A46 Newark Bypass

TR010065/APP/6.3

6.3 Environmental Statement

Appendix 13.2 Flood Risk Assessment

APFP Regulation 5(2)(a)

Planning Act 2008

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

Volume 6

March 2025

Infrastructure Planning

Planning Act 2008

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

A46 Newark Bypass

Development Consent Order 202[x]

ENVIRONMENTAL STATEMENT

APPENDIX 13.2 Flood Risk Assessment

Regulation Number:	Regulation 5(2)(a)
Planning Inspectorate Scheme Reference	TR010065
Application Document Reference	TR010065/APP/6.3
Author:	A46 Newark Bypass Project Team, National Highways

Version	**Date**	**Status of Version**
Rev 1	April 2024	DCO Application
Rev 2	February 2025	Deadline 6 Submission
Rev 3	March 2025	Deadline 7 Submission

Contents

Table of figures

Table of tables

1 Introduction

1.1 Commission

1.1.1 This Flood Risk Assessment (FRA) has been prepared to support the Development Consent Order (DCO) application for the A46 Newark Bypass (the “Scheme”). It forms Appendix 13.2 of the Environmental Statement Appendices (contained in Volume 6.3 of the Environmental Statement). This assessment and its discussion of flood alleviation measures, including scour protection and mitigation, applies to interventions being delivered by National Highways (the “Applicant”) only.

1.1.2 This FRA has been developed in line with the Design Manual for Roads and Bridges (DMRB), LA113 – Road drainage and the water environment[1] to document the assessment and management of associated impacts of the highway on the water environment. This FRA has also been developed to comply with the National Policy Statement for National Networks (NPSNN) and the National Planning Policy Framework (NPPF) policy on flood risk, which advise that FRAs should be prepared to accompany applications for projects in the following locations[2]:

- Flood Zones 2 and 3, medium and high probability of river and sea flooding;
- Flood Zone 1 (low probability of river and sea flooding) for projects of 1 hectare or greater, projects which may be subject to other sources of flooding (local watercourses, surface water, groundwater or reservoirs), or where the Environment Agency has notified the local planning authority that there are critical drainage problems.

1.1.3 As the Scheme is partly located within Flood Zone 3 and is over 1 hectare in size, this FRA has been prepared to accompany the DCO application for the Scheme.

1.1.4 The Scheme comprises approximately 6.5km of the A46 between Farndon roundabout and Winthorpe that is to be widened to form a dual

[1] Design Manual for Roads and Bridges, LA113 Road drainage and the water environment (Rev 1, Mar 2020): d6388f5f-2694-4986-ac46-b17b62c21727 (standardsforhighways.co.uk).

[2] Paragraph 5.92 of the NPSNN (December 2014): https://assets.publishing.service.gov.uk/media/6650b0d10c8f88e868d33252/npsnn-web.pdf, Paragraph 5.131 of the NPSNN 2024 https://assets.publishing.service.gov.uk/media/65e9c5ac62ff48001a87b373/national-networks-national-policy-statement-web.pdf, and paragraph 181 of the NPPF with footnote 63 of the NPPF (December 2024): https://assets.publishing.service.gov.uk/media/67aafe8f3b41f783cca46251/NPPF_December_2024.pdf

carriageway. A detailed description of the Scheme can be found in Chapter 2 (The Scheme) of the ES [APP-046].

1.2 Scope, assumptions, and Scheme area

1.2.1 The aim of this FRA is to assess the flood risk impact of the operational and construction stages of the Scheme.

1.2.2 The potential sources of flood risk considered are fluvial, surface water, groundwater, sewer and artificial sources. Tidal flooding has not been considered as the Scheme is approximately 6km upstream of the Cromwell Weir, which is the current upper tidal reach on the River Trent.

1.2.3 The assessment has included information provided by statutory consultees (the Environment Agency and Nottinghamshire County Council (NCC) acting as the Lead Local Flood Authority (LLFA)). Information was also provided by stakeholders (Trent Valley Internal Drainage Board (IDB) and the Canal and River Trust) and has involved extensive liaison with these stakeholders so that all flood sources have been adequately considered and assessed. In addition, Statements of Common Ground (SoCG) with the Environment Agency [REP6-028] and NCC as the LLFA [REP6-030] have been prepared post-application during the course of the Examination and provide commentary on the discussions held between the parties in relation to this FRA and identify those specific issues that have not yet been agreed or are still under discussion.

1.2.4 Section 6 of this FRA describes the baseline flood risk from all flood risk sources within the study area to receptors.

1.2.5 The following sections address flood risk in the operational and construction stages of the Scheme. For each stage it is defined as:

- The flood risk to the Scheme – operational stage (Section 7).
- The flood risk from the Scheme – operational stage (Section 8).
- The flood risk to the Scheme and to other receptors – construction stage (Section 9).

1.2.6 The flood risk to and from the Scheme would be mitigated by measures set out in the First Iteration Environmental Management Plan (EMP) [REP6-012]. The First Iteration EMP will be developed into a Second Iteration EMP for implementation during construction and secured through Requirement 3 of the draft DCO [REP6-004] so that no significant risk arises from, or to, the Scheme. These considerations have been included in the Statements of Common Ground with the Environment Agency [REP6-028] and NCC as the LLFA [REP6-030].

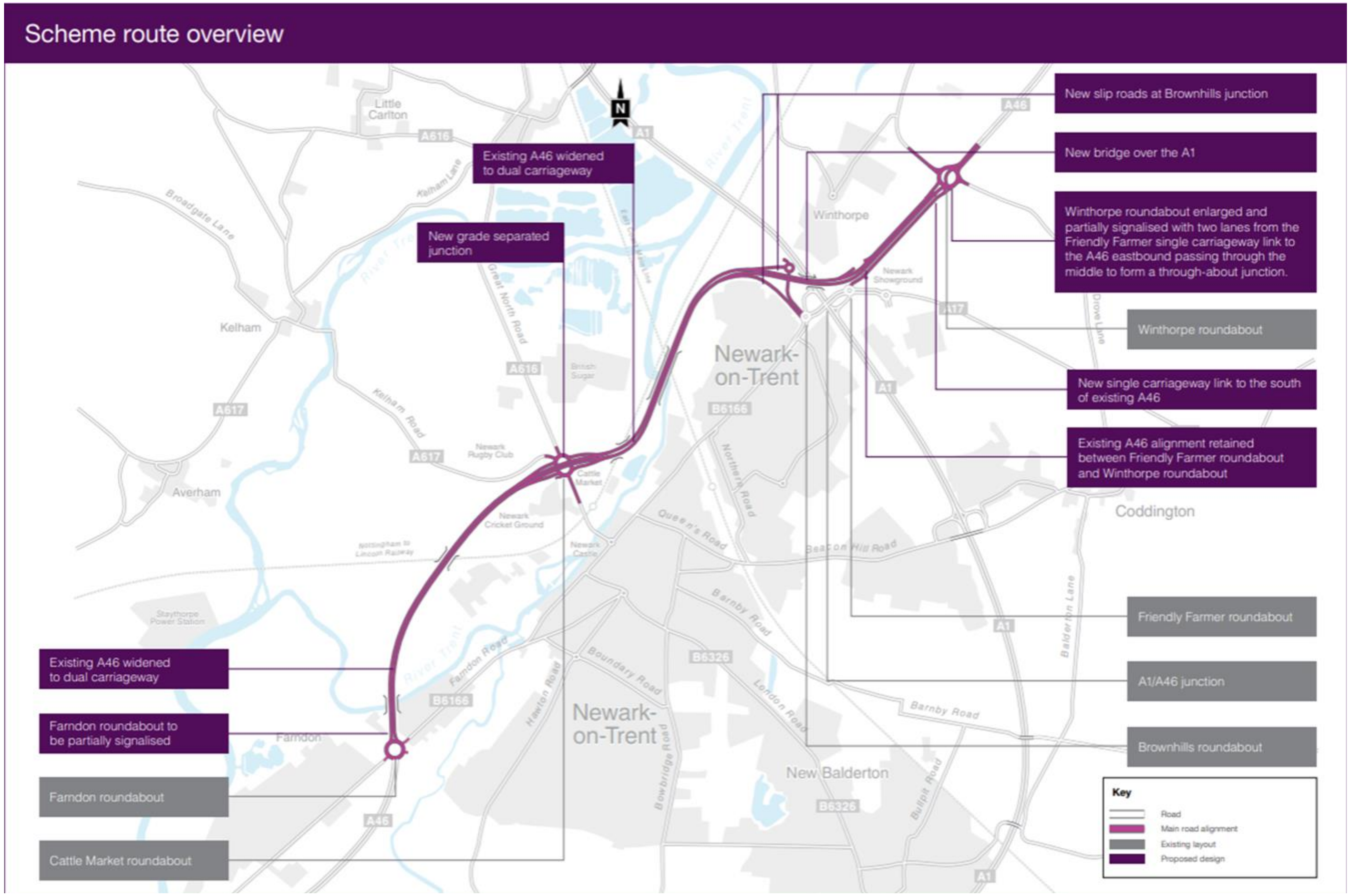
1.2.7 Section 10 of this FRA provides a summary of Sections 7 to 9 of this FRA discussing the Sequential and Exception Test assessments for the identified sources within the study area.

1.2.8 Detailed 1D-2D fluvial hydraulic modelling has been undertaken for the area, focusing on the River Trent, associated floodplain and tributaries. This is discussed in more detail in Sections 7, 8 and 9 of this FRA.

1.2.9 This FRA discusses the main features of the water environments crossing the Scheme. It also discusses the areas to be used for operational purposes. Figure 1-1 shows an overview of the Scheme area and the main operational features.

1.2.10 The consultant has followed accepted procedure in providing the services but given the residual risk associated with any prediction and the variability which can be experienced in flood conditions, the consultant takes no liability for and gives no warranty against actual flooding of any property (client's or third party) or the consequences of flooding in relation to the performance of the service. This report has been prepared for the purposes of assisting the flood risk assessment of the A46 Newark Bypass scheme only.

Figure 1-1: Overview of Scheme and main operational features



Source: Service Layer Credits - Contains OS data © Crown Copyright and database right 2022. Contains data from OS Zoomstack, Contains OS data © Crown Copyright and database right 2019.

2 Study area hydrological context

2.1 Overview

2.1.1 This section provides an overview of the hydrology and hydrogeology of the study area.

2.1.2 The detailed geological and hydrogeological conditions of the study area are provided in Chapter 9 (Geology and Soils) of the Environmental Statement [REP5-010].

2.2 Topography

2.2.1 The majority of the existing road sits within the floodplain of the River Trent.

2.2.2 North of Farndon, the existing A46 is on an embankment as it crosses the River Trent, with the road raised approximately 5m above the floodplain. As the A46 crosses over the Nottingham – Lincoln railway line, the elevation of the road increases to approximately 8m above the floodplain, before dropping to approximately 5m above the floodplain as it crosses the Old Trent Dyke south-west of Cattle Market roundabout.

2.2.3 North-east of Cattle Market roundabout, the road is raised to approximately 8m above the floodplain as the road crosses the River Trent for a second time. South-west of Brownhills the Scheme crosses a lower elevation section of the River Trent floodplain. The ground in this area generally slopes up from the north-west to the south-east, with land to the south-east of the A46 being around 2-3m higher than land to the north-west.

2.2.4 Beyond the Friendly Farmer Roundabout, the north-east extent of the Scheme area sits outside of the River Trent floodplain, at approximately 19mAOD.

2.2.5 The existing River Trent floodplain from the south at Farndon Roundabout to the Brownhills Junction varies in elevation from approximately 8mAOD to 12mAOD. The floodplain is crossed by multiple Network Rail and local road crossings, with each linear feature typically raised above existing ground elevations to reduce risk of flooding. These existing infrastructure features are likely to have an impact on the conveyance capacity of the floodplain during times of a fluvial flood event.

2.3 Hydrogeology

2.3.1 According to the British Geological Survey (BGS), the Scheme is underlain entirely by the Mercia Mudstone Group.[3] Superficial deposits include the Balderton Sand and Gravel Member to the north of the Scheme. Alluvium is present along much of the Scheme, interspersed with smaller areas of the Holme Pierrepoint Sand and Gravel member.

2.3.2 The Mercia Mudstone Group is designated by the BGS as a Secondary B Aquifer which is defined as the presence of "lower permeability layers which may store and yield limited amounts of groundwater due to localised features such as fissures, thin permeable horizons and weathering".[4] The overlying Superficial deposits, where present, are classified as a Secondary A Aquifer, defined as "'permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers. These are generally aquifers formerly classified as minor aquifers".

2.3.3 The Environment Agency has mapped aquifer vulnerability nationally using information on recharge, soil leaching properties, superficial cover, and the unsaturated zone above the groundwater table. Aquifer vulnerability mapping indicates that much of the Scheme is in an area of medium to high groundwater vulnerability.

2.4 Hydrology

Main watercourse – River Trent

2.4.1 The River Trent, designated as a Main River by the Environment Agency, flows from south-west to north-east within the study area. The study area, and watercourses within it, are identified in Figures 13.1 (Surface Water Constraints) [AS-073], Figure 13.2 (River Waterbody Catchments) [AS-074], Figure 13.3 (Flooding Constraints) and Figure 13.4 (Groundwater Constraints) [AS-076] of the Environmental Statement Figures.

2.4.2 The existing A46 road is generally elevated on an embankment due to the low-lying floodplain of the River Trent. The River Trent is crossed by

[3] British Geological Survey. (Accessed 2022). BGS Geology Viewer 0.0.48 (Beta). Retrieved from BGS Geology Viewer: https://geologyviewer.bgs.ac.uk/?_ga=2.142580980.733296288.1669808516-270301649.1669808516.
4 British Geological Survey (c). (2022, 07). Aquifer Designation Map (Bedrock) England. Retrieved from Magic: https://magic.defra.gov.uk/MagicMap.aspx.

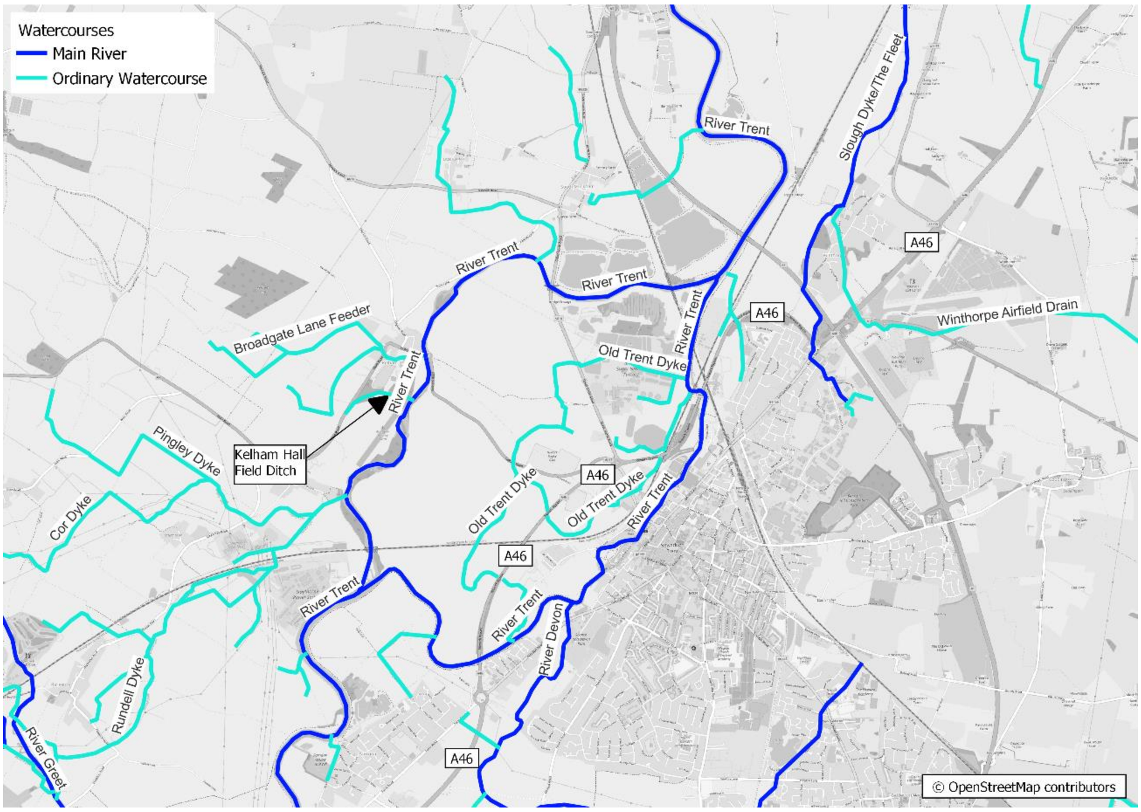
the Scheme at two points, north of Farndon Roundabout and east of the British Sugar factory at Nether Lock Viaduct.

2.4.3 The Environment Agency maximum water depth recorded for the River Trent in this area was 2.759m at the Farndon gauging station on 09 November 2000.

Secondary watercourses

2.4.4 Within the study area are several secondary watercourses (Figure 2-1). The Slough Dyke and the River Devon are classified as Main Rivers. The Fleet (a tributary of the Slough Dyke) is also within the study area.

Figure 2-1: Watercourses within the study area

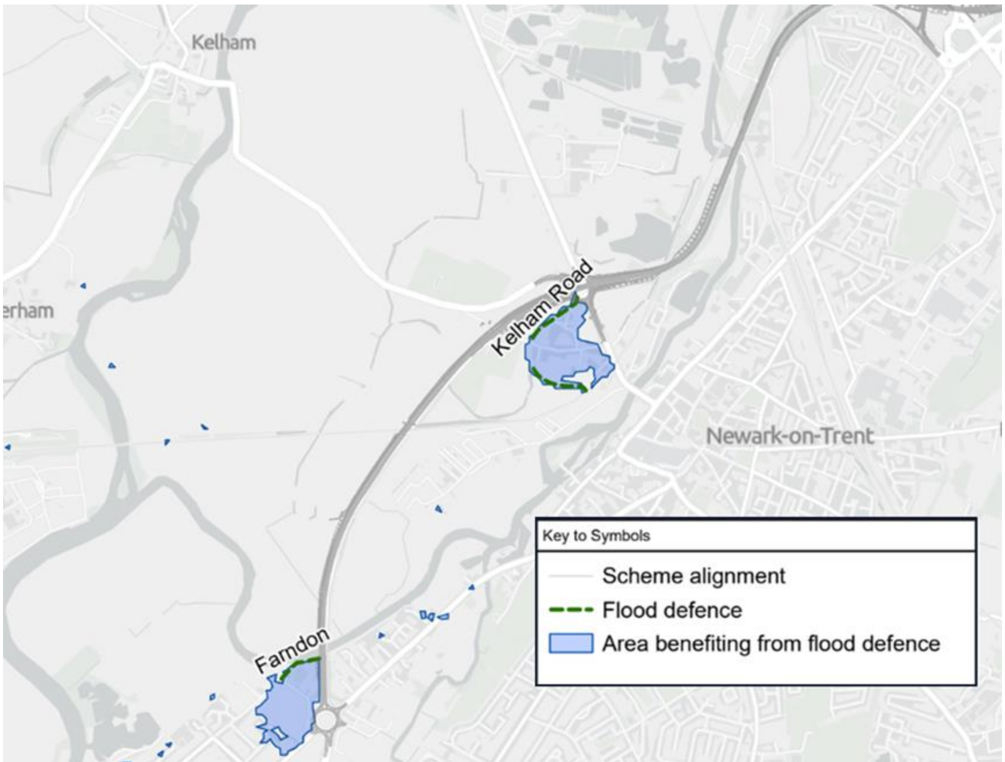


Source: Contains OS data © Crown Copyright and database right 2022. Contains mapping from © Open Street Map contributors.

Flood defences

2.4.5 Based on data from the Environment Agency, the area of Newark-on-Trent benefits from multiple flood defences. There are two flood embankments located within proximity of the Scheme, situated at Farndon and Kelham Road. These existing flood defences and areas benefiting from flood defences must all be considered when looking at the flood risk for the Scheme. There are also several defences located further from the Scheme at Little Carlton, South Muskham and North Muskham. The Environment Agency's 'Reduction in Risk of Flooding from Rivers and Sea due to Defences' map shows that the Scheme has two sections that benefit from flood defences (Figure 2-2). The Scheme design directly interfaces with these flood defences and suitable measures have been put in place so that the existing defences are not structurally compromised or altered in terms of crest height. This has therefore maintained the effectiveness of existing flood defences. The map containing all flood defences within the area is found in Appendix C.

Figure 2-2: Environment Agency reduction in risk of flooding from rivers and sea due to defences map



Source: Flood Defence Data © Environment Agency copyright and/or database right 2020. All rights reserved. Service Layer Credits - Contains OS data © Crown Copyright and database right 2022. Contains data from OS Zoomstack, Contains OS data © Crown Copyright and database right 2019.

3 Scheme description

3.1 Need for the Scheme

3.1.1 The A46 forms part of the strategic Trans-Midlands Trade Corridor between the M5 in the south-west and the Humber Ports in the north-east. The improvements to the A46 corridor are detailed within the Road Investment Strategy (RIS2) as a mechanism for underpinning the wider economic transformation of the country. RIS2 makes a commitment to create a continuous dual carriageway from Lincoln to Warwick.

3.1.2 The stretch of A46 between the Farndon Junction, to the west of Newark and the A1 to the east of Newark, is the last remaining stretch of single carriageway between the M1 and A1 and consequently queuing traffic is a regular occurrence, often impacting journey time reliability. The Case for the Scheme [REP5-030] provides further detail.

3.2 Scheme location

3.2.1 The Scheme would provide a dual carriageway on the A46 between Farndon and Winthorpe in Nottinghamshire. The Farndon roundabout is located at the western extent of the Scheme where the B6166 Farndon Road joins the A46. The Winthorpe junction is located at the eastern extent where the A1133 joins the A46. Along its route, the A46 crosses the A617 and B6326, at the Cattle Market junction, and the A1 between the Friendly Farmer and Brownhills roundabouts. Figure 1-1 shows the location of the Scheme. Figure 2.1 (Scheme Location Plan) of the Environmental Statement Figures [AS-024] shows the Scheme in its wider geographical context.

3.2.2 The section of the A46 that is to be upgraded is approximately 6.5km in length. The Scheme comprises on-line widening for most of its length between Farndon roundabout and the A1. A new section of offline dual carriageway would be provided between the western and eastern sides of the A1 before the new dual carriageway ties into the existing A46 to the west of Winthorpe roundabout. The widening works include earthwork widening along the existing embankments, and new structures where the route crosses the railway lines, the River Trent and the A1.

3.2.3 A detailed description of the Scheme can be found in Chapter 2 (The Scheme) of the Environmental Statement [APP-046].

3.3 Operational stage features

3.3.1 The Scheme includes the following key operational stage features that have the potential to impact flood risk, all of which are shown on the General Arrangement Plans [AS-007]:

- Widened A46, Cattle Market and Brownhills Junction roundabouts.
- Floodplain Compensation Areas (FCAs).
- Embankments and cuttings.
- Landscaping.
- Realignment of Slough Dyke.

Widened A46, Cattle Market and Brownhills Junction roundabouts

3.3.2 The new roundabouts and increased footprint of the dualled A46 would increase the impermeable coverage within the area, potentially increasing surface water flood risk. The Scheme is required to manage surface water effectively and sustainably.

Floodplain compensation areas - overview

3.3.3 As the Scheme is located within a floodplain, flood compensation is required to provide, level for level, volume for volume compensation for the displacement of floodplain storage. This must be in close proximity to both the Scheme and within or adjacent to the floodplain the compensation is being provided for.

3.3.4 The floodplain volume loss due to the Scheme (as at DCO submission) is 184,497m^3 (Appendix G). Therefore, the Scheme is required to provide equivalent floodplain compensation or demonstrate through hydraulic modelling where this is unnecessary.

3.3.5 Construction of the FCAs will be begun as a part of the pre-commencement works, in advance of the Scheme features for which they are required. This is set out in Requirement 15 of the draft DCO [REP6-004].

3.3.6 To ensure provision of floodplain compensation areas the Applicant will be acquiring the necessary land and will ensure the maintenance of the FCAs for the operational life of the Scheme.

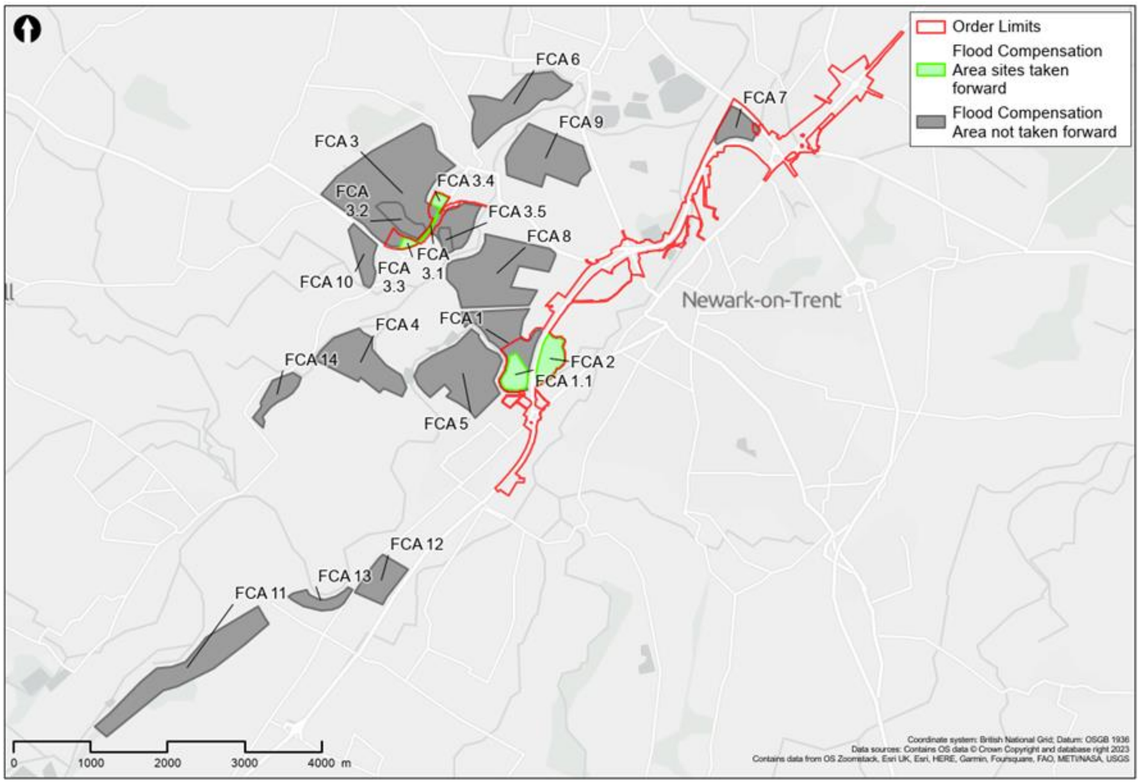
Floodplain Compensation Areas – site screening

3.3.7 At the early works stage of development, the Kelham & Averham site as a ‘single site’ solution was considered unlikely to be viable due to several risk factors. Some of these are listed as follows:

- The site is downstream of most of the high-elevation floodplain encroachment and is therefore largely indirect floodplain compensation.
- Using the site as a single site solution requires a large land-take in that location, reducing the economic viability of the Scheme.
- The land-take required for a single site solution would have conflicted significantly with other development proposals for the land. Enabling hydraulic connectivity for a single-site solution would have required a significant modification to an existing watercourse near the site.
- The site would be significantly flooded (on at least a yearly basis) which would change its existing usage.

3.3.8 Due to the above risk factors, further compensation sites were reviewed to find a ‘multi-site’ solution. This process is also detailed in Chapter 3 (Assessment of Alternatives) of the Environmental Statement [APP-047]. Figure 3-1 shows the locations of all 29 sites considered. All sites considered needed to be within close hydraulic proximity to the Scheme, ruling out sites both upstream of Hazelford weir and downstream of the portion of the Scheme that passes through the floodplain.

Figure 3-1: Map of screened FCA sites



Source: Mott MacDonald Ltd/Skanska. Contains data from OS Zoomstack, Contains OS data © Crown Copyright and database right 2019.

3.3.9 The 29 considered sites shown in Figure 3-1 were initially selected on the following basis:

- Correct topographic elevations for the required level for level, volume for volume floodplain compensation.
- Existing land use, considering sites as suitable where there are less vulnerable receptors.
- Proximity to the Scheme and the River Trent so that there is a degree of hydraulic connectivity.

3.3.10 All 29 possible FCA sites then went through a site screening process which included a RAG (Red, Amber, Green) rating of each site, which is provided in Appendix G (Floodplain Compensation Areas – RAG Matrix). This rating was based on an extensive list of criteria including the following key considerations:

- Hydraulic connectivity and associated impact on flood risk. For an FCA to be effective, the land can only be utilised for purposes that will not cause loss of floodplain capacity.
- Existing land usage, land availability (including future planning applications) and public rights of way.
- Ecology.
- Archaeology and heritage.

- Utilities.
- Land contamination.
- Groundwater.
- Geotechnical.

Floodplain compensation areas – final selected sites

3.3.11 The outcome of the screening process selected two broad compensation areas:

- Kelham & Averham Area – based primarily on correct topographic elevations, reasonable proximity to the Scheme and located adjacent to the central floodplain impacted by the Scheme.
- Farndon Area – based on a combination of reasons including immediate proximity to the Scheme, correct topographic elevations and existing land use.

3.3.12 Once the Kelham & Averham Area for FCA had been identified, 12 land parcels (FCA 3, 3.1-3.11) were then screened within this area to optimise the final site selection in consultation with key stakeholders, resulting in sites FCA 3.1, FCA 3.3, FCA 3.4, FCA 3.9, FCA 3.10 and FCA 3.11 being selected.

3.3.13 For the Farndon Area, the FCA sites were further refined through consultation with key stakeholders, resulting in sites FCA 1.1 and FCA 2 being selected.

3.3.14 For floodplain lost between 8.6 – 9.6m AOD (approximately 2139m^3), compensation is to be implemented by embankment toe ditches. These are required for surface water drainage of the maintenance tracks at the base of the new embankment, at a depth of typically 8 – 10m AOD over a total length of more than 3km. With a typical design of toe ditches having a cross sectional area greater than 0.8m^2, the toe ditches would replace existing embankment drainage ditches that account for the lost floodplain volume at the lowest elevations.

3.3.15 For the selected FCA sites to be effective, the land can only be utilised for purposes that will not cause loss of floodplain capacity. The sites must remain as such to enable flood water to enter and then recede following a flood. The FCAs must also be maintained to allow it to flood freely and for its designed capacity to be retained.

Kelham and Averham FCA

3.3.16 The Kelham and Averham FCA is to provide a combination of direct and indirect compensation to floodplain lost between 11.4-13.0mAOD. The maintenance of this FCA and all of its features will be ensured by the Applicant for the operational life of the Scheme.

3.3.17 There are eight features of note as shown on General Arrangement Plan Sheet 7 [AS-007]:

- The existing Kelham Hall Field Ditch between the River Trent and the A617, adjacent to the Kelham Hall boundary wall. Sections of this ditch are constrained by other local features including an access road from the field into Kelham Hall land. The ditch channel itself would need to be cleared of vegetation obstructions to improve flow conveyance, where this does not interfere with the boundary wall. Due to risks relating to use of the existing Kelham Hall Field Ditch as a drain-down feature, land is to be acquired by the Applicant within the Order Limits for this ditch to be maintained. Section 8.7 of this FRA describes the residual risk related to maintenance of this channel in more detail.
- A series of culverts beneath the A617 to enable flood water conveyance to the FCA. This arrangement would consist of five concrete/reinforced plastic pipes laid in parallel, each with a 600mm internal diameter. To enable this, the existing six-inch gas main would need to be diverted. The culverts would be wetted for the 5% annual exceedance probability (AEP) and larger flood events, as shown by hydraulic modelling, and therefore would often be dry. Responsibility for maintenance and other safety considerations of these features were discussed on 23 February 2023 at the monthly Drainage and Flooding Steering Group meeting held during the preliminary design stage. The Drainage and Flooding Steering Group consists of representatives from the Principal Contractor, the Environment Agency, the Internal Drainage Boards, Newark and Sherwood District Council and Nottinghamshire County Council.[5]
- Access to the FCA site would be from the western side of the A617. The existing access points to the land would be acquired (paragraph 3.3.6) with at least one culverted crossing to allow vehicular access to the adjacent land. The crossing design will be finalised as part of discharging DCO Requirement 14 (as detailed in the draft DCO [REP6-004]).
- A connecting channel is to act as floodplain compensation in its own right. To enable the connecting channel, culvert, and adjacent FCAs to be accessed, an access track would be implemented with a width of 3m, allowing access to the adjacent field. So that this access track is usable in all but the most extreme flood events, and to limit new flood pathways on the western side of the A617, this access track will be situated on a variable height bund that follows the existing elevation of the adjacent A617.
- The northern area. This currently has ground levels at approximately 12mAOD. The works involve lowering ground levels in this field to approximately 11.4mAOD, providing an average change in elevation of

[5] Meeting minutes HE551478-SKAG-HDG-CONWI_CONW-MI-CD-00013, 23 February 2023.

0.6m. To enable drainage as flood water recedes, the ground would be profiled towards the connecting channel on the western side of the A617, with a minimum 1:1000 gradient. The land can only be utilised for purposes that will not cause loss of floodplain capacity.

- The southern area. This is closest to the village of Averham. An existing pond, storage and access track would need to be relocated within the site boundary. This site would be formed with a similar approach to the northern FCA; however, the minimum elevation of this site would become 11.8mAOD, from the existing ground level of approximately 12.6mAOD. Therefore, an average change in elevation of 0.8m is expected.
- The land can only be utilised for purposes that will not cause loss of floodplain capacity. The area is susceptible to groundwater flooding, however monitoring shows that in an event of a flood, groundwater would be conveyed to the nearest watercourse, hence flooding in the FCA area would not increase due to groundwater level. Groundwater flood risk is discussed in Section 8.4.
- An additional area adjacent to the northern area. This is to be partially utilised. This would be an extension of the FCA, with similar ground levels.

Farndon West FCA

3.3.18 An FCA would be provided between the A46 and the River Trent immediately north of Windmill Viaduct, shown on the General Arrangement Plan Sheet 2 [AS-007]. This is to provide a combination of direct and indirect compensation to floodplain lost between 10.6-11.6mAOD due to the new A46 road embankment being instated in the floodplain. The minimum elevation of the site would be 10.6mAOD. Therefore, there would be an average change in depth of approximately 0.5m. The maintenance of this FCA and all of its features will be ensured by the Applicant for the operational life of the Scheme.

3.3.19 This site is to partially remain as arable land with a part of the site to become a floodplain grazing marsh. The FCA would be connected to the Old Trent Dyke overland to the left bank of the dyke which enables the FCA to drain down following a flood event. The connection point to the Old Trent Dyke was chosen so that this area can make maximum use of the land, whilst also not generating a new overland flow path in flood conditions bypassing the existing River Trent.

Farndon East FCA

3.3.20 An FCA would be provided between the A46 and the River Trent immediately north of Windmill Viaduct, shown on the General Arrangement Plan Sheet 2 [AS-007]. This is to provide a combination of direct and indirect compensation to floodplain lost between 9.6-11.0mAOD due to the new A46 road embankment being instated in the floodplain. The maintenance of this FCA and all of its features will be ensured by the Applicant for the operational life of the Scheme.

3.3.21 The connection to the Old Trent Dyke to enable flood water conveyance would be facilitated through a connection to the bank of the watercourse. This approach was chosen so that this area can make maximum use of the land, whilst also not generating a new flood flow path from the River Trent through breaking the high left bank.

3.3.22 The design incorporation of these FCAs and the hydraulic modelling undertaken to demonstrate correct functionality are detailed in Appendix A.

Embankments and cuttings

3.3.23 The Scheme includes the introduction of embankments and cuttings to integrate the widened A46 into the existing landscape, shown on the General Arrangement Plans [AS-007]. Adjustments to the land profile to facilitate the creation of embankments and cuttings have the potential to change the catchment characteristics, such as altering surface water overland flow paths and displacing fluvial floodwater.

Landscaping

3.3.24 The landscape design for the Scheme, as shown on Figure 2.3 (Environmental Masterplan) of the Environmental Statement Figures AS-026] consists of varying depths of fill and re-soiling along the route. These changes include landscaping associated with the implementation of embankments and cuttings, along with larger landscape areas for screening or habitat creation. Permanent topographic changes following embankment creation have the potential to impact flood risk by altering flow paths.

3.3.25 Some landscape areas would have varying depths of topsoil and there is a possibility that this topsoil could affect the conveyance of surface water flows in these areas.

3.3.26 A meeting with the Environment Agency on 20 June 2023 involved discussions regarding the requirement for works near a main river. This included discussions relating to the inclusion of fish escape passages within the Farndon East FCA wetland design (now relevant to Farndon West FCA). Outcomes of the discussion included a confirmed Environment Agency preference for more ‘natural’ channel profiles for the proposed fish escapes (to reflect the location of these features lower in the river catchment and to offer great biodiversity interest) and for all pools / ponds to be connected back to the river (to avoid entrapment of fish during flood events). The specific fish passage design would be finalised during detailed design.

Realignment of Slough Dyke

3.3.27 The Slough Dyke located on the northern side of Newark-on-Trent drains a semi-urban catchment in a northerly direction, crossing the existing A46 before passing under the A1 and discharging into Winthorpe Drain just north of Winthorpe village. The watercourse is designated as an Environment Agency Main River and crosses the Scheme alignment by Brownhills Junction.

3.3.28 The existing channel comprises a watercourse with a small cross-section running parallel with the A1 before passing under the highway and entering the wider River Trent floodplain. Due to a crossing of the watercourse with the Scheme, a minor realignment would move the channel approximately 7-8m to the east to be aligned closer to the A1 highway and thus combine the watercourse crossing with the new bridge over the A1 (Figure 3-2).

Figure 3-2: Realigned Slough Dyke in relation to Scheme alignment, with the realignment area highlighted in red

Source: Service Layer Credits - Contains OS data © Crown Copyright and database right 2022.

3.3.29 The existing channel geometry would be retained in the localised realignment, and it is not predicted to alter the current hydraulics, and therefore flooding regime of this watercourse in the local area, which is currently not predicted to flood at this location in the 1% AEP plus climate change event.

3.4 Design philosophy

3.4.1 To mitigate flood risk, the design of the Scheme has been influenced by key considerations described in this section.

Fluvial flooding

3.4.2 The Scheme would be raised on embankments, at levels equivalent to that of the existing A46 carriageway. This would provide protection for the Scheme from fluvial flooding during operation. The Scheme is designed to tie-in to the existing Environment Agency flood defences where the Scheme interacts with these.

3.4.3 The fluvial design philosophy aims to minimise earthworks within the River Trent floodplain, as these have the potential to displace fluvial flood water. Where the current A46 crosses watercourses, structures such as culverts and flood channels have been extended to mimic existing geometry, as informed by the WFD Compliance Assessment (Appendix 13.1 of the ES Appendices [APP-176]) and River Basin Management Plans (RBMP).

Surface water drainage

3.4.4 The Drainage Strategy Report (DSR) (Appendix 13.4 of the Environmental Statement Appendices [APP-179] describes the implemented design philosophy for the management of surface water runoff. The drainage strategy seeks to minimise flood risk by attenuating run-off within above-ground storage features.

3.4.5 Any pluvial event greater than the 3.33% AEP plus climate change would be managed within the River Trent floodplain. An assessment has been carried out for each area so that the unattenuated run-off does not impact third parties and sensitive receptors, see Appendix D. The drainage infrastructure would be protected from fluvial flooding up to the 50% AEP event plus climate change (as agreed at the Flood and Drainage Steering Group meeting on 30 November 2022[6] and in writing on the 22 March 2023[7]). Detention basins are designed to outfall to watercourses in the vicinity, which includes the River Trent, the Old Trent Dyke, the Fleet and some land drains throughout the Scheme. Basin outfall levels are set above the average water level in the receiving watercourse and have been raised above the assumed groundwater level (at existing ground level or up to 200mm below existing ground level). Detention basins have a 0.7m depth, which includes a 0.2m allowance to account for future uncertainty (additional run-off due to climate change) and a permanent wet pond within the basin. Basins outside the floodplain also have an extreme event overflow area. A toe swale is provided along the embankment with regularly placed check dams. The swale acts as the primary surface water runoff treatment stage for the Scheme and also to provide some retention of run-off.

3.4.6 The toe drain at the northern edge of the A46 embankment would be replaced at existing elevations so that the same levels of drainage are

[6] Meeting minutes HE551478-SKAG-HDG-CONWI_CONW-MI-CD-00014, 30 November 25023.

[7] See Appendix E for the relevant email record.

provided within the River Trent floodplain, as required by the Trent Valley IDB.

3.4.7 The DSR (Appendix 13.4 of the Environmental Statement Appendices [APP-179] outlines the use of Sustainable Drainage Systems (SuDS), and how these have been incorporated in the design of the Scheme, in accordance with CIRIA SuDS manual (C753), DMRB and planning policy requirements in greater detail.

Flood mitigation design standard

3.4.8 To minimise flood risk, the Scheme design incorporates current design standards and climate change allowances for drainage and fluvial modelling, as described in Section 5 and Section 8 of this FRA.

4 Policy context and consultation

4.1.1 The following sections summarise the planning policy and regulatory framework that dictates the structure and content of this FRA.

4.2 National planning policy context

National Policy Statement for National Networks (NPSNN) (2015)

4.2.1 The 2015 NPSNN is the primary national policy document that will guide decision making on the DCO application. Sections 4 and 5 of the NPSNN, set out policies to guide how DCO applications will be decided and how impacts of national networks infrastructure should be considered. Compliance of the Scheme with the 2015 NPSNN is detailed within the NPSNN (2015) Accordance Tables [REP6-016]

4.2.2 Paragraphs 5.90 - 5.115 of the 2015 NPSNN state that the Secretary of State for Transport should be satisfied that flood risk will not be increased elsewhere and should only consider development appropriate in areas at risk of flooding where it can be shown that: the most vulnerable development is located in areas of lowest flood risk unless there are overriding reasons to prefer a different location; development is appropriately flood resilient and resistant, including safe access and escape routes where required; that any residual risk can be safely managed, including by emergency planning; and that priority is given to the use of SuDS. Applications for projects should be accompanied by an FRA to assess all risks of flooding and take climate change into account.

4.2.3 In preparing an FRA an 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 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 for Transport to apply the Sequential Test and Exception Test as appropriate (see Section 4.3).

4.2.4 At the time of the DCO application submission in April 2024, a Draft NPSNN (2024) Accordance Table [APP-192] was submitted with the application which summarised compliance of the Scheme with the draft NPSNN. This was because, even though the NPSNN 2024 was still in draft at that time (having been published for consultation in March 2023), it was still capable of constituting a material consideration in the Secretary of State's decision on the Application. As the 2024 NPSNN was designated on 24 May 2024, the Draft NPSNN (2024) Accordance Table [APP-192] has been superseded by the NPSNN (2024) Accordance Table [REP5-032], which assesses the Scheme against the designated 2024 NPSNN. The application for development consent for the Scheme was accepted for examination on 23 May 2024. As set out in the transitional provisions of the 2024 NPSNN (paragraphs 1.16 and 1.17), the 2015 NPSNN has effect for any application for development consent accepted for examination prior to 24 May 2024 and will inform decisions made by the Secretary of State in relation to those applications. However, it is noted that the 2024 NPSNN may still be an important consideration for the Secretary of State for Transport when determining whether to consent the DCO for this Scheme. Therefore, the NPSNN (2024) Accordance Tables [REP5-032] summarised compliance of the Scheme with the 2024 NPSNN.

National Planning Policy Framework (NPPF)

4.2.5 The NPPF, originally published in 2012 and last updated in December 2024, is supported by the Planning Policy Guidance (PPG), an online resource first published in March 2014 and updated regularly.

4.2.6 The NPPF and PPG must be considered in the preparation of local and neighborhood plans and are a material consideration in planning decisions.

4.2.7 The NPPF and PPG recommend that Local Plans should be supported by a Strategic Flood Risk Assessment (SFRA) and develop policies to manage flood risk from all sources, taking account of advice from the Environment Agency and other relevant flood risk management bodies, such as LLFAs and IDB. Local plans should apply a sequential, risk-based approach to the location of development to avoid, where possible, flood risk to people and property and manage any residual risk, taking account of the impacts of climate change, by:

- Applying the Sequential Test to steer new development to areas with the lowest risk of flooding (see paragraph 4.3.1)
- Applying the Exception Test where it is not possible to locate development in areas with a lower risk of flooding (see paragraph 4.3.4)
- Safeguarding land from development that is required for current and future flood management.
- Using opportunities offered by new development to reduce the causes and impacts of flooding.

- Seeking opportunities to facilitate the relocation of existing development, including housing, to more sustainable locations where climate change is expected to increase flood risk.

4.3 Sequential and exception test

4.3.1 The sequential test is intended to steer new development to areas with the lowest risk of flooding from any source. NPPF paragraph 174 advises that development should not be permitted if there are reasonably available sites appropriate for a proposed development in areas with a lower risk of flooding. In designing the Scheme and choosing its route the Applicant has considered whether there are any reasonably available sites that are appropriate for the Scheme and are located in areas with a lower risk of flooding. Discussion of the scheme in relation to the Sequential Test is provided in Section 10 of this document.

4.3.2 As there are no reasonably available routes to locate the Scheme in areas with a lower risk of flooding, taking into account wider sustainability development objectives as demonstrated in Chapter 3 (Assessment of Alternatives) of the Environmental Statement [APP-047], it is necessary to consider whether the Exception Test needs to be applied. The need for the Exception Test depends on the potential vulnerability of the site and of the development proposed, in line with the Flood Risk Vulnerability Classification set out in Annex 3 to the National Planning Policy Framework. The Flood Risk Vulnerability Classification identifies "Essential transport infrastructure (including mass evacuation routes) which has to cross the area at risk" as Essential Infrastructure.

4.3.3 The Scheme passes through Flood Zone 3a and 3b in the floodplain of the River Trent (see Figure 13.3 (Flooding Constraints) of the Environmental Statement Figures [AS-075]). The 2015 NPSNN and NPPF advise that in Flood Zones 3a and 3b development should not be permitted unless it is Essential Development and the Exception Test is met. The Scheme is part of the strategic road network, the need for upgrading of which is set out in the Case for the Scheme [REP5-030]. Accordingly, the Scheme is considered to be essential transport infrastructure that has to cross the area(s) at risk. Therefore, the Scheme must be assessed against the Exception Test.

4.3.4 For the Exception Test to be passed it must be demonstrated that:

- the Scheme provides wider sustainability benefits to the community that outweigh the flood risk; and
- the Scheme would be safe for its lifetime taking account of the vulnerability of its users, without increasing flood risk elsewhere, and, where possible, would reduce flood risk overall.

4.3.5 The application of the Exception Test to that part of the Scheme that lies within Flood Zone 3 is undertaken in Section 10.3 of this document, based upon evidence (in the form of hydraulic modelling) in the subsequent sections (sections 5 to 9).

4.4 Strategic flood risk assessments

Newark and Sherwood District Council Level 1 and 2 SFRA

4.4.1 A Strategic Flood Risk Assessment (SFRA) is a tool for planning authorities to identify and evaluate flood risk in their area. The Level 1 SFRA was produced in 2009 and examines the planning policies and historical flood events data for the Newark and Sherwood District in the East Midlands. This was intended by Newark and Sherwood District Council to provide an overview of flood risk in the county and identify places where flood risk is a pertinent issue. The document provides information on modelled flood outlines, historic flood extents, spot flood locations and identifies all sources of flood risk. The SFRA relies on information from the Planning Policy Statement 25 (PPS25), but since the SFRA was published, the PPS25 was replaced by the NPPF.

4.4.2 The Newark and Sherwood District SFRA entirely covers the Scheme area and looks at flooding from a variety of different sources, namely fluvial, pluvial, sewer and groundwater flooding. Localised surface water flooding, along with surface runoff and overland flow are also covered within the SFRA. The Level 2 SFRA identifies the Scheme as being partially within the functional floodplain (Flood Zone 3b).

4.4.3 As indicated within the Potential Sources of Flooding section of the SFRA, the main source of flood risk within the Newark and Sherwood District is fluvial flooding. In the context of the Scheme area, this relates to fluvial flooding primarily caused by the River Trent. Historic flood records show that the region has previously experienced several major fluvial floods.

4.4.4 As well as the types of flood risk mentioned above, the SFRA also mentions the presence of seven reservoirs within the catchment area. These reservoirs could potentially cause a risk of flooding and so must also be assessed within the FRA (Section 6.7).

Nottinghamshire Preliminary Flood Risk Assessment

4.4.5 The Preliminary Flood Risk Assessment (PFRA) aims to provide a high-level overview of flood risk from all sources of flooding within the local area, including the consideration of surface water, groundwater, ordinary watercourse, and canals, for both historical and future instances.

4.4.6 The 2023 Nottinghamshire PFRA provides large scale data on properties at risk from different sources. The comparison of past and future flooding map from the PFRA shows that Newark sits in an area where flood risk is an issue, having experienced 9-10 flood years on record. The source of this flooding is primarily the River Trent, with some sewer, pluvial and surface water flooding also recorded.

Catchment Flood Management Plan

4.4.7 Catchment Flood Management Plans (CFMPs) are the Environment Agency's high-level strategic plans for the sustainable management of flood risk at a large catchment-scale. The plan assesses the size, nature, and distribution of current and potential future flood risk. From the CFMP assessments, long-term flood risk management policies are created to provide an indication of who is responsible, and the types of responses required, to meet those policies that have been identified.

4.4.8 The River Trent CFMP defines six flood risk management policy options and assigns a vision and preferred policy option for each of the ten sub-regions within the River Trent catchment.

4.5 Flood risk management strategies

Nottinghamshire Local Flood Risk Management Strategy (LFRMS)

4.5.1 The Flood and Water Management Act (FWMA) 2010 requires all LLFAs in England to develop, maintain, apply, and monitor the application of a strategy for local flood risk in their area. This strategy is to outline how they will seek to manage flooding from surface water run-off, ordinary watercourses, and groundwater.

4.5.2 The Nottinghamshire LFRMS was published in 2015. This established NCC as a LLFA. The document is aimed at better understanding and managing flood risk. It sets out the legislative context and a clear understanding of flood management roles and responsibilities.

4.5.3 The LFRMS states that rivers running within the Newark and Sherwood District should have their flood risk managed by allowing floodplains to flood within areas where there is no effect on the built environment. The Scheme therefore should not take away from the volume of the River Trent floodplain, ensuring that the risk from fluvial flooding is not increased.

4.6 Other relevant policy and guidance

Design Manual for Roads and Bridges

4.6.1 Guidance outlined in DMRB was referenced during the analysis of flood risk for watercourse crossings such as culverts and bridges.

