:00	0.198	0.528	0.693	0.887	1.646	1.463
50:40:00	0.196	0.521	0.683	0.875	1.624	1.444
51:20:00	0.193	0.514	0.674	0.863	1.602	1.424
52:00:00	0.191	0.507	0.665	0.852	1.580	1.405
52:40:00	0.188	0.500	0.656	0.840	1.559	1.386
53:20:00	0.185	0.494	0.648	0.829	1.538	1.368
54:00:00	0.183	0.487	0.639	0.818	1.518	1.350
54:40:00	0.180	0.480	0.630	0.807	1.497	1.331
55:20:00	0.178	0.474	0.622	0.796	1.477	1.314
56:00:00	0.176	0.468	0.613	0.785	1.458	1.296
56:40:00	0.173	0.461	0.605	0.775	1.438	1.279
57:20:00	0.171	0.455	0.597	0.765	1.419	1.262
58:00:00	0.169	0.449	0.589	0.754	1.400	1.245
58:40:00	0.166	0.443	0.581	0.744	1.381	1.228
59:20:00	0.164	0.437	0.573	0.734	1.362	1.212
60:00:00	0.162	0.431	0.566	0.724	1.344	1.195
60:40:00	0.160	0.426	0.558	0.715	1.326	1.179
61:20:00	0.158	0.420	0.551	0.705	1.308	1.163
62:00:00	0.156	0.414	0.543	0.696	1.291	1.148
62:40:00	0.154	0.409	0.536	0.686	1.274	1.133
63:20:00	0.151	0.403	0.529	0.677	1.257	1.117
64:00:00	0.149	0.398	0.522	0.668	1.240	1.102
64:40:00	0.147	0.392	0.515	0.659	1.223	1.088
65:20:00	0.145	0.387	0.508	0.650	1.207	1.073
66:00:00	0.144	0.382	0.501	0.642	1.191	1.059
66:40:00	0.142	0.377	0.494	0.633	1.175	1.044
67:20:00	0.140	0.372	0.488	0.625	1.159	1.030
68:00:00	0.138	0.367	0.481	0.616	1.143	1.017
68:40:00	0.136	0.362	0.475	0.608	1.128	1.003
69:20:00	0.134	0.357	0.468	0.600	1.113	0.990
70:00:00	0.132	0.352	0.462	0.592	1.098	0.976
70:40:00	0.131	0.348	0.456	0.584	1.083	0.963
71:20:00	0.129	0.343	0.450	0.576	1.069	0.950
72:00:00	0.127	0.338	0.444	0.568	1.054	0.938
72:40:00	0.125	0.334	0.438	0.561	1.040	0.925
73:20:00	0.124	0.329	0.432	0.553	1.026	0.913
74:00:00	0.122	0.325	0.426	0.546	1.013	0.900
74:40:00	0.120	0.321	0.421	0.538	0.999	0.888

75:20:00	0.119	0.316	0.415	0.531	0.986	0.876
76:00:00	0.117	0.312	0.409	0.524	0.972	0.865
76:40:00	0.116	0.308	0.404	0.517	0.959	0.853
77:20:00	0.114	0.304	0.398	0.510	0.947	0.842
78:00:00	0.113	0.300	0.393	0.503	0.934	0.830
78:40:00	0.111	0.296	0.388	0.497	0.921	0.819
79:20:00	0.110	0.292	0.383	0.490	0.909	0.808
80:00:00	0.108	0.288	0.378	0.483	0.897	0.798
80:40:00	0.107	0.284	0.372	0.477	0.885	0.787
81:20:00	0.105	0.280	0.367	0.470	0.873	0.776
82:00:00	0.104	0.276	0.363	0.464	0.861	0.766
82:40:00	0.102	0.273	0.358	0.458	0.850	0.756
83:20:00	0.101	0.269	0.353	0.452	0.838	0.746
84:00:00	0.100	0.265	0.348	0.446	0.827	0.736
84:40:00	0.098	0.262	0.344	0.440	0.816	0.726
85:20:00	0.097	0.258	0.339	0.434	0.805	0.716
86:00:00	0.096	0.255	0.334	0.428	0.794	0.706
86:40:00	0.094	0.251	0.330	0.422	0.784	0.697
87:20:00	0.093	0.248	0.325	0.417	0.773	0.688
88:00:00	0.092	0.245	0.321	0.411	0.763	0.678
88:40:00	0.091	0.242	0.317	0.406	0.753	0.669
89:20:00	0.090	0.238	0.313	0.400	0.743	0.660
90:00:00	0.088	0.235	0.308	0.395	0.733	0.651
90:40:00	0.087	0.232	0.304	0.390	0.723	0.643
91:20:00	0.086	0.229	0.300	0.384	0.713	0.634
92:00:00	0.085	0.226	0.296	0.379	0.704	0.626
92:40:00	0.084	0.223	0.292	0.374	0.694	0.617
93:20:00	0.083	0.220	0.288	0.369	0.685	0.609
94:00:00	0.081	0.217	0.284	0.364	0.676	0.601
94:40:00	0.080	0.214	0.281	0.359	0.667	0.593
95:20:00	0.079	0.211	0.277	0.354	0.658	0.585
96:00:00	0.078	0.208	0.273	0.350	0.649	0.577
96:40:00	0.077	0.205	0.269	0.345	0.640	0.569
97:20:00	0.076	0.203	0.266	0.340	0.632	0.562
98:00:00	0.075	0.200	0.262	0.336	0.623	0.554
98:40:00	0.074	0.197	0.259	0.331	0.615	0.547
99:20:00	0.073	0.195	0.255	0.327	0.607	0.539
100:00:00	0.072	0.192	0.252	0.323	0.598	0.532
100:40:00	0.071	0.189	0.249	0.318	0.590	0.525
101:20:00	0.070	0.187	0.245	0.314	0.582	0.518
102:00:00	0.069	0.184	0.242	0.310	0.575	0.511
102:40:00	0.000	0.182	0.239	0.306	0.567	0.504
103:20:00	0.000	0.180	0.235	0.301	0.559	0.497

104:00:00	0.000	0.177	0.232	0.297	0.552	0.491
104:40:00	0.000	0.175	0.229	0.293	0.545	0.484
105:20:00	0.000	0.172	0.226	0.290	0.537	0.478
106:00:00	0.000	0.170	0.223	0.286	0.530	0.471
106:40:00	0.000	0.168	0.220	0.282	0.523	0.465
107:20:00	0.000	0.166	0.217	0.278	0.516	0.459
108:00:00	0.000	0.163	0.214	0.274	0.509	0.453
108:40:00	0.000	0.161	0.211	0.271	0.502	0.447
109:20:00	0.000	0.159	0.209	0.267	0.495	0.441
110:00:00	0.000	0.157	0.206	0.263	0.489	0.435
110:40:00	0.000	0.155	0.203	0.260	0.482	0.429
111:20:00	0.000	0.153	0.200	0.256	0.476	0.423
112:00:00	0.000	0.151	0.198	0.253	0.469	0.417
112:40:00	0.000	0.149	0.195	0.250	0.463	0.412
113:20:00	0.000	0.147	0.192	0.246	0.457	0.406
114:00:00	0.000	0.145	0.190	0.243	0.451	0.401
114:40:00	0.000	0.143	0.187	0.240	0.445	0.395
115:20:00	0.000	0.141	0.185	0.236	0.439	0.390
116:00:00	0.000	0.139	0.182	0.233	0.433	0.385
116:40:00	0.000	0.137	0.180	0.230	0.427	0.380
117:20:00	0.000	0.135	0.177	0.227	0.421	0.375
118:00:00	0.000	0.133	0.175	0.224	0.416	0.370
118:40:00	0.000	0.132	0.173	0.221	0.410	0.365
119:20:00	0.000	0.130	0.170	0.218	0.405	0.360
120:00:00	0.000	0.128	0.168	0.215	0.399	0.355
120:40:00	0.000	0.126	0.166	0.212	0.394	0.350
121:20:00	0.000	0.125	0.164	0.209	0.389	0.346
122:00:00	0.000	0.123	0.161	0.207	0.383	0.341
122:40:00	0.000	0.121	0.159	0.204	0.378	0.336
123:20:00	0.000	0.120	0.157	0.201	0.373	0.332
124:00:00	0.000	0.118	0.155	0.198	0.368	0.327
124:40:00	0.000	0.117	0.153	0.196	0.363	0.323
125:20:00	0.000	0.115	0.151	0.193	0.358	0.319
126:00:00	0.000	0.113	0.149	0.191	0.354	0.314
126:40:00	0.000	0.112	0.147	0.188	0.349	0.310
127:20:00	0.000	0.110	0.145	0.186	0.344	0.306
128:00:00	0.000	0.109	0.143	0.183	0.340	0.302
128:40:00	0.000	0.108	0.141	0.181	0.335	0.298
129:20:00	0.000	0.106	0.139	0.178	0.331	0.294
130:00:00	0.000	0.105	0.137	0.176	0.326	0.290
130:40:00	0.000	0.103	0.135	0.173	0.322	0.286
131:20:00	0.000	0.102	0.134	0.171	0.317	0.282
132:00:00	0.000	0.101	0.132	0.169	0.313	0.279

