A47 Wansford to Sutton Dualling

Scheme Number: TR010039

Volume 6
6.3 Environmental Statement Appendices
Appendix 13.1 Flood risk assessment

APFP Regulation 5(2)(a)

Planning Act 2008

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

March 2022

Deadline 3

Infrastructure Planning

Planning Act 2008

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

A47 Wansford to Sutton Development Consent Order 202[x]

ENVIRONMENTAL STATEMENT APPENDICES
Appendix 13.1 – Flood risk assessment

Regulation Number:	Regulation 5(2)(a)
Planning Inspectorate Scheme Reference	TR010039
Application Document Reference	TR010039/APP/6.3
BIM Document Reference	E551494-GTY-EWE-000-RP-LE-30008
Author:	A47 Wansford to Sutton Project Team, National Highways

Version	Date	Status of Version
Rev 0	July 2021	Application Issue
Rev 1	March 2022	Deadline 3

Table of contents

Captions

Tables

1. Introduction

1.1. Scope of work

Aims and objectives

1.1.1. This appendix supports the environmental assessment presented in ES Chapter 13 (Road drainage and water environment) (**TR010039/APP/6.1**).

1.1.2. This Flood Risk Assessment (FRA) has considered the following:

- risk of flooding (of any source) posed to the Proposed Scheme
- predicted impacts of climate change
- risk of flooding (of any source) posed by the Proposed scheme
- measures to reduce flooding risk to the Proposed Scheme
- mitigation measures required for any impacts from the Proposed Scheme

Methodology

1.1.3. 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) LA 113 Road Drainage and the Water Environment (Highways England, 2019), hereafter referred to as DMRB LA113.

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

1.1.5. 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, 2021a), Surface Water, Reservoir, River and Tidal Flood Risk (Environment Agency, 2021b)
- Historic Flood Map (Environment Agency, 2021c)
- Environment Agency data request information (Annex A)
- A47 Wansford to Sutton Dualling Drainage Strategy Report (Volume 3, Appendix 13.2) (**TR010039/APP/6.3**)

- PCF Stage 3 Environmental Scoping Report (Highways England, 2018)
- British Geological Survey GeoIndex (British Geological Survey, 2021)
- Proposed scheme design information
- Previous and ongoing strategic flood studies conducted by the Environment Agency and Local Authorities including Huntingdon District Council Strategic Flood Risk Assessment (SFRA) (JBA, 2017), Peterborough SFRA (Royal HaskoningDHV, 2018) and Peterborough Local Flood Risk Management Strategy (LFRMS) Peterborough City Council (2015).

2. Legislation, policy framework and climate change

2.1. Legislation

Flood and Water Management Act

2.1.1. The Flood and Water Management Act (FWMA) 2010 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. Peterborough City Council is the Lead Local Flood Authority (LLFA) in the area of the Proposed Scheme. The River Nene is the boundary between Peterborough City Council and Cambridgeshire County Council. Cambridgeshire County Council have been consulted on the hydraulic modelling for matters pertaining to the River Nene.

2.1.2. In 2012, various amendments were introduced to the FWMA 2010. Amongst other changes the amendments specified 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

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

2.1.4. The Act also states that if a flood occurs, 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.

Floods Directive

2.1.5. The European Floods Directive 2007/60/EC came into force in 2008 aiming to provide a consistent approach to flood risk management across all of Europe.

The Directive provides a framework for managing all sources of flood risk which take place as part of a six year cycle and requires:

- preliminary flood risk assessments
- flood risk and flood hazard maps
- flood risk management plans
- co-ordination of flood risk management at a strategic level
- improved public participation in flood risk management
- co-ordination of flood risk management with the Water Framework Directive.

2.1.6. The Flood Risk Regulations 2009 transpose the EU Floods Directive into law in England and Wales.

The Environmental Permitting Regulations

2.1.7. The Environmental Permitting Regulations (EPR) 2016, and the 2018 amendment, aims to protect groundwater and surface waters from pollution by controlling the inputs of potentially harmful and polluting substances. The Environmental Permitting (England and Wales) Regulations 2016 have been amended by the Environmental Permitting (England and Wales) (Amendment) (EU Exit) Regulations 2019 so as to continue to function after the United Kingdom leaves the EU.

2.1.8. The need for a Flood Risk Activity Permit now falls under the ERP regulations systems and replaces the Flood Defence Consents.

2.2. Policy framework

National Policy Statement for National Networks

2.2.1. 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.

2.2.2. 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

The National Planning Policy Framework

2.2.3. he 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

2.2.4. 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.

Environment Agency

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

2.2.6. 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.

2.3. Local planning policy

2.3.1. Local policies of relevance to the proposed scheme include:

- Peterborough Local Plan 2016-2036 contains the following policies relevant to flood risk:
    - Policy LP24- Nene Valley. Development which would increase flood risk, compromise the performance of flood defence or existing navigation facilities, or restrict access to such facilities will not be permitted.

- Policy LP32- Flood and Water Management. Development proposals should adopt a sequential approach to flood risk management, taking into account the requirements of the NPPF and the further guidance and advice set out in the council's Flood and Water Management SPD.
- Policy LP32- Development located in areas known to be at risk from any form of flooding will only be permitted following: The incorporation of Sustainable Drainage Systems (SuDS) into the proposals.

2.4. Climate change

2.4.1. 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."*

2.4.2. 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."

2.4.3. 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.

2.4.4. Although the majority of the Proposed Scheme is located within Flood Zone 1 it does pass through areas of Flood Zone 3. The Anglian region 'higher central', 'upper end' and 'H++' categories are 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 35%, 65% and 80% respectively. 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. Description of the Proposed Scheme

3.1. Existing site description

3.1.1. 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.

3.1.2. The Proposed Scheme is located on the single-carriageway section of the A47 the runs from the A1 in the west near Wansford to the dual-carriageway section near the village of Sutton in the east. The Proposed Scheme is largely off-line crossing to the north of the existing A47 east of the Sutton Heath Road.

3.1.3. Peterborough lies approximately 9km east of the Proposed Scheme. Beyond Peterborough, the A47 continues to Norwich and towards the east coast at Great Yarmouth. The corridor intersects with key strategic routes including the A1, A10 and A11, which provide links to other urban centres including Cambridge, Ely and London.

3.1.4. The Proposed Scheme lies adjacent to the River Nene and the Nene Valley. Arable farmland is the predominant land cover in the area, divided into relatively small agricultural enclosures interconnected by narrow rural lanes, and defined by hedgerows and ditches throughout the landscape. The fields are interspersed with fragmented patches of woodland and clusters of farms and residential settlements.

3.1.5. Elevations are highest in the west of the site near Wansford Junction at ~34m above Ordnance Datum (AOD). Elevations reduce to ~18m AOD further eastwards and then rise again towards Sutton Heath Road. The land around Sutton Heath Road rises slightly to ~24mAOD and falls steadily to ~20mAOD at Sutton.

3.2. Existing drainage

3.2.1. Highways Agency Drainage Data Management System (HA DDMS) (Highways England, 2021) provides details on the existing drainage network which is summarised below:

- The catchment draining the A1 discharges runoff via one outfall to Mill Stream and is currently classified as low pollution risk according to HA DDMS (2021).
- The catchment draining the A47 from the A1, at the west of the Proposed Scheme, to the east of Wittering Brook is drained via a cluster of 12 outfalls currently classified as low pollution risk. Both baseline assessment and

information provided on HA DDMS suggests these assets are in a catchment with soakaways and may not be outfalls. Due to this these were assessed as soakaways in 2020 (Highways England, 2021).

- The catchment draining the east of the Proposed Scheme discharges runoff from the A47 to an unnamed watercourse at the east of the Proposed Scheme, outside of the Proposed Scheme boundary. It is drained via two outfalls currently classified as very high pollution risk.
- HA DDMS also identified 12 soakaways, which are all currently classified as low pollution risk. Eight of the soakaways receive run-off from the west of the Proposed Scheme near the A1 junction and four receive run-off from east of Wittering Brook, at The Drift junction.

3.2.2. The existing drainage network, including the outfalls and soakaways identified above, require verification through drainage survey.

3.2.3. HA DDMS (Highways England, 2021) identified six previous flooding events on the existing A47 and A1 carriageway within the Proposed Scheme boundary. These are detailed in Section 4.2.3. There are no flooding hotspots recorded in HA DDMS within the Proposed Scheme boundary.

3.2.4. A number of catch-pits and gully pots were identified on HA DDMS (Highways England, 2021) to the east and west of the Proposed Scheme, within the Proposed Scheme boundary. To the west these are located along the A1 and its junction with the A47. To the east they are located where the existing A47 is a dual carriageway. No other surface water outfalls, soakaways or attenuation features were identified within the Proposed Scheme area.

3.3. Description of the Proposed Scheme

3.3.1. The Proposed Scheme comprises upgrading the existing 2.6km section of single carriageway between Wansford and Sutton to dual carriageway. The new dual carriageway would tie into the existing carriageway at the eastern roundabout at the A1 / A47 interchange and to the existing A47 dual carriageway north of Nene Way.

3.3.2. At the western end, the Proposed Scheme would also include a free flow link between the A1 southbound carriageway and the new eastbound carriageway of the A47. The existing A1/A47 eastern roundabout would be enlarged as part of the proposals. At the eastern end, the existing Nene Way junction would be removed and a new junction connecting to Sutton Heath Road and the existing A47 proposed.

3.3.3. As part of the overall proposal, associated side road alterations and walking, cycling and horse-riding connections along the length of the Proposed Scheme are proposed.

3.4. Existing hydrology and hydrogeology

Hydrological setting

3.4.1. The River Nene is the main river located within the study area and is located to the south of the Proposed Scheme. It flows in an easterly direction adjacent to, but outside of, the Proposed Scheme boundary until its confluence with Wittering Brook, it then proceeds to flow south.

3.4.2. A flow gauging station is located to the east of the A1 on the River Nene (32010 - Nene at Wansford), where the Q95 was identified as 2.9 m^3/s (National River Flow Archive, 2021a)

3.4.3. Wittering Brook, an ordinary watercourse, is located west of Sutton Heath Road and flows in a southerly direction through Sutton Heath Bog Site of Special Scientific Interest (SSSI) and under the existing A47 before its confluence with the River Nene. There are five drainage ditches located adjacent to Wittering Brook, one of these drains into Wittering Brook, one feeds a pond and the remaining ditches feed into an ordinary watercourse which is a tributary of Wittering Brook. This ordinary watercourse originates from the north-east, flows under the Proposed Scheme at Sutton Heath Road before its confluence with Wittering Brook.

3.4.4. A flow gauging station was located near the River Nene confluence on Wittering Brook (32020 – Wittering Brook at Wansford), where the Q95 was identified to 0.091 m3/s (National River Flow Archive, 2021b). The gauging station is now closed

3.4.5. Mill Stream, an ordinary watercourse, is located approximately 0.3km north of the A47. It flows in an easterly direction, passing through the Proposed Scheme boundary where it flows beneath the A1. It then flows through a large mill pond before joining Wittering Brook at the upstream end of Sutton Heath and Bog SSSI.

3.4.6. An unnamed watercourse is located at the east of the Proposed Scheme, outside of the Proposed Scheme boundary but within the study area. It flows in a southerly direction beneath the existing A47 and then flows for approximately 2km before its confluence with the River Nene.

3.4.7. Numerous ponds are present within the vicinity of the Proposed Scheme. Two ponds are located within the construction area of the Proposed Scheme, to the west of Upton Road (south of the Proposed Scheme) and west of Wittering Brook (north of the Proposed Scheme).

3.4.8. Both the main river and ordinary watercourses identified above would be impacted by the works.

3.4.9. An Anglian Water pumping station is located east of Wansford Junction which abstracts water from the River Nene. Water is conveyed (untreated) to Rutland Water.

Hydrogeological setting

3.4.10. The designated aquifers present within the study area briefly comprise:

- the Lincolnshire Limestone Formation Principal Aquifer, which is found along the A1 and the western half of the A47, as well as a small area to the west of the Sutton Heath Road junction – Principal Aquifers are layers of rock or drift deposits with high permeability which, therefore, provide a high level of water storage and baseflow to rivers
- the Grantham Formation Secondary (undifferentiated) Aquifer is present adjacent to the Lincolnshire Limestone Formation, to the west of the Sutton Heath Road – Secondary undifferentiated Aquifers are rock types of varying permeability that may only store and yield limited amounts of groundwater or may be capable of supporting local water supplies.
- alluvium and river terrace deposits Secondary A Aquifers are found along the course of the River Nene and Wittering Brook – these can provide locally important water resources and may support baseflow to rivers.
- the Rutland Formation Secondary B Aquifer is present at the eastern extents of the A47 – Secondary B Aquifers are lower permeability layers of rock or drift deposits which may store and yield limited amounts of groundwater

3.4.11. The Lincolnshire Limestone Formation Principal Aquifer was found to be mostly unsaturated beneath the Proposed Scheme during the 2018 ground investigation, with groundwater levels recorded at the top of the underlying Grantham Formation. It is highly permeable, however, and springs issue from the contact point between the Lincolnshire Limestone Formation and the underlying Grantham Formation. It is likely that the springs locally control groundwater levels. The springs flow towards either the Mill Stream, Wittering Brook or the River Nene (via superficial deposits beneath the River Nene). Groundwater modelling undertaken by the Environment Agency highlights that in the areas around Mill Stream and Wittering Brook, groundwater levels are close to ground level, and that the Mill Stream and Wittering Brook both receive groundwater baseflow. Further away from the watercourses, such as within the

Sutton Heath and Bog SSSI, groundwater modelling indicated a downwards groundwater flow direction within the Lincolnshire Limestone Formation.

3.4.12. Groundwater monitoring data was collected between September 2018 and January 2019 and also between September 2020 and February 2021. During this period groundwater levels ranged between of 0.00m below ground level (bGL) at BH01A and 8.6m bGL at BH16. BH01A is located adjacent to the A1 carriageway and Mill Stream in the north-west of the study area of the Environmental Statement. Groundwater monitoring also shows that groundwater flow is predominantly towards the south and the River Nene.

3.4.13. The Proposed Scheme is within a groundwater Nitrate Vulnerable Zone (NVZ) associated with the Lincolnshire Limestone and the Rutland Formation.

3.4.14. Further details of the hydrogeology of the study area are contained in Volume 1 of the Environmental Statement Chapter 13 (Road drainage and water environment) (**TR010039/APP/6.1**) and in Volume 3, Appendix 13.4 Groundwater assessment (**TR010039/APP/6.3**).

3.4.15. A Groundwater Source Protection Zone (SPZ) 2 (Outer Protection Zone) is present approximately 1km north of the A47, cutting across the Sutton Heath Road.

3.5. Summary of consultation

3.5.1. The Environment Agency, Anglian Water and Peterborough City Council (as Lead Local Flood Authority (LLFA)) responded to the PCF Stage 3 EIA Scoping Report (Highways England, 2018) via the Planning Inspectorate. Their responses relevant to flood risk (supported by Cambridgeshire County Council due to their additional expertise with flooding), which were documented in the Scoping Opinion (Planning Inspectorate, 2018) are summarised below.

- There are existing water mains within the Proposed Scheme boundary of the site which potentially could be affected by the Proposed Scheme. It is therefore suggested that the Environmental Statement should include reference to existing water mains as well as the Wansford Anglian Water pumping station. Anglian Water would also wish to be consulted on the content of the proposed FRA if a connection to the public sewerage network is required.
- The FRA will need to confirm that there will be no loss of floodplain as a result of the Proposed Scheme and provide details on how this can be achieved on a volume for volume basis.

- The Environment Agency have a river level monitoring station present between the Proposed Scheme and the River Nene, adjacent to Wansford Anglian Water pumping station. The FRA would need to ensure that this is not affected at any point during the works. The FRA will also need to consider the design of the surface water management network for the Proposed Scheme.
- Flood Risk Activity Permit - Under the terms of the Environmental Permitting Regulations 2016 (as amended), a Flood Risk Activity Permit or exemption may be required for any proposed works or structures, in, under, over or within 8 m of the River Nene designated a 'Main River'.

3.5.2. Peterborough City Council were consulted on the proposed methodology for flood modelling in May 2020 and their advice was incorporated into the subsequent assessments. It was agreed a simple approach to hydraulic assessment of the existing and extended culverts would be undertaken for the A1 Mill Stream culvert.

3.5.3. The Environment Agency were consulted in 2018, then again in 2020 and 2021. Relevant comments made in 2018 consultation are provided below:

- Any loss of floodplain should be compensated for on a level for level, volume for volume basis (that is, re-grade the land at the same level as that taken up by the development) therefore providing a direct replacement for the lost storage volume. The location of any compensation works must relate hydraulically and hydrologically to the location of the site, and excavation of the compensation must be complete before infilling commences.
- For discharge into the River Nene (Main River), the discharge rate will be based on the calculated pre-development (greenfield) runoff rate for the site. For a simple control structure this will be based on the QBAR rate. Complex discharge controls should reflect the original discharge or run-off rates from the site across the range of storm events.

3.5.4. The Environment Agency were consulted on the impacts on the WFD in relation to the culverting proposed on Wittering Brook and Mill Stream in November 2020. They noted the following:

- Wittering Brook A47 Wansford Sluice should be opened up, replacing the old culvert as well, to allow full mammal access
- if throttling of the flow was required then the flow should be attenuated upstream using natural flood management techniques

3.5.5. The Environment Agency and Peterborough City Council were further consulted in November 2020 to discuss flood risk and WFD. They noted the following:

- removing the throttle was agreed to be the preferred option as the model demonstrates it was not impacting the flow and therefore had minimal impact downstream

  the Environment Agency Lower Nene model was used and revised with new climate change allowances to 35% to estimate the design flood level to calculate flood compensatory storage volumes

3.5.6. Peterborough City Council were consulted again in March 2021 via Cambridgeshire County Council to review the Wittering Brook hydraulic report and assessment. Cambridgeshire County Council confirmed they would not raise any objection to the proposed culvert option but have requested more information regarding the detriment across the floodplain of Wittering Book during the 10% AEP event so the impacts can be fully understood.

3.5.7. The Environment Agency were consulted again in March 2021 to review the River Nene flood compensation and the Wittering Brook hydraulic model and report. The Environment Agency stated they were satisfied in principle with the proposals for floodplain compensation for the River Nene. Overall, the Environment Agency accepted the findings of the hydraulic model and report, however they also required additional information:

- the origin of the 1 in 50 year stage used in one of the sensitivity tests at the downstream boundary of the Wittering Brook model was queried.
- whether any flows from the River Nene could have any impacts upstream in Wittering Brook with the proposed A47 Wansford Sluice was also queried.
- further justification, beyond being a conservative approach, for the use of ReFH 2.3 was requested.

3.5.8. The queries are addressed within the FRA and the hydraulic modelling report (Annex B). The Environment Agency and the LLFA accepted the findings of the modelling.

4. Sources of potential flooding

4.1. Overview

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

- fluvial (rivers) and tidal
- pluvial (surface water)
- risk of flooding from sewers
- risk of flooding from reservoirs
- groundwater

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

4.1.3. The tidal limit for the River Nene is located approximately 23 km downstream at the Dog in a Doublet Sluice. The site is not subject to tidal waters and therefore is considered to be not at risk of tidal flooding.

4.2. Historical flooding

4.2.1. The Environment Agency's Historic Flood Map (Environment Agency 2021c) indicates land associated with the River Nene and its floodplain, south of the Proposed Scheme, as an area of historic flooding within the Proposed Scheme boundary and study area. This is in agreement with both Huntingdon District Council SFRA (JBA, 2017) and Peterborough SFRA (Royal HaskoningDHV, 2018).

4.2.2. In April 1998 heavy rain led to saturated ground and excessive surface water runoff. Levels in the River Nene were very high, with the flood flow peak at Wansford being approximately 200 m^3/s. During this event 18 homes were flooded from the River Nene in a variety of locations and many roads across Peterborough were flooded from surface water (Peterborough City Council, 2015).

4.2.3. HA DDMS (Highways England, 2021) identified six previous flooding events on the existing A47 and A1 carriageway within the Proposed Scheme boundary. The flooding is classified in terms of severity based on road type, extent of closure, traffic flow and duration of closure and ranges from zero to ten (Highways England, 2021). Three of these historic instances were identified to be of medium severity and three low severity:

- One low severity flood event on 26 June 2020 where possible flooding across both carriageways of the A47, east of the A1 junction, was reported. No details of the flood event were provided.
- One low severity flood event on 17 October 2009 where the main carriageway of the A47, east of the A1 junction was flooded. Notes on HA DDMS indicate this was due to water flooding in a toilet area which spread. No further details of the flood event were provided.
- One low severity flood event on the 6 August 2009 where surface water flooding was observed across both carriageways of the A47, east of the A1 junction.
- One medium severity flood event on the 23 February 2020 where "a 15ft long and 1ft deep puddle of standing water" was observed in lane 1 of the A1, north of the A47 junction.
- One medium severity flood event on 9 March 2016 where surface water was observed running from fields causing flooding on lane 1 and going onto lane 2 of the A47, west of Sutton Drift.
- One medium severity flood event 30 November 2012 where flooding was observed across bridge deck of the A1, north of the A47 junction. This was identified as an Anglian Water burst water main.

4.3. Fluvial flood risk

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

4.3.2. The Proposed Scheme crosses three watercourses: Wittering Brook, a tributary of Wittering Brook and Mill Stream and encroaches into the floodplain of the River Nene and Wittering Brook.

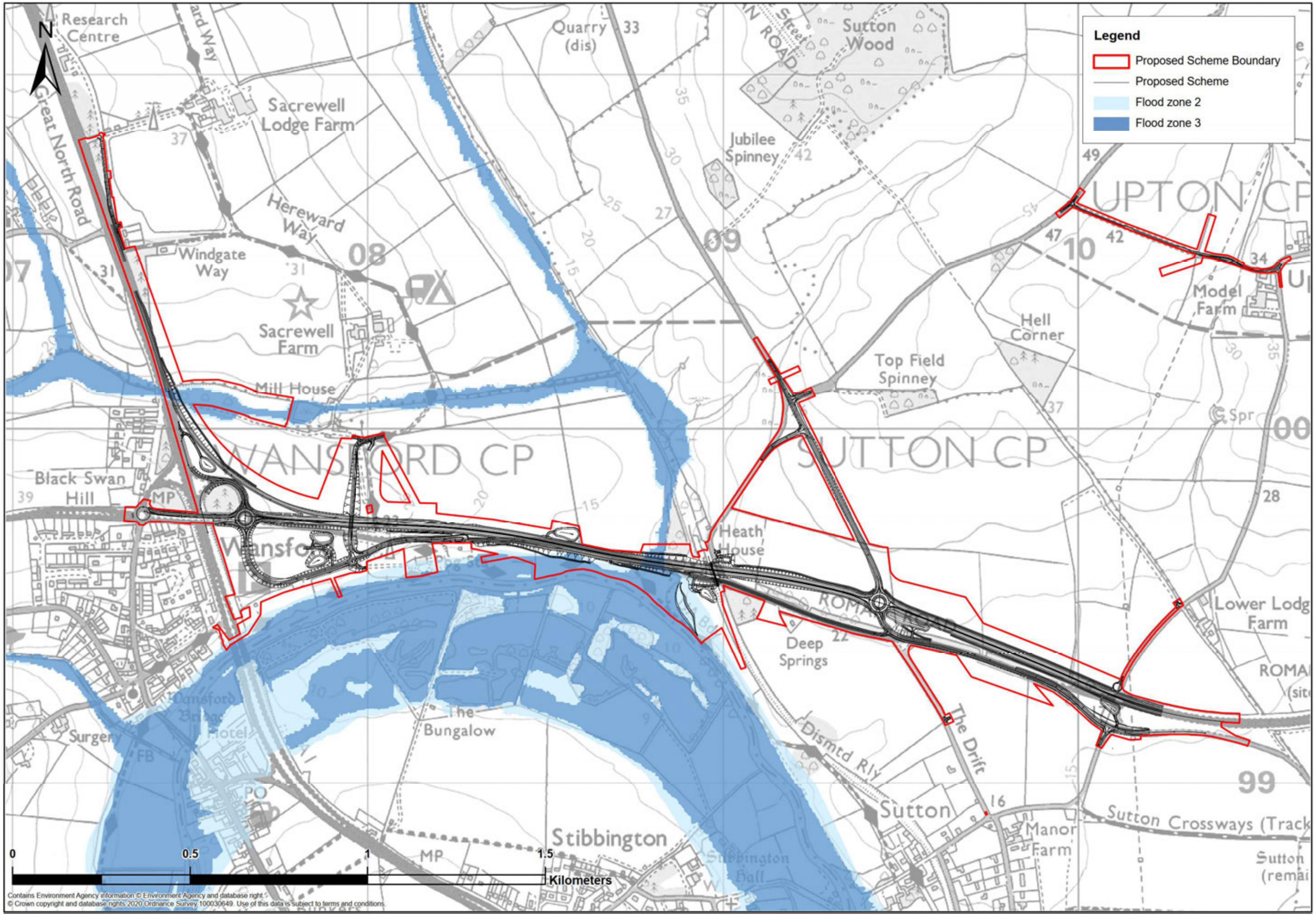
4.3.3. According to the Environment Agency's flood map for planning (Environment Agency, 2020a), the majority of the Proposed Scheme is located within Flood Zone 1. This can be seen in Caption 4.1. Flood Zone 1 is associated with a low risk of flooding from fluvial sources (an annual probability of less than 1 in 1,000 (0.1%) of river flooding).

4.3.4. The land immediately surrounding the River Nene, Wittering Brook and Mill Stream is primarily designated as Flood Zones 2 and 3 (Environment Agency, 2021a). The Proposed Scheme crosses three sections of Flood Zone 2 and 3 where the A1 crosses Mill Stream, where the A47 crosses Wittering Brook and immediately to the west of this crossing. In these locations, the A1 and A47 are elevated above the floodplain. The Proposed Scheme runs adjacent to Flood Zones 2 and 3 associated with the River Nene.

4.3.5. Huntingdon District Council SFRA (JBA, 2017) and Peterborough SFRA (Royal HaskoningDHV, 2018) identifies the land surrounding the River Nene to be Flood Zone 3b. Flood Zone 3 associated with both Wittering Brook and Mill Stream are identified to be within Flood Zone 3a:

- Flood Zone 3a comprises of land assessed as having a 1 in 100 or greater annual probability of river flooding; or land having a 1 in 200 or greater annual probability of sea flooding.
- Flood Zone 3b comprises as land where water has to flow or be stored in times of flood.

4.3.6. According to the Environment Agency's flood map for planning (Environment Agency, 2021a) there are no flood defences, areas benefitting from defences or flood storage areas within the Proposed Scheme area.



Caption 4-1 - Proposed Scheme and the Environment Agency Flood Zones

*Contains OS data © Crown copyright and database right 2020 and contains Environment Agency information © Environment Agency and/or database right.

Hydraulic modelling

Wittering Brook

4.3.7. Hydraulic modelling has been undertaken to characterise both the existing and the proposed Scheme flooding conditions of Wittering Brook and the respective floodplain. The 1D and 2D model was built using InfoWorks Integrated Catchment Modelling (ICM, Version 10). Detailed model results can be found in Annex B.

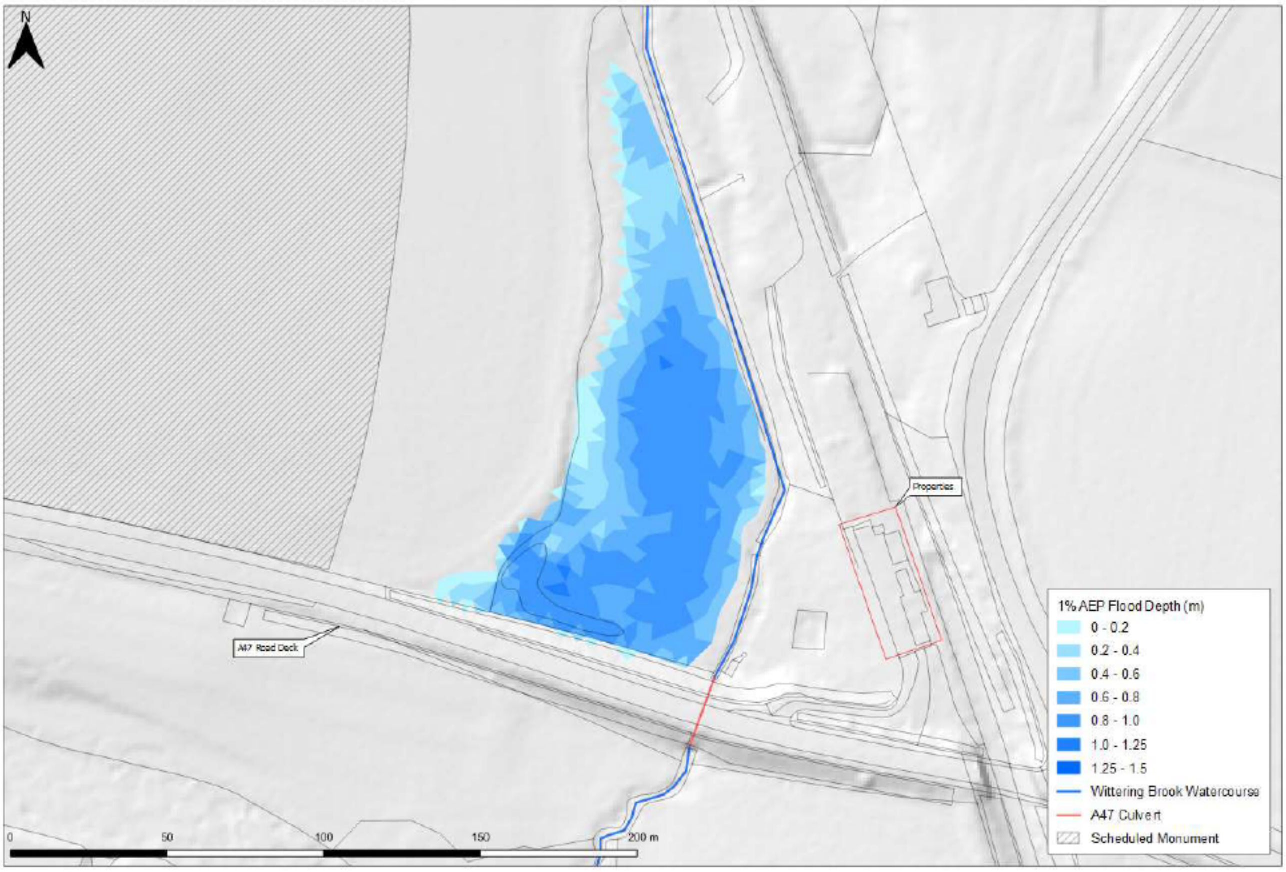
4.3.8. The Environment Agency's Flood Zones and the site-specific hydraulic modelling confirmed that the embankment for the Proposed Scheme west of Wittering Brook encroaches onto the existing Flood Zones 2 and 3.

4.3.9. As stated in paragraph 2.4.4, the PPG climate change allowance for fluvial flood risk with an anticipated projection for 2080s is a 35%, 65% and 80% increase in peak river flows respectively.

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

- 1 in 10-year event (10% annual exceedance probability (AEP))
- 1 in 100-year event (1% AEP)
- 1 in 100-year event plus 35% climate change
- 1 in 100-year event plus 65% climate change
- 1 in 100-year event plus 80% climate change

4.3.11. For the 1 in 100-year event (Caption 4.2), flooding remains exclusively within the Wittering Brook floodplain located north-west of the A47 Wansford Sluice. The 1 in 100-year event shows water rising up the north side of the A47 embankment; however, flows do not overtop the A47 road deck. There is no out of bank flow over the left bank and the properties to the north-east of the A47 Wansford Sluice are not predicted to flood. Flow is throttled by the A47 Wansford Sluice and remains in-bank south of the A47 before discharging to the River Nene.



Caption 4-2 - The 1 in 100-year event flood map.

* Contains OS data © Crown copyright and database right 2020 and contains Environment Agency information © Environment Agency and/or database right.

4.3.12. Table 4.1 shows the maximum flood depths, flood volumes and flooded area recorded in the 2D domain. The model predicts that climate change uplift increases flood depths, flooded area and volume in the 2D model domain and Wittering Brook floodplain.

Table 4-1 - Predicted maximum flood depth, flooded area and flooded volume

	1 in 10-year event	1 in 100-year event	1 in 100-year event (35% climate change)	1 in 100-year event (65% climate change)	1 in 100-year event (80% climate change)
Maximum Depth (m)	0.60	1.00	1.27	1.51	1.60
Maximum Flooded Area (m^2)	6567	8153	8942	10566	11069
Maximum Flooded Volume (m^3)	2156	5226	7438	9705	10406

A1 Mill Stream culvert extension

4.3.13. An analysis of the A1 culvert was carried out using HY-8 v7.70.1.0 (Federal Highway Administration, 2021). This simple assessment was agreed with Peterborough City Council (Section 3.5). Survey data was used to define the software input parameters such as channel dimensions, roadway data and culvert data. The culvert consists of a 2.05m diameter concrete pipe followed by a 2.15m diameter corrugated steel pipe extension. The concrete pipe had become silted up over time, the full length of the culvert is 40.60m. It was assumed that flows would be throttled by the smaller diameter concrete pipe at the upstream end and as such the concrete pipe has been modelled for the full length of the culvert, this is considered a conservative representation.

4.3.14. The following summer storm peak flows were modelled, the results of which can be seen in Table 4.2:

- 1 in 2-year event (50% AEP)
- 1 in 10-year event (10% AEP)
- 1 in 100-year event (1% AEP)
- 1 in 100-year event with a 35% allowance for climate change
- 1 in 100-year event with a 65% allowance for climate change

Table 4-2 - Results from the HY-8 culvert analysis

Event	Peak Culvert Flow (m^3/s)	Headwater Depth (m)	Tailwater Depth (m)
QMED	0.78	0.86	0.44
1 in 10 year	1.64	1.16	0.66
1 in 100 year	4.39	1.83	1.08
1 in 100 year + 35%	5.56	2.09	1.21
1 in 100 year + 65%	6.57	2.32	1.31

4.4. Pluvial (surface water) flood risk

4.4.1. Ground becomes saturated during extreme rainfall leading to overland flow that follows topological features and accumulates in low lying ground and along barriers. Saturated ground conditions can also surcharge drains and sewers which are then unable to convey surface water away.

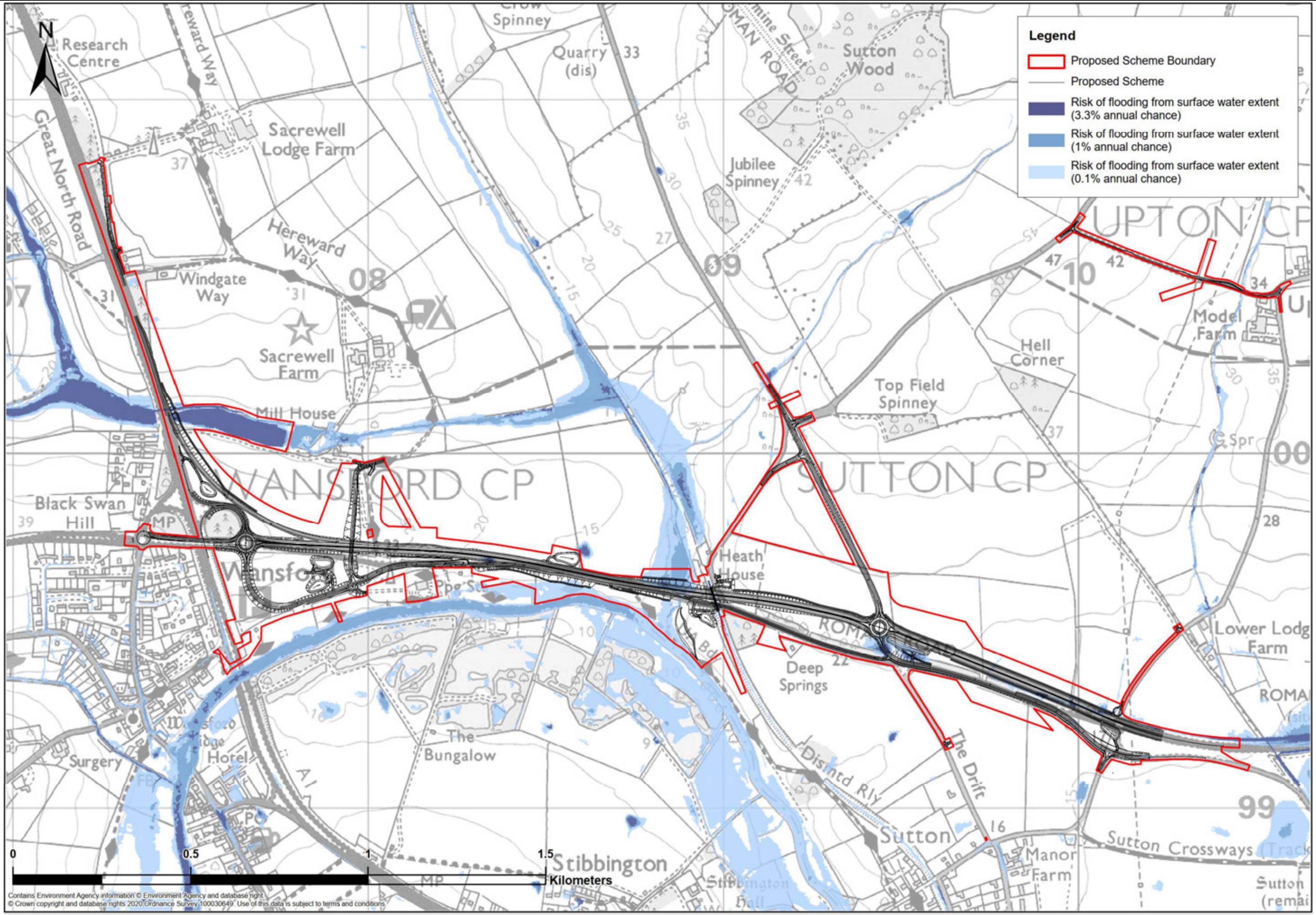
4.4.2. The Environment Agency's indicative long-term flood risk map (Environment Agency, 2021b) shows that the majority of the Proposed Scheme is at very low risk of surface water flooding (see Caption 4.3). However, there are areas of low to high risk of surface water flood risk. These are classified by the Environment Agency as:

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

4.4.3. The Proposed Scheme crosses areas of low to high surface water flood risk; where the A1 crosses Mill Stream (up and downstream of the culvert), where the A47 crosses Wittering Brook, to the west of the existing culvert, and where Sutton Heath Road crosses an unnamed ordinary watercourse. Ponding is identified within the permanent construction area of the Proposed Scheme to the west of Wansford Sluice and at the proposed Sutton Heath Road roundabout.

4.4.4. Isolated areas of low to high flood risk associated with surface water flow pathways are identified along the Proposed Scheme. East of the A47 Wansford Sluice a flow pathway is identified which runs in a northerly direction. East of the Sutton Heath Road roundabout flow pathways are identified which drain in an easterly direction towards an unnamed watercourse at the east of the Proposed Scheme, outside of the Proposed Scheme boundary.

4.4.5. Land within the immediate vicinity of the River Nene is at low to medium surface water flood risk with small sections of high risk. Elevated areas of medium to high surface water flood risk are located at the eastern extents of the Proposed Scheme area which appear to be associated with localised ponding.



Caption 4-3- Proposed Scheme and the surface water flood risk extent.

* Contains OS data © Crown copyright and database right 2020 and contains Environment Agency information © Environment Agency and/or database right.

4.4.6. Flooding from direct surface water runoff occurs early in any given rainfall event due to a fast response of impermeable runoff, it is therefore likely to have receded prior to the onset of any significant flooding from the watercourses. On this basis there is unlikely to be any significant cumulative effect due to combined flooding from direct rainfall runoff and from the watercourse that would not already be accounted for in the flood risk from rivers analysis discussed previously. Although negligible, there is a residual surface water flood risk from a combined event. There is likely to be sufficient elevation between the A47 road deck and the Wittering Brook surface water flood flow pathway to avoid any significant impact to receptors. However, climate change influences are likely to increase surface water flood risk to the Proposed Scheme due to increasing rainfall intensity. Highway drainage is designed to account for an increase in rainfall intensity due to climate change, therefore, flood risk from the rivers will be the dominant source of flood risk to the Proposed Scheme with additional effects from direct runoff likely to be negligible.

4.5. Risk of flooding from sewer or water supply infrastructure failure

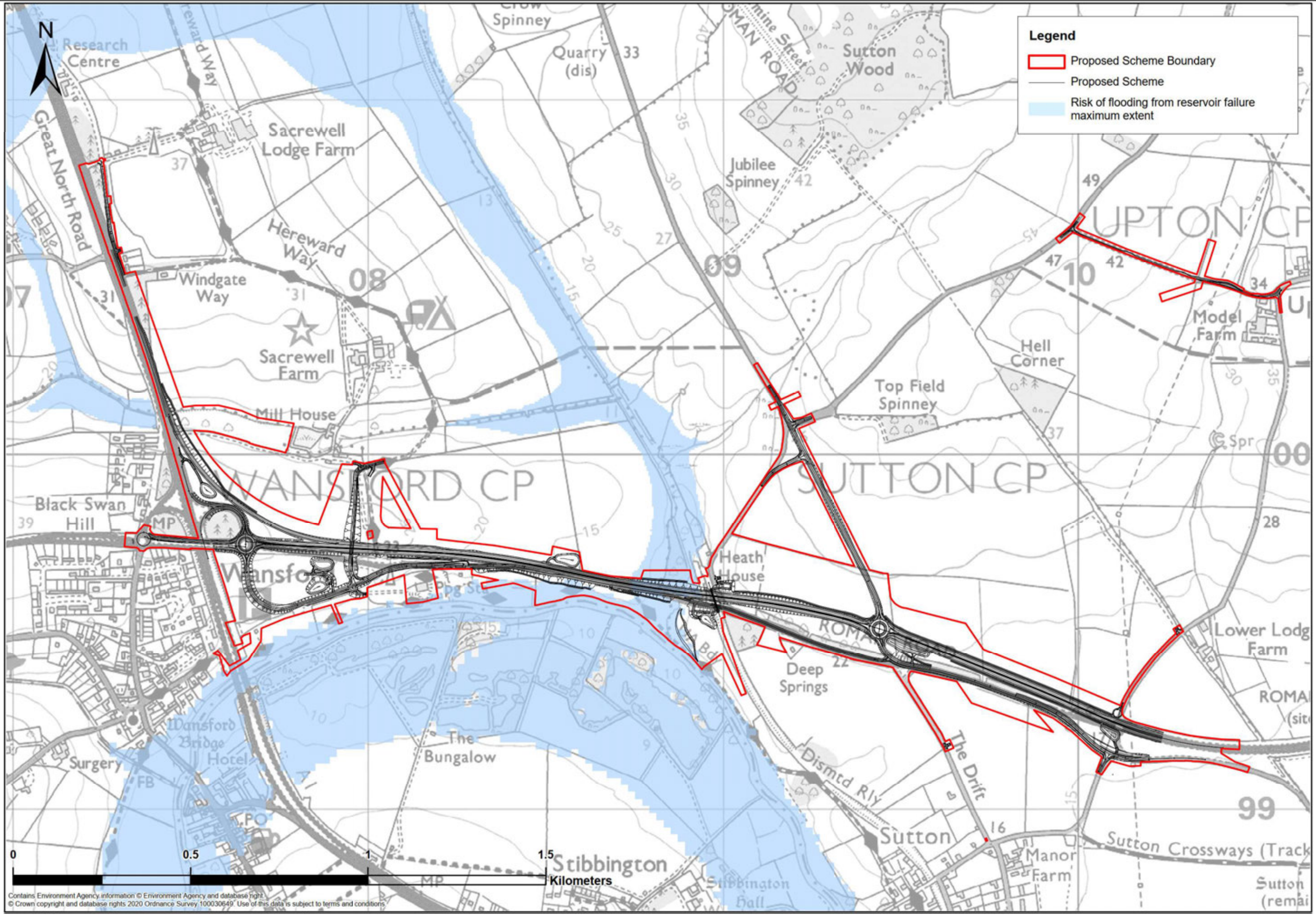
4.5.1. Peterborough SFRA (Royal HaskoningDHV, 2018) identifies one foul water sewer within the Proposed Scheme boundary associated with the housing estate to the west of the A1. The SFRA indicated there have been two instances of flooding within the postcode area to the east and south-east of Wittering Brook and 7 to the west. However, it is unclear where the exact location of sewer flooding occurred. Anglian Water confirmed there are no records of flooding in the vicinity that can be attributed to capacity limitations in the public sewerage system.