4.6.2 DMRB LA113 Road drainage and the water environment Table 3.70 defines the importance of water environment attributes as the sensitivity of the receptors (e.g., highly vulnerable), reproduced in Table 4.1 of this report. The typical examples refer to classifications used in NPPF Annex 3. Table 3.71 defines the magnitude of a change impact on an attribute, reproduced in Table 4.2 of this FRA. When combining the importance and magnitude from these tables, the potential significance of effect can be defined in accordance with the Significance Matrix in Table 3.8.1[8] of DMRB LA104, provided in Figure 4-1 for reference. The terminology in these three tables is used throughout this FRA.

4.6.3 The assessment of the significance of effects on flood risk sources during the construction and operation of the Scheme is undertaken within Chapter 13 (Road Drainage and the Water Environment) of the Environmental Statement [APP-057].

Table 4.1: Attributing the importance of water environment attributes

Sensitivity/ Importance	Typical Criteria	Typical example
Very High	Nationally significant attribute of high importance	Essential infrastructure or highly vulnerable development e.g. Solar farm, residential caravans
High	Locally significant attribute of high importance	More vulnerable development e.g. residential properties
Medium	Of moderate quality and rarity	Less vulnerable development e.g. commercial premises
Low	Lower quality	Water compatible development e.g. Sewage transmission infrastructure and pumping stations.

Source: DMRB LA 113 Road drainage and the water environment Revision 1. Table 3.70

Table 4.2: Magnitude of impact definitions

Magnitude	Criteria	Typical example
Major adverse	Results in loss of attribute and/or quality and integrity of the attribute	Increase in peak flood level (> 100mm).
Moderate adverse	Results in some measurable change in attributes, quality or vulnerability	Increase in peak flood level (> 50mm).
Minor adverse	Results in some measurable change in attributes, quality or vulnerability	Increase in peak flood level (> 10mm).
Negligible	Results in some measurable change in attributes but of insufficient	Negligible change to peak flood level (<+/- 10mm).

[8] Design Manual for Roads and Bridges, LA 104 Environmental assessment and monitoring, Revision 1, Highways England, August 2020: [redacted]

Magnitude	Criteria	Typical example
	magnitude to affect the use or integrity	
Minor beneficial	Results in some beneficial effect on attribute or a reduced risk of negative effect occurring	Creation of flood storage and decrease in peak flood level (>10mm).
Moderate beneficial	Results in moderate improvement of attribute quality	Creation of flood storage and decrease in peak flood level (>50mm).
Major beneficial	Results in major improvement of attribute quality	Creation of flood storage and decrease in peak flood level (>100mm).
No change	No loss or alteration of characteristics, features or elements; no observable impact in either direction.	

Source: DMRB LA 113 Road drainage and the water environment Revision 1. Table 3.71

Figure 4-1: Significance Matrix – significant effects outlined in red

	Magnitude of impact (degree of change)					
		No change	**Negligible**	**Minor**	**Moderate**	**Major**
Environmental value (sensitivity)	**Very high**	Neutral	Slight	Moderate or large	Large or very large	Very large
	High	Neutral	Slight	Slight or moderate	Moderate or large	Large or very large
	Medium	Neutral	Neutral or slight	Slight	Moderate	Moderate or large
	Low	Neutral	Neutral or slight	Neutral or slight	Slight	Slight or moderate
	Negligi-ble	Neutral	Neutral	Neutral or slight	Neutral or slight	Slight

Source: DMRB LA104 Revision 1 (2020)[8]

Environment Permit

4.6.4 Any development within 8m of an Environment Agency main river may require an Environment Permit (Flood Risk Activities) from the Environment Agency. The requirement for this permit may be disapplied in the DCO application.

4.6.5 Any changes to flood defences of the River Trent and its tributaries may require an Environment Agency Flood Risk Activity Permit for works involving temporary or permanent structure in, over or under a main river, dredging/ removing any material from a main river, any activity within 8m of the bank of a main river or any activity within 8m of any flood defence structure or culvert on a main river.

4.6.6 IDB consent would be required for all activity in, under, or within 9m of IDB managed watercourses.

4.6.7 An Environment Agency Permit to Pump (Water Discharge Activity Permit) would be required for dewatering discharge to watercourses that do not meet the criteria of the Environment Agency Regulatory Position Statement (RPS) 261 ‘Temporary dewatering from excavations to surface water’ (Environment Agency, 2023).

4.7 Consultation

4.7.1 The following parties have been consulted throughout the development of the Scheme:

- Environment Agency.
- Newark Area IDB.
- NCC – LLFA.
- Newark and Sherwood District Council.
- Severn Trent Water.
- Network Rail.
- Canal and River Trust.

4.7.2 Under the FWMA 2010, the Environment Agency has direct responsibility for the mitigation and remediation of flood damage for main rivers. The designated IDB and LLFAs for this Scheme are responsible for the management of local flooding from surface water, groundwater, and ordinary watercourses. Severn Trent Water is the sewage undertaker in the vicinity of the Scheme.

4.7.3 Discussion and agreement of approaches and methodologies has been undertaken with the Flood Risk Management Authorities so that the assessment of flood risk within the study area is appropriate for the nature and scale of the Scheme, through the A46 Flood and Drainage Steering Group Meetings.

4.7.4 The Scheme has three bridges that cross Network Rail lines at different points. In order that flood risk is not increased at these areas, Network Rail must also be consulted throughout the design and planning stages of the Scheme.

NCC – LLFA – relaxation of storage retention requirements

4.7.5 During discussions with stakeholders through regular Drainage and Flood Management Steering Group meetings, NCC, as the LLFA, stated that they are willing to look into and reconsider how the drainage attenuation requirements are applied for basins located within the floodplain. This was caveated with the provision of an impact assessment which would demonstrate negligible impact on surrounding landowners. At the time of writing the volume impact assessment has been through two rounds of comments and feedback from the Environment Agency and is Appendix D of this document.

4.7.6 Current guidance requires all surface water run-off generated on the highway during a 1% AEP plus climate change storm event, to be attenuated prior to it being discharged. It is proposed that this is modified to attenuate surface water for the 3.33% AEP plus climate change storm event, with the additional run-off generated during larger storm events managed within the surrounding floodplain. For further details on the agreement see Appendix E.

4.7.7 This has been proposed due to the fact that a considerable part of the Scheme, and the proposed retention storage, is located within Flood Zones 2 and 3 of the River Trent. Residential areas have already been located above and away from the floodplain and existing flood defences are in places for extreme fluvial events. An impact assessment in Appendix D demonstrates the attenuation of the storm events up to the 3.33% AEP +CC event.

4.7.8 The impact assessment was carried out to demonstrate that the unattenuated run-off from all events above the 3.33% AEP plus climate change would have negligible material impact on nearby properties and land during the following scenarios:

- 1% AEP plus climate change pluvial event.
- Joint 1% AEP plus climate change pluvial event with:
  - 50% AEP plus climate change fluvial flood event.
  - 3.33% AEP plus climate change fluvial flood event.
  - 1% AEP plus climate change fluvial flood event.

4.7.9 The climate change allowances were 40% for storm events and 39% for fluvial events.

4.7.10 The full impact assessment is detailed in Appendix D.

Assumptions

4.7.11 The impact assessment assumes the peak fluvial flood levels and a pluvial flood incident coincides, which in terms of probability is considered very low. Therefore, this impact assessment considers an extreme event scenario.

4.8 Climate change

4.8.1 The Environment Agency published climate change guidance in February 2016, which was updated in May 2022.[9] The guidance indicates that climate change is likely to increase river flows, sea levels,

[9] Environment Agency (Accessed 2023). *Flood risk assessments: climate change allowances*. Retrieved from UK Government Website: Flood risk assessments: climate change allowances - GOV.UK (www.gov.uk).

rainfall intensity, and wave height and wind speed. The 2020 latest information and advice has therefore been used to complete this FRA.

Peak river flow allowances by river catchment district

4.8.2 The peak river flow allowances show the anticipated changes to peak flow by river catchment. The range of climate change allowances is based on percentiles (Table 4.3).

Table 4.3: Climate change allowance for Lower Trent and Erewash Management Catchment

River Catchment 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)
Lower Trent and Erewash Management Catchment	Upper End	29	38	62
	Higher Central	18	23	39
	Central	13	18	29

Peak river flow allowances for different assessments

4.8.3 For FRAs, the "flood risk vulnerability classification" (Table 2 in the NPPF Planning Practice Guidance for Flood Risk and Coastal Change Guidance[9] for the type of development) and the "flood zone" (Table 1 in the guidance) should be used to decide which peak river flow allowances (allowance category) to use based on the lifetime of the Scheme. The classifications from the Environment Agency's climate change guidance are shown in Table 4-2. The Scheme assessed in this FRA is considered essential infrastructure, therefore the Higher Central allowance was applied for the design, at 39%.

4.8.4 The Scheme is being designed to be resilient to flooding over its predicted lifetime. The lowest point of the carriageway is at 10.90mAOD at chainage 4525.255 and the results from the hydraulic modelling for the 1% AEP including 39% climate change allowance for this location at the operational stage, predict no flooding of the A46 carriageway. Additionally, the FCAs would include an allowance for climate change increase to accommodate increased flooding over the lifetime of the Scheme.

Table 4.4: Peak river flow allowances based on flood risk vulnerability classification and Flood Zone 2

Flood Zone 2 or 3a
Essential infrastructure – use the Higher Central allowance Highly vulnerable infrastructure – use Higher Central allowance More vulnerable – use the Central allowance Less vulnerable – use the Central allowance Water compatible – use the Central allowance
Flood Zone 3b
Essential infrastructure – use the Higher Central allowance Highly vulnerable – development should not be permitted More vulnerable – development should not be permitted Less vulnerable – development should not be permitted Water compatible – use the Central allowance

Peak river flow allowances for the Scheme

4.8.5 It is assumed that the lifetime of the Scheme is 120 years therefore the peak river flow climate change allowances for the lifetime of the Scheme should be assessed as shown in Table 4.5.

Table 4.5: Peak river flow allowances for the Scheme hydraulic modelling

Criteria	Scheme
River Catchment District	Lower Trent and Erewash Management Catchment
Flood Zone	1, 2 and 3 (including 3b functional floodplain)
Flood Risk Vulnerability Classification	Essential infrastructure (transport link)
Lifetime of scheme	120 years
Climate Change Allowance used	Higher Central Allowance (39%)

Floodplain compensation areas

4.8.6 The assessment of the floodplain storage compensation is based on the Environment Agency's climate change guidance.[9]

4.8.7 The use of the affected land defines the level of allowance required, with the Higher Central allowance (39%) being used.

Drainage and rainfall

4.8.8 Increased rainfall affects river levels and land and urban drainage systems. Table 4.6 shows anticipated changes in extreme rainfall intensity in small and urban catchments. For FRAs, both the central and upper end allowances need to be assessed to understand the range of impact. For this Scheme, the drainage design is based off the Central allowance (25%) for the carriageway design and the Upper End (40%) for the storage features.

Table 4.6: Peak rainfall intensity allowance

Applies across all of England	Total potential change anticipated for 2010 to 2039	Total potential change anticipated for 2040 to 2069	Total potential change anticipated for 2070 to 2115
Upper End	10%	20%	40%
Central	5%	10%	**25%**

4.9 Other planned developments within Scheme area

4.9.1 Alongside the Scheme, there are three other developments within the Scheme area that may have an impact on flood risk that must be considered, see Figure 4-2.

Tolney Lane

4.9.2 The Tolney Lane site is located to the south-east of the Scheme and is an area that has previously experienced fluvial flooding. There is an existing travelling community in this area. Many of these receptors are considered as caravans (highly vulnerable under NPPF) and this FRA includes assessment of the impact to this community through the fluvial modelling carried out.

4.9.3 There are currently some plans to develop the road in to and out of Tolney Lane, to improve access and allow emergency evacuation in times of flooding.

4.9.4 Given that this is not yet a committed development and the design is still in development, it is difficult to determine the cumulative impacts of the Scheme and the Tolney Lane developments. The Scheme would not impact the ability of the local authorities to develop the Tolney Lane site as any changes in the floodplain would be mitigated locally. The Tolney Lane development is not considered further within this FRA as it has yet to go through the planning process.

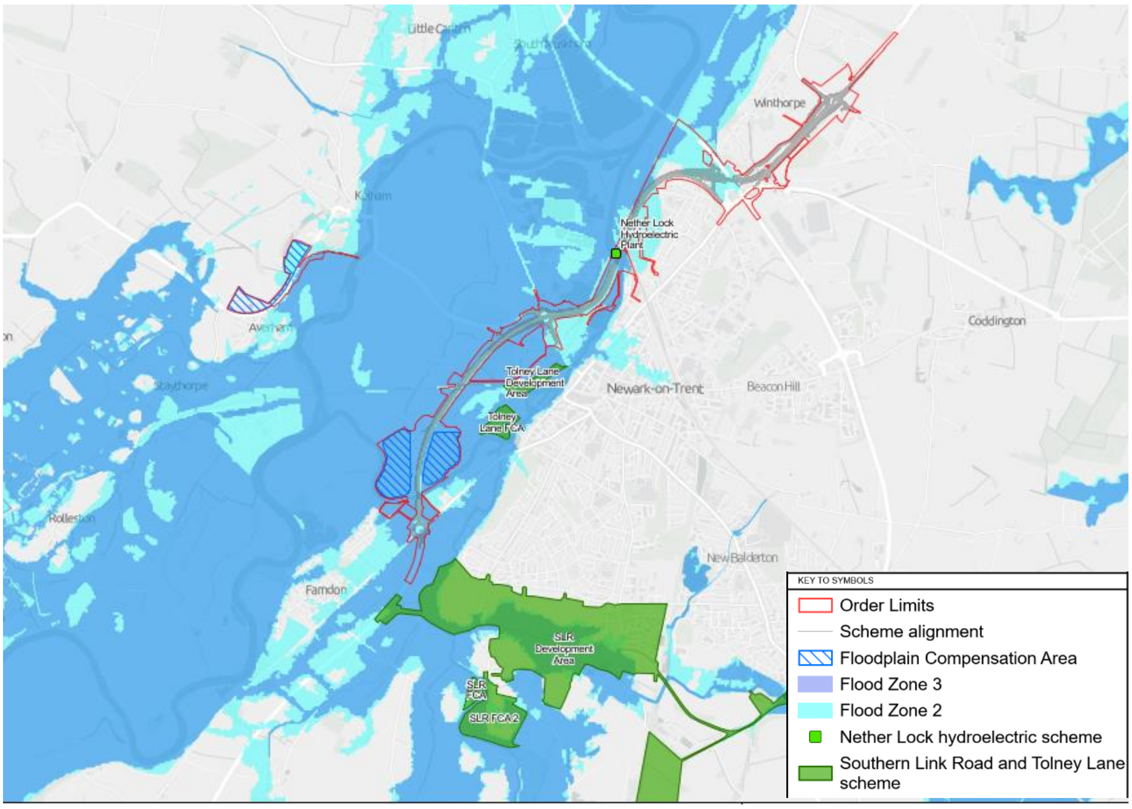
Hydroelectric weirs

4.9.5 The Canal and River Trust are currently in the process of building variable height weir structures at points along the River Trent, with these being used to generate hydroelectric power. These structures have a failsafe whereby they can be lowered during flooding events, and so should have no impact on flooding to the Scheme. This failsafe means the weirs pose no flood risk to the Scheme and so do not need to be considered.

Southern link road

4.9.6 The Southern Link Road (SLR) promoted by Newark and Sherwood District Council aims to provide a better transport link to a proposed development south of Newark-on-Trent. The SLR has started development and comprises of extending an existing lane between the A46 and the A1. The link road will be raised on an embankment due to flood risk from the River Devon, with FCAs to be constructed in order to offset the impact of the SLR footprint in the floodplain. A new roundabout will also be constructed at the A46 end of the road. Hydraulic modelling has been conducted to see whether the SLR would have any effect on the Scheme (see Hydraulic Modelling Technical Note – Appendix A of this FRA). The results of this modelling show that the SLR and the Scheme are not linked, meaning this development does not need to be considered within this FRA.

Figure 4-2: The Scheme in relation to Tolney Lane, Southern Link Road and the Nether Lock Hydroelectric Weir



Source: Flood Defence Data © Environment Agency copyright and/or database right 2020. All rights reserved. Service Layer Credits - Contains OS data © Crown Copyright and database right 2022. Contains data from OS Zoomstack, Contains OS data © Crown Copyright and database right 2019.

5 Flood risk assessment methodology

5.1 Methodology approach

5.1.1 The approach to this FRA is based on the Source-Pathway-Receptor model in accordance with the NPPF which emphasises the need for this approach.

5.1.2 The Source-Pathway-Receptor model firstly identifies the causes or 'sources' of flooding to and from a development. The identification is based on a review of local conditions and consideration of the effects of climate change using Environment Agency guidance. The magnitude and likely extent of flooding arising from any one source is considered, e.g., whether such flooding is likely to be localised or widespread.

5.1.3 The presence of a flood source does not always infer a risk. It is the exposure pathway or the 'flooding mechanism' that determines the risk to the receptor and the effective consequence of exposure. For example, sewer flooding does not necessarily increase the risk of flooding unless the sewer is local to the site and groundwater levels encourage surcharged water to accumulate.

5.1.4 The varying effect of flooding on the 'receptors' depends largely on the sensitivity of the target. Receptors include any people or buildings within the range of the flood source, which are connected to the sources of flooding by a pathway.

5.1.5 For there to be a flood risk, all elements of the model (a flood source, a pathway and a receptor) must be present. Furthermore, effective mitigation can be provided by removing one element of the model, for example by removing the pathway or receptor.

5.1.6 As outlined in Section 1, this FRA assesses the risks of all relevant forms of flooding to and from the Scheme.

5.1.7 The approach to assess flood risk has been developed in line with the DMRB, LA113 – Road drainage and the water environment[1] to capture the impacts and associated management of the highway on the water environment.

5.2 Source-pathway-receptor

5.2.1 The potential flood sources which could be impacted from the operational stage features of the Scheme are identified as:

- Fluvial.
- Surface water.
- Groundwater.
- Sewers.
- Artificial sources (such as reservoirs).

5.2.2 The pathways present or potentially impacted by the Scheme are identified as:

- Floodplain inundation due to the river levels exceeding the channel capacity.
- Overland flow paths (fluvial and surface water).
- Flow of groundwater through the superficial deposits.

5.2.3 The receptors of concern include any roads or buildings within the range of the flood source, which are connected to it by a pathway.

5.2.4 More information on the groundwater approach is set out in Chapter 13 (Road Drainage and the Water Environment) of the Environmental Statement [APP-057].

5.3 Modelling

5.3.1 Hydraulic modelling was undertaken to support the development of this FRA to provide a more detailed understanding of the baseline flood risk within the study area. The outputs were used to augment existing Environment Agency flood risk mapping and to assess the potential impacts of flood risk to and from the Scheme.

5.3.2 Further detail on the hydraulic modelling for the Scheme is available in Appendix A of this FRA. A detailed hydrology study undertaken to support this hydraulic modelling for the Scheme is available in Appendix B. Further sensitivity testing of the hydraulic model is provided in Appendices H & I of this FRA.

Fluvial

5.3.3 The hydraulic modelling approach used for this Scheme employed 1D-2D Flood Modeller Pro (FMP)-TUFLOW to assess the River Trent and its tributaries throughout the area, supported by consultation with the Environment Agency.

5.3.4 A linked 1D-2D FMP-TUFLOW hydraulic model allows for a detailed assessment of the interaction of the channel (1D) and inundation on the floodplain (2D). When the capacity of the 1D channel is exceeded, water spills into the 2D model. The grid based 2D model allows water to propagate across the floodplain according to complex topography and other factors such as surface roughness. This facilitates a more accurate calculation of flood depths and extents that are used to generate map outputs.

5.3.5 The peak river flow climate change allowances adopted to consider the impacts on future fluvial flood risk were agreed with the Environment Agency at the outset of the Scheme. For the River Trent the 1% AEP design event including an allowance for climate change (1% AEP +39% increase in peak flows) has been simulated for the baseline and proposed operational stage scenarios. The allowance of +39%

corresponds to the 'Higher Central' allowance for the Lower Trent and Erewash Management Catchment River Basin District.

Surface water (pluvial)

5.3.6 Surface water (pluvial) modelling has not been undertaken as part of this assessment. A review of the Environment Agency's Risk of Flooding from Surface Water (RoFSW) map was undertaken at the outset of this Scheme, and it was confirmed that the Scheme crosses several key surface water flow paths. However, these flow paths are typically where existing watercourses are considered within the fluvial modelling for the FRA. In areas where there are no existing watercourses, an assessment of the flow paths and localised ponding areas of surface water has been undertaken to inform the FRA.

Surface water (highway drainage)

5.3.7 Where surface water runoff is associated directly with the Scheme, a more detailed assessment of highway drainage has been carried out (see the DNR Appendix 13.4 of the Environmental Statement Appendices [APP-179]). This has informed the drainage design for the Scheme, ensuring the risk of surface water flooding is not increased along the widened highway or along access roads.

Groundwater

5.3.8 Groundwater modelling is not being carried out within the Scheme; however, it does include a ground investigation into the height of the water table and what effect new permanent features are likely to cause.

6 Flood risk baseline

6.1 Overview

6.1.1 This section discusses the baseline flood risk for the identified sources within the study area.

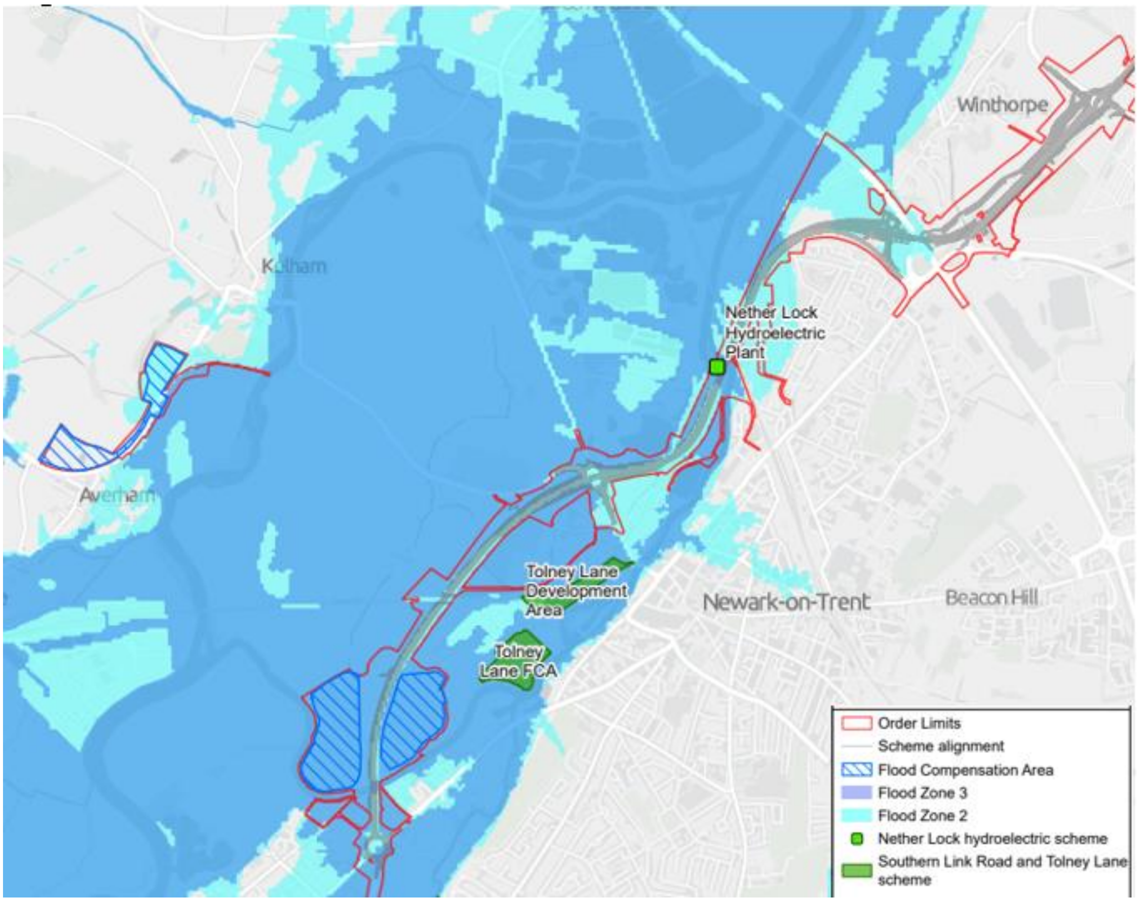
6.2 Fluvial flood risk

Flood sources

6.2.1 The Environment Agency's Flood Map for Planning presents a set of flood zones for use by developers, councils, and communities to explain the probability of fluvial and tidal flooding for Main Rivers.[10] As presented in Figure 6-1, the main flood source within the study area when considering Main Rivers is the River Trent. Much of the study area is located in low-lying land and the Environment Agency Flood Zone maps suggest most of the Scheme area is impacted by this source of flooding.

[10] Environment Agency (Accessed 2023). *Flood Map for Planning*. Retrieved from UK Government Website: Flood risk maps 2019 - Flood risk maps 2019 - GOV.UK (www.gov.uk).

Figure 6-1: Environment Agency's Flood Map, showing the Scheme alignment and Order Limits



Source: Flood Defence Data © Environment Agency copyright and/or database right 2020. All rights reserved. Service Layer Credits - Contains OS data © Crown Copyright and database right 2022. Contains data from OS Zoomstack, Contains OS data © Crown Copyright and database right 2019.

6.2.2 As shown in Figure 6-1, most of the Scheme is located in Flood Zone 3 (high probability), due to its proximity to the River Trent. The Scheme is based within the functional floodplain of the Trent for approximately 65% of its length. The north-eastern end of the Scheme is situated within Flood Zone 1 (low probability). The Scheme runs parallel with the existing A46 road above ground and is typically in line with the floodplain. It is therefore not expected to materially increase fluvial flood risk. To see the full map of the Scheme alongside the Flood Zones, see Appendix C.

Historic flooding

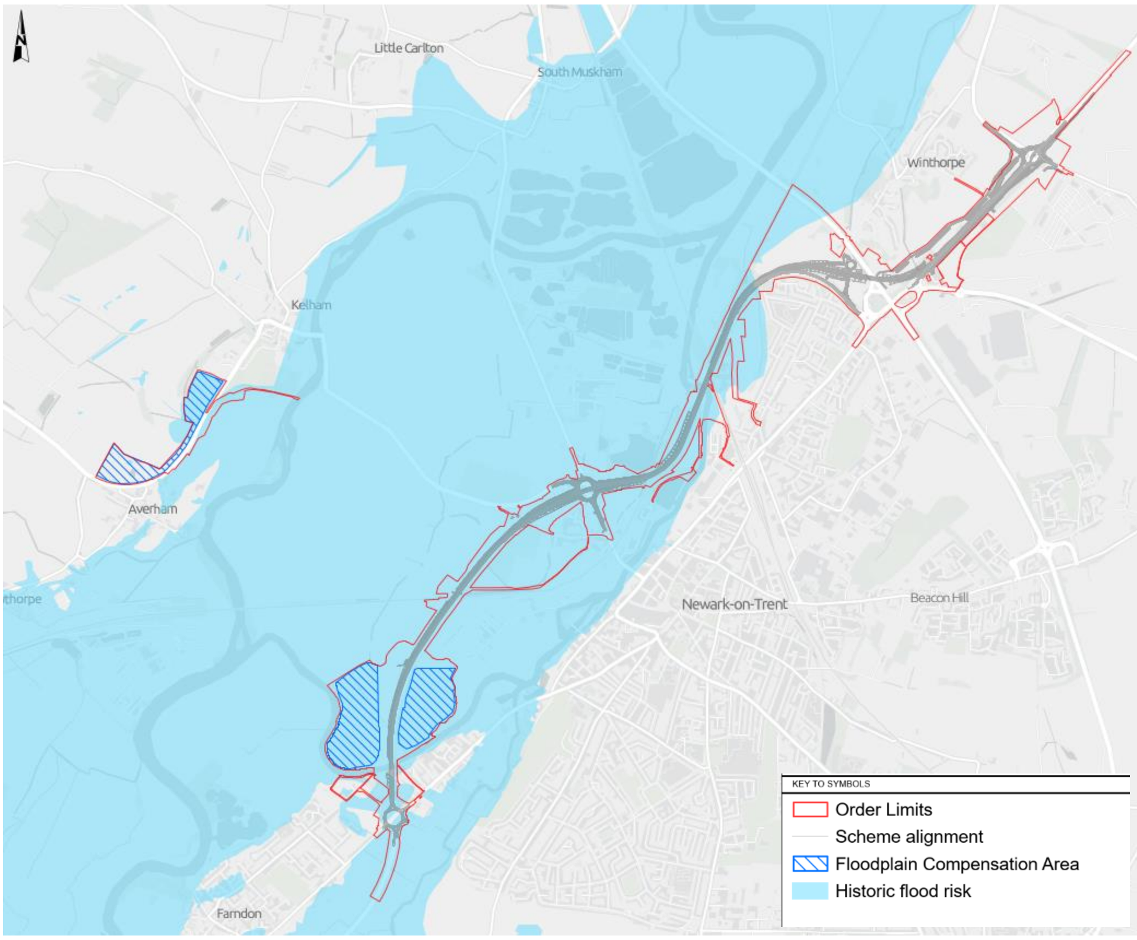
6.2.3 Records of historical flooding events in the study area have been collected from the Newark and Sherwood District SFRA, shown in Table 6.1 and Figure 6-2.

6.2.4 Based upon the fluvial flood sources and historic flooding, the baseline fluvial flood risk is considered to be high.

Table 6.1: Records of historic floods, taken from the Newark and Sherwood District SFRA

Date	Location	Source	Cause/details
1795	Newark	River Trent	0.2% AEP event (estimate derived from analysis of historic data). Considered worst flooding on record.
1910	Newark	Pluvial	Continuous rain following a fall of snow. Flood waters two foot deep along Kelham Road.
March 1947	Newark	River Trent	Prolonged rainfall, snow melt and high spring tides.
1979	Newark	River Devon	Fluvial bank overtopping.
2000	Newark	Unknown	Flooding included Tolney Lane.
November 2000	Kelham	River Trent	Fluvial bank overtopping.

Figure 6-2: Environment Agency Historic Flood Map for the Newark-on-Trent area, alongside the Order Limits



Source: Flood Defence Data © Environment Agency copyright and/or database right 2020. All rights reserved. Service Layer Credits - Contains OS data © Crown Copyright and database right 2022. Contains data from OS Zoomstack, Contains OS data © Crown Copyright and database right 2019.

6.3 Baseline hydraulic modelling

6.3.1 To provide an improved understanding of the fluvial flood risk in and around Newark, detailed hydraulic modelling has been completed using a 1D/2D Flood Modeller (FMP) TUFLOW model.

Existing hydraulic models

6.3.2 As part of the Scheme, the Environment Agency provided several 1D-2D FMP-TUFLOW models that were originally commissioned to produce strategic flood mapping for watercourses within the Newark and Sherwood area. The models provided were as follows:

- EA River Trent and Tributaries model 2011.
- River Trent and Tributaries 2020 (PCF Stage 2 model, based on Environment Agency River Trent and Tributaries 2011 model).
- Slough Dyke 2020.
- River Devon 2021.

6.3.3 The River Devon 2021 model covers a catchment that is a considerable distance (approximately 12.5km) from the southern end of the Scheme therefore is not considered relevant for the current study and has not been included. A map of the existing model domains is included within Appendix C.

River Trent and Tributaries 2011 and 2020

6.3.4 The 2011 version is the Environment Agency approved model. It was updated in 2020 for the Scheme during the development of options. The updates included the latest topography (LiDAR) data at the time and updated hydrology for the latest climate change allowance.

6.3.5 It was decided that the 2011 model would be used as the basis of the update for the Scheme hydraulic model, as the 2020 version only contained minor updates. The model is a 1D-2D FMP TUFLOW multi-domain model with a 2D 20m cell size for most areas except Rolleston/Southwell which has a 10m grid. The 1D FMP model includes:

- 36.0km reach of the River Trent.
- 9.6km reach of the River Devon.
- 3.9km reach of Middle Beck.
- 2.2km reach of Sodbridge Brook.

6.3.6 The existing model had a simulation time of around 8 hours.

Slough Dyke 2020

6.3.7 The Slough Dyke model consisted of a single domain FMP TUFLOW model that was around 8.5km long. This model has been incorporated into the Trent and Tributaries model to form the full hydraulic model for the Scheme

Modelling configuration for the National Highways A46 Newark Trent 2023 Fluvial Hydraulic model

6.3.8 The model for this FRA is an updated version of the 2011 River Trent and Tributaries model. The model is a 1D-2D FMP TUFLOW multi-domain model.

6.3.9 The 2D TUFLOW domain of the model consists of a primarily 20m grid, with some urban sections within Newark-on-Trent and along the alignment of the Scheme using a higher resolution 10m grid. The 1D FMP model includes:

- 36.0km reach of the River Trent.
- 9.6km reach of the River Devon.
- 3.9km reach of Middle Beck.
- 2.2km reach of Sodbridge Brook.
- 8.5km reach of Slough Dyke.

6.3.10 The original model had a simulation time of around 8 hours, and this was reduced by trimming the model down and removing approximately 15km of upstream length. The River Trent and Tributaries 2011 model was updated to reflect newly included watercourses, and inflow hydrographs were estimated based on the most recent available data.

6.3.11 Topographic, channel and structure surveys were carried out in 2022/23 and were used to update the hydraulic model to improve the representation of the baseline model and to inform design. Full details of hydraulic modelling are found in Appendix A.

6.3.12 The model has been used to assess the existing flood risk and the predicted risk after the construction of the Scheme to assess any potential impacts that the Scheme could have on third parties.

6.3.13 A discussion of the findings of the Scheme assessment provided in Sections 7 and 8 of this FRA. Further detail regarding the modelling can be found in the supplementary Hydraulic Modelling Technical Report in Appendix A.

6.4 Surface water flood risk

6.4.1 It can be identified from the Environment Agency's RoFSW dataset (Figure 6-3) that areas at risk from surface water flooding are present within the study area. The RoFSW dataset has its own risk classification, ranging from 'Very low' to High'. This classification is outlined as follows:

- High - each year, the area has a chance of flooding of greater than 1 in 30 (3.3% AEP)
- Medium - each year, the area has a chance of flooding of between 1 in 100 (1%) and 1 in 30 (3.3% AEP)

- Low - each year, the area has a chance of flooding of between 1 in 1000 (0.1%) and 1 in 100 (1% AEP)
- Very low - each year, the area has a chance of flooding of less than 1 in 1000 (0.1% AEP)

6.4.2 Most of the surface water flood risk in the study area is categorised as 'Very low' (less than 0.1% AEP). However, there are sections of the existing A46 where the surface flood risk increases, becoming 'Low' (between 0.1% and 1% AEP) and 'Medium' (between 1% and 3.33% AEP). Risk is higher in areas closest to watercourses, as shown in Figure 6-3.

Surface water (pluvial)

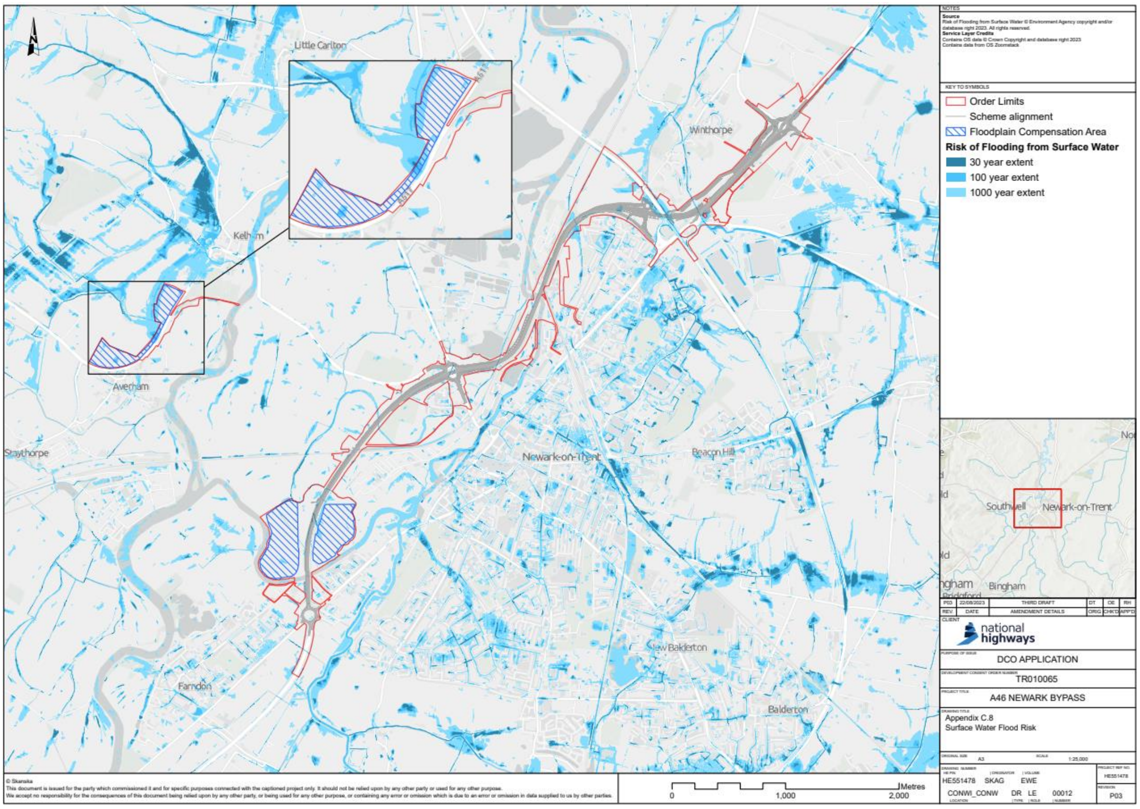
6.4.3 As some surface water flow paths are associated with the fluvial watercourses running underneath the Scheme, these have already been considered as part of the fluvial assessment. Where the flow paths are not associated with fluvial watercourses, an assessment of the overland flow paths and localised ponding areas of surface water has been undertaken to inform this FRA. Based on this assessment, the baseline risk is considered to be low.

Surface water (highway drainage)

6.4.4 The Scheme already contains a drainage system that conveys runoff from the highway into watercourses such as the Old Trent Dyke. As requested by the Trent Valley IDB, the existing land drainage regime is maintained like for like by the Scheme.

6.4.5 The baseline surface water flood risk to and from the Scheme is considered to be low.

Figure 6-3: Environment Agency RoFSW map for the Scheme area



Source: Flood Defence Data © Environment Agency copyright and/or database right 2020. All rights reserved. Service Layer Credits - Contains OS data © Crown Copyright and database right 2022. Contains data from OS Zoomstack, Contains OS data © Crown Copyright and database right 2019.

6.5 Groundwater flood risk

6.5.1 Newark Strategic FRA (Level 2) indicates that the Scheme is located within an area that is highly susceptible to groundwater flooding.[11] Preliminary groundwater monitoring across the Scheme from August to December 2021 indicates relatively shallow groundwater levels, varying from 0.3m to 4.1m below ground level.[12] Groundwater levels from the current groundwater monitoring programme, which commenced in January 2023, are also within this range.

6.5.2 As the Scheme is located within an area that is considered to be highly susceptible to groundwater flooding and given that shallow groundwater

[11] WSP. (2012). *Strategic Flood Risk Assessment Level 2 Stage 2*. Retrieved from Newark & Sherwood District Council: https://www.newark-sherwooddc.gov.uk/media/newark-and-sherwood/images-and-files/planning-policy/pdfs/flooding-and-water-infrastructure/strategic-flood-risk-assessment-level-2-part-2/Main-Text.pdf

[12] Tetra Tech. (2022). A46 North Newark Bypass. Factual Ground Investigation Report. V1.1.

was indicated in 2021 and confirmed in 2023, the baseline risk of groundwater flooding is considered medium to high.

6.6 Sewer flood risk

6.6.1 Severn Trent's records within the SFRA for Newark and Sherwood District Council show that the locations with the greatest numbers of flooding records are localised in more urban areas within the borough, not adjacent to the Scheme.

6.6.2 The nearest recorded sewer flooding events occurred in Little Carlton (approximately 3km north-west of the Scheme), Balderton (approximately 3.5km south-east of the Scheme) and East Stoke (approximately 4km south-west of the Scheme). Sewers within the area have additionally been designed to be highly resistant to pipe bursts and flood events. Given the distance of the Scheme from these previous incidents, the baseline flood risk from sewers is therefore considered to be low.

6.7 Artificial sources of flood risk

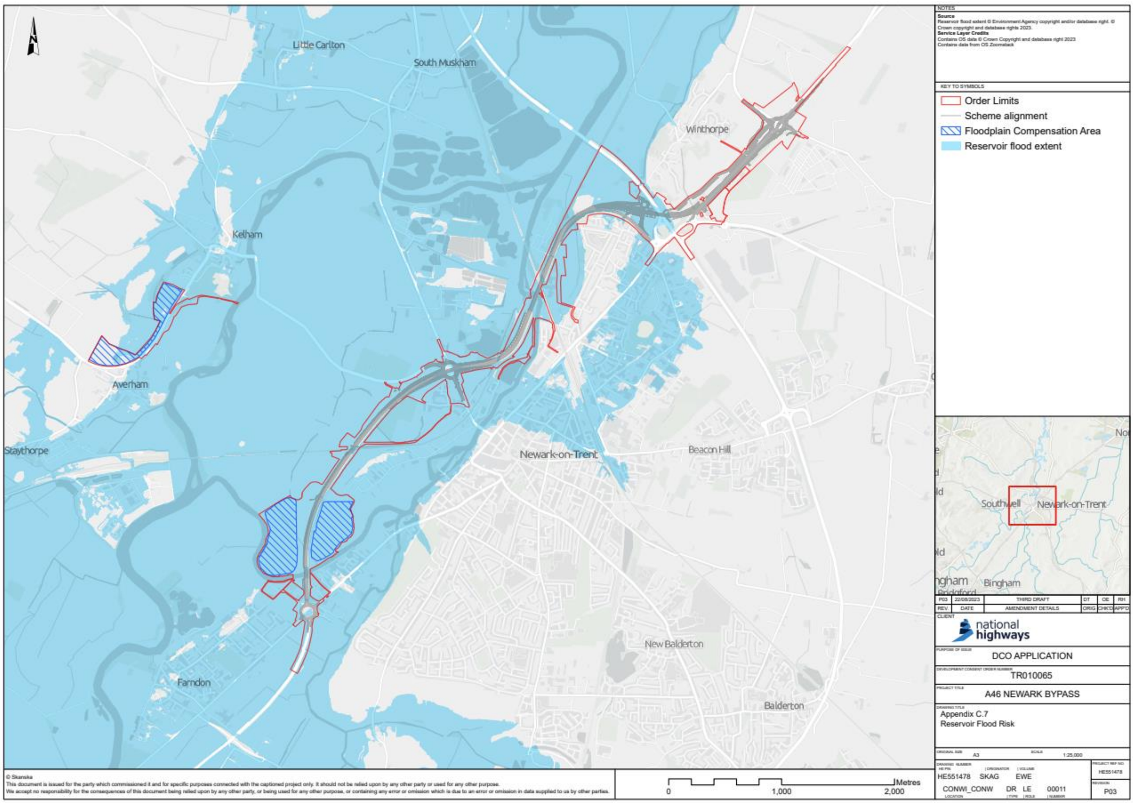
6.7.1 The risk of flooding from reservoirs due to dam failure is very low throughout the United Kingdom. Based on Environment Agency data, the following registered reservoirs (i.e., capacity of 25,000m^3 or more of water above ground level) could present a flood risk to part of the study area in the unlikely event of a dam failure (Table 6.2).

Table 6.2: List of nearby reservoirs that could potentially affect the Scheme in the event of a breach

Reservoir	Distance from the Scheme (km)
Ash Buffer Lagoon Besthorpe	8.2
Rufford Lake	18.5
Sherwood Forest Lake	18.5
South Farm Reservoir 1	24.8
South Farm Reservoir 2	24.8
Thoresby Lake (Upper)	24.0
Thoresby Lake	24.0

6.7.2 An extract of the published flood risk map from reservoirs obtained from the Environment Agency website is included in Figure 6-4.

Figure 6-4: Environment Agency Reservoir Flood Extent (fluvial contribution) map with Order Limits added



Source: Flood Defence Data © Environment Agency copyright and/or database right 2020. All rights reserved. Service Layer Credits - Contains OS data © Crown Copyright and database right 2022. Contains data from OS Zoomstack, Contains OS data © Crown Copyright and database right 2019.

6.7.3 The flood risk map indicates that, for the majority of the reservoirs in the vicinity of the Scheme, floodwater would follow the route of the River Trent northwards in the case of a dam failure. Although the consequences of flooding from dam failure are potentially high within the Scheme area, the reservoirs are inspected on an annual basis, making the risk of reservoir failure low.

6.7.4 Based on this information, the risk of flooding from reservoirs is considered to be low and is therefore not considered further within this assessment.

6.8 Snowmelt

6.8.1 Snowmelt was one of the main factors that led to the catastrophic river floods that began in mid-March 1947 throughout the United Kingdom. The combination of snowmelt, frozen ground and rainfall, caused the flooding of the River Trent over the course of the event. Several locations within the Newark and Sherwood District, including Newark, were reported to have flooded during this time.

6.8.2 A review of the Met Office ‘Days of Snow Lying’ annual average for the period 1961 to 1990 against the period 1991 to 2020 indicates that there is a decrease in snow lying days. According to the Met Office, the average number of snow days for the Newark area is currently 7.24 days per year, and this number is likely to further decrease with climate change.

6.8.3 The risk of flooding from this source, having considered the historical atmospheric trends, is considered to be low and is not assessed further in this FRA.

7 Flood risk to the Scheme – operational stage

7.1 Overview

7.1.1 This section addresses the risk of flooding *to* the Scheme from the identified sources within the study area.

7.1.2 The risk of flooding *from* the Scheme, once fully operational, to other receptors is discussed in Section 8.

7.2 Fluvial flood risk

7.2.1 All schemes on motorways and all-purpose trunk roads must be designed to remain operational and safe for users in times of flood[19].

7.2.2 The fluvial flood risk to the A46 during operation is reduced as the highway is raised above the River Trent floodplain. Details of the A46 highway deck level versus peak water levels and associated freeboards are presented in Table 7.1.

7.2.3 In accordance with the requirements of DMRB 356[13], the design flood event is the 1% AEP plus climate change (normal climate change allowance) event. The check event is the 0.5% AEP event plus climate change (higher climate change allowance) event. So that the whole of the route remains operational when assessing the freeboard for river

[13] Design Manual for Roads and Bridges, CD 356 Design of highway structures for hydraulic action, Revision 1, Highways England, March 2020: https://www.standardsforhighways.co.uk/search/559b43dc-82db-46c9-be1a-f2b718e8db62.

crossings, the 0.1% AEP event was used as proxy for the 0.5% AEP event plus climate change, as a conservative approach.

Table 7.1: A46 road level vs peak fluvial flood levels

Location (chainage m)	New Road Level (mAOD)	Peak Fluvial Flood level (1% AEP plus 39% CC) (mAOD)	Peak Fluvial Flood level (0.1% AEP used as a proxy event for 0.5% AEP plus 62%CC) (mAOD)	Freeboard to Highway (using 1% AEP plus 39%) (m)
Downstream of Windmill viaduct (750.000)	**13.11**	**12.77**	**13.11**	**0.34***
South of Cattle Market roundabout (2100.000)	**14.37**	**11.99**	**12.27**	**2.38**
North of East Coast Mainline railway line crossing with the Nottingham to Lincoln Western Railway Line (435.000)	**13.94**	**11.13**	**11.37**	**2.81**

7.2.4 *Freeboard reduced at this location as the Scheme deck levels are required to tie into the existing deck level of the A46 highway.

7.2.5 Table 7.1 demonstrates the main carriageway would remain operational in fluvial flood conditions with the lowest sections of the earthworks embankments situated being above both the design and check events.

7.2.6 For structures crossing the river, a minimum freeboard allowance of 600mm is required above the maximum water level, for the check event (0.5% AEP event plus climate change)[14]. Using the 0.1% AEP event as a proxy for the 0.5% AEP event plus climate change event, the minimum freeboard identified when assessing all river crossings was at the Farm access underpass which achieves a freeboard of 1.46m (Table 8.1).

7.2.7 Whilst the main carriageway sits on the embankment and out of an area of risk, there are still some other elements of the Scheme which are at risk from fluvial flooding for the 1% AEP design event, including an

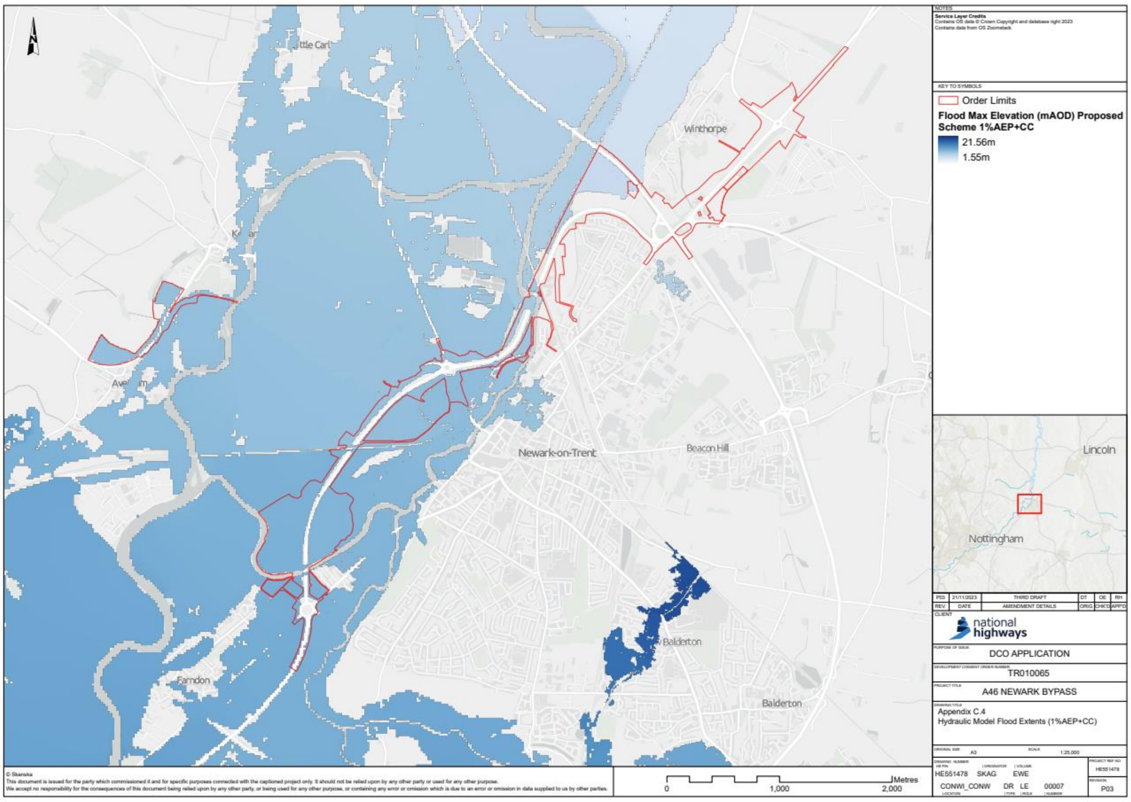
[14] Design Manual for Roads and Bridges, CD 356 Design of highway structures for hydraulic action, Revision 1, Highways England, March 2020: https://www.standardsforhighways.co.uk/search/559b43dc-82db-46c9-be1a-f2b718e8db62.

allowance for climate change (1% AEP +39% increase in peak flows). This requirement is due to these Scheme elements connecting into the existing highway network, which is at a much lower existing road level, such as:

- Cattle Market roundabout, including the slip-road earth embankments either side of the roundabout.
- West side of the A46 earth embankment, north of the Nether Lock Viaduct.
- West side of the A46 earth embankment, north of Cattle Market roundabout.
- West side of the A46 earth embankment, north of Windmill Viaduct.