132:40:00	0.000	0.099	0.130	0.167	0.309	0.275
133:20:00	0.000	0.098	0.128	0.164	0.305	0.271
134:00:00	0.000	0.097	0.127	0.162	0.301	0.267
134:40:00	0.000	0.095	0.125	0.160	0.297	0.264
135:20:00	0.000	0.094	0.123	0.158	0.293	0.260
136:00:00	0.000	0.093	0.122	0.156	0.289	0.257
136:40:00	0.000	0.091	0.120	0.154	0.285	0.253
137:20:00	0.000	0.090	0.118	0.152	0.281	0.250
138:00:00	0.000	0.089	0.117	0.150	0.277	0.247
138:40:00	0.000	0.088	0.115	0.147	0.274	0.243
139:20:00	0.000	0.087	0.114	0.146	0.270	0.240
140:00:00	0.000	0.085	0.112	0.144	0.266	0.237
140:40:00	0.000	0.084	0.111	0.142	0.263	0.234
141:20:00	0.000	0.083	0.109	0.140	0.259	0.231
142:00:00	0.000	0.082	0.108	0.138	0.256	0.228
142:40:00	0.000	0.081	0.106	0.136	0.252	0.224
143:20:00	0.000	0.080	0.105	0.134	0.249	0.221
144:00:00	0.000	0.079	0.103	0.132	0.246	0.218
144:40:00	0.000	0.078	0.102	0.131	0.242	0.216
145:20:00	0.000	0.077	0.101	0.129	0.239	0.213
146:00:00	0.000	0.076	0.099	0.127	0.236	0.210
146:40:00	0.000	0.075	0.098	0.125	0.233	0.207
147:20:00	0.000	0.074	0.097	0.124	0.230	0.204
148:00:00	0.000	0.073	0.095	0.122	0.227	0.201
148:40:00	0.000	0.072	0.094	0.120	0.224	0.199
149:20:00	0.000	0.071	0.093	0.119	0.221	0.196
150:00:00	0.000	0.070	0.092	0.117	0.218	0.194
150:40:00	0.000	0.000	0.090	0.116	0.215	0.191
151:20:00	0.000	0.000	0.089	0.114	0.212	0.188
152:00:00	0.000	0.000	0.088	0.113	0.209	0.186
152:40:00	0.000	0.000	0.087	0.111	0.206	0.183
153:20:00	0.000	0.000	0.086	0.110	0.203	0.181
154:00:00	0.000	0.000	0.084	0.108	0.201	0.178
154:40:00	0.000	0.000	0.083	0.107	0.198	0.176
155:20:00	0.000	0.000	0.082	0.105	0.195	0.174
156:00:00	0.000	0.000	0.081	0.104	0.193	0.171
156:40:00	0.000	0.000	0.080	0.102	0.190	0.169
157:20:00	0.000	0.000	0.079	0.101	0.188	0.167
158:00:00	0.000	0.000	0.078	0.100	0.185	0.165
158:40:00	0.000	0.000	0.077	0.098	0.183	0.162
159:20:00	0.000	0.000	0.076	0.097	0.180	0.160
160:00:00	0.000	0.000	0.075	0.096	0.178	0.158
160:40:00	0.000	0.000	0.074	0.095	0.175	0.156

161:20:00	0.000	0.000	0.073	0.093	0.173	0.154
162:00:00	0.000	0.000	0.072	0.092	0.171	0.152
162:40:00	0.000	0.000	0.071	0.091	0.168	0.150
163:20:00	0.000	0.000	0.070	0.090	0.166	0.148
164:00:00	0.000	0.000	0.069	0.088	0.164	0.146
164:40:00	0.000	0.000	0.000	0.087	0.162	0.144
165:20:00	0.000	0.000	0.000	0.086	0.160	0.142
166:00:00	0.000	0.000	0.000	0.085	0.157	0.140
166:40:00	0.000	0.000	0.000	0.084	0.155	0.138
167:20:00	0.000	0.000	0.000	0.083	0.153	0.136
168:00:00	0.000	0.000	0.000	0.081	0.151	0.134
168:40:00	0.000	0.000	0.000	0.080	0.149	0.133
169:20:00	0.000	0.000	0.000	0.079	0.147	0.131
170:00:00	0.000	0.000	0.000	0.078	0.145	0.129
170:40:00	0.000	0.000	0.000	0.077	0.143	0.127
171:20:00	0.000	0.000	0.000	0.076	0.141	0.126
172:00:00	0.000	0.000	0.000	0.075	0.139	0.124
172:40:00	0.000	0.000	0.000	0.074	0.138	0.122
173:20:00	0.000	0.000	0.000	0.073	0.136	0.121
174:00:00	0.000	0.000	0.000	0.072	0.134	0.119
174:40:00	0.000	0.000	0.000	0.071	0.132	0.117
175:20:00	0.000	0.000	0.000	0.070	0.130	0.116
176:00:00	0.000	0.000	0.000	0.069	0.129	0.114
176:40:00	0.000	0.000	0.000	0.000	0.127	0.000
177:20:00	0.000	0.000	0.000	0.000	0.125	0.000
178:00:00	0.000	0.000	0.000	0.000	0.123	0.000
178:40:00	0.000	0.000	0.000	0.000	0.122	0.000
179:20:00	0.000	0.000	0.000	0.000	0.120	0.000
180:00:00	0.000	0.000	0.000	0.000	0.119	0.000
180:40:00	0.000	0.000	0.000	0.000	0.117	0.000
181:20:00	0.000	0.000	0.000	0.000	0.115	0.000
182:00:00	0.000	0.000	0.000	0.000	0.114	0.000
182:40:00	0.000	0.000	0.000	0.000	0.112	0.000
183:20:00	0.000	0.000	0.000	0.000	0.111	0.000
184:00:00	0.000	0.000	0.000	0.000	0.109	0.000
184:40:00	0.000	0.000	0.000	0.000	0.108	0.000
185:20:00	0.000	0.000	0.000	0.000	0.106	0.000
186:00:00	0.000	0.000	0.000	0.000	0.105	0.000
186:40:00	0.000	0.000	0.000	0.000	0.104	0.000
187:20:00	0.000	0.000	0.000	0.000	0.102	0.000
188:00:00	0.000	0.000	0.000	0.000	0.101	0.000
188:40:00	0.000	0.000	0.000	0.000	0.100	0.000
189:20:00	0.000	0.000	0.000	0.000	0.098	0.000

190:00:00	0.000	0.000	0.000	0.000	0.097	0.000
190:40:00	0.000	0.000	0.000	0.000	0.096	0.000
191:20:00	0.000	0.000	0.000	0.000	0.094	0.000
192:00:00	0.000	0.000	0.000	0.000	0.093	0.000
192:40:00	0.000	0.000	0.000	0.000	0.092	0.000
193:20:00	0.000	0.000	0.000	0.000	0.091	0.000
194:00:00	0.000	0.000	0.000	0.000	0.089	0.000
194:40:00	0.000	0.000	0.000	0.000	0.088	0.000
195:20:00	0.000	0.000	0.000	0.000	0.087	0.000
196:00:00	0.000	0.000	0.000	0.000	0.086	0.000
196:40:00	0.000	0.000	0.000	0.000	0.085	0.000
197:20:00	0.000	0.000	0.000	0.000	0.084	0.000
198:00:00	0.000	0.000	0.000	0.000	0.082	0.000
198:40:00	0.000	0.000	0.000	0.000	0.081	0.000
199:20:00	0.000	0.000	0.000	0.000	0.080	0.000
200:00:00	0.000	0.000	0.000	0.000	0.079	0.000
200:40:00	0.000	0.000	0.000	0.000	0.078	0.000
201:20:00	0.000	0.000	0.000	0.000	0.077	0.000
202:00:00	0.000	0.000	0.000	0.000	0.076	0.000
202:40:00	0.000	0.000	0.000	0.000	0.075	0.000
203:20:00	0.000	0.000	0.000	0.000	0.074	0.000
204:00:00	0.000	0.000	0.000	0.000	0.073	0.000
204:40:00	0.000	0.000	0.000	0.000	0.072	0.000
205:20:00	0.000	0.000	0.000	0.000	0.071	0.000
206:00:00	0.000	0.000	0.000	0.000	0.070	0.000
206:40:00	0.000	0.000	0.000	0.000	0.069	0.000
207:20:00	0.000	0.000	0.000	0.000	0.000	0.000
208:00:00	0.000	0.000	0.000	0.000	0.000	0.000
208:40:00	0.000	0.000	0.000	0.000	0.000	0.000
209:20:00	0.000	0.000	0.000	0.000	0.000	0.000
210:00:00	0.000	0.000	0.000	0.000	0.000	0.000
210:40:00	0.000	0.000	0.000	0.000	0.000	0.000
211:20:00	0.000	0.000	0.000	0.000	0.000	0.000
212:00:00	0.000	0.000	0.000	0.000	0.000	0.000

Table B-4: Design hydrographs for DS Extent 14 hr Summer Storm

Time	2 yr	25 yr	50 yr	100 yr	1000 yr	100+1.65 yr
00:00:00	0.074	0.074	0.074	0.074	0.074	0.122
00:40:00	0.074	0.075	0.076	0.076	0.078	0.126
01:20:00	0.076	0.081	0.083	0.085	0.092	0.141
02:00:00	0.081	0.093	0.098	0.103	0.120	0.170
02:40:00	0.089	0.112	0.122	0.132	0.165	0.218
03:20:00	0.100	0.141	0.157	0.175	0.233	0.288