4.5.2. The medium severity flooding event identified by HA DDMS (Highways England, 2021) in Section 4.2 occurred due to a burst water main flowing across the carriageway. Other than this one event, the carriageway of the Proposed Scheme has historically not been known to flood as a consequence of water infrastructure.

4.5.3. Based on the above information, the overall risk of flooding from sewer or water supply infrastructure failure are considered low.

4.6. Risk of flooding from reservoir failure

4.6.1. The Environment Agency’s indicative flood risk map (Caption 4.4 - Environment Agency, 2020b) shows the maximum extent of flooding as a result of the reservoir dam wall breaching and inundating the surrounding area.



Caption 4-4- Proposed Scheme and the Environment Agency risk of flooding from reservoirs map

*Contains OS data © Crown copyright and database right 2020 and contains Environment Agency information © Environment Agency and/or database right.

4.6.2. The Environment Agency's indicative flood risk map (Environment Agency, 2020b) shows that there is risk of flooding from reservoirs where the Proposed Scheme crosses Mill Stream, Wittering Brook and adjacent to the River Nene. In the event of a reservoir breach, flood flows would be expected to be rapid with a high energy, resulting in an elevated risk of erosion and scour. The sources of flooding are White Water Reservoir situated approximately 7.6km upstream of the Proposed Scheme and a small unnamed reservoir located immediately east of the A1, 500m north of the Proposed Scheme boundary. Flood flow energies are likely to be reduced by the time floodwaters reach the Proposed Scheme.

4.6.3. The Environment Agency's indicative flood risk map (Environment Agency, 2020b) shows the maximum extent of flood should reservoirs be breached and shows the largest area that might be flooded if a reservoir were to fail and release the water it holds. Since this is a prediction of a credible worst-case scenario, it's unlikely that any actual flood would be this large.

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

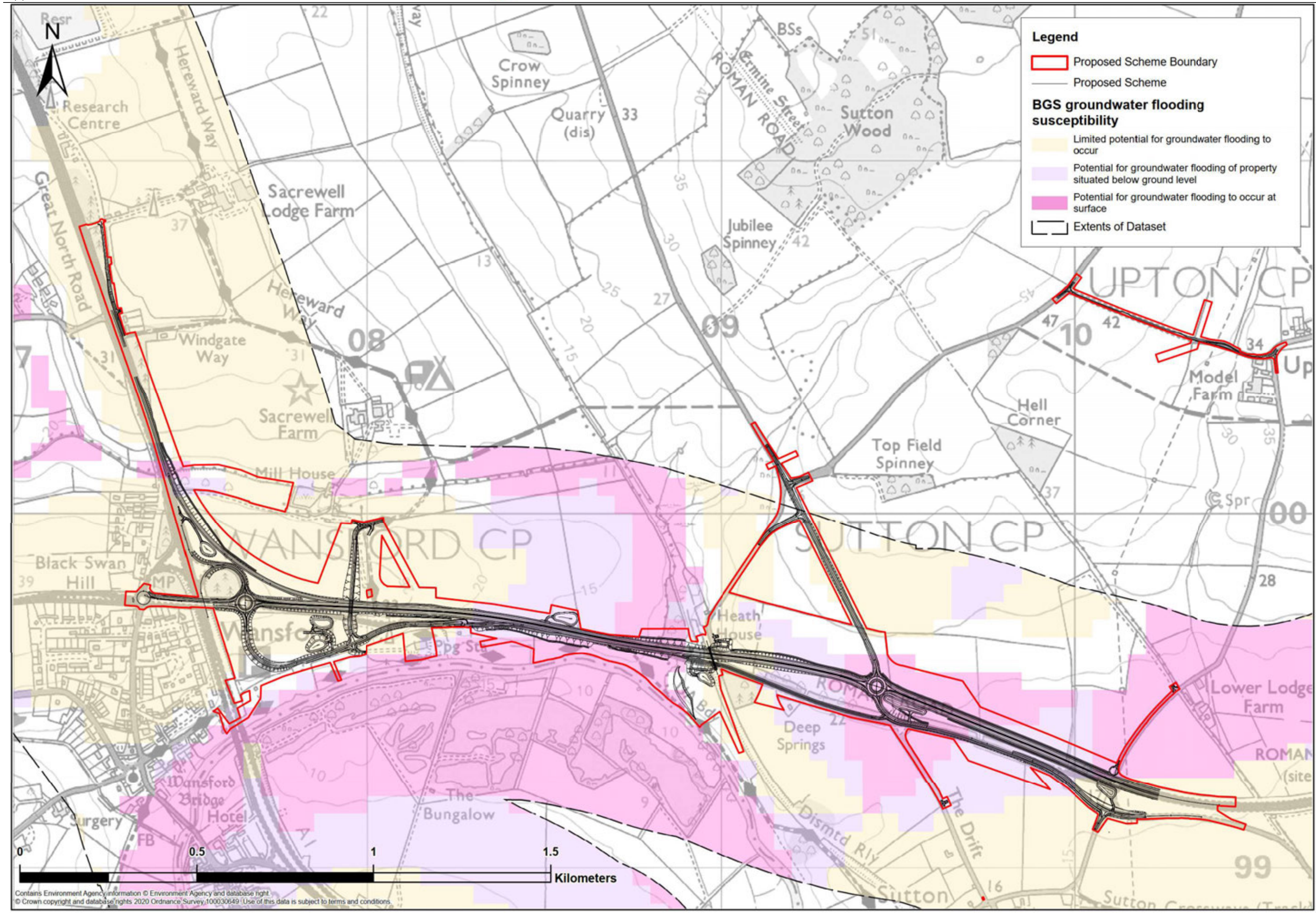
4.7. Groundwater flood risk

4.7.1. British Geological Survey (BGS; British Geological Survey, 2020) provides information on groundwater flooding susceptibility for the area encompassing the Proposed Scheme (as shown in Caption 4.5). Most of the site to the east of Wansford East Roundabout is susceptible to groundwater flooding of properties situated below ground level. In addition, several areas are susceptible to groundwater flooding at surface, generally coincident with the location of watercourses (Wittering Brook, Mill Stream and the River Nene).

4.7.2. There are no records of groundwater flooding within the vicinity of the site.

4.7.3. The climate change projections for groundwater suggest that the overall annual recharge volumes for groundwater are to remain constant, 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).

4.7.4. Groundwater monitoring data (Section 3.4) confirms that there is a risk of groundwater flooding occurring at the surface within the vicinity of Mill Stream in the north-west of the study area, and in the vicinity of Wittering Brook and River Nene in the middle of the study area, where groundwater levels are shallow and likely provide baseflow. 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.



Caption 4-5- The Proposed Scheme and BGS groundwater flooding susceptibility.

*Contains OS data © Crown copyright and database right 2020 and contains Environment Agency information © Environment Agency and/or database right.

4.8. Summary of existing flood risk to the development

4.8.1. The Environment Agency flood map for planning and SFRA identifies sections of the Proposed Scheme as being located within Flood Zone 3a and 3b. The Proposed Scheme crosses Flood Zone 3a associated with both Wittering Brook and Mill Stream. Flood Zone 3b associated with the River Nene encroaches the Proposed Scheme west of Wittering Brook. However, the majority of the Proposed Scheme is within Flood Zone 1.

4.8.2. A detailed hydraulic model assessment of Wittering Brook confirmed that under baseline conditions water rises up the north side of the A47 embankment (under 1 in 100-year event conditions). However, flows do not overtop the A47 carriageway. There is no out of bank flow over the left bank and the properties to the north-east of the A47 Wansford Sluice are not predicted to flood. Flow appears to be throttled by the A47 Wansford Sluice and remains in-bank south of the A47 before discharging to the River Nene. The existing A47 Wansford Sluice (1.83m x 1.64m) was modelled for the 1 in 100-year plus 65% climate change which indicated the maximum predicted depth to be 1.64m both upstream and downstream of the culvert. The risk of **fluvial** flooding is considered to be high but only towards the base of the road embankments. The carriageway and the road users are at low risk of fluvial as they are elevated above Flood Zone 3.

4.8.3. The Proposed Scheme is at no risk of **tidal** flooding due to the distance from any tidal effects on the River Nene.

4.8.4. 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, with significant high risk areas being observed up and downstream of the A1 culvert, upstream and to the west of the A47 Wansford Sluice and where Sutton Heath Road crosses an unnamed ordinary watercourse.

4.8.5. Since flooding from direct surface water runoff occurs early in any given rainfall event, it is likely to have receded prior to the onset of any significant flooding from the watercourses. On this basis there is unlikely to be any significant cumulative effect due to combined flooding from direct runoff and from the watercourse that would not already be accounted for in the flood risk from rivers analysis discussed previously. As a result, flood risk from the rivers will be the dominant source of flood risk to the Proposed Scheme with additional effects from direct runoff likely to be negligible. There are isolated surface water flow pathways which are defined as low to high risk. However, the majority of the Proposed Scheme is defined as very low risk.

4.8.6. The consequences of failure of the **sewer and water supply infrastructure** are considered to be low.

4.8.7. The Environment Agency reservoir flood risk map identifies the Proposed Scheme is at risk of flooding if White Water Reservoir or the small unnamed reservoir were to fail. Given this is a very low probability event, the risk of flooding from **reservoir failure** is considered to be very low.

4.8.8. 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 generally concurrent with surface water courses (River Nene, Wittering Brook and Mill Stream). 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 Mill Stream.

5. NPPF guidance

5.1.1. The Proposed Scheme is considered to be essential transport infrastructure and it is therefore classified as "Essential Infrastructure". Section 4.2 indicated that the Proposed Scheme lies partly within Flood Zones 1, 2, 3a and 3b.

5.1.2. NPPF guidance states that a Sequential Test is required for the Proposed Scheme in Flood Zone 2 or 3 in order to assess other available sites to find out which has the lowest flood risk. Although route options were assessed during Stage 2, the Proposed Scheme is an upgrade of a trunk road on the strategic road network it would not be appropriate to assess alternative sites. It is therefore assumed that the Proposed Scheme passes the Sequential Test.

5.1.3. According to the NPPF guidance, set out in Table 5.1, and Section 5.94 of the NPS NN the Site is considered appropriate for the Proposed Scheme in Flood Zone 3b providing it passes the requirements of the Exception Test.

Table 5-1 - NPPF Guidance on Flood Risk Vulnerability

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.

5.1.4. In addition to passing the Exception Test, the PPG notes that permitted essential infrastructure in Flood Zone 3b should be designed and constructed to:

- remain operational and safe for users in times of flood
- result in no net loss of floodplain
- not impede water flows and not increase flood risk elsewhere

5.1.5. 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.

5.1.6. The first criteria imposed by the NPPF is met by the Proposed Scheme delivering wider benefits to the strategic road network. The Proposed Scheme of the A47 Wansford to Sutton will alleviate traffic congestion, improving the traffic flow, reducing journey times on the route, increasing the route safety and resilience and improving the environment. The Proposed Scheme is also intended to support economic growth by making journeys safer and more reliable.

5.1.7. 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.

5.1.8. The second criteria are considered in Sections 6 and 7 of this FRA.

6. Flood risk from the development

6.1.1. The potential impacts of the Proposed Scheme 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.

6.2. Fluvial flood risk

6.2.1. Construction works within Mill Stream, Wittering Brook, Wittering Brook floodplain and the River Nene floodplain have the potential to displace fluvial flood waters which may in turn increase flood risk to others. Construction in these areas include the construction of the A1 culvert extension, A47 Wansford Sluice and both the embankments and carriageways of the proposed A47. In addition to this, the construction of the embankments and the carriageway west of Wittering Brook would result in a loss of floodplain for Wittering Brook and the River Nene.

6.2.2. Severing of drainage ditches has the potential to displace flood waters which may in turn increase flood risk to others. The Proposed Scheme would cross two drainage ditches located to the west of Upton Road, which would be severed and redirected.

6.3. Surface water flood risk

6.3.1. The Proposed Scheme, through the construction of the new carriageway, would result in an increase in impermeable area and an alteration of ground elevations due to the re-profiling and construction of embankments. Without mitigation this would increase the rate of surface water runoff and could exacerbate downstream flood risk. Similarly, several sections of the Proposed Scheme would tie-into the existing drainage, which will discharge to a tributary of the River Nene (an unnamed watercourse at the east of the Proposed Scheme) and tributaries of Wittering Brook; Mill Stream and one unnamed watercourse. Without mitigation, this could increase flood risk to parts of the existing drainage network.

6.4. Groundwater flood risk

6.4.1. Road drainage design incorporates unlined road drainage in the form of filter drains as well as infiltration to ground through infiltration basins. A detailed groundwater quality and road runoff assessment has been completed, incorporating consideration of groundwater levels and the infiltration capacity of the infiltration features, and the results are presented in the Groundwater assessment (Volume 3, Appendix 13.4 of the Environmental Statement) (**TR010039/APP/6.3**).

6.4.2. Infiltration features overlying the Lincolnshire Limestone Formation and river terrace deposits are likely to have an acceptable infiltration efficacy and as such do not pose an additional risk of groundwater flooding.

6.4.3. Filter drains to the east of Sutton Heath Road discharge to the Rutland Formation, where the groundwater conditions and flow pathways are not fully understood. The Rutland Formation is expected to have relatively low permeability due to its Secondary B Aquifer status and there is, therefore, a risk that infiltration may be limited. Slow or limited infiltration, along with shallow groundwater levels, may therefore result in a flood risk to the immediate surrounding area. Groundwater conditions are to be confirmed by a supplementary ground investigation.

6.5. Reservoir failure flooding

6.5.1. Reservoir flooding flow paths will be unchanged and any adverse impacts on flow will be minimal. The risk of flooding due to reservoir failure is very low. The Proposed Scheme would have no impact on this source of flood risk.

7. Flood risk mitigation

7.1. Fluvial flood risk

7.1.1. The Proposed Scheme should not result in an increase in flood risk compared to existing conditions. To ensure this:

- loss of floodplain due to the Proposed Scheme should be accounted for
- flows through Wittering Brook and Mill Stream culverts should not be altered through constriction or otherwise
- severed drainage ditches should be intercepted and diverted

7.1.2. It is currently proposed that any increase or redirection of flow associated with the Proposed Scheme crossing two drainage ditches located west of Upton Road will be intercepted using appropriately designed drains at the toe of the Proposed Scheme embankment. This will divert the flow from the drainage ditches to the east, along the toe of the embankment and will tie into the drainage design. However, the drainage ditches may be required to be retained under the Proposed Scheme and additional culverts may be required. At the time of writing drainage survey detailing connectivity was being collected to confirm connectivity. Further details can be found in the Drainage Strategy (Volume 3 of the Environmental Statement, Appendix 13.2) (**TR010039**/**APP/6.3**).

Wittering Brook

7.1.3. To assess the impact of the Proposed Scheme on flood risk in more detail hydraulic modelling was undertaken. A comprehensive overview can be found in the Wittering Brook hydraulic modelling technical note (Annex B).

7.1.4. A hydraulic model was developed using InfoWorks Integrated Catchment Modelling (ICM, Version 10). The model was built using a combination of surveyed cross sections, DTM LiDAR, geomorphology survey photographs and Google satellite imagery.

7.1.5. The Proposed Scheme requires construction within Wittering Brook floodplain to widen the A47 carriageway. As such, there is a need to extend the A47 Wansford Sluice to a maximum length of 60m to continue to convey flow beneath the carriageway. Initially, three options were considered for the Proposed Scheme. Each option was required to achieve 0.6m freeboard and 0.3m soft bed for the 1 in 100-year plus 65% climate change event. A proposed mammal ledge was to be accounted for within the freeboard:

- Option 1 consists of an extension of the existing 24m culvert by 33m to the north and 3m to the south using a 2.0m x 2.5m boxed concrete culvert.
- Option 2a consists of replacing the existing culvert with a 2.0m x 2.5m boxed concrete culvert for a proposed 60m in length.
- Option 2b consists of a 2.5m x 2.5m concrete boxed culvert for a proposed length of 60m.

7.1.6. Table 7.1 shows the predicted maximum water depth, peak flow and freeboard through the culvert options.

Table 7-1 - Proposed Option predicted maximum depths (1 in 100-year plus 65% CC)

Option	Maximum Depth (m)		Peak Flow (m^3/s)		Freeboard (m)	
	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
1	1.47	1.57	6.56	6.56	1.03	0.93
2a	1.19	1.54	6.56	6.56	1.31	0.96
2b	1.06	1.46	6.57	6.57	1.44	1.04

7.1.7. All three scenarios provided a minimum of 0.6m freeboard for the 1 in 100-year plus 65% climate change event and pose as viable options for the Proposed Scheme. However, Option 2b increases peak flow, provides greater freeboard and lowest maximum depths.

Climate Change Impacts

7.1.8. Climate change impacts for the Proposed Scheme (Option 2b culvert) have been assessed for the 1 in 100-year plus 35% and 65% climate change allowances. Table 7.2 below indicates the predicted impact from climate change on the Proposed Scheme. The maximum flood extents have been presented as both peak depths and peak water levels for reference (Caption 7.1 to Caption 7.4).

7.1.9. The Proposed Scheme is not at risk of overtopping in either climate change scenario, with the Option 2b culvert allowing for 600mm freeboard above the 1 in 100-year plus 65% climate change flood level.

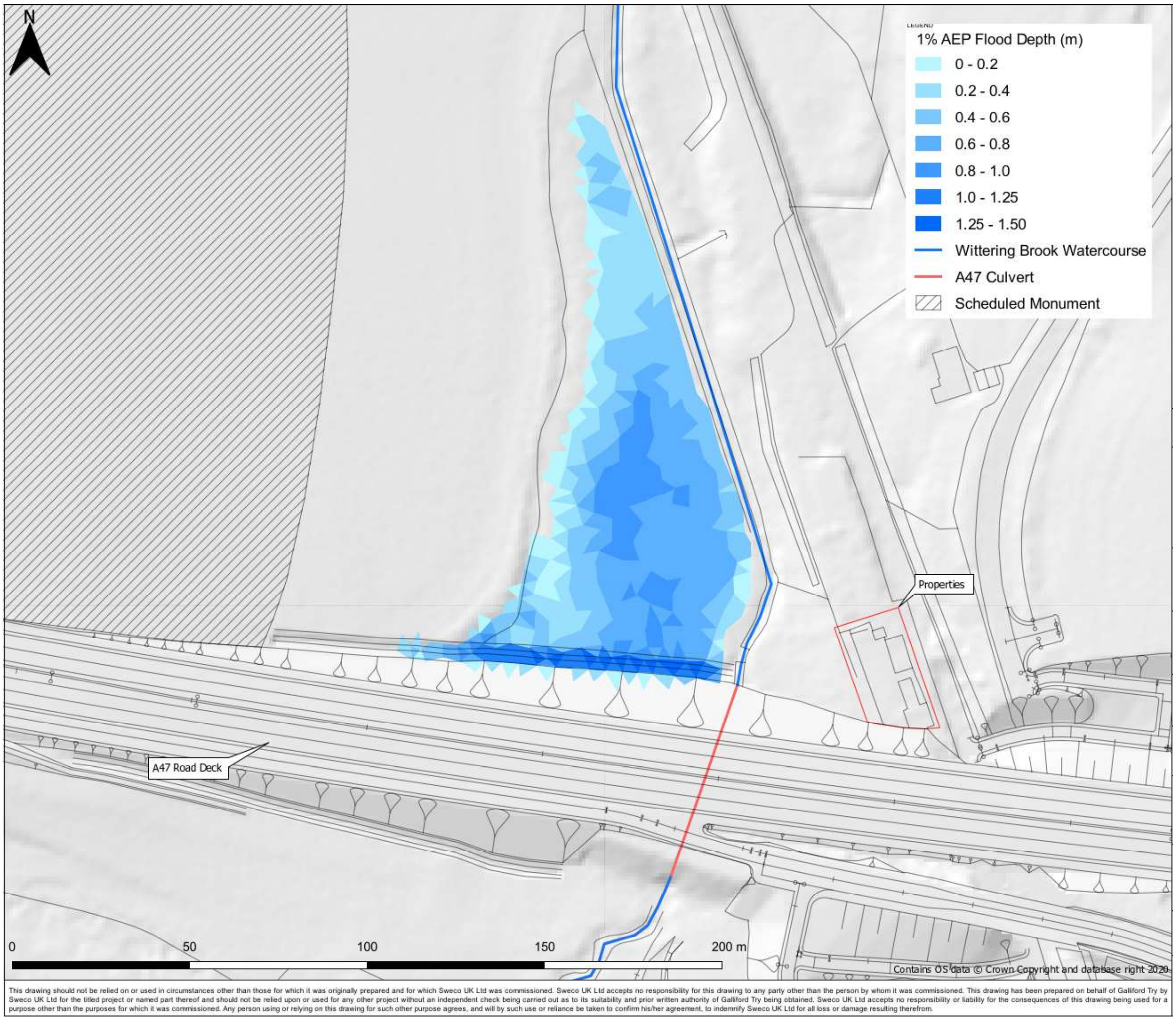
7.1.10. The H++ scenario has also been modelled to test the resilience of the Proposed Scheme in an extreme climate change scenario. The peak river flow allowance for the H++ scenario for the Anglian region is 80%. The predicted impact to water depths and levels at the Option 2b culvert are shown in Table 7-2 and in the figures below. The figures indicate no predicted change to the flooding extent; however, depths increase yet the scheme is not at risk of overtopping.

Table 7-2: Predicted maximum depths for the Proposed Scheme (Option 2b culvert)

	1 in 100-year event	1 in 100-year event (35% CC)	1 in 100-year event (65% CC)	1 in 100-year event (80% CC)
Maximum Depth (m) (Culvert Inlet)	0.81	0.95	1.06	1.12
Maximum Flooded Area (m^2)	6734.04	7035.29	7369.77	7635.74
Maximum Flooded Volume (m^3)	3738.51	4754.49	5734.06	6247.89

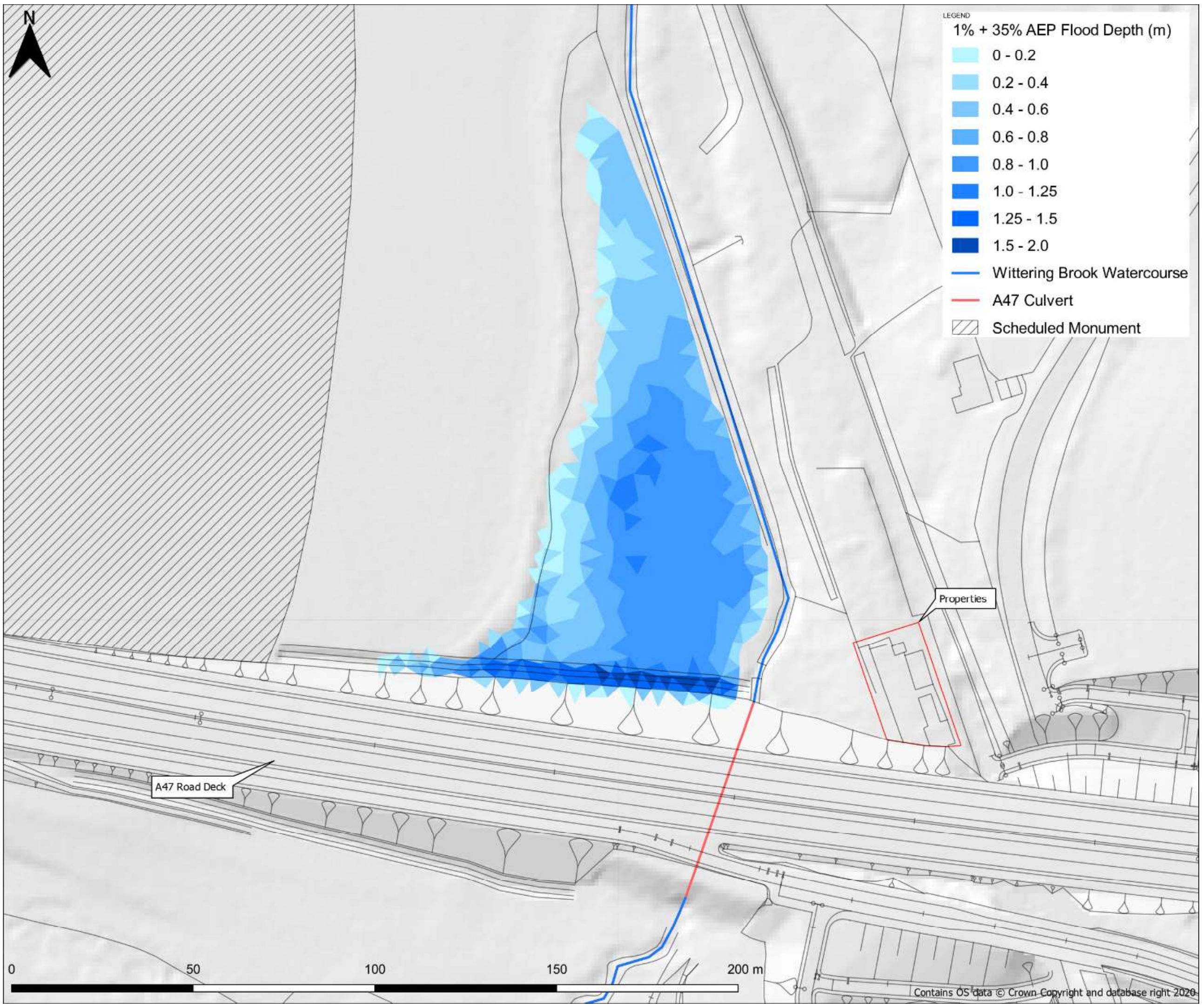
7.1.11. The water depth at the inlet to the Option 2b culvert is predicted to decrease by approximately 250mm for the 1 in 100-year event and decrease by 700mm for the H++ climate change event. The Option 2b culvert will provide 600mm freeboard on top of the 1 in 100-year plus 65% peak water level. This will also provide at least 600mm of freeboard in the H++ scenario. The Proposed Scheme increases water depths on the floodplain adjacent to the Wittering Brook and within the Wittering Brook, however the Proposed Scheme is not considered to increase risk of flooding to receptors, or to be at risk of flooding or overtopping in any climate change scenario.

7.1.12. The proposal for Option 2b culvert design was presented to the Environment Agency, Cambridgeshire County Council and Peterborough City Council for review. Following their review and receipt of comments on the 4 March 2021, neither consultee presented objections to the proposed Option 2b.



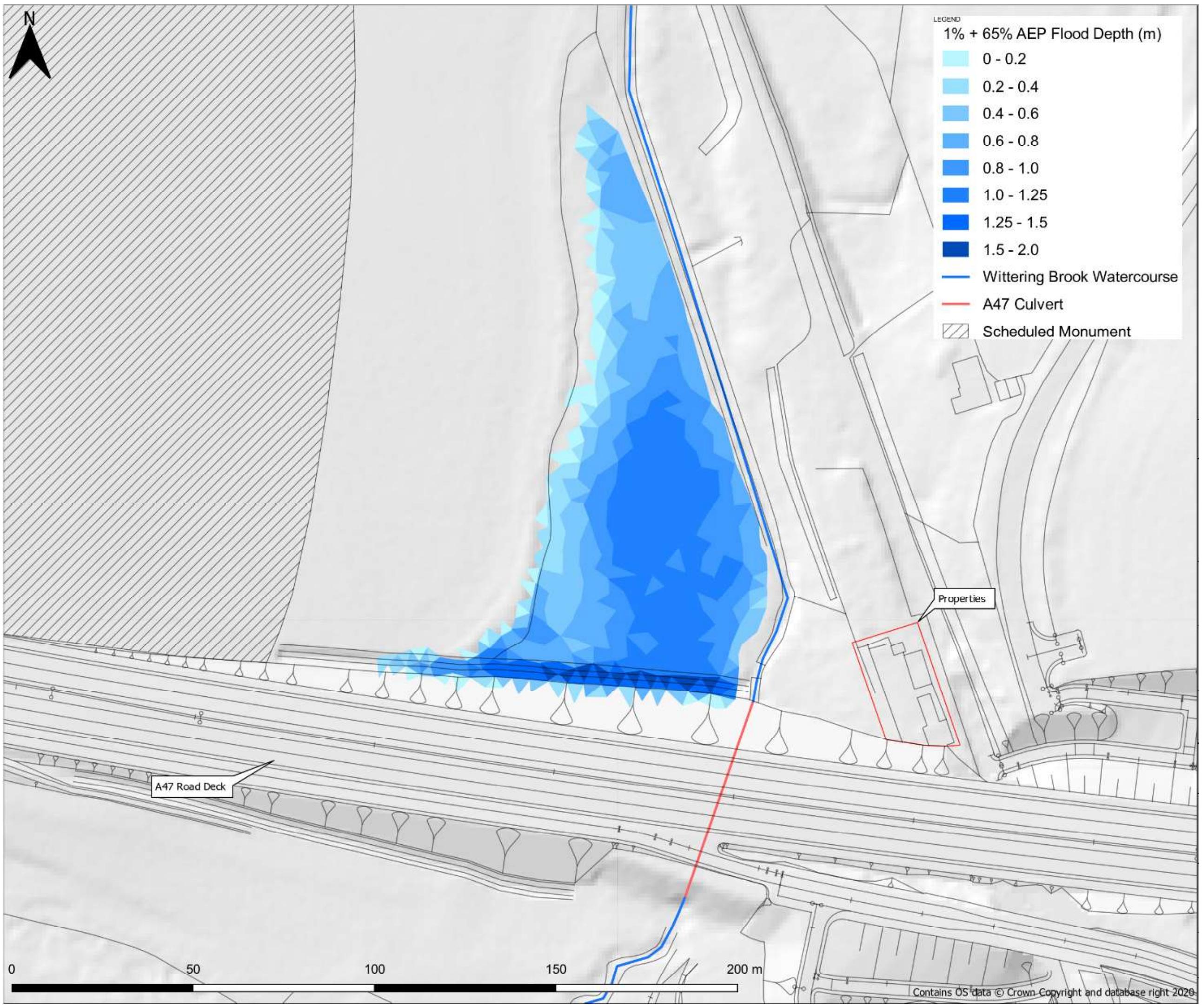
Caption 7-1 - 1 in 100-year predicted maximum flood extent for the Proposed Scheme

*Contains OS data © Crown copyright and database right 2020 and contains Environment Agency information © Environment Agency and database right.



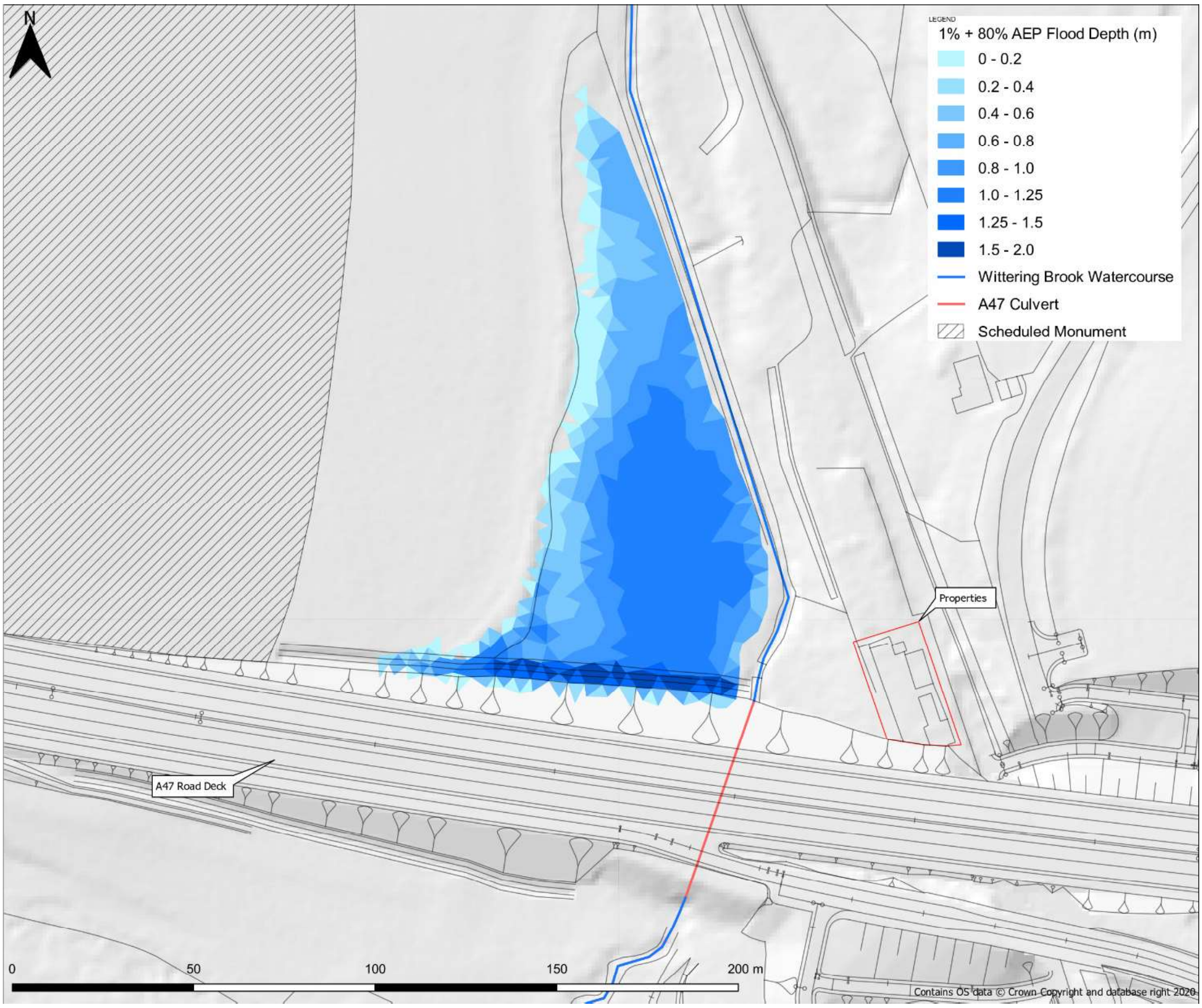
Caption 7-2 - 1 in 100-year plus 35% predicted maximum flood extent for the Proposed Scheme

*Contains OS data © Crown copyright and database right 2020 and contains Environment Agency information © Environment Agency and database right.



Caption 7-3 - 1 in 100-year plus 65% predicted maximum flood extent for the Proposed Scheme

*Contains OS data © Crown copyright and database right 2020 and contains Environment Agency information © Environment Agency and database right.



Caption 7-4 - 1 in 100-year plus 80% predicted maximum flood extent for the Proposed Scheme

*Contains OS data © Crown copyright and database right 2020 and contains Environment Agency information © Environment Agency and database right.

A1 culvert extension

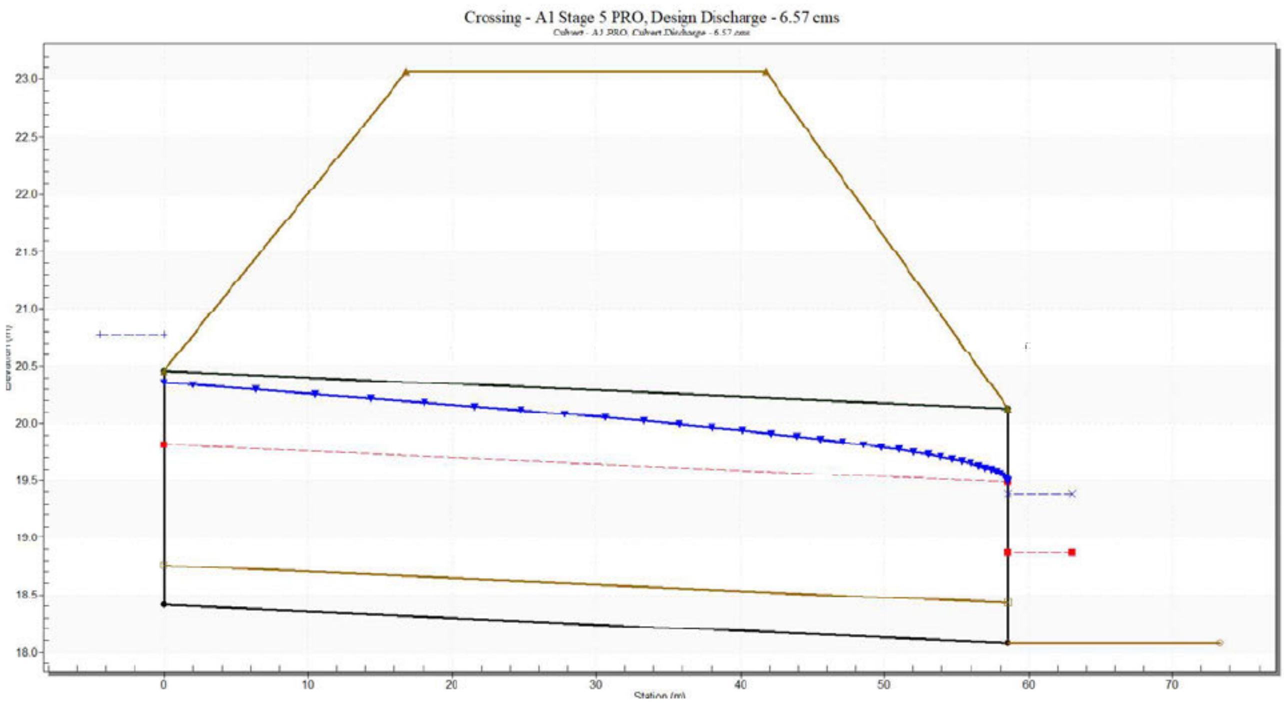
7.1.13. The existing culvert beneath the A1 would be extended at the downstream face by 18m as part of the Proposed Scheme. The extended section would match the 2.2m diameter of the existing. The final extended culvert would be 58.60m in length.

7.1.14. A HY-8 analysis was carried out for the A1 culvert extension (Table 7-3). The proposed culvert extension results in minor increases to water depths upstream of the culvert of no more than 4mm for the 1 in 100 year event (including a 65% allowance for climate change). These depth increases do not pose any additional risk of flooding to the A1 carriageway or to others upstream or downstream.

7.1.15. Caption 7-5 shows a long-section plot from HY-8 of the proposed extended A1 culvert with water levels for the 1 in 100-year plus 65% climate change event.

Table 7-3: Results from the HY-8 culvert analysis (A1 culvert extension)

Event	Peak Culvert Flow (m³/s)	Headwater Depth and difference vs. existing (m)	Tailwater Depth and difference vs. existing (m)
QMED	0.78	0.86 (+0.00)	0.44 (+0.00)
1 in 10-year	1.64	1.16 (+0.00)	0.66 (+0.00)
1 in 100-year	4.39	1.85 (+0.02)	1.08 (+0.00)
1 in 100-year + 35%	5.56	2.12 (+0.03)	1.21 (+0.00)
1 in 100-year + 65%	6.57	2.36 (+0.04)	1.31 (+0.00)



Caption 7-5: HY-8 A1 long section and 1 in 100-year plus 65% climate change event (A1 culvert extension)

7.2. Flood Compensatory Storage

Wittering Brook and Mill Stream

7.2.1. The Proposed Scheme consists of widening the A47 carriageway which will encroach into the Wittering Brook floodplain on the north side embankment. Construction within a floodplain reduces the available area for flood water volume. The lost storage as a consequence of the Proposed Scheme should be replaced elsewhere within the floodplain. Matters pertaining to flood compensatory storage requirements relating to ordinary watercourse rest with the LLFA, Peterborough City Council.

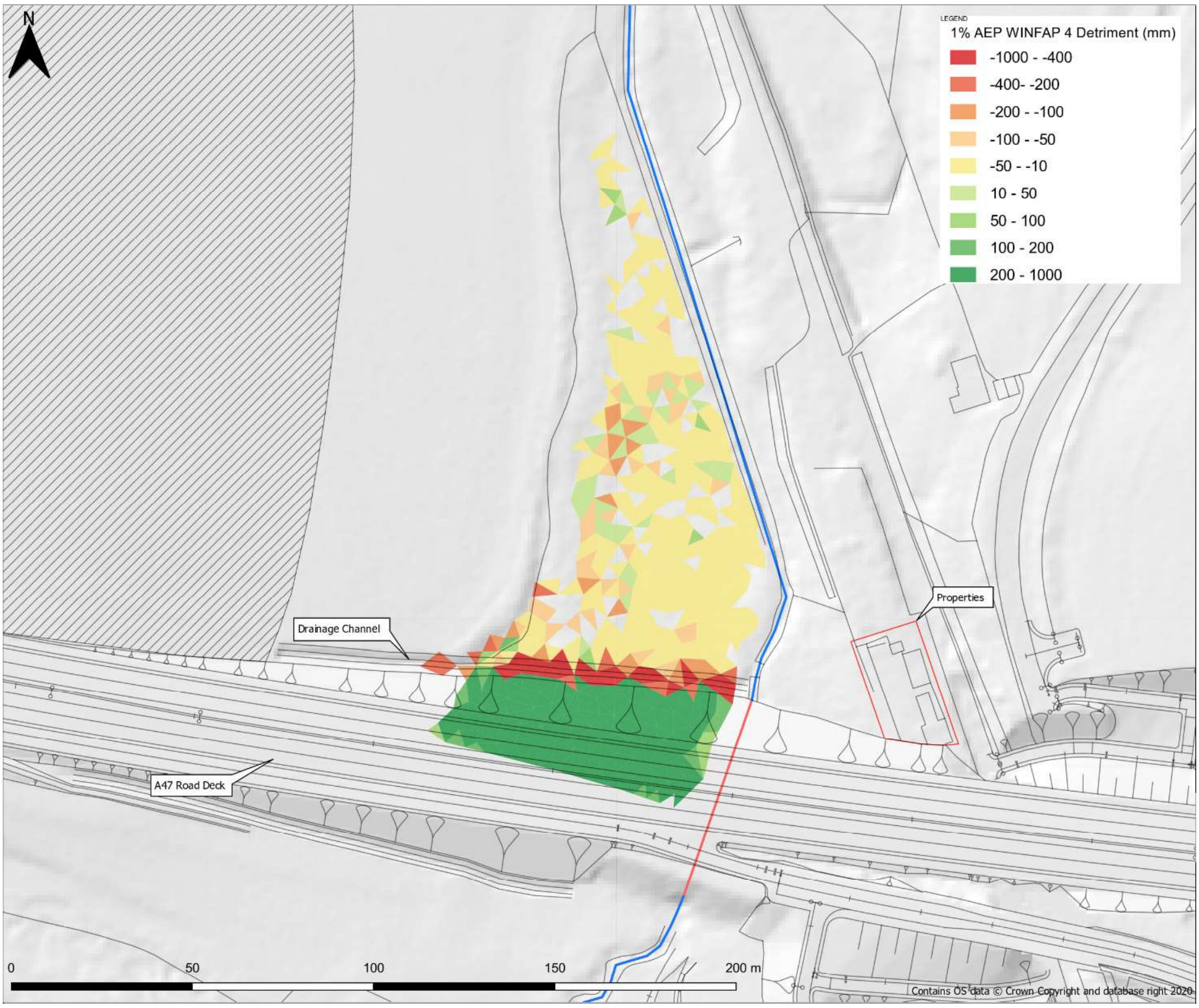
7.2.2. A detriment analysis was carried out to determine the difference in floodplain depths between the baseline and the Proposed Scheme Option 2b culvert scenarios.

7.2.3. Caption 7.6 shows the detriment map for the 1 in 10-year event. Betterment is generally predicted across the floodplain up to a maximum depth of 0.1m. An area of betterment is predicted up to 1.0m within the area of the Proposed Scheme embankment due to it no longer being able to flood. The increase in predicted flood depths at the toe of the Proposed Scheme embankment is due to a proposed drainage channel. Detriment maps for the 1 in 100-year plus climate change allowances are shown in Caption 7.7 to Caption 7.9. The maps predict a maximum of 0.2m detriment across the floodplain for all design events.