7.2.8 The Brownhills Junction comprises a single span concrete structure that carries the widened A46 over a new junction underneath. This new junction will sit within the flood extents of the modelled 1% AEP + 39% climate change event, and therefore would be at risk of fluvial flooding (Figure 7-1). The structure design was informed by the hydraulic modelling outputs. Hydraulic modelling (with the Scheme) has shown that the aperture is wide enough to allow floodwater to pass through without altering flood levels elsewhere.

Figure 7-1: A46 Newark Trent 2023 Fluvial Hydraulic model 1% AEP + Climate Change (+39%) water levels



Source: Flood Defence modelled by Mott MacDonald, 2023. All rights reserved. Service Layer Credits - Contains OS data © Crown Copyright and database right 2022. Contains data from OS Zoomstack, Contains OS data © Crown Copyright and database right 2019.

7.2.9 Where the A46 is to be raised above the Cattle Market Junction, the existing roundabout would be increased in size to form a gyratory. This larger roundabout would sit within flood extents of the modelled 1% AEP plus climate change event, meaning it is at risk from fluvial flooding, which is consistent with existing conditions. In order that fluvial flood levels are not altered by the junction upgrades, the existing flood relief culvert would be extended to allow floodwater conveyance. Also, the finished highway deck level of the gyratory would not be higher than the existing Cattle Market roundabout so that any existing overland flow path across the roundabout is maintained in the Scheme scenario. However, flood modelling outputs suggest this flow path would not be utilised post-Scheme. This is due to changes in the flooding upstream of Cattle Market roundabout. Modelling outputs in this area are discussed in Appendix A.

7.2.10 The River Trent FCAs are designed to compensate for the displacement of the floodplain as a result of the widened Scheme embankment. As such, the areas the FCAs are situated in would experience a greater level of fluvial flooding during flood events. This is acceptable as these areas are intended to replace floodplain storage removed by the widened embankment.

7.2.11 The drainage infrastructure for the Scheme has been designed to withstand a 50% AEP plus climate change fluvial flood event (refer to Appendix 13.4 DSR of the Environmental Statement Appendices [APP-179]). Mitigating fluvial flood events greater than the 50% AEP plus climate change event was deemed unfeasible as drainage infrastructure would need to be raised to 1-1.5m above existing ground levels. This would therefore have required oversizing of the FCAs to accommodate this additional drainage infrastructure footprint in the floodplain.

7.2.12 With design mitigation, the risk of fluvial flooding to the Scheme is considered to be low.

7.3 Surface water flood risk

7.3.1 As mentioned in Section 3 of this FRA, the inclusion of widened embankments alongside a widening of the existing carriageway has the potential to alter surface water flow paths and/or displace predicted surface water ponding which could potentially impact flood risk. The impact of this has been addressed through either:

- An assessment of predicted risk as detailed in the Environment Agency’s RoFSW.
- Through detailed hydraulic modelling with mitigation as appropriate within the Scheme design.

Surface water (pluvial)

7.3.2 The Scheme has the potential to impact existing surface water flooding by increasing the overall impermeable area and impacting flow paths. Following assessment, in the operational stage existing flow paths are unlikely to be materially affected by the Scheme therefore the risk of flooding from this source is considered to be low.

Surface water (highway drainage)

7.3.3 There is a low risk of the A46 flooding due to the highway drainage, as the road is raised on the embankment and run-off can flow down the embankment unimpeded during a storm event.

Mitigation Measures

7.3.4 The new dual carriageway is designed to minimise the risk of flooding by incorporating current design standards and future climate change allowance to improve its resilience using sustainable drainage techniques. Where surface water flow paths cross the Scheme, the drainage design mitigates this so that there is no increased flood risk to the Scheme.

7.3.5 Along the new sections of the A46, the existing drainage regime would be updated like for like. This would result in there being no net loss in drainage and therefore no increased surface water flood risk to the new highway.

7.3.6 From ground investigation surveys it was discovered that groundwater levels vary across the Scheme with levels noticeably lower towards the north. Infiltration may be possible within the Balderton Sand and Gravel member, provided groundwater monitoring shows sufficient cover between groundwater levels and the base of any soakaway features and investigations prove no contamination in or around the area.

7.3.7 Infiltration testing, to be done at detailed design, would confirm the feasibility of infiltration in these areas and ground investigations would confirm any contamination. For more information on the features used to sustainably manage and discharge surface water for the lifetime of the Scheme, please refer to Appendix 13.4 (Drainage Strategy Report) of the Environmental Statement Appendices [APP-179].

7.3.8 With the designed mitigation, the risk to the Scheme from surface water flooding is considered to be low.

7.4 Groundwater flood risk

7.4.1 Groundwater flooding has the potential to impact structures at or below ground level. The Scheme would be elevated from the River Trent floodplain and therefore would not be impacted by groundwater flooding. The drainage strategy (Appendix 13.4 (Drainage Strategy Report) of the Environmental Statement Appendices [APP-179]) considers the risk of shallow groundwater and seeks to prevent groundwater ingress to, or flotation of, the proposed drainage systems. Subsurface structures such as piling and retaining walls would be groundwater resilient.

7.4.2 FCAs are unlined excavations below ground level. There is potential for groundwater ingress into FCAs, particularly at times of year when groundwater is close to ground level.

7.4.3 Farndon East and West FCAs would become a wetland habitat with expected groundwater baseflow. The design philosophy of the wetlands incorporates groundwater.

7.4.4 At Kelham and Averham FCA, groundwater seepage from the sides and base of the FCA is expected to be insignificant with respect to the fluvial flows and volume that the FCA is designed to accommodate. Furthermore, any groundwater seepage into the FCA will be continually discharged under gravity to the River Trent. Groundwater ingress is therefore not expected to significantly affect FCA function.

7.4.5 With design mitigation, the risk of groundwater flood risk to the Scheme is considered low.

7.5 Sewer flood risk

7.5.1 The risk from sewer and drainage flooding is minimised by incorporating design standards and future climate change allowances. Retention features have been designed to detain runoff from all events expected to occur with 1% annual probability or more frequently which would reduce the risk of flooding when the drainage network is unable to discharge due to high water levels. Further details on the drainage strategy for the Scheme are included in Appendix 13.4 (Drainage Strategy Report) of the Environmental Statement Appendices [APP-179].

7.5.2 Given the lack of known records of previous incidents, flood risk from sewers and drains to the Scheme, once fully operational, is considered low.

7.6 Artificial sources of flood risk

7.6.1 External artificial sources of flood risk are considered unlikely to affect the Scheme in a different way than in the baseline, and therefore the risk to the Scheme is low.

7.7 Residual flood risk

7.7.1 It is a requirement of this FRA that any residual risk to the Scheme can be safely managed at the operational stage of the Scheme.

7.7.2 The Scheme is designed to tie-in to existing Environment Agency flood defences where the Scheme interacts with these (Section 2.4 of this FRA). The Scheme design directly interfaces with these flood defences and suitable measures have been put in place in order that the existing defences are not structurally compromised or altered in terms of crest height. This has therefore maintained the effectiveness of existing flood defences. There could be a residual risk to the Scheme if these flood defences were to fail. However, this risk is low due to the extensive engineering inspection programmes for all Environment Agency flood defence assets.

8 Flood risk from the Scheme – operational stage

8.1 Overview

8.1.1 This section discusses the risk of flooding from the Scheme, once fully operational, to other receptors.

8.2 Fluvial flood risk

8.2.1 To determine the potential change in flood risk from the Scheme once operational (as described in Section 3 of this FRA), detailed 1D-2D hydraulic modelling has been undertaken for the River Trent. Details of how the Scheme elements have been represented, alongside a full suite of results are included in the National Highways A46 Newark Trent 2023 Fluvial Hydraulic Report (Appendix A). To summarise:

- Topographic amendments have been applied in the 2D model to represent the new dual carriageway embankment.
- Piers modelled using flow constrictions to represent sub-grid blockage.
- The FCAs have been represented using topographic amendments to the floodplain, to compensate for the floodplain storage volume lost due to the new embankment. These have been designed with good hydraulic connectivity to the River Trent.

8.2.2 The following paragraphs explain the minor differences in flood depths and extents for the 1% AEP plus 39% climate change event for the Scheme scenario compared to the equivalent baseline scenario (see also Figure 8-1). Other locations have shown localised increases or decreases in depth.

8.2.3 Sensitivity testing has been undertaken for localised depth increases at vulnerable receptors, with results presented in Appendix H of this document.

Location 1 and 2: Floodplain upstream of Averham weir near Staythorpe power station

8.2.4 Upstream from the point at which the River Trent bifurcates, a decrease in water levels of up to 50mm was observed in the Scheme plus mitigation scenario. This is attributed to the Farndon FCAs, which permit a portion of the flow to enter the left bank floodplain earlier.

Location 3: Floodplain west of A46

8.2.5 As flooding is caused by the FCAs earlier than in the baseline, the Scheme and the Nottingham to Lincoln railway line hold back water, leading to an increase in upstream water levels of up to 16mm.

Location 4: Windmill Viaduct

8.2.6 Upstream of Windmill Viaduct, the widening of the carriageway, the addition of piers and the increased embankment width have caused a restriction to water flowing from west to east on the right bank of the River Trent. This has resulted in local flood level increase by up to 26mm in an area of receptors classed as “miscellaneous”. The increase in flood levels appears to be caused by the protrusion of the embankment into the floodplain. Overall, water levels increase up to 10mm on top of a depth of 0.3-1.7m in the baseline design event and therefore the change is deemed slight.

Location 5: Floodplain east of A46

8.2.7 A localised decrease in peak water levels up to 111mm beneath Windmill Viaduct, however, generally there appears to be a decrease up to 10mm caused by the Scheme.

Location 6: Great North Road

8.2.8 A small area of 0.18km^2 with depths up to 5mm greater in comparison with the baseline scenario is shown near Great North Road. It is noted, that it appears at the same location of instability at culvert NCC_3218. Due to this location being a significant distance from the Scheme and vulnerable receptors, the instabilities noted in the baseline and Scheme scenario have not been rectified at this stage.

8.2.9 Due to the instabilities noted in this area, the model results should not be used to inform flood risk.

8.2.10 Immediately south of Location 6, infrastructure at the British Sugar site (including a car park and buildings) are shown to be affected in the 50% and 20% AEP storm events. This is shown in Appendix C.11 and C.12. In the baseline event, flooding in this area is approximately 500mm in depth and is shown in the hydraulic model to increase by 5-10mm by the scheme. This is considered to be a minor adverse effect. Analysis of the modelling concludes that this is not due to numerical error and is likely due in part to interpolation of the DTM (Digital Terrain Model) at this location.

Location 7: Kelham and Averham FCA

8.2.11 Kelham and Averham FCA forms an extension of the floodplain and starts flooding in the 3.33% AEP event. In the 1% AEP plus climate change flood event, the FCA fills up to a depth of approximately 1.05m fulfilling its design purpose.

Location 8: Floodplain between Kelham Road and Nottingham to Lincoln railway line

8.2.12 It has been observed that the water level at the base of the new embankment has a localised increase of up to 86mm from the baseline. It is deemed to be of low impact and slight significance, particularly as there are no vulnerable receptors nearby and the area is predominantly agricultural.

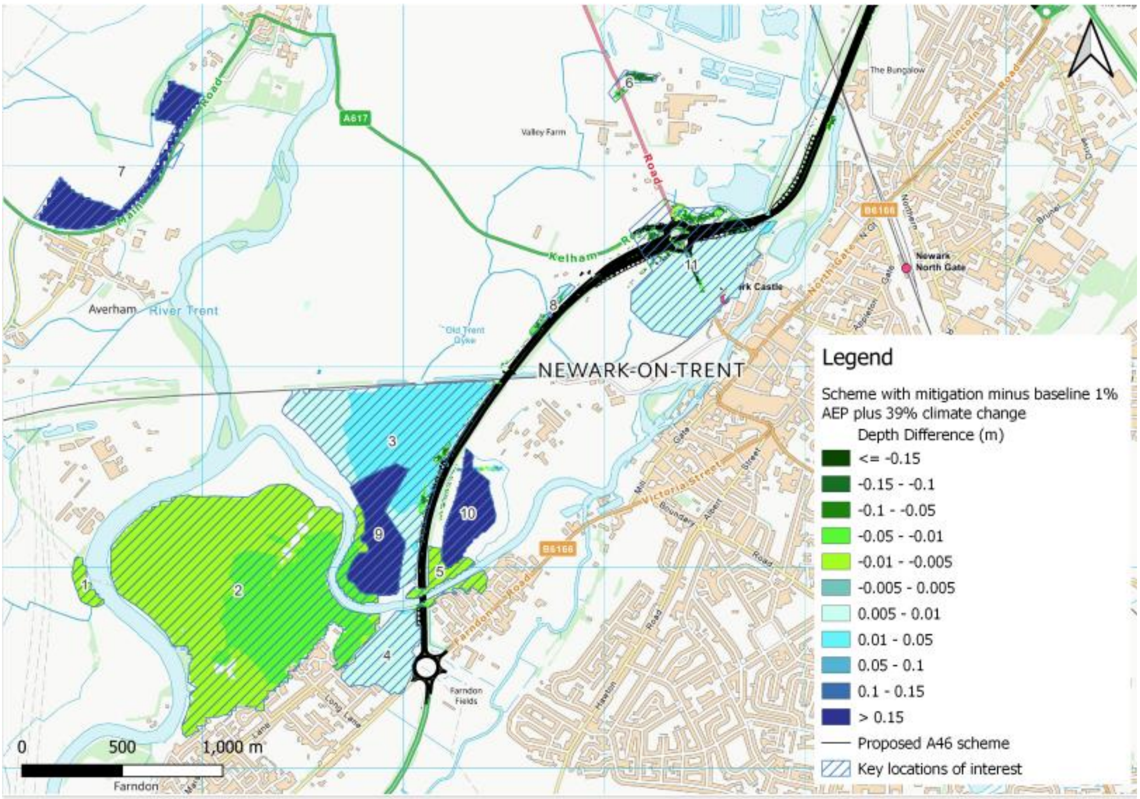
Location 9 and 10: Farndon FCA

8.2.13 Farndon FCA forms an extension of the floodplain and starts flooding in the 50% AEP event. In the 1% AEP plus climate change flood event, the FCA fills up to a depth of approximately 3.8m in the eastern FCA and 2.7m in the western FCA.

Location 11: Cattle Market

8.2.14 An increase in water levels is observed of up to 20mm between the bund and Nottingham to Lincoln railway line. This increase in water level appears to be caused by flows overtopping the railway line and ponding behind the Cattle Market roundabout as flows can no longer overtop the A46 from south to west.

Figure 8-1: Baseline vs Mitigated Scheme – 1% AEP + Climate Change (39%) – peak water level differences



Source: Flood Data modelled by Mott MacDonald, 2023. Contains public sector information licensed under the Open Government Licence v3.0.

Tolney Lane

8.2.15 As shown in Figure 8-1 the Tolney Lane residential area experiences negligible change in flood levels during the operational stage of the Scheme when compared to the baseline for the 1%AEP+CC event. The Tolney Lane highway itself also experiences negligible change in flood levels for the 1%AEP+CC event.

Baseline vs Scheme (with FCA mitigation)

8.2.16 When comparing baseline against the Scheme with mitigation, there is a general increase in water levels up to 20mm in the land around the Farndon West FCA. Upstream of culverts beneath the A46 scheme, localised increase can be seen, but can be attributed to minor hydraulic modelling instabilities.

8.2.17 This increase of flooding within FCAs is expected, as they have been designed to store flood water. Overall, the modelling of the Scheme with associated FCAs shows a minor adverse increase less than 20mm in a low vulnerability receptor (i.e., farmed land) with reduction in flood risk observed in areas adjacent or within higher vulnerability receptors (i.e., commercial at the Sugar Factory and residential on the right bank of the River Trent around Farndon Roundabout). More information on the hydraulic modelling can be found within the National Highways A46 Newark Trent 2023 Fluvial Hydraulic Modelling Report (Appendix A).

8.2.18 It has been observed that the hydraulic model is sensitive to minor variations in the crest level of the existing flood defence to the south of Cattle Market roundabout. It has been assessed and is understood for outline design that the likely variation of flood levels in this area is +/-10mm and thus will not cause any significant effects. It is recommended at detailed design stage that further data collection and analysis is undertaken on this asset to ascertain the resulting peak water level and any associated minor change in flood risk level as a consequence of the mitigated Scheme. Further assessment of the flood risk in this area is discussed in Appendix A.

8.2.19 As described in DMRB standards document CD 356, for new structures in the floodplain, a minimum freeboard allowance of 600mm is required above the maximum water level for the largest flood event for design (0.1% AEP).

8.2.20 Comparison of peak water levels is shown in Table 8.1. Generally, there are small changes in freeboard between baseline and Scheme with mitigation.

8.2.21 It is noted that freeboard was not met for the existing Cattle Market roundabout flood relief culvert in the baseline scenario and this freeboard will not be changed in the Scheme with mitigation scenario.

Table 8.1: Comparison of peak water levels for 0.1% AEP fluvial event

Structure	Baseline 0.1% Peak water level (mAOD)	Freeboard (m) Baseline	Scheme with mitigation 0.1% Peak water level (mAOD)	Freeboard (m) Scheme with mitigation	Soffit level (mAOD)
Windmill Viaduct	13.01	3.60	13.01	3.60	16.61
Farm access underpass	13.01	1.50	13.04	1.47	14.51
Nottingham to Lincoln Railway Line West	12.57	6.56	12.87	6.61	19.48
Nottingham to Lincoln Railway Line East	12.23	6.57	12.33	6.47	18.80
Cattle Market Roundabout flood relief culvert	12.44	-1.10	12.47	-1.07	11.40
Nether Lock Viaduct	11.74	10.12	11.74	10.12	21.86
Sewage Works Access Underpass	No flood	N/A	No flood	N/A	-
Brownhills A1 Crossing	No flood	N/A	No flood	N/A	-

Floodplain compensation areas

8.2.22 FCAs have been designed to mitigate the decrease in floodplain footprint from the widened A46. FCAs situated at Kelham, Farndon East and Farndon West are being provided in the Scheme. This is to provide volume for volume compensation floodplain lost due to the new above ground infrastructure.

8.2.23 Sensitivity testing of the volume of floodplain compensation has been undertaken, with results provided in Appendix I.

8.2.24 The FCAs are not to be bunded (with the exception of Kelham & Averham FCA) and are freely draining, meaning they will not increase the risk of artificial flooding elsewhere.

8.2.25 There is localised bunding to be provided on the western side of the northerly section of the FCA at Kelham & Averham so that the existing natural low point is filled, preventing any floodwater exiting the FCA and entering Mission Drain to the north.

8.2.26 At this preliminary design stage, compensation for any floodplain storage for Mission Drain that may be affected by the extent of the FCA has not been accounted for in the Kelham & Averham FCA design. However, the floodplain associated with Mission Drain is small compared to the size of the FCA and at detailed design the approach to construction would be further refined and finalised, any required amendments to the FCA can be made, in order that there is no loss of Mission Drain floodplain.

8.2.27 Note that despite the Kelham & Averham FCA being bunded, it likely does not constitute a reservoir under the Reservoirs Act 1975 because the FCA is free draining following a flood event. This will be confirmed at Detailed Design.

Flood hazard maps

Figure 8-2: Flood hazard map for Baseline Model 1% AEP + Climate Change (39%)

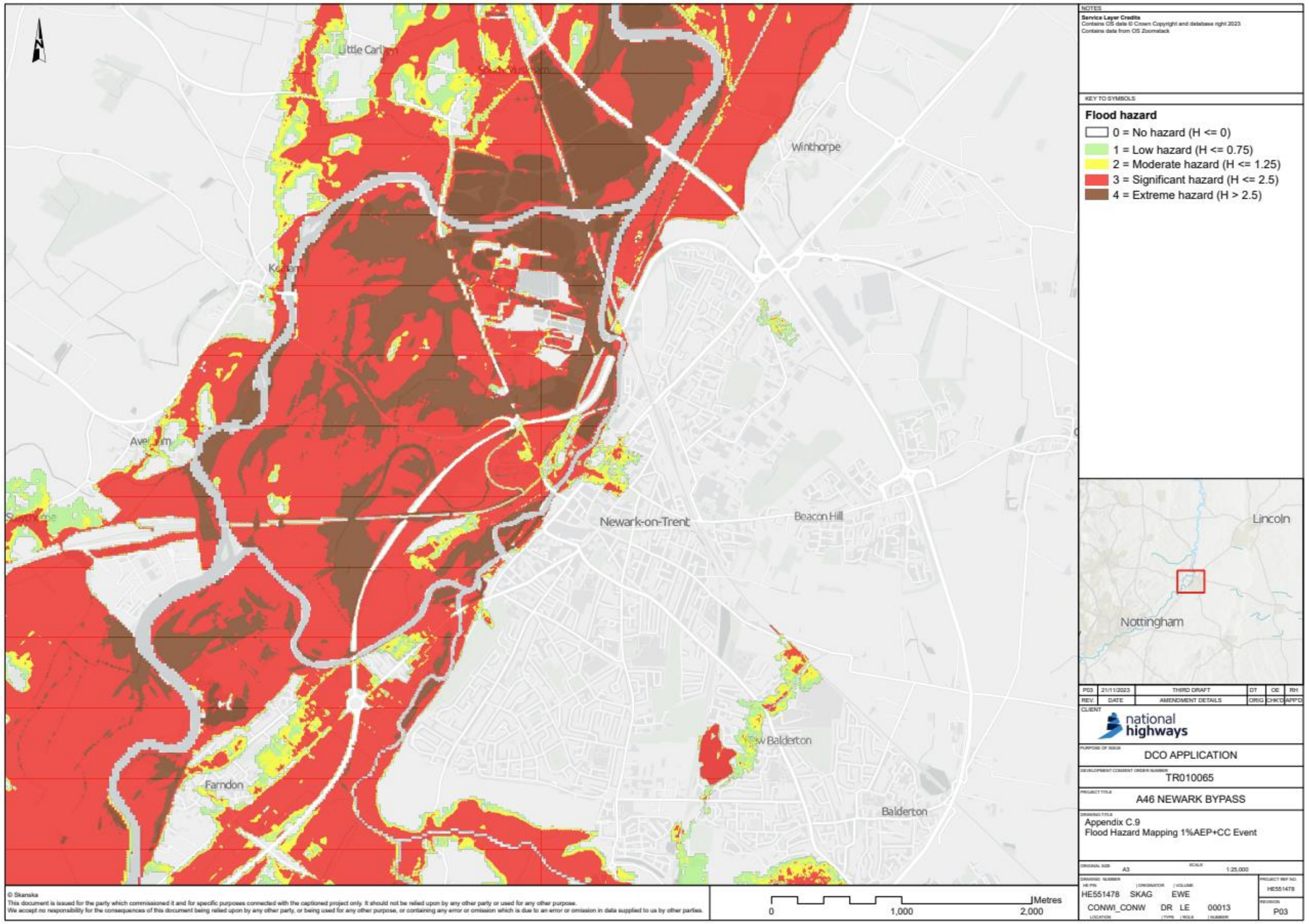
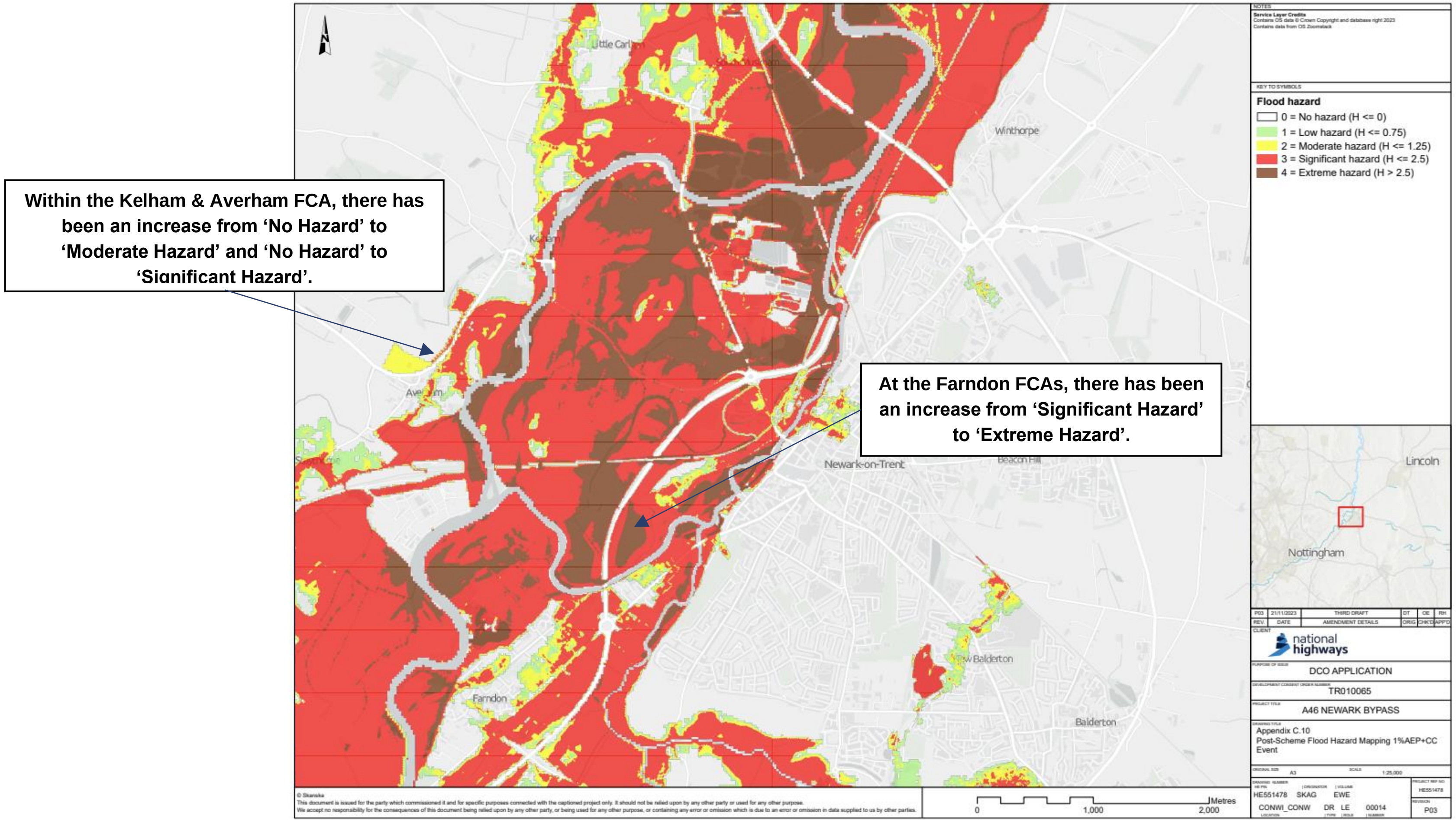


Figure 8-3: Flood hazard map for Mitigated Scheme Model 1% AEP + Climate Change (39%)



8.2.28 A comparison between the flood hazard maps for the baseline (Figure 8-2) and mitigated Scheme (Figure 8-3) shows that despite a change in flood levels, the Scheme only slightly increases flood hazard in the Farndon, Kelham & Averham Areas. Farndon experiences an increase in hazard from 'Significant Hazard' to 'Extreme Hazard'. Kelham & Averham experiences an increase in hazard from 'No Hazard' to 'Moderate Hazard' and Significant Hazard'.

8.2.29 These increases in hazard are acceptable as they are caused by and are contained within agricultural land. This land is within and adjacent to the new FCAs, which have been designed to store flood waters during large flooding events.

8.2.30 The results of the hydraulic modelling show that a change in flood level occurs in some developed regions of the River Trent floodplain, where higher sensitivity receptors (i.e., residential buildings) are situated. As seen in Figure 8-1, this change is acceptable as there are only negligible impacts. Further sensitivity testing is provided in Appendix H of this document to confirm that the impacts are negligible.

8.2.31 With design mitigation, the risk of fluvial flooding from the Scheme is considered to be low.

8.3 Surface water flood risk

Highway runoff

8.3.1 The elements of the Scheme (when fully operational) which have the potential to change surface water flood risk are:

- Junction upgrades: surface water flood risk could be impacted by an increase in impermeable area.
- Increased road surface: the new impermeable surface area would increase the surface water run-off with the potential to increase flood risk on-site and further downstream by uncontrolled discharge to receiving waterbodies.

8.3.2 A detailed drainage strategy has been produced for the Scheme so that surface water is managed effectively and sustainably. Details relating to the design and results of this strategy are located within Appendix 13.4 (Drainage Strategy Report) of the Environmental Statement Appendices [APP-179].

8.3.3 Detention basins are bunded to protect them against the aspirational 50% AEP fluvial event[15]. The detention basins have been designed to the 3.33% AEP plus climate change pluvial event (+20% climate

[15] As agreed and recorded in the meeting minutes HE551478-SKAG-HDG-CONWI_CONW-MI-CD-00014_P01_S2.

change). Run-off that exceeds this threshold is being managed by overland flow routes into existing watercourses and the FCA's.

8.3.4 Within the floodplain, any rainfall volume from storm events above the 3.33% AEP plus climate change pluvial event would not be attenuated. An assessment has been undertaken as a part of the drainage strategy (see Section 4.5 of this FRA), that outlines why it is acceptable for attenuation within the floodplain only to be provided up to the 3.33%AEP plus climate change pluvial event. This assessment included in Appendix D. This has been reviewed and accepted by the Environment Agency and NCC.

8.3.5 Outside of the floodplain, any rainfall volume from storm events above the 3.33% AEP pluvial event would be managed within an overflow attenuation area sized to store the additional run-off generated during the 1% AEP plus climate change pluvial event.

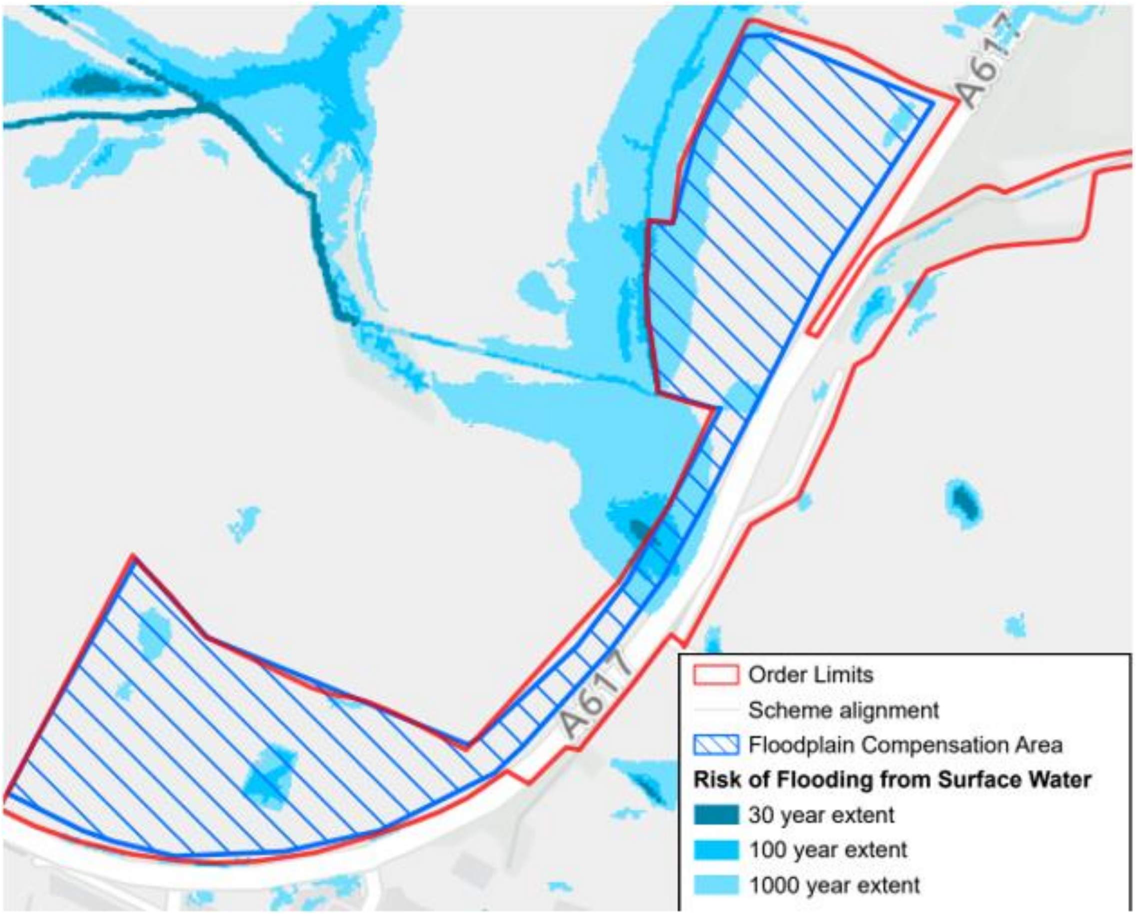
8.3.6 With the above outlined mitigation, the flood risk resulting from increased highway runoff is considered to be low.

Disruption of existing surface water flow paths and ponding areas

8.3.7 Throughout the Scheme area, some new features can be seen to disrupt or block current surface water flow paths, see Figure 6-3. The Scheme interacts with these flow paths at the crossing with the A1, the crossing with the Great North Road and at crossings with watercourses along the Scheme length. The drainage upgrades to the toe drain along the foot of the Scheme embankment would allow these flow paths to continue safely draining without increasing the risk of surface water flooding.

8.3.8 The new FCA at Kelham & Averham crosses an existing predicted area of localised surface water ponding caused by the existing raised A617 (see Figure 8-4). As the FCA would be bunded it would marginally reduce the area of predicted surface water ponding resulting in a negligible increase in peak surface water levels in the existing arable field.

Figure 8-4: Environment Agency RoSWF map for Kelham & Averham



Source: Flood Data © Environment Agency copyright and/or database right 2020. All rights reserved. Service Layer Credits - Contains OS data © Crown Copyright and database right 2022. Contains data from OS Zoomstack, Contains OS data © Crown Copyright and database right 2019.

8.3.9 This predicted surface water flood risk is based on national high-level mapping. To confirm if this surface water risk is likely to occur, enquiries were made with relevant utility companies to check for any existing surface water drainage features present under the A617 at this low point to drain any of the predicted surface water ponding into the River Trent floodplain. The review identified that no local drainage features are present and therefore this is not likely to be a source of flood risk.

8.3.10 With the above considerations, the flood risk from this source is considered to be low.

8.4 Groundwater flood risk

8.4.1 When the Scheme is operational, permanent below-ground infrastructure such as piling and retaining walls have the potential to create a barrier to groundwater flow, locally disrupting the existing groundwater flow regime.

FCAs may intercept groundwater and disrupt the groundwater flow regime.

Concrete bored piling

8.4.2 Concrete bored piling would be located at:

- Windmill Viaduct.
- Nottingham to Lincoln Line Eastern & Western Railway Crossing.
- Cattle Market Junction.
- Nether Lock Viaduct.
- Nether Lock Railways Crossing.
- New A1 Crossing.

8.4.3 The indicative arrangement of concrete bored piles is unlikely to provide a significant barrier to groundwater flow, as groundwater would simply flow around the piles.

Retaining walls

8.4.4 Retaining walls would be located at:

- Farndon.
- Cattle Market Junction.
- Nottingham to Lincoln Line Western Railway Crossing.

8.4.5 The preliminary design indicates that retaining walls are also unlikely to behave as a significant barrier to groundwater flow, due to their alignment sub-parallel to the regional groundwater gradient.

Floodplain compensation areas

8.4.6 FCAs would be located at:

- Farndon East.
- Farndon West.
- Kelham and Averham.

8.4.7 There is potential for groundwater ingress into FCAs, particularly at times of year when groundwater is very close to ground level. Discharge of any minor amounts of intercepted groundwater from the FCAs to adjacent watercourses would in effect reduce the direct groundwater flood risk within the immediate vicinity of the FCAs.

8.4.8 At Kelham and Averham FCA, the very minor amounts of groundwater intercepted by the FCA at times of year when groundwater levels are very high would be negligible in relation to FCA capacity and would therefore not be expected to impact fluvial flood risk.

8.4.9 At Farndon East and West FCA and associated groundwater-fed wetland habitat, there would be connections to the Old Trent Dyke to allow flood water conveyance. At times of year when groundwater levels are high, there is potential that flood water conveyed to Old Trent Dyke could include a groundwater component.

8.4.10 Overall, the groundwater flood risk from the Scheme is considered to be low.

8.5 Sewer flood risk

8.5.1 No sewers are being altered or diverted by the Scheme. There is one location where a major sewer crosses beneath the Scheme, north of Nether Lock viaduct next to a sewage treatment works. However, this sewer is too deep to be impacted by the operation of the Scheme. Therefore, the Scheme is not expected to increase the risk of sewer flooding within the Newark and Sherwood area, resulting in a low risk level. The Applicant will liaise with the asset owner and gain consent to carry out the construction of the Scheme, if required.

8.6 Artificial sources of flood risk

8.6.1 The risk of flooding from the FCAs is not changed by the Scheme as demonstrated by the hydraulic modelling undertaken. The drainage swales and attenuation basins are bunded and therefore result in a risk of artificial flooding. This risk is mitigated, as features are designed to drain towards receptor watercourses immediately adjacent to the designed swales and basins, with adjacent ground topography following these routes to discharge. Therefore, the risk from the Scheme is considered to be low.

8.7 Residual flood risk

8.7.1 It is a requirement of the FRA that any residual risk from the Scheme to third parties can be safely managed at the operation stage of the Scheme.

8.7.2 There is a residual risk of increased flooding due to overgrown vegetation in the existing Kelham Hall Field Ditch between the River Trent and the A617, adjacent to the Kelham Hall boundary wall. Throughout, the ditch channel itself may need to be cleared of vegetation obstructions to improve flow conveyance, where this does not interfere with the boundary wall.

8.7.3 The existing culverts under the A46 are being extended during construction, whilst the existing carriageway is still operational. The existing A46 culverts would also have counterparts below haul roads. The extensions would retain the existing structure dimensions and a blockage assessment would inform any changes that might be required.

This is so that extending the culverts would not negatively impact the conveyance of flood water.

8.7.4 With the mitigation measures outline above, the residual flood risk from the Scheme is considered to be low.

9 Flood risk from and to the Scheme – construction stage

9.1 Flood risk from the Scheme

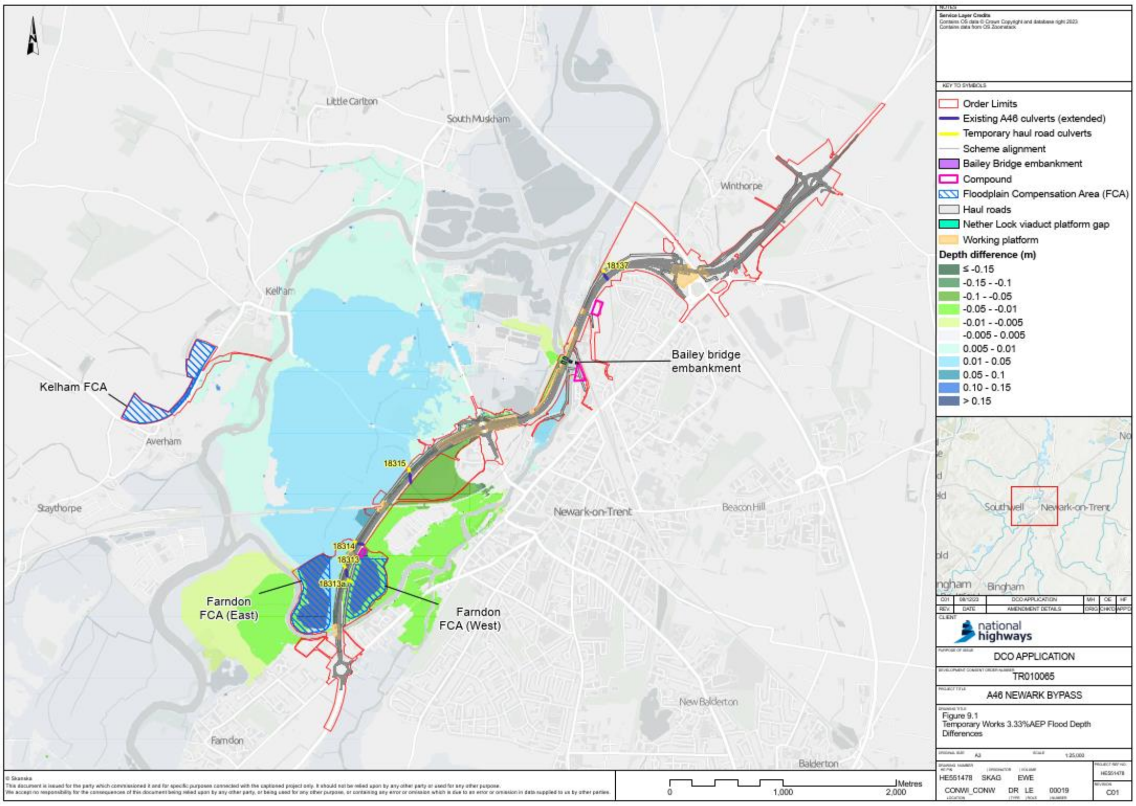
9.1.1 Flood risk from the Scheme during the construction phase is from the same sources as would be present in the later operational phase, however the level of impact would be different.

9.1.2 To determine the potential change in flood risk from the scheme and temporary works, detailed 1D-2D hydraulic modelling has been undertaken for the River Trent. Details of the representation of elements of the Scheme plus temporary works, within the National Highways A46 Newark Trent 2023 Temporary Works Fluvial Hydraulic Modelling Technical Report (Appendix F of this FRA).

9.1.3 Temporary works considered in the model include haul roads and haul road culverts, working platforms, compounds, and temporary bridges. Conservatively, modelling has been undertaken of the Scheme plus temporary works, as both temporary and permanent works may be in place simultaneously towards the end of the construction period.

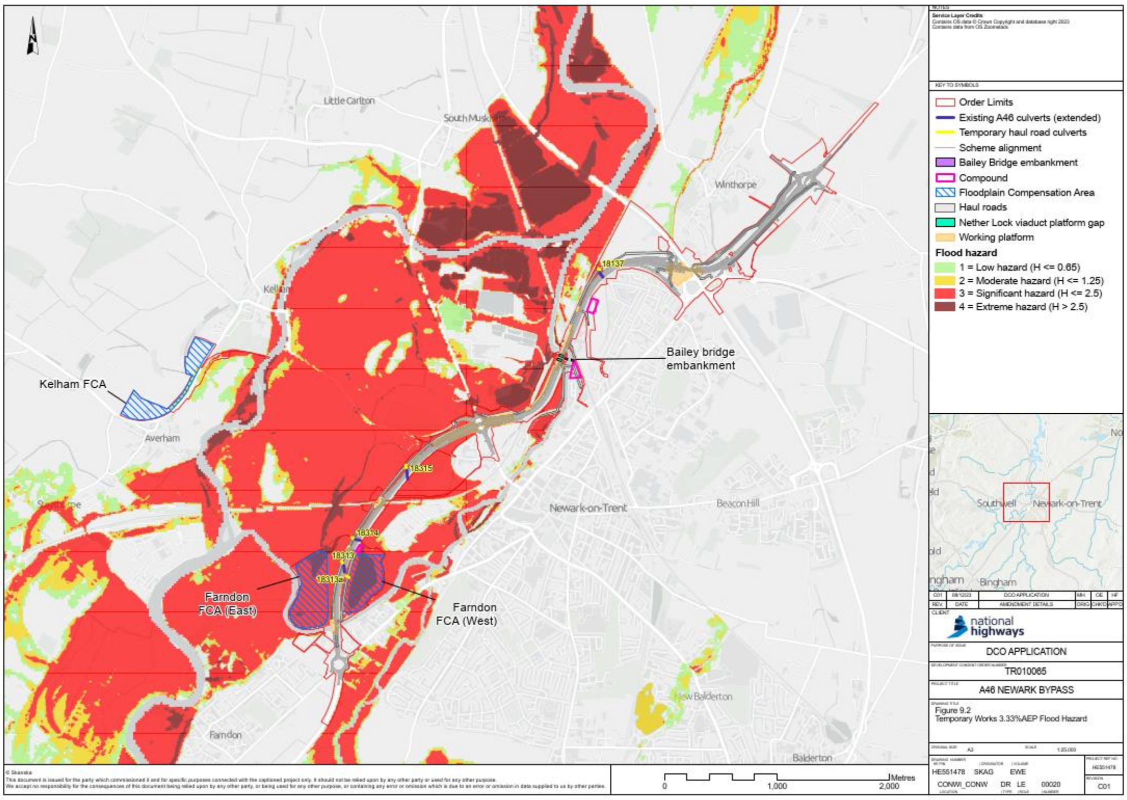
9.1.4 The design event for the Scheme plus temporary works is the 3.33% AEP event. Flood depths from the 3.33% AEP event were compared with the baseline scenario (Figure 9-1). Flood hazard classifications for the Scheme plus temporary works in the 3.33% AEP event is shown in Figure 9-2 .

Figure 9-1: Flood depth difference with addition of the Scheme and temporary works structures to baseline conditions - 3.33% AEP event



Source: Flood Data modelled by Mott MacDonald, 2023. Service Layer Credits - Contains OS data © Crown Copyright and database right 2022. © OpenStreetMap contributors

Figure 9-2: Flood hazard with addition of the Scheme and temporary works - 3.33% AEP event



Source: Flood Data modelled by Mott MacDonald, 2023. Service Layer Credits - Contains OS data © Crown Copyright and database right 2022. © OpenStreetMap contributors

Receptor sensitivity

9.1.5 As discussed in Section 4.6 of this FRA, significance of effect is defined in accordance with the Significance Matrix in Table 3.8.1[8] of DMRB LA104 (see Figure 4-1 in this FRA).

9.1.6 For this assessment, receptors were identified using the Environment Agency National Receptor Database (NRD) which classifies receptors according to the NPPF Annex 3: Flood risk vulnerability classification.[16] The dataset classifies a range of receptors, including care and nursing homes, commercial properties, residential properties, factories, and industrial sites and workshops.

9.1.7 Inspection of the Environment Agency NRD[17] indicates that the area over which flood depths would be increased by the permanent and temporary works is mostly farmland, which the NPPF classifies as "less vulnerable". There is also a mixture of "water-compatible" and other "less vulnerable"

[16] DLUHC. (2012) https://www.gov.uk/guidance/national-planning-policy-framework/annex-3-flood-risk-vulnerability-classification

[17] Environment Agency (2014) NRD2014 Guidance Version 1 September 2015.

receptors such as commercial properties, marinas, and amenity open spaces which would be affected.

9.1.8 There are no “highly vulnerable” receptors in any areas over which flood depths would be increased by the permanent and temporary works.

9.1.9 Table 3.70 in DMRB LA113 indicates that residential receptors should be classified as being of “high importance” due to their “more vulnerable” NPPF classification. Furthermore, the DMRB LA104 Environmental assessment and monitoring[8] guidance designates receptors of “high importance” as having “high sensitivity”.

9.1.10 According to Table 3.71 in the DMRB LA113 Road drainage and the water environment[18] guidance, the magnitude of flood risk impact for an increase in peak flood level of less than 0.01m is described as ‘negligible’ and is therefore not further considered in this report. The magnitude of flood risk impact for an increase in peak flood level of between 0.01m and 0.05m is defined as “minor adverse”.

Flood risk to receptors

9.1.11 In a 3.33% AEP flood event, the Scheme with the addition of temporary works structures would increase flood depths to the west of the Scheme and decrease them in the east. Flood depth differences compared to the baseline are typically less than 0.05m as shown in Figure 9-1. South-west of the Nottingham to Lincoln West Railway line, flood depth differences are between 0.05m and 0.06m as shown in Figure 9-1.

9.1.12 The increase in depths to the west of the Scheme arises from the displacement of flood waters by the Scheme and temporary haul roads. This is further affected by the working platforms at the Nottingham to Lincoln Line Western Railway crossing and the crossing of the River Trent by working platforms. The working platforms obstruct flow pathways that are observed during baseline conditions. Flow can only be conveyed eastwards via the existing and temporary culverts, and therefore more flow moves northwards through the floodplain and over the Nottingham to Lincoln Line Western Railway line. West of the Scheme, at Kelham Lane, this may potentially impact three “More Vulnerable” residential receptors to a maximum increase in peak flood levels of 0.02m, compared to the baseline. The flood hazard classification would not change at any of these three receptors when compared to baseline conditions. Two “More Vulnerable” receptors at Newark Rugby Club might be impacted by a maximum increase in peak flood level of 0.01m compared to the baseline. However, the NRD indicates that there is “Low Confidence” in the vulnerability rating at the

[18] Design Manual for Roads and Bridges, LA 113 Road drainage and the water environment, Revision 1, Highways England, March 2020: https://www.standardsforhighways.co.uk/search/d6388f5f-2694-4986-ac46-b17b62c21727.

Rugby Club, and it is unlikely that these receptors are residential dwellings.

9.1.13 The obstruction from working platforms results in a decrease in flood depths to the east of the Scheme. At the eastern end of Tolney Lane caravan park, in a 3.33% AEP flood event, flood depths would decrease by up to 0.02m, when compared to the baseline. Flood depths in the western area of Tolney Lane caravan site would however be unchanged compared to the baseline. The flood hazard classification at Tolney Lane caravan park would not change compared to the 3.33% AEP baseline.

9.1.14 Near Nether Lock, the Bailey Bridge embankments, a working platform, and haul roads slightly obstruct River Trent flow. This results in an upstream maximum increase in peak flood levels of 0.02m, potentially impacting four “More Vulnerable” receptors, which are houseboats, at King’s Marina. The flood hazard classification at Kings Marina would not change compared to the 3.33% AEP baseline.