04:00:00	0.117	0.182	0.208	0.236	0.330	0.390
04:40:00	0.140	0.237	0.277	0.320	0.463	0.527
05:20:00	0.171	0.311	0.369	0.432	0.644	0.712
06:00:00	0.210	0.408	0.491	0.582	0.891	0.960
06:40:00	0.263	0.542	0.661	0.791	1.245	1.305
07:20:00	0.342	0.745	0.921	1.116	1.812	1.841
08:00:00	0.445	1.021	1.278	1.566	2.615	2.584
08:40:00	0.562	1.339	1.691	2.091	3.568	3.450
09:20:00	0.684	1.677	2.135	2.657	4.611	4.384
10:00:00	0.805	2.020	2.587	3.237	5.694	5.341
10:40:00	0.916	2.345	3.019	3.795	6.757	6.262
11:20:00	1.010	2.620	3.389	4.280	7.706	7.063
12:00:00	1.070	2.828	3.675	4.661	8.477	7.690
12:40:00	1.100	2.937	3.830	4.874	8.939	8.042
13:20:00	1.100	2.962	3.875	4.945	9.132	8.159
14:00:00	1.080	2.933	3.846	4.919	9.135	8.116
14:40:00	1.040	2.862	3.761	4.819	8.992	7.952
15:20:00	1.000	2.762	3.635	4.665	8.736	7.697
16:00:00	0.954	2.638	3.477	4.468	8.392	7.372
16:40:00	0.902	2.498	3.296	4.239	7.980	6.994
17:20:00	0.847	2.350	3.103	3.994	7.532	6.590
18:00:00	0.794	2.205	2.913	3.752	7.088	6.191
18:40:00	0.743	2.063	2.727	3.514	6.647	5.798
19:20:00	0.692	1.922	2.542	3.278	6.207	5.408
20:00:00	0.644	1.789	2.366	3.052	5.787	5.036
20:40:00	0.600	1.664	2.202	2.842	5.393	4.689
21:20:00	0.559	1.550	2.052	2.648	5.030	4.369
22:00:00	0.523	1.445	1.913	2.470	4.692	4.075
22:40:00	0.489	1.347	1.783	2.302	4.373	3.797
23:20:00	0.456	1.255	1.660	2.142	4.069	3.535
24:00:00	0.427	1.167	1.544	1.992	3.780	3.286
24:40:00	0.399	1.086	1.436	1.851	3.509	3.054
25:20:00	0.374	1.013	1.337	1.723	3.260	2.843
26:00:00	0.355	0.955	1.258	1.619	3.057	2.672
26:40:00	0.340	0.909	1.197	1.539	2.899	2.540
27:20:00	0.328	0.873	1.148	1.475	2.772	2.434
28:00:00	0.318	0.844	1.109	1.423	2.669	2.348
28:40:00	0.310	0.819	1.076	1.380	2.584	2.277
29:20:00	0.303	0.799	1.049	1.344	2.514	2.218
30:00:00	0.298	0.782	1.026	1.314	2.456	2.169
30:40:00	0.292	0.768	1.007	1.289	2.407	2.128
31:20:00	0.288	0.756	0.990	1.268	2.367	2.093
32:00:00	0.284	0.745	0.977	1.251	2.333	2.063

32:40:00	0.281	0.736	0.965	1.236	2.305	2.039
33:20:00	0.278	0.728	0.954	1.222	2.279	2.016
34:00:00	0.275	0.720	0.943	1.208	2.253	1.993
34:40:00	0.272	0.712	0.933	1.194	2.228	1.971
35:20:00	0.268	0.704	0.922	1.181	2.203	1.948
36:00:00	0.265	0.696	0.912	1.168	2.178	1.926
36:40:00	0.262	0.688	0.901	1.154	2.153	1.905
37:20:00	0.259	0.680	0.891	1.141	2.129	1.883
38:00:00	0.257	0.672	0.881	1.129	2.105	1.862
38:40:00	0.254	0.665	0.871	1.116	2.081	1.841
39:20:00	0.251	0.657	0.861	1.103	2.058	1.820
40:00:00	0.248	0.650	0.852	1.091	2.035	1.800
40:40:00	0.245	0.643	0.842	1.078	2.012	1.780
41:20:00	0.242	0.635	0.833	1.066	1.989	1.759
42:00:00	0.240	0.628	0.823	1.054	1.967	1.740
42:40:00	0.237	0.621	0.814	1.042	1.945	1.720
43:20:00	0.234	0.614	0.805	1.031	1.923	1.701
44:00:00	0.232	0.607	0.796	1.019	1.901	1.681
44:40:00	0.229	0.600	0.787	1.008	1.880	1.662
45:20:00	0.226	0.594	0.778	0.996	1.858	1.644
46:00:00	0.224	0.587	0.769	0.985	1.837	1.625
46:40:00	0.221	0.580	0.760	0.974	1.817	1.607
47:20:00	0.219	0.574	0.752	0.963	1.796	1.589
48:00:00	0.216	0.567	0.743	0.952	1.776	1.571
48:40:00	0.214	0.561	0.735	0.941	1.756	1.553
49:20:00	0.212	0.555	0.727	0.931	1.736	1.536
50:00:00	0.209	0.548	0.719	0.920	1.717	1.518
50:40:00	0.207	0.542	0.710	0.910	1.697	1.501
51:20:00	0.205	0.536	0.702	0.900	1.678	1.484
52:00:00	0.202	0.530	0.695	0.889	1.659	1.468
52:40:00	0.200	0.524	0.687	0.879	1.640	1.451
53:20:00	0.198	0.518	0.679	0.869	1.622	1.435
54:00:00	0.195	0.512	0.671	0.860	1.604	1.418
54:40:00	0.193	0.506	0.664	0.850	1.586	1.402
55:20:00	0.191	0.501	0.656	0.840	1.568	1.387
56:00:00	0.189	0.495	0.649	0.831	1.550	1.371
56:40:00	0.187	0.490	0.642	0.822	1.533	1.356
57:20:00	0.185	0.484	0.634	0.812	1.515	1.340
58:00:00	0.183	0.479	0.627	0.803	1.498	1.325
58:40:00	0.181	0.473	0.620	0.794	1.481	1.310
59:20:00	0.179	0.468	0.613	0.785	1.465	1.295
60:00:00	0.176	0.463	0.606	0.776	1.448	1.281
60:40:00	0.174	0.457	0.599	0.768	1.432	1.266

61:20:00	0.173	0.452	0.593	0.759	1.416	1.252
62:00:00	0.171	0.447	0.586	0.750	1.400	1.238
62:40:00	0.169	0.442	0.579	0.742	1.384	1.224
63:20:00	0.167	0.437	0.573	0.734	1.368	1.210
64:00:00	0.165	0.432	0.566	0.725	1.353	1.197
64:40:00	0.163	0.427	0.560	0.717	1.338	1.183
65:20:00	0.161	0.422	0.554	0.709	1.323	1.170
66:00:00	0.159	0.418	0.547	0.701	1.308	1.157
66:40:00	0.158	0.413	0.541	0.693	1.293	1.144
67:20:00	0.156	0.408	0.535	0.685	1.278	1.131
68:00:00	0.154	0.404	0.529	0.678	1.264	1.118
68:40:00	0.152	0.399	0.523	0.670	1.250	1.105
69:20:00	0.151	0.395	0.517	0.662	1.236	1.093
70:00:00	0.149	0.390	0.511	0.655	1.222	1.081
70:40:00	0.147	0.386	0.506	0.648	1.208	1.068
71:20:00	0.146	0.381	0.500	0.640	1.194	1.056
72:00:00	0.144	0.377	0.494	0.633	1.181	1.044
72:40:00	0.142	0.373	0.489	0.626	1.168	1.033
73:20:00	0.141	0.369	0.483	0.619	1.154	1.021
74:00:00	0.139	0.365	0.478	0.612	1.141	1.010
74:40:00	0.138	0.360	0.472	0.605	1.128	0.998
75:20:00	0.136	0.356	0.467	0.598	1.116	0.987
76:00:00	0.134	0.352	0.462	0.591	1.103	0.976
76:40:00	0.133	0.348	0.457	0.585	1.091	0.965
77:20:00	0.131	0.344	0.451	0.578	1.078	0.954
78:00:00	0.130	0.341	0.446	0.572	1.066	0.943
78:40:00	0.128	0.337	0.441	0.565	1.054	0.932
79:20:00	0.127	0.333	0.436	0.559	1.042	0.922
80:00:00	0.126	0.329	0.431	0.552	1.031	0.912
80:40:00	0.124	0.325	0.427	0.546	1.019	0.901
81:20:00	0.123	0.322	0.422	0.540	1.008	0.891
82:00:00	0.121	0.318	0.417	0.534	0.996	0.881
82:40:00	0.120	0.315	0.412	0.528	0.985	0.871
83:20:00	0.119	0.311	0.408	0.522	0.974	0.861
84:00:00	0.117	0.308	0.403	0.516	0.963	0.852
84:40:00	0.116	0.304	0.398	0.510	0.952	0.842
85:20:00	0.115	0.301	0.394	0.505	0.941	0.833
86:00:00	0.113	0.297	0.390	0.499	0.931	0.823
86:40:00	0.112	0.294	0.385	0.493	0.920	0.814
87:20:00	0.111	0.291	0.381	0.488	0.910	0.805
88:00:00	0.110	0.287	0.377	0.482	0.900	0.796
88:40:00	0.108	0.284	0.372	0.477	0.889	0.787
89:20:00	0.107	0.281	0.368	0.471	0.879	0.778

90:00:00	0.106	0.278	0.364	0.466	0.869	0.769
90:40:00	0.105	0.275	0.360	0.461	0.860	0.760
91:20:00	0.104	0.271	0.356	0.456	0.850	0.752
92:00:00	0.102	0.268	0.352	0.450	0.840	0.743
92:40:00	0.101	0.265	0.348	0.445	0.831	0.735
93:20:00	0.100	0.262	0.344	0.440	0.822	0.727
94:00:00	0.099	0.259	0.340	0.435	0.812	0.718
94:40:00	0.098	0.257	0.336	0.431	0.803	0.710
95:20:00	0.097	0.254	0.332	0.426	0.794	0.702
96:00:00	0.096	0.251	0.329	0.421	0.785	0.694
96:40:00	0.095	0.248	0.325	0.416	0.776	0.687
97:20:00	0.094	0.245	0.321	0.411	0.768	0.679
98:00:00	0.093	0.242	0.318	0.407	0.759	0.671
98:40:00	0.091	0.240	0.314	0.402	0.750	0.664
99:20:00	0.090	0.237	0.311	0.398	0.742	0.656
100:00:00	0.089	0.234	0.307	0.393	0.733	0.649
100:40:00	0.088	0.232	0.304	0.389	0.725	0.641
101:20:00	0.087	0.229	0.300	0.384	0.717	0.634
102:00:00	0.086	0.226	0.297	0.380	0.709	0.627
102:40:00	0.085	0.224	0.293	0.376	0.701	0.620
103:20:00	0.085	0.221	0.290	0.372	0.693	0.613
104:00:00	0.084	0.219	0.287	0.367	0.685	0.606
104:40:00	0.083	0.216	0.284	0.363	0.678	0.599
105:20:00	0.082	0.214	0.280	0.359	0.670	0.593
106:00:00	0.081	0.212	0.277	0.355	0.662	0.586
106:40:00	0.080	0.209	0.274	0.351	0.655	0.579
107:20:00	0.079	0.207	0.271	0.347	0.647	0.573
108:00:00	0.078	0.204	0.268	0.343	0.640	0.566
108:40:00	0.077	0.202	0.265	0.339	0.633	0.560
109:20:00	0.076	0.200	0.262	0.335	0.626	0.554
110:00:00	0.075	0.198	0.259	0.332	0.619	0.547
110:40:00	0.075	0.195	0.256	0.328	0.612	0.541
111:20:00	0.000	0.193	0.253	0.324	0.605	0.535
112:00:00	0.000	0.191	0.250	0.321	0.598	0.529
112:40:00	0.000	0.189	0.248	0.317	0.591	0.523
113:20:00	0.000	0.187	0.245	0.313	0.585	0.517
114:00:00	0.000	0.185	0.242	0.310	0.578	0.511
114:40:00	0.000	0.183	0.239	0.306	0.572	0.506
115:20:00	0.000	0.181	0.237	0.303	0.565	0.500
116:00:00	0.000	0.178	0.234	0.300	0.559	0.494
116:40:00	0.000	0.176	0.231	0.296	0.552	0.489
117:20:00	0.000	0.174	0.229	0.293	0.546	0.483
118:00:00	0.000	0.173	0.226	0.290	0.540	0.478