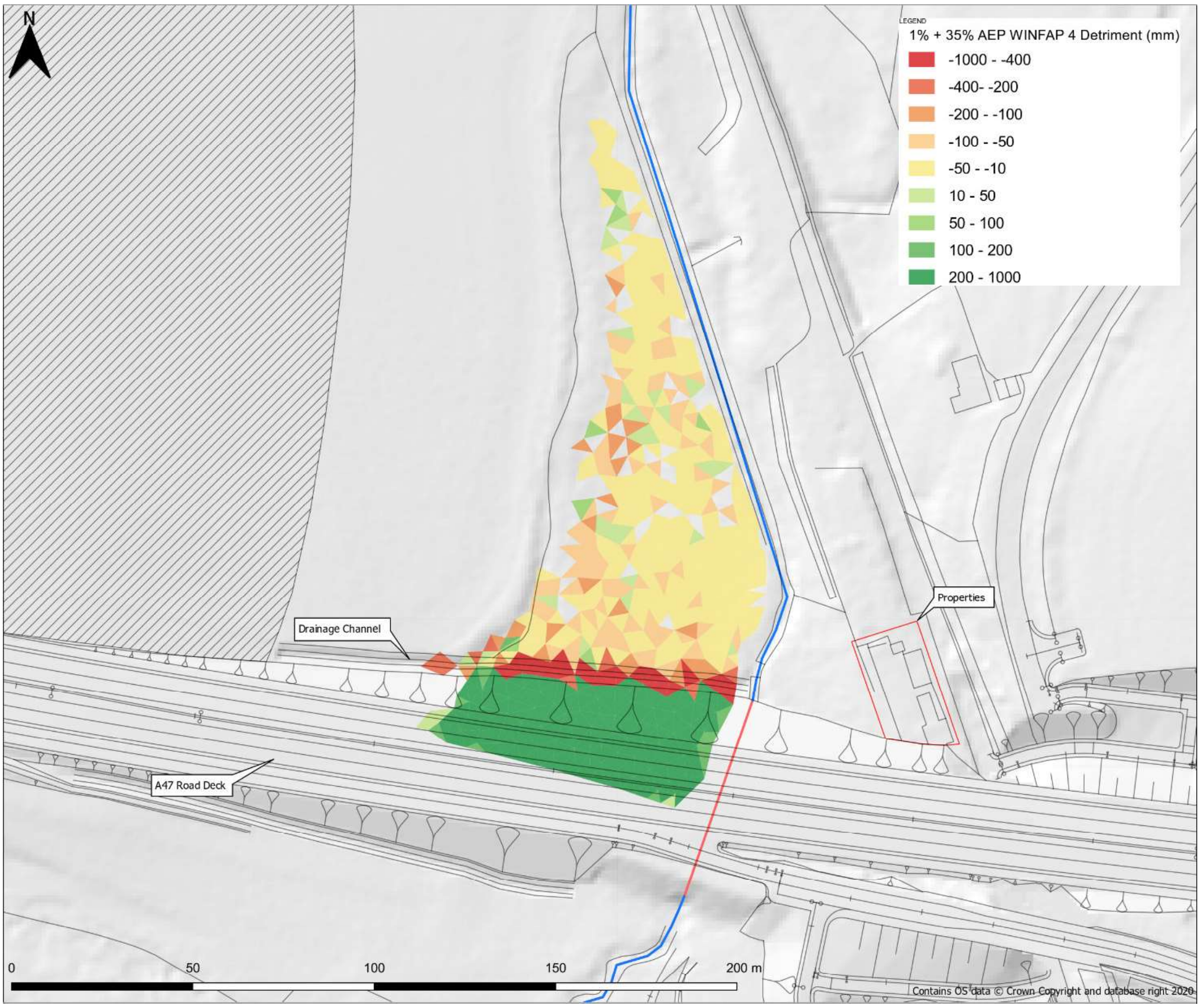
7.2.4. Cambridgeshire County Council were consulted on behalf of Peterborough City Council regarding the requirement to provide flood compensatory storage for the Wittering Brook floodplain. Cambridgeshire County Council were satisfied no compensation would be required given the increase in flood depths remained below 0.2m for all events and the area impacted is not of a vulnerable class. This was confirmed by email on 18th March 2021.

Caption 7-6 - The 1 in 10-year flood depth difference map

*Contains OS data © Crown copyright and database right 2020 and contains Environment Agency information © Environment Agency and database right.



Caption 7-7 - The 1 in 100-year flood depth difference map



Caption 7-8 - The 1 in 100-year plus 35% climate change allowance flood depth difference map

*Contains OS data © Crown copyright and database right 2020 and contains Environment Agency information © Environment Agency and database right.

Caption 7-9 - The 1 in 100-year plus 65% climate change allowance flood depth difference map

*Contains OS data © Crown copyright and database right 2020 and contains Environment Agency information © Environment Agency and database right.

River Nene

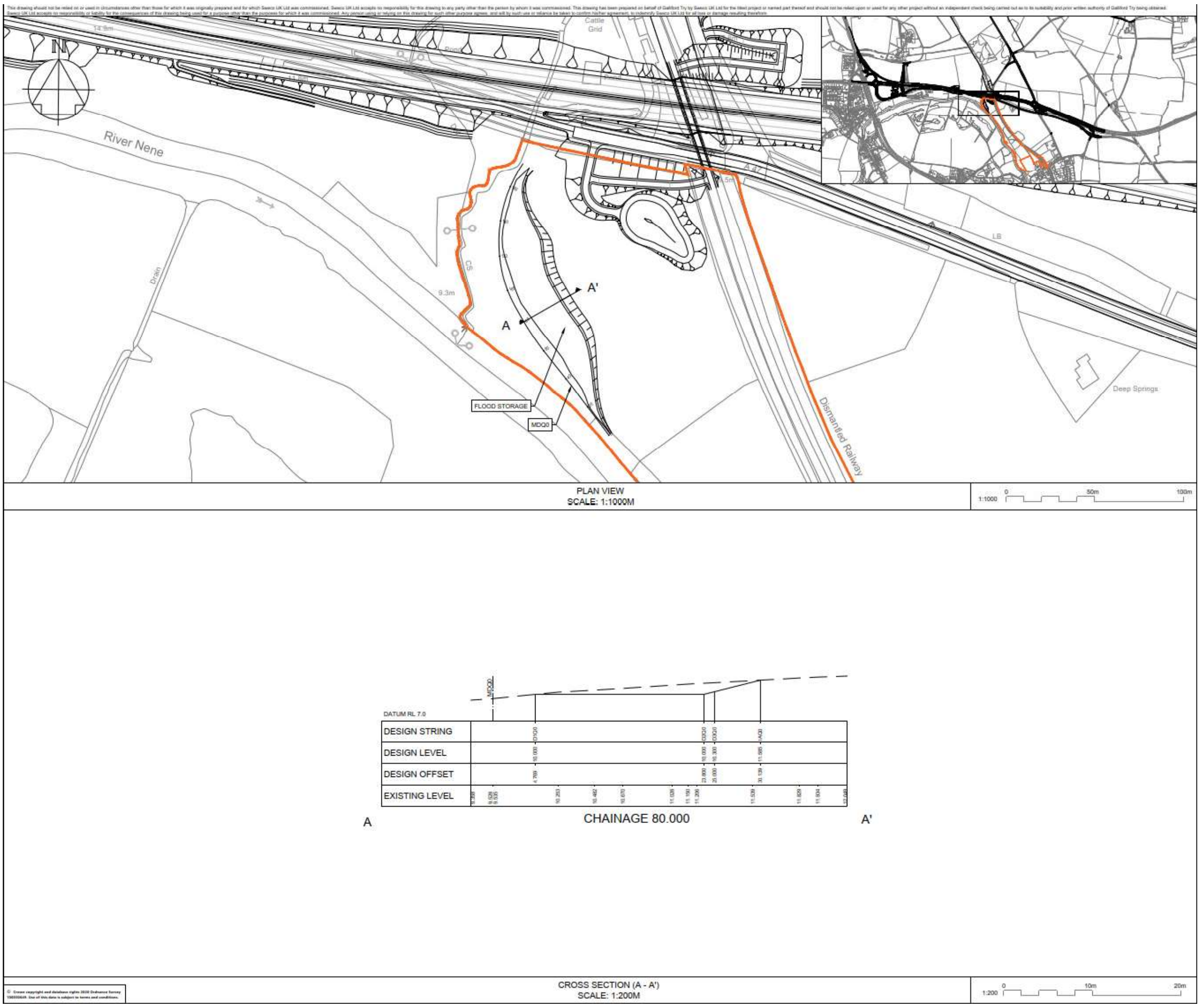
7.2.5. The Proposed Scheme consists of widening the A47 carriageway which will encroach into the River Nene floodplain on the south side embankment. To ensure there is no increased flood risk created by the Proposed Scheme, flood compensation requirements were calculated for the design event 1 in 100-year plus 35% climate change. A comprehensive review can be found in the River Nene Flood Impact Study (Annex C).

7.2.6. The Environment Agency Lower Nene hydraulic model provided for this study included the previous climate change allowance of 20%. The climate change allowance level was updated to 35% and applied to the 1 in 100-year event.

7.2.7. The peak estimated design level of 10.3mAOD at the Wittering Brook and River Nene confluence was used as the basis for the flood compensation calculation.

7.2.8. The volume of floodplain which will be lost by constructing the Proposed Scheme was calculated using ‘Triangulated Terrain Surfaces’ in MX Road Design software (Bentley, 2021). Initially, a boundary beyond the extents of the location where the bottom of the earthworks meets the flood level was taken. The volume from the existing ground level to the design level within the boundary was then calculated. The calculation was repeated from the Proposed Scheme surface to the flood level. The difference between the two, the lost volume, was estimated to be 560m^3. The lost volume was calculated within MX Road Design software.

7.2.9. Whilst level for level compensation is the preferred option this was not achievable given the Environment Agency’s preference for creating new floodplain rather than providing compensation within the existing Flood Zone 3. Considering this and in agreement with the Environment Agency, volume for volume compensation was provided between Flood Zone 3 and the 1 in 100-year plus 35% climate change level, 9.8 and 10.3mAOD respectively. The proposed location for the flood compensation is shown in Caption 7.10. The proposed flood compensation is taken from the left embankment of the River Nene, downstream of Wittering Brook and River Nene confluence. The Environment Agency has approved (March 2021) the proposed flood compensation area location and size based on the specification at the time of writing.



Caption 7-10 - Primary location for the flood compensation area for the River Nene

7.2.10. The above proposal is in line with Environment Agency advice, the loss of floodplain will be offset by flood compensation area constructed on a volume for volume basis. At the time of writing, the flood compensation has been proposed between Flood Zone 3 and the 1 in 100-year plus 35% climate change design level. This may change if level for level compensation is required.

7.2.11. In terms of fluvial flooding, it is considered there will be no additional risk posed by the Proposed Scheme compared to existing, and the risk to the carriageway or road users from Wittering Brook and the River Nene is considered to be low. The base of the embankments only remains at high risk of flooding. This does not impact the use of the A47 carriageway.

A47 Wansford Sluice design

7.2.12. The Option 2b culvert was further refined during the design process to a boxed culvert 2.5m wide by 2.45m internal height for a length of 54m and termed

Option 2c. Additional hydraulic modelling was carried out for the Option 2c culvert, however negligible differences were observed compared to the Option 2b results. Where differences were observed, they showed a reduction in flood volumes, flooded areas and depths within the culvert. The values presented in Table 7-2 and flood maps presented in this report are for the Option 2b culvert and present the worst-case scenario, however, the Option 2c culvert was chosen as the preferred culvert arrangement for the Proposed Scheme.

7.2.13. The proposed box culvert has therefore been designed to be 54m in length, box shaped with a width of 2.5m and height of 2.45m and is designed to convey a 1 in 100-year peak flow (including a 65% climate change allowance) with a freeboard exceeding 600mm. It will be located 10m west from the existing culvert with a minor watercourse realignment. A natural bed would be installed in the base of the culvert and a mammal ledge provided to maintain connectivity of habitat.

7.2.14. A drawing of the proposed design is shown in the DCO General arrangement drawings (**TR0100**/**APP**/**2.6**).

A1 culvert design

7.2.15. The existing culvert beneath the A1 would be extended downstream by 18m as part of the Proposed Scheme. The extended section would match the 2.2m diameter of the existing. The final extended culvert would be 58.60m in length.

7.3. Surface water flood risk

7.3.1. The Proposed Scheme, through the construction of new carriageway, would result in an increase in impermeable area. To ensure that this does not increase peak runoff rates and detrimentally impact flood risk an appropriate drainage strategy has been proposed. Further details can be found in the Drainage Strategy (Volume 3 of the Environmental Statement, Appendix 13.2) (**TR010039**/**APP**/**6.3**).

7.3.2. The Drainage Strategy was informed using a drainage survey completed in 2018. Further survey has been recommended prior to PCF Stage 5, however at the time of writing no dates have been confirmed.

7.3.3. The Drainage Strategy (Volume 3 of the Environmental Statement, Appendix 13.2) (**TR010039**/**APP**/**6.3**) proposed all road drainage would drain to groundwater and surface water. Road drainage discharging to surface water would discharge to seven locations, utilising five new outfalls, which are to be confirmed through a drainage survey. The receiving watercourses include Mill Stream, Wittering Brook, a tributary of Wittering Brook, River Nene and an unnamed watercourse at the east of the Proposed Scheme (via existing road drainage). The location of the outfalls can be found in the Surface water quality assessment (Volume 3, Appendix 13.3 of the Environment Statement). Prior to entering the watercourses, highway runoff from new outfalls must be directed through attenuation features such as detention basins and infiltration basins. Any increase in surface water runoff shall also be attenuated using detention basins, infiltration basins or oversized pipes. Where existing drainage systems are being adapted, the drainage shall be designed to attenuate to existing runoff rates and includes a 1 in 100-year storm event plus 20% climate change allowance to allow for changes in peak rainfall intensity. Where carriageway widening or realignment occurs the additional contributing area shall be attenuated to greenfield runoff rates up to a 1 in 100-year storm event plus 40% climate change. Where attenuation basins are not appropriate, attenuation would be in the form of flow controls and oversized pipes. This would ensure there is no increase in peak surface water runoff rates resulting from the Proposed Scheme.

7.3.4. Any increase in overland runoff associated with the alteration of ground elevation due to the re-profiling and construction of embankments will be intercepted using appropriately designed drains along the Proposed Scheme. Drainage ditches have been provided at the toe of embankments where possible and existing drainage ditch flow paths have been retained where possible from the existing drainage network. Drainage ditches are not provided to the outfalls into the River Nene, this is to reduce the impact on the land south of the A47 which is partially located within Flood Zones 2 and 3. Surface water pathways have been directed along the north side of the embankment, intercepting surface water pathways and connecting into existing drainage ditches which flow from west to east away from the Proposed Scheme and the Wittering Brook. The surface water pathways connect to existing drainage before discharging to an unnamed ordinary watercourse east of the Proposed Scheme boundary.

7.3.5. Further details can be found in the Drainage Strategy (Volume 3 of the Environmental Statement, Appendix 13.2) (**TR010039**/**APP**/**6.3**).

7.3.6. The peak of an extreme pluvial event is considered unlikely to coincide precisely with a peak fluvial event. Furthermore, the River Nene flood compensation area would be graded and not within an area of surface water flood risk and therefore unlikely to have standing water. Only shallow surface water flooding may persist by the time the peak fluvial event occurs.

7.4. Groundwater flooding

7.4.1. The assessment of groundwater flood risk indicates that, although there are no specific historic records, there is a potential risk of groundwater flooding based on an assessment of the underlying hydrogeology. Should any groundwater flooding occur then it is likely that water would follow existing surface water routes.

7.4.2. The proposed drainage design discharges to groundwater via filter drains and infiltration basins and to surface water via attenuation basins. Infiltration efficacy has been reviewed and no additional flood risk to the Proposed Scheme has been determined over the majority of the scheme. Infiltration features are not to be used in areas where groundwater levels are shallow and there is an unacceptable infiltration capacity. In areas where the groundwater conditions are not fully understood, the infiltration capacity will be reviewed following the supplementary ground investigation. Further details can be found in the Drainage Strategy (Volume 3 of the Environmental Statement, Appendix 13.2) (**TR010039/APP/6.3**). and in the Groundwater Assessment (Volume 3, Appendix 13.4 of the Environmental Statement) (**TR010039/APP/6.3**).

8. Construction related flood risk

8.1. Construction related flood risk

8.1.1. This section details the potential impacts on flood risk to the Proposed Scheme and elsewhere during the construction phase. Further details of the construction approach are available in Volume 1 of the Environmental Statement, Chapter 2 (The Proposed Scheme) (**TR010039/APP/6.1**).

8.1.2. During construction there would be an increase in new hardstanding areas, including the compounds and infilling of ponds, which, if not mitigated, would increase the volume and flow rate of runoff from the construction areas. This could result in increased localised flooding to the Proposed Scheme and other flood-sensitive downstream receptors. Additionally, this could adversely impact upon downstream flood-sensitive receptors, aquatic environments, value to economy, water quality and recreational users of surface water features including Mill Stream, Wittering Brook, the River Nene, ordinary watercourses (including an unnamed watercourse at the east of the Proposed Scheme and Wittering Brook tributary), drainage ditches and ponds.

8.1.3. During construction, there is an increased risk of flooding during and following extreme rainfall events, including those areas identified as at risk of surface water flooding. Works may lead to temporary changes in the surface water runoff regime by the alteration of ground elevations and overland flow pathways, pond infilling (two for the construction of the Proposed Scheme), construction of embankments or the construction of above ground structures acting as a barrier to flow. This could cause localised flooding to the Proposed Scheme and nearby receptors due to changes in surface water flow pathways. Indirectly, overloading of the temporary drainage system could adversely impact on surface water features including Mill Stream, Wittering Brook, the River Nene, ordinary watercourses (including an unnamed watercourse at the east of the Proposed Scheme and Wittering Brook tributary), drainage ditches and ponds where works are in close proximity.

8.2. Mitigation of construction related flood risk

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

8.2.2. Any temporary and permanent drainage arrangements would be implemented before construction. The potential increase in flood risk and negative impacts on surface water receptors shall be managed by the implementation of a construction-phase drainage system, where the construction will take place offline.

8.2.3. During construction, best practice methods for mitigation of temporary flood risk to and from the Proposed Scheme will be implemented as part of the wider Environmental Management Plan (EMP) (**TR03900/APP/7.5**).

8.2.4. There are construction activities planned within Mill Stream, Wittering Brook and their floodplains, ordinary watercourse and drainage ditches. Approval must be sought for a land drainage (ordinary watercourse) consent from Peterborough City Council before any construction works is undertaken. There are construction activities planned within 8m of an Environment Agency designated main river (River Nene) and its floodplain. As such, consent in the form of a Flood Risk Activity Permit would be required from the Environment Agency.

8.2.5. A temporary works drainage strategy shall be specified within the EMP (**TR03900/APP/7.5**) and this would include measures to attenuate runoff from construction sites, compounds and material lay down areas; this would be informed by the Drainage Strategy (Volume 3 of the Environmental Statement, Appendix 13.2) (**TR010039/APP/6.3**) and this assessment. In addition, the temporary works drainage strategy would propose how flood risk from surface water flow pathways would be managed. Discharges to surface water or ground would only be made with the appropriate consents or permits in place and infiltration features would be suitably designed considering local ground conditions.

8.2.6. Works would lead to temporary changes in overland flow and volume by the alterations of ground elevations due to re-profiling, pond infilling and construction of above ground structures and embankments acting as a barrier to flow. This increased flood risk and negative impacts on surface water receptors must be managed by the implementation of a construction-phase drainage strategy and the temporary surface water drainage strategy.

8.2.7. SuDS would be implemented as part of the temporary works drainage strategy to attenuate runoff to greenfield runoff rates, or as a minimum for existing road drainage or impermeable areas, existing runoff rates as well as provide water treatment; this must be incorporated into the EMP (**TR03900/APP/7.5**).

8.2.8. A flood emergency response plan must be developed as part of the temporary within the EMP (**TR03900/APP/7.5**) to manage the flood risk impacts during construction and to ensure construction workers are not exposed to increased levels. The Proposed Scheme is within an area that receives Environment flood warnings and alerts and should sign up for Middle Nene and Lower Nene alerts, and Areas near the River Nene from Elton to Wansford warnings. The flood emergency response plan shall specify safe access and egress routes for all construction areas in the event of anticipated flooding.

8.2.9. Given the above mitigation, it is anticipated that the Proposed Scheme would be at the same level of risk of flooding during construction as it would under the operational scenario and will not cause an increase in flood risk elsewhere.

9. Conclusion

9.1.1. The assessment of flood risk to the Proposed Scheme and the risk posed by the Proposed Scheme has been undertaken in accordance with the NPPF, its associated PPG for flood risk and coastal change and the NPS NN. The assessment has been undertaken in accordance with Highways England's technical guidance provided in DMRB LA 113.

9.1.2. Consultation with the Environment Agency, Peterborough City Council and Cambridgeshire County Council was undertaken in 2018, 2020 and 2021 as part of the assessment and is ongoing.

9.1.3. According to the Environment Agency's flood risk for planning map, the majority of the Proposed Scheme is located within Flood Zone 1. However, there are areas located within Flood Zone 2 and 3. The Proposed Scheme crosses three sections of Flood Zone 2 and 3: where the A1 crosses Mill Stream, where the A47 crosses Wittering Brook and its floodplain and immediately to the west of Wittering Brook where is encroaches on the River Nene floodplain. SFRA's identifies the land surrounding the River Nene to be Flood Zone 3b. Flood Zone 3 associated with both Wittering Brook and Mill Stream are identified to be within Flood Zone 3a.

9.1.4. The flood risk maps indicate the Proposed Scheme is not in an area benefitting from flood defences.

9.1.5. A detailed hydraulic modelling assessment of Wittering Brook was undertaken to assess the impact of the Proposed Scheme embankment west of Wittering Brook encroaching onto the existing Flood Zones 2 and 3. The proposed A47 Wansford Sluice on Wittering Brook has been designed to be approximately 54m in length, box shaped with a width of 2.5m and height of 2.45m.

9.1.6. The hydraulic model predicts that during the 1 in 100-year event, flood flows are throttled by the existing A47 Wansford Sluice causing water to rise up the north, upstream, side of the existing embankment. However, flows did not overtop the road deck. Climate change impacts increase the predicted flood depths, flooded area and volume within the Wittering Brook floodplain. The proposed A47 Wansford Sluice has been designed to convey a 1 in 100-year peak flow (including a 65% climate change allowance) with a freeboard exceeding 600mm. The north side of the Proposed Scheme is considered to be at high risk of fluvial flooding. However, only the embankments of the Proposed Scheme are considered to be high risk and not the carriageway or users, which would be classified as low risk due to the carriageway being elevated above Flood Zone 3.

9.1.7. A simplified hydraulic assessment, as agreed with Peterborough City Council, was undertaken in the A1 Mill Stream culvert using HY-8 to determine peak culvert flow, headwater depth and tailwater depth for baseline conditions. The results for the 1 in 100-year event indicate the headwater elevation was 1.83m and the tailwater depth was 1.08m, climate change influences increased these water elevations. The existing risk of fluvial flooding is considered to be high immediately upstream of the culvert although there is no risk to the A1 carriageway.

9.1.8. The existing culvert beneath the A1 would be extended at the downstream face by 18m as part of the Proposed Scheme. The extended section would match the 2.2m diameter of the existing. The final extended culvert would be 58.60m in length. The proposed culvert extension results in minor increases to water level upstream of the culvert. These level increases do not pose any additional risk of flooding to the A1 carriageway or to others upstream.

9.1.9. Mitigating measures have been proposed to ensure the Proposed Scheme does not increase fluvial flood risk. A detriment analysis was carried out to determine the difference in floodplain depths between the baseline and the Proposed Scheme culvert arrangement. The maps predict a maximum of 0.2m detriment across the floodplain for all design events. Cambridgeshire County Council were consulted on behalf of Peterborough City Council regarding the requirement to provide flood compensatory storage for the Wittering Brook floodplain. Cambridgeshire County Council were satisfied no compensation would be required given the increase in flood depths remained below 0.2m and the area impacted is not of a vulnerable classification.

9.1.10. To mitigate for the loss of River Nene floodplain, 560m^3 of flood compensation would be required, constructed on a level for level / volume for volume basis, in line with the Environment Agency’s requirements. The location and specifications of flood compensation was confirmed with the Environment Agency in March 2021.

9.1.11. 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, with significant high risk areas being observed up and downstream of the A1 culvert, upstream and to the west of the A47 Wansford Sluice and where Sutton Heath Road crosses an unnamed ordinary watercourse.

9.1.12. The risk of flooding from reservoir, sewer or water main infrastructure failure is considered to be low and very low respectively. The Environment Agency reservoir flood risk map identifies the Proposed Scheme to be at risk of flooding should the White Water Reservoir or the small unnamed reservoir fail. Given this is a very low probability event, the risk of flooding is considered to be very low.

9.1.13. The Proposed Scheme is within an area which is susceptible to medium to high risk of groundwater flooding. Although, there are no historical records of groundwater flooding within the vicinity of the Proposed Scheme, it is possible that groundwater flooding events are under recorded. The medium to high risk rating is based on a coarse 1 km grid square assessment of the area.

9.1.14. The highway drainage shall utilise two existing outfalls plus an additional five new outfalls. Where existing drainage is adapted, the drainage shall be designed to attenuate to existing runoff rates and includes a 1 in 100-year storm event plus 20% climate change allowance to allow for changes in peak rainfall intensity. Where carriageway widening or realignment is proposed the additional contributing area shall be attenuated to greenfield runoff rates up to a 1 in 100-year storm event plus 40% climate change.

9.1.15. The Proposed Scheme would increase the impermeable area, and hence runoff rates. To mitigate this, SuDS features are proposed as part of the drainage strategy to treat and attenuate surface water runoff. Drainage ditches shall be provided at the toe of embankments where possible and existing drainage ditch flow paths shall be retained where possible from the existing drainage network.

9.1.16. Where filter drains and infiltration basins are proposed, infiltration capacity has been reviewed to confirm efficacy and that they do not pose any additional flood risk to the Proposed Scheme.

9.1.17. It is considered that there would be no increase in the risk of flooding (from any source) to or from the Proposed Scheme and it therefore meets the requirements of the Exception Test and the flood risk requirements of the NPS NN section 5.94.

10. References

- Bentley (2020) *MX Road, Version 8i*
- British Geological Survey (2020) Geoindex Onshore. Available at [redacted] accessed February 2021
- DEFRA (2015) Sustainable Drainage Systems. Non-statutory technical standards for sustainable drainage systems
- Department for Transport (2014) National Policy Statement for National Networks. Available at: https://www.gov.uk/government/publications/national-policy-statement-for-national-networks, accessed February 2021
- Environment Agency (2019) National groundwater recharge assessment under climate change. Project summary SC160018
- Environment Agency (2021a) Flood Map for Planning. Available online at: https://flood-map-for-planning.service.gov.uk/, accessed February 2021
- Environment Agency (2021b) Long Term Risk Assessment for Locations in England. Available online at https://flood-warning-information.service.gov.uk/long-term-flood-risk, accessed February 2021
- Environment Agency (2021c) Historic Flood Map. Available online at https://environment.data.gov.uk/DefraDataDownload/?mapService=EA/HistoricFloodMap&Mode=spatial, accessed February 2021
- Environment Agency (2021d) Flood risk assessments: climate change allowances. Available online at: https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances, accessed February 2021
- Federal Highway Administration (2021) US Department of Transportation, HY-8 Version 7.70.1.0
- Highways England (2018). A47 Wansford to Sutton EIA Scoping Report (HEWNSFRD-MMSJV-EGN-000-RP-LX-00002)
- Highways England (2021a) Highways England Drainage Data Management System
  v5.12.0 (HADDMS). Available online at [redacted] accessed February 2021
- Highways England (2021) A47 Wansford to Sutton Dualling Drainage Strategy Report (HE551494-GTY-HDG-000-RP-CD-00001)
- Highways England (2020a) Highways England Design Manual for Roads and Bridges (DMRB) CG 501, Design of highway drainage systems
- Highways England (2019a). Highways England Design Manual for Road and Bridges (DMRB) LA 113, Road Drainage and the Water Environment
- Highways England (2019b) Highways England Design Manual for Roads and Bridges (DMRB) CG 502, The Certification of Drainage Design
- JBA Consulting (2017) Huntingdonshire District Council Level 1 and 2 Strategic Flood Risk Assessment Final Report June 2017. Available online at

https://www.huntingdonshire.gov.uk/media/2640/strategic-flood-risk-assessment.pdf, accessed February 2021

- Ministry of Housing, Communities and Local Government (2016). Planning Practiceguidance. Flood Risk and Coastal Change. Available online at https://www.gov.uk/guidance/flood-risk-and-coastal-change, accessed February 2021
- Ministry of Housing, Communities and Local Government (2018) Meeting the challenge of climate change, flooding and coastal change. Available online at:https://www.gov.uk/guidance/national-planning-policy-framework/10-meeting-the-challenge-of-climate-change-flooding-and-coastal-change, accessed February 2021
- Ministry of Housing, Communities and Local Government (2019). National Planning Policy Framework. Available at https://www.gov.uk/government/publications/national-planning-policy-framework--2, accessed February 2021
- Planning Inspectorate (2018) Scoping Opinion: Proposed A47 Wansford to Sutton. Available online at https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/TR010039/TR010039-000013-WANS%20-%20Scoping%20Opinion.pdf, accessed February 2021

Annex A Environment Agency information

Karen Dunton
[redacted]

Our ref: CCN/2020/157897

Date: 11 February 2020

Dear Karen

Provision of Flood Risk Information for A47 in Wansford area

Thank you for your request to use our flood risk information in the development of the Flood Risk Assessment (FRA) for the above site. The information is set out below and attached. It is important you read any contextual notes on the maps provided.

We aim to review our information on a regular basis, so if you are using this data more than twelve months from the date of this letter, please contact us again to check it is still valid.

Flood Map

The attached map includes the current Flood Map for your area. The Flood Map indicates the area at risk of flooding, **assuming no flood defences exist**, for a flood with a 0.5% chance of occurring in any year for flooding from the sea, or a 1% chance of occurring for fluvial (river) flooding. It also shows the extent of the Extreme Flood Outline which represents the extent of a flood with a 0.1% chance of occurring in any year, or the highest recorded historic extent if greater.

In some locations, such as around the fens and the large coastal floodplains, showing the area at risk of flooding assuming no defences may give a slightly misleading picture in that if there were no flood defences, water would spread out across these large floodplains. This flooding could cover large areas of land but to relatively shallow depths and could leave pockets of locally slightly higher land as isolated dry islands. It is important to understand the actual risk of the flooding to these dry islands, particularly in the event of defence failure.

The Flood Map also shows the location of formal raised flood defences and flood storage reservoirs. It represents areas at risk of flooding for present day only and does not take account of climate change.

The Flood Map only indicates the extent and likelihood of flooding from rivers or the sea. It should also be remembered flooding may occur from other sources such as surface water sewers, road drainage, etc.

Historic Flood Extent Map

A copy of the Historic Flood Extent Map showing the extent of previous recorded flooding in your area is attached. This only covers information we hold and it is possible other flooding may have occurred which other organisations, such as the Local Authority or Internal Drainage Boards, may have records.

Fluvial Flood Risk Information

Fluvial Defence Information

There are no formal flood defences reducing the risk of flooding to this site. The nearby 'main river' channel reduces the risk of flooding (adjacent to the river) to a nominal chance of occurring in any year.

Modelled Levels and Flows

Available modelled fluvial flood levels and flows for the model nodes shown on the attached map are set out in the data table attached. This data is taken from the model named on the data table, which is the most up-to-date model currently available.

Please note these levels are "in-channel" levels and therefore may not represent the flood level on the floodplain, particularly where the channel is embanked or has raised defences.

Modelled Flood Extents

Please find attached a map showing available modelled flood extents, taking into account flood defences, for your area. This data is taken from the model named on the map, which is the most up-to-date model currently available.

Development Planning

If you would like local guidance on preparing a flood risk assessment for a planning application, please contact our Sustainable Places team at lnplanning@environment-agency.gov.uk. It will help if you mention this data request and attach your site location plan.

We provide free preliminary advice; additional/detailed advice, review of draft FRAs and meetings are chargeable at a rate set to cover our costs, currently £100 (plus VAT) per hour of staff time. Further details are available on our website at https://www.gov.uk/guidance/developers-get-environmental-advice-on-your-planning-proposals.

General advice on flood risk assessment for planning applications can be found on GOV.UK at https://www.gov.uk/guidance/flood-risk-assessment-for-planning-applications

Climate change will increase flood risk due to overtopping of defences. Please note the climate change data included has an allowance for 20% increase in flow. Updated guidance on how climate change could affect flood risk to new development - 'Flood risk assessments: climate change allowances' was published on GOV.UK in February 2016. The appropriate updated climate change allowance should be applied in a Flood Risk Assessment.

You should also consult the Strategic Flood Risk Assessment produced by your local planning authority.

Supporting Information

Please see the Standard Notice or licence for details of permitted use. The Standard Notice can be found at the link below.
http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/

We respond to requests for recorded information we hold under the Freedom of Information Act 2000 (FOIA) and the associated Environmental Information Regulations 2004 (EIR).

Further information on flood risk can be found on the GOV.UK website at:

Ceres House, Searby Road, Lincoln, LN2 4DT
Customer services line: 03708 506 506
Email: enquiries@environment-agency.gov.uk
www.gov.uk/environment-agency

https://www.gov.uk/browse/environment-countryside/flooding-extreme-weather

Other Flood Risk Management Authorities

The information provided with this letter relates to flood risk from main river or the sea. Additional information may be available from your Lead Local Flood Authority (i.e. county council or unitary authority) or, where they exist, the Internal Drainage Board.

Further Contact

I hope we have correctly interpreted your request. If you are not satisfied with our response to your request for information, you can contact us within two calendar months to ask for our decision to be reviewed.

If you have any queries or would like to discuss the content of this letter further please contact Sarah Curl using the details below.

Yours sincerely,

[redacted]

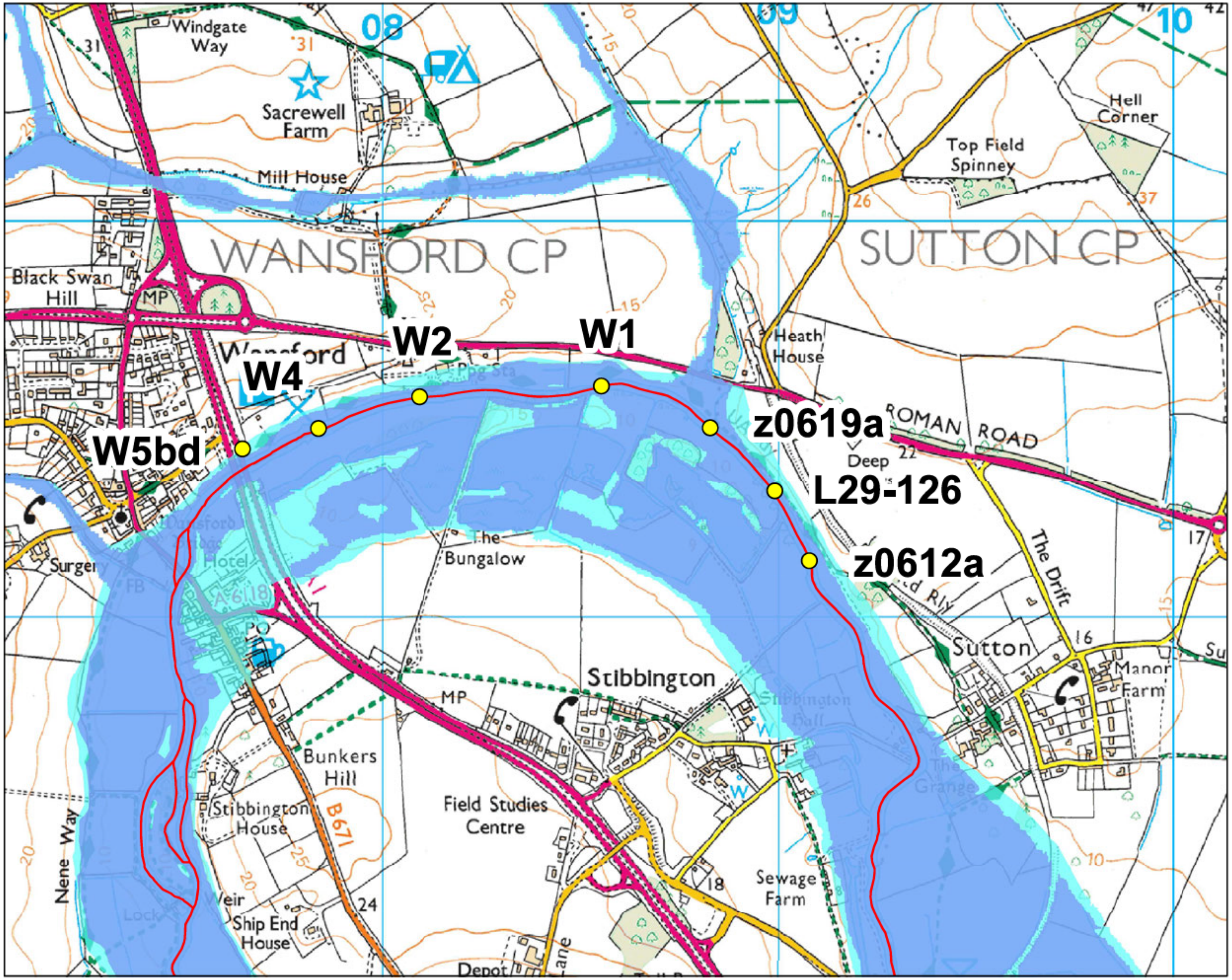
Alastair Windler
Partnerships and Strategic Overview Team Leader - Welland and Nene

[redacted]

Enc.
Flood Map
Historic Flood Extent Map
Modelled Fluvial Levels and Flows Data Sheet
Modelled Flood Extent Maps

Ceres House, Searby Road, Lincoln, LN2 4DT
Customer services line: 03708 506 506
Email: enquiries@environment-agency.gov.uk
www.gov.uk/environment-agency

Flood Map centred on TL 08298 99678 - created February 2020 [Ref: CCN-2020-157897]



Environment Agency

Scale 1:10,000

N

Legend

- Modelled Node
- Main River
- Raised Defences
- Flood Storage Areas
- Area at Risk of Flooding from Rivers or The Sea
- Extreme Flood Outline

Dark blue shows the area that could be affected by flooding, either from rivers or the sea, if there were no flood defences. This area could be flooded:

- from the sea by a flood that has a 0.5% (1 in 200) or greater chance of happening each year.

- or from a river by a flood that has a 1% (1 in 100) or greater chance of happening each year.

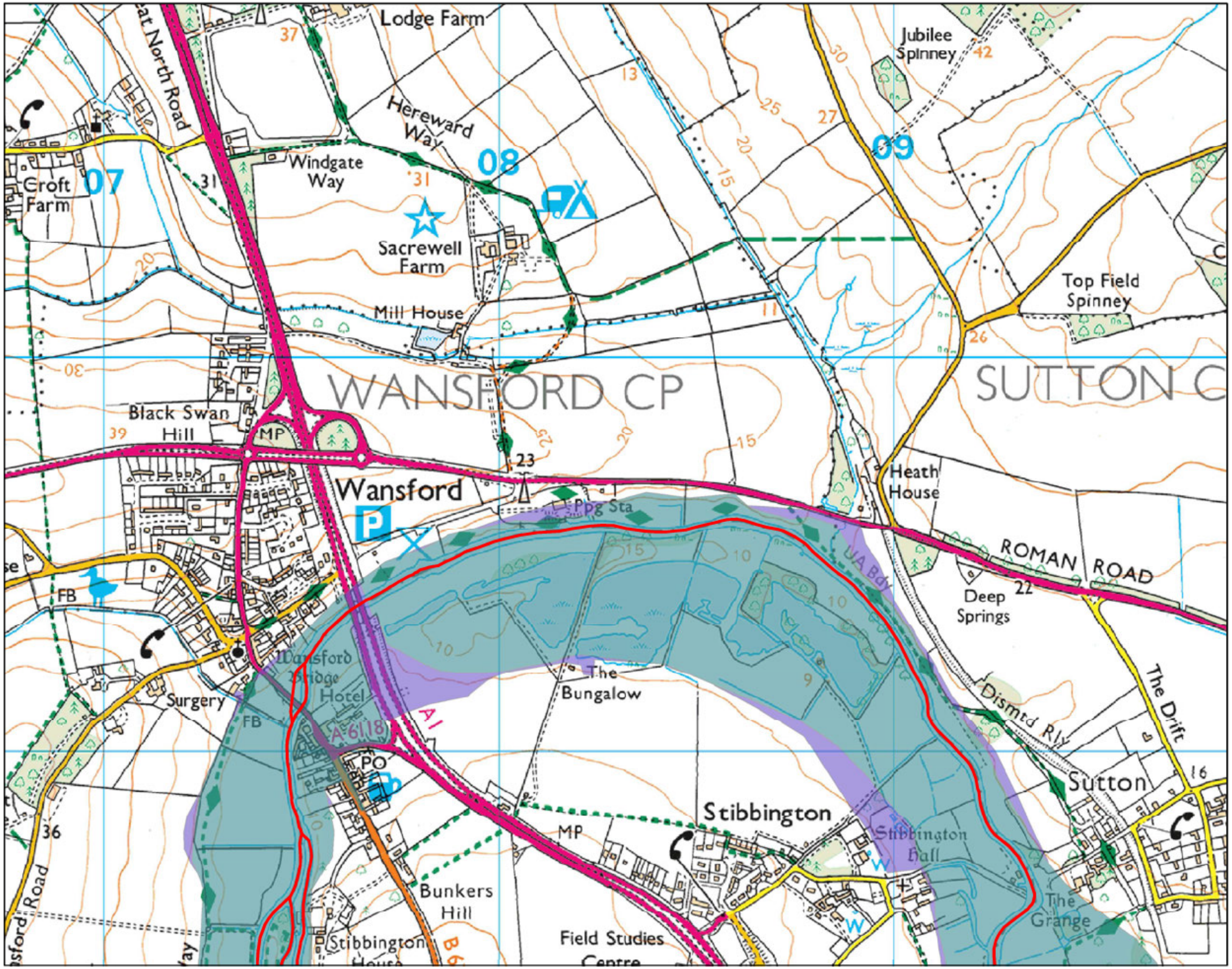
Light blue shows the extent of the Extreme Flood Outline, which represents the extent of a flood event with a 0.1% chance of occurring in any year, or the highest recorded historic extent if greater.

These two colours show the extent of the natural floodplain if there were no flood defences or certain other manmade structures and channel improvements. Sites outside the two extents, but behind raised defences, may be affected by flooding if the defences are overtopped or fail.

Created by the Partnerships and Strategic Overview Team, Kettering

Contact Us: National Customer Contact Centre, PO Box 544, Rotherham, S60 1BY. Tel: 03708 506 506 (Mon-Fri 8-6). Email: enquiries@environment-agency.gov.uk

Historic Flood Map centred on TL 08298 99678 - created February 2020 [Ref: CCN-2020-157897]



Environment Agency

Scale 1:10,000

N

Legend

- Main River
- Easter 1998 on the River Nene d/s of Northampton
- March 1947 on the River Nene d/s of Northampton

Created by the Partnership & Strategic Overview Team, Kettering

Contact Us: National Customer Contact Centre, PO Box 544, Rotherham, S60 1BY. Tel: 03708 506 506 (Mon-Fri 8-6). Email: enquiries@environment-agency.gov.uk

Fluvial Flood Levels (mODN)

The fluvial flood levels for the model nodes shown on the attached map are set out in the table below. They are measured in metres above Ordnance Datum Newlyn (mODN).