9.1.15 According to Table 3.71 in the DMRB LA113 Road drainage and the water environment[19] guidance, the magnitude of flood risk impact for an increase in peak flood level of between 0.01m and 0.05m is defined as “minor adverse”.

9.1.16 In a 3.33% AEP flood event therefore, the Scheme plus temporary works may increase flood depths by up to 0.02m, which would have a “minor adverse impact” on three “More Vulnerable” residential receptors at Kelham Lane, two “More Vulnerable” receptors at the Rugby Club, which are unlikely to be residential, and four “More Vulnerable” houseboats at Kings Marina, which would be resilient to minor changes in water level.

9.1.17 A minor adverse flood risk impact to high sensitivity “More Vulnerable” residential receptors at Kelham Lane, potentially leads to either a “slight or moderate” effect, according to Table 3.8.1 in DMRB LA104[8] (see Figure 4-1 in this report).

9.1.18 A high degree of conservatism has been applied in modelling temporary works elements. In addition, there is likely to be a very limited timeframe in which both temporary and permanent works would simultaneously be in place, which is likely to occur only towards the end of the construction period. At the potentially impacted highly sensitive “More Vulnerable” residential receptors, the flood hazard classification would be unaffected by the Scheme plus temporary works in the 3.33% AEP flood event.

9.1.19 Based on the above assumptions, the significance of effect of the Scheme plus temporary works in the 3.33% AEP flood event, upon the majority of high sensitivity “More Vulnerable” receptors, is considered

[19] Design Manual for Roads and Bridges, LA 113 Road drainage and the water environment, Revision 1, Highways England, March 2020: https://www.standardsforhighways.co.uk/search/d6388f5f-2694-4986-ac46-b17b62c21727.

"slight". Therefore, overall the flood risk from the Scheme plus temporary works during construction is considered low.

9.2 Flood risk to the Scheme during construction

9.2.1 There is the potential for the construction stage of the Scheme to be affected by flood risk. These risks are set out below:

- Risk to the existing asset during construction. The Scheme seeks to improve upon the existing condition of the A46 and the construction is sequenced to mitigate this risk.
- Risk to the asset being constructed. Flood risk mitigation forms part of the pre-commencement works, mitigating this risk.
- Risk to construction equipment and facilities used to carry out the construction. This forms part of the risk to the construction works themselves, discussed in paragraph 9.2.2 below.
- Risk to personnel on site. This forms part of the risk to the construction works themselves, discussed in paragraph 9.2.2 below.

9.2.2 Any risk to the construction works is to be mitigated by the Principal Contractor, to ensure no significant risk to the Scheme. The First Iteration Environmental Management Plan (EMP) [REP6-012] includes mitigation measures related to flood risk, the references of which are included below.

- ES – CH13 RDWE 1,2,4,5,6,7,13,15 *To mitigate potential adverse effects upon surface waters and groundwater during the construction phase.*
- ES – CH13 RDWE3 *To mitigate potential adverse effects upon surface waters during the construction phase.*
- ES – CH13 RDWE8 *To prevent spread of INNS and contamination of surface waters during construction.*
- ES – CH13 RDWE12 *To mitigate potential adverse effects upon groundwater during the construction phase.*
- ES – CH13 RDWE14 *To mitigate potential adverse effects upon fluvial flooding during the construction phase.*
- ES – CH14 C5 *Construction to be resilient to weather.*

9.2.3 Mitigation measures with regards to flood response will be set out in the "Emergency Response Plan for Flood Events" referred to in the First Iteration EMP [REP6-012] and secured through the draft DCO [REP6-004]. This document will be produced to accompany the Second Iteration EMP for implementation during construction of the Scheme in accordance with Requirement 3 of the draft DCO [REP6-004].

9.2.4 Following application of these mitigations, the flood risk to the Scheme during construction is considered to be low.

10 Application of the Sequential and Exceptions Tests

10.1 Overview

10.1.1 This section applies the Sequential and Exception tests that are introduced in Section 4.3 of this document.

10.2 Sequential Test

10.2.1 The Scheme seeks to improve an existing highway route that passes through Flood Zone 3. Owing to the existing route of the A46, there is no alternative to the location of parts of the Scheme within Flood Zone 3.

10.2.2 The Scheme alignment was developed following a comprehensive assessment of different alignment options, which considered all environmental impacts (inclusive of flood risk) during the options selection stage of the Scheme. This process is discussed in detail in Chapter 3 (Assessment of Alternatives) of the Environmental Statement [APP-043].

10.2.3 The Scheme option selected in Chapter 3 (Table 3-7) is Option C, which did not score as well as other options with regards to flood risk. However, Option C was selected due to good performance with regards to other performance characteristics.

10.2.4 Following selection of Option C, the alignment was then narrowed down to two Options, of which a modified version of Option 2 was selected. Table 3-9 of Chapter 3 (Assessment of Alternatives) of the Environmental Statement [APP-043] identifies no substantial difference between these two options with regards to flood risk.

10.2.5 As discussed, taking into account wider functionality, economic and sustainability objectives (as described in the Case for the Scheme [REP5-030]), there are no reasonably available alternatives to locate the Scheme in areas of lower flood risk.

10.3 Exception Test

10.3.1 To inform the application of the Exception Test, hydraulic modelling has been developed to assess the flood risk to and from the Scheme. This modelling is discussed in Sections 5 to 9 of this FRA. Overall, the modelling results demonstrate that there is a negligible impact on flood risk once the Scheme is operational and during the construction stage. Instances where there are increases in maximum flood depths and levels associated with the Scheme are clearly detailed within this FRA and in Appendices A, B, C and H of this report. Decreases in flood risk are observed in some areas due to the flood risk mitigation provided by the Scheme. Sensitivity tests provided in Appendices H and I demonstrate that localised increases in maximum flood depths and levels of greater than 0.01m are due to modelling precision and model boundary effects.

10.3.2 There will be a negligible impact to fluvial flood risk to the neighboring land uses. No increase in surface water runoff is predicted as a result of the Scheme with the application of identified mitigation measures. The approach to be taken by the Secretary of State in assessing flood risk is set out in Sections 4 and 5 of the NPSNN, which guides how DCO applications will be decided and how impacts of national networks infrastructure should be considered (Section 4.2). Further details of the Scheme compliance with the 2015 NPSNN can be found in the NPSNN Accordance Tables [REP6-016]. Details of the Scheme compliance with the 2024 NPSNN can be found in the National Policy Statement for National Networks (2024) Accordance Tables produced during the DCO Examination [REP5-032].

10.3.3 Following completion of the Hydraulic Modelling Technical Note (Appendix H) by the Applicant, the Environment Agency confirmed that the Scheme satisfies the requirements of Part 2 of the Exception Test. This is recorded in the Statement of Common Ground with the Environment Agency submitted at Deadline 6 of the Examination [Rev 3].

10.3.4 Since the Scheme is also defined as a Nationally Significant Infrastructure Project (NSIP), the Exception Test is satisfied in terms of the benefits to the community and safety. The information presented within this FRA demonstrates that mitigation measures have been incorporated into the design. This would result in a new road that is at a low risk of flooding and would be safe for the lifetime of the development without increasing flood risk to receptors elsewhere.

11 Summary and conclusions

11.1 Key flood risk sources assessed

11.1.1 The main flood risk sources to the construction and operation of the Scheme are fluvial, surface water and groundwater. As demonstrated in Section 10 of this FRA the Sequential Test requirements are considered to have been met, and the Exception Test is considered to have been passed.

11.1.2 The risk from sewer flooding is minimal given the Scheme would not interact with sewer networks, and a lack of historical sewer flooding has been recorded in the vicinity of the Scheme (Section 7.5). The risk of artificial flooding is similarly Low, as the reservoirs in the area are regularly inspected. Additionally, the FCAs are free draining so do not increase the risk of artificial flooding due to a burst. Mitigations provided in the First Iteration EMP [REP6-012] address flood risk both to and from the Scheme during construction.

11.1.3 A summary of flood risk is outlined below (Table 11.1).

Fluvial – risk to the Scheme

11.1.4 Most of the Scheme will be situated in Flood Zone 2 and 3, with only the north-eastern extent located in Flood Zone 1. Detailed hydraulic modelling has defined the impact the Scheme has on fluvial flooding within the area.

11.1.5 The fluvial flood risk to the A46 itself would be minimal during operation, but there are some access roads that would be flooded during the 1% AEP plus climate change event:

- Brownhills Roundabout.
- Cattle Market Junction.

Fluvial – risk from the Scheme

11.1.6 The Scheme has been shown not to change overall flood risk, despite increasing flood water levels in some areas. The flood hazard map output shows that the only area that shows detriment is within the new FCAs, which is to be expected. Appendices H and I provide further justification to demonstrate that the Scheme presents no increase in fluvial flood risk.

11.1.7 This FRA has shown that the Scheme presents no increase in fluvial flood risk.

Surface water – risk to and from the Scheme

Overland (pluvial)

11.1.8 Most of the surface water flood risk in the study area is categorised as ‘Very Low’; with some localised areas categorised as ‘Low’, ‘Medium’ and 'High', representing surface water flow paths. Where the Scheme disrupts these flow paths, mitigation in the form of pipelines and culverts has been provided, to maintain sufficient surface water drainage.

Highway drainage

11.1.9 Appendix 13.4 (Drainage Strategy Report) of the ES Appendices [APP-179] has been provided, in which the drainage design for the Scheme is discussed, with the existing drainage regime is maintained and upgraded where relevant. This is in order that surface water can freely drain from the widened A46 embankment during storm events.

11.1.10 These mitigations are sufficient in ensuring the surface water drainage regime is maintained. This FRA has shown that the Scheme presents no increase in surface water flood risk.

Groundwater – risk to the Scheme

11.1.11 While the groundwater in the area is high, the main A46 structure would be elevated from the River Trent floodplain and would not be impacted by any groundwater flooding. Subsurface structures such as piling and retaining walls have been designed to be groundwater resilient and would also not be impacted. The design philosophy of the wetland habitat at Farndon East and West FCAs incorporates groundwater baseflow. Groundwater seepage into Kelham and Averham FCA would be continually discharged under gravity to the River Trent. Groundwater ingress is therefore not expected to significantly affect FCA function.

Groundwater – risk from the Scheme

11.1.12 New features of the Scheme such as concrete piling and retaining walls are not expected to increase groundwater flood risk. The piles have been designed so that groundwater can flow round them, whilst the walls are aligned sub parallel to the regional groundwater gradient.

11.1.13 At Kelham and Averham FCA, the minor quantity of groundwater intercepted by the FCA at times of year when groundwater levels are very high; would be negligible in relation to FCA capacity and would therefore not be expected to impact fluvial flood risk. At Farndon East and West FCA, flood water discharged to Old Trent Dyke may include a groundwater component at times of year when groundwater levels are high.

11.1.14 With these mitigations, this FRA has shown that the Scheme presents no increase in groundwater flood risk.

Residual risk – risk to the Scheme

11.1.15 Residual risk to the Scheme from flood defences failure are expected to be negligible, due to the maintenance regime in place on these assets.

Residual risk – risk from the Scheme

11.1.16 There is a small residual risk from the Scheme to third parties at construction stage. If this risk increases, sensitivity testing would be undertaken to evaluate the risk to third parties and to manage these risks during construction. At operational stage, maintenance of structures and watercourses and sensitivity testing of structures would be considered to minimise these risks.

11.2 Summary of flood risks to and from the Scheme

Table 11.1: Summary of flood risks to and from the Scheme

Source of flooding	Baseline flood risk	Operational Stage		Construction Stage	
		To the Scheme	From the Scheme	From the Scheme	To the Scheme
Fluvial	**High**	**Low** – A46 route raised above flood level, local access roads and junctions connecting into the A46 route are inundated in 1% AEP plus climate change event.	**Low** – Scheme has negligible impact to displacement of flood water and no impact to conveyance of flooding. FCAs included to accommodate lost floodplain volume.	**Low** – temporary works structures would increase flood depths by up to 0.05m in a 3.33% AEP flood event due to displacement of flood waters. This would have a "minor adverse" impact on three residential receptors, leading to a "slight or moderate" effect, according to Table 3.8.1 in DMRB LA104[8].	**Low** –mitigation measures outlined in the First Iteration EMP [REP6-012].
Surface water (highway run-off)	**Low**	**Low** – A46 highway is at low risk from surface water flooding as the embankment allows water to drain during storm events.	**Low** – The existing highway drainage regime will be maintained and improved, ensuring no increase in surface water flooding elsewhere.	N/A	**Low** –mitigation measures outlined in the First Iteration EMP [REP6-012]
Surface water (surface water flow paths and ponding)	**Low**	**Low**	**Low** – Relevant drainage updates so that the Scheme does not increase the flood risk to other receptors.	N/A	**Low** –mitigation measures outlined in the First Iteration EMP [REP6-012]
Groundwater	**Medium to High**	**Low** – A46 route raised above River Trent floodplain, so unaffected by groundwater flooding	**Low** – A46 permanent features designed as to not exacerbate groundwater flood risk.	N/A	**Low** –mitigation measures outlined in the First Iteration EMP [REP6-012]
Sewers	**Low**	**Low** – Sewers crossing the Scheme are too deep to be affected by the Scheme, so will have no impact on the Scheme.	**Low** – Scheme does not directly interact with or alter any sewer networks, so will not increase sewer flooding elsewhere.	**Low** - Sewers within the Scheme area are deep, however any protection measures required to protect sewers during construction of the Scheme will be implemented by the Principal Contractor	N/A
Artificial sources	**Low**	**Low** – UK reservoirs are regularly inspected and are highly unlikely to burst.	**Low** – scheme design mitigates for risk of flooding from bunded features.	N/A	N/A
Residual risk	**N/A**	**Low** – Residual risk will be managed.	**Low** – Residual risk will be managed, and may be reduced to negligible during construction through sensitivity tests.	N/A	N/A

.

12 Appendices

A.National Highways A46 Newark Trent 2023 Fluvial Hydraulic Modelling Technical Report: HE551478-SKAG-HDG-CONWI_CONW-RP-CD-00021

Contents

[redacted]

Executive Summary

- The Delivery Integrated Partnership (DIP) consisting of Skanska and Mott MacDonald are currently in the Stage 3 design phase for the A46 Newark Bypass scheme. Mott MacDonald has been commissioned by National Highways to undertake the Flood Risk Assessment (FRA) in support of the PCF Stage 3 and Stage 5 design phases of the Scheme.
- The DIP A46 Newark Bypass scheme entails the development of Section 7 of the A46 that spans between Farndon Junction and Winthorpe Junction. The scheme aims to upgrade an existing single carriageway road in Newark-on-Trent to a dual carriageway.
- As a part of this early stage of the works, Mott MacDonald is undertaking a hydraulic modelling study of the River Trent and its major sub-catchments. This study will assess the flood risk that will result due to construction of the scheme, to enable mitigatory assessment which complies with National Planning Policy Framework (NPPF) requirements.
- The hydraulic modelling approach used for this scheme employed 1D-2D FMP-TUFLOW modelling to assess the River Trent and its tributaries throughout the area, supported by consultation with the Environment Agency.
- The National Highways A46 Newark Trent 2023 Fluvial Hydraulic model consists of a linked 1D-2D FMP-TUFLOW hydraulic model allowing for a detailed assessment of the interaction of the channel (1D) and inundation on the floodplain (2D). When the capacity of the 1D channel is exceeded, water spills into the 2D model. The grid based 2D model allows water to propagate across the floodplain according to complex topography and other factors such as surface roughness. This facilitates an accurate calculation of flood depths, velocities and extents that are used to generate map outputs.
- The peak river flow climate change allowances adopted to consider the impacts on future fluvial flood risk were agreed with the Environment Agency at the outset of the project. For the River Trent the 1% AEP design event including an allowance for climate change (1% AEP +39% increase in peak flows) has been simulated for the baseline and proposed operational stage scenarios. The climate change peak flow increase used is the Lower Trent and Erewash Management Catchment Higher estimate for the 2080s.
- Due to the level of assessment of climate change which informed the scheme design, the hydraulic modelling approach for the River Trent should therefore be considered as robust and conservative. This should be considered whilst viewing the hydraulic modelling results contained within this report and the associated provision of mitigation and scheme assessment.
- Results from model calibration and verification against four historical events suggest a good match between observed and simulated peak water levels. Instabilities have been observed in locations away from

the area of interest. These are deemed not to significantly impact the peak water level in the vicinity of the proposed scheme.

- Comparison between the baseline and scheme with mitigation model, has indicated increase of less than 10mm in the 1% AEP plus 39% climate change event in the residential area west of Windmill Viaduct, caused by the encroachment of a proposed viaduct abutment into the floodplain. Although the analysis indicates an increase in this area, this is on top of a peak flood depth of 1.7m in the baseline design event and therefore the change is deemed insignificant.
- It is noted that Farndon West Flood Compensation Area (FCA), encourages an early onset of flooding which increases the flood depth behind the proposed scheme by up to 50mm. The increase is limited to agricultural land use in an area of low vulnerability.

Abbreviations and acronyms

AEP	Annual Exceedance Probability
AMAX	Annual Maximum
AOD	Above Ordnance Datum
CC	Climate Change (allowance for future effects of)
DIP	Delivery Integrated Partnership
DTM	Digital Terrain Model
EA	Environment Agency
FCA	Floodplain Compensation Area
FEH	Flood Estimation Handbook
FMP	Flood Modeller Pro
FRA	Flood Risk Assessment
IDB	Internal Drainage Board
NPPF	National Planning Policy Framework
RDP	Regional Development Partnership
ReFH	Revitalised Flood Hydrograph
SLR	Southern Link Road

1 Introduction

Background

1.1.1 The Delivery Integrated Partnership (DIP) consisting of Skanska and Mott MacDonald are currently in the Stage 3 design phase for the A46 Newark Bypass scheme. Mott MacDonald has been commissioned by National Highways to undertake the Flood Risk Assessment (FRA) in support of the Project Control Framework (PCF) Stage 3 and Stage 5 design phases of the Scheme.

1.1.2 The DIP A46 Newark Bypass scheme entails the development of Section 7 of the A46 that spans between Farndon Junction and Winthorpe Junction. The scheme aims to upgrade an existing single carriageway road in Newark-on-Trent to a dual carriageway.

1.1.3 As a part of this early stage of the works, Mott MacDonald is undertaking a hydraulic modelling study of the River Trent and its major sub-catchments. This study will assess the flood risk that will result due to construction of the scheme, to enable mitigatory assessment that comply with National Planning Policy Framework (NPPF) requirements.

Model objectives

1.1.4 The objectives of the proposed flood modelling are to:

1.1.5 Produce an FRA for the National Highways A46 Newark Bypass - Regional Development Project (RDP) to satisfy the requirements of the NPPF. This will provide evidence to demonstrate that flood risk can be managed.

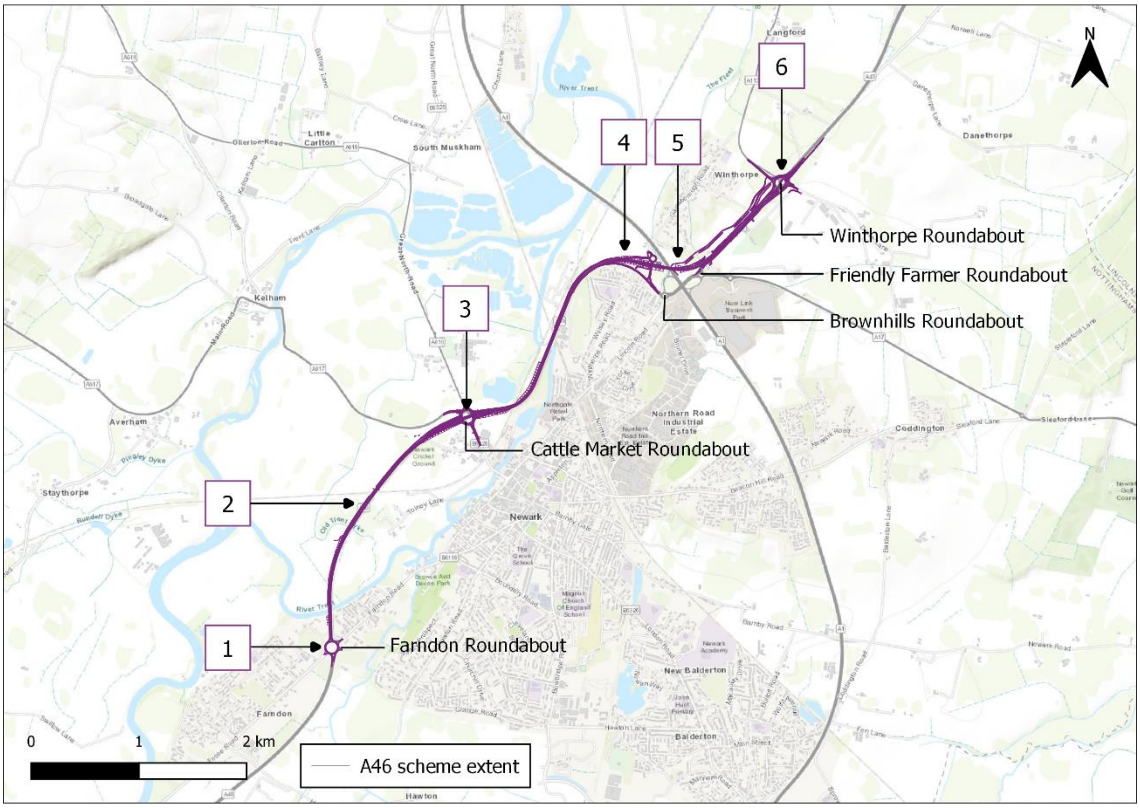
- Identify and develop flood mitigation measures including (not limited to) the design of the floodplain compensation to manage the impact of the scheme’s encroachment into the floodplain. This will be achieved through using the peak water level hydraulic modelling outputs from 1% Annual Exceedance Probabilities (AEP) plus 39% climate change flood event (see Section 10) to assess the volumetric flood water displacement at 200mm increments for all elevations the scheme has an increased encroachment into the floodplain.

1.1.6 Provide technical details of flows, velocities, water levels and flood propagation for 50%, 20%, 5%, 3.33%, 2%, 1%, 0.1% AEP present day and the 1% AEP+39% climate change scenarios to other design disciplines (including earthworks, drainage, structures, geomorphology and scour design disciplines) to support the Stage 3 design development.

Scheme details

1.1.7 Figure 1-1 shows an overview of the scheme area and the main operational features. Table **1-1** summarises the principal scheme elements.

Figure 1-1: Scheme overview



Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

Table 1-1 Summary of scheme principal elements

Location reference	Scheme element description
1	Partial signalisation of Farndon Roundabout at the southern extents of the scheme.
2	Widening of the existing A46 to a dual carriageway for 6.5 kilometers (approximately 4 miles) to provide two traffic lanes in both directions.
3	A new grade separated junction at Cattle Market junction with the A46 elevated to pass over the roundabout. Larger roundabout beneath the A46 to provide increased capacity.
4	New grade separated roundabout junction (Brownhills junction) providing local access with a two-way link road on the southern arm to connect with the existing Brownhills Roundabout. Proposed off-line section approximately between Brownhills Roundabout and Friendly Farmer Roundabout.
5	A new bridge structure across the existing A1, located to the north of the existing bridge.

Location reference	Scheme element description
6	An upgraded roundabout with possible signal controls at Winthorpe junction.

1.1.8 At its south-western limits, the scheme ties in with the northern arm of the existing Farndon Roundabout which already has two lanes on the entry and exit. Travelling north-eastwards, the route follows the alignment of the existing A46 for 2.5km and crosses over the River Trent and the Nottingham to Lincoln Railway Line.

1.1.9 As the route approaches Cattle Market Roundabout, it begins to elevate and passes over the top of the southern half of the existing roundabout. The route then remains elevated and continues to follow the alignment of the A46 whilst it passes over the Nottingham to Lincoln Railway Line for a second time, the River Trent for a second time, and the East Coast Mainline. Throughout this stretch, between Farndon and just beyond the East Coast Mainline, the route is being widened to the north away from Newark-on-Trent.

1.1.10 Following this, the existing A46 bends eastward whilst the route of the scheme diverts to the north where it crosses at a skew over the A1. The route then ties back into the existing A46 dual-carriageway and follows this alignment before it ties into Winthorpe Roundabout at the north-eastern extent of the scheme.

1.1.11 Other additional features include the following:

- New drainage
- Improvements to existing infrastructure
- Landscape planting
- Environmental mitigation
- Lighting
- Traffic signage
- Utility diversions
- Improvements to non-motorised user facilities for walkers, cyclists and horse riders.

1.1.12 Floodplain compensation will be provided to account for loss of floodplain due to the scheme footprint.

2 Data review

History of modelling in the catchment

2.1.1 The following hydraulic models have been provided by the Environment Agency:

- EA River Trent&Tribs 2011 model
- River Trent&Tribs 2020 (PCF Stage 2 model, based on EA River Trent&Tribs 2011 model)
- Slough Dyke 2020
- River Devon 2021

2.1.2 As well as these models, the 2017 modelling report for the Southern Link Road scheme has been provided by the Environment Agency.

2.1.3 There is no hydraulic modelling data available for the Internal Drainage Board (IDB) watercourses. These watercourses have instead mostly been represented within the 2D domain using a 1m DTM.

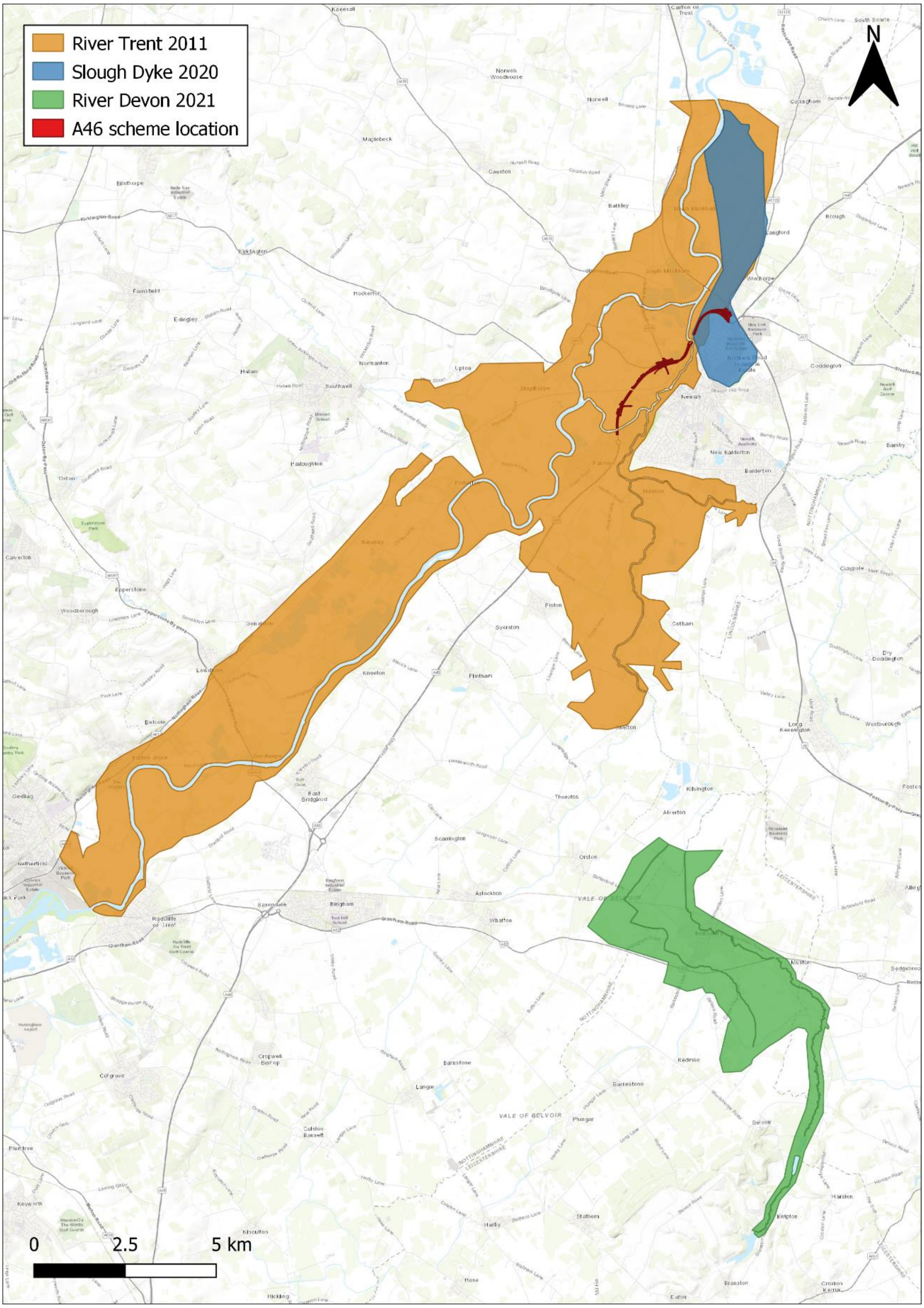
2.1.4 A diagram of the existing model domains is shown in Figure 1-2. Table 1-2 presents the model extents. Key findings of each model review are outlined in the following sub-sections.

Table 1-2: Existing models

EA models	Data available	Review summary
EA River Trent&Tribs model 2011 (Product_7 ISIS-TUFLOW model)	Report, flood model and channel survey information.	Key findings: The model is multi domain, which requires a multi domain license to run the model A few additional catchments, previously not in the model but subject to more recent modelling or needed for floodplain compensation assessment, need to be included. Grid size and time step not deemed adequate and needs to be updated. Large model extent could be reduced to decrease model run time. Further review of the downstream boundary is needed, due to glass walling. Further review of 1D/2D boundary is needed. 1D and 2D topographic data to be updated with latest survey and Light Detection and Ranging (LiDAR) data, where required Roughness and OS MasterMap need to be updated. Climate Change Allowance needs to be updated. TUFLOW control file and FMP run parameters need to be reviewed and updated to standard approach. Hydrology and calibration need to be updated with more recent data and approach.
River Trent&Tribs 2020 (PCF Stage 2 model, based on EA River Trent&Tribs 2011 model)	Report and flood model.	The change in the model undertaken by the PCF Stage 2 designer included: Update of the LiDAR Updated inflows for the climate change scenario. Added Scheme element
Slough Dyke model 2020	No reports available to review. Therefore, a review has been undertaken based on the model files and channel survey information.	The key findings of the review are: The model is FMP-TUFLOW Built on 4m grid. Upstream of the Sough Dyke is urban and close to the proposed A46 scheme. Therefore, 4 m grid size seems suitable. However, downstream reach is rural, which could be modeled in a coarse (20m) grid to reduce simulation time. The downstream boundary used in the model is not sensible considering the River Trent levels. The downstream boundary needs to be reviewed and updated in the A46 Newark Bypass model.
Southern Link Road (SLR) modelling Study June 2017	Report, flood model and survey.	The report suggests that the modelled area is located at a distance from the scheme, and therefore it is considered not useful in the current study. As the site is out of the scope, no further review is suggested.
Newark Southern Link Road (SLR) Hydraulic Model June 2017		The Newark Southern Link Road (SLR) scheme hydraulic model (2017) model was used to inform the Newark SLR scheme. As documented in HE551478-SKAG-HDG-CONWI_CONW-TN-CD-00002[1] and as agreed in consultation with the Environment Agency, implementing the SLR scheme is unlikely to have any significant impact upon existing overall flood risk. Therefore, the SLR scheme will not be included in the A46 Bypass model.
The River Devon (2021)		The River Devon (2021) model is an FMP-TUFLOW model. The model covers a catchment that is a considerable distance (approximately 12.5km) from the southern end of the scheme, therefore is not considered relevant for the current study and has not been included.

[1] HE551478-SKAG-HDG-CONWI_CONW-TN-CD-00002, Revision P01, "Assessment of Cumulative Flood Risk Impacts from the Southern Link Road Scheme".

Figure 1-2: Existing model domains



Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

River Trent&Tribs 2011 and 2020

2.1.5 The River Trent&Tribs 2011 model is the Environment Agency approved model. The PCF Stage 2 designer updated the model in 2020 with the latest topography (LiDAR) data and updated hydrology for the climate change allowance. In this report, the EA River Trent&Tribs 2011 model will be referred to as the basis of the update for the A46 Newark Bypass hydraulic model.

2.1.6 The EA River Trent&Tribs 2011 model is a multi-domain Flood Modeller Pro (FMP)-TUFLOW model with most of the model within the Trent domain (20m grid) and small areas at Rolleston/Southwell and within Newark-on-Trent using 10m grids.

2.1.7 The 1D FMP model includes:

- 36km reach of the River Trent (plus 6km bifurcation reach to the north of Newark-on-Trent)
- 9.6km reach of the River Devon
- 3.9km reach of Middle Beck
- 2.2km reach of Sodbridge Brook

2.1.8 The model starts approximately 2km downstream of Nottingham city centre at Colwick, where the railway line intersects the floodplain. This is around 20km upstream of the proposed A46 scheme.

2.1.9 The downstream boundary of the 2D model is at Cromwell Weir which is approximately 0.75km downstream of North Muskham gauge.

2.1.10 According to the hydraulic modelling, Cromwell Weir is predicted to be drowned out during high-stage flood events combined with high tide. However, under these conditions, the tidal influence is negligible upstream of North Muskham gauge.

2.1.11 Single Manning’s n values are currently applied to each watercourse in this model which will be reviewed and updated in the A46 Newark Bypass Model. Manning’s n values are applied to the 2D area using OS MasterMap data which is over 12 years old and should be updated in the A46 Newark Bypass model.

2.1.12 For the 2D topography, the EA River Trent&Tribs 2011 model uses a combination of LiDAR and IfSAR due to incomplete LiDAR coverage. The PCF Stage 2 designer updated the model with the latest LiDAR data available in 2019. The latest LiDAR available on the DEFRA website is from 2020 and covers the whole model domain. The model will be updated accordingly.

Slough Dyke (2020)

2.1.13 No modelling and hydrology reports were available to review. Therefore, a review has been undertaken based on the model files. No model results were provided; therefore, a test run was undertaken to understand the simulation time, model health, and flood extents.

2.1.14 Slough Dyke is a single domain FMP-TUFLOW Model. The 2D domain covers the entire reach of the 1D model. The modelled Slough Dyke reach is around 8.5km long, and the 2D grid size is 4m.

2.1.15 The 2D topography used in the model is based on the latest LiDAR data available in 2019.

2.1.16 The upstream reach of the Slough Dyke model is urban and close to the proposed A46 scheme. Therefore, a 4m grid size was likely suitable for this model. However, the downstream reach is rural, which could be updated in the A46 Newark Bypass Model to a coarser (20m) grid to reduce simulation time.

2.1.17 The upstream boundary is around 2km south of the A46 scheme at Brownhills Roundabout. The downstream limit is at its confluence with the River Trent. A fixed level of 6.3m AOD was chosen for the downstream boundary. The water level used as the downstream boundary appears too low considering the extreme water level at the River Trent in this area, which is greater than 9mAOD in a 1% AEP plus climate change scenario as per the existing River Trent&Tribs model 2020. Considering the River Trent water level, the downstream boundary should be reviewed and updated in the A46 Newark Bypass model.

2.1.18 Manning’s n values are applied to the 2D domain using OS MasterMap data. It was not known when the OS MasterMap data was produced; therefore, it should be reviewed and updated in the A46 Bypass model. Manning’s n values assigned for various features must also be checked and updated.

River Devon (2021)

2.1.19 The River Devon (2021) model is an FMP-TUFLOW model. The model covers a catchment that is a considerable distance (approximately 12.5km) from the southern end of the scheme, therefore is not considered relevant for the current study and has not been included.

Newark Southern Link Road scheme hydraulic model (2017)

2.1.20 The Newark Southern Link Road (SLR) scheme hydraulic model (2017) model was used to inform the Newark SLR scheme. As documented in HE551478-SKAG-HDG-CONWI_CONW-TN-CD-00002[2] and as agreed in consultation with the Environment Agency, implementing the SLR scheme is unlikely to have any significant impact upon existing overall flood risk. Therefore, the SLR scheme will not be included in the A46 Bypass model.

Historic Topographic survey

2.1.21 Data has been collected from the EA and Skanska to inform this assessment. The historic channel survey data made available is summarised in Table 1-4 and their locations are presented in Figure 1-3.

2.1.22 The historic topographic survey was reviewed at the start of the project to assess whether the data was suitable for use within the hydraulic model. The gap analysis concluded that additional topographic survey was needed to improve confidence in the outputs of the hydraulic model.

2.1.23 The existing survey used in the EA River Trent&Tribs 2011 model was procured between 1992 and 2010. It was not believed that incorporating a new channel survey of the River Trent would have a significant impact to the model results. However, the channel topography may have changed slightly over this time. A comparison between the previous survey and what has been updated using new survey data is found in Table **1**-**3**.

New Topographic Survey

2.1.24 A survey of several critical structures on the River Trent was therefore requested to update the A46 Newark Bypass hydraulic model. The survey presented both hard and soft bed levels, however, to account for siltation the soft bed was utilised.

2.1.25 Storm Geomatics were commissioned in November 2022 to collect additional data. Additionally, 40SEVEN were commissioned in December 2022 to collect data at the Flood Compensation Areas and Kelham Hall Field Ditch.

---

[2] HE551478-SKAG-HDG-CONWI_CONW-TN-CD-00002, Revision P01, "Assessment of Cumulative Flood Risk Impacts from the Southern Link Road Scheme".

2.1.26 Detailed information and diagrams of survey locations can be found within the A46 Newark Bypass Drainage and Flood Management Survey Scope.[3]

Table 1-3: Summary of model changes based on 2022 survey.

Survey Node in National Highways A46 Newark Trent 2023 Fluvial Hydraulic Model	Changes applied based on 2022 survey
403541020	Cross section updated based on surveyed section CS_123
CS_124	Cross section updated based on surveyed section CS_124. Model node previously called 403540480i2
403526149sl	289m of spills split over 4 nodes. 403540210, 403540210i1 and 403540050R.
403526149s2	
403526149s3	
403526149s4	
403525810	1D cross section updated using surveyed section BR_1. Layered flow constriction added to represent 31 piers on left bank. Aerial imagery and available survey information has been used to estimate area of pier foot print. The piers in the watercourse have not been modelled as it is unlikely to have an impact on hydraulics. No amendments made to right bank.
CS_125	Cross section updated based on surveyed section CS_125.
CS_126	Cross section updated based on surveyed section CS_126.
403524425	Cross section updated based on surveyed section CS_127.
CS_128	Not incorporated as the cross section did not full channel width. Interpolate added between 403524196 and CS_129.
CS_129	Cross section updated based on surveyed section CS_129.
403523425	BR_7 represented as a bridge structure.
403521671	BR_8 represented as a bridge structure.
403520501	BR_20 represented as a bridge structure.
403520195	Cross section updated based on surveyed section CS_138.
CS_48	CS_48 was surveyed at the River Trent confluence near Crankley Point. This cross section has not been included as the western tributary is represented by CS_138. The bed profile for the southern tributary joining the confluence was compared with the original the channel profile from the Trent&Tribs 2011 model. This showed minor differences in channel, therefore was not

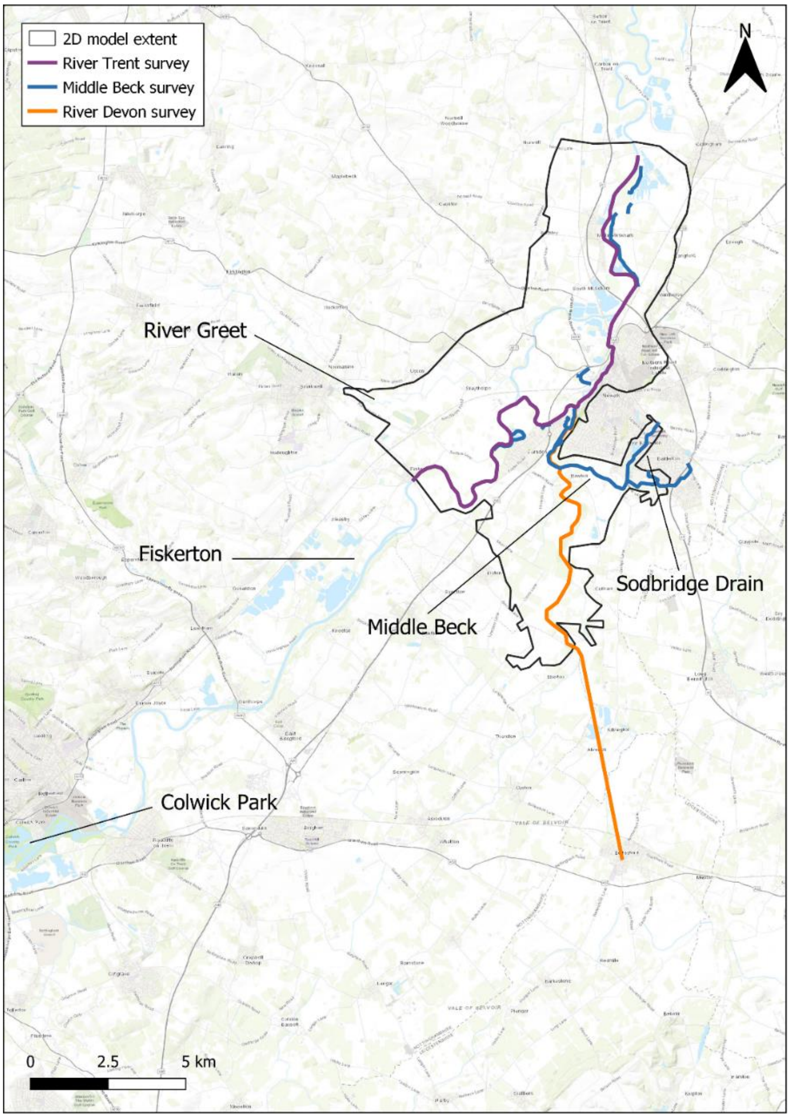
[3] HE551478-SKAG-HDG-CONWI_CONW-RP-CD-00004, Revision P01.7

	included.
CS_49	Cross section updated based on surveyed section CS_49.
403515700	Cross section 403515700 has been updated with surveyed section W_4. The structure immediately downstream was represented as a Bernoulli loss in the Trent&Tribs 2011 model. As the restrictions caused by the piers with respect to the flows in this watercourse are likely to be insignificant, no changes have been made to the model to prevent further instabilities.
403510000	Cross section updated based on surveyed section CS_139.
CromUS	Weir level updated based on surveyed section W_5.
CS_141	Cross section updated based on surveyed section CS_141.

Table 1-4: Summary of historic topographic survey

Title	File Name	Date	Location	Description of the survey	Relevance to flood compensation area work	Relevance for fluvial hydraulic modelling
Atkins topographic survey	TOPOGRAPHIC ADDITIONS TO HE551478-ATK-VTO-XX-M3-VT-000001.dwg	2021	Burrow Pits, A46 road	Topographic survey of the area along the A46	Used to design Burrow Pits FCA, verification of ditch levels for 2D model	For consistency, not to be used directly in the hydraulic model (preference for direct LiDAR)
River Trent Contour survey	AVERHAM.dwg	1997	River Trent at Averham	Channel survey of River Trent and topographic survey of floodplain from confluence with Rundell Dyke to downstream of Averham	Could be used to verify design of Kelham FCA connection	Not suitable as these are too old and too detailed for 1D model build
Brewers Wharf	Newark Topo.dwg	2001	Central Newark Trent bank/locality survey	Topographic survey of Brewers Wharf in Newark	Not applicable	Verification of bank and 2D LiDAR levels
Newark survey	Newark_Survey.dwg	2005	Central Newark Trent and Kelham Road flood defence	Topographic survey of River Trent banks and its surrounding from Great North Road to downstream of the Marina. Includes topographic survey of Kelham Road flood defence. Reference to left and right bank cross-sections and drawings separately.	Not applicable	Verification of bank and 2D LiDAR levels
Farndon	TFR01.dwg	2001	67 Farndon Road, Newark	Topographic survey including pumping station and small embankment between house and pumping station.	Not applicable	Verification of bank and 2D LiDAR levels
Slough Dyke channel survey	X-J01425-01-05.pdf	2020	Slough Dyke, north Newark	Channel survey of Slough Dyke from headwater in Newark Business Park to confluence with River Trent	Not applicable	Model survey used to produce Slough Dyke hydraulic model
River Devon	FR-LP.dwg and various small files	2005/2000	River Devon, southern Newark	Topographic spot survey along Farndon Road Flood Defence (2005) Channel survey of River Devon (2000)	Not applicable	Channel survey is too old, topographic survey could be used for verification
River Devon/Middle Beck survey	C00518_Survey_Report.pdf and various small files	2021	River Devon, southern Newark	Topographic survey & cross-section of flood defence and embankment along the River Devon in Newark	Not applicable	Most up to date channel survey of the River Devon and Middle Beck watercourses
River Trent survey	NRA.dwg	1992	River Trent, Nottingham to downstream of Newark	Channel survey	Not applicable	Survey used to produce EA River Trent&Tribs 2011 hydraulic model

Figure 1-3: Available channel survey



Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

2.1.27 Based on the review of the data collected by the EA and Skanska, a survey request was made for the following watercourses:

- Winthorpe Airfield Drain
- Crankley Point Drain
- Old Trent Dyke
- Mission Drain

2.1.28 Further information on the survey carried out for the scheme can be found within the A46 Newark Bypass Drainage and Flood Management Survey Scope.[4] Information on updates to structures using survey data is provided in Section 0.

4 HE551478-SKAG-HDG-CONWI_CONW-RP-CD-00004, Revision P02

3 Modelling Approach

Model concept

3.1.1 The source-pathway-receptor concept is a widely accepted model for FRA. Each of these components are outlined in Table **3-1** for this study. The detailed model concept is presented in the FRA.[5]

Table 3-1: Source-pathway-receptor model

Element	Comment
Source	Primary sources of flooding in the study area: • Fluvial • Surface water • Groundwater • Sewers • Artificial sources (such as reservoirs)
Pathway	The primary pathway occurs as water spills from the watercourse onto the floodplain. When peak flows exceed the capacity of the channel, the water level will overtop the bank and spill out of the channel onto the floodplain. Other pathways include overland flow paths (fluvial and surface water) and flow of groundwater through the superficial deposits.
Receptor	The floodplain of the River Trent and its tributaries is heavily urbanised. The key receptors for fluvial flood risk are properties near the river, including residential and non-residential properties, vehicles, infrastructure, people, agricultural land, and animal habitats, which are connected to the river network by a pathway.

[5] Flood Risk Assessment (HE551478-SKAG-HDG-CONWI_CONW-RP-CD-00022)

4 Choice of modelling approach

4.1.1 The hydraulic modelling undertaken by the EA in 2011 for the River Trent and its tributaries was updated with new channel section/topographical survey data, LiDAR and new hydrological inputs. The hydrology updates are described in Section 0. The approach taken to complete this hydraulic modelling assessment is presented in the A46 Newark Bypass Hydraulic Modelling Methodology report.[6] The EA were engaged throughout the modelling process.

4.1.2 The modelling for this project will adopt a fluvial 1D-2D linked approach, using FMP and TUFLOW software packages.

4.1.3 FMP is a 1D hydrodynamic modelling software which has functionality for modelling in-channel structures such as those seen in the catchment. It was developed for use on UK rivers and is well-suited to modelling the complex interaction of flow in urban and rural catchments in the UK, such as the study area.

4.1.4 TUFLOW is a 2D modelling software which is used to model the spread of water over a floodplain. It is highly customisable and can be adapted to represent the unique details and dynamics of flow passing over floodplains such as those seen in the study area. FMP and TUFLOW can be linked and run concurrently to dynamically transfer flow from the channel to the floodplain and back during a simulation.

4.1.5 FMP and TUFLOW are industry-standard modelling software packages which are well-suited to modelling the flood conditions seen in this catchment. Both FMP and TUFLOW have been benchmarked by the EA as suitable to use for flood modelling in the UK.

4.1.6 The A46 Newark Bypass Model uses the latest version of FMP backwards compatible with the EA River Trent&Tribs 2011 model (Version 4.6) and the single precision version of TUFLOW Classic modules (2020-01-AB-iSP-w64).

4.1.7 These versions are appropriate for use in this assessment and recent updates to the software will not affect confidence in the conclusions when using TUFLOW Classic.

4.1.8 The original EA River Trent&Tribs 2011 model was trimmed by ~15km of upstream length to reduce run time and improve model stabilities. After trimming the model, it was used as the base for the A46 Newark Bypass hydraulic model. The present report describes the updates made to this model.

[6] A46 Newark Bypass Hydraulic Modelling Methodology (HE551478-SKAG-HDG-CONWI_CONW-RP-CD-00007)

Choice of method for defining design flood flows

4.1.9 A detailed hydrological assessment[7] was required for the proposed modelling following the latest Flood Estimation Guidance (LIT 11832 – Flood estimation guidelines, July 2022) and the HiFlows dataset. The hydrological estimation approach is provided in the A46 Newark Bypass – Drainage and Flood Management Hydrology Method Input Statement.[8]

4.1.10 The FEH statistical method was the preferential choice to derive model inflows for the main River Trent and other input catchments given that:

- There is a very good availability of gauged data within the catchment
- The length of records available at sites (notably gauges on the River Trent) are generally long
- The size and scale of the catchments which are to be assessed have a moderate to very large catchment area. This includes the River Trent, which is approximately 7,500km^2 at Colwick and over 8,000km^2 at North Muskham. Rainfall runoff approaches may potentially result in an overestimate of flow for these catchments.
- The Trent has a wide, extensive floodplain and extensive upstream features (such as flood risk alleviation schemes, offline storage, and lake features)

4.1.11 Flood flow estimates derived by the FEH statistical method were, where appropriate, compared against flood flow estimates derived by the ReFH2 rainfall-runoff method, as detailed in the Flood Estimation Report.[5]

4.1.12 The climate change uplift was selected based on the latest guidance from the Environment Agency. This guidance is discussed in greater detail in Section 8.

---

[7] Flood Estimation Report (HE551478-SKAG-HDG-CONWI_CONW-RP-CD-00017)

[8] A46 Newark Bypass – Drainage and Flood Management Hydrology Method Input Statement (HE551478-SKAG-HDG-CONWI_CONW-RP-CD-00012)

5 Hydraulic Model Baseline Components

Source model

5.1.1 The EA Trent&Tribs 2011 model was used as the source to which updates were added for this project. The key changes to the baseline model are shown below.

Model domain

5.1.2 A multi domain model was used for the scheme, so that different grid sizes could be used to represent different areas. The A46 scheme, Greet, Sodbridge, the upstream reach of Middle Beck and Slough Dyke have been represented using a 10m grid. The River Trent floodplains and the River Devon have been represented using a 20m grid.

5.1.3 Multidomain modelling tests were set up with a finer grid resolution of 5m, but the outcomes were unsatisfactory due to runtime length and instabilities.