118:40:00	0.000	0.171	0.224	0.286	0.534	0.472
119:20:00	0.000	0.169	0.221	0.283	0.528	0.467
120:00:00	0.000	0.167	0.219	0.280	0.522	0.462
120:40:00	0.000	0.165	0.216	0.277	0.516	0.457
121:20:00	0.000	0.163	0.214	0.274	0.510	0.451
122:00:00	0.000	0.161	0.211	0.270	0.505	0.446
122:40:00	0.000	0.159	0.209	0.267	0.499	0.441
123:20:00	0.000	0.158	0.206	0.264	0.493	0.436
124:00:00	0.000	0.156	0.204	0.261	0.488	0.431
124:40:00	0.000	0.154	0.202	0.258	0.482	0.426
125:20:00	0.000	0.152	0.200	0.256	0.477	0.422
126:00:00	0.000	0.151	0.197	0.253	0.471	0.417
126:40:00	0.000	0.149	0.195	0.250	0.466	0.412
127:20:00	0.000	0.147	0.193	0.247	0.461	0.408
128:00:00	0.000	0.146	0.191	0.244	0.456	0.403
128:40:00	0.000	0.144	0.189	0.241	0.450	0.398
129:20:00	0.000	0.142	0.186	0.239	0.445	0.394
130:00:00	0.000	0.141	0.184	0.236	0.440	0.390
130:40:00	0.000	0.139	0.182	0.233	0.435	0.385
131:20:00	0.000	0.138	0.180	0.231	0.430	0.381
132:00:00	0.000	0.136	0.178	0.228	0.426	0.376
132:40:00	0.000	0.134	0.176	0.226	0.421	0.372
133:20:00	0.000	0.133	0.174	0.223	0.416	0.368
134:00:00	0.000	0.131	0.172	0.221	0.411	0.364
134:40:00	0.000	0.130	0.170	0.218	0.407	0.360
135:20:00	0.000	0.128	0.168	0.216	0.402	0.356
136:00:00	0.000	0.127	0.166	0.213	0.398	0.352
136:40:00	0.000	0.126	0.165	0.211	0.393	0.348
137:20:00	0.000	0.124	0.163	0.208	0.389	0.344
138:00:00	0.000	0.123	0.161	0.206	0.384	0.340
138:40:00	0.000	0.121	0.159	0.204	0.380	0.336
139:20:00	0.000	0.120	0.157	0.201	0.376	0.332
140:00:00	0.000	0.119	0.156	0.199	0.372	0.329
140:40:00	0.000	0.117	0.154	0.197	0.367	0.325
141:20:00	0.000	0.116	0.152	0.195	0.363	0.321
142:00:00	0.000	0.115	0.150	0.192	0.359	0.318
142:40:00	0.000	0.113	0.149	0.190	0.355	0.314
143:20:00	0.000	0.112	0.147	0.188	0.351	0.310
144:00:00	0.000	0.111	0.145	0.186	0.347	0.307
144:40:00	0.000	0.110	0.144	0.184	0.343	0.304
145:20:00	0.000	0.108	0.142	0.182	0.339	0.300
146:00:00	0.000	0.107	0.140	0.180	0.335	0.297
146:40:00	0.000	0.106	0.139	0.178	0.332	0.293

147:20:00	0.000	0.105	0.137	0.176	0.328	0.290
148:00:00	0.000	0.104	0.136	0.174	0.324	0.287
148:40:00	0.000	0.102	0.134	0.172	0.321	0.284
149:20:00	0.000	0.101	0.133	0.170	0.317	0.280
150:00:00	0.000	0.100	0.131	0.168	0.313	0.277
150:40:00	0.000	0.099	0.130	0.166	0.310	0.274
151:20:00	0.000	0.098	0.128	0.164	0.306	0.271
152:00:00	0.000	0.097	0.127	0.162	0.303	0.268
152:40:00	0.000	0.096	0.125	0.161	0.300	0.265
153:20:00	0.000	0.095	0.124	0.159	0.296	0.262
154:00:00	0.000	0.094	0.123	0.157	0.293	0.259
154:40:00	0.000	0.092	0.121	0.155	0.289	0.256
155:20:00	0.000	0.091	0.120	0.153	0.286	0.253
156:00:00	0.000	0.090	0.118	0.152	0.283	0.250
156:40:00	0.000	0.089	0.117	0.150	0.280	0.247
157:20:00	0.000	0.088	0.116	0.148	0.277	0.245
158:00:00	0.000	0.087	0.115	0.147	0.274	0.242
158:40:00	0.000	0.086	0.113	0.145	0.270	0.239
159:20:00	0.000	0.085	0.112	0.143	0.267	0.237
160:00:00	0.000	0.084	0.111	0.142	0.264	0.234
160:40:00	0.000	0.084	0.109	0.140	0.261	0.231
161:20:00	0.000	0.083	0.108	0.139	0.258	0.229
162:00:00	0.000	0.082	0.107	0.137	0.256	0.226
162:40:00	0.000	0.081	0.106	0.135	0.253	0.223
163:20:00	0.000	0.080	0.105	0.134	0.250	0.221
164:00:00	0.000	0.079	0.103	0.132	0.247	0.218
164:40:00	0.000	0.078	0.102	0.131	0.244	0.216
165:20:00	0.000	0.077	0.101	0.129	0.241	0.214
166:00:00	0.000	0.076	0.100	0.128	0.239	0.211
166:40:00	0.000	0.075	0.099	0.127	0.236	0.209
167:20:00	0.000	0.075	0.098	0.125	0.233	0.206
168:00:00	0.000	0.000	0.097	0.124	0.231	0.204
168:40:00	0.000	0.000	0.096	0.122	0.228	0.202
169:20:00	0.000	0.000	0.094	0.121	0.226	0.200
170:00:00	0.000	0.000	0.093	0.120	0.223	0.197
170:40:00	0.000	0.000	0.092	0.118	0.221	0.195
171:20:00	0.000	0.000	0.091	0.117	0.218	0.193
172:00:00	0.000	0.000	0.090	0.116	0.216	0.191
172:40:00	0.000	0.000	0.089	0.114	0.213	0.189
173:20:00	0.000	0.000	0.088	0.113	0.211	0.186
174:00:00	0.000	0.000	0.087	0.112	0.208	0.184
174:40:00	0.000	0.000	0.086	0.110	0.206	0.182
175:20:00	0.000	0.000	0.085	0.109	0.204	0.180

176:00:00	0.000	0.000	0.084	0.108	0.201	0.178
176:40:00	0.000	0.000	0.083	0.107	0.199	0.176
177:20:00	0.000	0.000	0.082	0.106	0.197	0.174
178:00:00	0.000	0.000	0.081	0.104	0.195	0.172
178:40:00	0.000	0.000	0.081	0.103	0.192	0.170
179:20:00	0.000	0.000	0.080	0.102	0.190	0.168
180:00:00	0.000	0.000	0.079	0.101	0.188	0.166
180:40:00	0.000	0.000	0.078	0.100	0.186	0.165
181:20:00	0.000	0.000	0.077	0.099	0.184	0.163
182:00:00	0.000	0.000	0.076	0.097	0.182	0.161
182:40:00	0.000	0.000	0.075	0.096	0.180	0.159
183:20:00	0.000	0.000	0.074	0.095	0.178	0.157
184:00:00	0.000	0.000	0.000	0.094	0.176	0.155
184:40:00	0.000	0.000	0.000	0.093	0.174	0.154
185:20:00	0.000	0.000	0.000	0.092	0.172	0.152
186:00:00	0.000	0.000	0.000	0.091	0.170	0.150
186:40:00	0.000	0.000	0.000	0.090	0.168	0.149
187:20:00	0.000	0.000	0.000	0.089	0.166	0.147
188:00:00	0.000	0.000	0.000	0.088	0.164	0.145
188:40:00	0.000	0.000	0.000	0.087	0.162	0.144
189:20:00	0.000	0.000	0.000	0.086	0.161	0.142
190:00:00	0.000	0.000	0.000	0.085	0.159	0.140
190:40:00	0.000	0.000	0.000	0.084	0.157	0.139
191:20:00	0.000	0.000	0.000	0.083	0.155	0.137
192:00:00	0.000	0.000	0.000	0.082	0.153	0.136
192:40:00	0.000	0.000	0.000	0.081	0.152	0.134
193:20:00	0.000	0.000	0.000	0.080	0.150	0.133
194:00:00	0.000	0.000	0.000	0.079	0.148	0.131
194:40:00	0.000	0.000	0.000	0.079	0.147	0.130
195:20:00	0.000	0.000	0.000	0.078	0.145	0.128
196:00:00	0.000	0.000	0.000	0.077	0.143	0.127
196:40:00	0.000	0.000	0.000	0.076	0.142	0.125
197:20:00	0.000	0.000	0.000	0.075	0.140	0.124
198:00:00	0.000	0.000	0.000	0.000	0.139	0.000
198:40:00	0.000	0.000	0.000	0.000	0.137	0.000
199:20:00	0.000	0.000	0.000	0.000	0.135	0.000
200:00:00	0.000	0.000	0.000	0.000	0.134	0.000
200:40:00	0.000	0.000	0.000	0.000	0.132	0.000
201:20:00	0.000	0.000	0.000	0.000	0.131	0.000
202:00:00	0.000	0.000	0.000	0.000	0.129	0.000
202:40:00	0.000	0.000	0.000	0.000	0.128	0.000
203:20:00	0.000	0.000	0.000	0.000	0.127	0.000
204:00:00	0.000	0.000	0.000	0.000	0.125	0.000