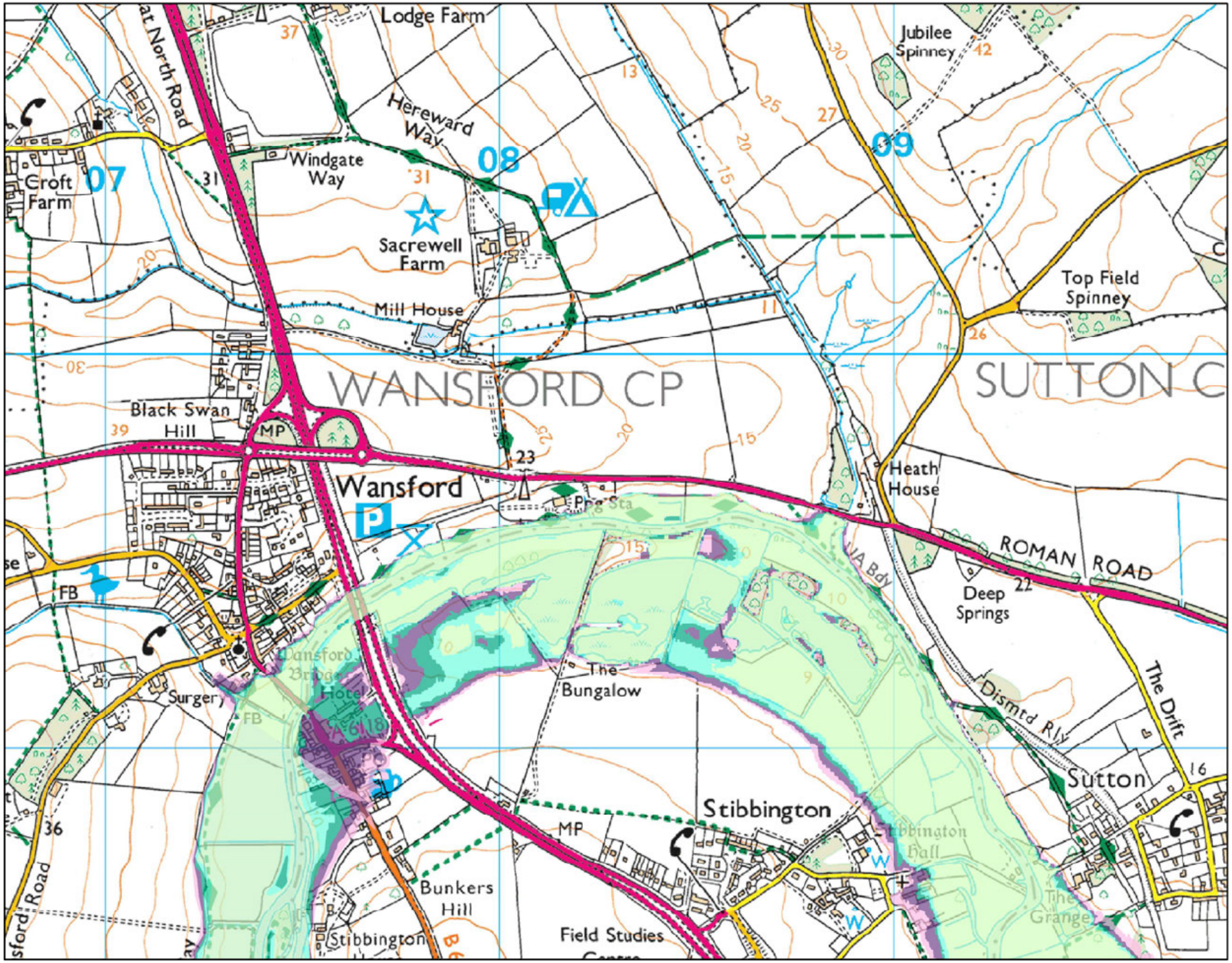
			Annual Exceedance Probability - Maximum Water Levels (mODN)											
Node Label	Easting	Northing	50% (1 in 2)	20% (1 in 5)	10% (1 in 10)	5% (1 in 20)	4% (1 in 25)	2% (1 in 50)	1.33% (1 in 75)	1% (1 in 100)	1% (1 in 100) inc 20% Climate Change	0.5% (1 in 200)	0.1% (1 in 1000)	0.1% (1 in 1000) inc 20% Climate Change
W5bd	507650	299424	9.48	9.80	9.90	10.03	10.06	10.23	10.25	10.29	10.45	10.41	10.72	10.93
W4	507842	299475	9.47	9.79	9.88	10.02	10.05	10.23	10.26	10.30	10.47	10.43	10.74	10.94
W2	508098	299556	9.44	9.75	9.83	9.97	10.00	10.19	10.22	10.26	10.45	10.41	10.75	10.98
W1	508558	299583	9.36	9.63	9.71	9.83	9.85	10.01	10.03	10.06	10.20	10.16	10.49	10.76
z0619a	508833	299477	9.27	9.50	9.57	9.68	9.70	9.85	9.88	9.91	10.05	10.01	10.38	10.68
L29-126	508996	299318	9.22	9.45	9.53	9.66	9.68	9.84	9.86	9.90	10.04	10.00	10.38	10.67
z0612a	509083	299142	9.22	9.45	9.53	9.66	9.68	9.84	9.87	9.90	10.05	10.01	10.39	10.68

Fluvial Flood Flows (m^3/s)

The fluvial flood flows for the model nodes shown on the attached map are set out in the table below. They are measured in metres cubed per second (m^3/s).

			Annual Exceedance Probability - Maximum Flows (m^3/s)										
Node Label	Easting	Northing	50% (1 in 2)	20% (1 in 5)	10% (1 in 10)	5% (1 in 20)	4% (1 in 25)	2% (1 in 50)	1.33% (1 in 75)	1% (1 in 100)	1% (1 in 100) inc 20% Climate Change	0.5% (1 in 200)	0.1% (1 in 1000)	0.1% (1 in 1000) inc 20% Climate Change
W5bd	507650	299424	60.18	88.20	100.33	120.49	124.17	150.85	155.84	163.16	196.92	188.02	258.78	312.81
W4	507842	299475	60.18	88.20	100.31	118.96	122.09	140.24	142.86	147.09	171.61	164.08	236.88	299.65
W2	508098	299556	60.17	85.89	94.52	104.50	105.62	112.37	113.05	114.01	119.69	117.90	136.15	158.29
W1	508558	299583	60.17	85.80	94.24	105.50	108.33	128.74	132.51	138.01	161.30	155.75	182.79	187.06
z0619a	508833	299477	60.24	83.19	88.36	98.43	100.23	110.20	111.66	113.70	123.79	121.54	129.27	130.53
L29-126	508996	299318	59.80	73.32	74.47	75.55	76.08	77.62	77.75	77.66	81.72	80.59	85.38	92.95
z0612a	509083	299142	59.80	70.83	72.33	73.89	74.48	75.84	75.91	75.85	77.00	77.37	78.39	91.34

Modelled Flood Extents (with defences)
Map centred onTL 08298 99678 - created February 2020 [Ref: CCN-2020-157897]



Environment Agency

Scale 1:10,000

N

Modelled Flood Extents (with defences)

Legend

- Main River
- 5% (1 in 20) Fluvial Event
- 1% (1 in 100) Fluvial Event
- 1% (1 in 100) Fluvial Event inc Climate Change
- 0.1% (1 in 1000) Fluvial Event
- 0.1% (1 in 1000) Fluvial Event inc Climate Change

Created by the Partnership & Strategic Overview Team, Kettering

Contact Us: National Customer Contact Centre, PO Box 544, Rotherham, S60 1BY. Tel: 03708 506 506 (Mon-Fri 8-6). Email: enquiries@environment-agency.gov.uk

Dunton, Karen

From:	National Requests <national.requests@environment-agency.gov.uk>
Sent:	25 March 2020 11:48
To:	Dunton, Karen
Subject:	NR160737
Attachments:	Abstraction points - licenced.xlsx; Abstraction reaches - licenced.xlsx; NR160737 returns.xlsx; NR160737 Consented discharges.xlsx

Dear Karen

Thank you for your enquiry which was received on 07 February 2020. Please accept my apologies for the delay in providing our response.

We respond to requests under the Freedom of Information Act 2000 and Environmental Information Regulations 2004.

I have attached the requested data to this email.

The following information is not available with the Open Government Licence but we may be able to license to you under the Environment Agency Conditional Licence:

- Subset of **Water Abstractions (AfA135)** coverage is within 5 km centred at NRG 645662, 265311 - **Description**: The water abstractions dataset details all sites covered under the Water Act 2003 where all abstractions of 20 cubic metres or more require an abstraction licence. The dataset consists of two tables: the first holds details of all live water abstraction licences in England and Wales. Expired, lapsed and revoked licences are excluded & the second (supplementary) table holds details of maximum annual and maximum daily abstraction quantities. The quantities are the maximum permitted under the licence; they give an indication of the size of the abstraction. Some licences may include aggregating conditions or other conditions which restrict the abstraction; these are not included in the dataset. **Format:** MS Excel. **Special Conditions:** Please use conditions as set out by the Register of Licence Abstracts for AfA135.
- **Aquifer Type for Live Licences**, area of coverage: Wansford area, Guyhirn, Tuddenham, Thickthorn and Blofield - **Description:** Aquifer Type(s) for the current version of live water abstraction licences (March 2020). **Format:** MS Excel. **Special Conditions:** Please use conditions as set out by the Register of Licence Abstracts for AfA135. **Information warnings:** **1)** Information provided is based on that available at the time of preparation (March 2020). **2)** 'AQUIFR_TYP' in some cases might not reflect the current lexicon. **3)** 'AQUIFR_TYP' might not be available for all licences.

However, you must first check the supporting information and the above link to determine if the conditions on use are suitable for your purposes. If they aren't, this information is not provided with a licence for use, and the data is provided for read right only."

Please get in touch if you have any further queries or contact us within two months if you'd like us to review the information we have sent.

Yours sincerely

Beth Allott
National Customer Contact Centre
Environment Agency

☎ Tel: 03708 506 506
Web Site: www.gov.uk/environment-agency

[redacted]

[redacted]

Abstraction reaches - licensed											
Section	LIC_NO	USE	ABS_START	ABS_END	SOURCE	POINT_NAME	CART1EAST	CART1NORTH	CART2EAST	CART2NORTH	AQUIFR_TYP
Wansford	5/32/10/*S/0014B	Milling & Water Power Other	01/04	30/09	SURFACE WATER SOURCE OF SUPPLY	WATERCOURSE AT SACREWELL	507800	301800	508900	299700	
Wansford	5/32/10/*S/0014B	Spray Irrigation - Direct	01/04	30/09	SURFACE WATER SOURCE OF SUPPLY	STREAM AT SACREWELL	507400	300100	508800	300100	
Wansford	5/32/10/*S/0008	Spray Irrigation - Direct	01/04	30/09	SURFACE WATER SOURCE OF SUPPLY	TRIB OF NENE "A - B"	506500	300900	507400	300100	
Wansford	5/32/10/*S/0008	Spray Irrigation - Direct	01/04	30/09	SURFACE WATER SOURCE OF SUPPLY	TRIB OF RIVER NENE "B - C"	507400	300100	505800	299900	
Wansford	5/32/09/*S/0225/R01	Spray Irrigation - Direct	01/04	30/09	SURFACE WATER SOURCE OF SUPPLY	RIVER NENE "G - H" AT SIBSON	509350	298621	509300	298030	
Wansford	5/32/09/*S/0225/R01	Spray Irrigation - Direct	01/04	30/09	SURFACE WATER SOURCE OF SUPPLY	RIVER NENE "E - F" AT SIBSON	509020	299261	509120	299041	
Abstraction points - licensed											
Wansford	5/32/10/*S/0061	Spray Irrigation - Storage	01/11	31/03	SURFACE WATER SOURCE OF SUPPLY	THORNHAUGH BECK AT THORNHAU	507900	300000			
Wansford	5/32/09/*S/0225/R01	Spray Irrigation - Storage	01/01	31/03	SURFACE WATER SOURCE OF SUPPLY	RIVER NENE "A" AT SIBSON	507890	299482			
Wansford	5/32/09/*S/0202	Transfer Between Sources (F	01/04	31/03	SURFACE WATER SOURCE OF SUPPLY	RIVER NENE - WANSFORD	508160	299580			

Info on Wansford and Guyhirn- NR160737

Guyhirn NGR *TF 39844 02987*

- Abstraction: No licensed abstractions in the area.
- Groundwater levels: Consult GWCL.
- Groundwater quality: Consult GWCL.
- Rainfall: https://www.gov.uk/government/publications/weekly-rainfall-and-river-flow-reports-for-england
- Pumping tests: Not sure what this means.
- Yare & North Norfolk regional groundwater model reports: Not sure what this means.
- SPZ: No source protection zones or locations within 1km.
- Surface water level and flow: https://www.gov.uk/government/publications/weekly-rainfall-and-river-flow-reports-for-england
- Surface water quality: https://environment.data.gov.uk/water-quality/view/landing
- Consented Discharges: Woodland Gardens PRNNF18055, Homelands PRNNF18777, Guyhirn Sewage Disposal Works, PR5NF191.
- Flood risk assessment map: Attached.

Wansford *TL 08981 99576*

- Abstraction: *Purpose:* Water Supply, *Use:* Transfer Between Sources (Post Water Act 2003), *Lic. no:* 5/32/09/*S/0202; *Purpose:* Agriculture, *Use:* Spray Irrigation – Storage, *Lic. no:* 5/32/09/*S/0225/R01. *Purpose:* Production Of Energy, *Use:* Milling & Water Power Other Than Electricity Generation, *Lic. no:* 5/32/10/*S/0014B, *Purpose:* Agriculture, *Use:* Spray Irrigation – Direct, *Lic. no:* 5/32/09/*S/0225/R01.
- Groundwater levels: Consult GWCL.
- Groundwater quality: Consult GWCL.
- Rainfall: https://www.gov.uk/government/publications/weekly-rainfall-and-river-flow-reports-for-england
- Pumping tests: Not sure what this means.
- Yare & North Norfolk regional groundwater model reports: Not sure what this means.
- SPZ: No source protection zones or locations within 1km.
- Surface water level and flow: https://www.gov.uk/government/publications/weekly-rainfall-and-river-flow-reports-for-england
- Surface water quality: https://environment.data.gov.uk/water-quality/view/landing
- Consented Discharges: None within 1km.
- Flood risk assessment map: Attached,

Annex B. Wittering Brook hydraulic modelling technical note

Table of contents

Figures

Tables

1. Introduction

1.1. General

1.1.1. Sweco were commissioned to provide a hydraulic modelling analysis of the Wittering Brook A47 Wansford Sluice and Mill Stream A1 culvert as part of the A47 Wansford to Sutton Dualling scheme ('Proposed Scheme').

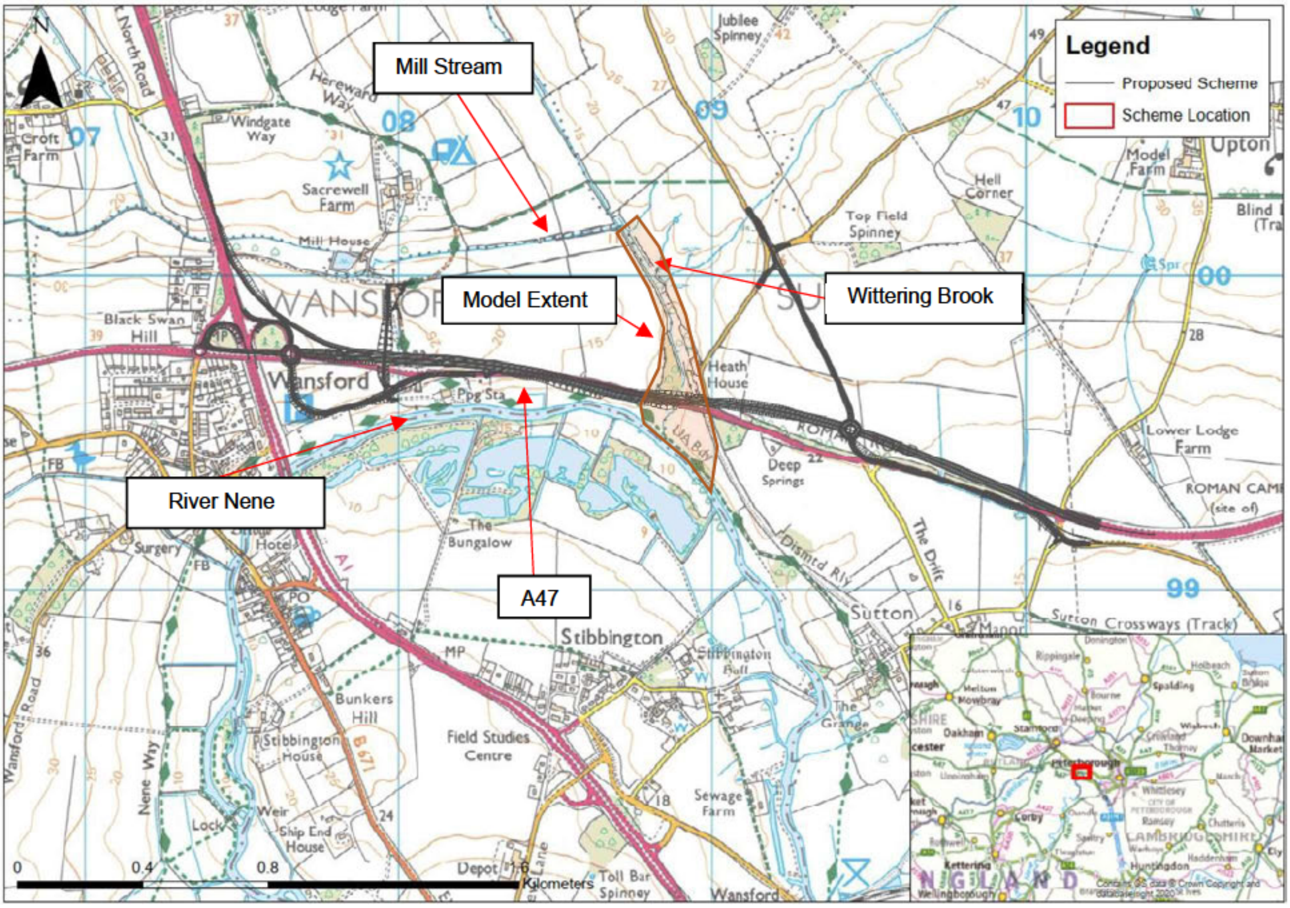
1.1.2. The Proposed Scheme involves the construction of a new length of dual carriageway which largely follows the existing A47 and replaces the existing 2.5km length of single lane carriageway. Widening of the carriageway at the Wittering Brook, will require detailed design of an extension or replacement to the A47 Wansford Sluice, conveying flow to outfall to the River Nene.

1.1.3. A hydraulic model of the Wittering Brook was developed to characterise the baseline flooding conditions of the brook and its respective floodplain to inform culvert design and flood compensatory storage. This technical note summarises the modelling procedures as well as the output results and analysis.

1.2. Study area

1.2.1. Wansford is a village within the administrative area of Peterborough City Council, Cambridgeshire. The village is located on the banks of the River Nene, adjacent to the A1 road junction with the A47. The Proposed Scheme is located approximately 1.6km east of Wansford. Figure 1-1 shows the general location of the study area and a more detailed map showing the Proposed Scheme.

Figure 1-1: Study area. Contains OS data (Crown copyright and database rights 2020).



1.2.2. The wider area is predominantly flat, low lying arable land interspersed with woodland areas. Wittering Brook is an ordinary watercourse which drains north to south towards Wansford Sluice, a Highways England culvert, beneath the A47. Flood risk matters pertaining to the Wittering Brook are the responsibility of Peterborough City Council. The Wittering Brook is mainly spring fed along with its tributary, Mill Stream.

1.2.3. The Wittering Brook drains a catchment area of approximately 47km^2 to the north of Wansford, the upstream extent stretches as far as RAF Wittering. The brook is mostly a naturally flowing unmade open watercourse with sections of small culvert mostly serving field access points in the upstream catchment.

1.3. Data sources

1.3.1. The following data sources were used to inform the hydraulic modelling:

- Cross section survey undertaken by Storm Geomatics in 2020 with associated drawings and photographs;
- Geomorphological survey with photographs undertaken by Sweco in 2020;

- Google Earth satellite imagery;
- 1m resolution DTM LiDAR flown in 2019 available (DEFRA, 2020);
- Ordnance Survey (OS) MasterMap data;
- Manning's n roughness table based on Chow, 1959 (Oregon State University Forestry Science Laboratory, 2006)

1.3.2. At project inception, Sweco submitted data requests to Peterborough City Council and the Environment Agency for access to any previous modelling studies. There was no previously available hydraulic model suitable for use in this study and therefore a new model was required.

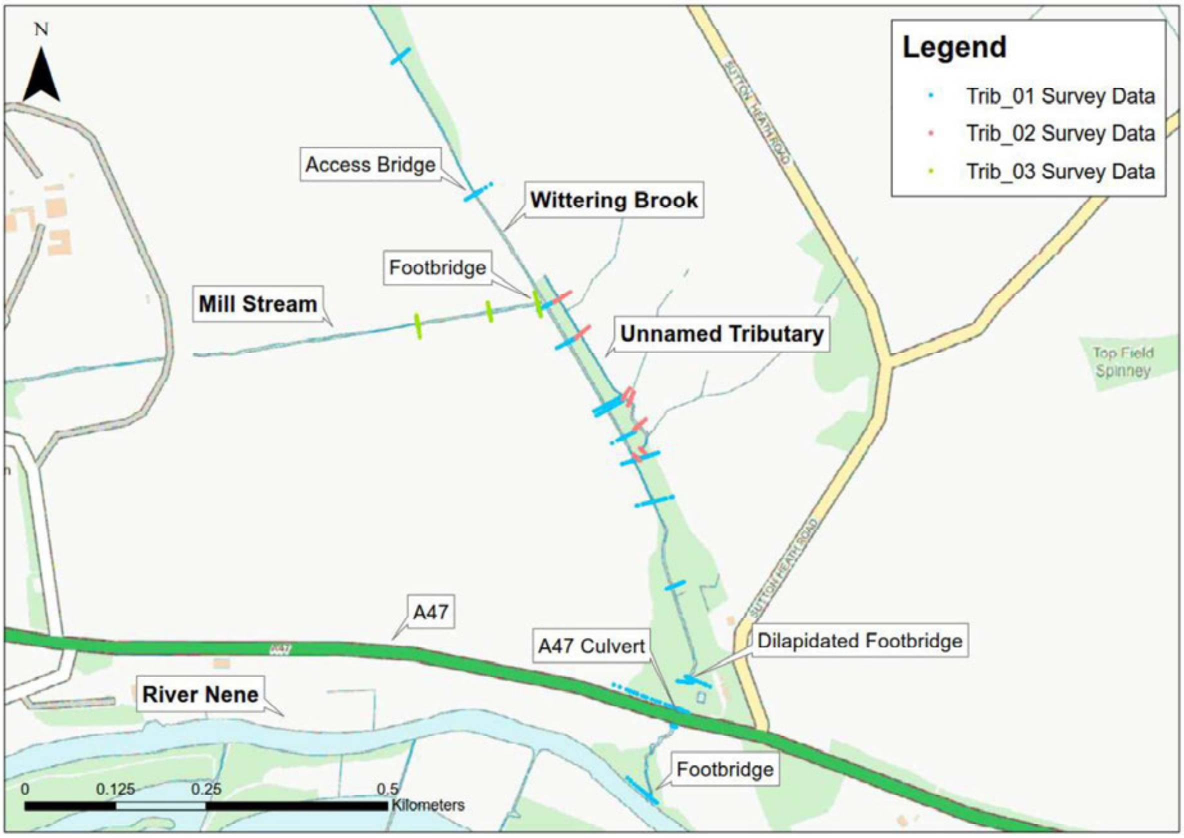
2. Survey data

2.1.1. A river survey of the Wittering Brook (Trib_01), an unnamed tributary (Trib_02) and Mill Stream (Trib_03) was carried out by Storm Geomatics in June 2020. The survey provided 29 channel cross sections including five hydraulic structures (see Figure 2-1).

2.1.2. The two key objectives from the hydraulic modelling were to determine peak flows at the upstream end of the A47 Wansford Sluice and to determine any compensatory storage volume requirements as a result of the Proposed Scheme land take displacing Wittering Brook floodplain. The output from the hydraulic modelling will ultimately inform the Flood Risk Assessment.

2.1.3. In the interest of simplicity, the surveyed sections upstream of Wittering Brook and Mill Stream confluence were omitted from the analysis. This also constitutes a conservative approach to the model build as any out of bank flows upstream of the confluence would now contribute to an increase in flood volumes and peak levels at the A47 Wansford Sluice. Furthermore, a number of sections of the unnamed tributary (which collects flow from agricultural land drains) were dry at the time of survey. It was assumed the tributary would have no hydraulic influence on flows downstream and was therefore omitted from the model.

Figure 2-1: River survey detail. *Contains OS data (Crown copyright and database rights 2020).

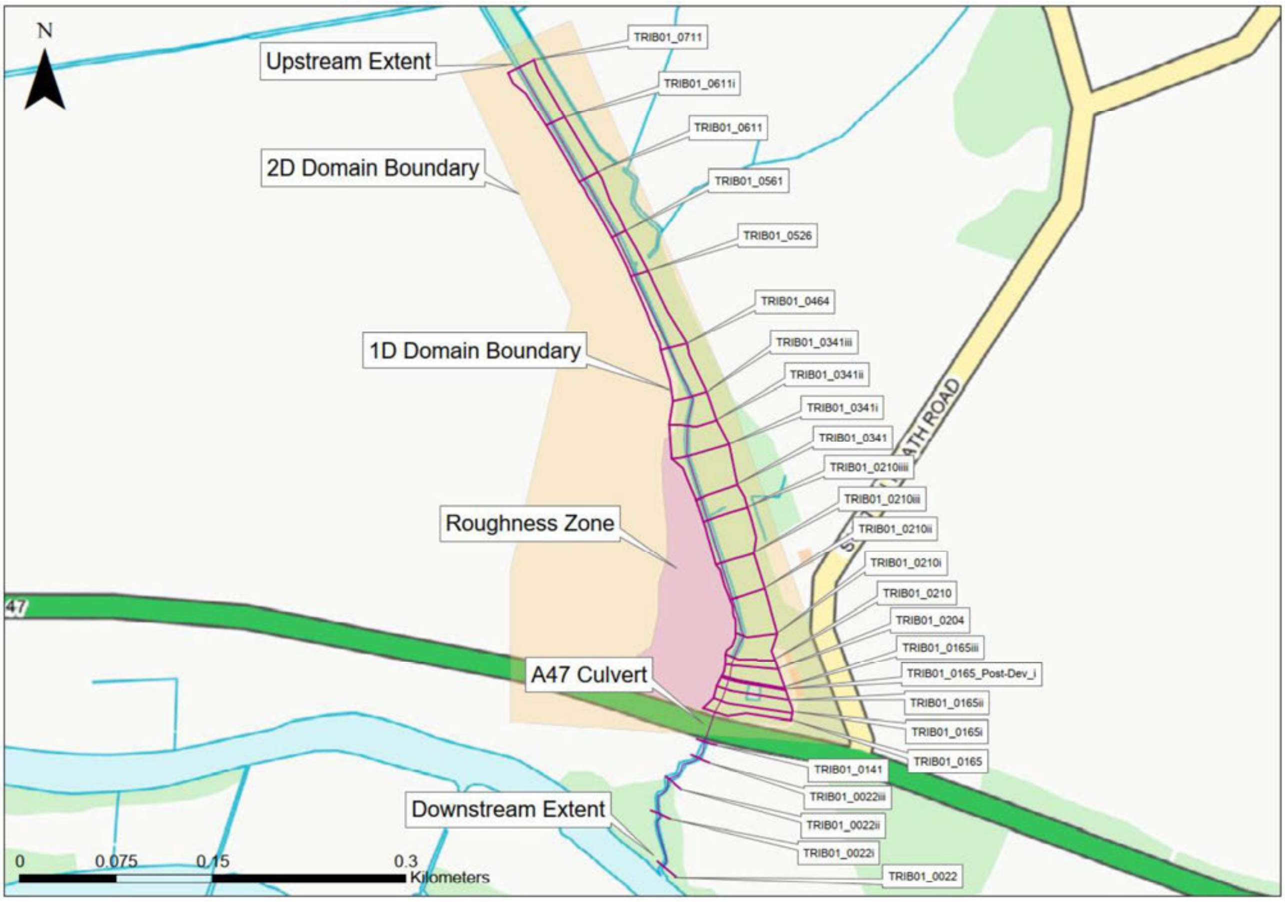


3. Hydraulic model build

3.1. Wittering Brook hydraulic model

3.1.1. A hydraulic model of the Wittering Brook was developed using InfoWorks Integrated Catchment Modelling (ICM, Version 9). The software allows for integration of 1D and 2D modelling and is therefore well suited to represent both in-channel and out of bank floodplain processes. The model was built using a combination of the surveyed cross sections, DTM LiDAR, geomorphology survey photographs and Google satellite imagery. Figure 3-1 gives an overview of the Wittering Brook InfoWorks ICM model.

Figure 3-1: InfoWorks model extent. Contains OS data (Crown copyright and database rights 2020).



3.1.2. The model consists of a 0.68km reach of Wittering Brook with 11 cross sections provided by surveyed data. A further 14 sections were created by interpolation to maintain a maximum distance of approximately 50m between sections to improve spatial resolution of 1D calculations. Additional interpolates were added upstream of the A47 to help convey flow through the culvert. Surveyed sections were named 'TRIB01_' followed by the distance in metres from where the Wittering Brook outfalls to the River Nene. Interpolated sections were assigned a prefix ‘i’ as appropriate. Section ‘TRIB01_0165_Post-Dev_i’ was added to the baseline network for continuity with the post-development networks.

3.1.3. The sections were compared against 2019 1m DTM LiDAR from the National LiDAR Programme. The LiDAR was confirmed to be a suitable fit with the surveyed sections and the 1D domain was extended to high points accordingly. Between sections TRIB01_0341ii and TRIB01_0210iiii, the 1D domain was extended to beyond the high point of the banks to include to a small drainage ditch running parallel to the main channel.

3.1.4. The panelling of the sections, which is attributed to changes in roughness, was conducted by inspection of photographs of the sections and Google Earth satellite images. A summary of channel roughness values used in the model is included in Table A.1 in Appendix A.

3.1.5. The A47 Wansford Sluice was modelled as an arch culvert with a natural bed. Inlet losses were accounted for using InfoWorks ICM recommended culvert inlet loss parameters. A normal head loss was applied to the outlet. Both LiDAR and survey data confirmed it was highly improbable for the road deck (14.35mAOD) to be overtopped by the 100-year plus climate change allowance peak level (10.81mAOD). As such, no weir was used to represent overtopping conditions.

3.1.6. Two structures viewed using OS MasterMap and Google Earth were identified as sheds belonging to properties located east of the A47 Wansford Sluice. Both sheds were within the Proposed Scheme boundary and would be removed during construction. Furthermore, it is assumed that during large storm events both sheds would flood as a result of the Wittering Brook.

3.1.7. The upstream extent of the model was placed at TRIB01_0711, 60m downstream of the Mill Stream and Wittering Brook confluence. The downstream extent of the model was placed at TRIB01_0022, 22m upstream of the River Nene and Wittering Brook confluence.

2D domain

3.1.8. The routing of overland flow is primarily influenced by the underlying terrain. The 2D domain was added to allow out of bank flow in the area of interest upstream of the A47 Wansford Sluice. The availability of higher resolution topographic data and advances in computing hardware mean that smaller cell sizes can now be modelled. This mesh was based on 1m LiDAR from the National LiDAR Programme flown in 2019 and a minimum element area of 5m² was applied. Terrain-sensitive meshing was also applied to improve resolution in areas with more significant elevation changes. The boundary of the 2D zone was set to a ‘normal depth’ condition, which assumes uniform flow out of the boundary.

3.1.9. Google Earth satellite imagery and survey photographs indicated the primary flood plain consists mainly of pasture land with high grass. A Manning's *n* roughness of 0.06 consistent with high grass pasture was applied. Key parameters including roughness used for the 2D domain are summarised in Table A.2 of Appendix A.

3.1.10. A void was created over the upstream section of the A47 Wansford Sluice to ensure no flow would pass out of the 2D domain and around the structure headwall. A 2D roughness zone was created in the model to represent the wooded area within the floodplain. An appropriate Manning's *n* roughness value for heavy stand of timber with little undergrowth was applied to the zone.

1D-2D connections

3.1.11. Firstly, an unsteady state analysis using desired design flows with allowances for climate change was run to determine appropriate locations for 1D-2D connections. Flows were only recorded out of bank for the section of the reach from the upstream extent to the A47 Wansford Sluice. Bank connections were therefore only added for this section of the model north of the A47.

3.1.12. The computational 1D-2D domain is defined by bank lines connecting the cross section ends. Further levels along the banks between cross sections were sampled using the high points of the 1m LiDAR. In some instances, cross sections were extended, with the extensions updated from LiDAR.

3.1.13. Banks were assigned discharge coefficients and modular limits in line with model computational limits. These were reduced within acceptable tolerance to 0.9 and 0.6 respectively to improve stability of out of bank flow. Model parameters are presented in Table A.1, Appendix A. Table 4-5 shows the results of the sensitivity analysis of the bank coefficients.

Boundary conditions

3.1.14. The methods used to create the design hydrographs for the model are explained in Appendix B - FEH Hydrological Assessment. Design hydrographs were derived using two separate hydrological methods, the ReFH2.3 and WINFAP 4 FEH Statistical methods. The ReFH2.3 hydrology produced more conservative flows and was used as the hydrological inflows for culvert design.

3.1.15. The hydrographs capture flows for the whole of the Wittering Brook catchment and were applied at cross section TRIB01_0711, the upstream extent of the model.

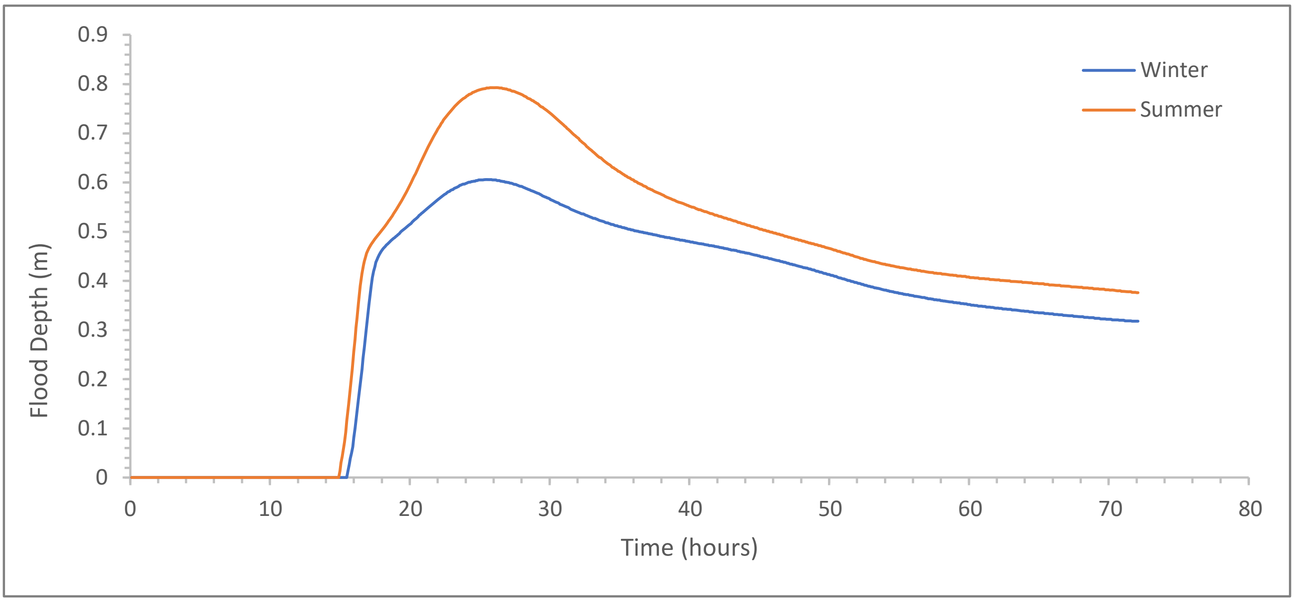
3.1.16. Allowances for climate change were made by scaling the hydrographs by a factor based on the most recent Environment Agency (2020) guidance for the

Anglian region. This was based on the 'Higher central', 'Upper end' and 'H++' allowances for 'Essential infrastructure' in Flood Zone 3 with a time horizon of '2080s'.

3.1.17. The model was initially tested using the 1 in 100-year summer and winter storm profiles to determine the most critical rainfall event duration. The summer event produced higher flows, levels and flood volumes in the 2D zone and was ultimately used for the design events.

3.1.18. Figure 3-2 compares the difference in flood depth between the 1 in 100-year summer and winter storm profiles in element 4704 of the baseline model.

Figure 3-2: 1 in 100-year seasonal depth profile



3.1.19. The following summer storm profile events were simulated:

- 1 in 2-year event (50% AEP);
- 1 in 10-year event (10% AEP);
- 1 in 100-year event (1% AEP);
- 1 in 100-year event with a 35% allowance for climate change;
- 1 in 100-year event with a 65% allowance for climate change.
- 1 in 100-year event with a 80% allowance for climate change

Run parameters

3.1.20. The model was run for 72 hours with a 1 second timestep and a results timestep output of 5 minutes. All run parameters remained as per default settings.

3.2. A1 culvert extension HY-8 analysis

3.2.1. An analysis of the A1 culvert was carried out using HY-8 (v7.70.1.0, June 2021; Federal Highway Administration, 2021). Survey data was used to define the software input parameters such as channel dimensions, roadway data and culvert data. The existing culvert consists of a 2.05m diameter concrete pipe followed by a 2.15m diameter corrugated steel pipe (Armco) extension. The concrete pipe had become silted up over time, the full length of the culvert is 40.60m. It was assumed that flows would be throttled by the smaller diameter concrete pipe at the upstream end and as such the 2.05m concrete pipe has been modelled for the full length of the culvert, this is considered a conservative representation.

3.2.2. The existing culvert was assessed using a Manning's n roughness of 0.035 for the bottom section of pipe and 0.012 for the upper section of pipe.

3.2.3. Invert levels of the culvert and downstream channel levels and dimensions were taken from the watercourse topographic survey.

3.2.4. A pipe embedment depth of 0.35m was used to represent the silting up of the existing culvert.

3.2.5. A square headwall arrangement was used within HY-8.

3.2.6. The following summer storm peak flows were assessed:

- 1 in 2-year event (50% AEP);
- 1 in 10-year event (10% AEP);
- 1 in 100-year event (1% AEP);
- 1 in 100-year event with a 35% allowance for climate change;
- 1 in 100-year event with a 65% allowance for climate change;
- 1 in 100-year event with a 80% allowance for climate change.

4. Baseline model results

4.1. Wittering Brook hydraulic model results

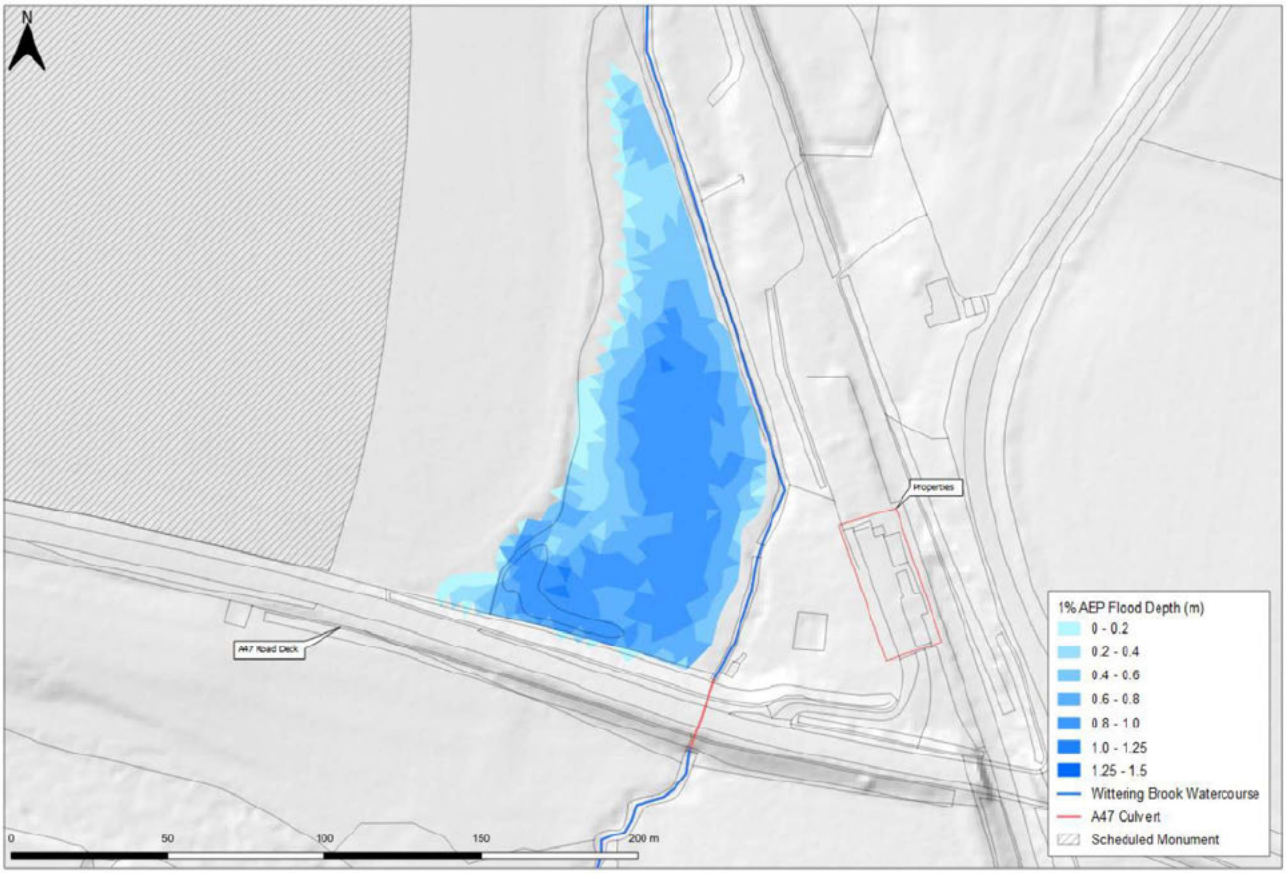
4.1.1. Maps of predicted flooding in the Wittering Brook floodplain are given in Appendix C. Table 4-1 gives the maximum flood depths, flood volumes and flooded area recorded in the 2D domain.

Table 4-1: Predicted baseline maximums

	1 in 10-year event	1 in 100-year event	1 in 100-year event (35% climate change)	1 in 100-year event (65% climate change)	1 in 100-year event (80% climate change)
Maximum Depth (m)	0.60	1.00	1.27	1.51	1.60
Maximum Flooded Area (m^2)	6567	8153	8942	10566	11069
Maximum Flooded Volume (m^3)	2156	5226	7438	9705	10406

4.1.2. As can be seen from Figure 4-1, flooding in the 2D domain remains exclusively to the Wittering Brook floodplain. The flooded area largely resembles the woodland located northwest of the A47 Wansford Sluice. The 1 in 100-year event shows water rising up the north side of the A47 embankment; however, flows do not overtop the A47 road deck, as expected. There is no out of bank flow over the left bank and the properties to the north east of the A47 Wansford Sluice are not predicted to flood. Flow is throttled by the A47 Wansford Sluice and remains in-bank south of the A47 before discharging to the River Nene.

Figure 4-1 The 1 in 100-year event flood map. Contains OS data (Crown copyright and database rights 2020).



4.1.3. The existing A47 Wansford Sluice (1.83m x 1.64m) was modelled for the 1 in 100-year plus 65% climate change event to enable comparison to the post-development options. Table 4-2 shows the maximum predicted depth and flow in the A47 Wansford Sluice for the 1 in 100-year plus 65% climate change event.

Table 4-2: A47 Wansford Sluice predicted maximums 1 in 100-year plus 65% climate change

	Upstream	Downstream
Maximum depth (m)	1.64	1.64
Peak flow (m^3/s)	6.59	6.56
Freeboard (m)	0.00	0.00

Sensitivity analysis

4.1.4. Additional simulations were run to test model sensitivity to variation in key parameters and boundary conditions. The following sensitivity tests were carried out using the 1 in 100-year event:

- Adjusting channel roughness values by +/- 20%

- Adding a constant water level of the 1 in 50-year peak River Nene level at the downstream extent
- Adjusting the inflow hydrographs by +/- 20%
- Adjusting 2D domain roughness values by +/- 20%
- Adjusting the bank discharge coefficients by +/- 20%
- Adjusting the bank modular limits by +/- 20%

4.1.5. Table 4-3 shows that the model is marginally sensitive to changes in channel roughness and flow with the 20% changes in input corresponding to 9.5% for roughness and 16.3% to flow, as expected. The addition of a downstream boundary corresponds to a 22.7% increase in depth to the downstream cross section in the model. The effects of the downstream boundary do not propagate upstream and significant changes to depths and levels remain exclusive to section TRIB01_0022 (the downstream section in the model).