5.1.4 It is noted that the full width of the Trent floodplain is utilised during a flood event and that the A46 scheme lies to the east and along the main direction of the floodplain flow. Therefore, the flood risk from the River Trent is strongly influenced by the linear features across the floodplain that divide it into a series of flood cells. Paying close attention to linear features and their connectivity guards against there being any fundamental differences in the modelling outcomes if a finer grid were employed around the A46 scheme.

5.1.5 To make sure that the grid resolution did not have a detrimental impact on the modelling results, a thorough check and refinement was undertaken of all linear features (flood defences, embankments, railways and roads) using new 2022 survey where it was available to ensure that their crest levels were captured properly and that all flow paths are represented. This included inverts and dimensions of culverts and underpasses. Where the grid size was at odds with the desired level of spatial detail, the modelling was updated to include TUFLOW lfcsh blockages to represent underpasses if it was possible that the grid size would have an impact on floodplain flows.

5.1.6 The model domain was truncated to exclude approximately 15km of the River Trent channel reach between Colwick Park and Fiskerton. This stretch of the reach was considered far enough upstream to not interact with the scheme and its exclusion would decrease run times and improve model stabilities. All inflows upstream of this point were removed from the model and a lumped catchment inflow was incorporated into the truncated section, upstream of the model.

5.1.7 There is a HX boundary at the downstream end of the 2D domain to capture floodplain flow and avoid any glass walling.

Incorporation of Slough Dyke Hydraulic Model

5.1.8 The Slough Dyke hydraulic model (2020) and its accompanying survey was incorporated into the A46 Newark Bypass Model. Prior to its incorporation, the Slough Dyke model was reviewed, and the findings are outlined in the Incoming Hydraulic Model Data Review technical note.[9] Its incorporation involved the following:

- Addition of the 1D FMP reach starting at Stephenson Way approximately 500m upstream of the scheme. The reach is linked to the 2D domain immediately downstream of the A1 and 50m downstream of the scheme. The 2020 Slough Dyke model was truncated downstream of the A1 to improve model stability.
- Levelling of the channel bed in the 2D domain to the 1D bank level using a 2D_zsh layer to prevent double counting of flows.
- A 4m grid was suggested for the Slough Dyke domain in the initial model review undertaken by Mott MacDonald, however, it was not possible to include an additional domain in the multi-domain model setup. Therefore, the existing A46 domain which has a grid size of 10m was extended to include the Slough Dyke catchment.
- A CN point was incorporated at each node of the 2D watercourse, with a HX line linking each node. This alternative method was opted for due to the disparity between the size of the channel and grid cell.
- The 1D Slough Dyke watercourse outfalls into the 2D domain via a CN point and SX line downstream of the A1.
- Downstream boundary was set to bank full level of the final spill unit.
- Initial water levels in Slough Dyke been set to 300mm above LiDAR elevations to represent normal conditions and ensure model stability.

5.1.9 Slough Dyke was removed from the hydraulic model when running calibration events and during flow sensitivity testing and the 0.1% AEP event, to ensure model stability. This was deemed acceptable as such analysis of the Slough Dyke was not necessary for the scope of the study.

Digital Terrain Model

5.1.10 Several 1m resolution LiDAR tiles were added, which had been flown at different times in 2020. The LiDAR tiles were downloaded and

[9] Incoming Hydraulic Model Data Review - Slough Dyke model (HE551478-SKAG-HDG-CONWI_CONW-RP-CD-00011)

merged. The LiDAR data has been used to represent the Digital Terrain Model (DTM) of the A46 Newark Bypass Model.

Survey updates

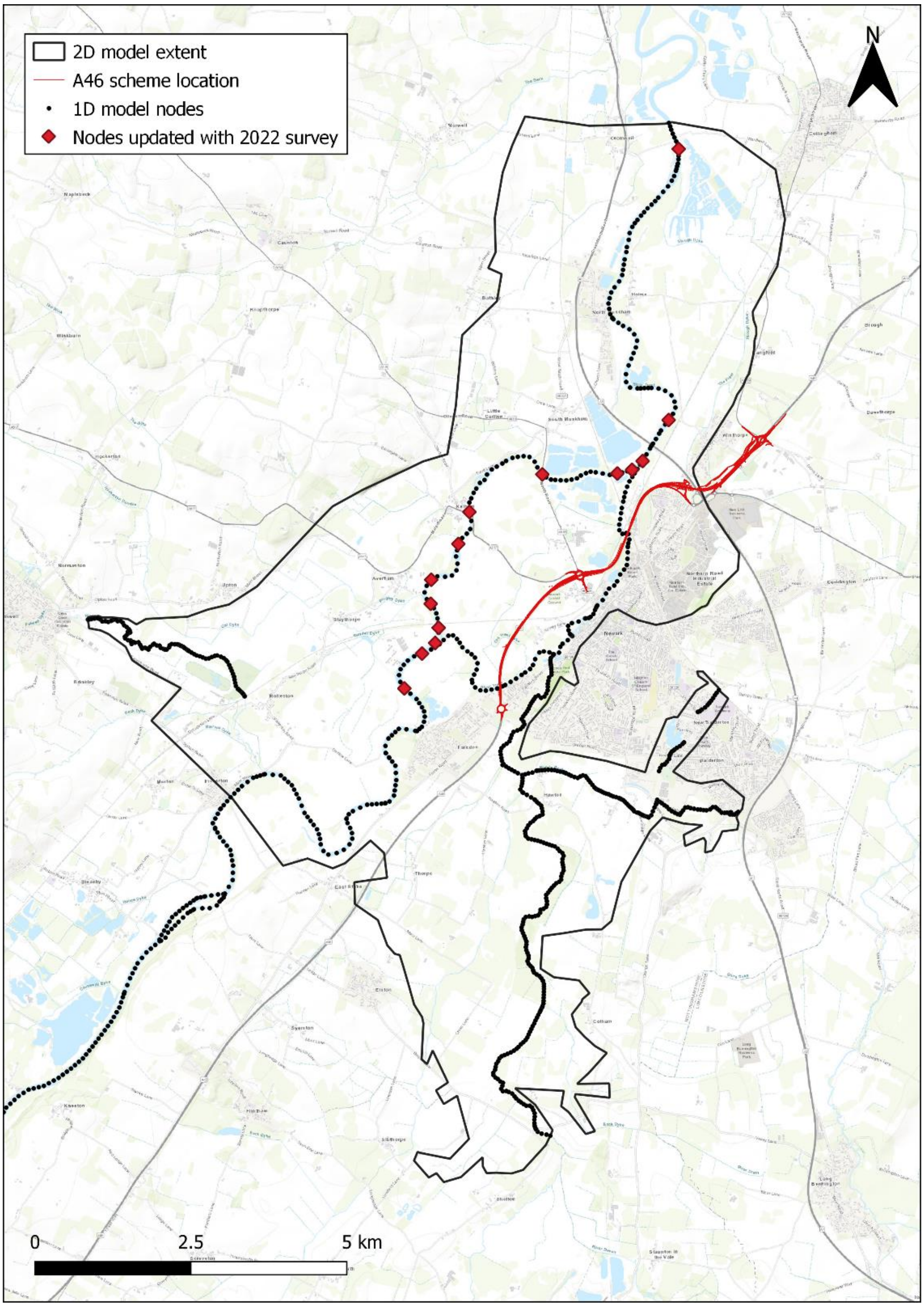
5.1.11 New topographic survey from 2022 has been incorporated into the model.

5.1.12 Figure 5-1 shows the nodes/cross section locations that were updated using new survey data.

5.1.13 The 2022 topographic survey data was used to check and update crest elevations along roads and railways around the Tolney Lane area, specifically, the Nottingham to Lincoln railway line and the Kelham Road flood defence.

5.1.14 Generally, significant changes were not noted between the new and old cross sections. The modifications made to the hydraulic model within the 1D channel based on new survey is unlikely to impact hydraulic modelling results.

Figure 5-1: Model nodes updated.



Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

Representation of Structures

5.1.15 FMP culverts were converted to ESTRY to improve stability and were moved to the correct domain. A full list of all 1D structures, their representation and any updates can be found in Table 5-1.

5.1.16 The representation of culverts beneath the A46 was reviewed and updated using survey data.

5.1.17 Model configuration of piers at the Windmill viaduct and Nether Lock viaducts were reviewed and updated to factor in pier representation.

Existing Structures

5.1.18 Summaries of structures included in the model are provided in Table 5-1 and Table 5-2.

5.1.19 60% and 80% TUFLOW lfcsh flow constrictions have been applied in in the Trent floodplain at the Nottingham to Lincoln Line and the East Coast Main Line railway line underpasses to account for flow widths that are smaller than the grid size.

5.1.20 A small number of structures were not included in the model, these are also presented here with reasoning for their omission. There are no sluice gates or locks within this model.

5.1.21 The baseline model review revealed that no prior modelling of Newark town lock navigation channel had been conducted. Survey results from 2022 suggest the channel contains two lock gates. However, a review of survey photographs revealed a third structure present along the right channel. The navigation channel and associated structures will not significantly affect water levels during higher AEPs. Furthermore, the attenuating effect of the channel is deemed negligible for lower AEPs. Therefore, these features were not included in the flood risk modelling, as their inclusion was not expected to alter the upstream water levels significantly.

General model updates

5.1.22 Further amendments to the model were required to improve the representation of structures within the floodplain. General updates included the following:

- Railway and flood defences were reinforced using survey data to pick up the high and low elevation points. They were not reinforced in the EA Trent&Tribs 2011 model.
- FMP orifice structures were replaced with ESTRY culverts as the former were unstable. In the EA Trent&Tribs 2011 model, orifice units showed

significant oscillations which could reduce confidence in model results. Oscillations reduced when units ESTRY culverts were incorporated.
- Two significant bridge structures on the River Trent (Great North road crossing and East Coast Mainline crossing) and Averham Weir were not included in the EA Trent&Tribs 2011 model.
- site specific topographic survey data of the floodplain at Averham Viaduct was not represented in the EA Trent&Tribs 2011 model. This was incorporated in the updated model as a flow constriction.
- Approximately five cross sections in the 1D domain had widths inconsistent with those in the 2D domain. This was corrected in the updated model.
- The Old Trent Dyke watercourse has been modelled in 2D using 1m DTM. This approach was taken as it is unlikely for the Old Trent Dyke to be utilised in the design event.

5.1.23 A review has been undertaken of errors and warning shown in hydraulic modeling diagnostic files to understand impacts on the hydraulic modelling results. Most of the check and warning messages were addressed. However, a few were left because they are purely informational, or do not have an impact on the modelling results in the area of interest:

- 2D-2D boundary warnings are due to multiple isolated 2D domains.
- 3D zline application warnings are due to gully lines being applied along region of DTM that make them redundant.
- Lowered ZC warnings at culverts are due to survey and DTM differences. Checks of culvert elevations have been made against survey data.
- Dangling 3D lines are due to mif conversions unsnapping the elevation points. Checks indicate that the 3D lines have elevations that are very close to intended values.
- High Manning’s n values (1.0) are for buildings and are intended. When mixed with the roughnesses for the garden and roads, the high Manning’s n value for buildings compensates for the grid size of 10m which would otherwise struggle to pick up the influence of the buildings on the flow paths in residential areas. Furthermore, the value of Manning’s n for buildings was retained from the Trent&Tribs 2011 modelling so that the modelling in this study remains based on an already accepted model.

Table 5-1: Structures within 1D model

Structure	Model node	Location (X, Y)	Type	Modelling approach / structure coefficients / comment
Averham Weir	403540210	476991, 353454	FMP Weir	Weir split over four weir units based on 2022 survey Weir coefficient set to 0.650
Averham Bridge	403525810	477105, 353880	FMP Bridge	Updated based on 2022 survey
A617 River Crossing	403523466BU	477617, 355634	FMP Bridge	Updated based on 2022 survey
Great North Road River crossing	403521671	478749, 356272	FMP Bridge	Updated based on 2022 survey
East Coast Mainline River Crossing	403520501	479863, 356255	FMP Bridge	Updated based on 2022 survey
Winthorpe Bridge	403515700u	480518, 356710	FMP Bernoulli loss	Cross section downstream of Bernoulli loss updated based in 2022 survey
Newark Road Bridge	CromUS	480915, 361074	FMP Weir	Updated based on 2022 survey
Longstone Bridge	403533250u	479253.00,353668.81	FMP Bridge	No updates to structure
Trent Bridge, Newark	403532620u	479632.29,354124.99	FMP Bridge	No updates to structure
Footbridge Upstream of Nether Lock Viaduct	403531480u	480142.05,355095.46	FMP Bridge	No updates to structure
River Devon Brecks Lane Bridge	RD10264BU	478672, 345758	FMP Bridge	No updates to structure
Moor Lane Bridge structure	RD7410BU	478772, 347723	FMP Bridge	No updates to structure
Farm Access Bridge	RD6996BU	478784, 348138	FMP Bridge	No updates to structure
Farm Access Timber Deck	RD6264BU	478518, 348771	FMP Bernoulli loss	No updates to structure
Devon Bridge at Hawton	RD2993BU	478658, 351040	FMP Bridge	No updates to structure
Access Bridge	SD2174BU	481453, 352603	FMP Orifice	No updates to structure
Culvert beneath Balderton residential area	SD1932C	479253, 353668	FMP Culvert	0.9m dia culvert beneath urbanised area in Balderton No updates to structure
Culvert beneath Catkin Way	SD1203OU	479632, 354124	FMP Orifice	Culvert modelled as orifice No updates to structure
Culvert beneath Hawton Lane	SD1082OU	480142, 355095	FMP Orifice	Culvert modelled as orifice

				No updates to structure
Culvert beneath Access track	SD0917BU	478672, 345758	FMP Bridge	Arch Bridge No updates to structure
Culvert beneath Flowserve	SD0758C	478772, 347723	FMP Culvert	1.04m dia culvert No updates to structure
Culvert beneath Staplelane	LD1400O2U	478784, 348138	FMP Orifice	Orifice used for stability purposes No updates to structure
Access Bridge	LD1122OU	478518, 348771	FMP Orifice	Orifice used for stability purposes No updates to structure
Access Bridge	MB2208OU	478658, 351040	FMP Orifice	Orifice used for stability purposes No updates to structure
Access Bridge	MB2125OU	481453, 352603	FMP Orifice	Orifice used for stability purposes No updates to structure
Access Bridge	MB2095BU	481267, 352454	FMP Bridge	No updates to structure
Bowbridge Road Bridge	MB1933BU	480891, 351849	FMP Bridge	No updates to structure
Bridle Bridge	MB1661BU	480815, 351760	FMP Bridge	No updates to structure
Access Bridge	MB1233BU	480739, 351621	FMP Bridge	No updates to structure
Farm Access Bridge	MB0614BU	480645, 351503	FMP Bridge	No updates to structure
Road Bridge at Hawton	MB0160BU	481796, 350845	FMP Bridge	No updates to structure
Culvert beneath Brunel Drive	SLOU_7361cu	481553, 350922	FMP Culvert	1m dia culvert No updates to structure.
Culvert beneath Lincoln Road	SLOU_7173cu	480477, 350761	FMP Culvert	1.100m dia culvert at Brunel Drive No updates to structure.
Culvert beneath A46 Newark Bypass	SLOU_6914cu	480403, 350788	FMP Culvert	1.190m dia culvert at Brunel Drive No updates to structure
Culvert beneath Winthorpe road track	SLOU_6402cu	480372, 350802	FMP Culvert	1.800m dia culvert at Brunel Drive No updates to structure
Culvert beneath A1	SLOU_6354cu	480230, 350883	FMP Culvert	1.795m dia culvert under A1 No updates to structure
Farm Access	A46_18307	478243, 353513	ESTRY Culvert	4.5m x 4.29m culvert Updates from FMP orifice to ESTRY culvert to reduce oscillations in flow hydrograph
Pipe Culvert No. 7	A46_18315	478708, 354160	ESTRY Culvert	3m dia culvert Updates from FMP orifice to ESTRY culvert to reduce oscillations in flow

				hydrograph
Cattle Market relief culvert	A46_18305	479366, 354656	ESTRY Culvert	4.2m x 2.4m culvert Updates from FMP orifice to ESTRY culvert to reduce oscillations in flow hydrograph
Culvert parallel to A1	A1_5377	481052, 356288	ESTRY Culvert	5.58m x 3m culvert Updates from FMP orifice to ESTRY culvert to reduce oscillations in flow hydrograph
Pipe culvert No. 5	A46_18313	478163, 353355	ESTRY Culvert	1.2m dia culvert Updates from FMP orifice to ESTRY culvert to reduce oscillations in flow hydrograph
Pipe Culvert No. 6	A46_18314	478284, 353613	ESTRY Culvert	1.2m dia culvert Updates from FMP orifice to ESTRY culvert to reduce oscillations in flow hydrograph
Pipe Culvert No. 12	A46_18316	479782, 354733	ESTRY Culvert	1.5m dia culvert Updates from FMP orifice to ESTRY culvert to reduce oscillations in flow hydrograph
Access track beneath A46	A46_18546	480276, 355657	ESTRY Culvert	3m x 5.13m culvert Updates from FMP orifice to ESTRY culvert to reduce oscillations in flow hydrograph
Pipe Culvert No. 16	A46_18137	480454, 355974	ESTRY Culvert	2.1m dia culvert Updates from FMP orifice to ESTRY culvert to reduce oscillations in flow hydrograph
Farndon Underpass	A46_27622	478103, 352607	ESTRY Culvert	4.4m x 2.78m culvert Updates from FMP orifice to ESTRY culvert to reduce oscillations in flow hydrograph
Nottingham to Lincoln Railway Bridge East	A46_18545	479802, 354732	ESTRY Culvert	18.5m x 5.31m bridge underpass Updates from FMP orifice to ESTRY culvert to reduce oscillations in flow

				hydrograph Updated using 2022 survey data
Cattle Market roundabout culvert	CMR_NW	479300, 354685	ESTRY Culvert	1.2m dia culvert Added based on 2022 survey data
Underpass beneath Great North Road	GNRUnderpass	479388, 354112	ESTRY Culvert	3.7m x 2.43m underpass Added based on 2022 survey data

Source: Mott MacDonald

Table 5-2: Structures within 2D model

Structure	Location (X, Y)	Type	Modelling approach / structure coefficients / comment
Averham Viaduct floodplain piers on left bank	476950, 353863	2d_fsch (flow constriction)	31 piers in floodplain equates to approximately 20% blockage in the floodplain. Obvert – 12.98m AOD.
Nether Lock Viaduct piers	480123, 355283	2d_fsch (flow constriction)	2 piers in floodplain equates to approximately 8% blockage for each pier in the floodplain. The proposed scenario will model an additional 10% blockage for the 2 new piers introduced as part of the scheme .
Windmill Viaduct piers	478092, 352850	2d_fsch (flow constriction)	5 piers in floodplain equates to approximately 6% blockage for each pier in the floodplain. The proposed scenario will model an additional 6% blockage for the 5 new piers introduced as part of the scheme.

Improvements to model stability

5.1.24 Initial conditions were updated alongside changes to the 1D hydraulic model.

5.1.25 Along 2D_bc lines, the ‘d’ parameter was uplifted to 50m to ensure a level two to three times the largest mesh size of 20m. This value determines the distance between points along the boundary that control the water level. It should not be less than the 2D cell size.

5.1.26 During development and stabilisation of the A46 modelling, the cross-catchment flow from the River Devon into Middle Beck caused significant instabilities. These were addressed through a sequence of adjustments which included removal of 1D interpolated sections, refinement of bank top elevations using 2020 LiDAR and, finally, strategic removal of HX boundary link lines, ensuring that overall flow connectivity was preserved and that the backwater from the downstream crossings still dominated the long profile.

5.1.27 Slough Dyke was truncated downstream of the A1 to reduce instabilities.

5.1.28 Negative depths occur around 40 hours into the model run, over a period of 8 hours, during initial flooding of the floodplains at the gravel pits downstream of Slough Dyke and in the canal upstream of Newark Town Lock. The flood peak occurs at 80 hours and is not affected by the negative depths.

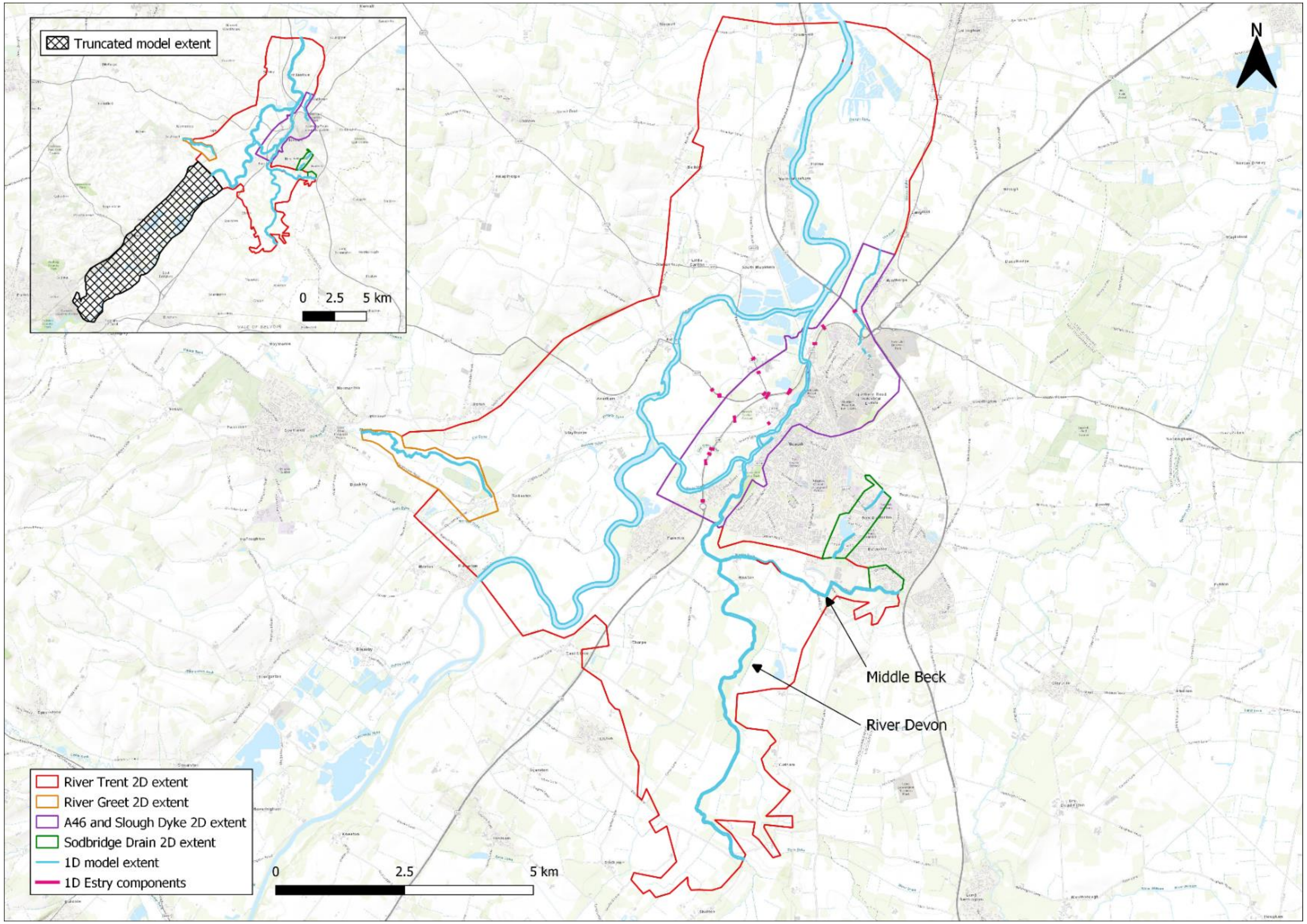
5.1.29 Due to the deep water over the River Trent floodplain, the Flood Modeller dflood parameter was increased from 3.0m to 5.0m for almost all models. The January 2021 calibration and the -20% roughness model runs exhibited transient instabilities in the 1D components which was solved by increasing dflood to 10.0m specifically for those two models.

5.1.30 The Flood Modeller maxitr parameter in the Trent&Tribs 2011 modelling was set to 21. It was reduced to 7 for the A46 modelling because it is a prime number (which can reduce cyclical behaviour) and close to the default value that would have been used in 2011. The value of maxitr in models that are set up using more recent versions of Flood Modeller defaults to 11, however the A46 modelling rarely iterates more than 3 times, except during initial flooding, and increasing to 11 would not have any impact on modelling stability.

5.1.31 For all model runs except blockage sensitivity test 1 (50% blockage of Cattle Market flood relief culvert), the MatrixDummy parameter was set to the default of zero.   The blockage sensitivity test 1 model required a small MatrixDummy value of 0.001 to help avoid matrix singularity problems.

5.1.32 A schematic of the model is presented in Figure 5-2

Figure 5-2: Model schematic



Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

Hydraulic roughness

5.1.33 The EA River Trent&Tribs 2011 model review highlighted that a single Manning's n value was applied to each watercourse. However, we expect variations, particularly in the sub-catchments. Manning's n values were reviewed as part of the update based on photographs, where available, or Google images. 1D channel roughness for newly modelled watercourses were determined based on survey photographs. Roughness values adopted were taken from standard guidance (Chow 1959).

5.1.34 Table 5-3 and Table 5-4 outline the roughness values applied to the hydraulic model in the Trent, Sodbridge and Greet domains. Table **5-5** outlines the roughness used in the A46 and Slough Dyke domain east of the East Coast mainline.

Table 5-3: 1D roughness in all watercourses

Watercourse	**Manning's '*n*' roughness coefficient**
River Trent	Bed: 0.029 Bank: 0.05
Rundell Dyke	Bed: 0.04 Bank: 0.06
Middle Beck	Bed: 0.04 Bank: 0.06
Sodbridge Beck	Bed: 0.04 Bank: 0.06
Lowfield Drain	Bed: 0.04 Bank: 0.06
Slough Dyke	Bed: 0.03 Bank: 0.05

Table 5-4: 2D roughness coefficients used in Trent, Sodbridge and Greet domains

OS MasterMap land use category	**Manning's '*n*' roughness coefficient**
Smooth grass	0.045
Trees	0.09
Scrubby Grass	0.05
Gardens/yards	0.045
Roads	0.03
Open water	0.02
Channel	0.04
Buildings	1.00
Dense scrub	0.06

Table 5-5: 2D roughness coefficients used in the A46 and Slough Dyke domains

OS MasterMap land use category	Manning's '*n*' roughness coefficient
Generic floodplain roughness values - Depth varying roughness applied with depths >2.0m	0.06
Boulders	0.065
Coniferous trees	0.12
Coniferous trees – scattered / Orchard	0.07
Coppice or osiers	0.09
Marsh Reeds or Saltmarsh	0.06
Non coniferous trees	0.09
Non-coniferous trees – scattered	0.06
Rough grassland	0.06
Scrub	0.07
Rock	0.07
Heath	0.09
Vegetated Banks	0.12
Building	1
General surface – multi surface, step, manmade	0.06
Glasshouse	0.2
Inland water	0.045
Landform (slope and cliff)	0.06
Vegetation	0.07
Path – step	0.05
Path	0.05
Rail	0.045
Road	0.035
Roadside	0.05
Structure	0.3
Structure – pylon	0.06
Tidal water – foreshore	0.055
Tidal water	0.055
Unclassified	0.06

1D model configuration

Table 5-6: 1D model summary

Item	Comment
Number of 1D nodes	1360 (FMP)
Number of ESTRY culverts	21 (FCA Model)
ESTRY Reach Length	809m
Length of 1D model (km)	99
Are out of bank flows represented in the 1D or 2D models?	All out of bank flows in the study reach for the scheme are modelled in 2D .
Is the model geo-referenced?	Partially, some nodes are not geo-referenced but this will not impact model findings.
Have bank markers been set up for the model?	Added to provide an indication of out of bank flow.

6 Model Scenarios

Proposed Scenarios

6.1.1 The following models, shown in Table 6-1 were produced to meet the objectives of the project scope. The development of the model is outlined in detail in subsequent sections.

Table 6-1: Model versions

Scenario	Purpose
Baseline	All structures assumed to be unblocked. Run for suite of design events and for model calibration.
Calibration	Calibration against three events undertaken using the baseline model with two events used for validation.
Sensitivity	Based on the baseline model, sensitivity testing was undertaken to understand the impact of assumptions, including: • Changes in hydraulic roughness • Adjustments to inflows • Blockages applied to structures • Adjustments to weir coefficients
Scheme + mitigation	Addition of scheme design and flood compensation areas (FCAs) to assess the impact of proposed mitigation alongside the scheme on flood risk.
Temporary works	Addition of temporary works structures onto the Scheme + mitigation scenario to represent the construction process and assess its impact on flood risk. The temporary works modelling assessment is discussed separately in Appendix D.

6.1.2 The A46 Newark Bypass model is summarised in Table 6-2. Model outputs will inform the different disciplines in their assessments as presented in Table 6-3. Table 6-4 describes the extents of each of the modelled reaches.

6.1.3 Justification for the chosen climate change allowance is discussed further in Section 8.

Table 6-2: A46 Newark Bypass Model summary

Item	Comment
Purpose of modelling (scheme appraisal)	To assess the existing baseline fluvial flood risk and identify and assess potential effects associated with the proposed National Highways A46 Newark Bypass - Regional Development Project (RDP).
Model type	Multi domain 1D-2D linked model

Software and version	FMP version 4.6 and single precision version of TUFLOW Classic modules (2020)
What events have been simulated (1%, 0.5% AEP etc)	50% AEP (2yr) 20% AEP (5yr) 5% AEP (20yr) 3.33% AEP (30yr) 2% AEP (50yr) 1% AEP (100yr) 3.33%+39%CC AEP (30yr+CC) 1% AEP+39%CC (100yr+CC) 0.1% AEP (1000yr)
Have climate change runs been undertaken?	Upper central allowance (39% uplift) applied to 1%, 3.33%, and 0.1%
Has a study for quantifying uncertainty been undertaken? (calibration, verification)	Calibration and verification undertaken

Table 6-3: Justification for choice of events for hydraulic modelling

Events probability	Justification
50% AEP **20% AEP**	Hydraulic model verification Drainage design Environmental analysis Channel design
3.33% AEP	Temporary works design
3.33% AEP plus 39% climate change allowance	Drainage design
1% AEP	Consistent with NPPF Flood Zone 3a for fluvial flooding Temporary works design
1% AEP plus 39% climate change allowance	FRA Scour assessment To inform culvert soffits design
0.1% plus 39% climate change allowance	To inform bridge design (soffits) Blockage analyses For assessing extreme levels for bridge design

Table 6-4: Extent of 1D modelled reach

Watercourse	Length (km)	Upstream limit	Downstream limit
River Trent	70km	River Trent at Fiskerton NGR SK 73735 51045	North Muskham NGR SK 80910 61110
River Greet	3.8km	River Greet, downstream of Upton Road NGR SK 71452 53941	Railway crossing at Rolleston SK 74003 52699
River Devon	10.3km	River Devon at Shelton NGR SK 78916 45659	Confluence with River Trent at Newark Marina NGR SK 78941 53360
Sodbridge Beck	2.2km	Sodbridge Drain at New	Sodbridge Drain at Newark

		Balderton SK 81602 52800	SK 80599 51040
Middle Beck	2.3km	Middle Beck at Newark SK 80478 50760	Middle Beck at Hawton SK 78460 51441
Lowfield Drain	1.6km	Lowfield Drain at Balderton SK 81914 50849	Lowfield Drain at Newark SK 80478 50760
Slough Dyke	1.3km	Slough Dyke at Newark on Trent SK 81350 55410	Slough Dyke at Winthorpe SK 81086 56308

Table 6-5: Watercourse excluded from 1D model

Watercourse	Length (km)	Reason not included in modelling
Winthorpe Airfield Drain	N/A	It has been determined that the scheme will cross this watercourse. However, it is expected that the proposed changes will not affect the existing flow mechanisms as the sizing of existing assets will be replaced with comparable assets to accommodate the same or increased flow and/or freeboard.
Crankley Point Drain	N/A	Crankley Point Drain is represented in the 2D model using available LiDAR. However, it is understood that the flapped outlet on Crankley Point Drain will remain closed during flood conditions. Therefore, detailed modelling of this watercourse was omitted.
Mission Drain	~1.3	Mission Drain has not been incorporated into the hydraulic modelling, as the initial FCA concept in which floodplain storage was to be provided at the upstream end of Mission Drain was superseded, with the FCA being moved alongside the A617. Therefore the inclusion of Mission Drain in the hydraulic model was no longer necessary. At the outline design (Stage 3), compensation for any floodplain storage for Mission Drain that may be affected by the extent of the FCA has not been accounted for in the Kelham FCA design. However, the floodplain associated with Mission Drain is small compared to the size of the FCA and it is planned the FCA will be reduced at Detailed Design to mitigate any loss of Mission Drain floodplain.

Baseline Model

6.1.4 Updates were made to The EA Trent&Tribs 2011 model as described in Section 5.

Scheme model with mitigation

6.1.5 To assess the impact of the scheme on flood risk, the scheme footprint and elevations were added to the baseline model. Key elements of the scheme scenario model are as follows:

- Addition of the scheme components as 2D_zsh layers which includes the following:
- Access tracks
- Embankments
- Highways
- Ponds
- Swales
- Changes to embankment elevations were modelled using 2D_zsh points and regions layer from Design Fix 3C. Due to 10m grid size being used, small changes in elevation could not be captured in detail, however, it is understood that this is unlikely to have an impact on the scheme results due to the high volume of water within the floodplain during the design event.
- Lowering of the Cattle Market roundabout scheme levels to 12.2mAOD to retain an existing flow pathway observed during baseline conditions.
- Representation of proposed piers at Windmill Viaduct and Nether Lock as 2D flow constrictions. This ensured the representation of the constriction of flow in the River Trent channel due to the large hydraulic structures.
- Updated hydraulic roughness to represent the change resulting from the scheme.
- The Slough Dyke watercourse alignment was retained from its original hydraulic model.
- Culvert structure lengths beneath the A46 were not amended with the addition of the proposed scheme, as it was not believed this would impact model results due to the low flows predicted through the structures and in large flood events the features are drowned out.

6.1.6 The design proposal of sheet piling behind the existing gabion baskets on the left bank of the River Trent immediately upstream Windmill viaduct has not been included in the hydraulic model. This is due to the assumption it is unlikely the gabion baskets will be washed out, exposing the sheet pilling and therefore marginally widening a short section of the watercourse. Also the exclusion of this design feature ensures the model remains conservative in any localised predicted restrictions on flow in the area.

6.1.7 To mitigate the risk of flooding presented by the scheme design, three Flood Compensation Areas (FCAs) were added to the scheme model. The FCAs are summarised in Table 6-6. The FCAs are suitable for the outline design and Design Fix 3C.

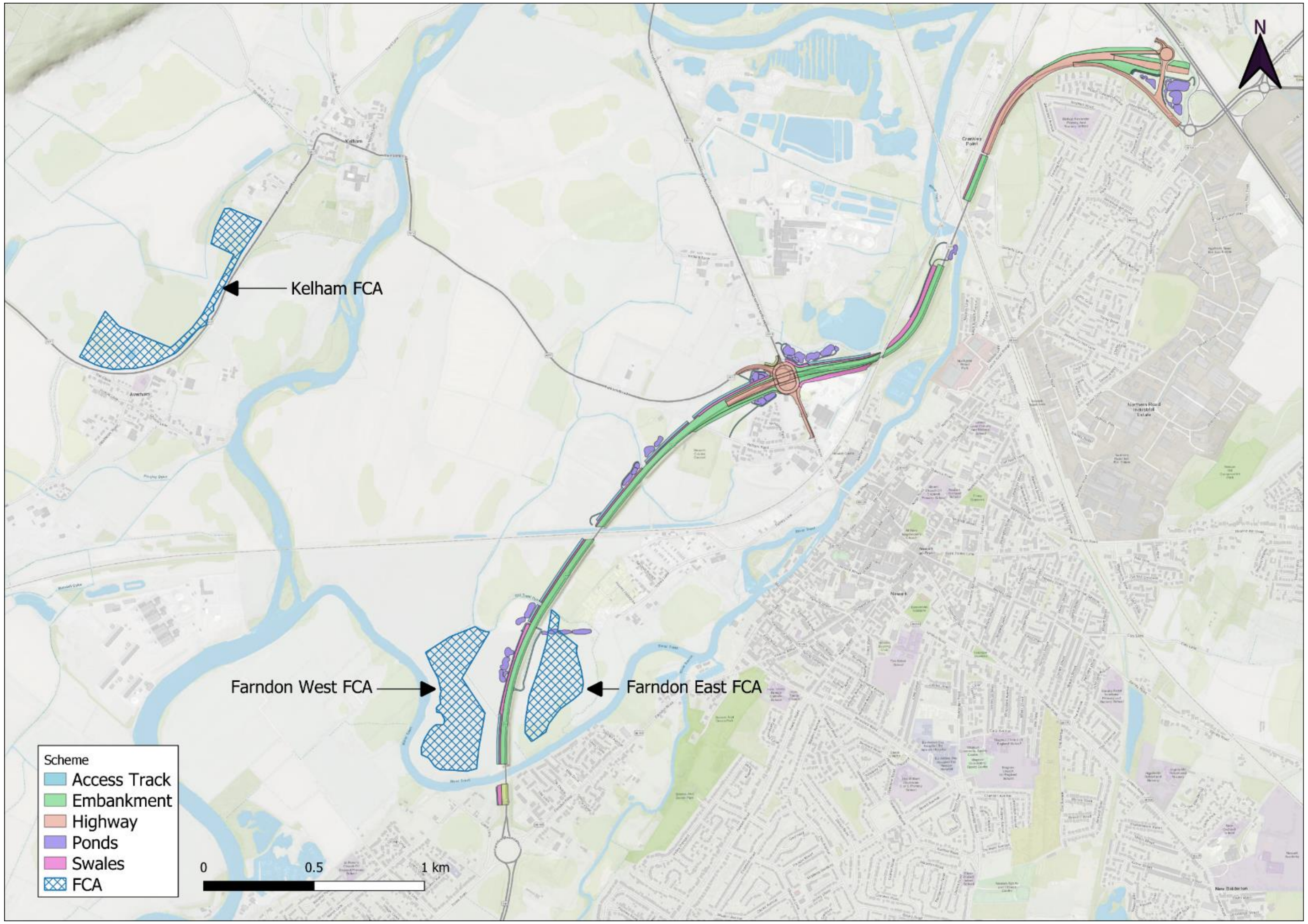
6.1.8 It is noted that the design FCA footprint shape with an increased extent has changed marginally in the Farndon West and Farndon West FCAs since hydraulic modelling was completed. However, no further changes were made to the FCA representation in the modelling as the change in design was to allow for future design flexibility in land take rather than any change to the core flood mitigation feature in terms of level for level, volume for volume capacity provided. It is recommended at detailed design that a cross check of the final design is undertaken to ensure the modelling results remain representative.

Table 6-6 FCA summaries

FCA	Area (km^2)	Lowest elevation (mAOD)	Description
Kelham	0.10	North eastern side: 11.4 Connecting ditch: 11.0 South western side: 11.8	Flood storage area linked to the floodplain by five 0.6m diameter circular pipes. The FCA is surrounded by a bund to prevent exchange of flows between Mission Drain and the FCA.
Farndon West	0.12	10.1	Flood storage area located west of the scheme at Farndon
Farndon East	0.08	8.8	Flood storage area located east of the scheme at Farndon

6.1.9 A schematic of the scheme and FCA locations is presented in Figure **6**-**1**.

Figure 6-1: Scheme and FCA model schematic



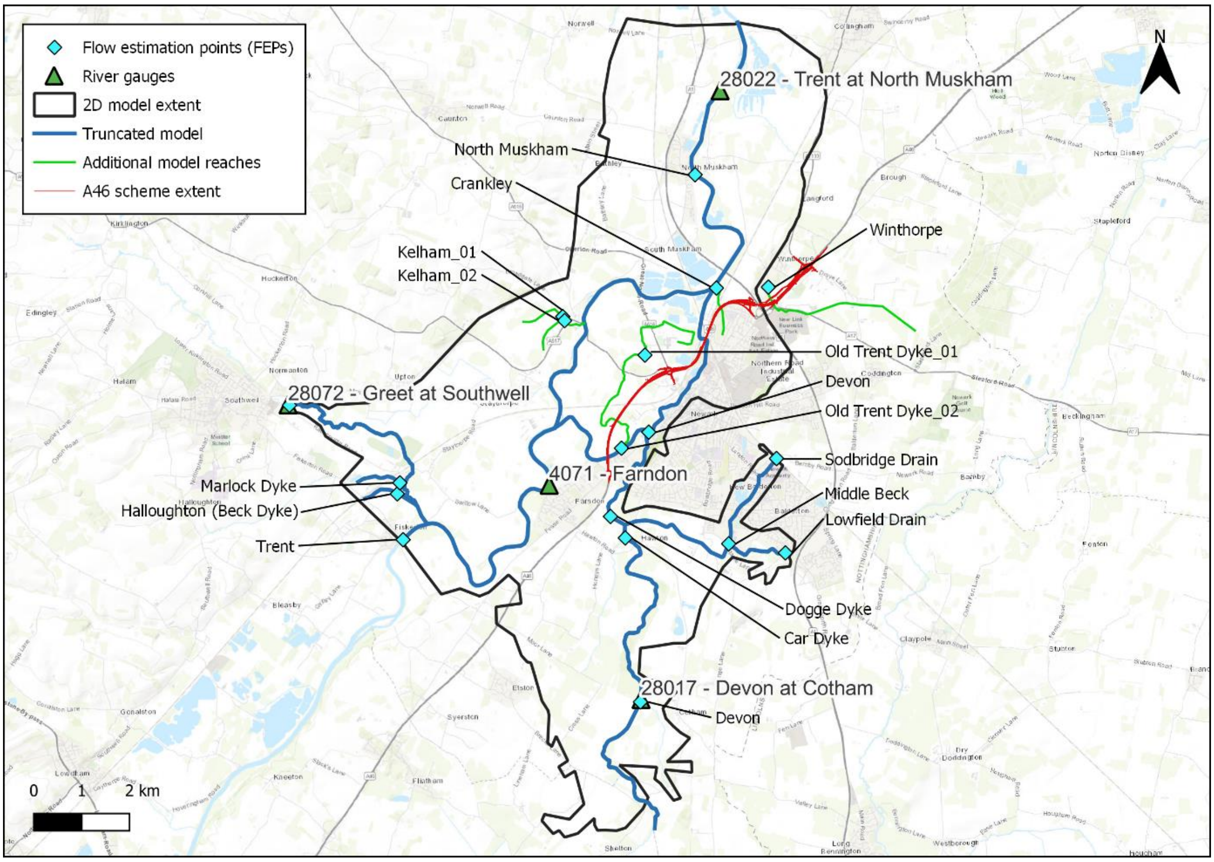
Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

7 Method of hydrological estimation

Hydrometric Data

7.1.1 Figure 7-1 presents the locations of flow estimation points and river gauges within the 2D hydraulic model domain.

Figure 7-1: Flow estimation points and river gauge locations



Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

7.1.2 There are three active flow gauging stations located within the study area; two on the River Trent at Colwick and North Muskham and one on the River Greet at Southwell. The River Devon at Cotham gauging station closed in December 2003. For the model, inflow hydrographs were estimated using the latest available hydrology data.

7.1.3 There is also a level gauging station on the River Trent at Farndon. Station details are tabulated below. For additional information on both the input hydrology data and the comparison events used for model calibration, see the Flood Estimation Report: A46 Newark Bypass Scheme.[10]

Table 7-1: Gauging stations (flow or level)

Watercourse	Station name	Gauging authority number	NRFA number	Catchment area (km²)	Type	Duration of record
River Trent	Colwick	4009	28009	7,486	Velocity area station	01/1958-present
River Trent	Farndon	4071	-	7,767	Level	10/1999-present
River Trent	North Muskham	4022	28022	8,231	Ultrasonic	09/1966-present
River Greet	Southwell	4072	28072	58.5	Crump Flat V weir	01/1974-present
River Devon	Cotham	4017	28017	284	Velocity area station	01/1966-12/2003

Hydrological estimation

7.1.4 Model inflows are based on flood estimates derived as part of a detailed hydrological assessment following the latest Flood Estimation Guidance (LIT 11832 – Flood estimation guidelines, July 2022) and the HiFlows dataset. Further detail is provided in the Flood Estimation Report.[8]

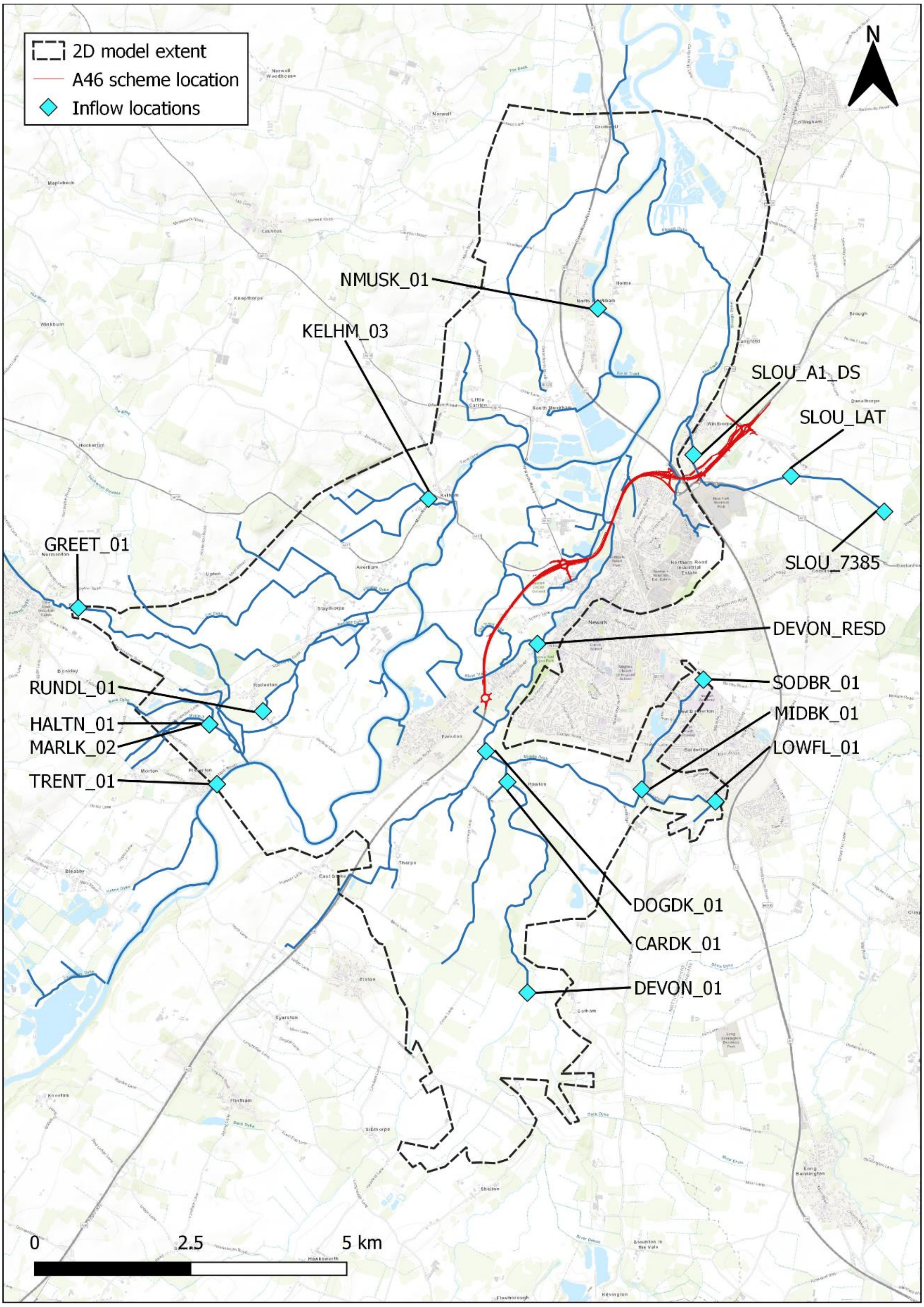
7.1.5 A summary of the results of the hydrological assessment is presented in Table 7-2. Figure 7-2 presents the inflow locations within the model domain.

[10] HE551478-SKAG-HDG-CONWI_CONW-RP-CD-00017

Table 7-2: Model inflows for a range of return periods

Flood peak (m^3/s) for the following return periods (in years)													
		2	**5**	**10**	**20**	**25**	**30**	**50**	**75**	**100**	**100 CC**	**200**	**1000**
Flood peak (m^3/s) for the following AEP (%) events													
		50	**20**	**10**	**5**	**4**	**3.3**	**2**	**1.3**	**1**	**1 CC**	**0.5**	**0.1**
Site code	**IED reference**	**Model Inflows**											
TRENT_01	Fiskerton	463	635	752	867	904	933	1018	1085	1134	1576	1252	2007
GREET_01	Greet	3.71	5.25	6.29	7.37	7.73	8.03	8.91	9.64	10.2	14.2	11.6	18.4
DEVON_01	RiverDevUS	29.9	42.6	51.5	60.9	64.1	66.8	74.7	81.4	86.4	120	100	132
DEVON_RESD	RiverDevLat	6.21	7.59	8.74	10.1	10.6	11.1	12.4	13.5	14.4	19.9	16.5	21.6
SODBR_01	NewarkSod	0.67	0.87	1.03	1.23	1.30	1.36	1.54	1.69	1.81	2.57	2.10	2.83
LOWFL_01	NewarkLow	0.16	0.21	0.25	0.30	0.32	0.33	0.38	0.41	0.44	0.63	0.51	0.69
MIDBK_01	NewarkMid	0.59	0.78	0.94	1.12	1.19	1.25	1.43	1.58	1.69	2.46	1.99	2.72
CARDK_01	CarDyke	8.40	12.0	14.5	17.1	18.0	18.8	21.0	22.9	24.3	33.8	28.0	38.4
DOGDK_01	DoggeDyke	1.20	1.48	1.71	1.98	2.07	2.16	2.41	2.64	2.82	3.95	3.28	4.45
MARLK_02	HalloughtonD	1.14	1.50	1.78	2.09	2.20	2.30	2.60	2.89	3.11	4.32	3.72	5.47
HALTN_01*	HalloughtonD	2.82	3.66	4.32	5.06	5.34	5.58	6.32	7.01	7.56	10.5	9.07	13.3
RUNDL_01	RundellDyke	5.27	6.86	8.10	9.51	10.0	10.5	11.8	13.1	14.1	19.6	16.9	24.5
KELHM_03	KelhLit&Gran	0.83	1.13	1.36	1.62	1.71	1.79	2.03	2.26	2.44	3.39	2.95	4.49
SLOU_7385	SLOU_7385	0.34	0.47	0.58	0.70	0.74	0.78	0.90	1.01	1.10	1.53	1.34	2.04
SLOU_A1_DS	SLOU_A1_DS	0.11	0.15	0.18	0.22	0.24	0.25	0.29	0.32	0.35	0.49	0.43	0.65
SLOU_LAT	SLOU_LAT	0.51	0.69	0.85	1.03	1.10	1.15	1.33	1.50	1.63	2.26	1.99	3.03
NMUSK_01	NorthMuskham	0.13	0.18	0.23	0.27	0.29	0.31	0.35	0.40	0.43	0.60	0.53	0.83
*Inflow has been combined with MARLK_02 in model													

Figure 7-2: Model inflow locations



Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

Storm duration

7.1.6 The initial hydrology assessment undertaken by Halcrow in 2011[11] indicated that the critical storm duration for the catchment was 48.1 hours. This selection was based on an extensive critical storm duration analysis produced by routing distributed ReFH units through the hydraulic model.