204:40:00	0.000	0.000	0.000	0.000	0.124	0.000
205:20:00	0.000	0.000	0.000	0.000	0.122	0.000
206:00:00	0.000	0.000	0.000	0.000	0.121	0.000
206:40:00	0.000	0.000	0.000	0.000	0.120	0.000
207:20:00	0.000	0.000	0.000	0.000	0.118	0.000
208:00:00	0.000	0.000	0.000	0.000	0.117	0.000
208:40:00	0.000	0.000	0.000	0.000	0.116	0.000
209:20:00	0.000	0.000	0.000	0.000	0.114	0.000
210:00:00	0.000	0.000	0.000	0.000	0.113	0.000
210:40:00	0.000	0.000	0.000	0.000	0.112	0.000
211:20:00	0.000	0.000	0.000	0.000	0.110	0.000
212:00:00	0.000	0.000	0.000	0.000	0.109	0.000
213:20:00	0.000	0.000	0.000	0.000	0.108	0.000
214:00:00	0.000	0.000	0.000	0.000	0.107	0.000
214:40:00	0.000	0.000	0.000	0.000	0.106	0.000
215:20:00	0.000	0.000	0.000	0.000	0.104	0.000
216:00:00	0.000	0.000	0.000	0.000	0.103	0.000
216:40:00	0.000	0.000	0.000	0.000	0.102	0.000
217:20:00	0.000	0.000	0.000	0.000	0.101	0.000
218:00:00	0.000	0.000	0.000	0.000	0.100	0.000
218:40:00	0.000	0.000	0.000	0.000	0.099	0.000
219:20:00	0.000	0.000	0.000	0.000	0.097	0.000
220:00:00	0.000	0.000	0.000	0.000	0.096	0.000
220:40:00	0.000	0.000	0.000	0.000	0.095	0.000
221:20:00	0.000	0.000	0.000	0.000	0.094	0.000
222:00:00	0.000	0.000	0.000	0.000	0.093	0.000
222:40:00	0.000	0.000	0.000	0.000	0.092	0.000
223:20:00	0.000	0.000	0.000	0.000	0.091	0.000
224:00:00	0.000	0.000	0.000	0.000	0.090	0.000
224:40:00	0.000	0.000	0.000	0.000	0.089	0.000
225:20:00	0.000	0.000	0.000	0.000	0.088	0.000
226:00:00	0.000	0.000	0.000	0.000	0.087	0.000
226:40:00	0.000	0.000	0.000	0.000	0.086	0.000
227:20:00	0.000	0.000	0.000	0.000	0.085	0.000
228:00:00	0.000	0.000	0.000	0.000	0.084	0.000
228:40:00	0.000	0.000	0.000	0.000	0.083	0.000
229:20:00	0.000	0.000	0.000	0.000	0.082	0.000
230:00:00	0.000	0.000	0.000	0.000	0.081	0.000
230:40:00	0.000	0.000	0.000	0.000	0.080	0.000
231:20:00	0.000	0.000	0.000	0.000	0.079	0.000
232:00:00	0.000	0.000	0.000	0.000	0.079	0.000
232:40:00	0.000	0.000	0.000	0.000	0.078	0.000
233:20:00	0.000	0.000	0.000	0.000	0.077	0.000

234:00:00	0.000	0.000	0.000	0.000	0.076	0.000
234:40:00	0.000	0.000	0.000	0.000	0.075	0.000

Annex C. Flood depth difference maps

Figure C-1: Flood depth difference between upstream boundary and Cantley Lane South (100-year event)

Figure C-2: Flood depth difference between upstream boundary and Cantley Lane South (100-year plus 35% event)

Figure C-3: Flood depth difference between upstream boundary and Cantley Lane South (100-year plus 65% event)

Figure C-4: Flood depth difference between upstream boundary and Cantley Lane South (100-year plus 80% event)

Figure C-5: Flood depth difference between Cantley Lane South and A47 (1000-year event)

Figure C-6: Flood depth difference between Cantley Lane South and A47 (100-year event)

Figure C-7: Flood depth difference between Cantley Lane South and A47 (100-year plus 35% event)

Figure C-8: Flood depth difference between Cantley Lane South and A47 (100-year plus 65% event)

Figure C-9: Flood depth difference between Cantley Lane South and A47 (100-year plus 80% event)

Figure C-10: Flood depth difference between Cantley Lane South and A47 (1000-year event)

Figure C-11: Flood depth difference between A47 and model outfall (100-year event)

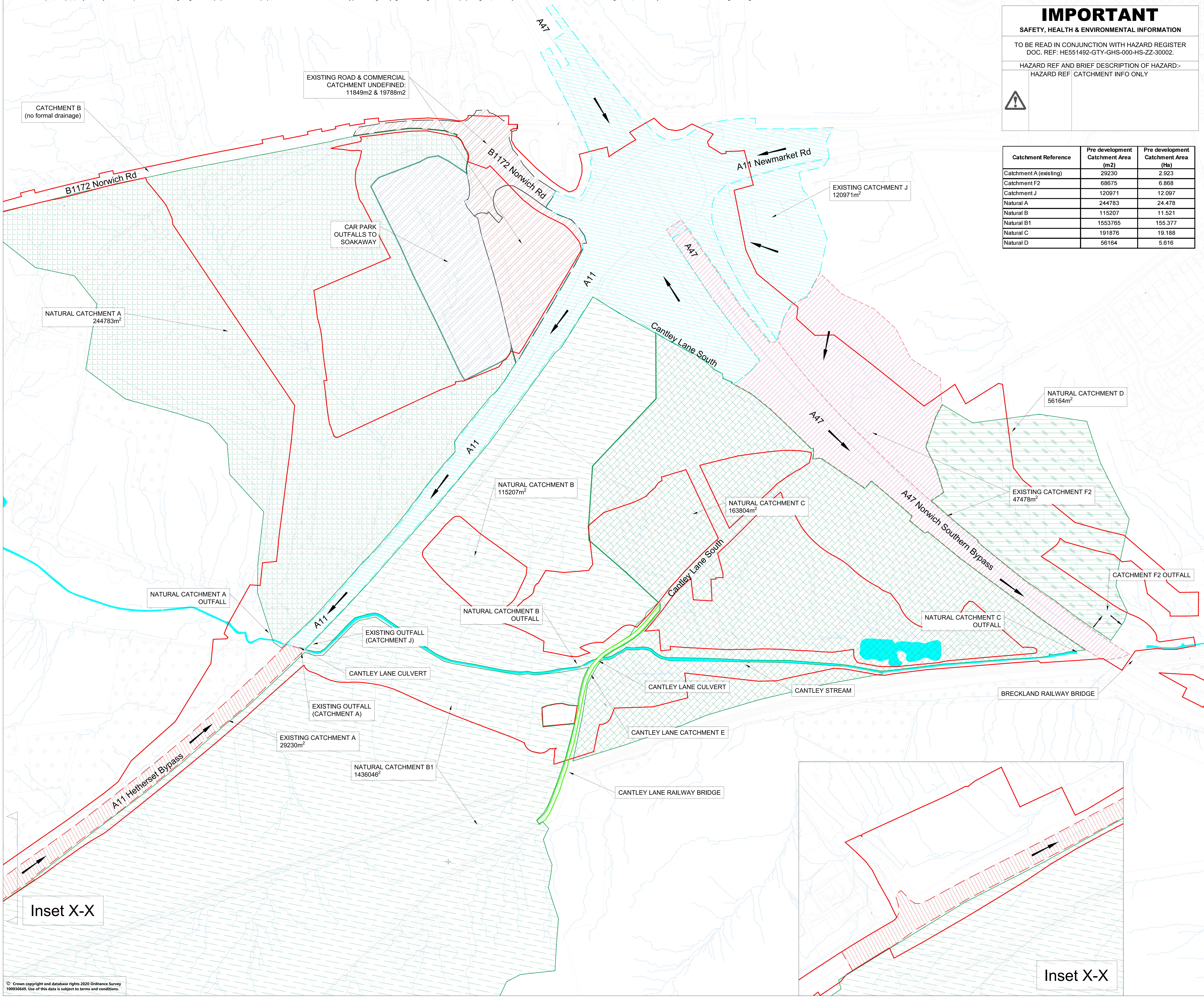
Figure C-12: Flood depth difference between A47 and model outfall (100-year plus 35% event)

Figure C-13: Flood depth difference between A47 and model outfall (100-year plus 65% event)

Figure C-14: Flood depth difference between A47 and model outfall (100-year plus 80% event)

Figure C-14: Flood depth difference between A47 and model outfall (1000-year event)

Annex D. Drainage catchment layout plans



IMPORTANT

SAFETY, HEALTH & ENVIRONMENTAL INFORMATION

TO BE READ IN CONJUNCTION WITH HAZARD REGISTER DOC. REF: HE551492-GTY-GHS-000-HS-ZZ-30002.