Table 4-3: 1D model sensitivity results

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% Channel Roughness	0.10	0.04	7.90%	3.40%
-20% Channel Roughness	-0.12	-0.05	-9.50%	-4.10%
Constant 1 in 50-year peak River Nene level at downstream boundary	0.90	0.01	22.70%	0.90%
+20% flows	0.21	0.15	16.30%	11.70%
-20% flows	-0.21	-0.14	-15.60%	-11.50%

4.1.6. The model is not sensitive to changes in roughness in the 2D domain, bank discharge coefficients or modular limits. Table 4-4 shows a 20% change to one of the model parameters equates to no more than a 5% change to maximum depth recorded in the 2D domain.

4.1.7. Table 4-5 shows a 20% change to one of the model parameters equates to no more than a 4.31% change to maximum volume recorded in the 2D domain.

Table 4-4: 2D model sensitivity results

Scenario	Maximum change in peak 2D depth (m)	Maximum change in peak 2D depth (%)
+20% 2D Roughness	0.05	5.00
-20% 2D Roughness	-0.04	-4.40
+20% Discharge coefficient	0.05	4.76
-20% Discharge coefficient	0.03	3.26
+20% Modular limit	0.00	0.00
-20% Modular limit	-0.01	-1.00

Table 4-5: 2D model sensitivity results continued

Scenario	Maximum change in peak 2D volume (m^3)	Maximum change in peak 2D volume (%)
+20% 2D Roughness	214.38	4.10
-20% 2D Roughness	-189.00	-3.62
+20% Discharge coefficient	234.66	4.31
-20% Discharge coefficient	177.25	3.27
+20% Modular limit	-14.83	-0.28
-20% Modular limit	-41.60	-0.80

4.2. A1 culvert assessment

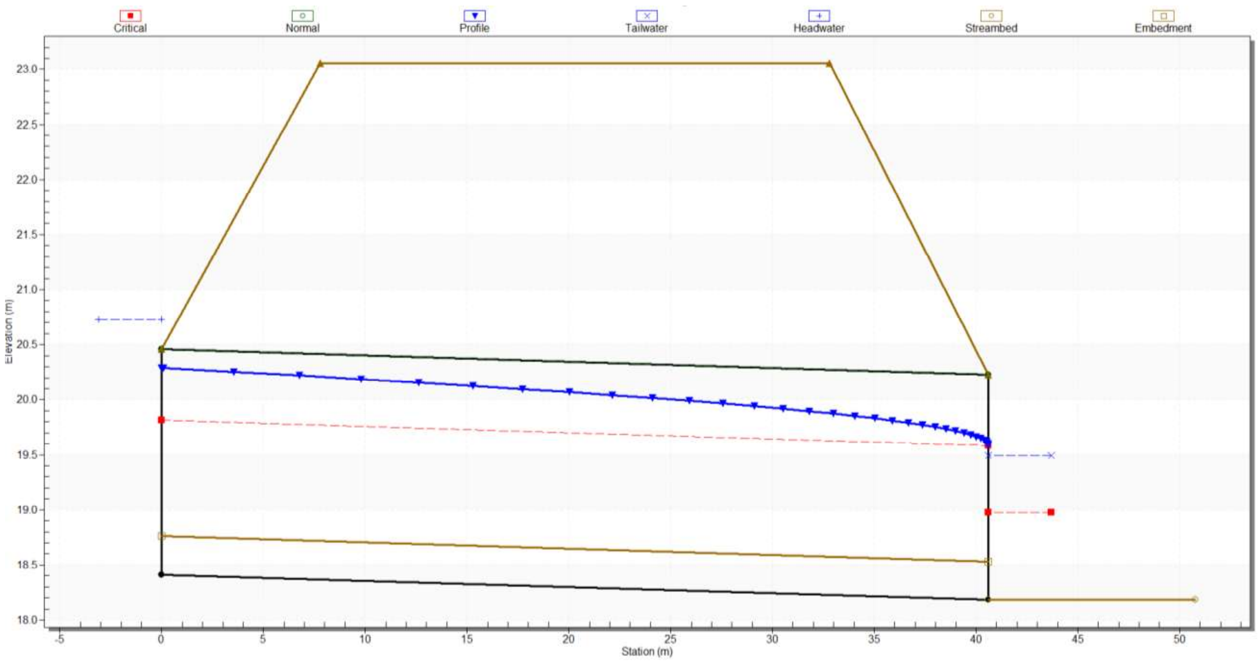
Baseline

4.2.1. The results for the A1 HY-8 culvert baseline analysis given in Table 4-6 shows a long section of the culvert for the 1 in 100-year plus 65% climate change event.

Table 4-6: Results from the HY-8 culvert analysis

Event	Peak Culvert Flow (m^3/s)	Headwater Depth (m)	Tailwater Depth (m)
QMED	0.78	0.86	0.44
1 in 10 year	1.64	1.16	0.66
1 in 100 year	4.39	1.83	1.08
1 in 100 year + 35%	5.56	2.09	1.21
1 in 100 year + 65%	6.57	2.32	1.31

Figure 4-2: HY-8 A1 long section and 1 in 100-year plus 65% climate change event



5. Proposed development

5.1.1. The Proposed Scheme requires constructing within the Wittering Brook floodplain and widening the A47 carriageway. As such, there is a need to extend the A47 Wansford Sluice to a maximum total length of 60m to continue to convey flow beneath the carriageway. Three options were considered for the Proposed Scheme. Each option was required to achieve 0.6m freeboard and 0.3m soft bed for the 1 in 100-year plus 65% climate change event. A proposed mammal ledge was to be accounted for within the freeboard. Flood depths for the Proposed Scheme options are given in Appendix C.

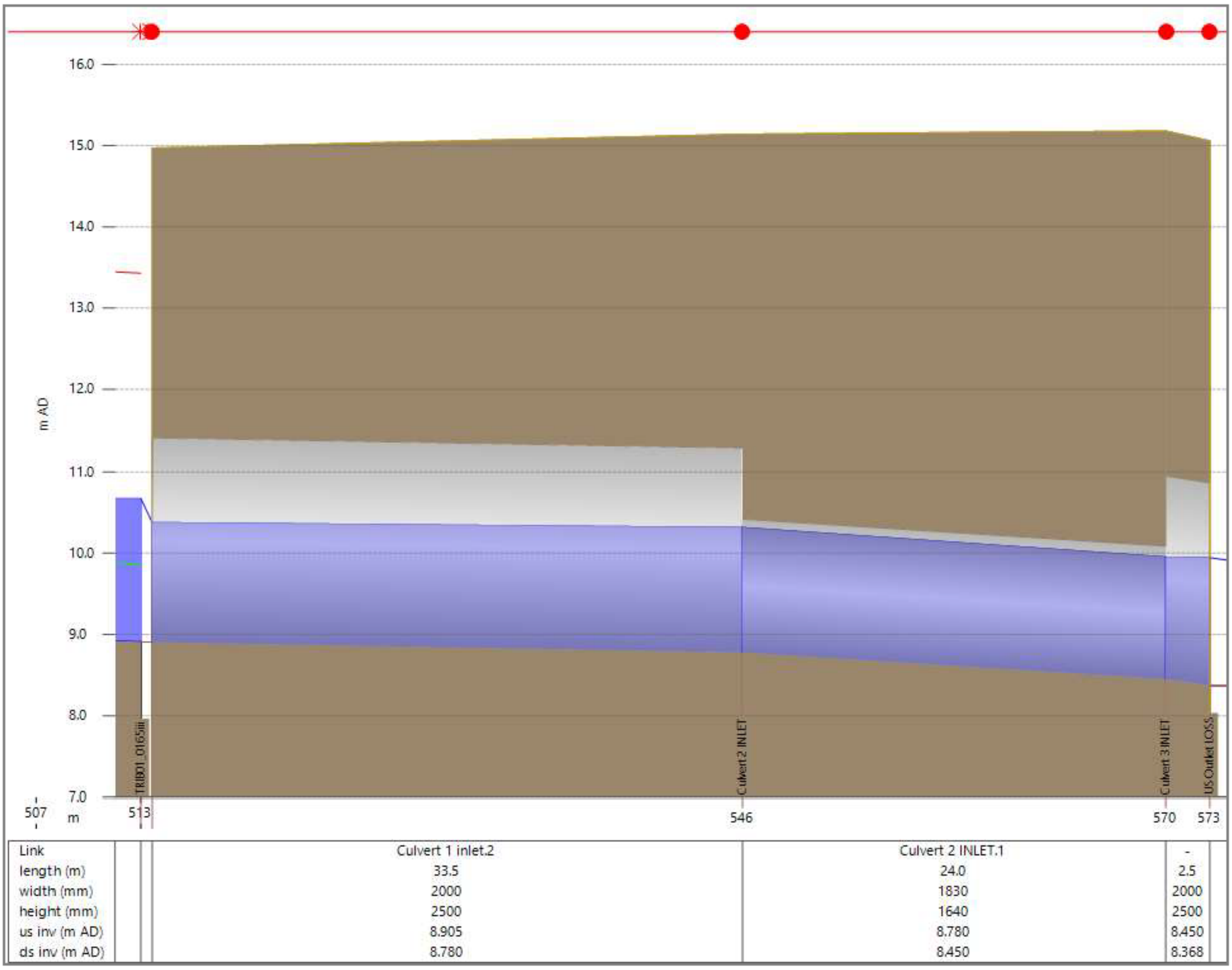
5.2. A47 Wansford Sluice - option 1

5.2.1. Option 1 consists of an extension of the existing 24m culvert by 33m to the north and 3m to the south using a 2.0m x 2.5m boxed concrete culvert. Table 5-1 gives the maximum predicted water depth, peak flow and the freeboard at the culvert inlet and outlet. A long section of the flow through the culvert is shown in Figure 5-1.

Table 5-1 Option 1 predicted maximums 1 in 100-year plus 65% climate change event

	Upstream	Downstream
Maximum Depth (m)	1.47	1.57
Peak Flow (m^3/s)	6.56	6.56
Freeboard (m)	1.03	0.93

Figure 5-1 Option 1 culvert long section 1 in 100-year plus 65% climate change event



5.3. A47 Wansford Sluice - option 2

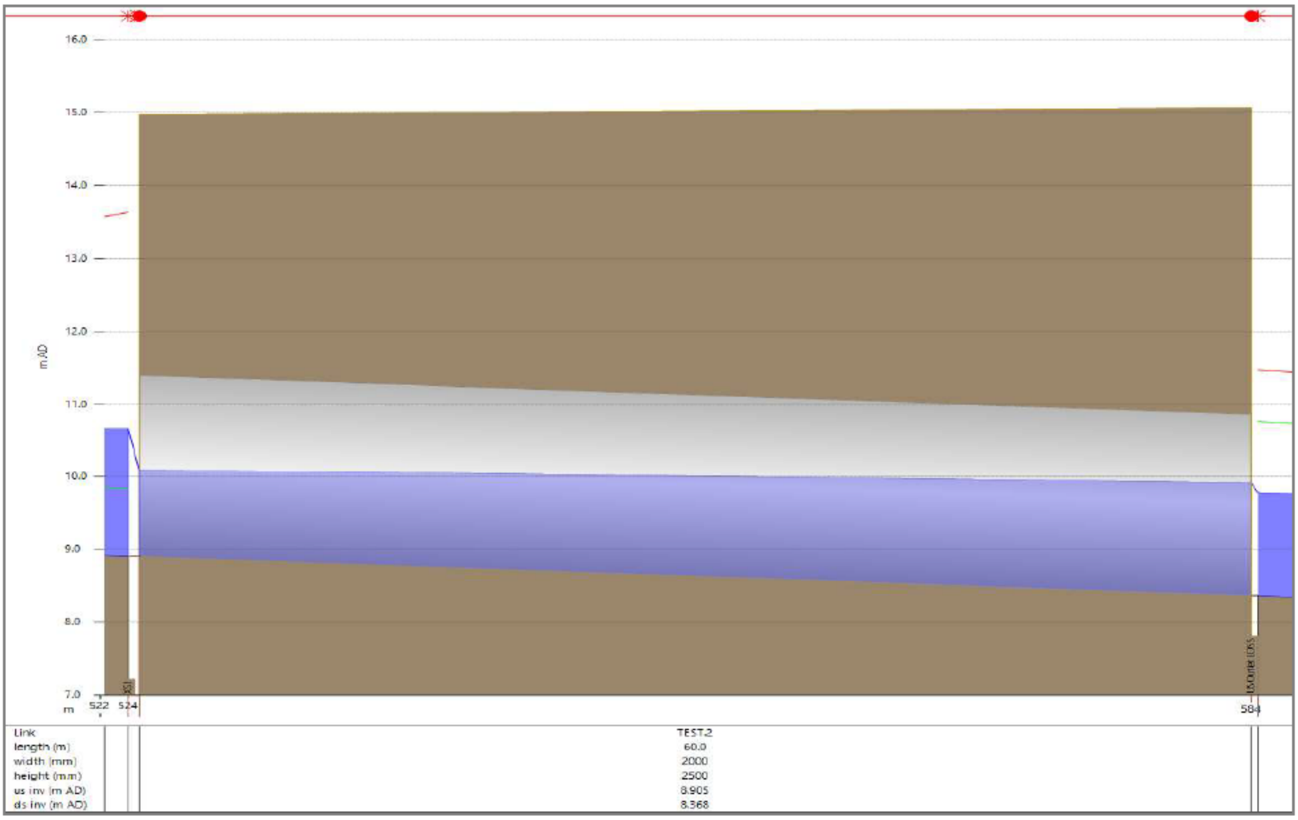
Option 2a

5.3.1. Option 2a consists of replacing the existing culvert with a 2.0m x 2.5m boxed concrete culvert for a proposed length of 60m. Table 5-2 shows the predicted maximum water depth, peak flow and freeboard through the culvert. A long section of the flow through the culvert is shown in Figure 5-2.

Table 5-2 Option 2a predicted maximums 1 in 100-year plus 65% climate change event

	Upstream	Downstream
Maximum Depth (m)	1.19	1.54
Peak Flow (m^3/s)	6.56	6.56
Freeboard (m)	1.31	0.96

Figure 5-2: Option 2a culvert long section 1 in 100-year plus 65% climate change event



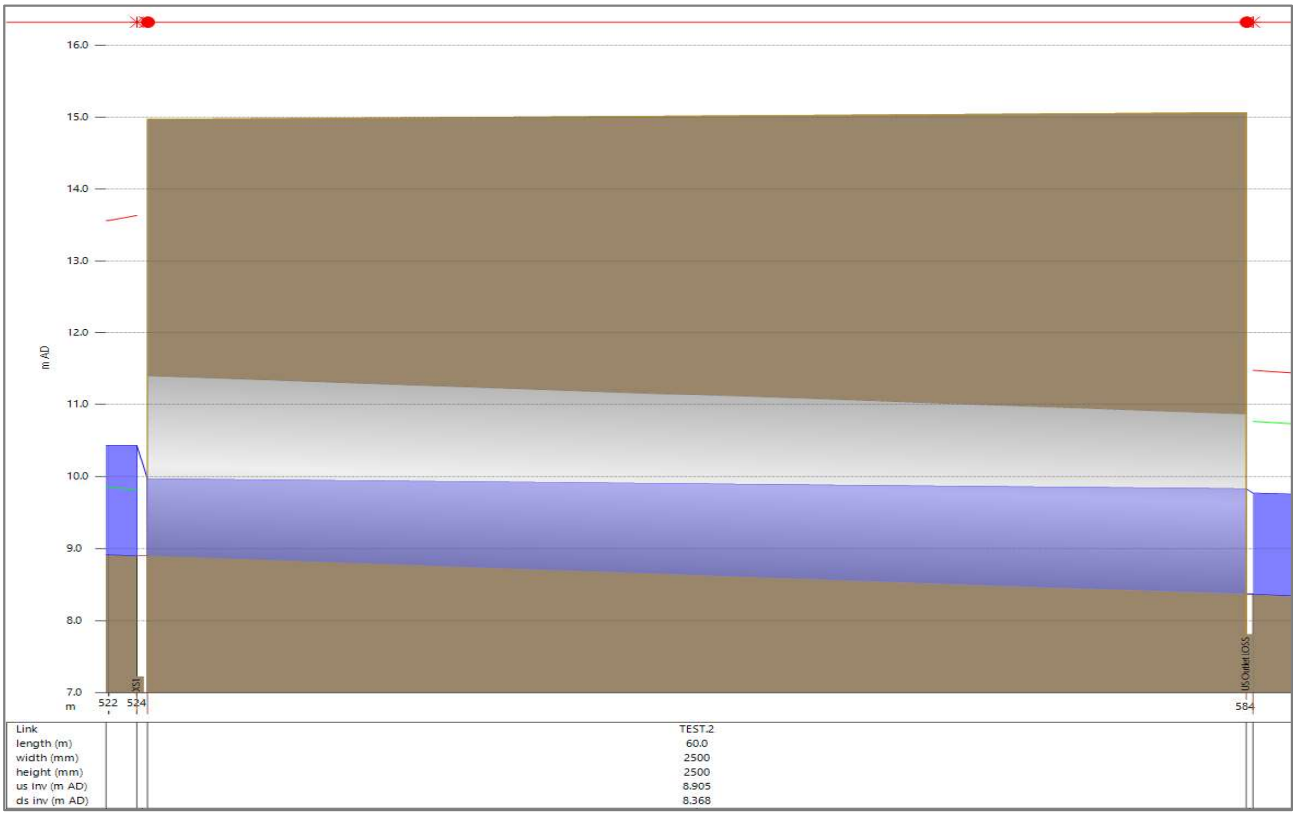
Option 2b

5.3.2. Option 2b consists of a 2.5m x 2.5m concrete boxed culvert for a length of 60m. Table 5-3 shows the predicted maximum water depth, peak flow and freeboard through the culvert. A long section of the flow through the culvert is shown in Figure 5-3.

Table 5-3: Option 2b predicted maximums 1 in 100-year plus 65% climate change event

	Upstream	Downstream
Maximum Depth (m)	1.06	1.46
Peak Flow (m^3/s)	6.57	6.57
Freeboard (m)	1.44	1.04

Figure 5-3: Option 2b culvert long section 1 in 100-year plus 65% climate change event



5.4. A1 culvert extension option

5.4.1. The existing culvert conveying the watercourse beneath the A1 will be extended as part of the Proposed Scheme. The extension at the downstream (east) end will be 18m in length. The extended section will match the 2.2m diameter of the existing Armco (corrugated steel) section at the downstream end.

5.4.2. The final extended culvert will be 58.60m in length.

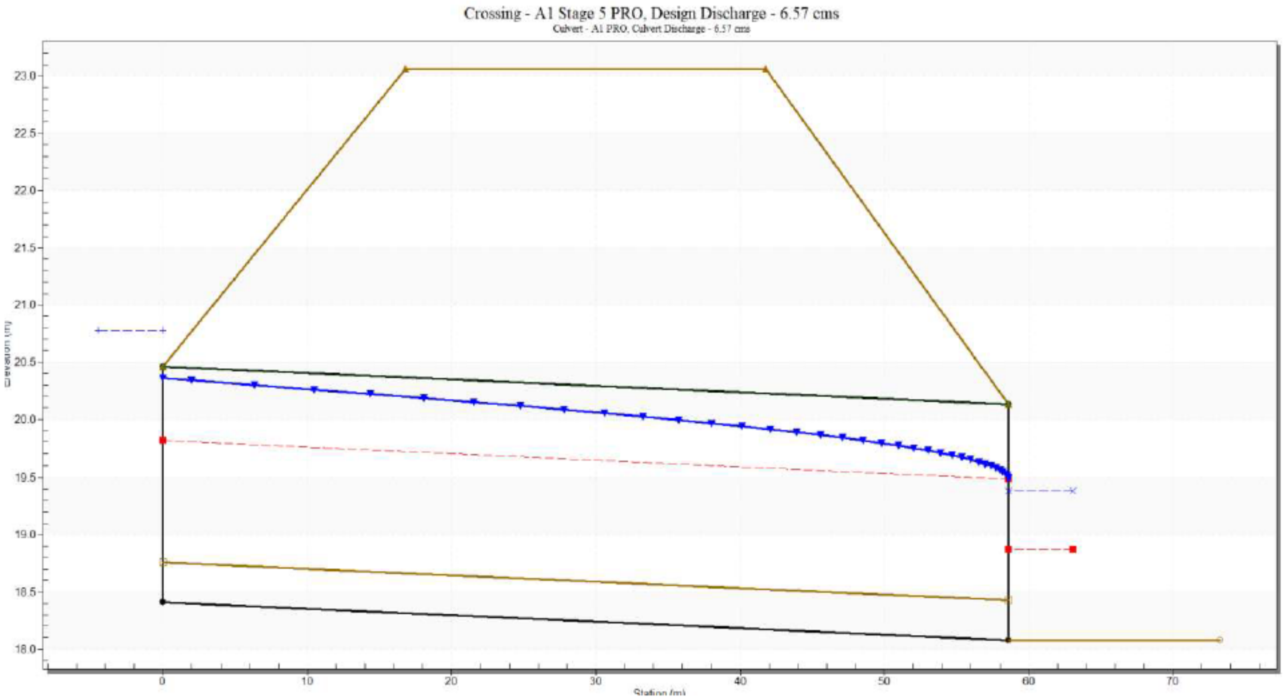
5.4.3. Table 5-4 below provides the relevant HY-8 results for the proposed extension scenario and comparison with the existing baseline scenario. The results show that the proposed culvert extension results in very minor increases in water level upstream of the A1 culvert. These level increases do not pose any additional risk of flooding to the A1 carriageway.

5.4.4. Figure 5-4 shows a long-section plot from HY-8 of the proposed extended A1 culvert with water levels for the 1 in 100-year plus 65% climate change event.

Table 5-4: Results from the HY-8 culvert analysis (A1 culvert extension)

Event	Peak Culvert Flow (m³/s)	Headwater Depth (m) and difference vs. existing (m)	Tailwater Depth and difference vs. existing (m)
QMED	0.78	0.86 (+0.00)	0.44 (+0.00)
1 in 10-year	1.64	1.16 (+0.00)	0.66 (+0.00)
1 in 100-year	4.39	1.85 (+0.02)	1.08 (+0.00)
1 in 100-year + 35%	5.56	2.12 (+0.03)	1.21 (+0.00)
1 in 100-year + 65%	6.57	2.36 (+0.04)	1.31 (+0.00)

Figure 5-4: HY-8 A1 long section and 1 in 100-year plus 65% climate change event (A1 culvert extension)



6. Flood compensatory storage

6.1.1. The Proposed Scheme consists of widening the A47 carriageway which will encroach into the Wittering Brook floodplain on the north side embankment. Construction within a floodplain reduces the available area for flood water volume. The lost storage as a consequence of the Proposed Scheme should be replaced elsewhere within the floodplain. Matters pertaining to flood compensatory storage requirements relating to an ordinary watercourse rest with the Lead Local Flood Authority (LLFA), Peterborough City Council.

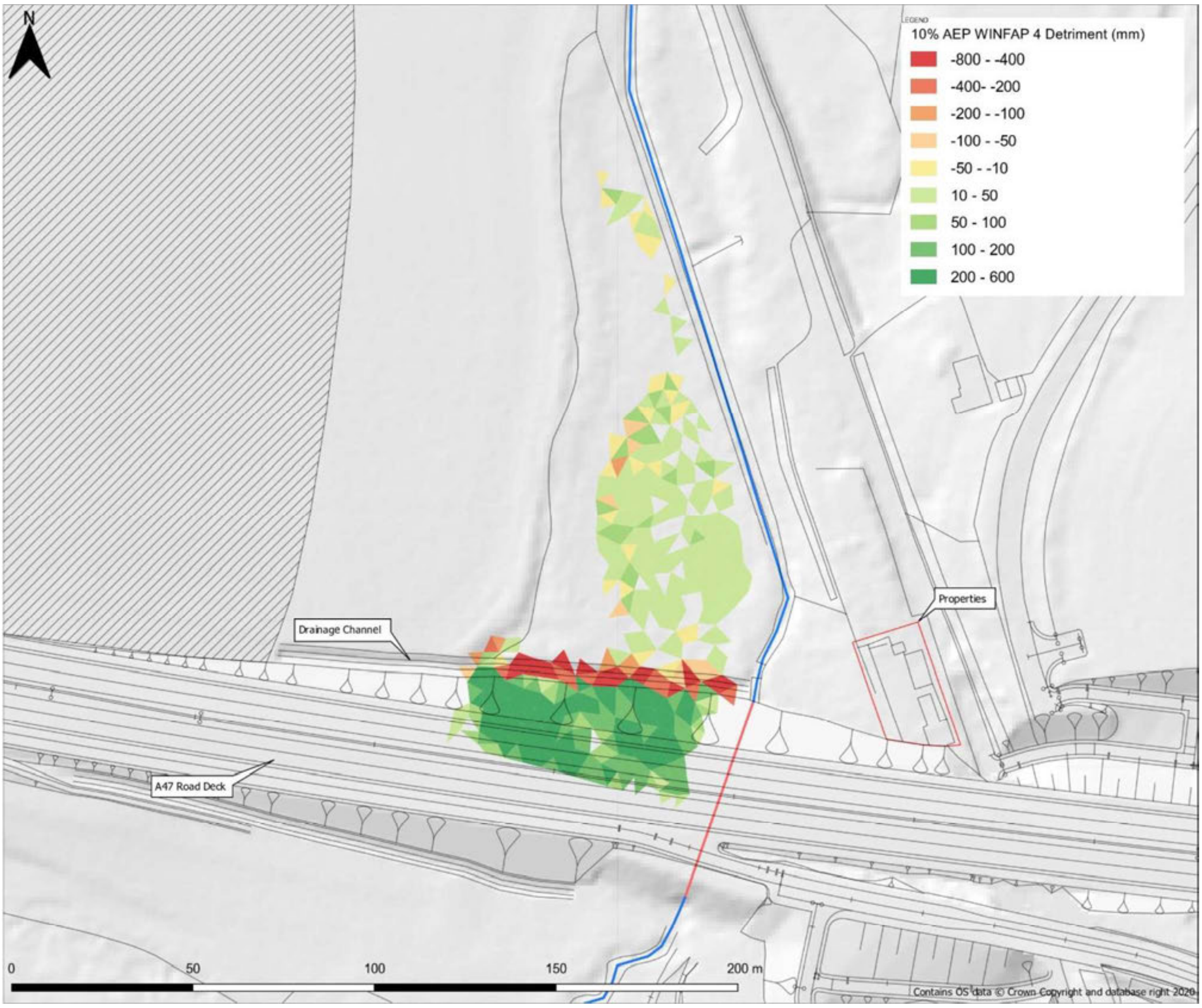
6.1.2. A detriment analysis was carried out to determine the difference in floodplain depths between the baseline and the Proposed Scheme Option 2b culvert scenarios.

6.1.3. The ReFH2.3 hydrological flow estimation method produced more conservative flow estimations than the WINFAP 4 FEH hydrology. However, the Environment Agency had greater confidence in the WINFAP 4 FEH hydrology and advised that it generally produced a more accurate estimation of flows. The WINFAP 4 FEH hydrology was therefore used as the final inflows to the hydraulic model for the detriment analysis.

6.1.4. Figure 6-1 shows the detriment map for the 1 in 10-year event. Betterment is generally predicted across the floodplain up to a maximum depth of 0.1m. An area of betterment is predicted up to 1.0m within the area of the Proposed Scheme embankment due to it no longer being able to flood. The increase in predicted flood depths at the toe of the Proposed Scheme embankment is due to a proposed drainage channel. The full set of detriment flood maps can be found in Appendix C which predict a maximum of 0.2m detriment across the floodplain for all design events.

6.1.5. Cambridgeshire County Council were consulted on behalf of Peterborough City Council regarding the requirement to provide flood compensatory storage for the Wittering Brook floodplain. Cambridgeshire County Council were satisfied no compensation would be required given the increase in flood depths remained below 0.2m for all events, this was confirmed by email on 18 March 2021.

Figure 6-1: 1 in 10-year detriment flood map. Contains OS data (Crown copyright and database rights 2020).



7. A47 Wansford Sluice design

7.1.1. A summary of the predicted model maximums for the Option 2b culvert is given in Table 7-1 below.

Table 7-1: Summary of predicted Option 2b maximums for all design events

	1 in 10-year event	1 in 100-year event	1 in 100-year event (35% CC)	1 in 100-year event (65% CC)	1 in 100-year event (80% CC)
Maximum Depth (m) (Culvert Inlet)	0.40	0.80	0.95	1.06	1.12
Maximum Flooded Area (m^2)	4865	6079	6400	6649	6935
Maximum Flooded Volume (m^3)	1694	3418	4312	5189	5655

Downstream impacts

7.1.2. Any changes to the A47 Wansford Sluice must not increase flood risk to downstream receptors. Option 2b increases peak flow rates discharging from the Wittering Brook in the River Nene by a negligible amount and therefore should be considered a viable alteration to the existing arrangement. Table 7-2 compares the peak flow through the culvert in the baseline and Option 2b scenarios. These are also compared with the peak flow in the River Nene at the Wittering Brook for the 1 in 100-year plus 35% event.

Table 7-2: Comparison of peak flows (1 in 100-year plus 35% climate change) between the Wittering Brook and River Nene

	Wittering Brook Baseline culvert	Wittering Brook Option 2b culvert	Difference	River Nene
Peak Flow (m^3/s)	5.53	5.56	+0.03	206.74
Wittering Brook discharge as % of River Nene Peak Flow	2.67%	2.69%	0.01%	-

7.1.3. The increase in flow as a result of a larger culvert to mitigate floodplain loss caused by the Proposed Scheme is predicted to be insignificant. In addition to this, the peak flow on the Wittering Brook is expected to drain through the River Nene prior to the peak hydrograph in the River Nene, and therefore no impact to water levels in the Nene during periods of flood are expected.

Refined design

7.1.4. The Option 2b culvert and results presented in this report are for a boxed 2.5m x 2.5m culvert for a length of 60m. The culvert design was refined to a boxed 2.5m x 2.45m concrete culvert for a length of 54m, termed Option 2c. Further hydraulic assessments were carried out for the Option 2c culvert, however negligible differences were observed to the results shown in Table 7-1. Where differences were observed they showed a reduction in flood volumes, flooded areas and depths within the culvert. The presented results and flood maps in this report for the Option 2b culvert therefore present a worst-case scenario. Option 2c is the preferred culvert arrangement.

Summary of Consultation

7.1.5. A meeting between Peterborough City Council (Lead Local Flood Authority) and Sweco was held on 6 May 2020 to agree assessment approaches for the A47 and A1 culverts on the Wittering Brook and Mill Stream respectively. Possible alignment changes were discussed and the agreement that a minimum assessment approach for the A1 culvert was acceptable. It was agreed that the new A47 Wansford Sluice would be designed to current standards for flow with appropriate climate change allowance. Preference was for a new culvert to be constructed below the A47 subject to detailed design works. A throttled scenario was also requested to ensure existing flow rates could be achieved as part of any change to the culvert. Peterborough City Council agreed HY-8 would be used to assess the A1 culvert hydraulics, a small hydraulic model of the Wittering Brook was agreed for the A47 Wansford Sluice assessment.

7.1.6. The Environment Agency were consulted in 2018, then again in 2020 and 2021. Relevant comments made in 2018 consultation are provided below:

- Any loss of floodplain should be compensated for on a level for level, volume for volume basis (i.e. re-grade the land at the same level as that taken up by the development) therefore providing a direct replacement for the lost storage volume. The location of any compensation works must relate hydraulically and hydrologically to the location of the site, and excavation of the compensation must be complete before infilling commences.
- For discharge into the River Nene (Main River), the discharge rate will be based on the calculated pre-development (greenfield) runoff rate for the site. For a simple control structure this will be based on the QBAR rate. Complex discharge controls should reflect the original discharge or run-off rates from the site across the range of storm events.

7.1.7. The Environment Agency were consulted on the impacts on the WFD in relation to the culverting proposed on Wittering Brook and Mill Stream in November 2020. They noted the following:

- Wittering Brook A47 Wansford Sluice should be opened up, replacing the old culvert as well, to allow full mammal access
- if throttling of the flow was required then the flow should be attenuated upstream using natural flood management techniques

7.1.8. The Environment Agency and Peterborough City Council were further consulted in November 2020 to discuss flood risk and WFD. They noted the following:

- removing the throttle was agreed to be the preferred option as the model demonstrates it was not impacting the flow and therefore had minimal impact downstream
- the Environment Agency Lower Nene model was used and revised with new climate change allowances to 35% to estimate the design flood level to calculate flood compensatory storage volumes

7.1.9. Peterborough City Council were consulted again in March 2021 via Cambridgeshire County Council to review the Wittering Brook hydraulic report and assessment. The LLFA (Cambridgeshire County Council) confirmed they would not raise any objection to the proposed culvert option but have requested more information regarding the detriment across the floodplain of Wittering Book during the 10% AEP event so the impacts can be fully understood.

7.1.10. The Environment Agency were consulted again in March 2021 to review the River Nene flood compensation and the Wittering Brook hydraulic model and report. The Environment Agency stated they were satisfied in principle with the proposals for floodplain compensation for the River Nene. Overall, the Environment Agency accepted the findings of the hydraulic model and report, however they also required additional information:

- The origin of the 1 in 50 year stage used in one of the sensitivity tests at the downstream boundary of the Wittering Brook model was queried.
- whether any flows from the River Nene could have any impacts upstream in Wittering Brook with the proposed A47 Wansford Sluice was also queried.
- further justification, beyond being a conservative approach, for the use of ReFH 2.3 was requested.

7.1.11. In response to the queries raised above the following is noted:

- The 50-year stage as the downstream boundary to the Wittering Brook model was taken from the River Nene model.
- With regards to the River Nene having any impacts upstream, the section of model reach downstream of the A47 Wansford Sluice is very steep, with a slope of 1 in 100. The model was therefore re-run with the proposed culvert for a 100-year plus 65% event with a 50-year downstream boundary. The addition of the downstream boundary corresponded to minimal increase in

depth to the next upstream cross-section. However, these effects did not propagate upstream and no increase in depths were observed to other upstream cross-sections.

- A hybrid method was chosen as the initial Wittering Brook hydrology inflow to the model, however upon review it was decided to adopt the ReFH2.3 design flows. The decision to use the ReFH2.3 inflows was based purely on conservatism and has ultimately informed a conservative design level for new A47 Wansford Sluice.
- The model has been re-run using the WINFAP hydrology by adopting a hybrid method to scale the ReFH2.3 hydrographs. The predicted noticeable difference between the hydrology is the variation in detriment mapping. The WINFAP hydrology (lower flows) results in less betterment predicted in the floodplain as a result of the proposed culvert.
- On average, the predicted detriment across all design flood events is approximately 50mm. For higher order events (100-year) the 50mm detriment is predicted across a larger area of the floodplain; however, this is partly due to mesh elevation averaging. These areas are represented in the Flood Maps in Appendix C of Annex B as the yellow and light green triangles with ranges of +/- 50mm. For lower order events, betterment is generally observed across more of the floodplain.

7.1.12. Supporting detriment mapping for both hydrological approaches has been provided to and approved by the Environment Agency, Cambridgeshire County Council and Peterborough City Council.

8. Conclusion

8.1.1. Sweco has undertaken a hydraulic modelling analysis of the Wittering Brook A47 and Mill Stream A1 culverts as part of the Proposed Scheme. Storm Geomatics provided survey data which was used to build the baseline model in InfoWorks ICM. The model was tested for a range of return periods, including allowances for climate change, to determine the extent of flooding in the Wittering Brook flood plain and to understand any flood plain loss as a result of the Proposed Scheme. Surveyed data was used to determine the baseline conditions for the A1 culvert.

8.1.2. An assessment of the proposed extension of the A1 culvert confirmed that there would be very minor changes in water level upstream of the culvert. These increases do not pose any additional flood risk to receptors or the A1 carriageway.

8.1.3. Three post-development options for the A47 Wansford Sluice have been assessed. Option 1 involved a 2.0m x 2.5m boxed culvert extension to the existing culvert and Option 2a, a 2.0m x 2.5m boxed concrete replacement to the existing culvert. The additional Option 2b culvert tested the hydraulic significance of increasing the width of the culvert to 2.5m. All three scenarios provided a minimum of 0.6m freeboard for the 1 in 100-year plus 65% climate change event and pose as viable options for the Proposed Scheme.

8.1.4. To ensure there is no increased flood risk created by the Proposed Scheme, a detriment analysis was carried out to determine the need for flood compensatory storage. For the Option 2b culvert, detriment was observed in the Wittering Brook flood plain up to a maximum of 0.2m for all design events. Cambridgeshire County Council, acting on behalf of Peterborough City Council, the LLFA, were satisfied that increases in flood depths remained below 0.2m and agreed there would be no need to provide flood compensatory storage.

8.1.5. Increases to peak flows in the downstream watercourse were found to be negligible and lead to no significant increase in flood risk to downstream receptors.

8.1.6. The culvert design was refined to Option 2c, a boxed 2.5m x 2.45m concrete culvert for a length of 54m. Further hydraulic assessments were carried out for the refined design. Negligible differences were observed to the results shown in this report for Option 2b. Any observed differences showed a reduction in flood volumes, flooded areas and depths within the culvert. The presented results in this report for the Option 2b culvert therefore present a worst-case scenario. Considering the above, Option 2c is the preferred culvert option arrangement.

9. References

Department for Environment & Rural Affairs (2020) Defra survey data download. Available at https://environment.data.gov.uk/DefraDataDownload/?Mode=survey accessed October 2020

Environment Agency (2020) Flood Risk Assessments: Climate Change Allowances. Available at https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances#table-1, accessed November 2020

Oregon State University Forestry Science Laboratory (2006) Manning's n Values. Available at [redacted] accessed November 2020

US Department of Transportation, Federal Highway Administration (2020) HY-8 Version 7.6

Appendix A. Key model parameters

Roughness values are based on Oregan State University Forestry Science Laboratory (2006).

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

Model object	Parameter	Value
River reaches	Panel roughness in main channel (Manning's n)	0.04
River reaches	Panel roughness on channel banks (Manning's n)	0.06
River banks	Discharge coefficient	0.9
River banks	Modular limit	0.6
Baseline Culvert	Manning's n (bottom)	0.04
Baseline Culvert	Manning's n (top)	0.02
Option Culvert	Manning's n (bottom)	0.015
Option Culvert	Manning's n (top)	0.015

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

Model object	Parameter	Value
2D zone	Maximum triangle area	20 m^2
2D zone	Minimum triangle area	5 m^2
2D zone	Maximum height variation	0.5 m
2D zone	Manning's n	0.06
Roughness zone	Manning's n	0.12

Appendix B. FEH hydrological assessment

Table of contents

Figures

Tables

1. Introduction

1.1.1. As part of the A47 Wansford to Sutton Dualling ('the Proposed Scheme'), a hydrological assessment of the Wittering Brook is required in order to inform the Flood Risk Assessment and associated detailed hydraulic modelling.

1.1.2. The Proposed Scheme involves a new length of dual carriageway which largely follows the existing A47 and replaces the existing 2.5km length of single lane carriageway. Widening of the carriageway at the Wittering Brook will require detailed design of an extension to the A47 culvert, conveying flow to the River Nene.

1.1.3. There is a short but incomplete flow record from 1970-1985 for the Wittering Brook gauge [redacted] which was deemed unsuitable for hydrological analyses. No previous hydrological assessments were available for Wittering Brook, 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) Revision 1, Highways England, 2020.

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

- National River Flow Archive peak flow dataset Version 9.
- The Chronology of British Hydrological Events.

1.2.3. The hydrological assessment of Wittering Brook 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 one flow estimation location along the Wittering Brook. These design flood hydrographs will be incorporated into a hydrodynamic model representing the Wittering Brook 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 year
- 1 in 10 year
- 1 in 50 year
- 1 in 100 year
- 1 in 1000 year
- 1 in 100 years plus 35% climate change.
- 1 in 100 year plus 65% climate change
- 1 in 100 year plus 80% climate change

2. Catchment description

2.1.1. Wittering Brook is an ordinary watercourse running in a north to south direction east of Wansford and the A1. It passes through a culvert beneath the A47 and joins the River Nene 100m further south. Mill Stream, an ordinary watercourse and tributary to the Wittering Brook, runs in a west to east direction before it joins with the Wittering Brook 600m north of the A47. The catchment used in this analysis covers a largely rural area. There are, however, urban areas of note which include Wittering village north of Wansford and the RAF Wittering airfield. There are sporadic patches of mixed woodland throughout the catchment although the majority of the land use is arable and pasture land. The major highways of the A1 and A47 both pass through the catchments as well as a number of smaller local roads. The Wittering Brook is lined by very small informal embankments which are subject to overtopping in peak flows.

2.1.2. Cranfield Soil and Agrifood Institute (2020) soil maps indicate the catchment soils are mostly freely draining shallow lime-rich soils over chalk or limestone (Soilscape 3). The Wittering Brook floodplain is underlain by freely draining slightly acidic but base-rich soils (Soilscape 7). A small portion of the soils west of the A1 are loamy and clayey which are slowly permeable and seasonally wet (Soilscape 18).

2.1.3. British Geological Survey (2020) maps indicate superficial geology for the catchment is mainly Lower Lincolnshire Limestone with areas of Whitby Mudstone.

2.2. Location of flow estimates

- One flow estimation location, taken at the downstream extent of the Wittering Brook, is required to build design hydrographs and to inform the hydraulic modelling. The location is shown in Figure 2-1 and Figure 2-2.
- Downstream extent at Ordnance Survey (OS) National Grid Reference (NGR) 508850, 299550

Figure 2-1: Wittering Brook flow estimation location. Contains OS data (Crown copyright and database rights 2020).

2.3. Catchment descriptors

2.3.1. Catchment descriptors and catchment boundaries for the Wittering Brook catchment were extracted from the FEH Web Service (2020). The boundaries were checked against 1m spatial resolution LiDAR flown in 2019 and obtained from the DEFRA (2020) Survey Data Download portal. The catchment boundary is 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: Wittering Brook FEH catchment boundary. Contains OS data (Crown copyright and database rights 2020).