7.1.7 The design events for the ReFH lumped catchments are summarised in Table 7-3.

Table 7-3: Design events for ReFH2 method: Lumped catchments

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)
TRENT_01	Urban	-	-
GREET_01	Urban	Winter	15.0
DEVON_01	Urban	Winter	48.1
DEVON_02*	Urban	Winter	48.1
SODBR_01	Urban	Winter	48.1
LOWFL_01	Urban	Winter	48.1
MIDBK_01	Urban	Winter	48.1
CARDK_01	Urban	Winter	48.1
DOGDK_01	Urban	Winter	48.1
MARLK_01	Urban	Winter	13.0
HALTN_01	Urban	Winter	13.0
RUNDL_01	Urban	Winter	15.0
KELHM_01	Urban	Winter	7.5
KELHM_02	Urban	Winter	7.5
OLDTR_01	Urban	Winter	11.0
OLDTR_02*	Urban	Winter	11.0
CRANK_01	Urban	Winter	4.5
CRANK_02	Urban	Winter	4.5
WINTH_01	Urban	Winter	13.0
NMUSK_01	Urban	Winter	9.0
TRENT_02	Urban	-	-

7.1.8 There are sixteen inflows representing the modelled River Trent catchment extent and its tributaries. All inflows are applied in 1D as flow-time boundaries using either point inflows for the upstream boundaries or lateral inflows for the intermediate catchments. A conservative approach has been taken in the application of the hydrological inflows which means that the peak flows at the downstream end of the model are higher than the target peak flows (see Appendix C) by approximately 215m^3/s in the 1% AEP plus

[11] Halcrow 2011 River Trent & Tributaries at Newark Flood Risk & Hazard Mapping Study report

climate change event. Following the calibration assessment, scaling of flows were not conducted as peak flows and stage were within a reasonable range.

7.1.9 The lateral inflows in the A46 modelling are used to distribute flows to Slough Dyke, Middle Beck and Rundell Dyke.

7.1.10 At Slough Dyke, there is a lateral inflow at the downstream end of the 1D-modelled section which accounts for the unnamed Winthorpe drain.

7.1.11 There is a second lateral inflow that spreads the Slough Dyke intermediate catchment flows upstream of the A1 at approximately even intervals whilst accounting for the influence of roads and culverted reaches. The even weightings of this lateral inflow were adopted as a reasonable approach because uncertainties in the detailed flow paths through this industrialized area preclude a more refined distribution.

7.1.12 The lateral inflow for Rundell Dyke attaches to a single node, representing the confluence between Rundell Dyke and the Trent.

7.1.13 The Middle Beck inflow is distributed via the NewarkMid node with lateral weightings adopted from the 2011 study. The weightings distribute flows according to the presence of culverts and road crossings. Because this reach is peripheral to the aim of this study and the 100yr+CC peak flow is small compared to the flow in the Devon (2.3m³/s versus 120m³/s), no attempt was made to revise the 2011 approach.

Downstream boundary

7.1.14 The downstream limit of the model extends 1.2km downstream of the North Muskham gauge on the River Trent and 5km downstream of the A46 bypass. Its location was retained from the EA River Trent&Tribs 2011 model. The model applies a high tide level of 4.68mAOD.

7.1.15 The level applied to the downstream boundary was sensitivity tested as part of the 2011 hydraulic modelling assessment. Tidal boundaries of 4.68mAOD and 0.61mAOD assuming respective high and low tides were assessed, and results indicated no notable effect at the scheme location. The impact of the downstream boundary was limited to the immediate vicinity of North Muskham Gauge and had no impact upstream. To be conservative, the high tide level was taken as the downstream boundary level. A 2D_bc slope boundary was applied at the downstream of the 2D domain.

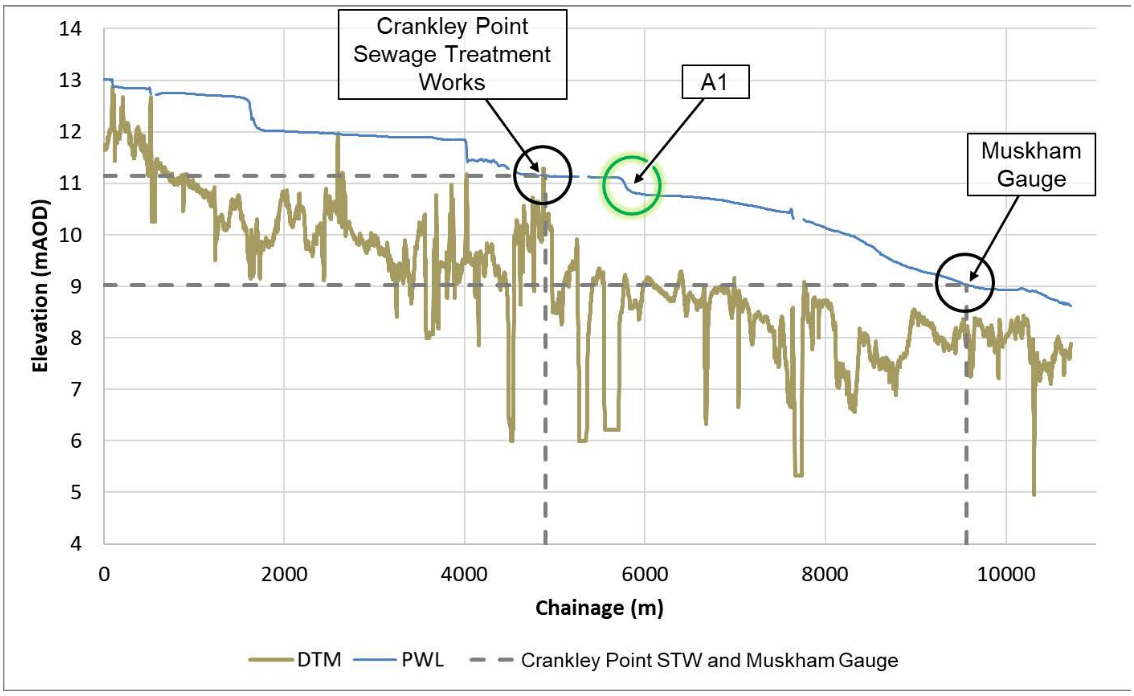
7.1.16 Other than updating the DTM using 2020 LiDAR, no changes were made to the downstream end of the hydraulic model compared to the Trent&Tribs 2011 model.

7.1.17 Sensitivity testing of the downstream boundary to the Trent&Tribs 2011 model was undertaken by varying the tidal boundary between 0.61mAOD and 4.68mAOD to represent the low tide and high tide extremes which are still relevant today. The 2011 results showed that the peak water level difference at Cromwell Weir is ~20mm, and the peak water level 800m upstream at North Muskham gauge is the same for both scenarios (9.3mAOD). Given that the downstream reach of the hydraulic model has not been altered from the Trent&Tribs 2011 modelling, the 2011 sensitivity testing remains relevant.

7.1.18 However, it is noted that the North Muskham gauge is 4.5km from the closest section of the scheme (near Severn Trent's Crankley Point Sewage Treatment Works (STW)). A long profile between North Muskham and Crankley Point STW shows a ~2.0m PWL difference in the design event, with a distinct 0.35m headloss associated with the A1 crossings (see Figure 7-3).

7.1.19 Therefore, the 2011 sensitivity testing remains relevant and there is a significant peak water level difference between the tidal impact limit at North Muskham gauge and the area impacted by the scheme. This means that the downstream boundary does not influence the modelling results and it was not necessary to undertake any further updates for this study.

Figure 7-3: 1% AEP + 39% climate change peak water level long profile



Slough Dyke hydrological inflows

7.1.20 The Slough Dyke watercourse was incorporated into the hydraulic model to understand the impacts of the proposed scheme to flood risk. Hydrological inflows were calculated for a catchment area of 3.2km^2 which includes the Slough Dyke and Winthorpe catchment areas.

7.1.21 Part of the culverted Slough Dyke watercourse was not accounted for in the hydrological inflows. A catchment drainage area was estimated based on LiDAR to determine an additional area of 1km^2. The additional catchment area has been used to upscale inflows.

7.1.22 As the Winthorpe watercourse has not been explicitly modelled in this study, catchment areas were separated into 3 inflows - SLOU_7385 (Upstream inflow), SLOU_LAT (Slough Dyke Lateral) and SLOU_6296 (Downstream of A1).

8 Climate change

8.1.1 To model the impact of flooding for future climate change scenarios, the peak flows for flood events were increased in accordance with EA guidance on the peak river flow allowances for schemes. The latest climate change guidance for FRAs was released in 2022 by the EA and last updated on 27 May 2022.[12]

8.1.2 The study area is situated in the Lower Trent and Erewash Management Catchment. The climate change allowances for this Management Catchment are shown in Table 8-1.

Table 8-1: Climate change allowances

Epoch	Central	Higher central	Upper end
2020s	13%	18%	29%
2050s	17%	23%	38%
2080s	29%	39%	62%

Source: (Climate change allowances for peak river flow in England data.gov.uk) accessed 28 July 2022)

8.1.3 Following discussion with the EA on 29 July 2022, it was decided that the higher central allowance (based on the 70th percentile) for the 2080s epoch would be applied. Applying the higher central allowance follows EA guidance with regards to provision of flood compensation in areas containing essential infrastructure and is also an FRA requirement for developments located in Flood Zone 3.

8.1.4 The climate change scenario will be applied to the 1% AEP event for the FRA requirement and the 0.5% AEP event for the highways design requirement. This has been applied by uplifting hydrographs by +39% by applying a scaling factor of 1.39 to all model inflows.

[12] Flood risk assessments: climate change allowances

https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

9 Model proving

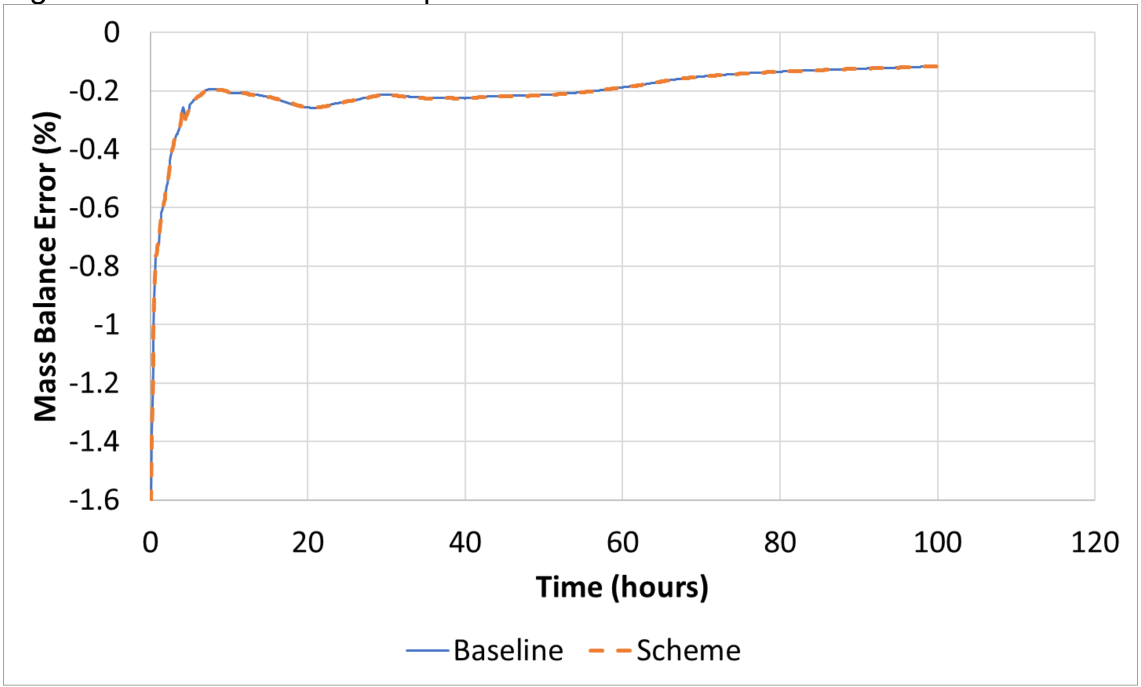
Baseline and scheme with mitigation run performance

9.1.1 Overall, satisfactory convergence was obtained for all return periods.

9.1.2 In the 1D domain, there is some non-convergence along Sodbridge Brook and Middle Beck due to culvert flows and flow passing from the 2D domain. However, the oscillations remain local to these channels and do not affect the water levels near the A46 scheme.

9.1.3 Figure 9-1 shows the 2D mass balance plots for the 1%AEP plus 39% climate change baseline and scheme run, which are almost identical. Mass balance drops below -1.6% before 0.25 hours, but beyond this remains above -1.0% throughout both model runs.

Figure 9-1: 2D mass balance plot for 1%AEP+39%CC baseline and scheme

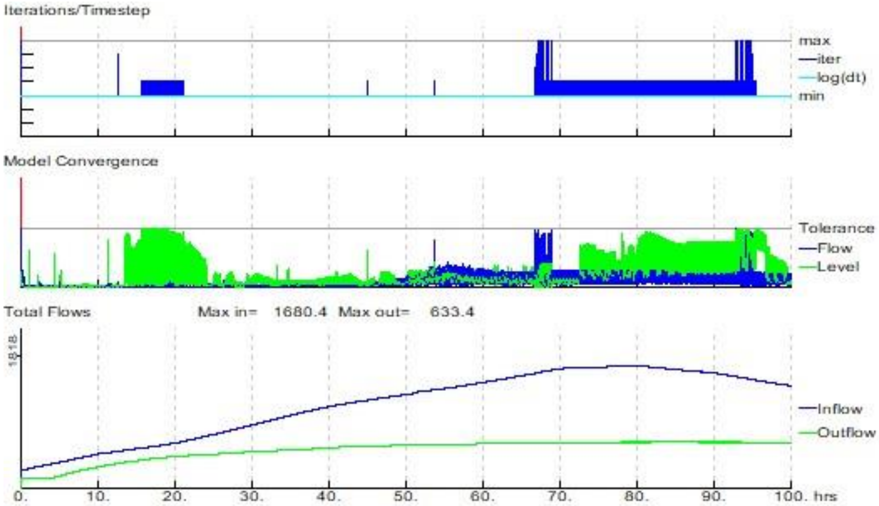


9.1.4 It is noted that across the model, fluctuations can be seen in the flow time series is caused by 1D-2D flow exchange. This is particularly predominant in the lower AEP events such as 1% AEP and 1% AEP plus climate change due to the depth of flood water over the floodplain and bank tops. The fluctuations are exhibited in the 1D water level time series, however, review of the 2D peak water levels near the scheme indicates that the instabilities caused by the 1D flow and level is not translated into the 2D domain.

9.1.5 Figure 9-2 and Figure 9-3 indicate that the 1D convergence is satisfactory throughout the 1% AEP plus 39% climate change event baseline and scheme model runs.

9.1.6 As shown in Figure 9-4 to Figure 9-6, the 20%, 5% and 3.33% AEP events exhibit poor convergence due to initial floodplain wetting between 5 and 15 hours. Nevertheless, convergence is satisfactory prior to the peak of the event.

Figure 9-2:: Baseline model 1D convergence - 1% AEP + 39% CC event



Datafile: ...\WORKING\UK_MODEL\FMP\DAT\A46_NB_BAS_117.DAT
Results: ...\RESULTS\A46_NB_FCA_100YR_2080_39CC_122.zzl
Ran at 23:49:05 on 15/11/2023
Ended at 06:39:19 on 16/11/2023
Start Time: 0.000 hrs
End Time: 100.000 hrs
Timestep: 2.5 secs

Current Model Time: 100.00 hrs
Percent Complete: 100 %

Figure 9-3: Scheme model 1D convergence - 1% AEP + 39% CC event

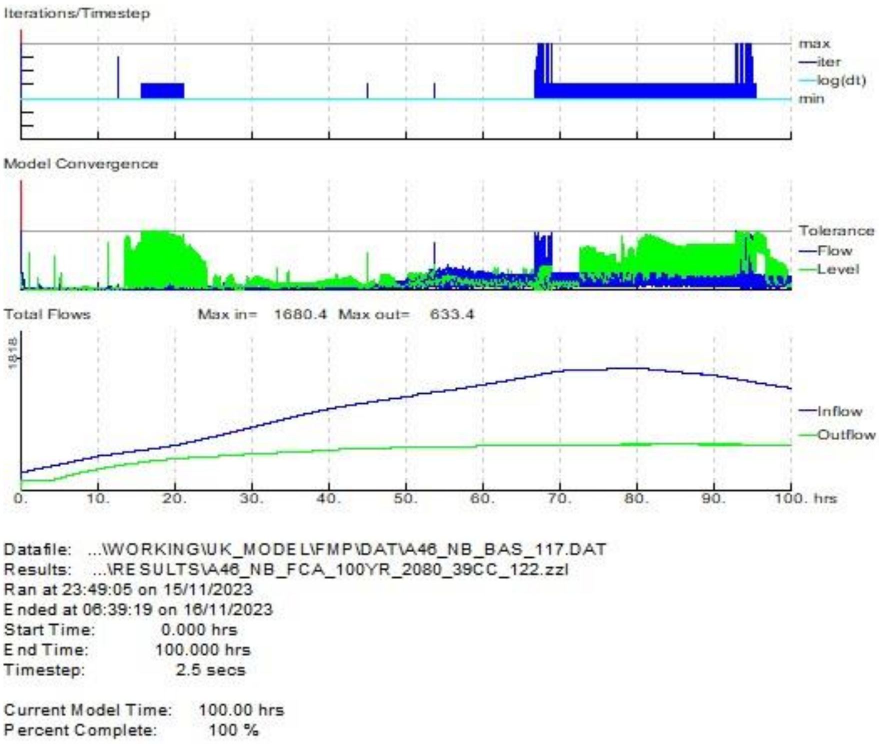


Figure 9-4: Baseline model 1D convergence - 20% AEP event

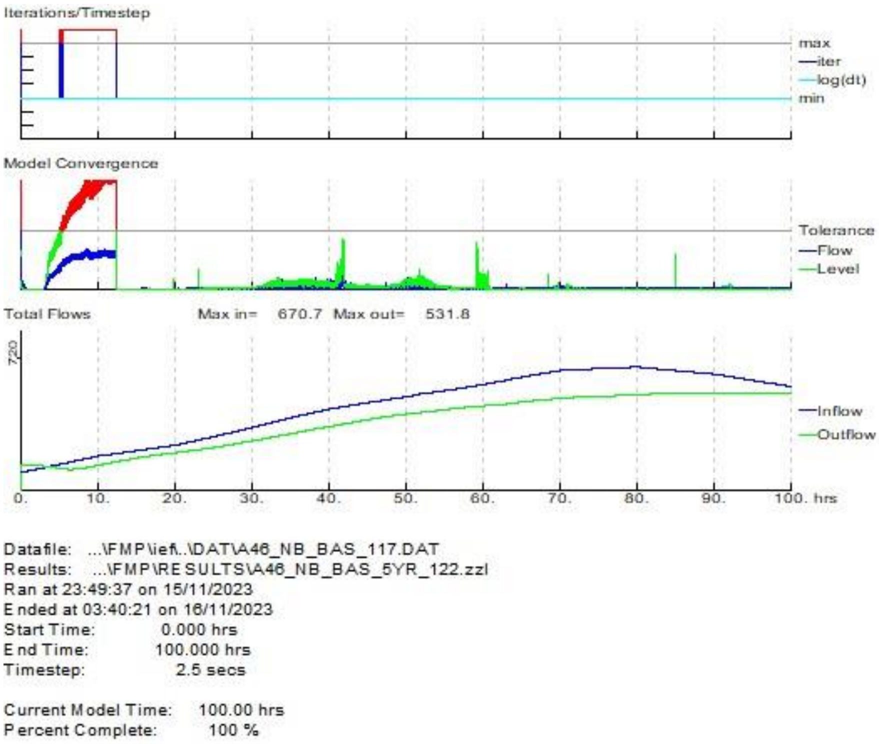


Figure 9-5: Baseline model 1D convergence - 5% AEP event

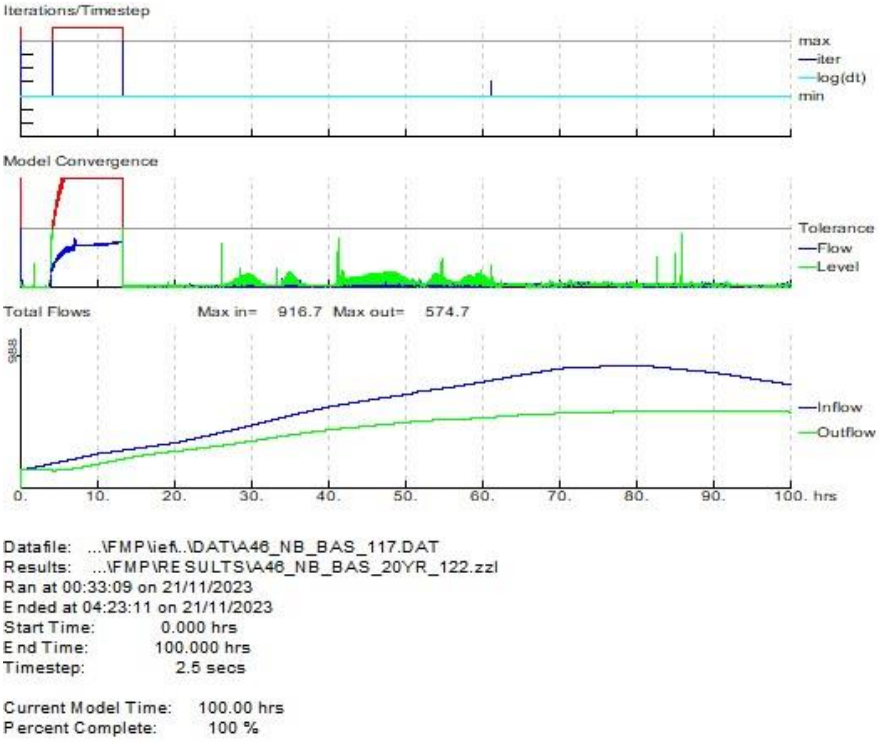
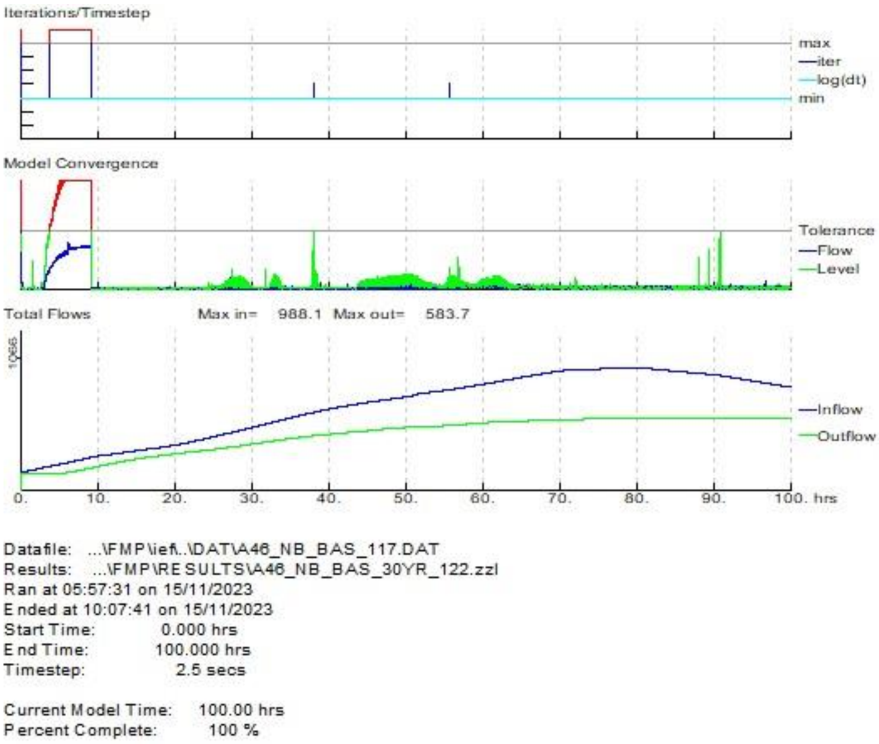


Figure 9-6: Baseline model 1D convergence - 3.33% AEP event



Temporary Works 3.33% AEP flood risk impact

9.1.7 There is some non-convergence in the 3.33% AEP models due to incipient flooding of the Riverside car park. This causes an underpass under the Nottingham to Lincoln railway line to exhibit flow that oscillates between positive and negative rapidly, producing minor instabilities in the flow over the cricket grounds that occupy the floodplain between Tolney Lane and the Kelham Road flood defence. The oscillations primarily affect the peak water levels at the cricket grounds but there are also minor impacts at Brewer's Wharf and between Kelham Road and Great North Road in the Trent Floodplain to the west of the scheme.

9.1.8 The oscillations in peak water level are of a similar magnitude for the baseline as they are for the temporary works model that includes stockpiles, making the peak water level results from these models comparable. Thus, for the temporary works with stockpiles, the modelling indicates a depth increase of approximately 40mm (±10mm due to the oscillations) during a 3.33% AEP event when compared to the baseline results.

9.1.9 However, the 3.33% AEP model for the temporary works *without* stockpiles does not exhibit instabilities in the railway underpass and a direct comparison with the baseline results leads to an exaggeration of the flood depth change. If the effect of the underpass instabilities is ignored, this leads to the impression that the temporary works without stockpiles produce a flood depth decrease of approximately 70mm, whilst the temporary works *with* stockpiles only leads to a flood depth decrease of approximately 50mm. This is clearly an unrealistic level of influence to attribute to the stockpiles given their relatively small size and remote location.

9.1.10 Due to the importance of understanding the flood risk impact of the temporary works and stockpiles, extra model tests were undertaken for the 3.33% AEP event in which the railway underpass was removed from the model. Removing the underpass from the 3.33% AEP model was justified on the basis that the net effect of the rapidly oscillating flow in the underpass is one of zero flow. It was also noted that, during the 3.33% AEP event, the peak water level either side of the underpass differs by less than 50mm so there is not a strong enough head to drive a significant flow through the underpass.

9.1.11 The extra modelling tests confirmed that, in the absence of the underpass, the oscillations in the peak water level over the cricket grounds were eliminated. Furthermore, the changes in flood depth compared to baseline were similar to the results reported above, with the exception of the temporary works without stockpiles which came into alignment with the results of the model for the temporary works with stockpiles. Thus, for the 3.33% event, the impact of the temporary works with or without stockpiles was confirmed as causing the same approximately 50mm decrease in flood depth.

9.1.12 It is notable that the flood depth across the cricket grounds is between 1.0m to 1.5m during the 3.33% AEP event and that the ±10mm error in peak water level discussed above is small compared to the depth. This means that the variation in flood depth due to the reported oscillations are not significant in terms of flood hazard.

9.1.13 Therefore, whilst a straight comparison of modelling results suggests otherwise, it has been confirmed that the temporary works (with or without stockpiles) are predicted to provide a similar reduction in flood depth of approximately 50mm over the area occupied by the cricket grounds during the 3.33% AEP event. Furthermore, the apparent impacts elsewhere at Brewer's Wharf and in the River Trent floodplain to the west of the scheme are also eliminated.

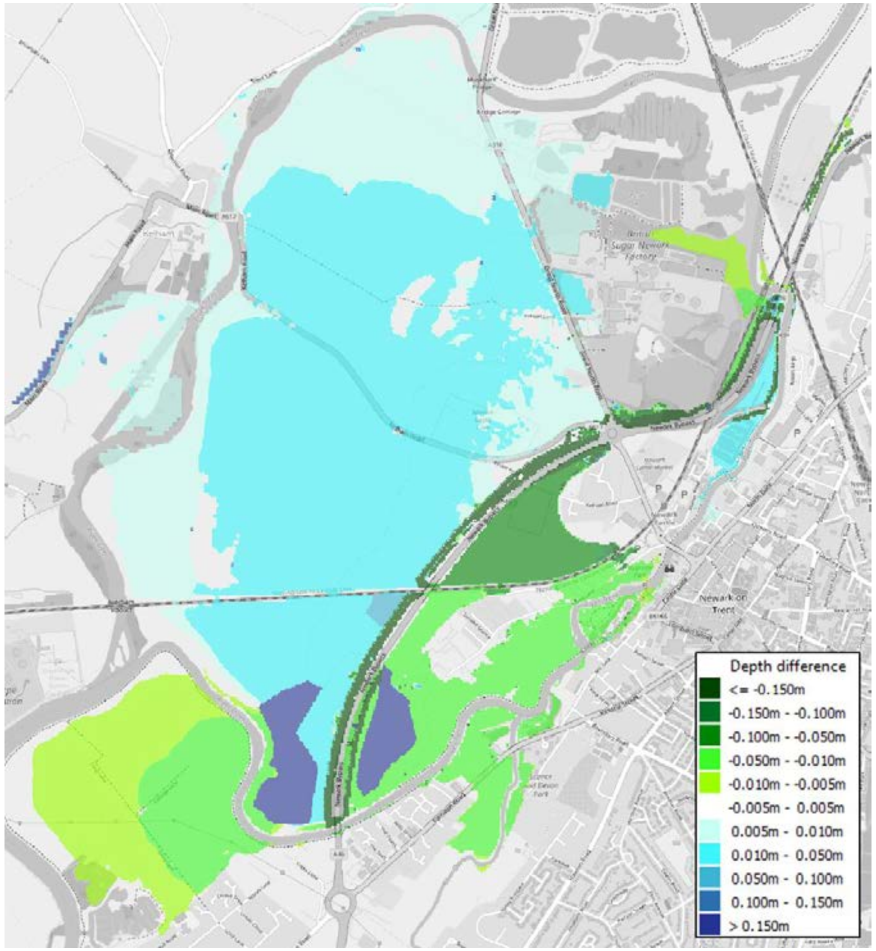
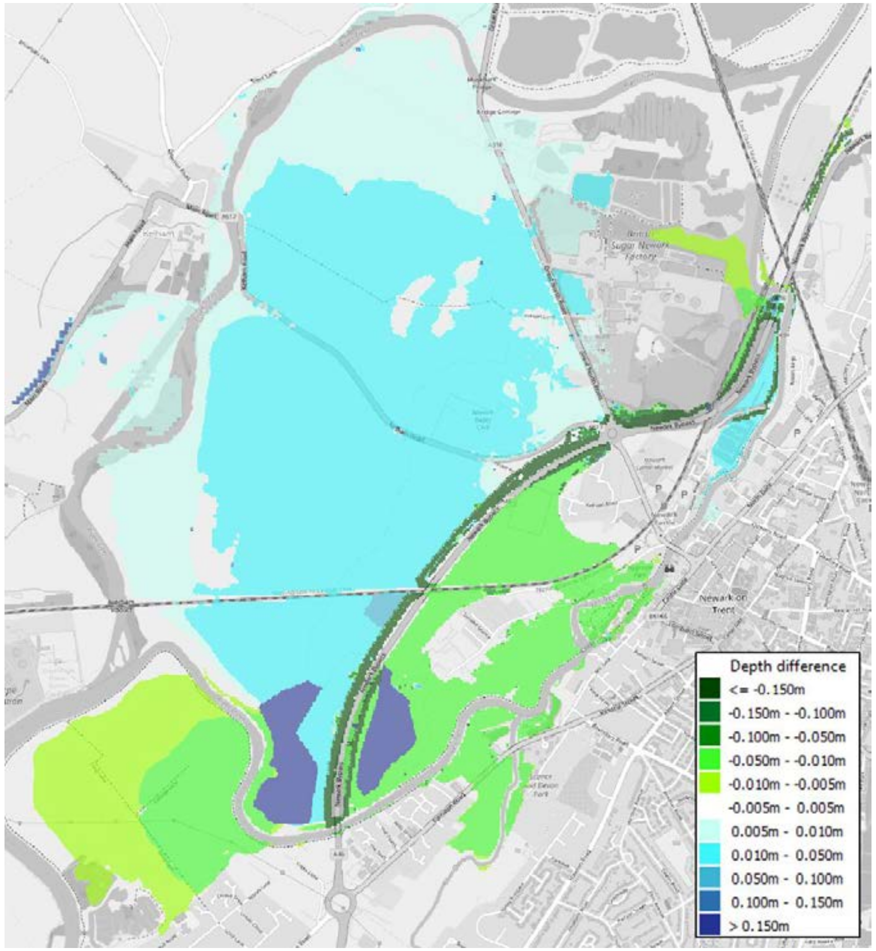
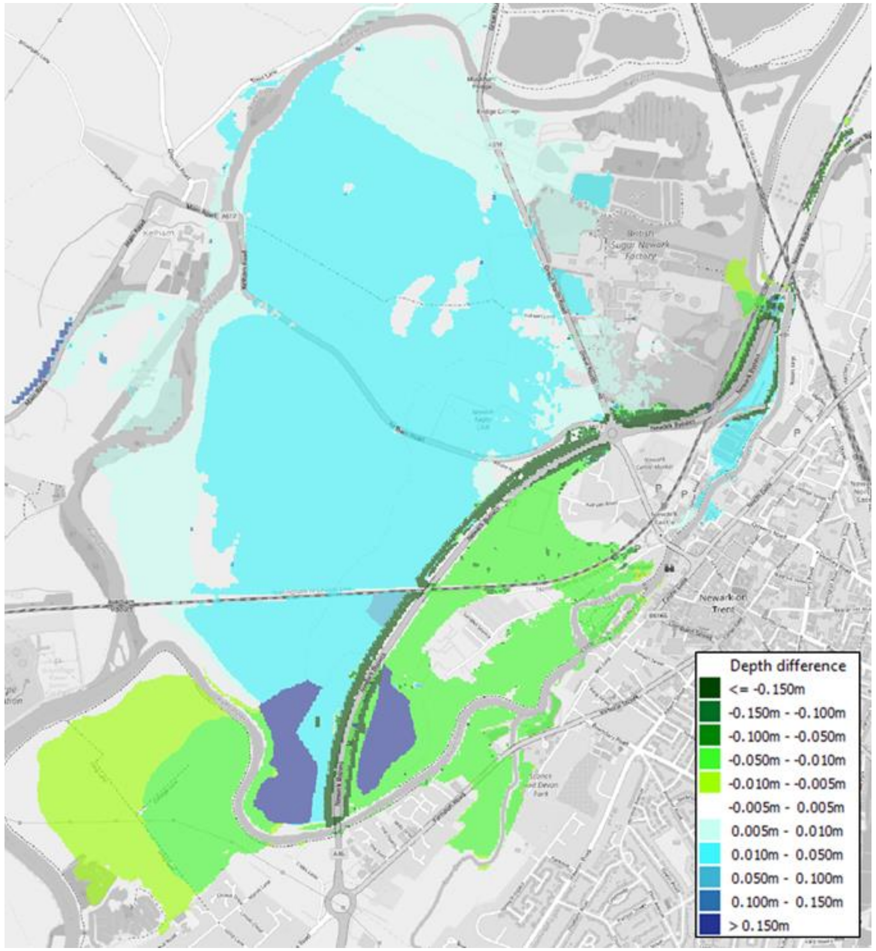
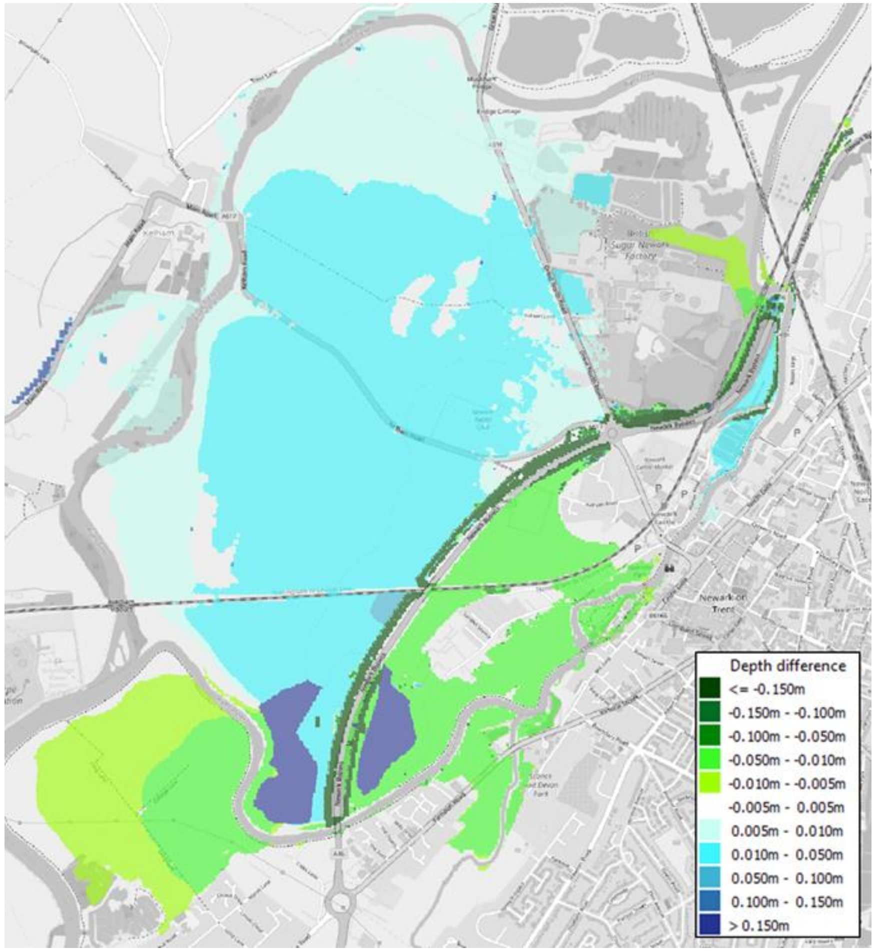
Figure 9-7: 3.33% AEP flood depth change from temporary works (no stockpiles) – with railway underpass	Figure 9-8: 3.33% AEP flood depth change from temporary works (no stockpiles) – no railway underpass
	
© OpenStreetMap. Data is available under the Open Database License.	© OpenStreetMap. Data is available under the Open Database License.

Figure 9-9: 3.33% AEP flood depth change from temporary works (with stockpiles) – with railway underpass	Figure 10: 3.33% AEP flood depth change from temporary works (with stockpiles) – no railway underpass
	

Model calibration

9.1.14 Event hydrology was derived by creating Thiessen polygons for the rainfall gauges at Calverton, Lambley, Staythorpe, and Waltham on the Wolds. The following catchments were weighted based on their proportion within the relative Thiessen polygons and rainfall series were then generated using ReFH2.3 for the following inflows:

- Winthorpe
- Sodbridge Drain
- Rundell Dyke
- Old Trent Dyke
- N Muskham Trib
- Middle Beck
- Marlock Dyke
- Lowfield Drain
- Unnamed Kelham
- Halloughton
- Greet at Southwell
- Dogge Dyke
- Devon at Cotham
- Crankley Point
- Car Dyke

9.1.15 The Winthorpe catchment was further proportioned into 3 inflows - SLOU_7385 (Upstream inflow), SLOU_LAT (Slough Dyke Lateral) and SLOU_6296 (Downstream of A1).

9.1.16 Farndon gauge is closest to the A46 scheme and has been operational since 1999. North Muskham gauge is downstream of the scheme and has been operational since 1966.

9.1.17 A check of the model performance was undertaken using the following calibration events:

- November 2012
- February 2020
- January 2021

9.1.18 Model verification was undertaken using data for the November 2019 event.

November 2012

9.1.19 In the November 2012 event, a good match was achieved between modelled results and measured data at the Farndon level gauge. During the rising limb, model results suggested higher water levels than that seen in the observed records, however, peak water levels were largely consistent around 170 hours.

9.1.20 Figure 9-11 shows a comparison of stage (solid line) and flow (dash line) at the North Muskham gauge. The stage comparison reveals closely aligned peak water levels around 130 hours, with a 0.15m difference between observed and modelled levels at the event's peak. The flow also shows a good match with a difference of 16m^3/s at the peak. Given the minimal 2% discrepancy in peak water levels and flows at 178 hours, no additional calibrations have been made to the model.

Figure 9-11: Comparison between observed and modelled stage at Farndon Level gauge for the November 2012 calibration event

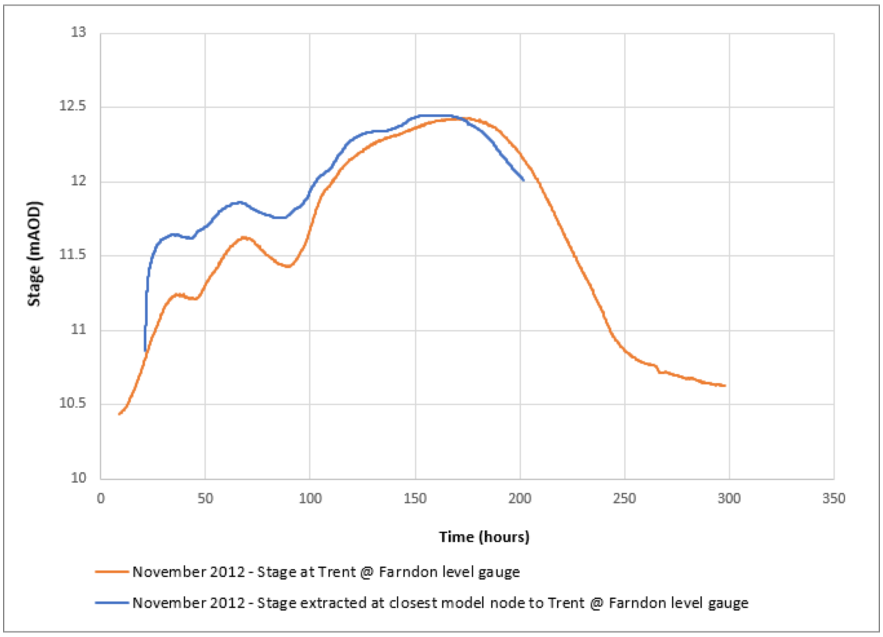
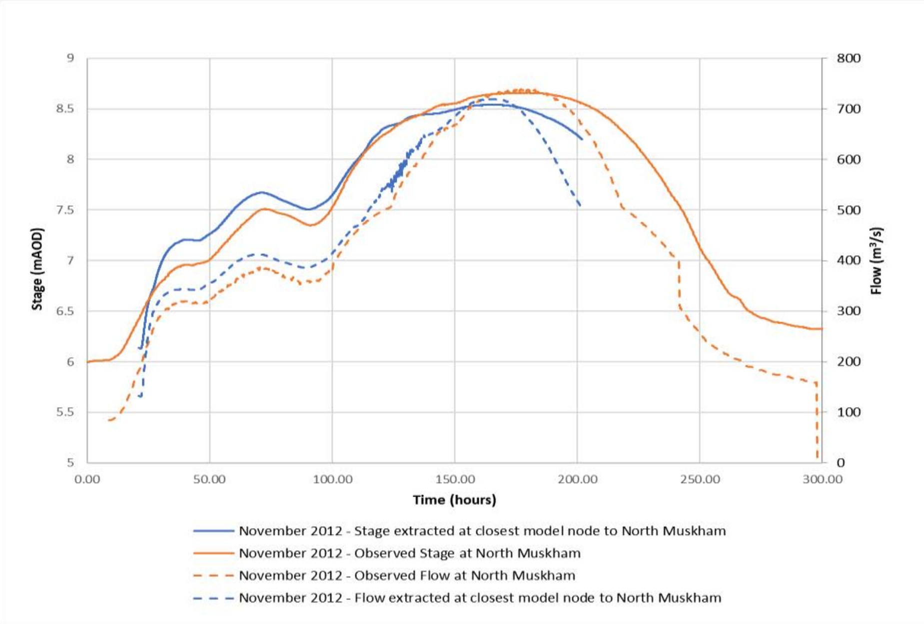


Figure 9-12: Comparison between observed and modelled stage and flow at North Muskham gauge for the November 2012 calibration event



February 2020

9.1.21 Figure 9-13 shows that at the Farndon level gauge a satisfactory match has been exhibited between the modelled and measured data. Peak water level closely aligned around 140 hours, with a slight 0.07m disparity between modelled and observed water levels.

Figure 9-14 shows a comparison of stage and flow at the North Muskham gauge. During the rising limb until the peak, both the stage and flow matches well with the observed data. Modelled and observed peak water levels and flow are closely aligned around 140 hours with a difference of 0.09m and 29m^3/s. Overall, the timing of the peak and shape of the rising limb show good consistency between modelled and observed data at North Muskham gauge.

Figure 9-13: Comparison between observed and modelled stage at Farndon gauge for the February 2020 calibration event

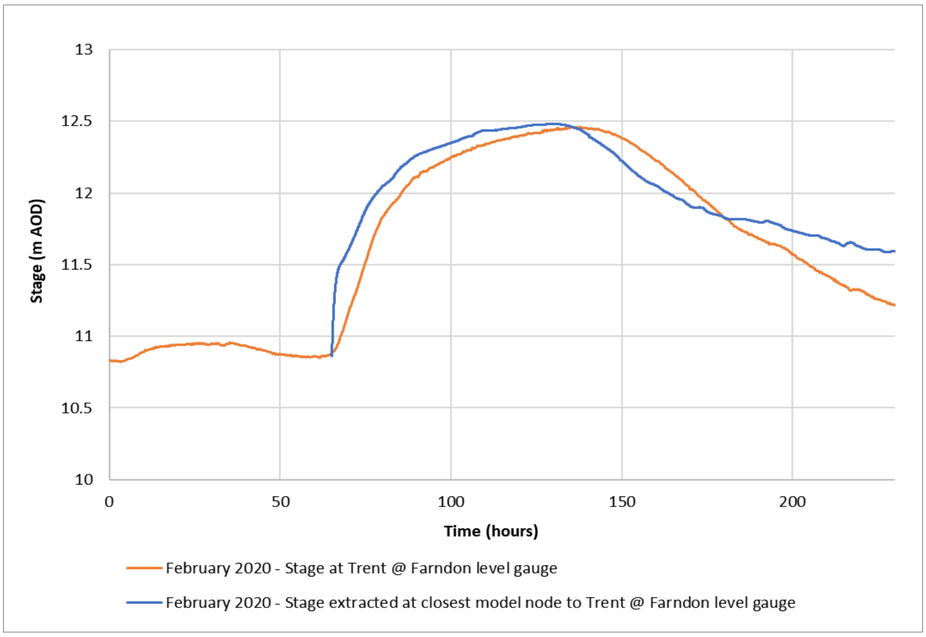
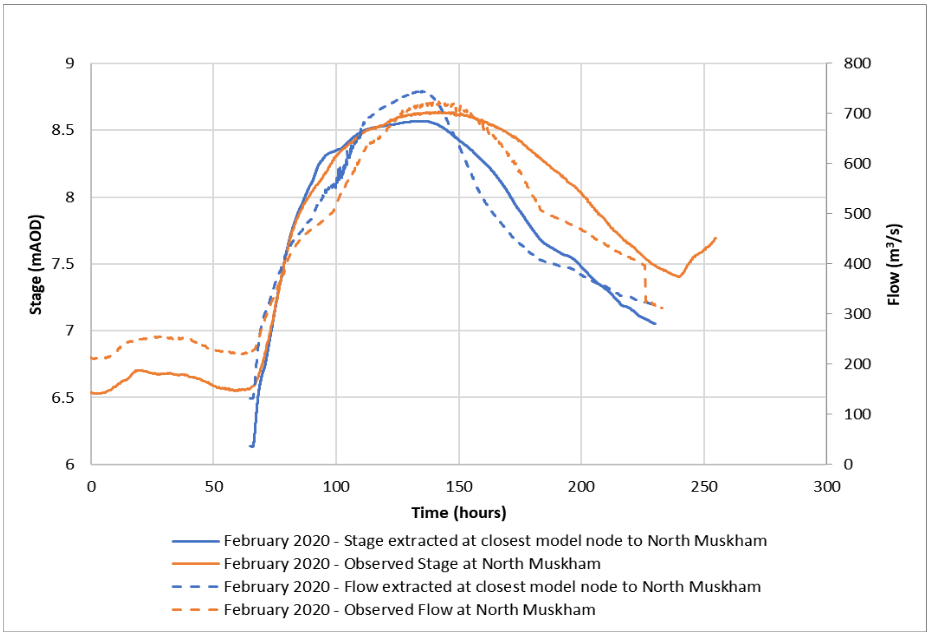


Figure 9-14: Comparison between observed and modelled stage and flow at North Muskham gauge for the February 2020 calibration event



January 2021

9.1.22 Figure 9-15 shows that for January 2021 event there is a good match in water level at Farndon gauge, with a 0.03m disparity between modelled and observed water levels.

9.1.23 Figure 9-16 shows that for the January 2021 event there is an underestimation of the water level at North Muskham gauge, with a maximum of 0.10m. The flow shows a good match with a disparity of $1m^3/s$.

Figure 9-15: Comparison between observed and modelled stage at Farndon gauge for the January 2021 calibration event.