HAZARD REF AND BRIEF DESCRIPTION OF HAZARD:-

	HAZARD REF	CATCHMENT INFO ONLY
⚠		

Catchment Reference	Pre development Catchment Area (m2)	Pre development Catchment Area (Ha)
Catchment A (existing)	29230	2.923
Catchment F2	68675	6.868
Catchment J	120971	12.097
Natural A	244783	24.478
Natural B	115207	11.521
Natural B1	1553765	155.377
Natural C	191876	19.188
Natural D	56164	5.616

NOTES

KEY TO SYMBOLS

- CATCHMENT A
- CATCHMENT F2
- CATCHMENT J
- CATCHMENT E
- NATURAL CATCHMENT A
- NATURAL CATCHMENT B
- NATURAL CATCHMENT C
- NATURAL CATCHMENT D
- DCO BOUNDARY
- OVERLAND FLOW PATHS

REV	DATE	REVISION NOTE	ORG	CHK'D	APP'D
P01	02/02/21	general updates	SG	CBuc	BWil
P02	09/03/21	area updated	SG	CBuc	BWil
P03	12/03/21	areas updated	SG	CBuc	BWil

DESIGNER

SWECO

CONTRACTOR

Galliford Try

CLIENT

highways england

PROJECT TITLE

A47/A11 THICKTHORN JUNCTION

PROJECT STAGE

PCF STAGE 3

DRAWING TITLE

EXISTING DRAINAGE CATCHMENTS

SUITABILITY

SUITABLE FOR INFORMATION

SHEET SIZE	SCALE	STATUS	REVISION
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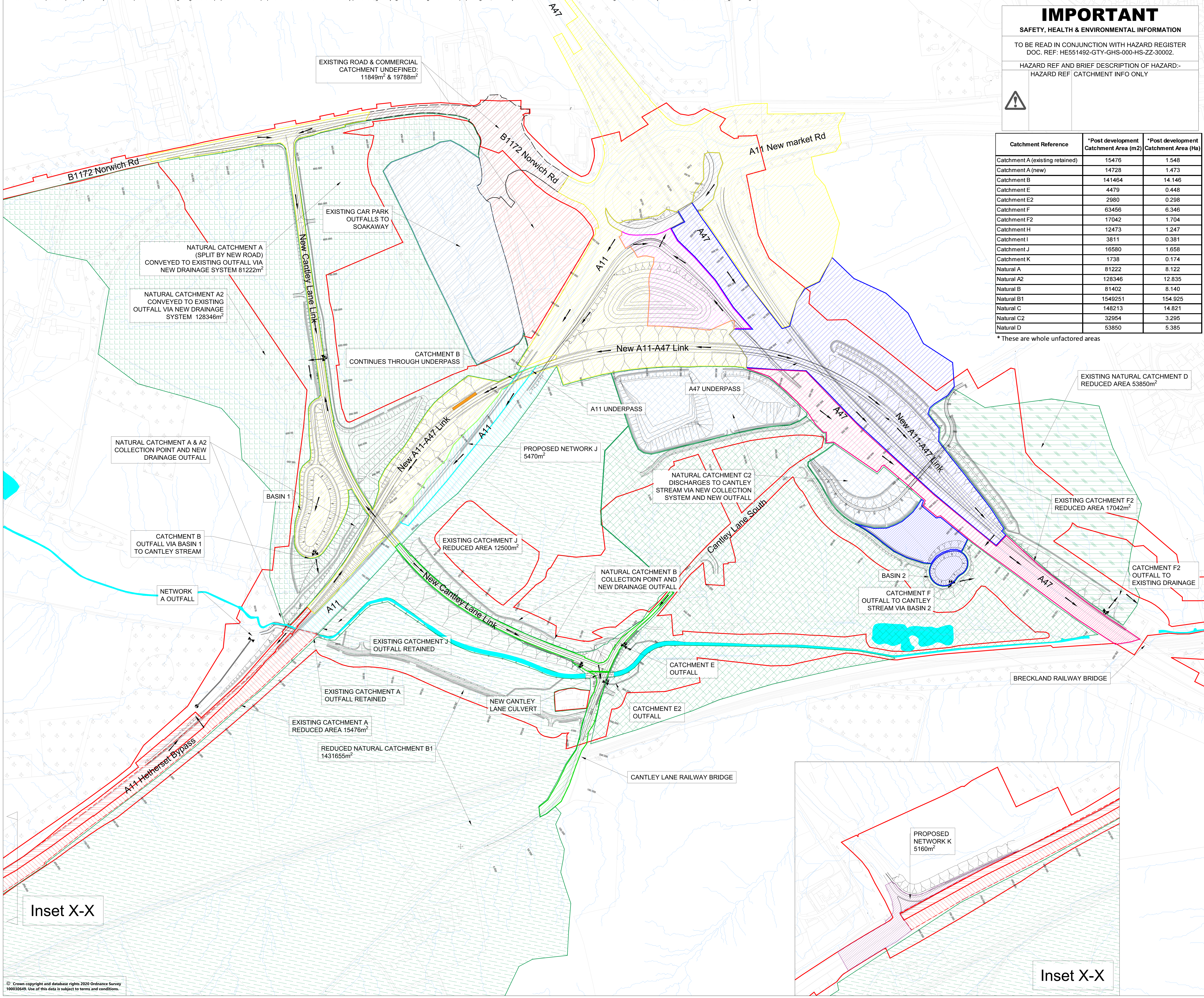
DRAWING NUMBER

HE551492-GTY-HDG-000-SK-CD-30010



IMPORTANT

SAFETY, HEALTH & ENVIRONMENTAL INFORMATION

TO BE READ IN CONJUNCTION WITH HAZARD REGISTER DOC. REF: HE551492-GTY-GHS-000-HS-ZZ-30002.

HAZARD REF AND BRIEF DESCRIPTION OF HAZARD:-

	HAZARD REF	CATCHMENT INFO ONLY
⚠		

Catchment Reference	*Post development Catchment Area (m2)	*Post development Catchment Area (Ha)
Catchment A (existing retained)	15476	1.548
Catchment A (new)	14728	1.473
Catchment B	141464	14.146
Catchment E	4479	0.448
Catchment E2	2980	0.298
Catchment F	63456	6.346
Catchment F2	17042	1.704
Catchment H	12473	1.247
Catchment I	3811	0.381
Catchment J	16580	1.658
Catchment K	1738	0.174
Natural A	81222	8.122
Natural A2	128346	12.835
Natural B	81402	8.140
Natural B1	1549251	154.925
Natural C	148213	14.821
Natural C2	32954	3.295
Natural D	53850	5.385

* These are whole unfactored areas

NOTES

KEY TO SYMBOLS

- DIRECTION OF SURFACE WATER DRAINAGE
- ATTENUATION TANK
- PUMPING CHAMBER
- PUMP SHAFT
- FLOW CONTROL DEVICE
- SHUT-OFF VALVE
- CATCHMENT A (existing)
- CATCHMENT A (new)
- CATCHMENT B
- CATCHMENT E
- CATCHMENT E2
- CATCHMENT F
- CATCHMENT F2
- CATCHMENT H
- CATCHMENT I
- CATCHMENT J
- CATCHMENT K
- NATURAL CATCHMENT A & A1
- NATURAL CATCHMENT B & B1
- NATURAL CATCHMENT C
- NATURAL CATCHMENT C 2
- NATURAL CATCHMENT D
- DCO BOUNDARY
- OVERLAND FLOW PATHS

REV	DATE	REVISION NOTE	ORG	CHK'D	APP'D
P01	02/02/21	GENERAL UPDATES	SG	CBuc	BWil
P02	12/03/21	area updated	SG	CBuc	BWil

DESIGNER
SWECO

CONTRACTOR
Galliford Try

CLIENT
highways england

PROJECT TITLE
A47/A11 THICKTHORN JUNCTION

PROJECT STAGE
PCF STAGE 3

DRAWING TITLE
DRAINAGE OUTFALL CATCHMENTS
SCHEME LAYOUT PLAN
SHEET 1 OF 1

SUITABILITY
SUITABLE FOR INFORMATION

SHEET SIZE	SCALE	STATUS	REVISION
A1	1:2500	S2	P02

DRAWING NUMBER
HE551492-GTY-HDG-000-DR-CD-30009

SCALE 1 : 1250
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IMPORTANT

SAFETY, HEALTH & ENVIRONMENTAL INFORMATION

TO BE READ IN CONJUNCTION WITH HAZARD REGISTER DOC. REF: HE551492-GTY-GHS-000-HS-ZZ-30002.

HAZARD REF AND BRIEF DESCRIPTION OF HAZARD:-

001	· SOURCE PROTECTION ZONE
002	· OVERHEAD ELECTRICITY SUPPLY
003	· FLOOD PLAIN
004	. DEEP DRAINAGE

NOTES

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KEY TO SYMBOLS

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- RISING MAIN
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- CATCHPIT / MANHOLE (HCD F11) (HCD F3 TO F7)
- GULLY (HCD F13) & CONNECTOR
- PROPOSED HEADWALL
- BYPASS INTERCEPTORS
- PUMP SHAFT
- CULVERT/PIPE CROSSING
- PED DITCH

REV	DATE	REVISION NOTE	ORG	CHK'D	APP'D
P01	27/03/20	Design developed	SG	CB	XC
P02	30/03/20	Work in progress	SG	CB	XC
P03	11/09/20	DESIGN DEVELOPMENT	RE	CB	BA
P04	27/11/20	DRAWING UPDATED FOR DFC	CMun	CBuc	BWil
P05	12/01/21	GT COMMENTS INCORPORATED	KMcC	CBuc	BWil
C01	12/01/21	GT COMMENTS INCORPORATED	KMcC	CBuc	BWil