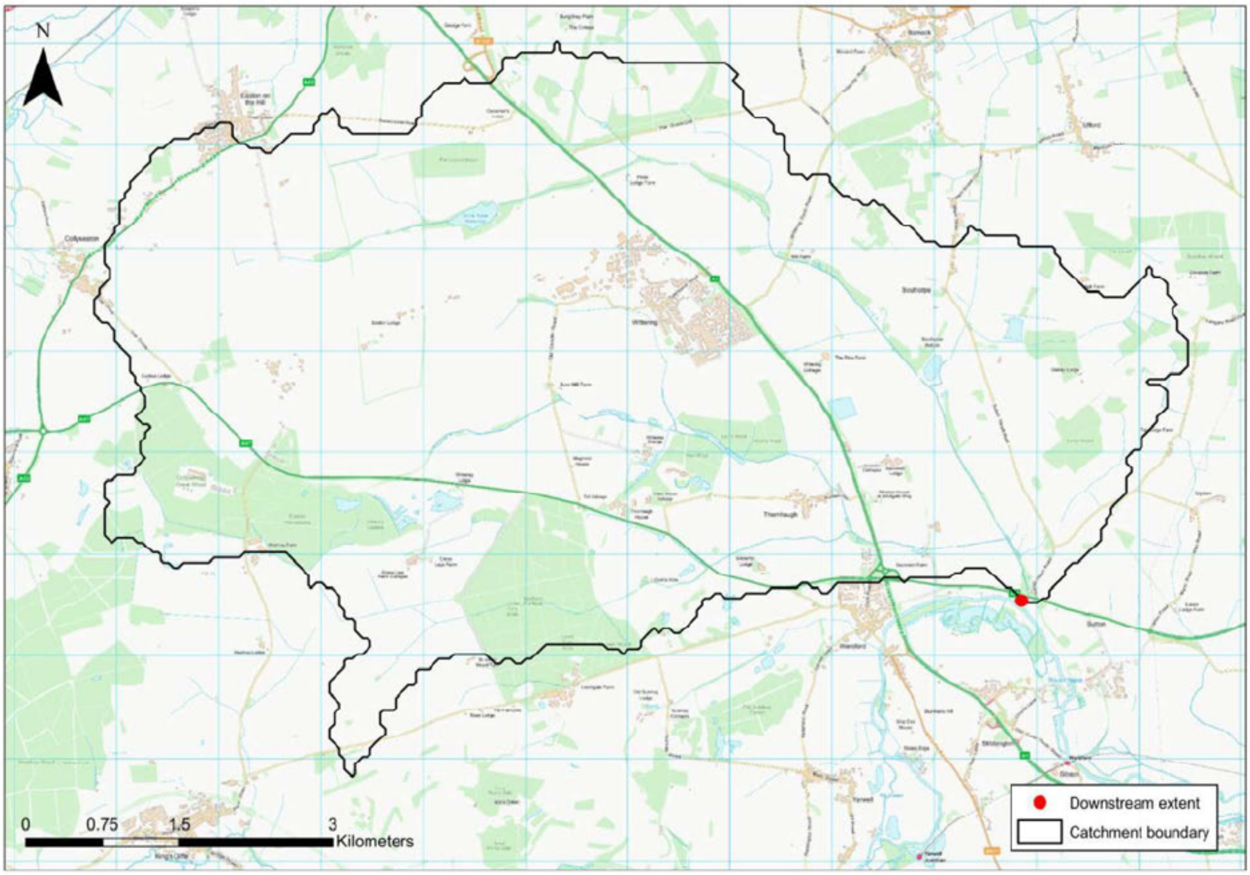


Table 2-1 : FEH catchment descriptors

Descriptor	Downstream Extent
AREA (km^2)	45.000
BFIHOST (-)	0.890
FARL (-)	0.974
SAAR (mm)	568
SPRHOST (-)	9.700
$URBEXT_{2000}$ (-)	0.022

2.3.2. The catchment descriptors indicate the catchment is rural and with highly 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 several ponds. The descriptors suggest the catchment would be suitable for routine FEH hydrological analysis and no adjustments to the catchment parameters would be required.

2.3.3. The BFIHOST value is above the 0.60 threshold for what is considered a 'permeable' catchment. Historically, ReFH2.3 methods have not been considered suitable for generating design hydrographs for permeable catchments, however, recommendations have changed recently with ReFH2.3. For this assessment, both the FEH statistical method with an allowance for permeable catchments and the ReFH2.3 method was used.

2.4. Historical flood information for Wittering Brook

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

3. Peak flow estimation

3.1.1. The estimates of peak flood flows for Wittering Brook 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 gauged 'donor' catchments.

3.2.2. Wittering Brook is a relatively small catchment which was gauged from 1970 to 1985. Due to the incomplete record length, no suitable gauged data was available for watercourse flow or level. As such, the only available approach was to estimate QMED from catchment descriptors and to consider suitable gauged 'donor catchments' with which to adjust the QMED estimate, if appropriate.

3.2.3. Six potential donor catchments were identified in WINFAP as:

- 31010 Chater at Fosters Bridge
- 31026 Egleton Brook at Egleton
- 31004 Welland at Tallington Total
- 32003 Harpers Brook at Old Mill Bridge
- 31025 Gwash South Arm at Manton
- 30017 Witham at Colsterworth

3.2.4. A donor adjustment produced a more conservative value for QMED. Table 3-1 below shows both the unadjusted and adjusted QMED value for the flow estimation location. The donor adjusted value of QMED was used in subsequent analyses.

Table 3-1 : Wittering Brook catchment QMED estimates

Catchment	QMED (unadjusted) (m^3/s)	QMED (donor) (m^3/s)
Wittering Brook	0.624	0.843

3.3. Pooled analysis

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

3.3.2. A review of the pooling group was made including parameters such as catchment area, SAAR, FARL and number of years of data.

3.3.3. Catchment 26013 Driffield Trout Stream at Driffield was removed from the pooling group due to a low record length and discordancy. Removal of this catchment increased the growth curve fittings for higher return periods and the homogeneity of the pooling group.

3.3.4. Catchments within the pooling group with BFIHOST>0.75 (highly permeable) were identified and adjusted accordingly (see Table 3-2). These included Babingley at Castle Rising and Foston Beck at Foston Mill.

Table 3-2: Permeable adjustment to pooling group

Station	L-CV	L-SKEW	L-CVadj	L-SKEWadj
33054 (Babingley at Castle Rising)	0.206	0.08	0.179	0.127
26003 (Foston Beck at Foston Mill)	0.25	0	0.146	0.041

3.3.5. Catchment 33032 Heacham at Heacham was removed. The catchment was replaced with 41022 Lod at Halfway Bridge to maintain 500 years of pooled data. The pooling group and growth fittings were adjusted for permeable catchments using the Wallingford HydroSolutions permeable adjustment worksheet, following Environment Agency (2020a) Flood Estimation guidelines.

3.3.6. The final pooling group is given in Table 3-3 below.

Table 3-3 : Final FEH pooling group

Pooling group station	Record length (years)
36003 (Box at Polstead)	52
36004 (Chad Brook at Long Melford)	22
36007 (Belchamp Brook at Bardfield Bridge)	50
33054 (Babingley at Castle Rising)	21
37016 (Pant at Copford Hall)	43
26003 (Foston Beck at Foston Mill)	52
30004 (Lymn at Partney Mill)	41
39033 (Winterbourne Stream at Bagnor)	59
53017 (Boyd at Bitton)	57
41022 (Lod at Halfway Bridge)	54
	Total record length: 530

3.3.7. The FEH recommends the use of the generalised logistic growth curve over other fitting methods available in WINFAP. The pooling group did produce an absolute Z value > 1.645 which is outside the recommended limits; however, .

3.3.9. Figure 3-1 shows that the general logistic growth curve provides a more conservative estimate of flow at higher return periods. This was deemed appropriate for the purposes of this assessment. Table 3-4 shows the Wittering Brook design peak flow estimates.

3.3.10. Figure 3-1 : Flow estimation growth curve

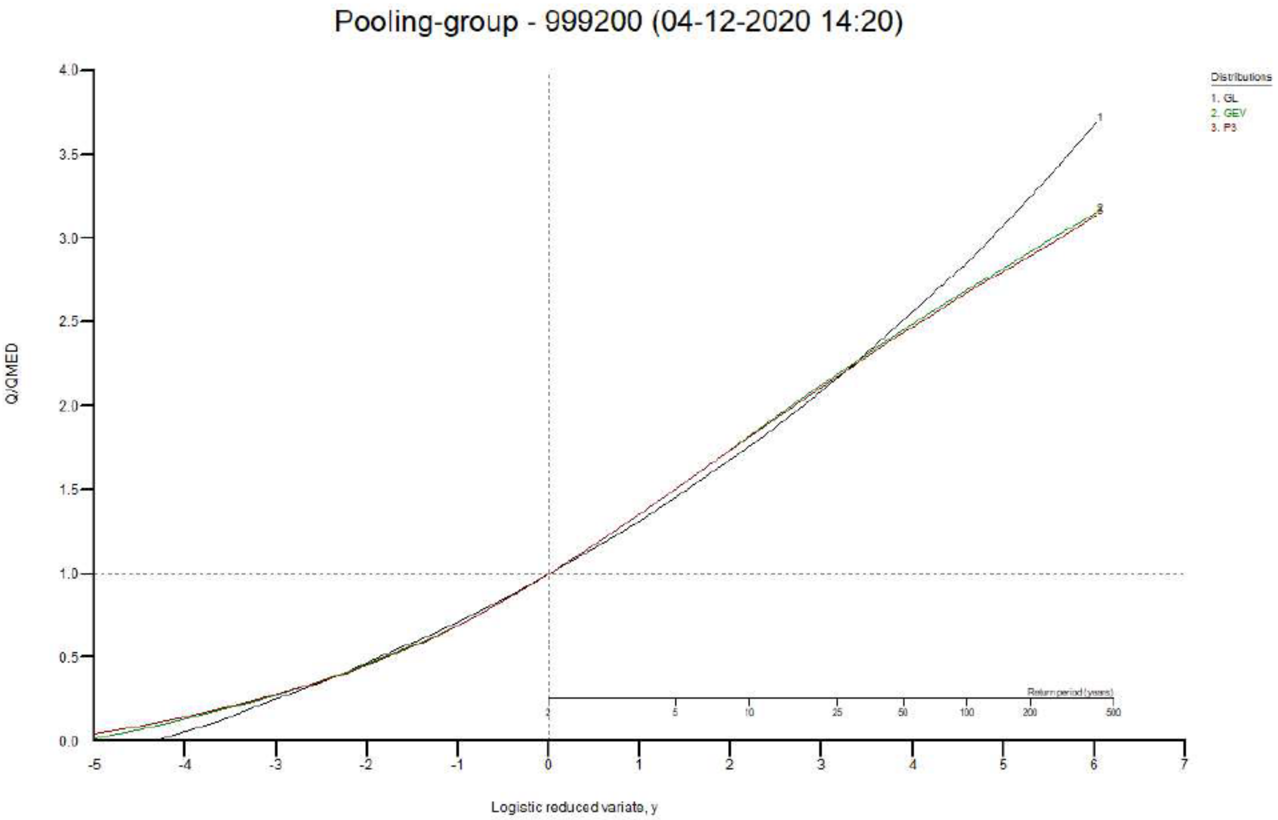


Table 3-4 : Wittering Brook design flow estimates (point inflows)

Return period (years)	Growth factor	Peak flow estimate ($m^3 s^{-1}$)
2	1.000	0.843
10	1.710	1.442
50	2.106	1.775
100	2.432	2.050
1000	4.238	3.573
100 + 35% CC	3.283	2.768
100 + 65% CC	4.013	3.383

3.4. Consideration of climate change

3.4.1. The Proposed Scheme development 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 3-5 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 3-5 : Peak river flow climate change allowances

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	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 Wittering Brook, 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%. The H++ (80% uplift) has been used to assess safety risks and risk of flooding to the Proposed Scheme, for this assessment, it has been used to assess the risk of the road embankment being overtopped.

UKCP18 climate change allowances

3.4.5. 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 suitable gauged river flow or level information for Wittering Brook, 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 ReFH2.3 model parameters were based on the default catchment-based equations outlined in the The Revitalised Flood Hydrograph model ReFH 2.3: Technical Guidance. The hydrographs were generated using the ReFH2.3 software. The ReFH2.3 hydrographs for both catchments are given in Figure 4-1 below. Full hydrograph data tables and ReFH2.3 parameters are given in Appendix B for reference.

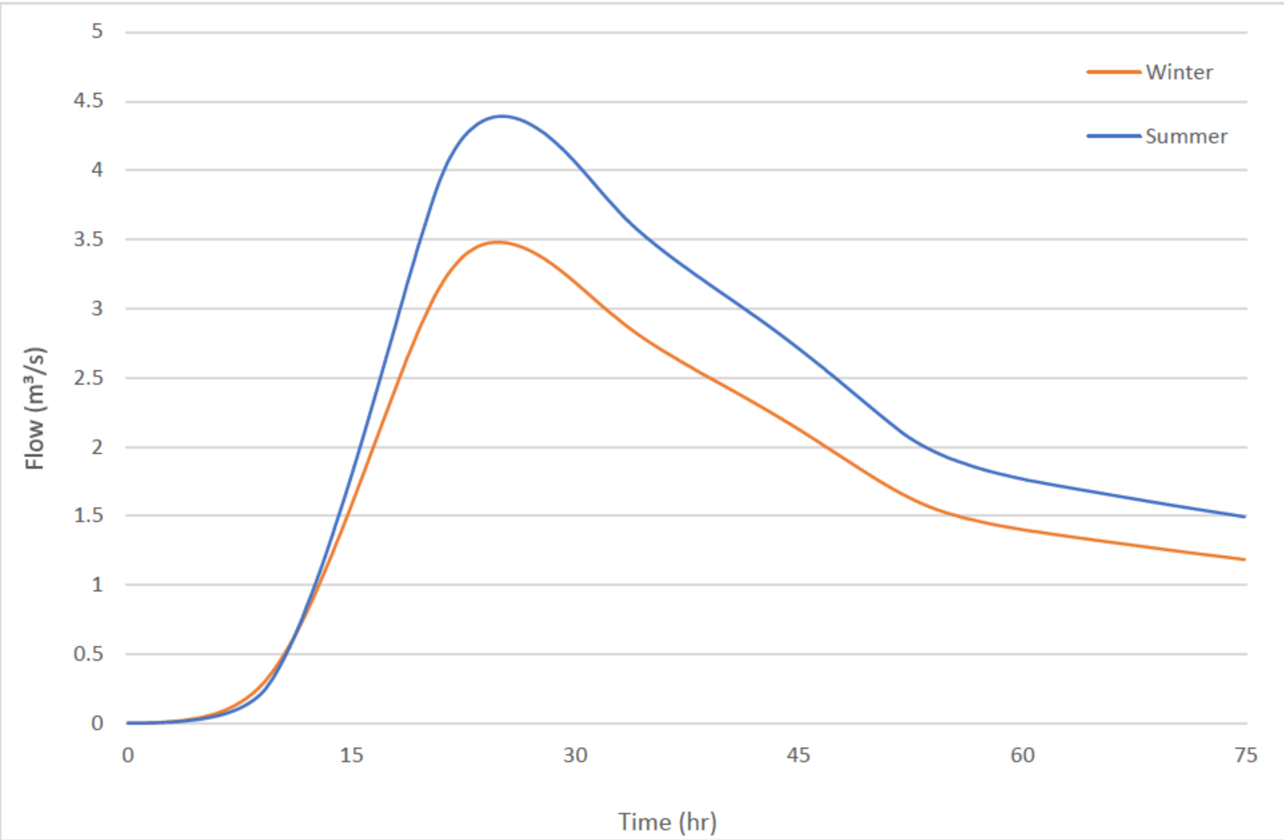
4.1.3. The default storm duration was used and the timestep reduced to 15 minutes to provide more accuracy in the model. Peak flow values are given in Table 4-1 below; these values are for an 18-hour duration, summer storm profile event. The summer storm profile gave the most conservative estimates for flows at higher return periods; however, both the 100-year summer and winter hydrographs were exported from ReFH2.3 to be tested in the model. The inflow equating to a greater flood volume in the 2D zone would ultimately be used as the design hydrographs. The growth factor for each storm event has been calculated for comparison with the FEH statistical method and completeness. The growth factor for the ReFH2.3 method is within the typical range. The ReFH2.3 method peak flow estimates in Table 4-1 are significantly higher than the WINFAP 4 peak flow estimates shown in Table 3-4.

4.1.4. Climate change uplifts were applied to the run-off component of the 100-year flows only. No changes were made to the baseflow.

Table 4-1 : ReFH2.3 summer profile peak flow estimates

Return period (years)	Growth factor	Peak flow estimate ($m^3 s^{-1}$)
2	1.000	0.780
10	2.106	1.643
50	4.279	3.338
100	5.631	4.392
1000	11.397	8.890
100 + 35% CC	7.131	5.562
100 + 65% CC	8.429	6.575

Figure 4-1 : ReFH2.3 1 in 100 year + 65% CC winter and summer hydrographs



4.2. Implementation of design hydrographs in the hydraulic model

4.2.1. Historically, the ReFH2.3 method should be used with caution for permeable catchments. Both the FEH Statistical and ReFH2.3 methods produce similar values of QMED; however, there are large discrepancies between the flood estimations for higher order events. The Environment Agency were consulted on their method of preference for the analysis. Given, the FEH method uses actual observed data, the Environment Agency advised they would prefer to use the FEH method as the inflows to the hydraulic model.

4.2.2. The ReFH2.3 method produced higher values of flow for higher return periods. The method constitutes a conservative approach and was used as the hydrological inflows for the culvert design. The FEH method was used as the hydrology for the flood compensatory storage analysis as it generally produced a more accurate estimation of flows and was the preferred method by the Environment Agency.

5. Assumptions, limitations and uncertainty

5.1.1. The catchment descriptors are a reasonable reflection of catchment urbanisation, however,, using catchment descriptor data to estimate flood flows without using gauged flow data for verification creates uncertainty in the flow estimates. The Wittering Brook flow gauge possessed an incomplete peak flow dataset from 1970 to 1985 which rendered it unsuitable for use in this analysis and therefore catchment descriptors have been used as part of a statistical approach only. This is considered acceptable for the study in agreement with the Environment Agency.

5.1.2. In order to improve the uncertainty of the flow estimation 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.

6. References

- British Hydrological Society (2020) Chronology of British Hydrological Events. Available at [redacted] last accessed October 2020
- British Geological Survey (2020) Geology of Britain Viewer Map. Available at [redacted], last accessed October 2020
- Cranfield Soil and Agrifood Institute (2020) Soilscapes Map. Available at [redacted], last accessed October 2020
- Department for Environment Flood & Rural Affairs (DEFRA) (2020) Defra Survey Data Download Available at https://environment.data.gov.uk/DefraDataDownload/?Mode=survey, last accessed October 2020
- Environment Agency (2020a) Flood Estimation Guidelines. *Guidance LIT 11832*
- Environment Agency (2020b) Environment Agency Flood Map for Planning. Available at: https://flood-map-for-planning.service.gov.uk/, accessed October 2020
- Environment Agency (2020c) *Flood risk assessments: climate change allowances*. Available online at https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances, accessed October 2020
- Environment Agency (2012) Estimating flood peaks and hydrographs for small catchments: Phase 1. Project: SC090031
- Highways England (2019) *Design Manual for Roads and Bridges LA 113 Road Drainage and the Water Environment*. Revision 1. Available at [redacted] last accessed October 2020
- Met Office (2018) UK Climate Projections (UKCP). Available at https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/index, last accessed October 2020
- Ministry of Housing, Communities and Local Government (2019) *National Planning Policy Framework*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/6077/2116950.pdf, last accessed October 2020
- UK Centre for Ecology & Hydrology (2020a) National River Flow Archive peak flow dataset Version 8. Available at [redacted] last accessed October 2020
- UK Centre for Ecology & Hydrology (2020b) Flood Estimation Handook Web Service. Available at [redacted] last accessed October 2020
- Wallingford HydroSolutions (2020a) *WINFAP, Version 4.2*
- Wallingford HydroSolutions (2020b) *ReFH, Version 2.3*

- 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	Downstream Extent
CATCHMENT	TL 08850 99550
CENTROID	TF 04705 01783
AREA	44.995
ALTBAR	60
ASPBAR	107
ASPVAR	0.34
BFIHOST	0.89
BFIHOST19	0.826
DPLBAR	6.73
DPSBAR	25.7
FARL	0.974
FPEXT	0.0922
FPDBAR	0.448
FPLOC	1.136
LDP	13.31
PROPWET	0.21
RMED-1H	11.6
RMED-1D	28.7
RMED-2D	37.8
SAAR	568
SAAR4170	590
SPRHOST	9.7
URBCONC1990	0.623
URBEXT1990	0.0134
URBLOC1990	0.974
URBCONC2000	0.745
URBEXT2000	0.0219
URBLOC2000	1.056
C	-0.02282
D1	0.33506

Descriptor	Downstream Extent
D2	0.28014
D3	0.20996
E	0.30581
F	2.48307
C(1 km)	-0.022
D1(1 km)	0.335
D2(1 km)	0.284
D3(1 km)	0.198
E(1 km)	0.304
F(1 km)	2.491

Appendix B. ReFH2.3 parameters

Table B-6-1: Key ReFH2.3 Parameters

Descriptor	Confluence West
Duration	18 hr Summer
Timestep	15 Minutes
Cini	26.00 mm
Cmax	1245.12 mm
BR	3.00
BL	89.27
Tp	12.04 hr

Table B-6-2: ReFH2.3 Design hydrographs for Wittering Brook 18hr summer and winter storm profiles

Time	Summer				Winter			
	10 yr	100 yr	100+35% yr	100+65% yr	10 yr	100 yr	100+35% yr	100+65% yr
0:00:00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0:15:00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0:30:00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0:45:00	0.000	0.000	0.001	0.001	0.000	0.001	0.001	0.001
1:00:00	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.002
1:15:00	0.001	0.001	0.002	0.002	0.001	0.002	0.002	0.003
1:30:00	0.001	0.002	0.002	0.003	0.001	0.002	0.003	0.004
1:45:00	0.001	0.003	0.003	0.004	0.002	0.003	0.004	0.005
2:00:00	0.002	0.003	0.005	0.006	0.002	0.004	0.006	0.007
2:15:00	0.002	0.004	0.006	0.007	0.003	0.006	0.008	0.010
2:30:00	0.003	0.006	0.008	0.009	0.004	0.007	0.010	0.012
2:45:00	0.004	0.007	0.009	0.011	0.005	0.009	0.013	0.015
3:00:00	0.004	0.009	0.011	0.014	0.006	0.012	0.015	0.019
3:15:00	0.005	0.010	0.014	0.017	0.007	0.014	0.019	0.023
3:30:00	0.006	0.012	0.017	0.020	0.009	0.017	0.023	0.027
3:45:00	0.008	0.015	0.020	0.024	0.011	0.020	0.027	0.033
4:00:00	0.009	0.017	0.023	0.028	0.012	0.024	0.032	0.038
4:15:00	0.010	0.020	0.027	0.033	0.015	0.028	0.037	0.045
4:30:00	0.012	0.023	0.031	0.038	0.017	0.032	0.043	0.052
4:45:00	0.014	0.027	0.036	0.044	0.020	0.037	0.050	0.060

5:00:00	0.016	0.031	0.041	0.050	0.023	0.043	0.057	0.069
5:15:00	0.018	0.035	0.047	0.057	0.026	0.049	0.065	0.079
5:30:00	0.020	0.040	0.054	0.065	0.029	0.056	0.075	0.091
5:45:00	0.023	0.046	0.061	0.074	0.033	0.064	0.085	0.103
6:00:00	0.026	0.052	0.069	0.084	0.038	0.072	0.096	0.117
6:15:00	0.029	0.059	0.078	0.095	0.043	0.082	0.109	0.132
6:30:00	0.033	0.066	0.088	0.107	0.048	0.092	0.122	0.148
6:45:00	0.037	0.075	0.100	0.121	0.054	0.103	0.138	0.167
7:00:00	0.041	0.084	0.112	0.136	0.060	0.116	0.154	0.187
7:15:00	0.046	0.095	0.126	0.152	0.067	0.130	0.173	0.210
7:30:00	0.051	0.106	0.141	0.171	0.075	0.145	0.193	0.234
7:45:00	0.057	0.119	0.159	0.192	0.083	0.162	0.216	0.261
8:00:00	0.064	0.134	0.178	0.216	0.093	0.181	0.240	0.291
8:15:00	0.071	0.151	0.200	0.242	0.103	0.201	0.267	0.324
8:30:00	0.080	0.169	0.225	0.273	0.114	0.224	0.297	0.360
8:45:00	0.089	0.191	0.254	0.308	0.126	0.249	0.330	0.400
9:00:00	0.100	0.216	0.287	0.348	0.139	0.276	0.366	0.444
9:15:00	0.113	0.247	0.328	0.397	0.153	0.306	0.406	0.491
9:30:00	0.127	0.283	0.376	0.455	0.169	0.338	0.449	0.543
9:45:00	0.144	0.323	0.429	0.520	0.186	0.373	0.495	0.600
10:00:00	0.162	0.367	0.488	0.592	0.204	0.411	0.545	0.660
10:15:00	0.181	0.415	0.552	0.669	0.223	0.451	0.598	0.724
10:30:00	0.201	0.467	0.620	0.751	0.243	0.494	0.655	0.792
10:45:00	0.223	0.521	0.692	0.839	0.264	0.539	0.714	0.864
11:00:00	0.245	0.578	0.768	0.930	0.286	0.587	0.777	0.940
11:15:00	0.269	0.638	0.847	1.026	0.309	0.636	0.842	1.018
11:30:00	0.293	0.701	0.930	1.126	0.333	0.688	0.910	1.100
11:45:00	0.319	0.766	1.016	1.230	0.358	0.741	0.980	1.185
12:00:00	0.345	0.833	1.105	1.337	0.383	0.797	1.053	1.273
12:15:00	0.372	0.903	1.196	1.448	0.410	0.854	1.128	1.364
12:30:00	0.400	0.975	1.291	1.561	0.437	0.913	1.206	1.456
12:45:00	0.428	1.048	1.387	1.678	0.464	0.973	1.285	1.551
13:00:00	0.457	1.123	1.486	1.797	0.492	1.035	1.365	1.648
13:15:00	0.486	1.200	1.587	1.918	0.521	1.098	1.447	1.747

13:30:00	0.517	1.279	1.690	2.042	0.550	1.162	1.531	1.847
13:45:00	0.547	1.359	1.794	2.168	0.580	1.227	1.616	1.950
14:00:00	0.578	1.441	1.901	2.295	0.610	1.294	1.703	2.053
14:15:00	0.610	1.524	2.009	2.425	0.640	1.361	1.790	2.158
14:30:00	0.642	1.608	2.119	2.557	0.671	1.429	1.878	2.264
14:45:00	0.674	1.694	2.230	2.690	0.702	1.498	1.968	2.370
15:00:00	0.707	1.781	2.343	2.825	0.733	1.568	2.058	2.478
15:15:00	0.740	1.868	2.457	2.961	0.765	1.638	2.149	2.587
15:30:00	0.773	1.957	2.572	3.099	0.796	1.709	2.240	2.696
15:45:00	0.807	2.047	2.688	3.238	0.828	1.780	2.332	2.805
16:00:00	0.841	2.138	2.805	3.377	0.860	1.852	2.424	2.915
16:15:00	0.875	2.229	2.923	3.518	0.892	1.924	2.516	3.025
16:30:00	0.909	2.321	3.042	3.660	0.924	1.996	2.609	3.135
16:45:00	0.944	2.414	3.161	3.802	0.956	2.068	2.701	3.244
17:00:00	0.978	2.508	3.281	3.944	0.988	2.140	2.793	3.354
17:15:00	1.013	2.601	3.402	4.088	1.019	2.212	2.885	3.463
17:30:00	1.048	2.696	3.522	4.231	1.051	2.284	2.977	3.571
17:45:00	1.082	2.790	3.643	4.374	1.082	2.355	3.067	3.678
18:00:00	1.117	2.885	3.764	4.517	1.113	2.426	3.157	3.784
18:15:00	1.152	2.979	3.884	4.660	1.144	2.496	3.246	3.889
18:30:00	1.186	3.073	4.004	4.802	1.174	2.565	3.334	3.992
18:45:00	1.220	3.167	4.123	4.943	1.203	2.634	3.420	4.093
19:00:00	1.254	3.260	4.241	5.081	1.232	2.700	3.504	4.192
19:15:00	1.287	3.351	4.357	5.218	1.260	2.766	3.585	4.288
19:30:00	1.320	3.442	4.471	5.352	1.287	2.829	3.665	4.381
19:45:00	1.352	3.531	4.582	5.484	1.314	2.891	3.741	4.470
20:00:00	1.383	3.618	4.691	5.612	1.339	2.950	3.815	4.555
20:15:00	1.413	3.703	4.797	5.735	1.363	3.007	3.885	4.637
20:30:00	1.442	3.784	4.899	5.854	1.386	3.062	3.951	4.714
20:45:00	1.470	3.863	4.996	5.967	1.407	3.113	4.014	4.785
21:00:00	1.495	3.936	5.086	6.071	1.427	3.161	4.071	4.851
21:15:00	1.518	4.002	5.166	6.164	1.446	3.206	4.124	4.912
21:30:00	1.538	4.060	5.235	6.242	1.462	3.246	4.172	4.965
21:45:00	1.556	4.111	5.295	6.310	1.477	3.283	4.215	5.013

22:00:00	1.571	4.157	5.347	6.367	1.491	3.317	4.252	5.055
22:15:00	1.584	4.197	5.392	6.417	1.503	3.346	4.285	5.090
22:30:00	1.596	4.233	5.431	6.458	1.513	3.373	4.314	5.120
22:45:00	1.606	4.264	5.464	6.493	1.522	3.396	4.338	5.145
23:00:00	1.615	4.291	5.492	6.521	1.530	3.416	4.358	5.165
23:15:00	1.622	4.315	5.514	6.542	1.536	3.433	4.373	5.179
23:30:00	1.628	4.335	5.532	6.558	1.541	3.447	4.385	5.190
23:45:00	1.633	4.352	5.546	6.569	1.545	3.459	4.394	5.195
24:00:00	1.637	4.365	5.555	6.574	1.548	3.468	4.399	5.197
24:15:00	1.640	4.376	5.560	6.575	1.550	3.474	4.400	5.195
24:30:00	1.642	4.384	5.562	6.571	1.551	3.478	4.399	5.189
24:45:00	1.643	4.389	5.560	6.563	1.551	3.480	4.395	5.179
25:00:00	1.643	4.392	5.555	6.551	1.550	3.480	4.388	5.167
25:15:00	1.642	4.392	5.546	6.536	1.548	3.479	4.379	5.151
25:30:00	1.640	4.390	5.535	6.517	1.546	3.475	4.368	5.133
25:45:00	1.638	4.386	5.521	6.494	1.543	3.470	4.354	5.112
26:00:00	1.635	4.380	5.504	6.468	1.539	3.463	4.338	5.088
26:15:00	1.631	4.371	5.485	6.440	1.535	3.454	4.320	5.062
26:30:00	1.627	4.361	5.463	6.408	1.530	3.444	4.300	5.034
26:45:00	1.622	4.350	5.440	6.374	1.524	3.433	4.279	5.004
27:00:00	1.616	4.336	5.413	6.337	1.518	3.420	4.256	4.972
27:15:00	1.610	4.321	5.385	6.298	1.512	3.406	4.231	4.938
27:30:00	1.603	4.304	5.355	6.256	1.505	3.391	4.205	4.903
27:45:00	1.596	4.286	5.323	6.212	1.497	3.376	4.178	4.866
28:00:00	1.589	4.267	5.290	6.166	1.489	3.359	4.149	4.827
28:15:00	1.580	4.246	5.254	6.118	1.481	3.341	4.120	4.788
28:30:00	1.572	4.224	5.217	6.068	1.473	3.322	4.089	4.747
28:45:00	1.563	4.200	5.178	6.017	1.464	3.302	4.057	4.705
29:00:00	1.553	4.176	5.138	5.964	1.454	3.282	4.025	4.661
29:15:00	1.544	4.150	5.097	5.909	1.445	3.261	3.991	4.617
29:30:00	1.533	4.123	5.054	5.853	1.435	3.239	3.957	4.573
29:45:00	1.523	4.095	5.010	5.795	1.425	3.217	3.922	4.527
30:00:00	1.512	4.066	4.965	5.736	1.415	3.194	3.887	4.481
30:15:00	1.501	4.037	4.919	5.676	1.405	3.171	3.851	4.434

30:30:00	1.490	4.006	4.872	5.614	1.394	3.148	3.815	4.387
30:45:00	1.478	3.976	4.825	5.553	1.384	3.124	3.779	4.340
31:00:00	1.467	3.945	4.778	5.492	1.373	3.100	3.743	4.293
31:15:00	1.455	3.914	4.731	5.431	1.363	3.077	3.707	4.247
31:30:00	1.444	3.883	4.684	5.371	1.353	3.054	3.671	4.200
31:45:00	1.432	3.852	4.637	5.310	1.342	3.030	3.636	4.155
32:00:00	1.421	3.821	4.591	5.250	1.332	3.007	3.601	4.110
32:15:00	1.410	3.790	4.544	5.190	1.322	2.984	3.566	4.065
32:30:00	1.398	3.760	4.498	5.131	1.312	2.962	3.532	4.021
32:45:00	1.387	3.730	4.453	5.073	1.302	2.939	3.499	3.978
33:00:00	1.377	3.700	4.409	5.016	1.293	2.918	3.466	3.936
33:15:00	1.366	3.672	4.366	4.962	1.284	2.896	3.434	3.895
33:30:00	1.356	3.645	4.326	4.909	1.274	2.875	3.403	3.855
33:45:00	1.347	3.619	4.287	4.859	1.266	2.855	3.372	3.815
34:00:00	1.338	3.594	4.249	4.811	1.257	2.835	3.342	3.777
34:15:00	1.329	3.570	4.213	4.764	1.248	2.816	3.313	3.740
34:30:00	1.320	3.546	4.177	4.718	1.240	2.797	3.285	3.704
34:45:00	1.312	3.523	4.142	4.673	1.232	2.779	3.258	3.668
35:00:00	1.303	3.501	4.109	4.630	1.224	2.761	3.231	3.634
35:15:00	1.295	3.478	4.075	4.587	1.217	2.743	3.204	3.600
35:30:00	1.287	3.457	4.043	4.545	1.209	2.725	3.178	3.566
35:45:00	1.280	3.436	4.011	4.505	1.201	2.708	3.153	3.534
36:00:00	1.272	3.415	3.980	4.464	1.194	2.692	3.128	3.502
36:15:00	1.264	3.394	3.949	4.425	1.187	2.675	3.104	3.471
36:30:00	1.257	3.374	3.919	4.386	1.180	2.659	3.079	3.440
36:45:00	1.249	3.354	3.889	4.348	1.173	2.643	3.056	3.410
37:00:00	1.242	3.334	3.860	4.310	1.166	2.627	3.032	3.380
37:15:00	1.235	3.314	3.830	4.273	1.159	2.611	3.009	3.350
37:30:00	1.227	3.295	3.802	4.236	1.152	2.596	2.986	3.321
37:45:00	1.220	3.275	3.773	4.200	1.145	2.580	2.964	3.292
38:00:00	1.213	3.256	3.745	4.164	1.138	2.565	2.941	3.264
38:15:00	1.206	3.237	3.717	4.128	1.131	2.550	2.919	3.235
38:30:00	1.199	3.218	3.689	4.093	1.125	2.535	2.897	3.207
38:45:00	1.192	3.199	3.661	4.057	1.118	2.519	2.875	3.180

39:00:00	1.185	3.180	3.634	4.023	1.111	2.504	2.853	3.152
39:15:00	1.177	3.161	3.606	3.988	1.104	2.489	2.831	3.125
39:30:00	1.170	3.143	3.579	3.954	1.098	2.474	2.810	3.097
39:45:00	1.163	3.124	3.552	3.919	1.091	2.459	2.788	3.070
40:00:00	1.156	3.105	3.525	3.885	1.084	2.444	2.767	3.043
40:15:00	1.149	3.086	3.498	3.851	1.077	2.429	2.745	3.016
40:30:00	1.142	3.068	3.471	3.818	1.071	2.414	2.724	2.989
40:45:00	1.135	3.049	3.445	3.784	1.064	2.399	2.702	2.962
41:00:00	1.128	3.030	3.418	3.750	1.057	2.384	2.681	2.935
41:15:00	1.121	3.011	3.391	3.717	1.050	2.369	2.660	2.909
41:30:00	1.114	2.993	3.364	3.683	1.043	2.354	2.638	2.882
41:45:00	1.107	2.974	3.338	3.650	1.037	2.338	2.617	2.855
42:00:00	1.099	2.955	3.311	3.617	1.030	2.323	2.595	2.828
42:15:00	1.092	2.936	3.284	3.583	1.023	2.308	2.574	2.801
42:30:00	1.085	2.917	3.258	3.550	1.016	2.292	2.552	2.775
42:45:00	1.078	2.897	3.231	3.516	1.009	2.277	2.530	2.748
43:00:00	1.070	2.878	3.204	3.483	1.002	2.261	2.508	2.720
43:15:00	1.063	2.858	3.176	3.449	0.994	2.245	2.486	2.693
43:30:00	1.055	2.838	3.149	3.415	0.987	2.229	2.464	2.666
43:45:00	1.048	2.819	3.121	3.381	0.980	2.213	2.442	2.638
44:00:00	1.040	2.798	3.093	3.346	0.973	2.196	2.419	2.610
44:15:00	1.033	2.778	3.065	3.312	0.965	2.180	2.397	2.583
44:30:00	1.025	2.758	3.037	3.277	0.958	2.163	2.374	2.555
44:45:00	1.017	2.737	3.009	3.242	0.950	2.147	2.351	2.527
45:00:00	1.009	2.716	2.981	3.207	0.943	2.130	2.329	2.499
45:15:00	1.001	2.695	2.952	3.172	0.935	2.113	2.306	2.471
45:30:00	0.993	2.674	2.923	3.137	0.928	2.096	2.283	2.443
45:45:00	0.985	2.653	2.895	3.102	0.920	2.079	2.260	2.415
46:00:00	0.977	2.632	2.866	3.066	0.912	2.062	2.237	2.387
46:15:00	0.969	2.610	2.837	3.031	0.905	2.045	2.214	2.358
46:30:00	0.961	2.588	2.808	2.995	0.897	2.027	2.190	2.330
46:45:00	0.953	2.567	2.778	2.960	0.889	2.010	2.167	2.302
47:00:00	0.945	2.545	2.749	2.924	0.881	1.993	2.144	2.274
47:15:00	0.937	2.523	2.720	2.888	0.874	1.975	2.121	2.246

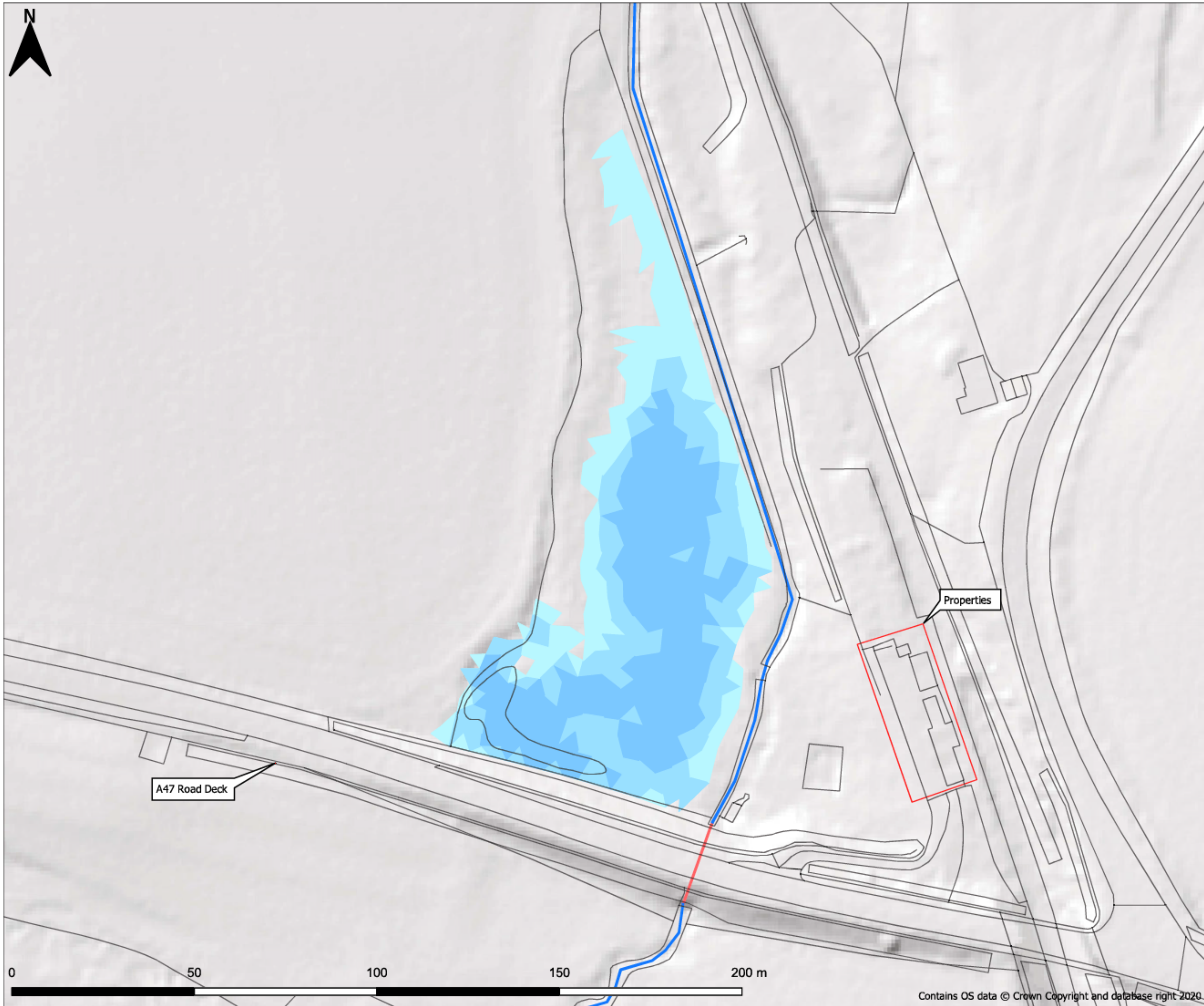
47:30:00	0.928	2.501	2.690	2.852	0.866	1.958	2.098	2.217
47:45:00	0.920	2.479	2.660	2.816	0.858	1.940	2.074	2.189
48:00:00	0.912	2.456	2.631	2.780	0.850	1.923	2.051	2.161
48:15:00	0.903	2.434	2.601	2.745	0.843	1.906	2.028	2.133
48:30:00	0.895	2.412	2.572	2.709	0.835	1.888	2.005	2.106
48:45:00	0.887	2.389	2.542	2.673	0.827	1.871	1.982	2.078
49:00:00	0.878	2.367	2.512	2.637	0.819	1.853	1.959	2.050
49:15:00	0.870	2.344	2.482	2.601	0.812	1.836	1.937	2.023
49:30:00	0.862	2.322	2.453	2.565	0.804	1.819	1.914	1.996
49:45:00	0.853	2.299	2.423	2.530	0.797	1.802	1.892	1.969
50:00:00	0.845	2.277	2.394	2.494	0.789	1.785	1.870	1.943
50:15:00	0.837	2.254	2.365	2.459	0.782	1.768	1.848	1.916
50:30:00	0.829	2.232	2.336	2.424	0.775	1.751	1.826	1.891
50:45:00	0.821	2.210	2.307	2.390	0.768	1.735	1.805	1.865
51:00:00	0.812	2.188	2.278	2.355	0.761	1.719	1.784	1.841
51:15:00	0.805	2.166	2.250	2.322	0.754	1.703	1.764	1.816
51:30:00	0.797	2.145	2.222	2.289	0.747	1.688	1.744	1.793
51:45:00	0.789	2.124	2.195	2.256	0.740	1.673	1.725	1.770
52:00:00	0.782	2.103	2.169	2.225	0.734	1.658	1.706	1.747
52:15:00	0.775	2.084	2.144	2.195	0.728	1.644	1.688	1.726
52:30:00	0.768	2.065	2.120	2.167	0.722	1.630	1.671	1.706
52:45:00	0.762	2.048	2.098	2.141	0.717	1.617	1.654	1.686
53:00:00	0.756	2.031	2.077	2.116	0.711	1.605	1.639	1.668
53:15:00	0.750	2.016	2.058	2.094	0.706	1.593	1.624	1.651
53:30:00	0.745	2.001	2.039	2.072	0.701	1.581	1.610	1.634
53:45:00	0.740	1.987	2.022	2.052	0.697	1.570	1.596	1.618
54:00:00	0.735	1.974	2.006	2.033	0.692	1.560	1.583	1.603
54:15:00	0.731	1.961	1.990	2.015	0.688	1.550	1.571	1.589
54:30:00	0.726	1.949	1.975	1.998	0.684	1.540	1.560	1.576
54:45:00	0.722	1.937	1.961	1.981	0.680	1.531	1.548	1.563
55:00:00	0.718	1.926	1.947	1.966	0.676	1.523	1.538	1.551
55:15:00	0.714	1.915	1.935	1.951	0.672	1.514	1.528	1.540
55:30:00	0.710	1.905	1.922	1.937	0.669	1.506	1.518	1.529
55:45:00	0.707	1.895	1.910	1.924	0.666	1.498	1.509	1.519