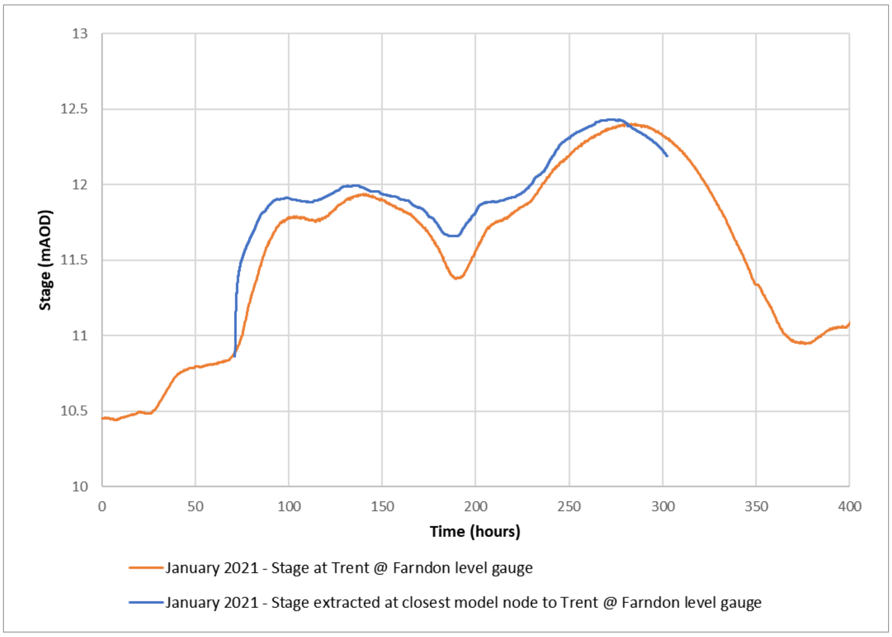
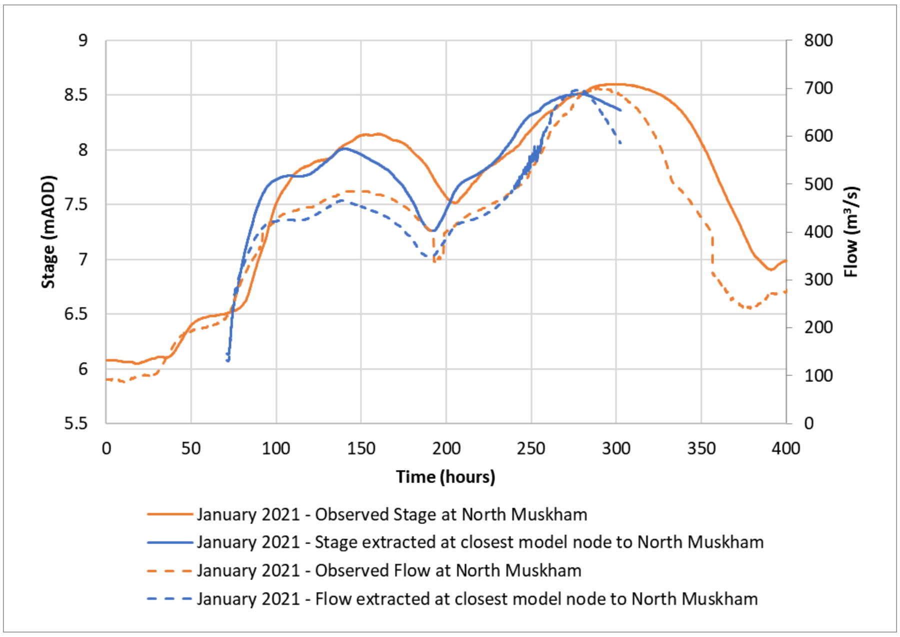


Figure 9-16: Comparison between observed and modelled stage and flow at North Muskham gauge for the January 2021 calibration event



Model verification

November 2019

9.1.24 The modelling methodology notes that the November 2019 will be used for model verification. The historical event took place between 05/11/2019 and 03/12/2019. The hydraulic model was run between 50 and 355 hours to capture the peak of the event only and to reduce overall run times.

9.1.25 This event consists of a fast response flooding with two peaks (around 100 hours and 260 hours). As shown in Figure 9-17, the Farndon level gauge indicates a good match between the modelled and observed data for this two-peak event. The modelled and measured peak water levels are closely aligned around 100 hours and 260 hours, with minor differences of 0.04m and 0.03m respectively.

9.1.26 Figure 9-18 shows a comparison of stage and flow at the North Muskham gauge. There is a good match at the first peak (difference of 0.09m). However, there is a tendency to underestimate the stage and flow at the second peak by a maximum of 0.24m and 96m^3/s. It is noted that the recorded level and flow at the Muskham gauge are higher in the second peak than the first, whilst at Farndon the second peak is lower than the first peak. This implies that the intermediate flows, such as from the Devon, made a larger than usual contribution to the overall flood peak in the second peak. Given the good match in flow and level during the calibration events at Farndon and North Muskham, and the good match on the first peak for the November 2019 event, it would not be beneficial overall to tune the inflow scaling and rainfall runoff parameters to address the discrepancy noted here.

Figure 9-17: Comparison between observed and modelled stage at Farndon gauge for the November 2019 calibration event

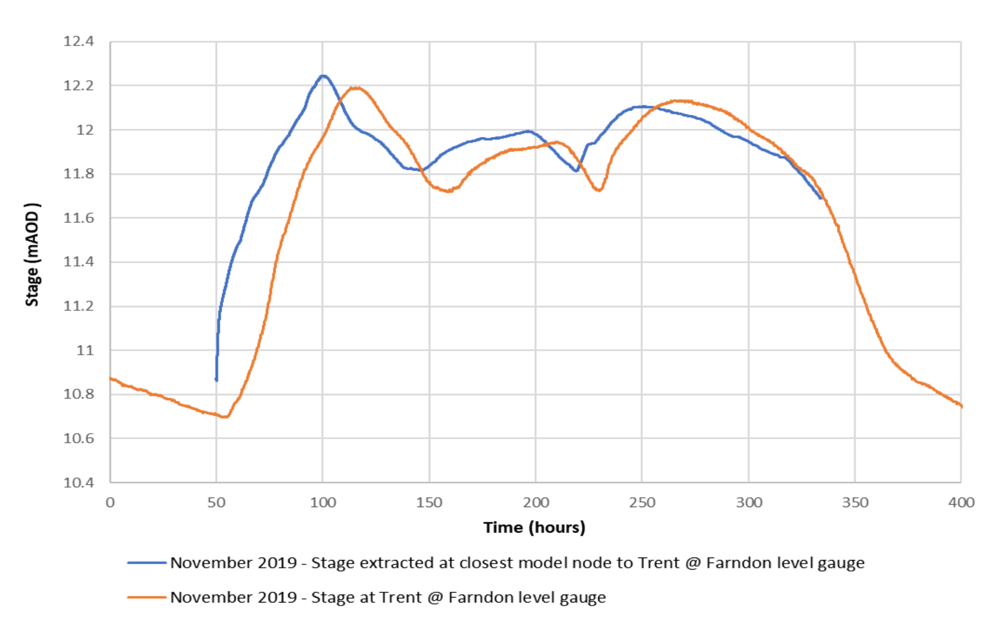
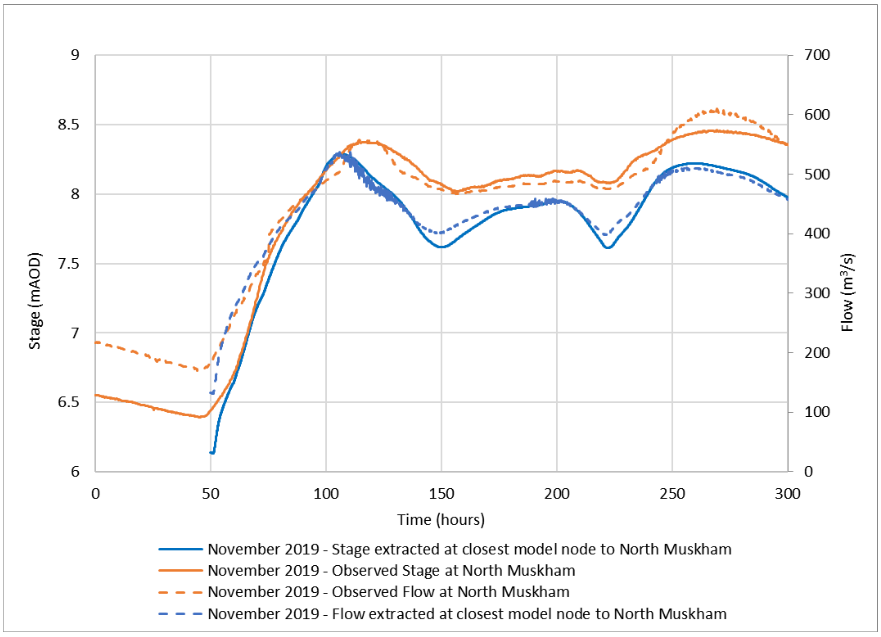


Figure 9-18: Comparison between observed and modelled stage and flow at North Muskham gauge for the November 2019 calibration event



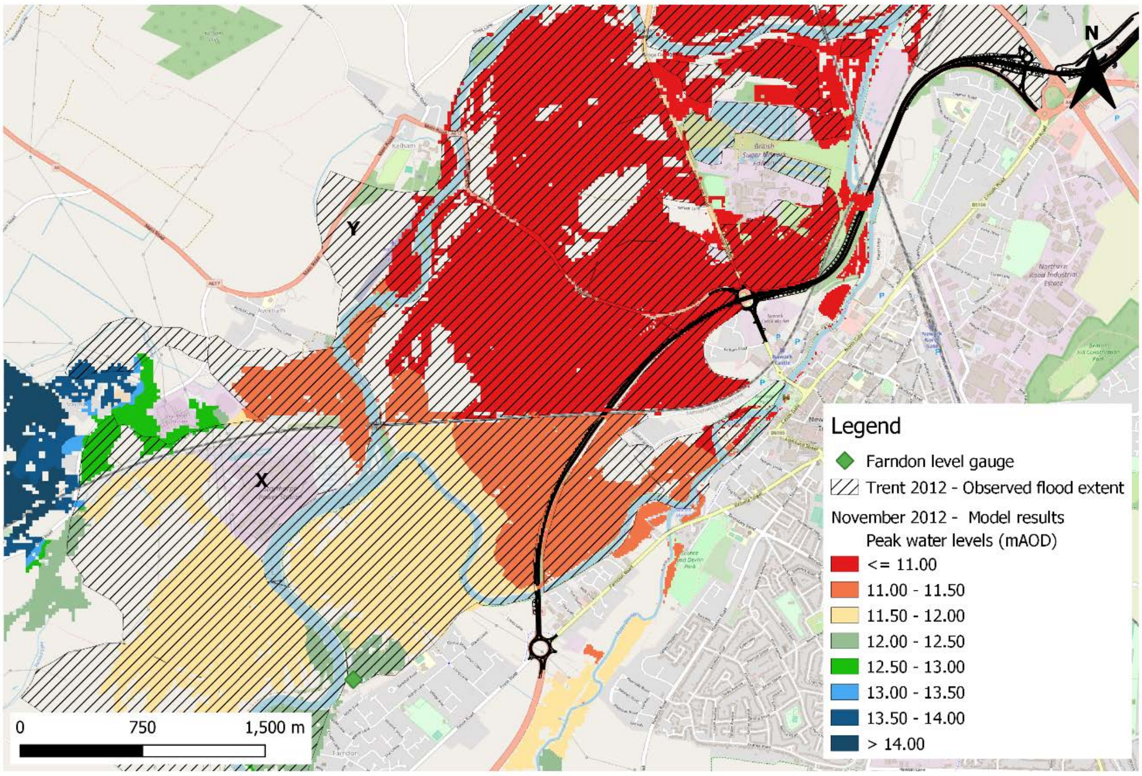
Model validation

9.1.27 The model results exhibit peak water levels that are generally higher at Farndon level gauge in all events. The Farndon gauge is the closest level gauge to the scheme, indicating that modelling results near the scheme provide a conservative estimate in peak water levels.

9.1.28 Flood extents were not available for the verification event, but they were available for the November 2012 event.

9.1.29 The observed flood extent shapefile indicates that Staythorpe Power Station had been affected by flooding (marked by Location X in Figure **9-19**) however, the modelling results did not show flooding.

Figure 9-19: Comparison between modelled and observed November 2012 flood extent



Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

9.1.30 In addition, photographs found through internet searches indicate that Staythorpe Power Station appears to have been unaffected by flooding on or around the 29/11/2012, the approximate date when the peak water levels were observed at Farndon Level Gauge.

9.1.31 Location Y shown in Figure 9-19, suggests that in the observed November 2012 event, there was flooding behind and over the A617. This is not possible as water levels must reach 12.4m AOD to overtop the road. Given that the observed peak water level during this event is 12.2m AOD at Farndon level gauge it is possible that the flooding in this location was not caused by the River Trent, therefore, no further changes were made to the model.

10 Model results

Impact of baseline model updates

10.1.1 The maximum water level results for the 1% AEP event have been compared to those of the original Trent&Tribs 2011 model, as shown in Table 10-1.

Table 10-1 Comparison of 1% AEP 1D Baseline Water Levels

Node	Maximum water level (mAOD)		Difference (m)
	Trent&Tribs 2011	MM 2023	
403546800	14.74	14.75	+0.01
403546800D	14.74	14.75	+0.01
403544340	14.22	14.23	+0.01
403544340DU	14.16	14.18	+0.02
403544340DD	14.16	14.18	+0.02
403543600DD	13.54	13.59	+0.05
403542630UU	13.13	13.19	+0.06
403542630UD	13.13	13.19	+0.06
403542630	13.13	13.19	+0.06
403542630D	13.13	13.19	+0.06
403540480	12.35	12.42	+0.06
403540480i1	12.27	12.35	+0.08
403540210	12.05	12.18	+0.13
403540210i1	12.41	12.20	-0.21
403540050R	12.4	12.28	-0.12
403540050Ri1	12.32	12.37	+0.04
403540050Ri2	12.36	12.40	+0.04
403536400	12.38	12.35	-0.03
403534950	12.29	12.23	-0.06
403534950D	12.29	12.23	-0.06
403534860	12.18	12.17	-0.01
403534860D	12.18	12.17	-0.01
403533730u	12.12	12.05	-0.07
403533730	12.12	12.05	-0.07
RD0000	12.13	12.06	-0.07
403533460i1	12.05	11.97	-0.08
403533250u	12.08	12.05	-0.03
403533250d	12.07	11.99	-0.09
403533250-a	12.07	11.99	-0.09
403532620u	11.60	11.57	-0.03
403532620d	11.55	11.52	-0.03
403531480u	10.86	10.97	+0.11
403531480d	10.86	10.97	+0.11
403531200u	11.04	11.12	+0.08
403531200d	10.96	11.06	+0.10
403530000u	10.72	10.71	-0.01
403530000d	10.72	10.71	-0.01
403530000n	10.72	10.71	-0.01
403515700u	10.75	10.66	-0.09
403515700	10.55	10.50	-0.06

10.1.2 There are minor changes in maximum water levels following updates to the hydraulic modelling. Throughout the model domain, water levels have generally either increased or decreased by below 0.1m to 0.2m.

10.1.3 Reasoning behind minor changes in maximum water levels are attributed to updates in the hydraulic model as summarised below:

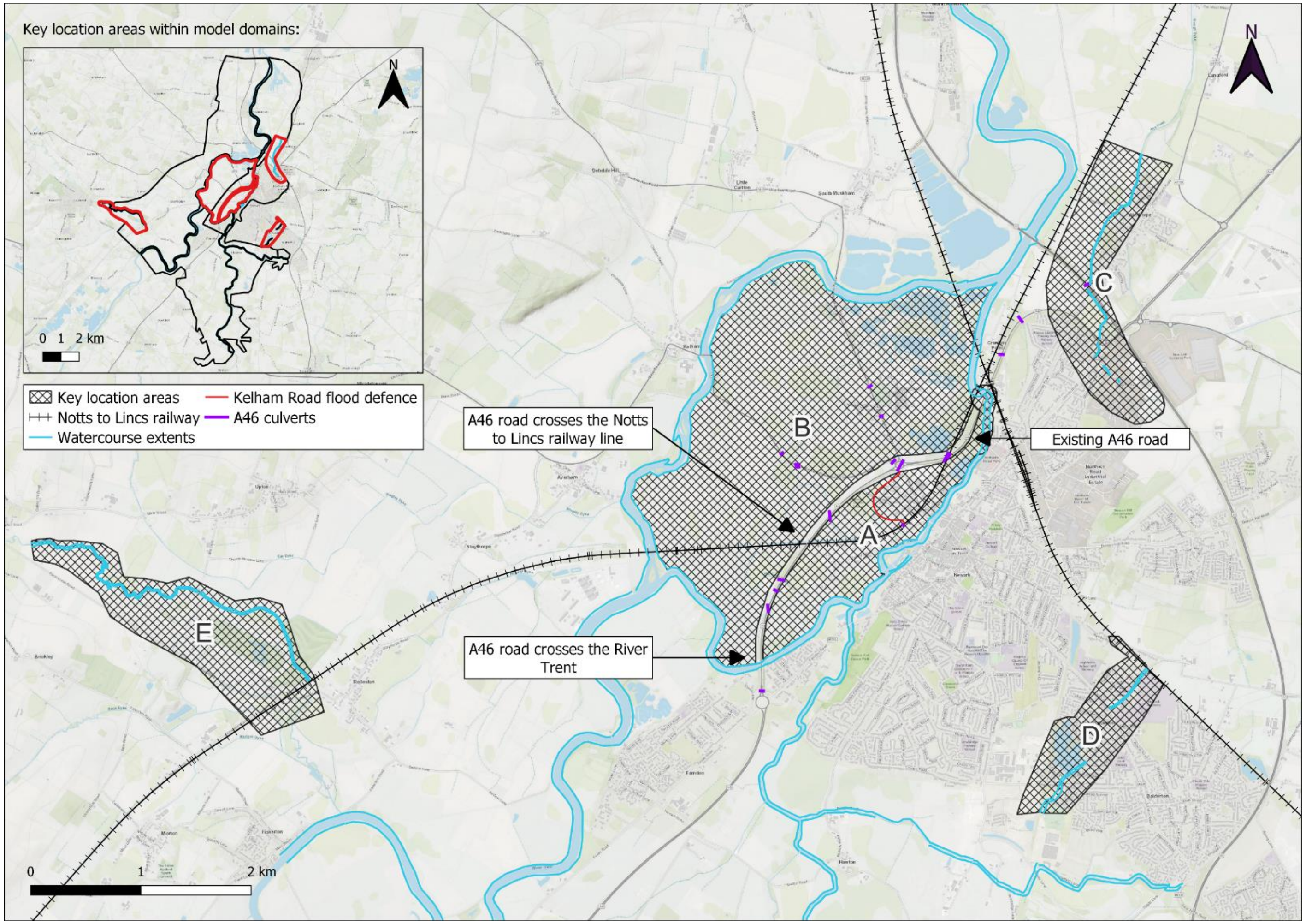
- Updated hydrology
- Inflow boundary conditions were updated to ensure that the current model hydrology is representative of the current catchment conditions. This has subsequently impacted water levels within the model.
- Updates to 1D channel and structure representation
- Several key structures near the A46, as summarised in Section 5 above, have been updated using new topographical survey. This is likely to have impacted flow conveyance in the River Trent and consequently maximum water levels.
- Updates to floodplain hydraulic roughness
- Changes in the roughness of the floodplain is likely to have impacted flow conveyance and therefore resulted in increased water levels in the River Trent particularly in areas where the urban extent has increased.
- The existing flood defence to the south of Cattle Market roundabout has been updated for this study. At the time of writing there are three conflicting sources of information on actual crest heights (Environment Agency defence database, LiDAR 2020, and topographic survey 2022). Where possible the 2022 topographic survey has been used in preference to other sources. It is recommended at detailed design stage that further data collection and analysis is undertaken on this asset to ascertain the resulting peak water level and any associated residual change in flood risk level as a consequence of the mitigated scheme.

Baseline flood risk

10.1.4 The baseline model was run to simulate results for the 50%, 20%, 10%, 5%, 3.33%, 2%, 1%, 1% + 39% climate change, 0.5% and 0.1% AEP events. Modelled flood extents and depths for each event are provided in Appendix C of the A46 FRA.

10.1.5 Results are presented and discussed for the 50%, 3.33% and 1% + 39% CC AEP events. Flood conditions at key locations throughout the model domain are summarised in Table 10-2. Figure 10-1 presents the key location areas within the model domain alongside key structures.

Figure 10-1: Key location areas



Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

Table 10-2: Summary of baseline results at key locations

Modelled event AEP %	Summary of flood conditions at key locations				
	Location A (Trent at A46)	**Location B (Trent at Kelham)**	**Location C (Slough Dyke)**	**Location D (Sodbridge Drain)**	**Location E (River Greet)**
50.00	No flooding of existing A46 road. Flooding to the east of A46. No flooding to the defended area at Kelham Road.	No flooding of existing A46 road. Widespread flooding to the west of A46.	Some flooding downstream of A1 Road	No flooding.	No flooding.
3.33	No flooding of existing A46 road. Widespread flooding to the east of the A46 road. No flooding to the defended area at Kelham Road.	No flooding of existing A46 road. Widespread flooding to the west of A46.	Flooding downstream of A1 Road	Localised flooding of Grove Street, Willow Road and Glebe Park. It is noted that New Orchard School is impacted but this isn't classified under the NRD.	Localised flooding across floodplain. No flooding of "more vulnerable" receptors.
1.00 + 39% CC	No flooding of existing A46 road. Widespread flooding to east of A46. Flooding of defended area at Kelham Road. Impact to 162 receptors. Of which 117 are "more vulnerable" receptors.	No flooding of existing A46 road. Widespread flooding to west of A46. Impact to 169 receptors identified. Of which 18 are "more vulnerable" receptors.	Localised flooding of Brunel Drive, Enterprise Park, and Stephenson Way. Widespread flooding near Winthorpe. A total of 12 receptors within the 1% AEP + 39% CC flood extent within Location C. However, only one property, namely Trent Cottage is a "more vulnerable" receptor.	Localised flooding of Grove Street, Willow Road, and Glebe Park. It is noted that New Orchard School is impacted but this isn't classified under the NRD.	Widespread flooding across floodplain, Racecourse Road, and Station Road. Impact to 58 receptors.

10.1.6 The following conclusions have been drawn from the baseline hydraulic modelling results at each location as summarised in Table 10-2.

Location A: River Trent at A46

10.1.7 This location refers to the right reach of the River Trent following its bifurcation at the sewage works near Averham. It is located approximately 0.7km east of the A46 at its farthest point.

- Overtopping of the left bank of the River Trent is the source of flooding at this location. This results in widespread flooding to the southeast of the A46 that increases in extent and depth with event magnitude. Depths are in the range of 1 to 3m during the 1% AEP + CC event.
- Initially, flows move eastwards and cross to the west of the A46 through Pipe Culvert No 5, the Farm Access Culvert and Pipe Culvert No 6, and via the archway at the southern side of the Nottingham to Lincoln railway crossing.
- Flow from this source also move north eastwards on the eastern floodplain. It overtops the Nottingham to Lincoln railway line at a low point and enters the area behind the flood defence near Kelham Road which is already flooded by flows from the west.
- During the 1% AEP + CC event only, flow from this source enters the defended area at Kelham Road via a low point in the Nottingham to Lincoln railway line further west near Great North Road. This results in flood depths in the range of 1 to 3.5m and impacts 162 receptors. A flood relief culvert at Cattle Market roundabout enables flow from this area to pass to the north.
- Where the A46 crosses the River Trent near Crankley Point, flows sourced from overtopping circulate on the floodplain but do not cause the A46 to flood.

Location B: River Trent at Kelham

10.1.8 This location refers to the left reach of the River Trent following the bifurcation. It is located approximately 2km west of the A46 at its farthest point.

- Overtopping of the right bank of the River Trent is the source of flooding at this location. This results in widespread flooding to the west of the A46 during the 3.33% and 1% + CC AEP events but is more localised during the 50% AEP event. Depths are in the range of 1 to 4m.
- Flows from this source move eastwards on the floodplain and join with flows crossing from the east of the A46. This combined flow overtops the Nottingham to Lincoln railway line at three low points and moves northwards through the floodplain along the A46. This does not cause flooding of the A46 during any of the reported events.
- Some of this combined flow moves back to the east of A46 via Pipe Culvert No7 following the route of Old Trent Dyke. It also moves to the east via the northern arch of the Nottingham to Lincoln railway crossing. This results in flooding of the area behind the flood defence near

Kelham Road at depths between 1 and 3m during the 1% + CC AEP event.

Location C: Slough Dyke

- No flooding occurs during the 50% and 3.33% AEP events upstream of the A1. Downstream of the A1, overtopping of the left bank occurs in the event
- Localised flooding sourced from overtopping of the left and right banks occurs during the 1% + CC AEP event. Flood depths are below 1m. No critical receptors are impacted.
- Widespread flooding occurs during the 1% AEP + CC event near Winthorpe due to overtopping of the Slough Dyke left bank and nearby River Trent right bank. Flood depths are between 1 and 2.5m.

Location D: Sodbridge Drain

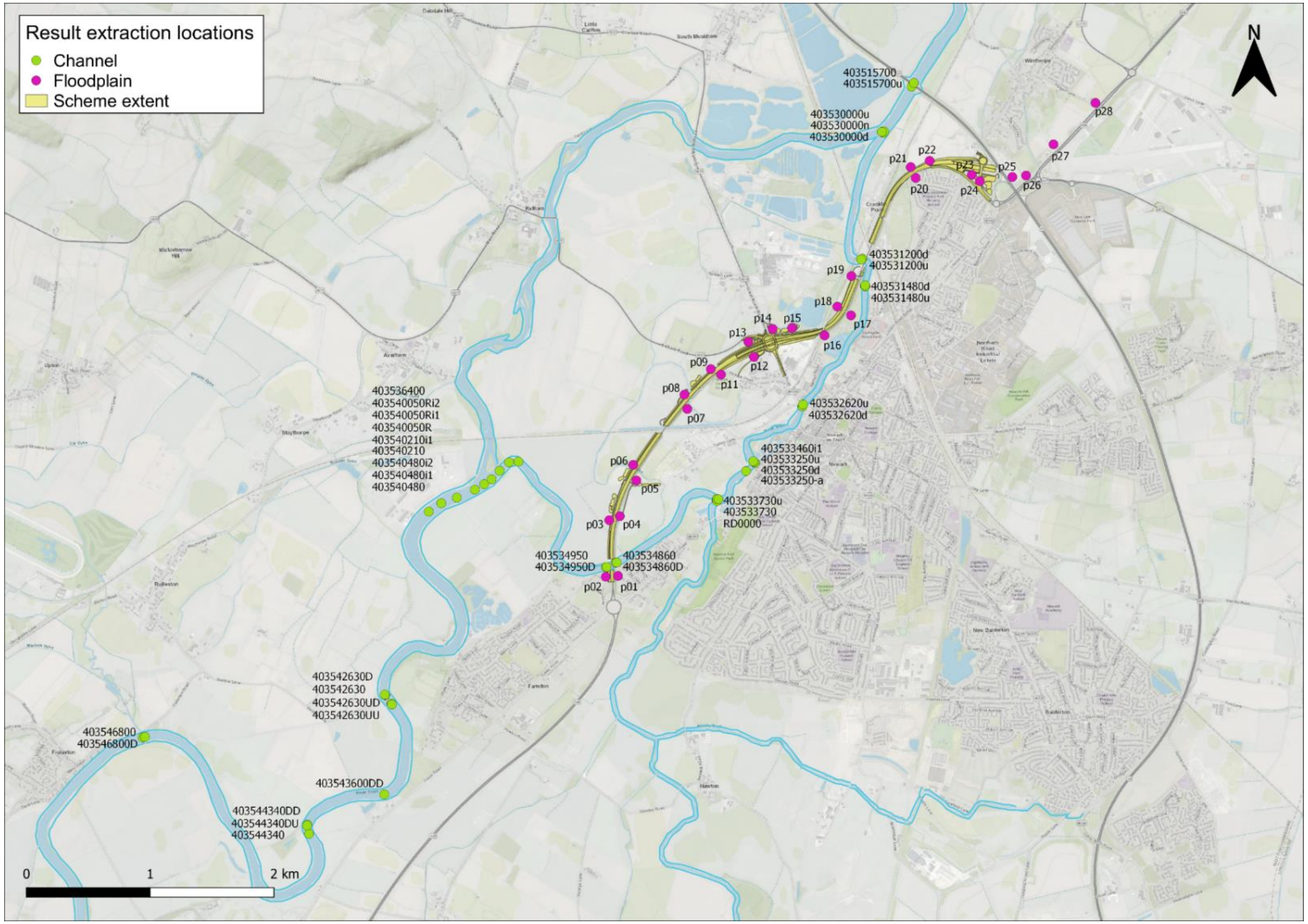
- No flooding occurs during the 50% AEP event.
- Localised flooding sourced from overtopping of the left and right banks occurs during the 3.33% AEP and 1% + CC AEP event. Flood depths are below 1m.
- Flooding is seen at New Orchard School despite not being included in the National Receptors Database.

Location E: River Greet

- No flooding occurs during the 50% AEP event.
- Localised flooding sourced from overtopping of the left and right banks occurs during the 3.33% AEP event. Flood depths are generally below 1m, but this level is exceeded at localised locations. No critical receptors are impacted.
- Widespread flooding across the floodplain and at Racecourse Road and Station Road occurs during the 1% + CC AEP event. This is sourced from overtopping of the River Greet left and right banks. This impacts 58 receptors ranging from more vulnerable to less vulnerable associated with Southwell Racecourse and Southwell Golf Course. Flood depths are generally between 1-2m.

10.1.9 Baseline flood levels have been extracted at key locations in the channel and on the floodplain as shown in Figure 10-2. They are presented in Table 10-3 for each of the reported events.

Figure 10-2: Result extraction locations



Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

Table 10-3: Model results for selected design events at extraction locations

Location	Node/ point name	% AEP event		
		50	3.33	1% AEP + 39% CC
Channel (1D)	403546800	13.444	14.484	15.088
	403546800D	13.444	14.484	15.088
	403544340	12.769	13.978	14.487
	403544340DU	12.707	13.918	14.430
	403544340DD	12.707	13.918	14.430
	403543600DD	12.522	13.405	13.808
	403542630UU	12.307	13.087	13.381
	403542630UD	12.307	13.087	13.381
	403542630	12.279	13.089	13.376
	403542630D	12.279	13.089	13.376
	403540480	11.655	12.159	12.900
	403540480i1	11.633	12.096	12.839
	403540210	11.597	11.976	12.615
	403540210i1	11.643	12.020	12.601
	403540050R	11.683	12.097	12.685
	403540050Ri1	11.725	12.189	12.745
	403540050Ri2	11.730	12.214	12.800
	403536400	11.687	12.152	12.747
	403534950	11.443	11.982	12.696
	403534950D	11.443	11.982	12.696
	403534860	11.408	11.925	12.613
	403534860D	11.408	11.925	12.613
	403533730u	11.204	11.778	12.524

	403533730	11.204	11.778	12.524
	RD0000	11.210	11.791	12.530
	403533460i1	11.143	11.721	12.373
	403533250u	11.130	11.778	12.532
	403533250d	10.984	11.692	12.481
	403533250-a	10.982	11.692	12.481
	403532620u	9.837	11.212	12.093
	403532620d	9.826	11.176	12.001
	403531480u	9.344	10.552	11.393
	403531480d	9.344	10.552	11.393
	403531200u	9.278	10.692	11.574
	403531200d	9.082	10.623	11.507
	403530000u	9.017	10.341	11.135
	403530000d	9.017	10.341	11.135
	403530000n	9.017	10.341	11.135
	403515700u	8.908	10.278	11.081
	403515700	8.844	10.142	10.832
Floodplain (2D)	p01	Not in flood extent	Not in flood extent	12.670
	p02	Not in flood extent	Not in flood extent	12.839
	p03	11.032	12.023	12.738
	p04	11.253	11.880	12.578
	p05	11.250	11.879	12.576
	p06	10.967	11.962	12.683
	p07	10.676	11.357	12.074
	p08	10.701	11.335	11.985
	p09	10.694	11.312	11.954
	p10	10.397	11.198	11.894
	p11	10.669	11.350	12.074

	p12	10.615	11.338	12.072
	p13	10.691	11.311	11.942
	p14	10.401	11.202	11.899
	p15	10.397	11.198	11.894
	p16	Not in flood extent	Not in flood extent	11.879
	p17	Not in flood extent	10.817	11.726
	p18	Not in flood extent	10.605	11.490
	p19	9.489	10.605	11.491
	p20	Not in flood extent	Not in flood extent	Not in flood extent
	p21	Not in flood extent	Not in flood extent	Not in flood extent
	p22	Not in flood extent	Not in flood extent	Not in flood extent
	p23	Not in flood extent	Not in flood extent	Not in flood extent
	p24	Not in flood extent	Not in flood extent	Not in flood extent
	p25	Not in flood extent	Not in flood extent	Not in flood extent
	p26	Not in flood extent	Not in flood extent	Not in flood extent
	p27	Not in flood extent	Not in flood extent	Not in flood extent
	p28	Not in flood extent	Not in flood extent	Not in flood extent

Scheme with mitigation model results

1D water level comparison

10.1.10 Table 10-4 displays the results from the scheme with mitigation scenario and a comparison with baseline levels for 1D nodes on the River Trent near the proposed scheme. Findings imply that the differences between the baseline and scheme with FCA mitigation fall within the range of ±0.01m. Between nodes 403535660 and 403534800 showcase a water level difference of less than -0.01m, this is likely due to the deployment of the proposed Farndon West FCA.

Table 10-4: 1D water level comparison between baseline and scheme with FCA mitigation in the 1% AEP + 39% climate change

	1% AEP + 39% climate change		
Node reference	**Scheme with FCA mitigation (m AOD)**	**Baseline (m AOD)**	**Difference (mm)**
CS_124	12.748	12.753	-0.005
403540210	12.612	12.615	-0.003
403540050R	12.681	12.685	-0.004
403536400	12.748	12.747	0.001
403536150	12.761	12.766	-0.005
403535880	12.735	12.735	0.000
403535660	12.765	12.774	-0.009
403535470	12.795	12.813	-0.018
403535470d	12.802	12.820	-0.018
403535230	12.782	12.799	-0.017
403534950	12.687	12.696	-0.009
403534950D	12.687	12.696	-0.009
403534860D	12.604	12.613	-0.009
403534800	12.585	12.593	-0.008
403534700	12.575	12.582	-0.007
403534480	12.575	12.579	-0.004
403534230	12.571	12.574	-0.003
403533990	12.546	12.549	-0.003
403533730u	12.521	12.524	-0.003
403533730	12.521	12.524	-0.003
403533460	12.496	12.499	-0.003
403533250u	12.529	12.532	-0.003

403533250d	12.478	12.481	-0.003
403533250-a	12.478	12.481	-0.003
403533250-L	12.478	12.481	-0.003
NewBr1u	12.461	12.464	-0.003
NewBr1d	12.445	12.448	-0.003
NewBr2	12.433	12.436	-0.003
NewBr3	12.340	12.342	-0.002
403532900-L	12.310	12.312	-0.002
403532900	12.310	12.312	-0.002
403532850	12.221	12.222	-0.001
403532810	12.284	12.285	-0.001
403532670	12.112	12.114	-0.002
403532620u	12.093	12.093	0.000
403532620d	12.001	12.001	0.000
403532580	12.022	12.022	0.000
403532340	11.890	11.890	0.000
403532070	11.855	11.855	0.000
403531840	11.770	11.770	0.000
403531740	11.727	11.727	0.000
403531530	11.720	11.720	0.000
403531480u	11.393	11.393	0.000
403531480d	11.393	11.393	0.000
403531430	11.499	11.499	0.000
403531250	11.467	11.468	-0.001
403531200u	11.572	11.574	-0.002
403531200d	11.506	11.507	-0.001
403531120	11.471	11.472	-0.001
403530940	11.420	11.420	0.000
403530680	11.308	11.308	0.000
403530420	11.170	11.170	0.000
403530140	11.130	11.130	0.000
403530000u	11.135	11.135	0.000
403530000d	11.135	11.135	0.000
CS_49	11.140	11.140	0.000
403530000n	11.135	11.135	0.000
403515970	11.123	11.123	0.000
403515740	11.085	11.085	0.000

403515700u	11.081	11.081	0.000
403515700	10.832	10.832	0.000
403515650	10.816	10.816	0.000
403515400	10.813	10.813	0.000
403526030	12.458	12.458	0.000
403525810	12.427	12.428	-0.001
CS_125	12.272	12.272	0.000
403525430	12.292	12.292	0.000
403525123	12.252	12.252	0.000
CS_126	12.219	12.219	0.000
403524645	12.085	12.084	0.001
403524425	12.058	12.057	0.001
403524196	12.038	12.037	0.001
CS_129	12.051	12.051	0.000
403523987	11.998	11.997	0.001
403523768	11.927	11.926	0.001
403523466	11.886	11.886	0.000
403523425	11.859	11.858	0.001
403523310	11.834	11.833	0.001
403523050	11.818	11.817	0.001
403522854	11.806	11.805	0.001
403522373	11.747	11.747	0.000
403521868	11.657	11.657	0.000
403521868a	11.610	11.609	0.001
403521671	11.510	11.510	0.000
403521671d	11.459	11.459	0.000
403521587	11.438	11.438	0.000
403521495	11.401	11.401	0.000
403521241	11.367	11.367	0.000
403520986	11.347	11.347	0.000
403520730	11.343	11.343	0.000
403520501	11.297	11.296	0.001
403520456	11.163	11.163	0.000
403520456e	11.169	11.169	0.000
403520195	11.141	11.141	0.000

Changes in flood risk

10.1.11 A comparison between scheme and baseline was undertaken to understand the impacts of proposed scheme in the 1% AEP plus 39% climate change flood event

10.1.12 Comparison of flood extents showed no significant changes, other than the extension of flooding into Kelham FCA.

10.1.13 Areas identified as “more vulnerable” by the National Receptors Database received special consideration. Figure 10-3 presents the depth difference between baseline and FCA with mitigation in the 1% plus 39% climate change event, identifying locations with changes in flood risk.

Location 1 and 2: Floodplain upstream of Averham weir near Staythorpe power station

10.1.14 Upstream from the point at which the River Trent bifurcates, a decrease in water levels of up to 50mm was observed in the Scheme plus mitigation scenario. This is attributed to the Farndon FCAs, which permit a portion of the flow to enter the left bank floodplain earlier.

Location 3: Floodplain west of A46

10.1.15 As flooding is caused by the FCAs earlier than in the baseline, the Scheme and the Nottingham to Lincoln railway line hold back water, leading to an increase in upstream water levels of up to 16mm.

Location 4: Windmill Viaduct

10.1.16 Upstream of Windmill Viaduct, the widening of the carriageway, the addition of piers and the increased embankment width have caused a restriction to water flowing from west to east on the right bank of the River Trent. This has resulted in local flood level increase by up to 26mm in an area of receptors classed as “miscellaneous”. The increase in flood levels are exacerbated by the conservative representation in the hydraulic model (due to cell size) of the protrusion of the embankment into the floodplain. Overall, water levels increase up to 10mm on top of a depth of 0.3-1.7m in the baseline design event and therefore the change is deemed slight.

Location 5: Floodplain east of A46

10.1.17 A localised decrease in peak water levels up to 111mm beneath Windmill Viaduct, however, generally there appears to be a decrease up to 10mm caused by the Scheme.

Location 6: Great North Road

10.1.18 A small area of 0.18km2 with depths up to 5mm greater in comparison with the baseline scenario is shown near Great North Road. It is noted that it appears at the same location of instability at culvert NCC_3218. Due to this location being a significant distance from the Scheme and vulnerable receptors, the instabilities noted in the baseline and Scheme scenario have not been rectified at this stage.

10.1.19 Due to the instabilities noted in this area, the model results should not be used to inform flood risk.

10.1.20 Immediately south of Location 6, infrastructure at the British Sugar site (including a car park and buildings) are shown to be affected in the 50% and 20% AEP storm events. This is shown in Appendix C.11 and C.12. In the baseline event, flooding in this area is approximately 500mm in depth and is shown in the hydraulic model to increase by 5-10mm by the scheme. This is considered to be a minor adverse effect. Analysis of the modelling concludes that this is not due to numerical error and is likely due in part to interpolation of the DTM (Digital Terrain Model) at this location.

Location 7: Kelham and Averham FCA

10.1.21 Kelham and Averham FCA forms an extension of the floodplain and starts flooding in the 3.33% AEP event. In the 1% AEP plus climate change flood event, the FCA fills up to a depth of approximately 1.05m fulfilling its design purpose.

Location 8: Floodplain between Kelham Road and Nottingham to Lincoln railway line

10.1.22 It has been observed that the water level at the base of the new embankment has a localised increase of up to 86mm from the baseline. It is deemed to be of low impact and slight significance, particularly as there are no vulnerable receptors nearby and the area is predominantly agricultural.

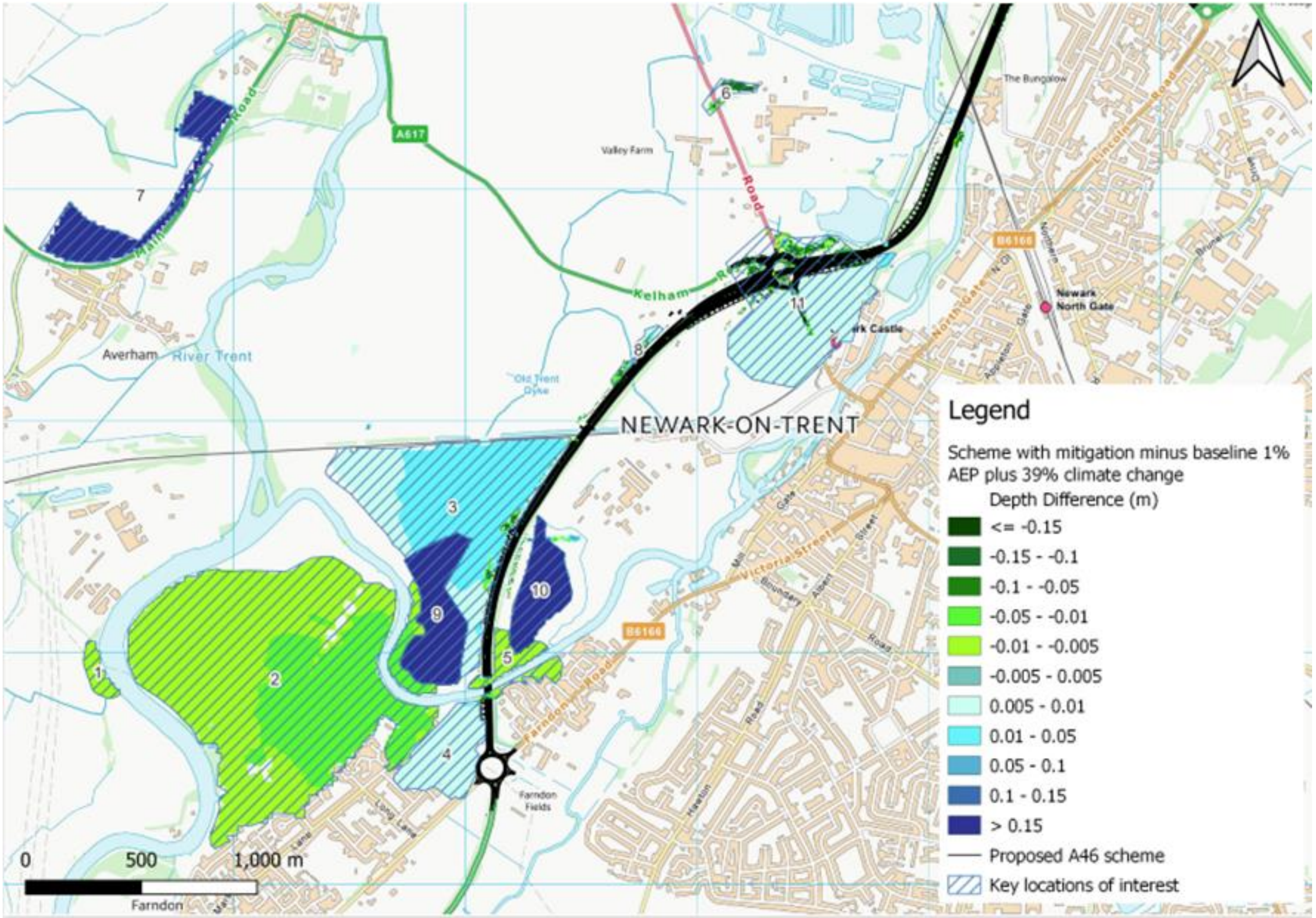
Location 9 and 10: Farndon FCA

10.1.23 Farndon FCA forms an extension of the floodplain and starts flooding in the 50% AEP event. In the 1% AEP plus climate change flood event, the FCA fills up to a depth of approximately 3.8m in the eastern FCA and 2.7m in the western FCA.

Location 11: Cattle market

10.1.24 An increase in water levels is observed of up to 20mm between the bund and Nottingham to Lincoln railway line. This increase in water level appears to be caused by flows overtopping the railway line and ponding behind the Cattle market roundabout as flows can no longer overtop the A46 from south to west.

Figure 10-3: Water level difference between baseline and FCA with mitigation in the 1% plus 39% climate change event



Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

Flood maps

10.1.25 Flood maps have been undertaken for this study. Final outputs can be found in Appendix C of the FRA.

11 Assumptions, limitations, and recommendations

11.1.1 The model has been updated to meet these aims and should be reviewed before being used for any other purpose.

11.1.2 The assumptions made in the development of this model are summarised in the following subsections.

Hydraulic modelling

- The model was designed to assess flood risk in the area surrounding the scheme. It was updated for the River Trent and six of its tributaries. Three watercourses (Winthorpe Airfield Drain, Crankley Point Drain, and Mission Drain) were excluded for the reasons provided in Section 5.
- Erratic node spacing and node spacing slope checks were run on the 1d elements of the model, with 37 and one node failing respectively. Spot checks indicated that this is acceptable due to the positioning of structures within shorter reaches.
- The model is not geo-referenced in some places; however, this does not impact model computations or results. It is recommended that this should be reviewed at detailed design.
- Smaller watercourses have been represented with a manning's value lower than would be anticipated for small, heavily vegetated watercourse. This, however, provides a more conservative estimate of flood risk at the scheme by increasing conveyance through the smaller channels.
- Glass walling occurs at several locations within the model during the 1% + 39% CC AEP event:
    - In the lower reach where the River Trent section has been extended. This is tidally controlled, however, and is sufficiently far enough downstream to not impact the scheme.
    - At isolated locations across the floodplain. These locations are located at a sufficient distance from the scheme and are minor in the context of the model.
- The model configuration at Newark Weir was updated to improve its representation. The reach of the channel to the east is represented in 2d and configured to improve representation of canal locks within the reach.
- Design updates at Windmill Viaduct to include sheet pilling moving away from the watercourse are not included in the model. This would increase conveyance; therefore, their exclusion provides a more conservative estimate of flood risk.

-
- It is noted that the design FCA footprint shape with an increased extent has changed marginally in the Farndon West and Farndon West FCAs since hydraulic modelling was completed. However, no further changes were made to the FCA representation in the modelling as the change in design was to allow for future design flexibility in land take rather than any change to the core flood mitigation feature in terms of level for level, volume for volume capacity provided. It is recommended at detailed design that a cross check of the final design is undertaken to ensure the modelling results remain representative.
- Canal lock gates have been modelled as closed given that the Trent is not deemed navigable during high flow events.
- The survey predates the model, however spot checks indicate this is acceptable.
- The model was calibrated using rainfall gauge data from three gauges within the River Trent catchment.
- Lengths of proposed culverts have not been extended as it is assumed that there will be no impact on hydraulics.
- Roughness has not been updated in the scheme with mitigation model as landscaping plans were not available at the time of modelling. It is noted that a 20% blanket increase in roughness in baseline sensitivity testing indicated a significant increase in water levels into high receptor locations. It is recommended that roughness sensitivity tests are referred to during Detailed Design to inform final landscaping design.
- A check event has not been run at this stage of the project as it is not critical to inform outline design. It is proposed that check events are considered at Detailed Design.
- It is recommended at detailed design stage that further data collection and analysis is undertaken on the existing flood defence to the south of Cattle Market roundabout to ascertain the resulting peak water level and any associated minor change in flood risk level as a consequence of the mitigated scheme.
- Whilst not tested for this study, it is anticipated that a quadtree approach may be beneficial for future modelling studies that develop from the modelling presented in this report.
- Water Level Lines (WLL) were not applied in this modelling assessment. It is recommended that water level lines should be considered for future studies as they can be helpful for visualisation.
- This study uses Flood Modeller (4.5.1) and TUFLOW Classic (2020-01-AB-iSP-w64). It is recommended that the model versions are updated to their latest issue in future model iterations.
- The majority of the model is georeferenced. However, there are some nodes in the downstream reach outside of the scheme area and at each of the 1D/2D-linked culverts which are not georeferenced. It is recommended that these nodes are updated for future iterations to improve visualisation of the model.

- A review of the channel roughness would be appropriate for future use of the model for area-specific flood risk mapping outside of this study of the impact of the A46 scheme on the wider area.
- It is recommended at Detailed Design stage that further data collection is undertaken at all flood defences, linear features and structures to ensure correct representation and improve confidence in modelling results.

Hydrology

11.1.3 For the River Trent, the study has adopted an AMAX series supplemented with historic AMAX entries from 1884 to 1954 as derived by Black & Veatch (2005).

11.1.4 The study assumes:

- The catchment and watercourse have been largely unchanged since the historic data recorded in the late 19th and early 20th century.
- All large floods have been identified during the historic review.

11.1.5 The study has derived the 0.1% AEP (1000-year return period) growth factors based on a rainfall runoff approach and assumes confidence is greater in rainfall growth curves than in flood growth curves for longer return periods.

11.1.6 Confidence in design (and event) flow estimates in the ungauged tributary watercourses is limited by the absence of gauged data. However, the impact and influence of this limitation on the overall conclusions of the assessment is deemed small as:

- These catchments are small and, when compared to the River Trent, are not the main contributor or significantly influence flood conditions which may impact the scheme

11.1.7 For modelling the event inflows, catchment rainfall has been derived and used within ReFH2 to derive the event hydrograph(s).

11.1.8 The inflows have been applied at upstream extents and as ‘top up inflows’ at specific locations across the model. Distributed lateral reaches have been used in the smaller channels using custom weighted factors. This may correspond to increases in the catchment area and therefore overestimation in some locations. It is unlikely that this has a significant impact on the model results given the size of the model. The dominant risk of flooding is driven by downstream levels on the River Trent.

Freeboard

11.1.9 A minimum freeboard allowance of 600mm is required above the maximum water level, for the largest flood event for design (0.1% AEP).

11.1.10 Comparison of peak water levels is shown in Table 11-1. Generally, there are small changes in freeboard between baseline and scheme with mitigation.

11.1.11 It is noted that freeboard was not met for Cattle Market Roundabout flood relief culvert in the baseline scenario and has not changed in the scheme with mitigation scenario.

Table 11-1: Comparison of peak water levels for 0.1% event

Structure	Baseline 0.1% Peak water level (mAOD)	Freeboard (m) Baseline	Scheme with mitigation 0.1% Peak water level (mAOD)	Freeboard (m) Scheme with mitigation	Soffit level (mAOD)
Windmill Viaduct	13.01	3.60	13.01	3.60	16.61
Farm access underpass	13.01	1.50	13.04	1.47	14.51
Nottingham to Lincoln Railway Line West	12.57	6.56	12.87	6.61	19.48
Nottingham to Lincoln Railway Line East	12.23	6.57	12.33	6.47	18.80
Cattle Market Roundabout flood relief culvert	12.44	-1.10	12.47	-1.07	11.40
Nether Lock Viaduct	11.74	10.12	11.74	10.12	21.86
Sewage Works Access Underpass	No flood	N/A	No flood	N/A	-

12 Conclusions

12.1.1 The A46 highway has been extended between Farndon and Brownhill roundabout. The extended embankments, pond, drainage features and access roads have been incorporated in the hydraulic model. Existing structures will be extended in the built scheme, but not within the scheme with mitigation model. It is believed that changes in structure lengths is unlikely to impact model results.