DESIGNER
SWECO

CONTRACTOR
GallifordTry

CLIENT
highways england

PROJECT TITLE
A47/A11 THICKTHORN JUNCTION

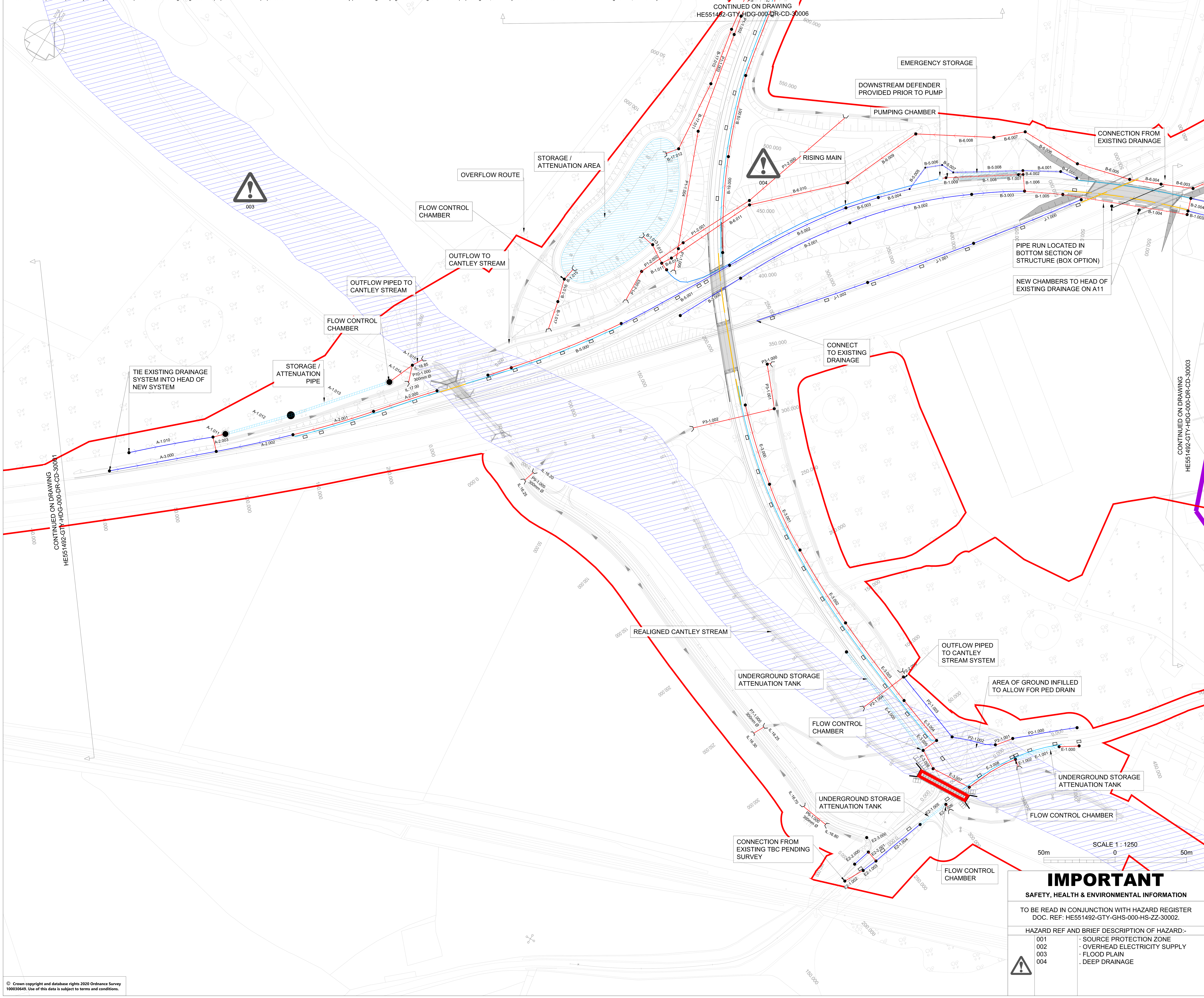
PROJECT STAGE
PCF STAGE 3

DRAWING TITLE
DRAINAGE LAYOUT
GENERAL LAYOUT PLAN
SHEET 1 OF 6

SUITABILITY
AUTHORISED AS STAGE 3 COMPLETED

SHEET SIZE	SCALE	STATUS	REVISION
N/A	1:1250	A3	C01

DRAWING NUMBER
HE551492-GTY-HDG-000-DR-CD-30001



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- GULLY (HCD F13) & CONNECTOR
- PROPOSED HEADWALL
- BYPASS INTERCEPTORS
- PUMP SHAFT
- CULVERT/PIPE CROSSING
- PED DITCH
- INDICATES THE EXTENTS OF THE FLOOD RISK BOUNDARY FOR LOCAL WATERCOURSE

REV	DATE	REVISION NOTE	ORG	CHK'D	APP'D
P01	27/03/20	Design developed	SG	CB	XC
P02	30/03/20	Work in progress	SG	CB	XC
P03	11/09/20	DESIGN DEVELOPMENT	RE	CB	BA
P04	27/11/20	DRAWING UPDATED FOR DFC	CMun	CBuc	BWil
P05	12/01/21	GT COMMENTS INCORPORATED	KMcC	CBuc	BWil
C01	12/01/21	GT COMMENTS INCORPORATED	KMcC	CBuc	BWil

DESIGNER: SWECO

CONTRACTOR: Galliford Try

CLIENT: highways england

PROJECT TITLE: A47/A11 THICKTHORN JUNCTION

PROJECT STAGE: PCF STAGE 3

DRAWING TITLE: DRAINAGE LAYOUT GENERAL LAYOUT PLAN SHEET 2 OF 6

SUITABILITY: AUTHORISED AS STAGE 3 COMPLETED

SHEET SIZE	SCALE	STATUS	REVISION
N/A	1:1250	A3	C01

DRAWING NUMBER: HE551492-GTY-HDG-000-DR-CD-30002

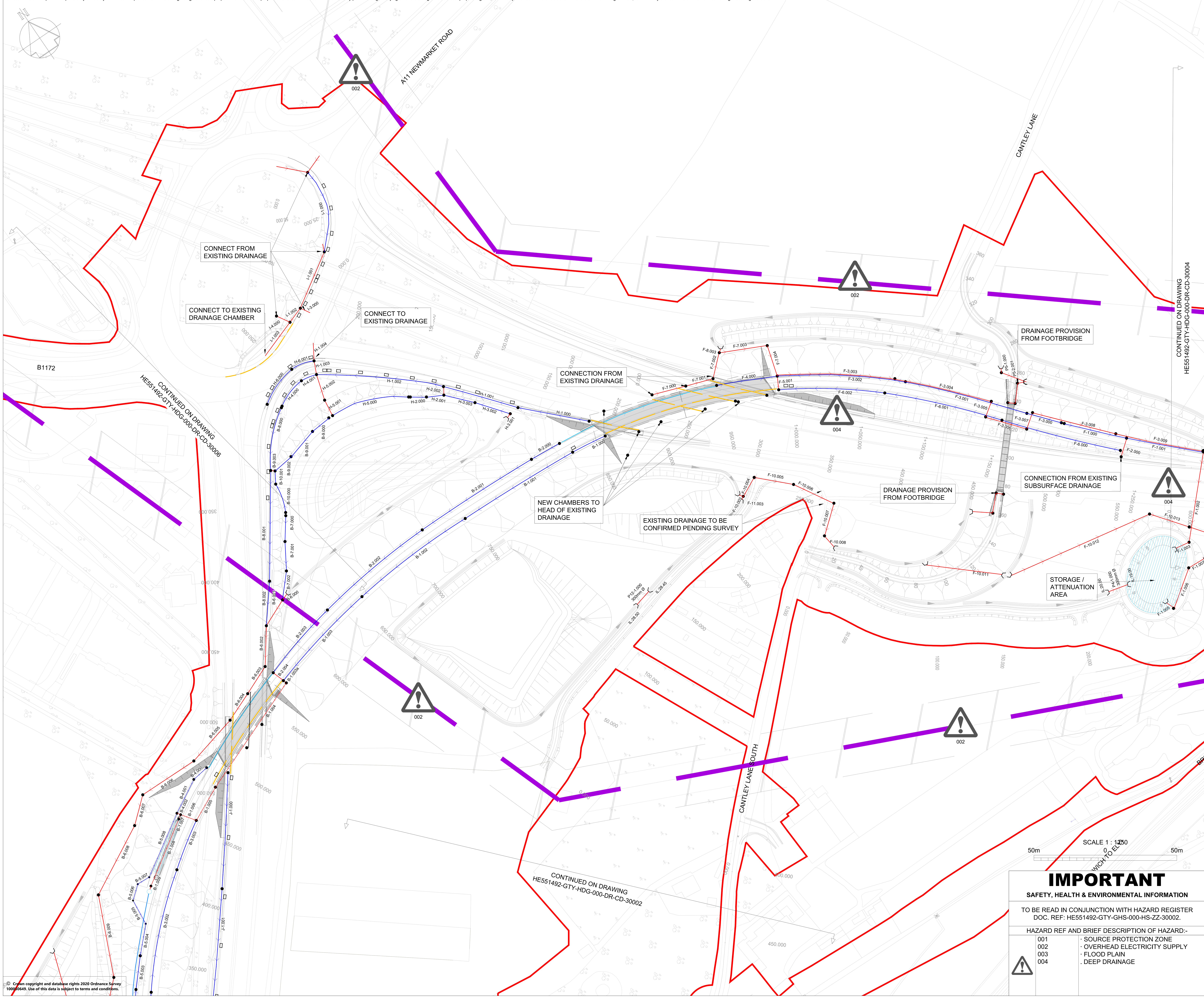
IMPORTANT

SAFETY, HEALTH & ENVIRONMENTAL INFORMATION

TO BE READ IN CONJUNCTION WITH HAZARD REGISTER DOC. REF: HE551492-GTY-GHS-000-HS-ZZ-30002.