56:00:00	0.703	1.885	1.899	1.911	0.663	1.491	1.501	1.509
56:15:00	0.700	1.876	1.888	1.899	0.660	1.484	1.493	1.500
56:30:00	0.697	1.867	1.878	1.888	0.657	1.477	1.485	1.491
56:45:00	0.694	1.858	1.868	1.877	0.654	1.470	1.477	1.483
57:00:00	0.691	1.850	1.859	1.866	0.651	1.464	1.470	1.475
57:15:00	0.688	1.842	1.850	1.856	0.648	1.458	1.463	1.467
57:30:00	0.685	1.834	1.841	1.846	0.646	1.452	1.456	1.460
57:45:00	0.682	1.827	1.832	1.837	0.643	1.446	1.450	1.453
58:00:00	0.680	1.820	1.824	1.828	0.641	1.441	1.444	1.447
58:15:00	0.677	1.813	1.817	1.820	0.639	1.435	1.438	1.440
58:30:00	0.675	1.806	1.809	1.812	0.636	1.430	1.432	1.434
58:45:00	0.672	1.799	1.802	1.804	0.634	1.425	1.427	1.428
59:00:00	0.670	1.793	1.795	1.797	0.632	1.420	1.422	1.423
59:15:00	0.667	1.786	1.788	1.790	0.630	1.415	1.417	1.418
59:30:00	0.665	1.780	1.782	1.783	0.628	1.411	1.412	1.412
59:45:00	0.663	1.774	1.775	1.776	0.626	1.406	1.407	1.407
60:00:00	0.661	1.769	1.769	1.770	0.624	1.402	1.402	1.403
60:15:00	0.659	1.763	1.764	1.764	0.622	1.397	1.398	1.398
60:30:00	0.657	1.758	1.758	1.758	0.620	1.393	1.393	1.394
60:45:00	0.655	1.752	1.752	1.753	0.618	1.389	1.389	1.389
61:00:00	0.653	1.747	1.747	1.747	0.616	1.385	1.385	1.385
61:15:00	0.651	1.742	1.742	1.742	0.615	1.381	1.381	1.381
61:30:00	0.649	1.737	1.737	1.737	0.613	1.377	1.377	1.377
61:45:00	0.647	1.732	1.732	1.732	0.611	1.373	1.373	1.373
62:00:00	0.646	1.727	1.727	1.727	0.609	1.369	1.369	1.369
62:15:00	0.644	1.722	1.722	1.722	0.608	1.366	1.366	1.366
62:30:00	0.642	1.718	1.718	1.718	0.606	1.362	1.362	1.362
62:45:00	0.640	1.713	1.713	1.713	0.604	1.358	1.358	1.358
63:00:00	0.638	1.708	1.708	1.708	0.603	1.354	1.354	1.354
63:15:00	0.637	1.703	1.703	1.703	0.601	1.350	1.350	1.350
63:30:00	0.635	1.699	1.699	1.699	0.599	1.347	1.347	1.347
63:45:00	0.633	1.694	1.694	1.694	0.598	1.343	1.343	1.343
64:00:00	0.631	1.689	1.689	1.689	0.596	1.339	1.339	1.339
64:15:00	0.630	1.684	1.684	1.684	0.594	1.335	1.335	1.335

64:30:00	0.628	1.680	1.680	1.680	0.593	1.332	1.332	1.332
64:45:00	0.626	1.675	1.675	1.675	0.591	1.328	1.328	1.328
65:00:00	0.624	1.670	1.670	1.670	0.589	1.324	1.324	1.324
65:15:00	0.623	1.666	1.666	1.666	0.588	1.320	1.320	1.320
65:30:00	0.621	1.661	1.661	1.661	0.586	1.317	1.317	1.317
65:45:00	0.619	1.656	1.656	1.656	0.584	1.313	1.313	1.313
66:00:00	0.617	1.652	1.652	1.652	0.583	1.309	1.309	1.309
66:15:00	0.616	1.647	1.647	1.647	0.581	1.306	1.306	1.306
66:30:00	0.614	1.642	1.642	1.642	0.580	1.302	1.302	1.302
66:45:00	0.612	1.638	1.638	1.638	0.578	1.298	1.298	1.298
67:00:00	0.610	1.633	1.633	1.633	0.576	1.295	1.295	1.295
67:15:00	0.609	1.629	1.629	1.629	0.575	1.291	1.291	1.291
67:30:00	0.607	1.624	1.624	1.624	0.573	1.288	1.288	1.288
67:45:00	0.605	1.620	1.620	1.620	0.571	1.284	1.284	1.284
68:00:00	0.604	1.615	1.615	1.615	0.570	1.280	1.280	1.280
68:15:00	0.602	1.611	1.611	1.611	0.568	1.277	1.277	1.277
68:30:00	0.600	1.606	1.606	1.606	0.567	1.273	1.273	1.273
68:45:00	0.599	1.602	1.602	1.602	0.565	1.270	1.270	1.270
69:00:00	0.597	1.597	1.597	1.597	0.563	1.266	1.266	1.266
69:15:00	0.595	1.593	1.593	1.593	0.562	1.263	1.263	1.263
69:30:00	0.594	1.588	1.588	1.588	0.560	1.259	1.259	1.259
69:45:00	0.592	1.584	1.584	1.584	0.559	1.256	1.256	1.256
70:00:00	0.590	1.579	1.579	1.579	0.557	1.252	1.252	1.252
70:15:00	0.589	1.575	1.575	1.575	0.556	1.249	1.249	1.249
70:30:00	0.587	1.570	1.570	1.570	0.554	1.245	1.245	1.245
70:45:00	0.585	1.566	1.566	1.566	0.553	1.242	1.242	1.242
71:00:00	0.584	1.562	1.562	1.562	0.551	1.238	1.238	1.238
71:15:00	0.582	1.557	1.557	1.557	0.549	1.235	1.235	1.235
71:30:00	0.580	1.553	1.553	1.553	0.548	1.231	1.231	1.231
71:45:00	0.579	1.549	1.549	1.549	0.546	1.228	1.228	1.228
72:00:00	0.577	1.544	1.544	1.544	0.545	1.224	1.224	1.224
72:15:00	0.576	1.540	1.540	1.540	0.543	1.221	1.221	1.221
72:30:00	0.574	1.536	1.536	1.536	0.542	1.217	1.217	1.217
72:45:00	0.572	1.531	1.531	1.531	0.540	1.214	1.214	1.214

73:00:00	0.571	1.527	1.527	1.527	0.539	1.211	1.211	1.211
73:15:00	0.569	1.523	1.523	1.523	0.537	1.207	1.207	1.207
73:30:00	0.568	1.519	1.519	1.519	0.536	1.204	1.204	1.204
73:45:00	0.566	1.514	1.514	1.514	0.534	1.201	1.201	1.201
74:00:00	0.564	1.510	1.510	1.510	0.533	1.197	1.197	1.197
74:15:00	0.563	1.506	1.506	1.506	0.531	1.194	1.194	1.194
74:30:00	0.561	1.502	1.502	1.502	0.530	1.191	1.191	1.191
74:45:00	0.560	1.497	1.497	1.497	0.528	1.187	1.187	1.187
75:00:00	0.558	1.493	1.493	1.493	0.527	1.184	1.184	1.184

Appendix C. Flood depth maps



LEGEND

10% AEP Flood Depth (m)

- 0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- Wittering Brook Watercourse
- A47 Culvert

DRAWN / CHECK	DATE OF ISSUE
RV / JP	19/04/21

DESIGNER: SWECO

CONTRACTOR: GallifordTry

CLIENT: highways england

PROJECT TITLE: A47 WANSFORD TO SUTTON DUALLING

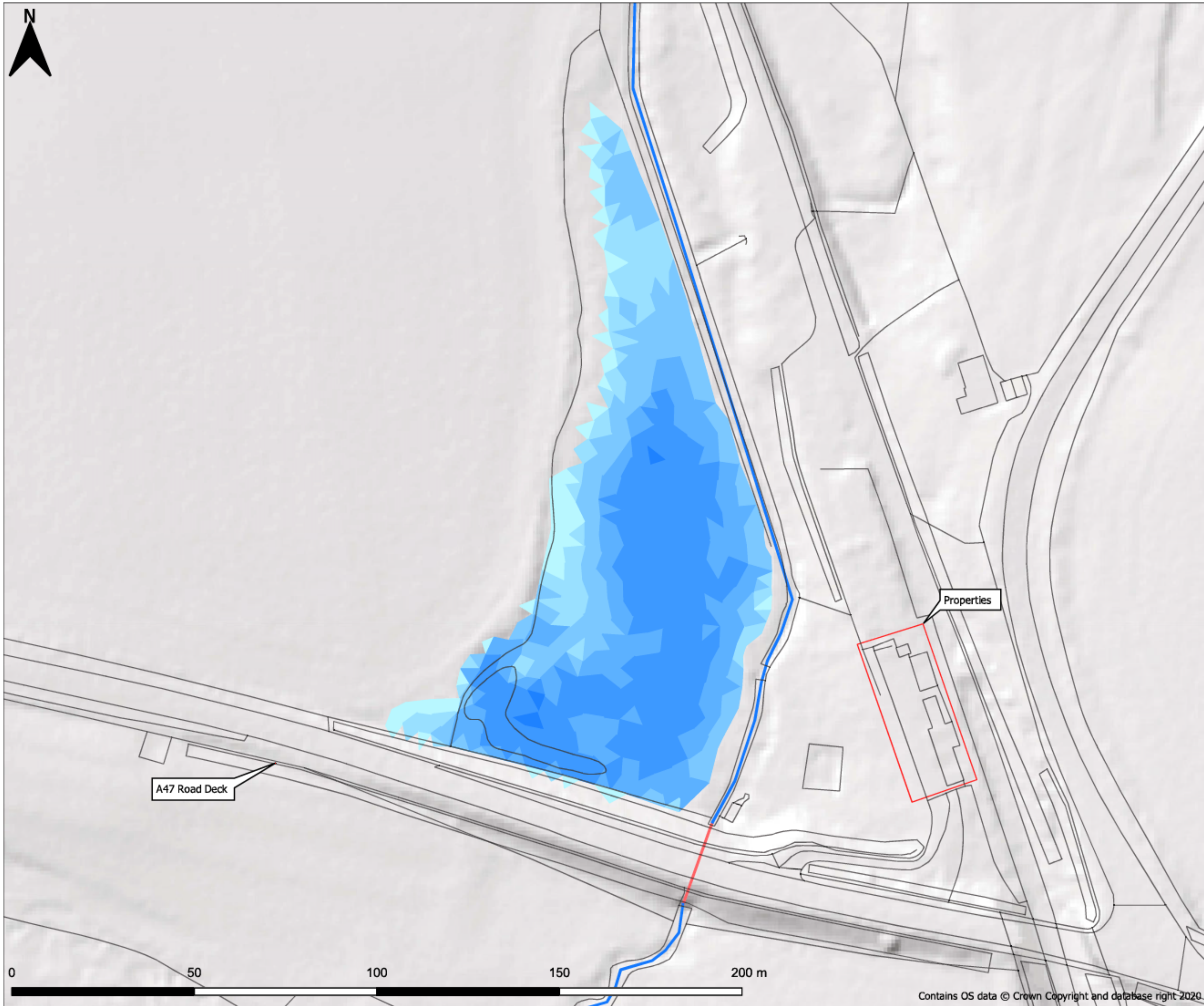
PROJECT STAGE: PCF STAGE 3

DRAWING TITLE: Baseline 10% AEP Flood Depth

SUITABILITY: FOR INFORMATION

SHEET SIZE	SCALE	REVISION
A3	1:1000	P01

DRAWING NUMBER: DWG.01

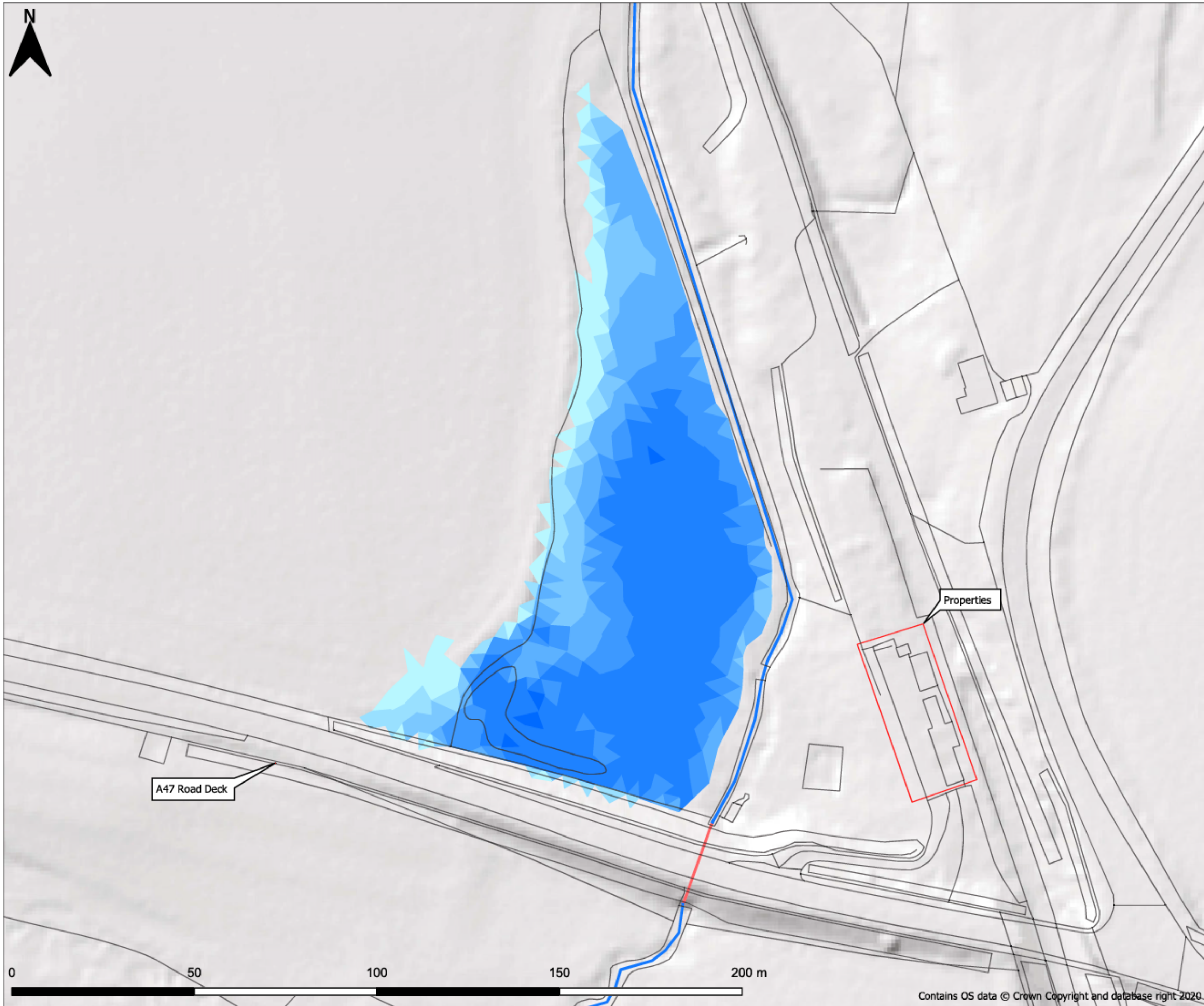


LEGEND

1% AEP Flood Depth (m)

- 0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0
- 1.0 - 1.25
- Wittering Brook Watercourse
- A47 Culvert

DRAWN / CHECK: RV / JP	DATE OF ISSUE: 19/04/21
DESIGNER: SWECO	
CONTRACTOR: Galliford Try	
CLIENT: highways england	
PROJECT TITLE: A47 WANSFORD TO SUTTON DUALLING	
PROJECT STAGE: PCF STAGE 3	
DRAWING TITLE: Baseline 1% AEP Flood Depth	
SUITABILITY: FOR INFORMATION	
SHEET SIZE: A3	SCALE: 1:1000	REVISION: P01
DRAWING NUMBER: DWG.02	

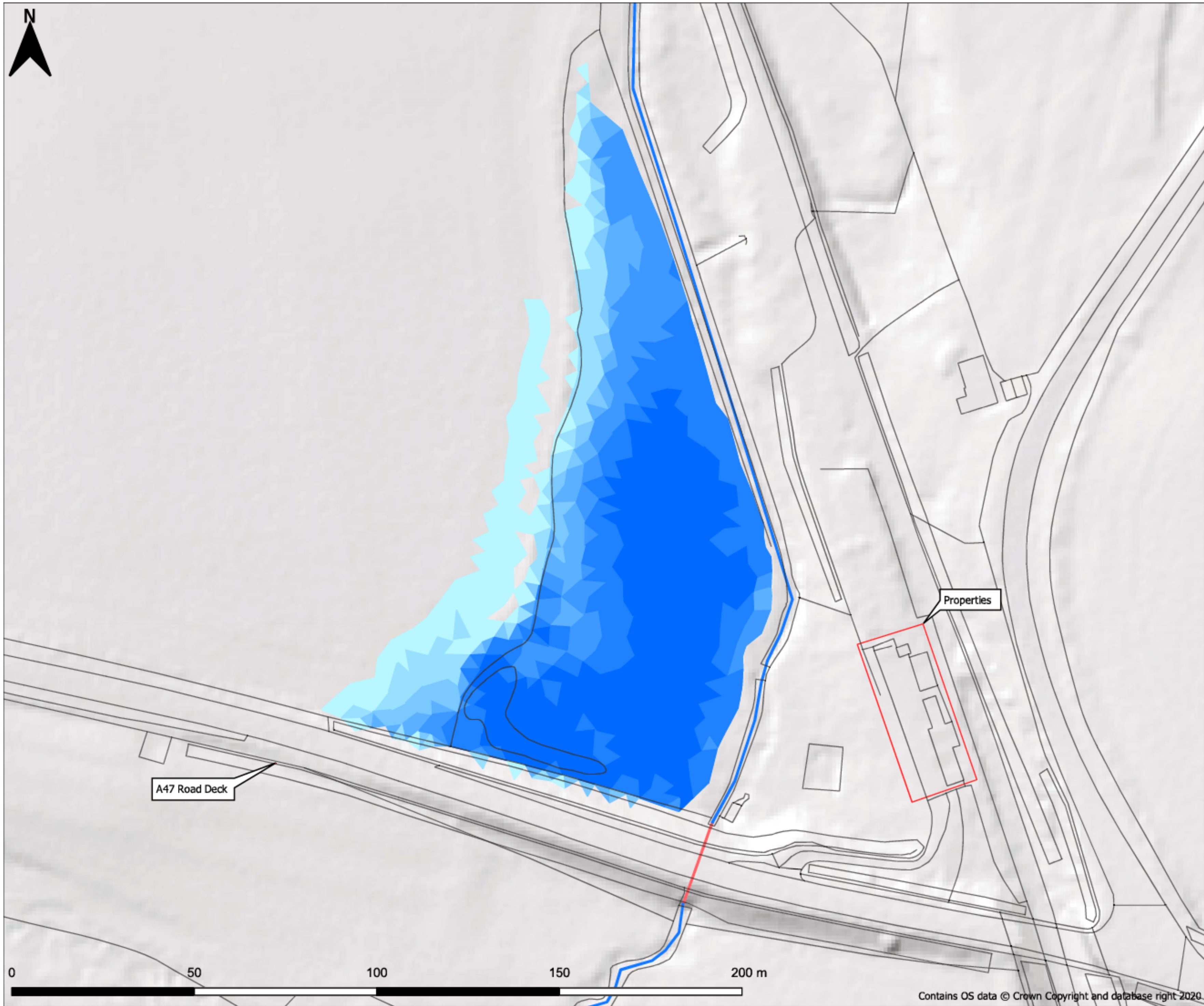


LEGEND

1% + 35% AEP Flood Depth (m)

- 0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0
- 1.0 - 1.25
- Wittering Brook Watercourse
- A47 Culvert

DRAWN / CHECK: RV / JP	DATE OF ISSUE: 19/04/21
DESIGNER: SWECO	
CONTRACTOR: GallifordTry	
CLIENT: highways england	
PROJECT TITLE: A47 WANSFORD TO SUTTON DUALLING	
PROJECT STAGE: PCF STAGE 3	
DRAWING TITLE: Baseline 1% + 35% AEP Flood Depth	
SUITABILITY: FOR INFORMATION	
SHEET SIZE: A3	SCALE: 1:1000
REVISION: P01	
DRAWING NUMBER: DWG.03	

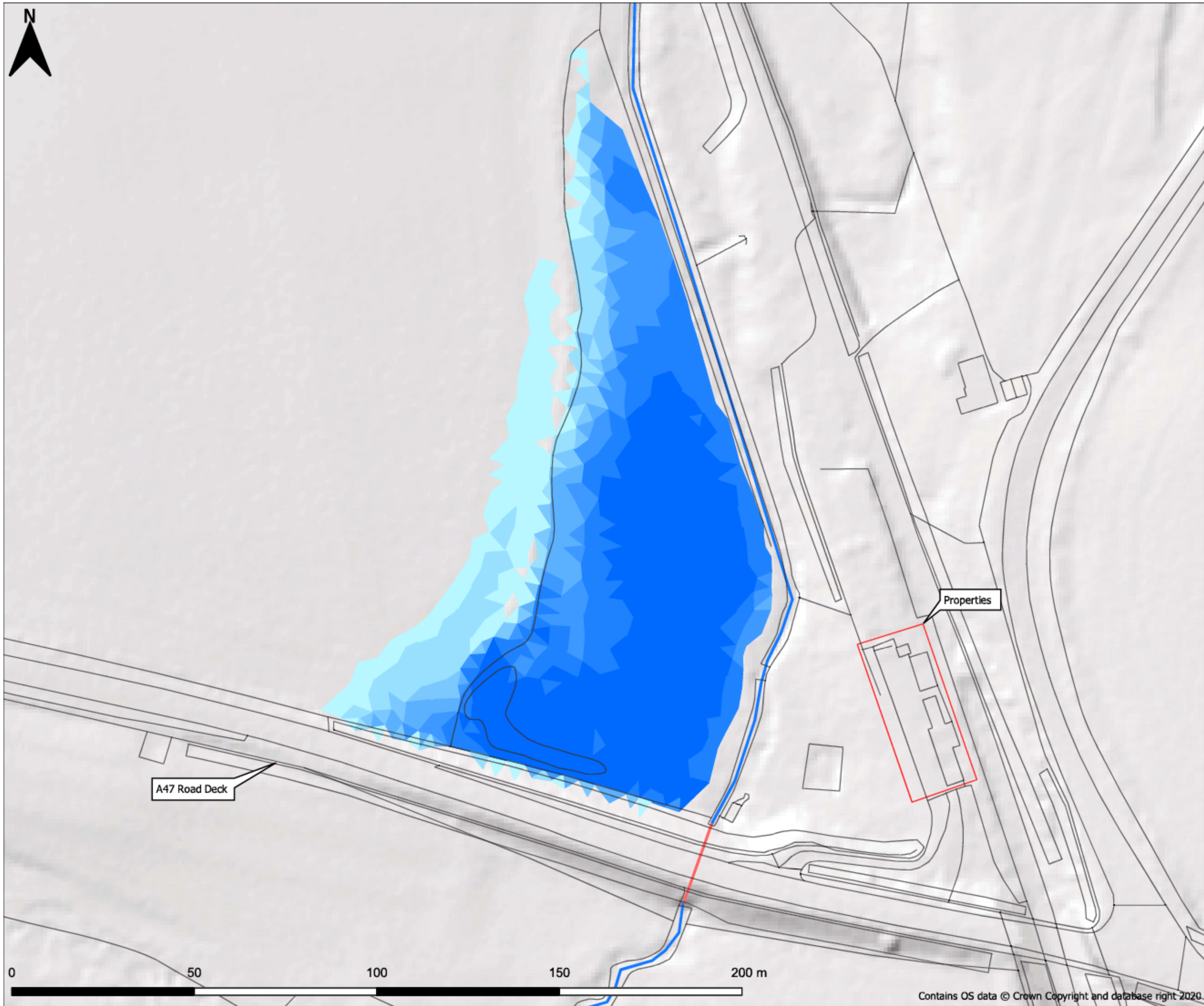


LEGEND

1% + 65% AEP Flood Depth (m)

- 0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0
- 1.0 - 1.25
- 1.25 - 1.50
- Wittering Brook Watercourse
- A47 Culvert

DRAWN / CHECK: RV / JP	DATE OF ISSUE: 19/04/21
DESIGNER: SWECO	
CONTRACTOR: GallifordTry	
CLIENT: highways england	
PROJECT TITLE: A47 WANSFORD TO SUTTON DUALLING	
PROJECT STAGE: PCF STAGE 3	
DRAWING TITLE: Baseline 1% + 65% AEP Flood Depth	
SUITABILITY: FOR INFORMATION	
SHEET SIZE: A3	SCALE: 1:1000
REVISION: P01	
DRAWING NUMBER: DWG.04	

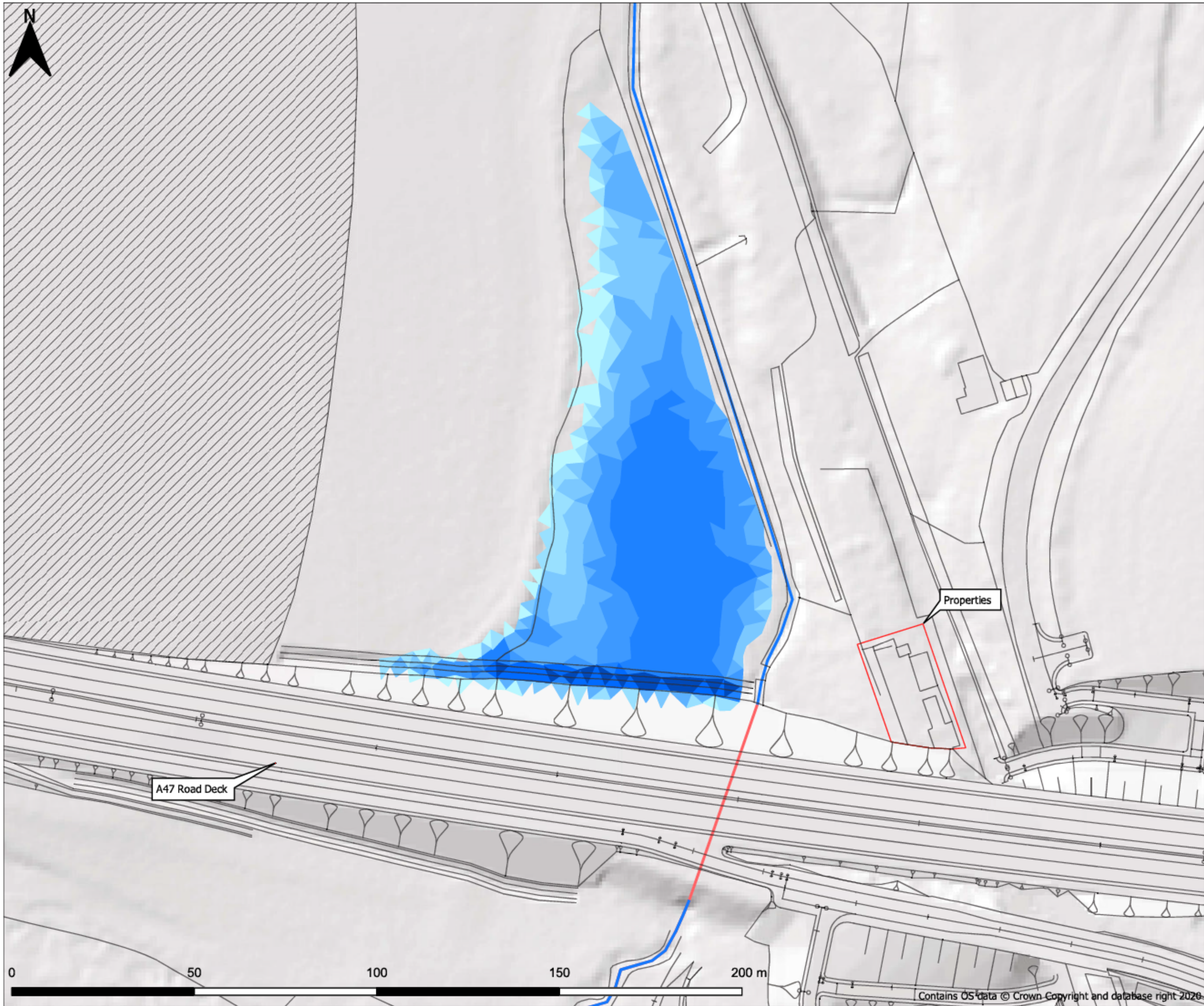


LEGEND

1% + 80% AEP Flood Depth (m)

- 0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0
- 1.0 - 1.25
- 1.25 - 1.50
- Wittering Brook Watercourse
- A47 Culvert

DRAWN / CHECK: RV / JP	DATE OF ISSUE: 19/04/21
DESIGNER: SWECO	
CONTRACTOR: GallifordTry	
CLIENT: highways england	
PROJECT TITLE: A47 WANSFORD TO SUTTON DUALLING	
PROJECT STAGE: PCF STAGE 3	
DRAWING TITLE: Baseline 1% + 80% AEP Flood Depth	
SUITABILITY: FOR INFORMATION	
SHEET SIZE: A3	SCALE: 1:1000
REVISION: P01	
DRAWING NUMBER: DWG.05	

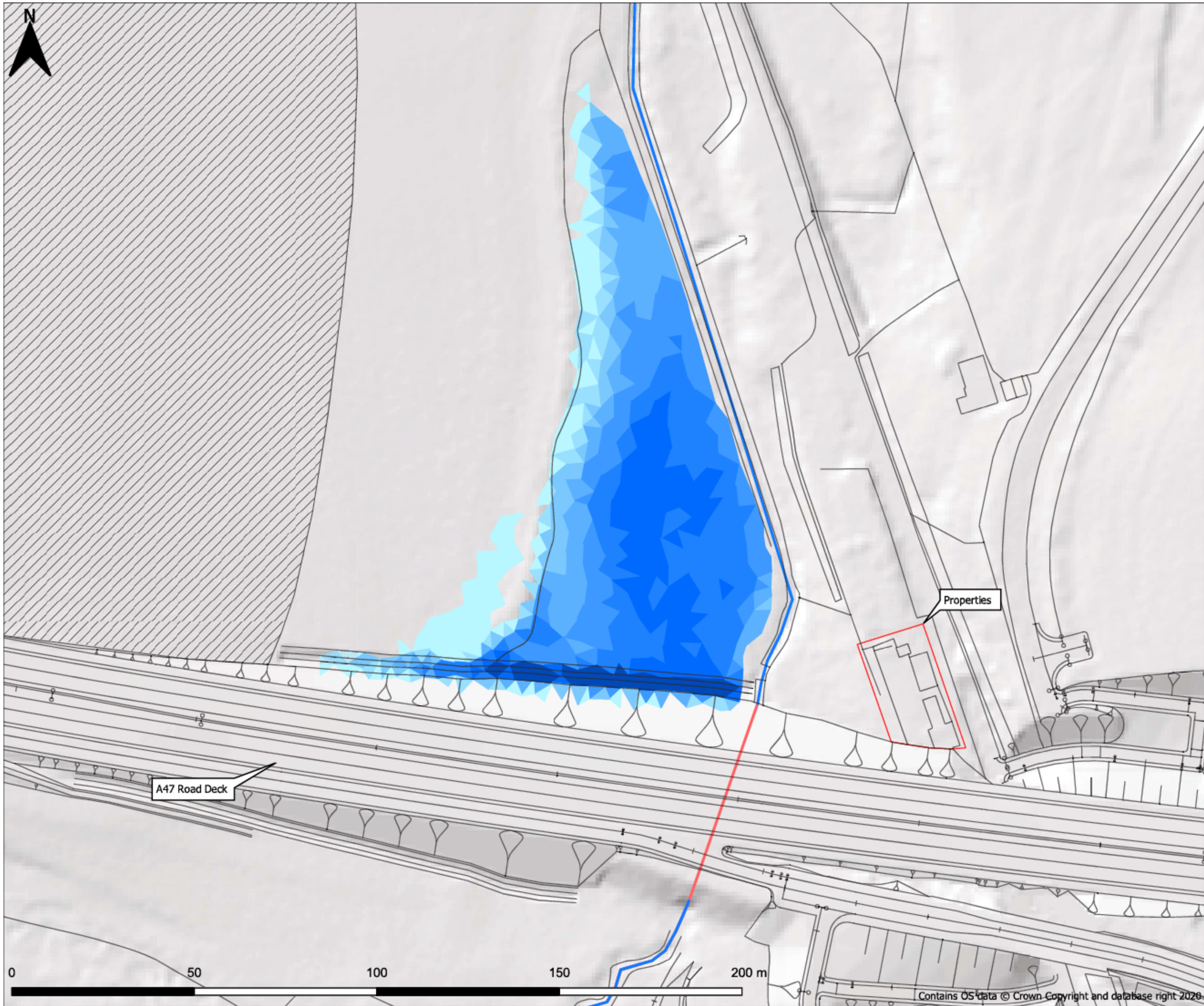


LEGEND

1% + 35% AEP Flood Depth (m)

- 0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0
- 1.0 - 1.25
- 1.25 - 1.5
- 1.5 - 2.0
- Wittering Brook Watercourse
- A47 Culvert
- Scheduled Monument

DRAWN / CHECK: RV / JP	DATE OF ISSUE: 19/04/21
DESIGNER: SWECO	
CONTRACTOR: GallifordTry	
CLIENT: highways england	
PROJECT TITLE: A47 WANSFORD TO SUTTON DUALLING	
PROJECT STAGE: PCF STAGE 3	
DRAWING TITLE: Option 1 1% + 35% AEP Flood Depth	
SUITABILITY: FOR INFORMATION	
SHEET SIZE: A3	SCALE: 1:1000
REVISION: P01	
DRAWING NUMBER: DWG.11	

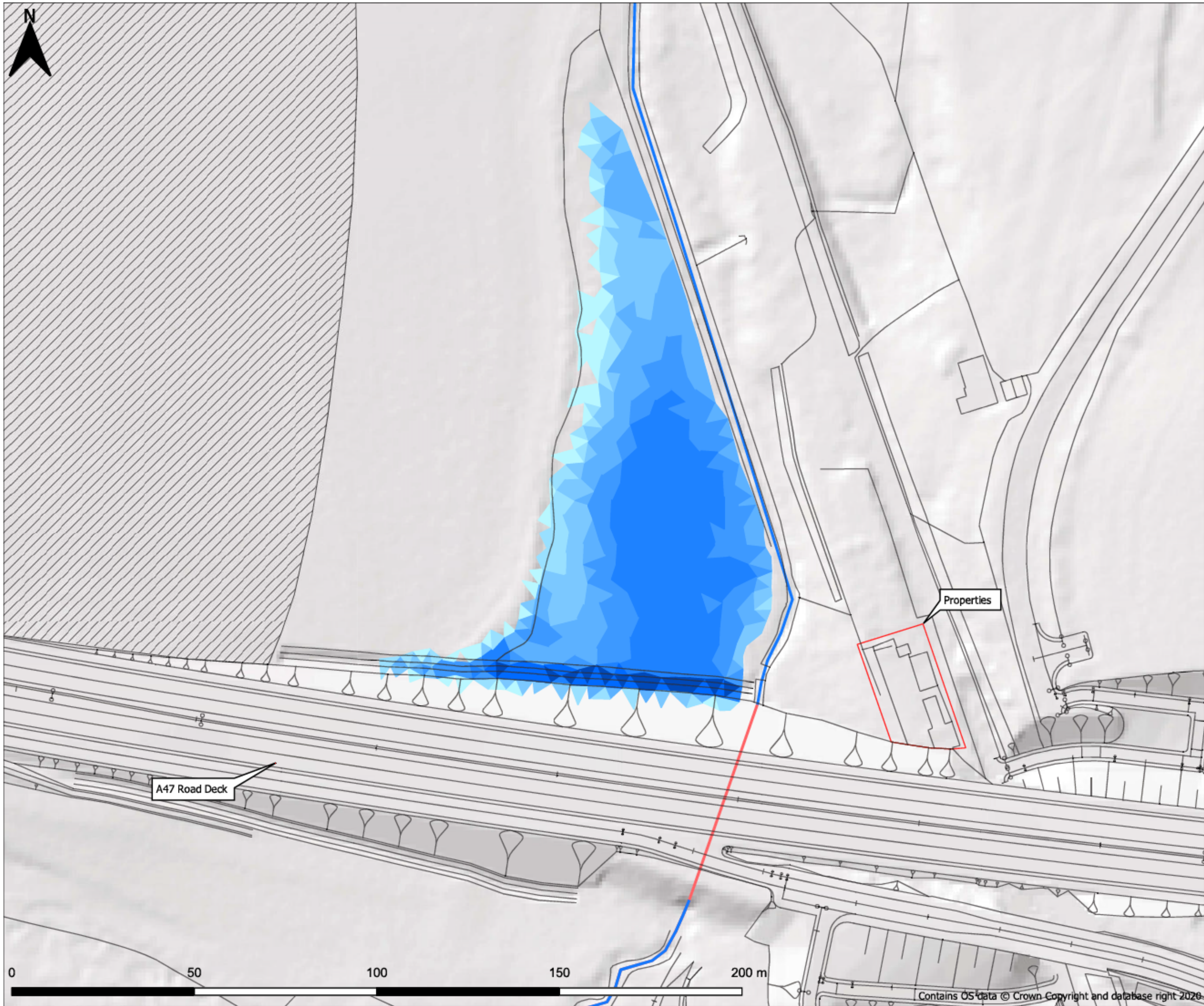


LEGEND

1% + 65% AEP Flood Depth (m)

- 0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0
- 1.0 - 1.25
- 1.25 - 1.5
- 1.5 - 2.0
- Wittering Brook Watercourse
- A47 Culvert
- Scheduled Monument

DRAWN / CHECK: RV / JP	DATE OF ISSUE: 19/04/21
DESIGNER: SWECO	
CONTRACTOR: Galliford Try	
CLIENT: highways england	
PROJECT TITLE: A47 WANSFORD TO SUTTON DUALLING	
PROJECT STAGE: PCF STAGE 3	
DRAWING TITLE: Option 1 1% + 65% AEP Flood Depth	
SUITABILITY: FOR INFORMATION	
SHEET SIZE: A3	SCALE: 1:1000
REVISION: P01	
DRAWING NUMBER: DWG.12	



LEGEND

1% + 35% AEP Flood Depth (m)

- 0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0
- 1.0 - 1.25
- 1.25 - 1.5
- 1.5 - 2.0
- Wittering Brook Watercourse
- A47 Culvert
- Scheduled Monument

DRAWN / CHECK	DATE OF ISSUE
RV / JP	19/04/21

DESIGNER: SWECO

CONTRACTOR: GallifordTry

CLIENT: highways england

PROJECT TITLE: A47 WANSFORD TO SUTTON DUALLING

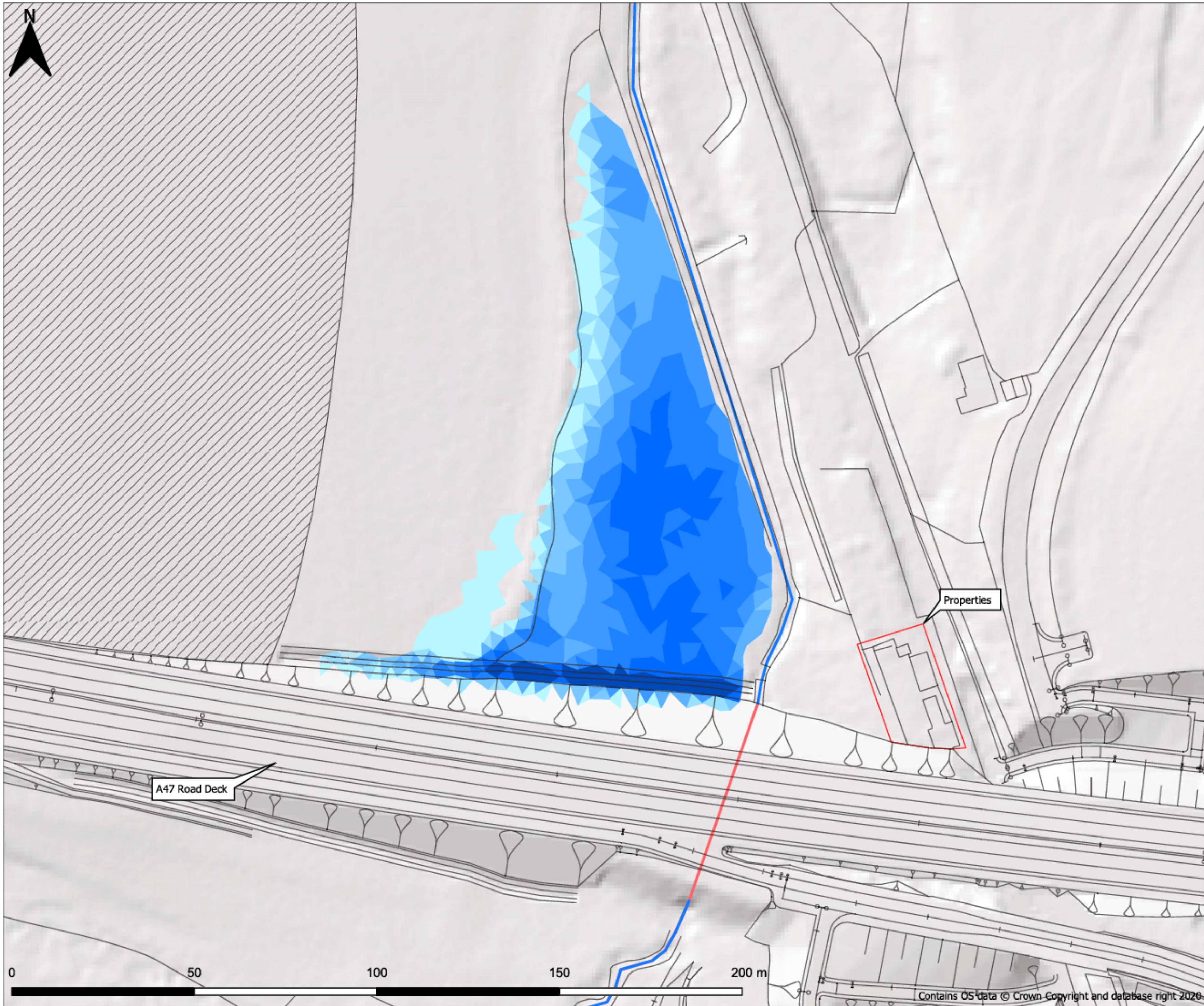
PROJECT STAGE: PCF STAGE 3

DRAWING TITLE: Option 2a
1% + 35% AEP Flood Depth

SUITABILITY: FOR INFORMATION

SHEET SIZE	SCALE	REVISION
A3	1:1000	P01

DRAWING NUMBER: DWG.21



LEGEND

1% + 65% AEP Flood Depth (m)

- 0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0
- 1.0 - 1.25
- 1.25 - 1.5
- 1.5 - 2.0
- Wittering Brook Watercourse
- A47 Culvert
- Scheduled Monument

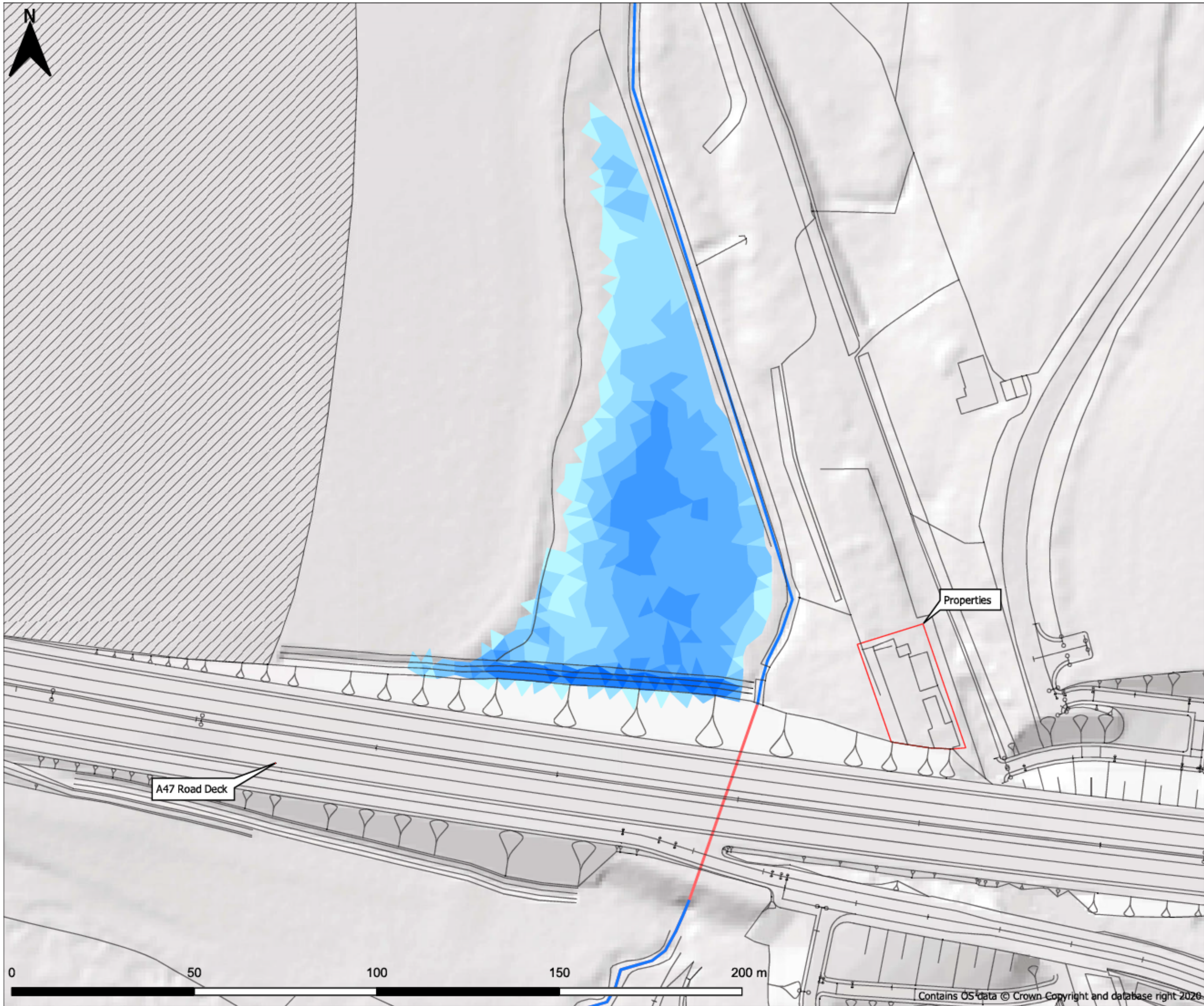
DRAWN / CHECK: RV / JP	DATE OF ISSUE: 19/04/21
DESIGNER: SWECO	
CONTRACTOR: GallifordTry	
CLIENT: highways england	
PROJECT TITLE: A47 WANSFORD TO SUTTON DUALLING	
PROJECT STAGE: PCF STAGE 3	
DRAWING TITLE: Option 2a 1% + 65% AEP Flood Depth	
SUITABILITY: FOR INFORMATION	
SHEET SIZE: A3	SCALE: 1:1000	REVISION: P01
DRAWING NUMBER: DWG.22	

LEGEND

10% AEP Flood Depth (m)

- 0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0
- 1.0 - 1.25
- 1.25 - 1.50
- Wittering Brook Watercourse
- A47 Culvert
- Scheduled Monument

DRAWN / CHECK	RV / JP
DATE OF ISSUE	19/04/21
DESIGNER	SWECO
CONTRACTOR	GallifordTry
CLIENT	highways england
PROJECT TITLE	A47 WANSFORD TO SUTTON DUALLING
PROJECT STAGE	PCF STAGE 3
DRAWING TITLE	Option 2b 10% AEP Flood Depth
SUITABILITY	FOR INFORMATION
SHEET SIZE	A3
SCALE	1:1000
REVISION	P01
DRAWING NUMBER	DWG.31

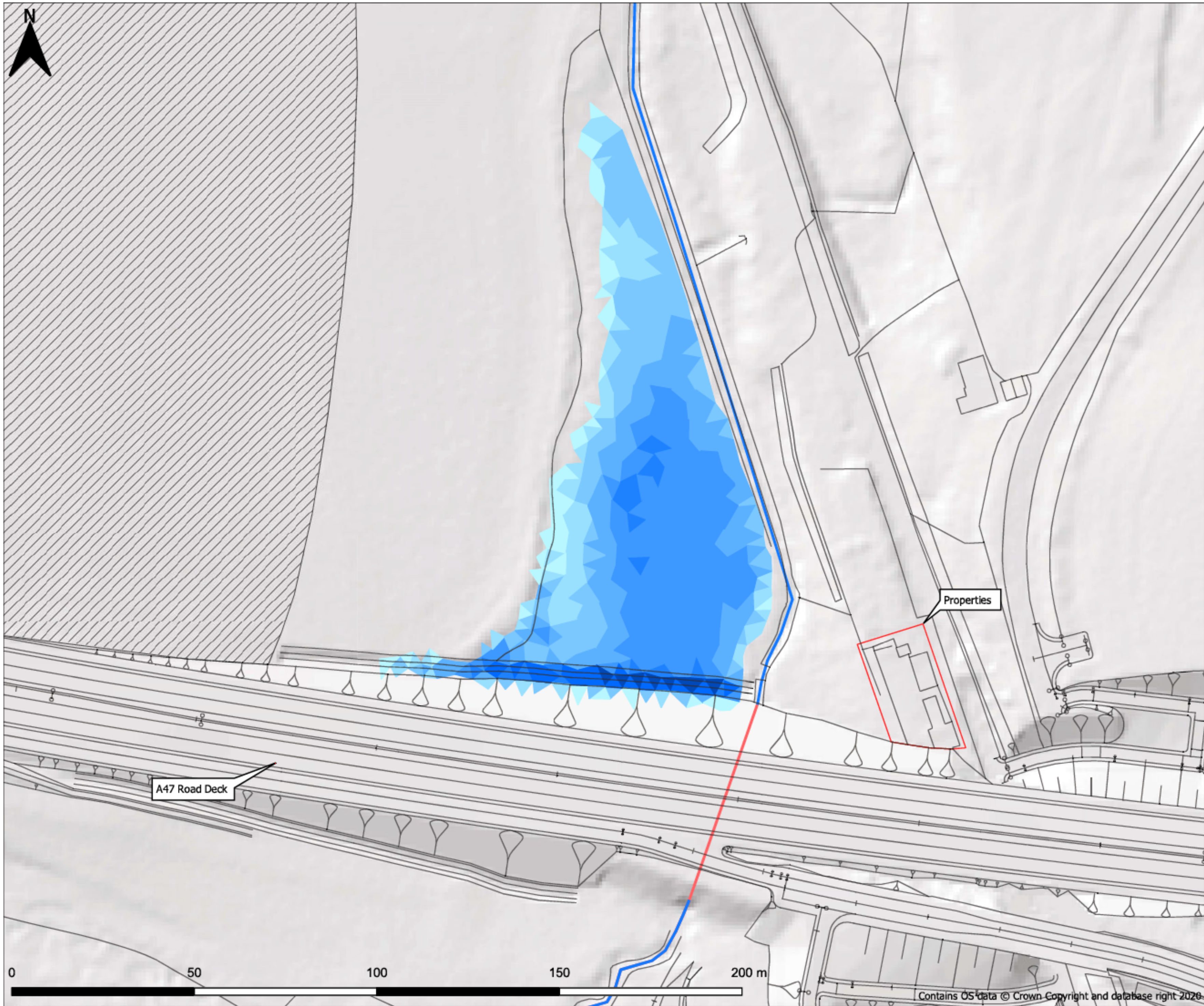


LEGEND

1% AEP Flood Depth (m)

- 0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0
- 1.0 - 1.25
- 1.25 - 1.50
- Wittering Brook Watercourse
- A47 Culvert
- Scheduled Monument

DRAWN / CHECK: RV / JP	DATE OF ISSUE: 19/04/21
DESIGNER: SWECO	
CONTRACTOR: GallifordTry	
CLIENT: highways england	
PROJECT TITLE: A47 WANSFORD TO SUTTON DUALLING	
PROJECT STAGE: PCF STAGE 3	
DRAWING TITLE: Option 2b 1% AEP Flood Depth	
SUITABILITY: FOR INFORMATION	
SHEET SIZE: A3	SCALE: 1:1000	REVISION: P01
DRAWING NUMBER: DWG.32	

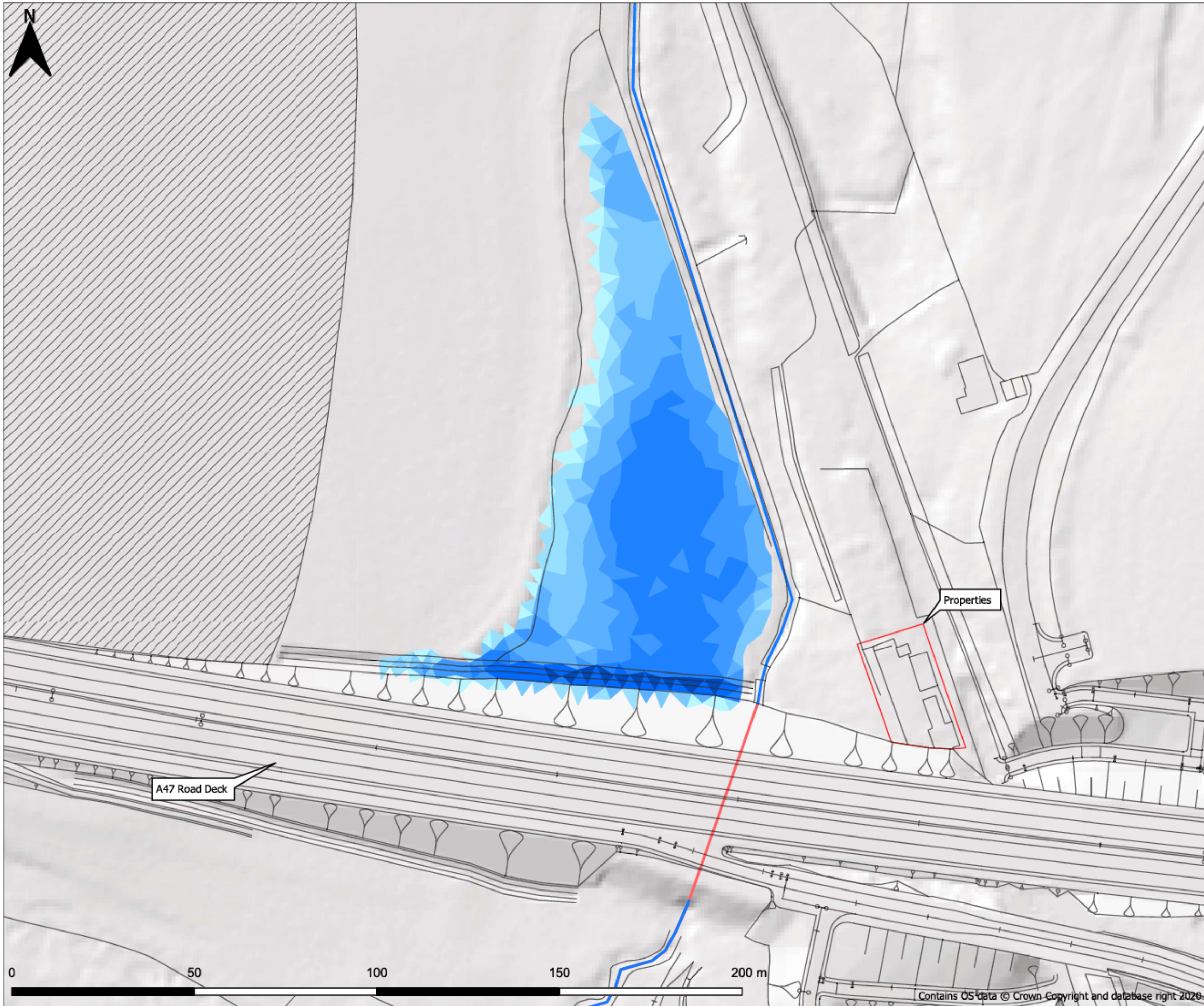


LEGEND

1% + 35% AEP Flood Depth (m)

- 0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0
- 1.0 - 1.25
- 1.25 - 1.5
- 1.5 - 2.0
- Wittering Brook Watercourse
- A47 Culvert
- Scheduled Monument

DRAWN / CHECK: RV / JP	DATE OF ISSUE: 19/04/21
DESIGNER: SWECO	
CONTRACTOR: Galliford Try	
CLIENT: highways england	
PROJECT TITLE: A47 WANSFORD TO SUTTON DUALLING	
PROJECT STAGE: PCF STAGE 3	
DRAWING TITLE: Option 2b 1% + 35% AEP Flood Depth	
SUITABILITY: FOR INFORMATION	
SHEET SIZE: A3	SCALE: 1:1000
REVISION: P01	
DRAWING NUMBER: DWG.33	



LEGEND

1% + 65% AEP Flood Depth (m)

- 0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0
- 1.0 - 1.25
- 1.25 - 1.5
- 1.5 - 2.0
- Wittering Brook Watercourse
- A47 Culvert
- Scheduled Monument

DRAWN / CHECK: RV / JP	DATE OF ISSUE: 19/04/21
DESIGNER: SWECO	
CONTRACTOR: GallifordTry	
CLIENT: highways england	
PROJECT TITLE: A47 WANSFORD TO SUTTON DUALLING	
PROJECT STAGE: PCF STAGE 3	
DRAWING TITLE: Option 2b 1% + 65% AEP Flood Depth	
SUITABILITY: FOR INFORMATION	
SHEET SIZE: A3	SCALE: 1:1000	REVISION: P01
DRAWING NUMBER: DWG.34	

LEGEND

1% + 80% AEP Flood Depth (m)

- 0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0
- 1.0 - 1.25
- 1.25 - 1.5
- 1.5 - 2.0
- Wittering Brook Watercourse
- A47 Culvert
- Scheduled Monument

DRAWN / CHECK	DATE OF ISSUE
RV / JP	19/04/21

DESIGNER: SWECO

CONTRACTOR: Galliford Try

CLIENT: highways england

PROJECT TITLE: A47 WANSFORD TO SUTTON DUALLING

PROJECT STAGE: PCF STAGE 3

DRAWING TITLE: Option 2b 1% + 80% AEP Flood Depth

SUITABILITY: FOR INFORMATION

SHEET SIZE	SCALE	REVISION
A3	1:1000	P01

DRAWING NUMBER: DWG.35

LEGEND

10% AEP WINFAP 4 Detriment (mm)

- -800 - -400
- -400- -200
- -200 - -100
- -100 - -50
- -50 - -10
- 10 - 50
- 50 - 100
- 100 - 200
- 200 - 600

Notes

The detriment map shows the difference between the baseline and Option 2b flood maps.

The observed increase in flood depths at the toe of the scheme embankment is as a result of a proposed filter drain.

DRAWN / CHECK	DATE OF ISSUE
RV / JP	19/04/21

DESIGNER: SWECO

CONTRACTOR: Galliford Try

CLIENT: highways england

PROJECT TITLE: A47 WANSFORD TO SUTTON DUALLING

PROJECT STAGE: PCF STAGE 3

DRAWING TITLE: WINFAP 4 FEH Statistical Detriment Map 10% AEP Flood Depth

SUITABILITY: FOR INFORMATION

SHEET SIZE	SCALE	REVISION
A3	1:1000	P01

DRAWING NUMBER: DWG.51

LEGEND

1% AEP WINFAP 4 Detriment (mm)

- -1000 - -400
- -400- -200
- -200 - -100
- -100 - -50
- -50 - -10
- 10 - 50
- 50 - 100
- 100 - 200
- 200 - 1000

Notes

The detriment map shows the difference between the baseline and Option 2b flood maps.

The observed increase in flood depths at the toe of the scheme embankment is as a result of a proposed filter drain.

DRAWN / CHECK RV / JP	DATE OF ISSUE 19/04/21
DESIGNER SWECO	
CONTRACTOR GallifordTry	
CLIENT highways england	
PROJECT TITLE A47 WANSFORD TO SUTTON DUALLING	
PROJECT STAGE PCF STAGE 3	
DRAWING TITLE WINFAP 4 FEH Statistical Detriment Map 1% AEP Flood Depth	
SUITABILITY FOR INFORMATION	
SHEET SIZE A3	SCALE 1:1000	REVISION P01
DRAWING NUMBER DWG.52	

LEGEND

1% + 35% AEP WINFAP 4 Detriment (mm)

- -1000 - -400
- -400- -200
- -200 - -100
- -100 - -50
- -50 - -10
- 10 - 50
- 50 - 100
- 100 - 200
- 200 - 1000

Notes

The detriment map shows the difference between the baseline and Option 2b flood maps.

The observed increase in flood depths at the toe of the scheme embankment is as a result of a proposed filter drain.

DRAWN / CHECK	DATE OF ISSUE
RV / JP	19/04/21

DESIGNER: SWECO

CONTRACTOR: Galliford Try

CLIENT: highways england

PROJECT TITLE: A47 WANSFORD TO SUTTON DUALLING

PROJECT STAGE: PCF STAGE 3

DRAWING TITLE: WINFAP 4 FEH Statistical Detriment Map 1% + 35% AEP Flood Depth

SUITABILITY: FOR INFORMATION

SHEET SIZE	SCALE	REVISION
A3	1:1000	P01

DRAWING NUMBER: DWG.53

LEGEND

1% + 65% AEP WINFAP 4 Detriment (mm)

- -1000 - -400
- -400- -200
- -200 - -100
- -100 - -50
- -50 - -10
- 10 - 50
- 50 - 100
- 100 - 200
- 200 - 1000

Notes

The detriment map shows the difference between the baseline and Option 2b flood maps.

The observed increase in flood depths at the toe of the scheme embankment is as a result of a proposed filter drain.

DRAWN / CHECK	DATE OF ISSUE
RV / JP	19/04/21

DESIGNER: SWECO

CONTRACTOR: GallifordTry

CLIENT: highways england

PROJECT TITLE: A47 WANSFORD TO SUTTON DUALLING

PROJECT STAGE: PCF STAGE 3

DRAWING TITLE: WINFAP 4 FEH Statistical Detriment Map 1% + 65% AEP Flood Depth

SUITABILITY: FOR INFORMATION

SHEET SIZE	SCALE	REVISION
A3	1:1000	P01

DRAWING NUMBER: DWG.54

Annex C. River Nene flood impact study

Table of contents

Figures

Tables

1. Scheme introduction

1.1.1. As part of the A47 Wansford to Sutton Dualling (‘Proposed Scheme’) there is a need to calculate peak flow estimates with allowances for climate change for the River Nene at Wansford in order to confirm the volumes of compensatory flood storage required.

1.1.2. The Proposed Scheme involves the construction of a new length of dual carriageway which largely follows the existing A47 and replaces the existing 2.5km length of single lane carriageway. Widening of the carriageway at the Wittering Brook will require detailed design of an extension to the A47 culvert, conveying flow to the River Nene.

1.1.3. The hydrological assessments carried out for the River Nene were compared to levels taken from the Environment Agency (EA) Lower Nene model for use in flood storage volume calculations. The model was provided as part of the Environment Agency Product 6 data request provided in January 2018. The model has since been confirmed as the latest version of the Lower Nene model.

1.1.4. The Lower Nene model was re-run using the updated flows to obtain a design level which would form the basis for the flood compensatory storage calculations.

1.1.5. 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), Revision 1. Highways England, 2020.

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

- National River Flow Archive peak flow dataset Version 9.

1.1.7. The hydrological assessment of the River Nene 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.

1.2. Scope of the assessment

1.2.1. Estimates of peak flood flows are required for the following return periods:

- 1 in 100-year
- 1 in 100-year plus 20%, 35% and 65% climate change

2. Catchment description

2.1.1. The River Nene is an Environment Agency designated Main River which flows generally in a west to northeast direction where it discharges at the Wash. The River Nene catchment used for this analysis covers an area of 1,516km^2. The catchment has a moderate to low permeability and contains predominately agricultural land with several small towns and the larger towns of Northampton and Kettering.

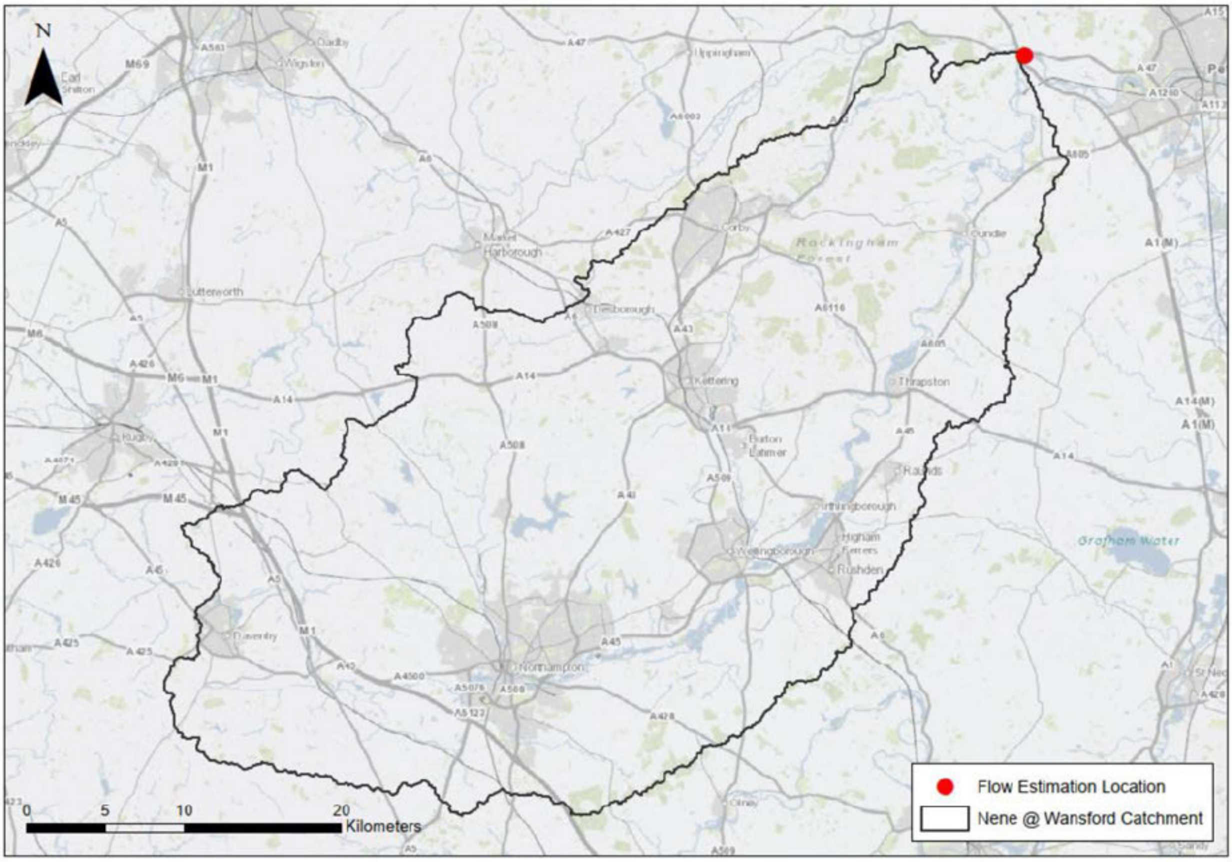
2.1.2. Cranfield Soil and Agrifood Institute (2020) soil maps indicate the catchment is underlain with mixed soils which range from lime-rich loamy and clayey soils with impeded drainage (Soilscape 9) to freely draining slightly acid but base-rich soils (Soilscape 7). The catchment has mixed geology.

2.1.3. British Geological Survey (2020) maps indicate superficial geology for the catchment is mainly Till- Diamicton.

2.2. Catchment descriptors

2.2.1. The catchment boundary and catchment descriptors were exported from the FEH Web Service (2020). The catchment boundary was confirmed against LiDAR data and can be seen in Figure 2-1.

Figure 2-1: Nene at Wansford catchment boundary exported from FEH website



2.2.2. The catchment descriptors can be seen in Appendix A and Table 2-1 below.

Table 2-1 : FEH catchment descriptors

Descriptor	Nene at Wansford
AREA (km2)	1516.080
BFIHOST (-)	0.520
FARL (-)	0.915
SAAR (mm)	620.0
SPRHOST (-)	36.560
URBEXT2000 (-)	0.049

2.2.3. The catchment descriptors indicate the catchment is urbanised with impermeable soils. There is some evidence of attenuation from lakes within the catchment although this is minor. The descriptors suggest the catchment would be suitable for routine FEH hydrological analysis with an urbanised adjustment factor applied.

3. Peak flow estimation

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

3.2. Wansford gauge

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 gauge 'donor' catchment.

3.2.2. The National River Flow Archive indicated the River Nene at Wansford possessed a gauged record length of 52 years of annual maxima peak flow data. A data review was carried out to assess the suitability of using the gauge in a FEH statistical analysis. The data was deemed appropriate and a value for QMED was calculated directly from the peak flow data series to be used in subsequent analysis (see Table 3-1).

Table 3-1 : River Nene at Wansford QMED estimate

Catchment	NRFA number	Grid reference	Catchment area (km^2)	Gauge type	QMED (unadjusted) (m^3/s)
Nene at Wansford	32010	TL080995	1530	Ultrasonic	62.591

3.2.3. Peak flows were measured by a 97m wide velocity / area station which has since been superseded by an ultrasonic station which was installed in 1996.

3.3. Enhanced single site analysis

3.3.1. QMED was scaled to higher return period flood flow estimates using an enhanced single site pooled analysis in WINFAP 4. The default pooling group was reviewed in detail to ensure all constituent stations were appropriate in relation to the River Nene catchment. A review of the pooling group was made including parameters such as catchment area, BFIHOST, SAAR and FARL.

3.3.2. The default pooling group was accepted and is given in Table 3-2 below.

Table 3-2 : Final FEH pooling group

Pooling group station	Record length (years)
32010 (Nene at Wansford)	52
53018 (Avon at Bathford)	49
43003 (Avon at East Mills Total)	47
39016 (Kennet at Theale)	57
27041 (Derwent at Buttercrambe)	45
27008 (Swale at Leckby Topcliffe)	29
27071 (Swale at Crakehill)	38
54029 (Teme at Knightsford Bridge)	48
27099 (Derwent at Malton A64 Road Bridge)	17
43007 (Stour at Throop)	45
25009 (Tees at Low Moor)	48
54008 (Teme at Tenbury)	62
11001 (Don at Parkhill)	37
	Total record length: 574

3.3.3. The FEH recommends the use of the generalised logistic growth curve over other fitting methods available in WINFAP 4. Figure 3-1 shows that the general 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 a flood frequency curve and peak flow estimates (Table 3-3).

Figure 3-1 : Nene at Wansford growth curve

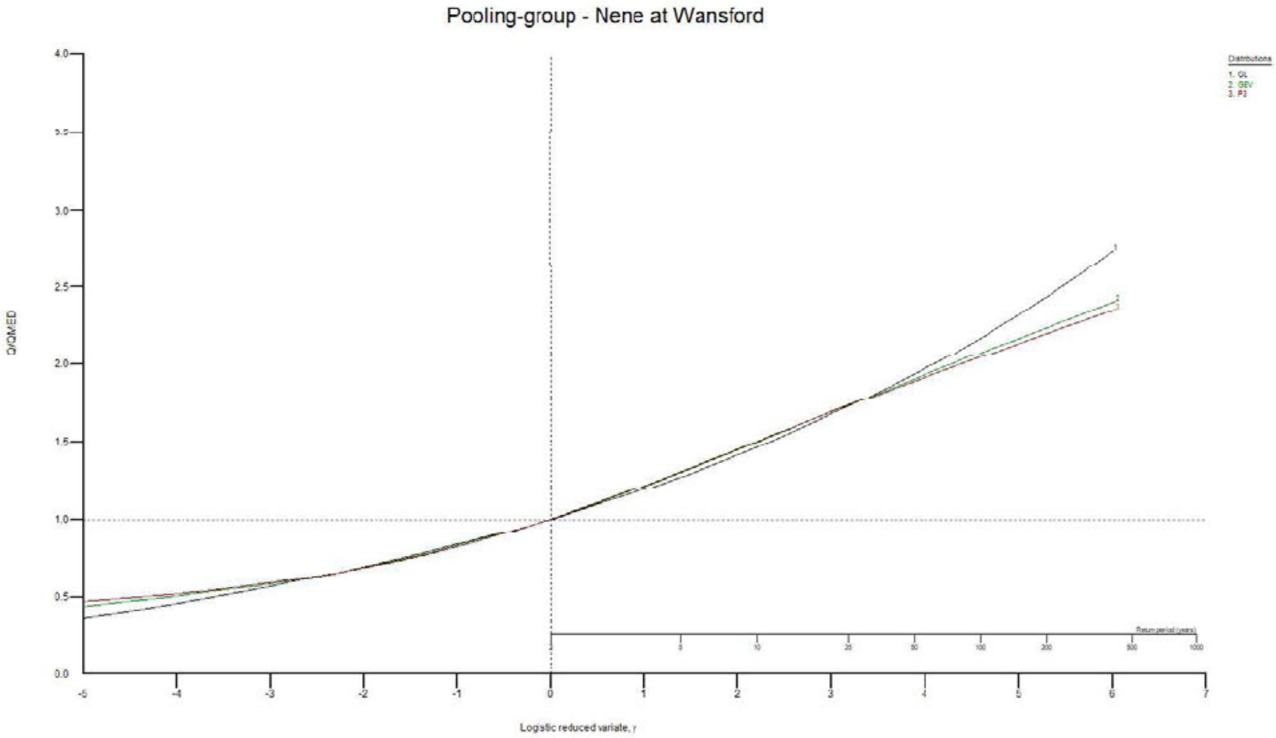


Table 3-3 : FEH statistical design flow estimates for the River Nene at Wansford

Return period (years)	Growth factor	Peak flow estimate (m^3/s)
1 in 2	1.000	62.6
1 in 100	2.176	136.2
1 in 100 + 20% CC	2.574	163.5
1 in 100 + 35% CC	2.938	183.9
1 in 100 + 65% CC	3.590	224.8

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 the flood compensation assessment (35%) 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	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 compensatory flood storage, the 1 in 100-year return period peak flow will be increased by 35% and 65% respectively.

3.4.5. The Environment Agency Lower Nene hydraulic model provided for this study included the previous climate change allowance of 20% and used a Mean High Water Spring tide as the downstream boundary. To allow a direct comparison of hydrological peaks between FEH ReFH2 and the original model peak flow, an allowance of 20% has been included for reference only in chapter 5 below.

4. Design hydrographs

4.1.1. The revitalised rainfall-runoff method, ReFH2 software version 2.3 was used to build hydrographs and estimate peak flows for the River Nene at Wansford (Wallingford HydroSolutions, 2020b).

4.1.2. Rainfall event duration (and subsequent flow hydrograph duration) and all other ReFH2.3 model parameters were based on the default catchment-based equations outlined in the ReFH2 Technical Report (Wallingford HydroSolutions, 2015). The hydrographs and ultimately peak flows were generated using the ReFH2.3 software. The ReFH2.3 parameters are given in Appendix A for reference.

4.1.3. Ten storm durations were tested for the catchment to determine the most conservative event (that is, critical storm duration). Peak flow values are given for five return period events in Table 4-1 below; these values are given for the duration that produced the peak flows, a 45-hour summer storm profile event. The growth factor for each storm event has been calculated for comparison with the FEH statistical method for completeness.

Table 4-1: ReFH2.3 design flow estimates for the River Nene at Wansford

Return period (years)	Growth factor	Peak flow estimate (m^3/s)
1 in 2	1.000	85.040
1 in 100	2.871	244.110
1 in 100 + 20% CC	3.445	292.932
1 in 100 + 35% CC	3.875	329.550
1 in 100 + 65% CC	4.736	402.780

5. Comparison of peak flows

5.1.1. A comparison of estimates for the 1 in 100-year peak flow with climate change allowances using the FEH statistical method, ReFH2.3 method and the Environment Agency Lower Nene model are shown in Table 5-1. The 1 in 100-year peak inflow to the Lower Nene model at Wansford has been extrapolated to higher return periods for direct comparison to the FEH statistical and ReFH2.3 peak flows.

Table 5-1: Comparison of peak design flow estimates for the River Nene at Wansford

Return period (years)	FEH Statistical (m^3/s)	ReFH2.3 (m^3/s)	Environment Agency Lower Nene hydraulic model inflow (m^3/s)
1 in 100	136.218	244.11	163.2
1 in 100 + 20% CC	163.46	292.93	195.84
1 in 100 + 35% CC	183.894	329.55	220.32
1 in 100 + 65% CC	224.759	402.78	269.28

5.1.2. The FEH enhanced single site analysis produced a lower estimate of peak flow compared to the existing flows from the Environment Agency Lower Nene model. However, the ReFH2.3 method produced substantially higher estimates of peak flow. Given the length of record data available at the Wansford gauge (52 years) and the very close proximity of the gauge to the Proposed Scheme, the enhanced single site approach is most appropriate.

5.1.3. Considering that the existing Environment Agency Lower Nene hydrology provides a peak flow estimate which is between the latest WINFAP 4 and ReFH2.3 estimates, and has previously been approved by the Environment Agency for use, confidence is considered to be greatest in this estimate and therefore it has been taken forward and applied in the modelling assessment. The Environment Agency Lower Nene peak flows are estimates derived from an enhanced single site approach, albeit based on fewer years of data.

6. Flood compensatory storage

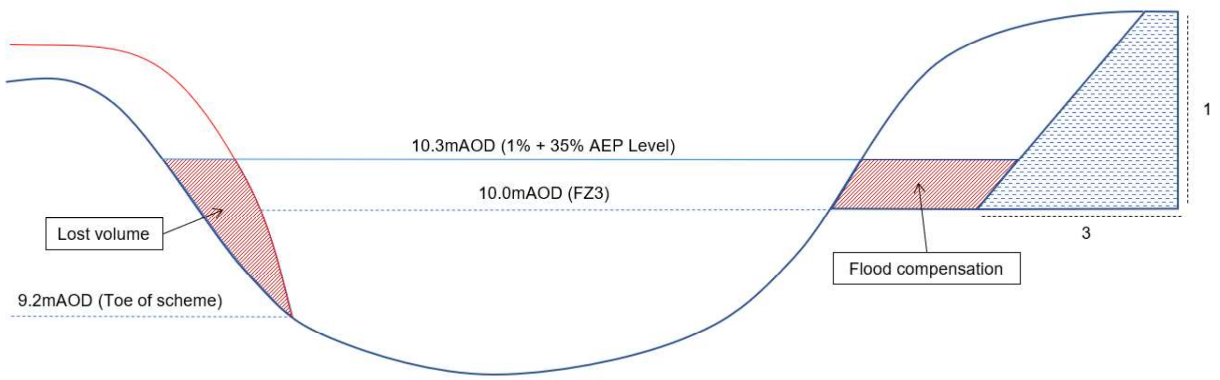
6.1.1. The Proposed Scheme consists of widening the A47 carriageway which will encroach into the River Nene flood plain on the south side embankment. To ensure there is no increased flood risk created by the Proposed Scheme, flood compensation requirements were calculated for the design event 1 in 100-year plus 35% climate change. Any identified flood compensation requirements would mitigate any lost flood plain as a result of the Proposed Scheme.

6.1.2. The Environment Agency Lower Nene model was run for the 1 in 100-year event with an updated climate change allowance of 35%. The inflows were applied at the upstream extent of the model. The peak estimated design level of 10.3mAOD at the Wittering Brook and River Nene confluence was used as the basis for the compensatory flood storage calculation. The volume of flood plain which will be lost by constructing the Proposed Scheme was calculated using 'Triangulated Terrain Surfaces' in MX Road Design software (Bentley, 2021). Initially, a boundary beyond the extents of the location where the bottom of the earthworks meets the flood level was taken. The volume from the existing ground level to the design level within the boundary was then calculated. The calculation was repeated from the Proposed Scheme surface to the flood level. The difference between the two, the lost volume from the Proposed Scheme, was calculated to be 560m^3.

6.1.3. Suitable locations for compensatory storage within the vicinity of the Wittering Brook and River Nene confluence were assessed. The Environment Agency require flood compensation to be considered above the Flood Zone 3 level, 10.0mAOD (land assessed as having a 1 in 100 or greater annual probability of river flooding (>1%) in any year), and on a level for level basis for the Proposed Scheme (below Flood Zone 3). For the purpose of this estimate, the volume has been provided above the Flood Zone 3 level and considered a worst case; however, the final decision will rest with the Environment Agency as to the final specification and location of flood compensation.

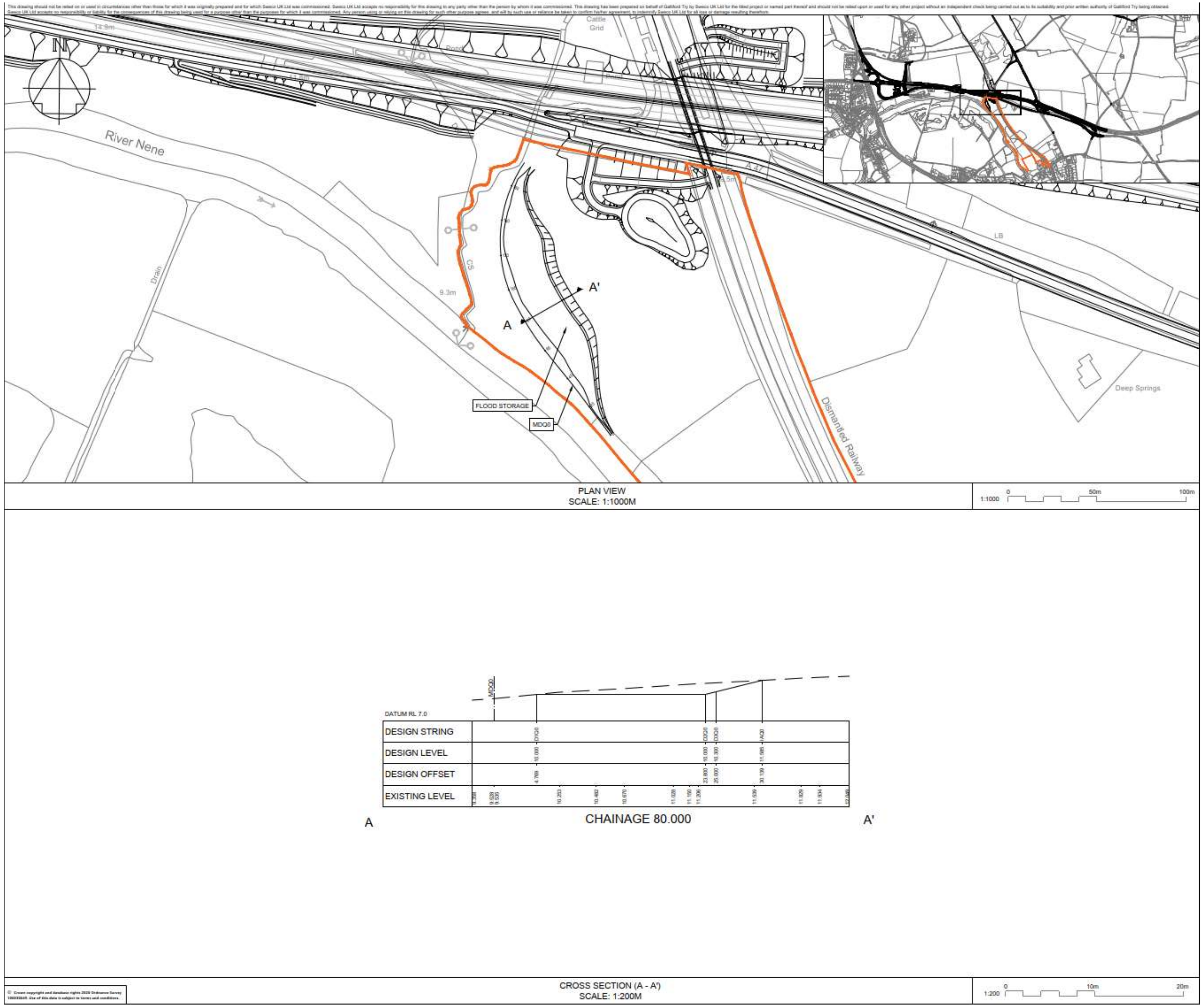
6.1.4. Compensation for the volume occupied by the Proposed Scheme was therefore provided between Flood Zone 3 and the 1 in 100-year plus 35% climate change level. Figure 6-1 shows a cross section of the River Nene where the red hatched areas represent equivalent volumes lost and provided for in the River Nene flood plain.

Figure 6-1: Conceptual cross-section of flood plain compensation



6.1.5. The suggested location for the flood compensation is shown in Figure 6-2 taken from the left embankment of the River Nene, downstream of the Wittering Brook and River Nene confluence. The compensated volume was estimated using 0.2m contour intervals cutting into the embankment. Once the required volume is excavated, the embankment would be regraded maintaining at least a 1:3 slope.

Figure 6-2: Primary location for compensatory flood storage for the River Nene



7. Assumptions, limitations and uncertainty

7.1.1. 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.

7.1.2. It was assumed the peak flow data record collected for the Nene from the gauge at Wansford was accurate.

7.1.3. There are large discrepancies between the design flows estimated from the two methods, leading to some uncertainty. Ultimately however, the original hydrology to the EA Lower Nene model was accepted and used to inform the design level for the flood compensatory storage.

8. References

- Bentley (2020) *MX Road, Version 8i*
- British Geological Survey (2020) Geology of Britain Viewer Map. Available at [redacted] last accessed October 2020
- Cranfield Soil and Agrifood Institute (2020) Soilscapes Map. Available at [redacted] last accessed October 2020
- Environment Agency (2020b) Environment Agency Flood Map for Planning. Available at: https://flood-map-for-planning.service.gov.uk/, accessed October 2020
- Environment Agency (2020c) *Flood risk assessments: climate change allowances*. Available online at https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances, accessed October 2020
- Environment Agency (2012) Estimating flood peaks and hydrographs for small catchments: Phase 1. Project: SC090031
- Highways England (2019) *Design Manual for Roads and Bridges LA 113 Road Drainage and the Water Environment*. Available at [redacted] last accessed October 2020
- Ministry of Housing, Communities and Local Government (2019) *National Planning Policy Framework*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/6077/2116950.pdf, last accessed October 2020
- UK Centre for Ecology & Hydrology (2020a) National River Flow Archive peak flow dataset Version 8. Available at [redacted] last accessed October 2020
- UK Centre for Ecology & Hydrology (2020b) Flood Estimation Handbook Web Service. Available at [redacted] last accessed October 2020
- Wallingford Hydrosolutions (2015) The Revitalised Flood Hydrograph Model ReFH2: Technical Guidance
- Wallingford HydroSolutions (2020a) *WINFAP, Version 4.2*
- Wallingford HydroSolutions (2020b) *ReFH, Version 2.3*

Appendix A. FEH catchment descriptors

Table A-1: FEH catchment descriptors

Descriptor	Nene @ Wansford
CATCHMENT	TL 08050 99600
CENTROID	SP 83491 72913
AREA	1516.08
ALTBAR	93
ASPBAR	91
ASPVAR	0.1
BFIHOST	0.52
BFIHOST19	0.507
DPLBAR	74.13
DPSBAR	36.2
FARL	0.915
FPEXT	0.0984
FPDBAR	1.04
FPLOC	0.902
LDP	121.32
PROPWET	0.28
RMED-1H	12.2
RMED-1D	30.7
RMED-2D	39.3
SAAR	620
SAAR4170	626
SPRHOST	36.56
URBCONC1990	0.705
URBEXT1990	0.0312
URBLOC1990	0.987
URBCONC2000	0.824
URBEXT2000	0.0492
URBLOC2000	1.001
C	-0.02562
D1	0.3364
D2	0.27331
D3	0.24312
E	0.30651

Descriptor	Nene @ Wansford
F	2.5354
C(1 km)	-0.021
D1(1 km)	0.329
D2(1 km)	0.289
D3(1 km)	0.198
E(1 km)	0.304
F(1 km)	2.502

Appendix B. ReFH2 parameters

Table B-1: Key ReFH2 parameters

Descriptor	Nene @ Wansford
Duration	45 hr Summer
Timestep	5 hours
Cini	75.86 mm
Cmax	448.22 mm
BR	1.20
BL	95.43
Tp	30.71 hr