HAZARD REF AND BRIEF DESCRIPTION OF HAZARD:-

001	· SOURCE PROTECTION ZONE
002	· OVERHEAD ELECTRICITY SUPPLY
003	· FLOOD PLAIN
004	. DEEP DRAINAGE



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- GULLY (HCD F13) & CONNECTOR
- PROPOSED HEADWALL
- BYPASS INTERCEPTORS
- PUMP SHAFT
- CULVERT/PIPE CROSSING
- PED DITCH

REV	DATE	REVISION NOTE	ORG	CHK'D	APP'D
P01	27/03/20	Design developed	SG	CB	XC
P02	30/03/20	Work in progress	SG	CB	XC
P03	11/09/20	DEISGN DEVELOPMENT	RE	CB	BA
P04	27/11/20	DRAWING UPDATED FOR DFC	CMun	CBuc	BWil
P05	12/01/21	GT COMMENTS INCORPORATED	KMcC	CBuc	BWil
C01	12/01/21	GT COMMENTS INCORPORATED	KMcC	CBuc	BWil

DESIGNER
SWECO

CONTRACTOR
Galliford Try

CLIENT
highways england

PROJECT TITLE
A47/A11 THICKTHORN JUNCTION

PROJECT STAGE
PCF STAGE 3

DRAWING TITLE
DRAINAGE LAYOUT
GENERAL LAYOUT PLAN
SHEET 3 OF 6

SUITABILITY
AUTHORISED AS STAGE 3 COMPLETED

SHEET SIZE	SCALE	STATUS	REVISION
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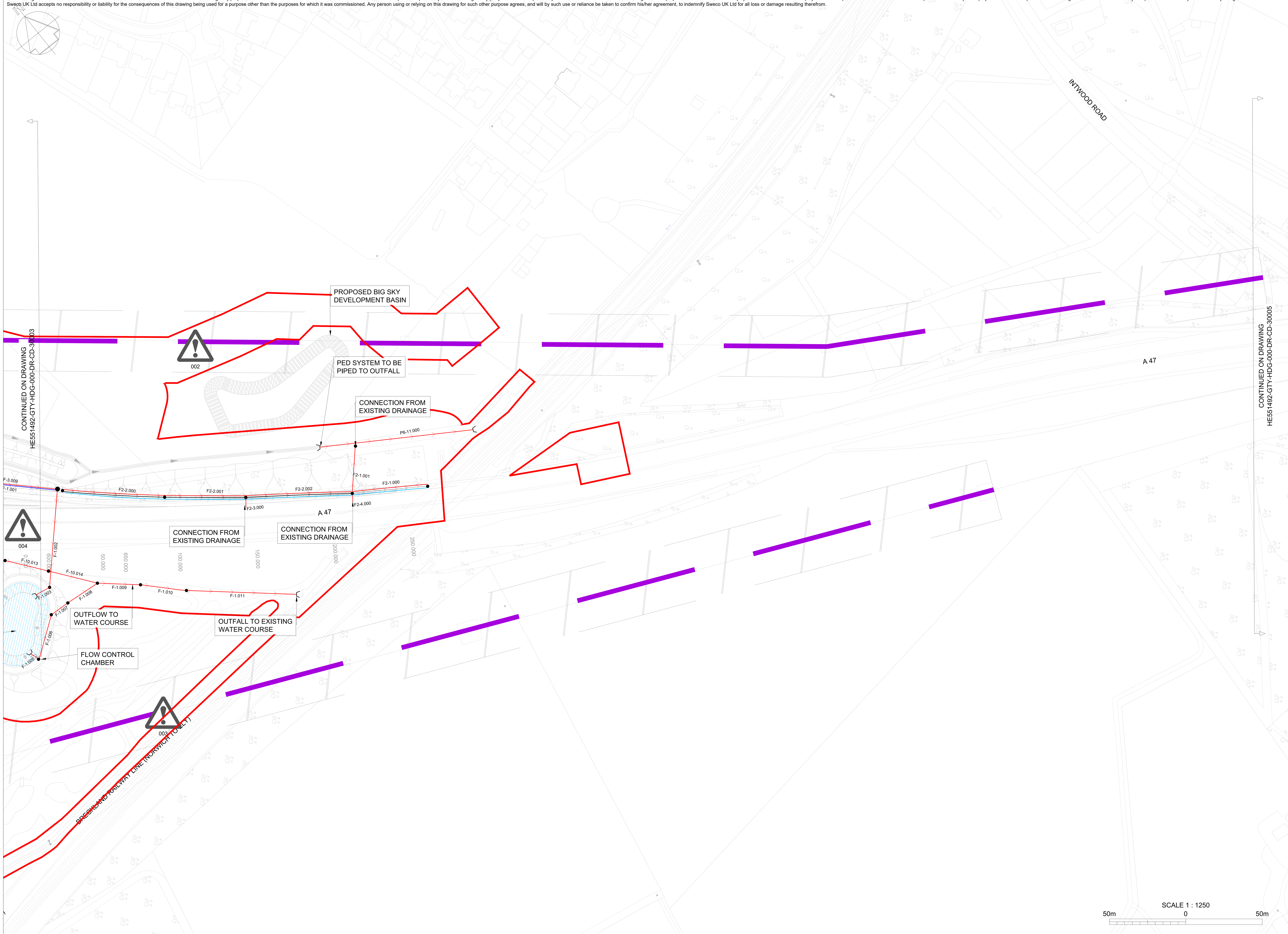
DRAWING NUMBER
HE551492-GTY-HDG-000-DR-CD-30003



SCALE 1 : 1250

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IMPORTANT

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TO BE READ IN CONJUNCTION WITH HAZARD REGISTER DOC. REF: HE551492-GTY-GHS-000-HS-ZZ-30002.

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DESIGNER

SWECO

CONTRACTOR

GallifordTry

CLIENT

highways england

PROJECT TITLE

A47/A11 THICKTHORN JUNCTION

PROJECT STAGE

PCF STAGE 3

DRAWING TITLE

DRAINAGE LAYOUT
GENERAL LAYOUT PLAN
SHEET 4 OF 6

SUITABILITY

AUTHORISED AS STAGE 3 COMPLETED

SHEET SIZE	SCALE	STATUS	REVISION
N/A	1:1250	A3	C01

DRAWING NUMBER

HE551492-GTY-HDG-000-DR-CD-30004

IMPORTANT

SAFETY, HEALTH & ENVIRONMENTAL INFORMATION

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DESIGNER

SWECO

CONTRACTOR

GallifordTry

CLIENT

highways england

PROJECT TITLE

A47/A11 THICKTHORN JUNCTION

PROJECT STAGE

PCF STAGE 3

DRAWING TITLE

DRAINAGE LAYOUT
GENERAL LAYOUT PLAN
SHEET 5 OF 6

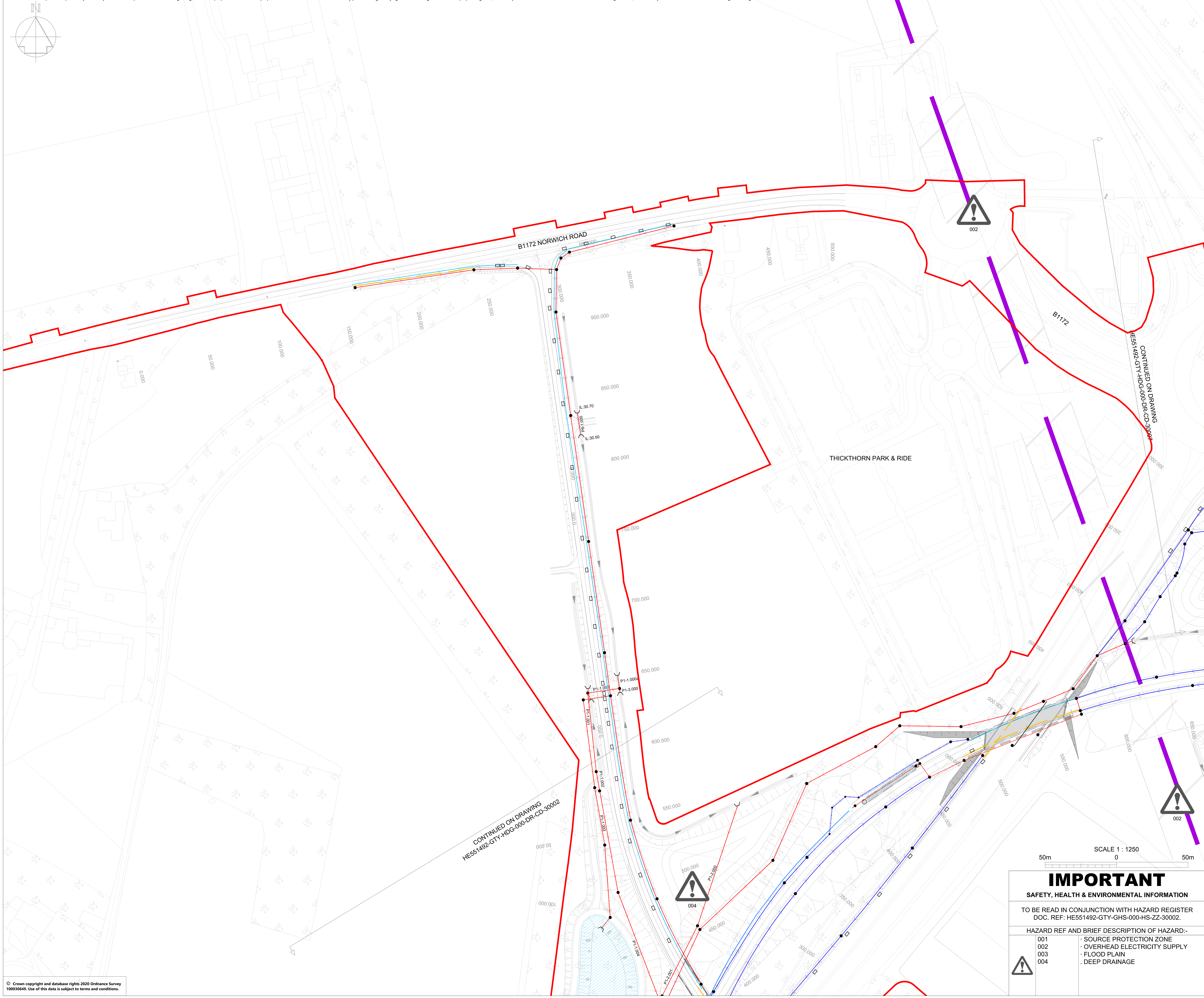
SUITABILITY

AUTHORISED AS STAGE 3 COMPLETED

SHEET SIZE	SCALE	STATUS	REVISION
N/A	1:1250	A3	C01

DRAWING NUMBER

HE551492-GTY-HDG-000-DR-CD-30005



SCALE 1 : 1250

50m 0 50m

IMPORTANT

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DESIGNER

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highways england

PROJECT TITLE

A47/A11 THICKTHORN JUNCTION

PROJECT STAGE

PCF STAGE 3

DRAWING TITLE

DRAINAGE LAYOUT
GENERAL LAYOUT PLAN
SHEET 6 OF 6

SUITABILITY

AUTHORISED AS STAGE 3 COMPLETED

SHEET SIZE	SCALE	STATUS	REVISION
N/A	1:1250	A3	C01

DRAWING NUMBER

HE551492-GTY-HDG-000-DR-CD-30006