12.1.2 Slough Dyke was incorporated into the hydraulic model due to changes at Brownhill's roundabout. Results have indicated that there would be no change in flood risk from baseline

12.1.3 The baseline model includes the River Trent and tributaries such as River Greet, Sodbridge drain and Slough Dyke. Mission Drain was considered but not included in the final hydraulic model to prevent instabilities in model runs.

12.1.4 The embankment at Windmill Viaduct, has been extended to support the proposed extension of the viaduct, the consequent impact is an increase of water levels on the upstream right bank near Crees Lane properties. However, it is noted that the increase is insignificant given that the depth water is already over 1m in this location.

12.1.5 The proposed scheme with mitigation increases water levels west of the proposed scheme and behind Nottingham to Lincoln railway line. However, this is an area of low risk agricultural land, so this is not an issue.

12.1.6 The scheme has shown to have little impact on water levels overall and the inclusion of the FCAs has had limited benefit.

Appendix A – Sensitivity Testing

A.1 Sensitivity testing

- Hydraulic modelling assessments involve several assumptions and uncertainties. To understand the impact on water levels and flood extents, it is necessary to test these assumptions.
- The sensitivity tests undertaken on the 1% AEP + 39% CC are summarised in Table 12-1. The model versions that the tests were undertaken on are also provided.
- Sensitivity testing at the downstream boundary was not conducted as discussed in Section 7.

Table **12-1**: Sensitivity tests

Sensitivity test	Description	Model version comparisons
Hydraulic roughness	Applied changes to Manning's n roughness in the 1D and 2D domains (±20%)	Baseline vs baseline (without Slough Dyke)
Inflows	Applied changes to model inflows applied in the 1D (±20%)	Baseline vs baseline
Weir coefficients	Applied changes to weir coefficients (±20%)	Baseline vs baseline

- Outputs of the sensitivity test demonstrate the following:

Hydraulic roughness

- Increase in roughness in channel, caused the baseline model to crash near Slough Dyke. Therefore, the baseline model was run without the Slough Dyke watercourse to prevent instabilities causing the model to crash at the peak of the simulation.
- Changes in the manning's roughness typically results in the expected relationship of higher water levels in the channel with higher hydraulic roughness and vice versa, results are presented in Figure 12-1 and Figure 12-2.
- Typical changes in water levels in the channel are within the range of ±0.01 to 0.2m throughout the model domain.
- Increased water levels result in a slightly larger flood extent. There are also increases in depth of approximately 0.1 to 0.2m near Cattle Market roundabout and the Sleaford Road area which did not flood previously.
- Reduced flood levels lead to small reductions in the flood extent. Flooding no longer occurs at locations where an increase was observed with increased hydraulic roughness.
- The model is considered to be sensitive to changes in the hydraulic roughness.

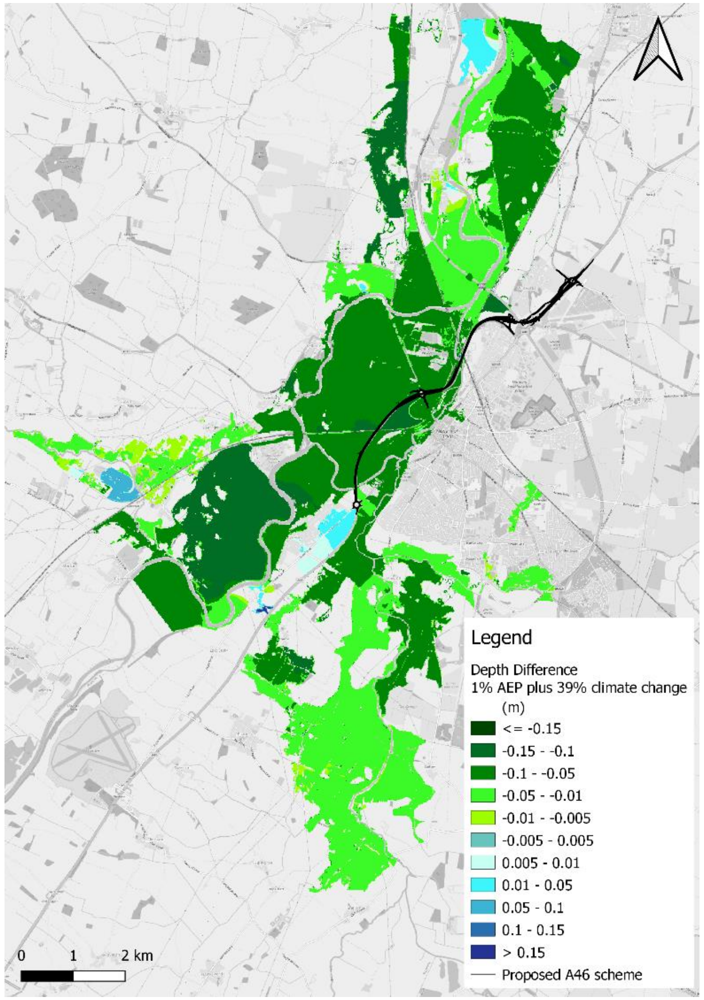
Inflows

- Water levels in the channel follow the expected relationship with increased inflows resulting in higher levels and vice versa. Results are presented in Figure 12-5 and Figure 12-6
- Typical changes in water levels are within the range of ±0 to 0.35m.
- Increased water levels result in increased flood depths throughout the model domain and an increase in the flood extent due to a higher volume of flow. Notable areas of increase that previously did not flood include Sleaford Road, the Northern Road industrial estate and agricultural land near Bathley.
- Reductions in flood levels reduces the flood extent with flooding no longer occurring in the Kelham Road defended area or the area surrounding Bathley.
- The model is considered to be sensitive to changes in inflow.

Weir coefficients

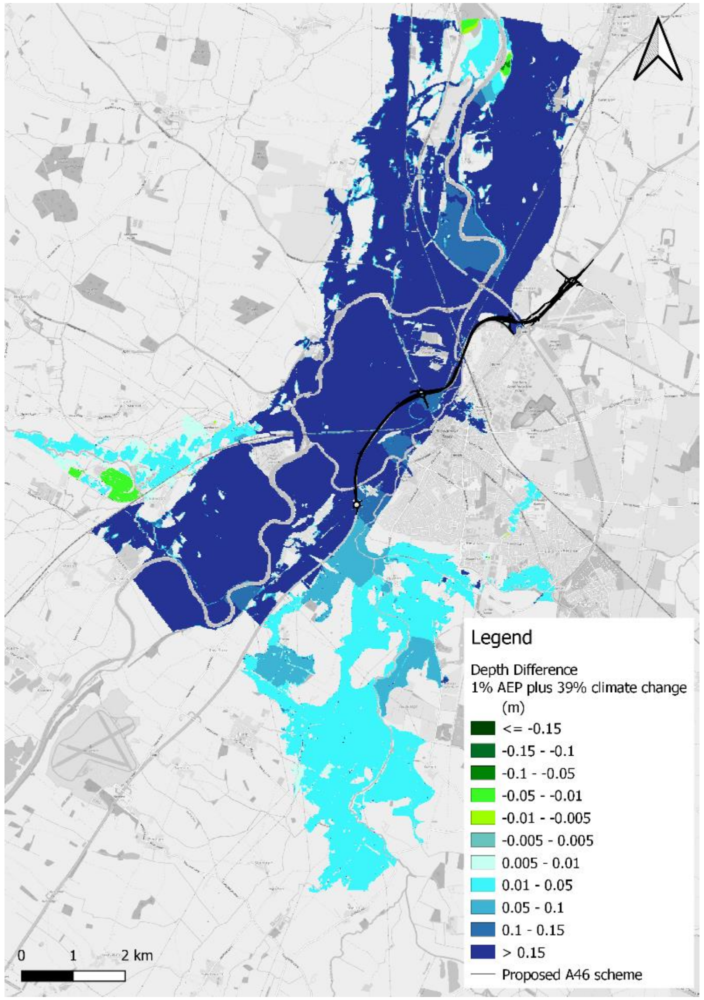
- A decrease in weir coefficients typically results in increased water levels in the channel and on the floodplain and vice versa. Results are presented in Figure 12-3 and Figure 12-4.
- Water levels in the channel generally increase by between 0.01 and 0.05m in locations proximal to weirs. However, an increase of 0.08 occurs immediately upstream of the large weir located at the River Trent bifurcation.
- Flood levels on the floodplain increase by up to 0.1m upstream of the weir with a subsequent decrease up to 0.05m downstream. This is attributed to a reduced volume of flow spilling over the weirs. The flood extent does not change, and no additional areas are flooded.
- The model is considered to be sensitive to changes in the weir coefficient.

Figure 12-1: Depth difference between baseline 1% plus climate change vs baseline with 20% decrease in roughness



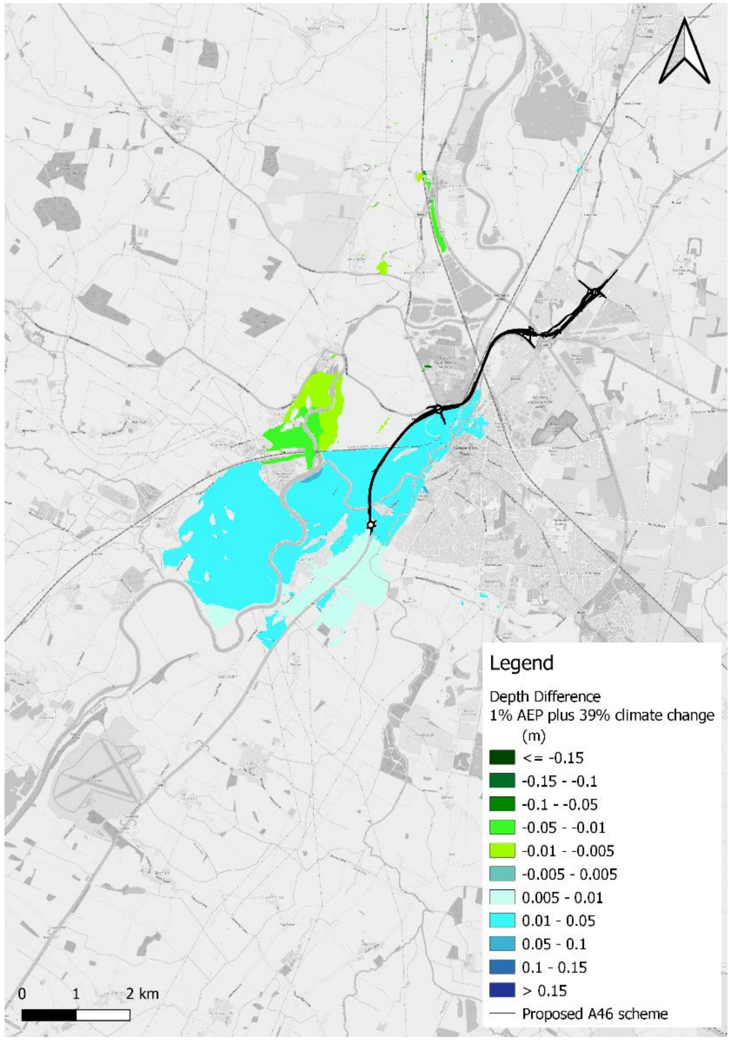
Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

Figure 12-2: Depth difference between baseline 1% plus climate change vs baseline with 20% increase in roughness



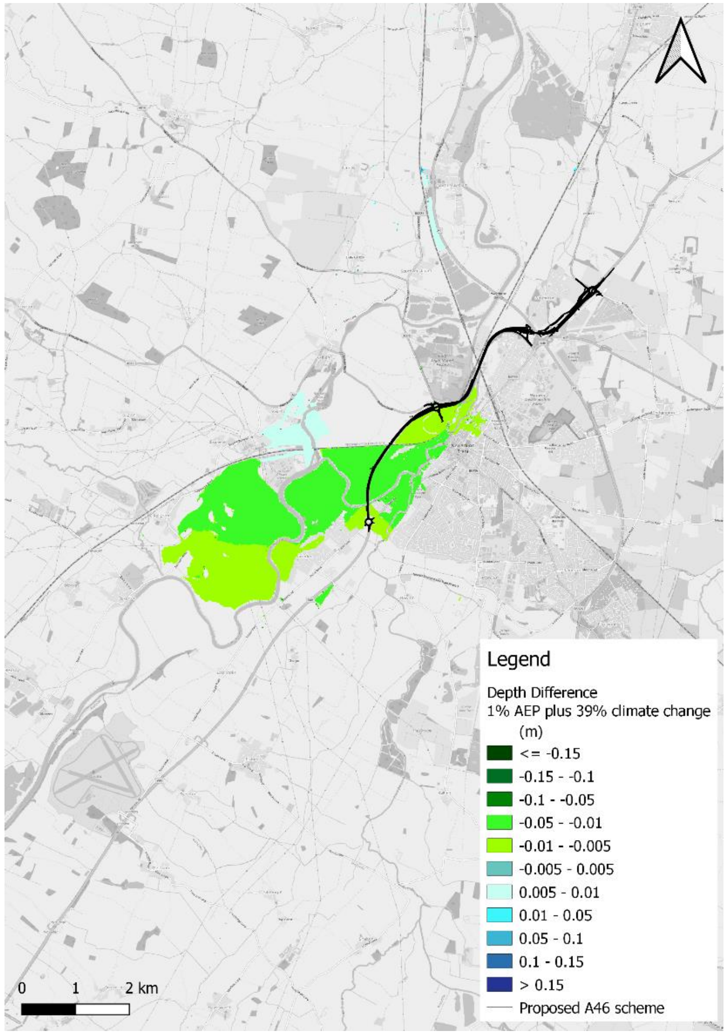
Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

Figure 12-3: Depth difference between baseline 1% plus climate change vs baseline with 20% decrease in weir coefficient at Averham weir



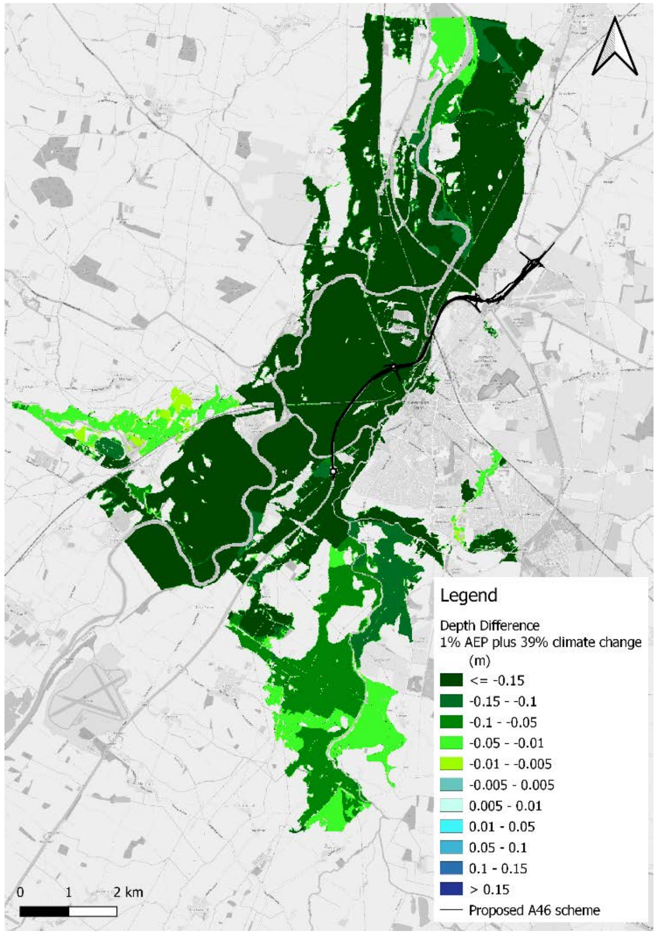
Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

Figure 12-4: Depth difference between baseline 1% plus climate change vs baseline with 20% increase in weir coefficient at Averham weir



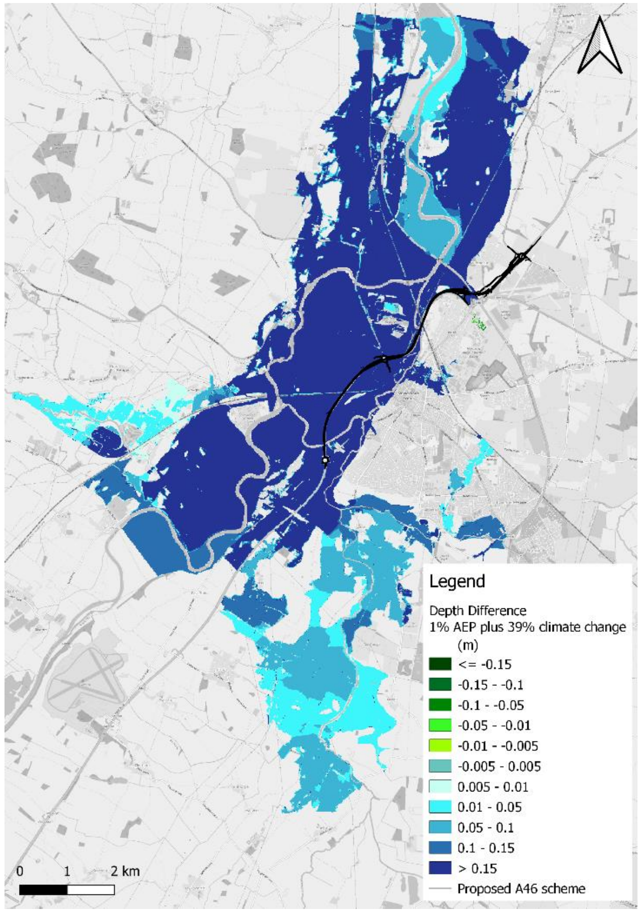
Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

Figure 12-5: Depth difference between baseline 1% plus climate change vs baseline with 20% decrease in flow



Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

Figure 12-6: Depth difference between baseline 1% plus climate change vs baseline with 20% increase in flow



Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

Appendix B – Blockage Assessment

A.2 Blockage assessment

Blockage scenarios were identified at critical locations which may cause a residual impact to third party receptors. The modelling methodology stipulates that a blockage between 50% and 75% be applied, however following further discussions with the Environment Agency the following scenarios were agreed for the 1% AEP with climate change scenarios:

- Blockage sensitivity scenario 1:
  - A 50% blockage will be applied to the Cattle Market flood relief culvert due to its larger opening of 4.2m by 2.4m. This blockage has been implemented in 1D within the culverts.
- Blockage sensitivity scenario 2:
  - A blockage of 75% has been applied to the five 600m diameter culverts connecting the Trent floodplain to the Kelham FCA. The larger percentage blockage has been chosen as small culverts are more likely to be blocked during large flood events. This blockage has been implemented in 1D within the culverts.
- Blockage sensitivity scenario 3:
  - A 50-75% blockage was deemed excessive for a large flood event at Windmill Viaduct. The 30m structure opening of Windmill Viaduct is likely to pass most debris, with only smaller debris such as tree branches likely to become trapped. As a result, a TUFLOW flow constriction layer was applied with a 50% increase in pier blockage.

Blockage Sensitivity Scenario 1 – Cattle Market flood relief culvert

- A 50% blockage was applied at the Cattle Market roundabout flood relief culvert in the baseline and scheme scenario.
- Figure 12-7 compares baseline *with* blockage against baseline *without* blockage, peak flood depths increase by between 0.01m and 0.05m in the Kelham Road defended area upstream of the culvert. An increase of water depths southwest of the defended bund indicates that there is an existing potential impact caused by blockages at Cattle Market roundabout flood relief culvert in the baseline scenario.
- Figure 12-8 compares scheme *with* blockage against scheme *without* blockage which shows a difference between 0.01m and 0.05m near the Cattle Market flood relief culvert which is within the same depth difference band as the baseline comparison. Further downstream near the A1 road, flood depth differences are due to the FCA sensitivity model being run without Slough Dyke due to instabilities associated with the Slough Dyke preventing the sensitivity test completing. The removal of Slough Dyke is not anticipated to have any impact on the residual flood risk near Cattle Market.

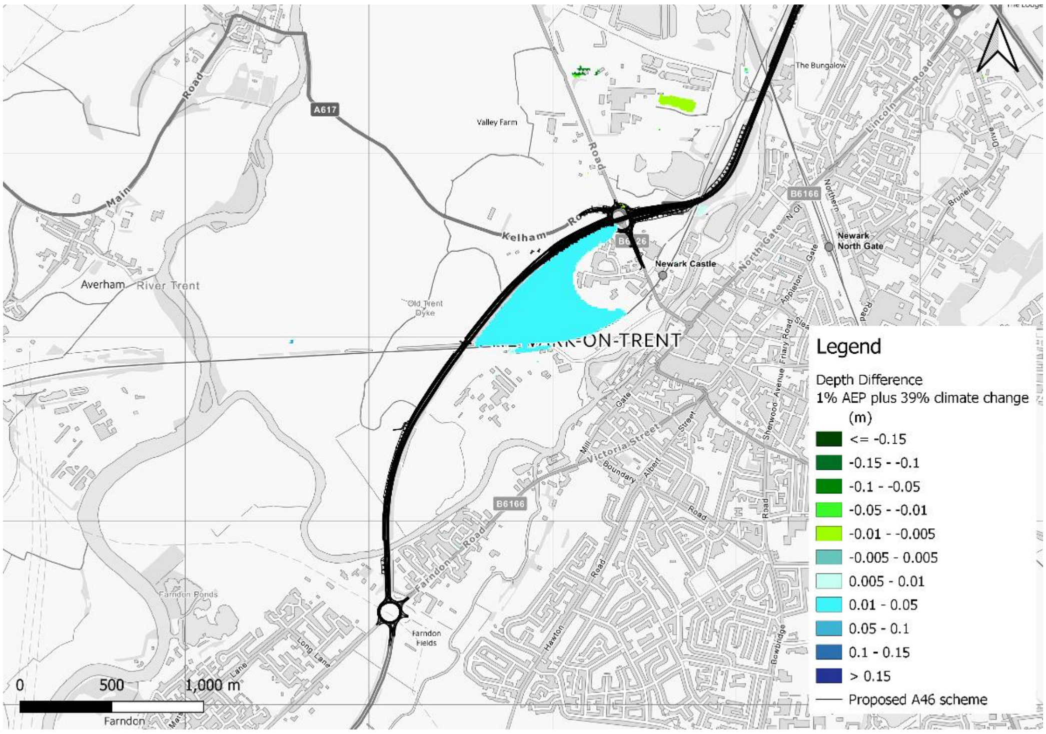
Blockage Sensitivity Scenario 2 – Kelham FCA culverts

- Figure 12-9 shows depth difference between scheme *with* blockage against scheme *without* blockage. Results indicate that in the *with* blockage scenario, a 75% blockage to the Kelham FCA culverts reduced the flow conveyed through the culvert from 0.7m^3/s to 0.3m^3/s.
- This indicates that if the Kelham culverts because blocked, then the effectiveness of the Kelham will reduce as less water can be stored in the FCA.

Blockage Sensitivity Scenario 3 – Windmill Viaduct piers

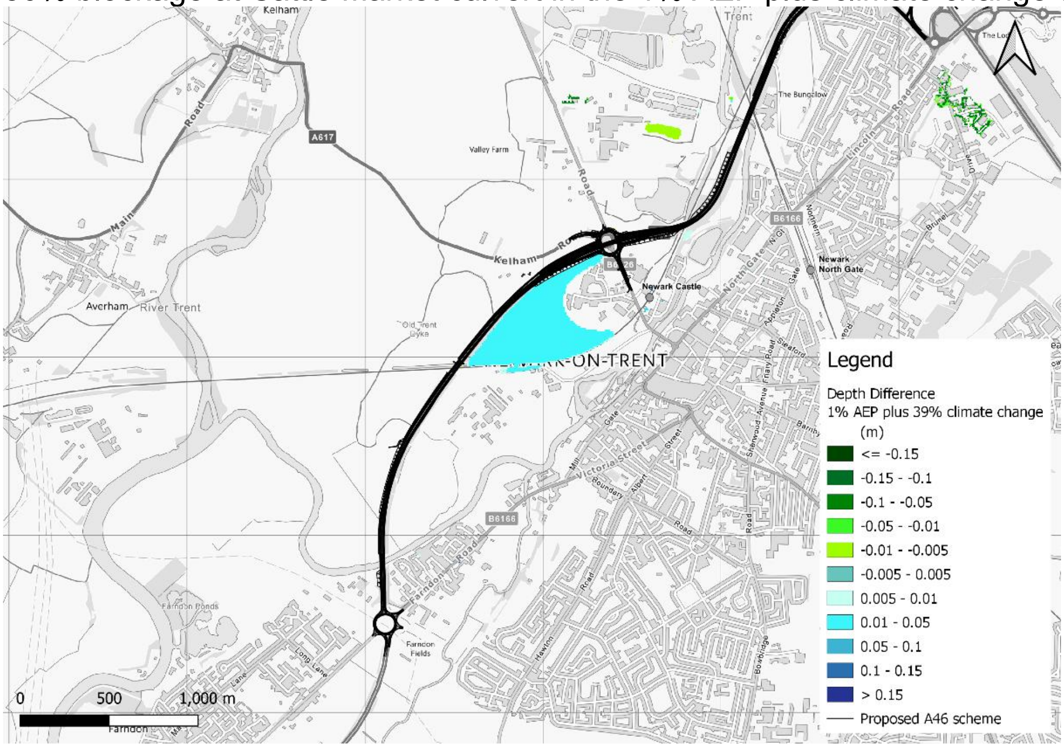
- Three comparisons have been undertaken to understand the impact of a 50% increase in pier blockage at Windmill Viaduct.
- The first comparison shown in Figure 12-10 is between scheme *with* blockage at Windmill Viaduct and scheme *without* blockage. Depth difference showed that there is no change in depth beyond the ±0.05m range.
- The second comparison shown in Figure 12-11 was undertaken between scheme *with* blockage at Windmill Viaduct and baseline *with* blockage at Windmill Viaduct. This showed the same depth differences seen in the baseline vs scheme scenario shown in Figure 10-3.
- Consequently, a 50% increase in pier blockage at Windmill Viaduct does not change the overall residual risk.

Figure 12-7: Depth difference between baseline without blockage and baseline with a 50% blockage at Cattle Market culvert in the 1% AEP plus climate change event



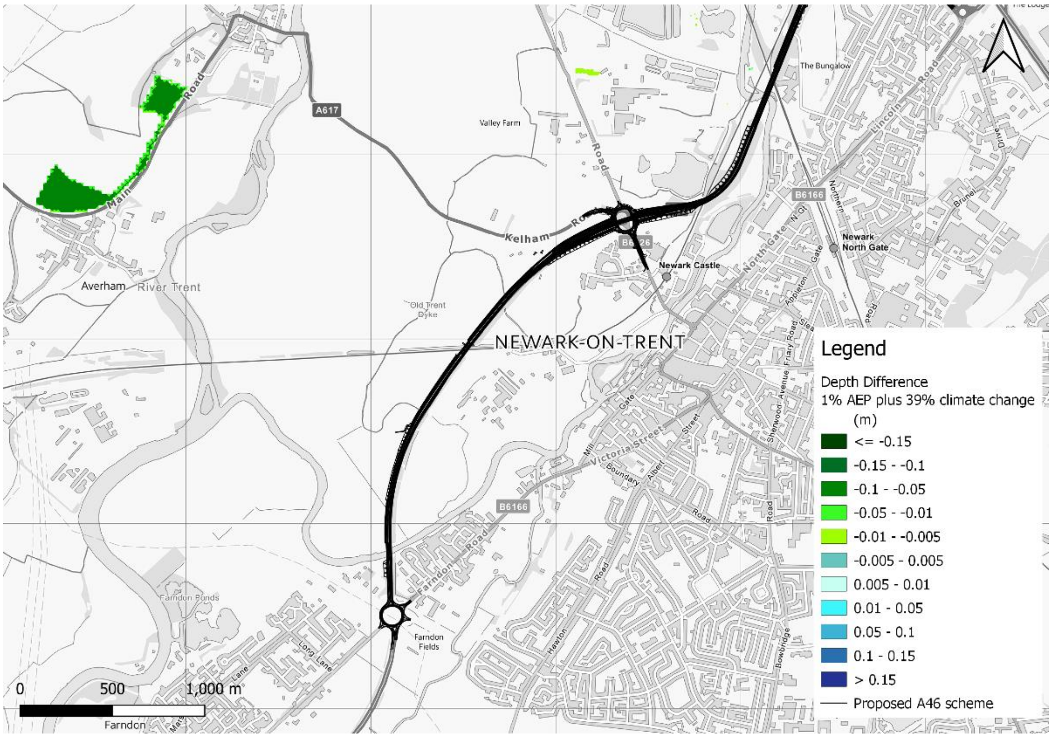
Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

Figure 12-8: Depth difference between scheme without blockage and scheme with a 50% blockage at Cattle Market culvert in the 1% AEP plus climate change event



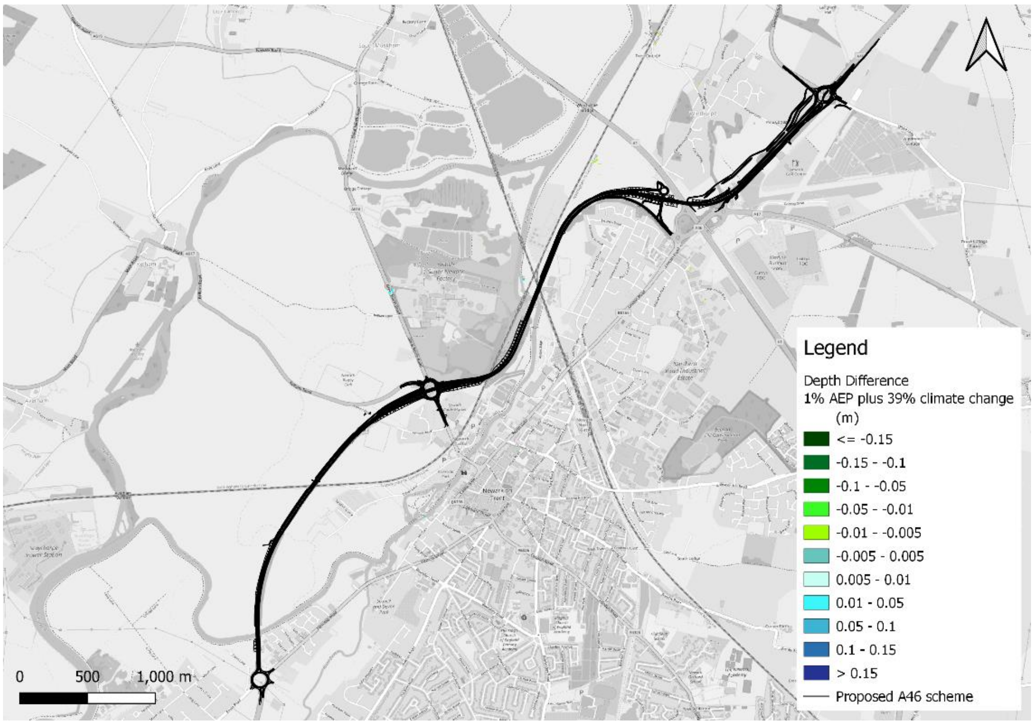
Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

Figure 12-9: Depth difference between scheme (without blockage) and scheme with a 75% blockage at Kelham Culvert in the 1% AEP plus climate change event



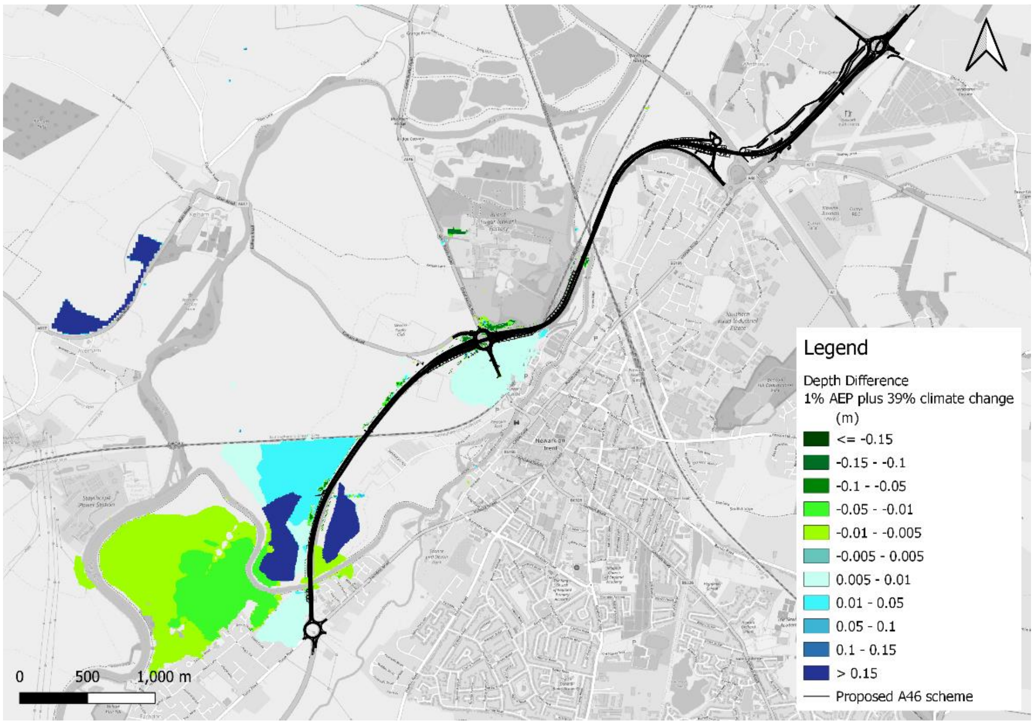
Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

Figure 12-10: Depth difference between scheme with blockage and scheme without 50% increase in pier blockage at Windmill Viaduct in the 1% AEP plus climate change event



Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

Figure 12-11: Depth difference between scheme with blockage and baseline with 50% increase in pier blockage at Windmill Viaduct in the 1% AEP plus climate change event



Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

Appendix C – Hydrology assessment

Please refer to file HE551478-SKAG-HDG-CONWI_CONW-RP-CD-00017.

Appendix D – Temporary works modelling report

Please refer to file HE551478-SKAG-HDG-CONWI_CONW-TN-CD-00007.

B.Flood Estimation Report - Hydrology: HE551478-SKAG-HDG-CONWI_CONW-RP-CD-00017

Flood estimation report: A46 Newark Bypass Scheme

November 2023

Contents

Tables

Figures

Tables – Appendices

Figures – Appendices

1 Approval

Revision stage	Analyst / Reviewer name & qualifications	Amendments	Date
Method statement preparation	[redacted]		November 2022
Method statement sign-off			November 2022
Calculations preparation			December 2022
Calculations sign-off			March 2023

2 Abbreviations

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

3 Summary of assessment

3.1 Summary

This table provides a summary of the key information contained within the detailed assessment in the following sections.

Catchment location	River Trent at Newark-on-Trent
Purpose of study and scope	Mott MacDonald Skanska Joint Venture (MMSJV) has been commissioned by National Highways to undertake a hydraulic modelling study of the River Trent and its major sub-catchments in support of the PCF Stage 3 design phase of the A46 Newark Bypass scheme .
Key catchment features	The River Trent is the third-longest river in the United Kingdom and at North Muskham has a catchment area of some 8,231km ^{2}. Catchment land use is largely grassland (42%), with arable / horticultural agriculture accounting for approximately a further 30%. The built urban area extends over 18% of the catchment with woodland accounting for approximately a further 7%. Underlying geology is predominately impervious (BFIHOST19 = 0.496) due to the presence of Mercia Mudstone overlain by glacial glayes, there are however more permeable areas of sandstone and limestone. In the Newark area the bedrock geology is mainly mudstone with some sandstone and siltstone overlain by superficial deposits of sand and gravels. The River Trent is subject to substantial flow modifications due to imports and industrial usage. Several large reservoirs are present within the catchment (FARL =0.95).
Flooding mechanisms	Flooding is expected to occur as result of peak flows exceeding channel capacity and/or the combination of flood peaks in the contributing tributaries coinciding with flood peaks in the receiving River Trent.
Gauged / ungauged	The study has made use of three active gauging stations within the study area, namely Trent at Colwick, the Greet at Southwell and the Trent at North Muskham.
Final choice of method	At all gauged locations and for Car Dyke, flow estimates derived by the FEH statistical method are adopted. The estimate of the 0.1% AEP (1000-year return period) event is derived by multiplying the FEH statistical 1% AEP (100-year return period) flow estimate by the ratio of the ReFH2.3 0.1% AEP flow estimate over the ReFH2.3 1% AEP flow estimate. For all other locations, the flow estimates derived by the ReFH2.3 method are adopted.
Key limitations / uncertainties in results	For the River Trent, the study has adopted an AMAX series supplemented with historic AMAX entries from 1884 to 1954 as derived by Black & Veatch (2005). The study assumes: - The catchment and watercourse have been largely unchanged since the historic data recorded in the late 19th and early 20th century. - all large floods have been identified during the historic review. The study has derived the 0.1% AEP (1000-year return period) growth factors based on a rainfall runoff approach and assumes confidence is greater in rainfall growth curves than in flood growth curves for longer return periods. Confidence in design (and event) flow estimates in the ungauged tributary watercourses is limited by the absence of gauged data. However, the impact and influence of this limitation on the overall conclusions of the assessment is deemed small as: - These catchments are small and, when compared to the River Trent, are not the main contributor or significantly influence flood conditions which may impact the scheme For modelling the event inflows, catchment rainfall has been derived and used within ReFH2 to derive the event hydrograph(s). The study assumes all input gauged data is appropriate and has been correctly scrutinised by the appropriate gauging authorities

3.2 Note on flood frequencies

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

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

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

Table 3.1: Annual exceedance probability (AEP) and related return period reference table

AEP (%)	50	20	10	5	3.33	2	1.33	1	0.5	0.1
AEP	0.5	0.2	0.1	0.05	0.033	0.02	0.0133	0.01	0.005	0.001
Return period (yrs)	2	5	10	20	30	50	75	100	200	1,000

4 Method statement

4.1 Requirements for flood estimates

Overview

The A46 Newark Bypass scheme entails the development of a stretch of the A46 that spans between Farndon Junction and Winthorpe Junction. The scheme aims to upgrade an existing single carriageway road in Newark-on-Trent to a dual carriageway.

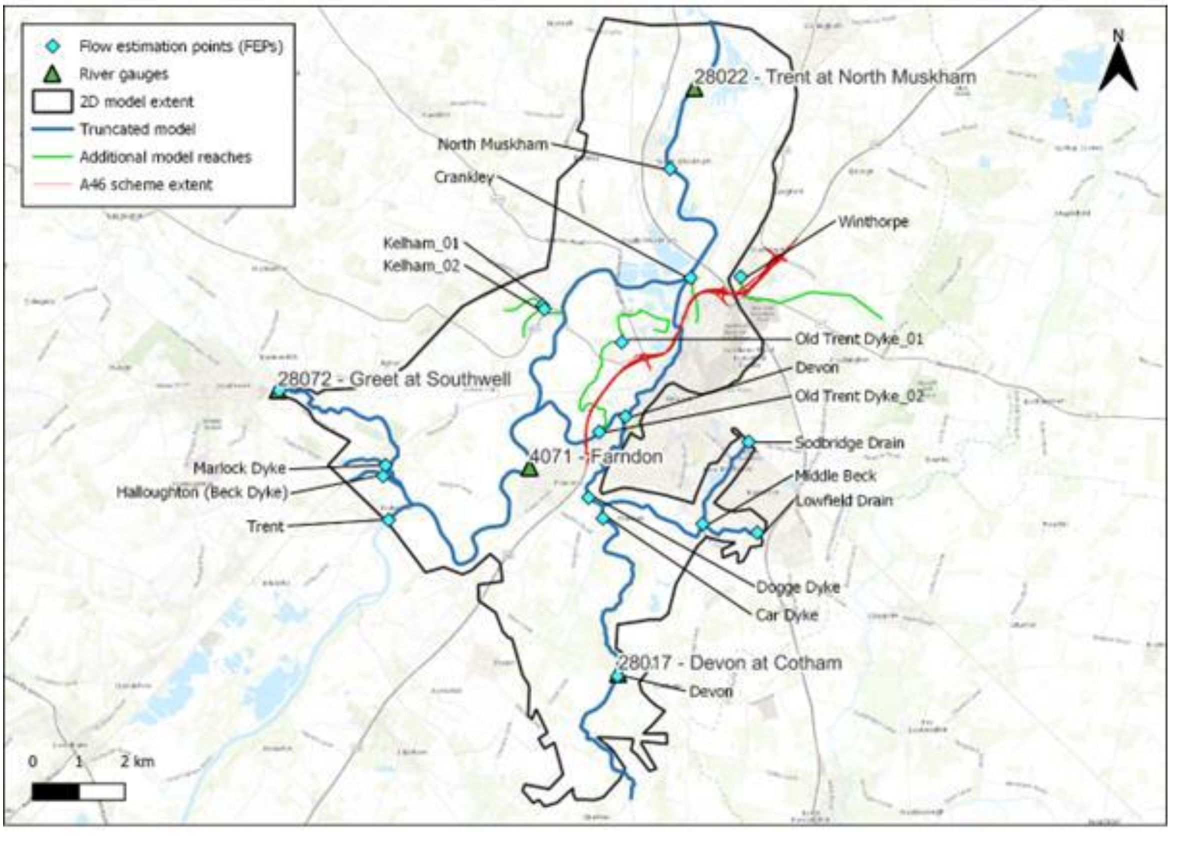
The improvement scheme requires the construction of a new carriageway that will run alongside the existing carriageway. These works will require new junctions and infrastructure such as watercourse crossings, utilities, public rights of way and accesses, which will include significant environmental mitigation work.

Hydraulic modelling was undertaken by Atkins in 2020 to inform the Project Control Framework (PCF) Stage 2 decision making process. The hydrology adopted within the Stage 2 modelling is understood to have been derived during the River Trent & Tributaries at Newark Flood Risk & Hazard Mapping Study undertaken by Halcrow (2011) [1] on behalf of the Environment Agency.

Atkins (2020) updated the hydrology to incorporate revised climate change guidance only i.e., the flood frequency understanding of the River Trent and its tributaries was not updated to incorporate the additional years of data now held in the National River Flow Archive (NRFA) Peak Flow Database.

This Method Statement, summarises the hydrological analyses undertaken for updating the model hydrology with the latest recommended methodologies, including making use of the current NRFA Peak Flow Dataset and the present-day station period of record where applicable.

Figure 4.1: Location Map Showing Hydraulic Model Extent



[1] Halcrow (2011) made use of analyses undertaken during previous studies on the River Trent and its contributing tributaries, namely:

Environment Agency Fluvial Trent Strategy undertaken by Black & Veatch (2005);

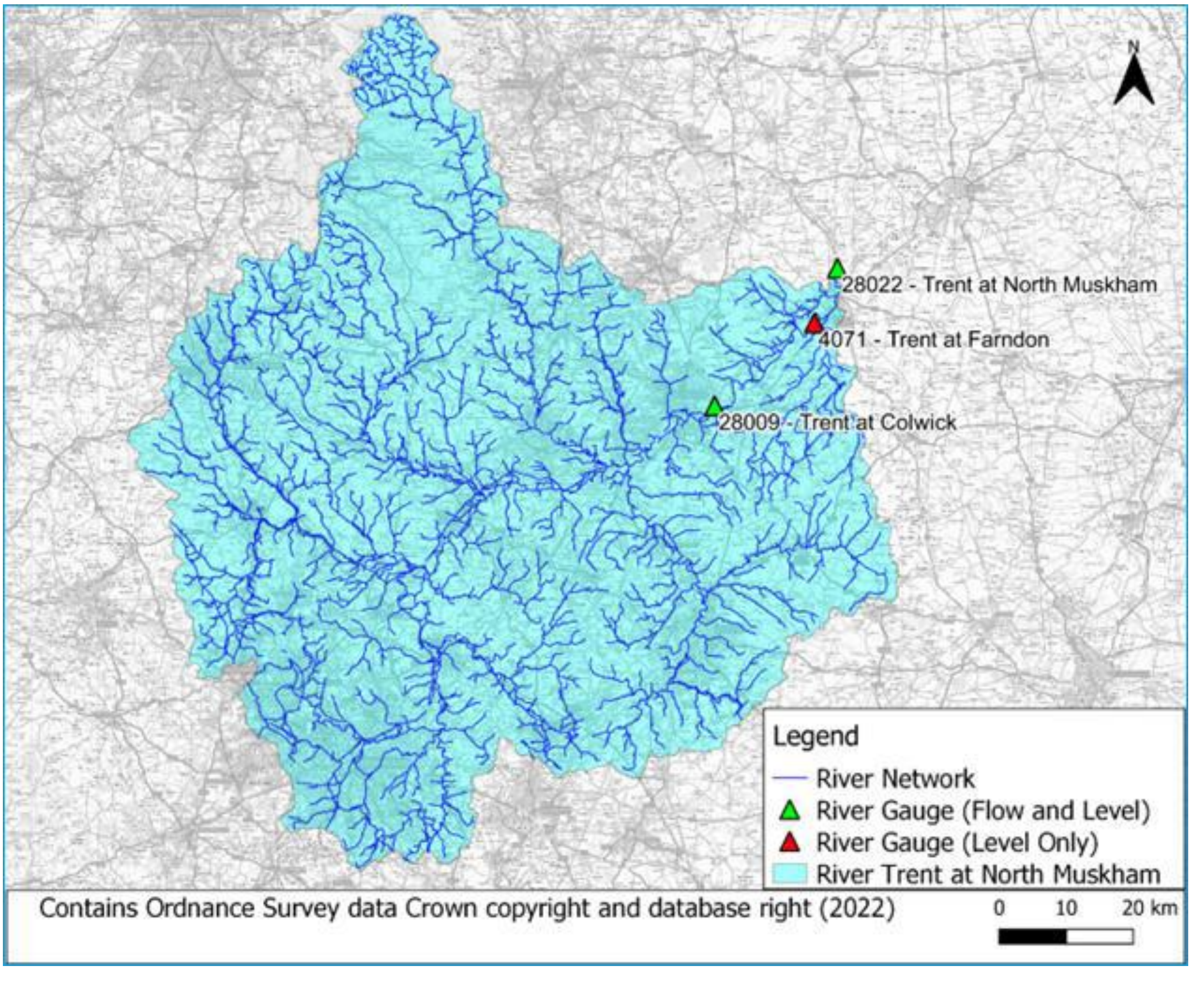
River Greet Strategic Flood Risk Mapping Draft Final Report (2008).

Overview	The A46 Newark Bypass scheme entails the development of a stretch of the A46 that spans between Farndon Junction and Winthorpe Junction. The scheme aims to upgrade an existing single carriageway road in Newark-on-Trent to a dual carriageway. The improvement scheme requires the construction of a new carriageway that will run alongside the existing carriageway. These works will require new junctions and infrastructure such as watercourse crossings, utilities, public rights of way and accesses, which will include significant environmental mitigation work. Hydraulic modelling was undertaken by Atkins in 2020 to inform the Project Control Framework (PCF) Stage 2 decision making process. The hydrology adopted within the Stage 2 modelling is understood to have been derived during the River Trent & Tributaries at Newark Flood Risk & Hazard Mapping Study undertaken by Halcrow (2011) [1] on behalf of the Environment Agency. Atkins (2020) updated the hydrology to incorporate revised climate change guidance only i.e., the flood frequency understanding of the River Trent and its tributaries was not updated to incorporate the additional years of data now held in the National River Flow Archive (NRFA) Peak Flow Database. This Method Statement, summarises the hydrological analyses undertaken for updating the model hydrology with the latest recommended methodologies, including making use of the current NRFA Peak Flow Dataset and the present-day station period of record where applicable.

Source: Contains OS data © Crown Copyright and database right 2021. Markup by MM 2023.

4.2 The catchment

Figure 4.2: Location map showing catchment and relevant river gauges (located on the Trent)



Description	The catchment (Figure 4.2) is described to station 28022 River Trent at North Muskham. The downstream model boundary is located approximately 1.6km downstream of station 28022. The River Trent at North Muskham has a catchment area of some 8,231km [2]. The watercourse drains a large part of the Peak District and the urban centres of Stoke on Trent, Burton Upon Trent, Tamworth, Sutton Coldfield, Cannock, Solihull, Stafford, Birmingham, Leicester, Loughborough, Derby and Nottingham. The Trent is augmented by several major rivers including the River Derwent, River Dove, River Sow, River Erewash, River Soar and River Tame. The catchment land use is largely grassland (42%), with arable / horticultural agriculture accounting for approximately a further 30%. The built urban area extends over 18% of the catchment with woodland accounting for approximately a further 7%. The underlying geology is predominately impervious due to the presence of Mercia Mudstone overlain by glacial glayes, there are however areas of more permeable sandstone and limestone. In the Newark area the bedrock geology is mainly mudstone with some sandstone and siltstone [2] overlain by superficial deposits of sand and gravels. There are substantial flow modifications due to imports and industrial usage. Runoff is reduced by public water supply abstraction and increased by effluent returns; it is also influenced by groundwater abstraction/recharge. Large reservoirs in the catchment include: • Peak District: Upper Derwent, Howden and Ladybower Reservoirs; • Derbyshire: Carsington Water, Foremark and Ogston Reservoirs; • Staffordshire: Rudyard Lake, Chasewater, Tittesworth, Staunton Harold and Blithfield Reservoirs; and • Nottinghamshire: Attenborough Nature Reserve Lakes. The presence of reservoirs is unlikely to influence the key flood driver of the River Trent and therefore will not impact hydrology estimates at the area of intertest. These can be seen in Figure 4.3.

4.3 Source of flood peak data

Source	NRFA peak flows dataset, Version 10, released on 27th August 2021. This contains data up to the end of September 2020. Please note, the study started in 2022 and was finalised in December 2022, meaning Version 10 was the most up to date version of NRFA at the time of assessment. A review of Version 11, released in September 2022, suggests none of the key sites in this study have been affected by the update. One site in the Trent catchment (28007) has changed suitability with regards to pooling. However, this site is not local to the site and so will not influence the estimates made during the assessment. Therefore, it is expected negligible changes would be seen if the assessment was redone with the updated version.

4.4 Gauging stations (flow or level)

There are three active flow gauging stations located within the study area; two on the River Trent at Colwick and North Muskham and one on the River Greet at Southwell. The River Devon at Cotham gauging station closed in December 2003.

There is also a level gauging station on the River Trent at Farndon. Station details are tabulated below. The level gauge at Farndon has not been used in this study as it does not have an appropriate rating curve. The gauge is attached to the bridge, so a rating would not be reliable for use in deriving flow for a flow-level relationship.

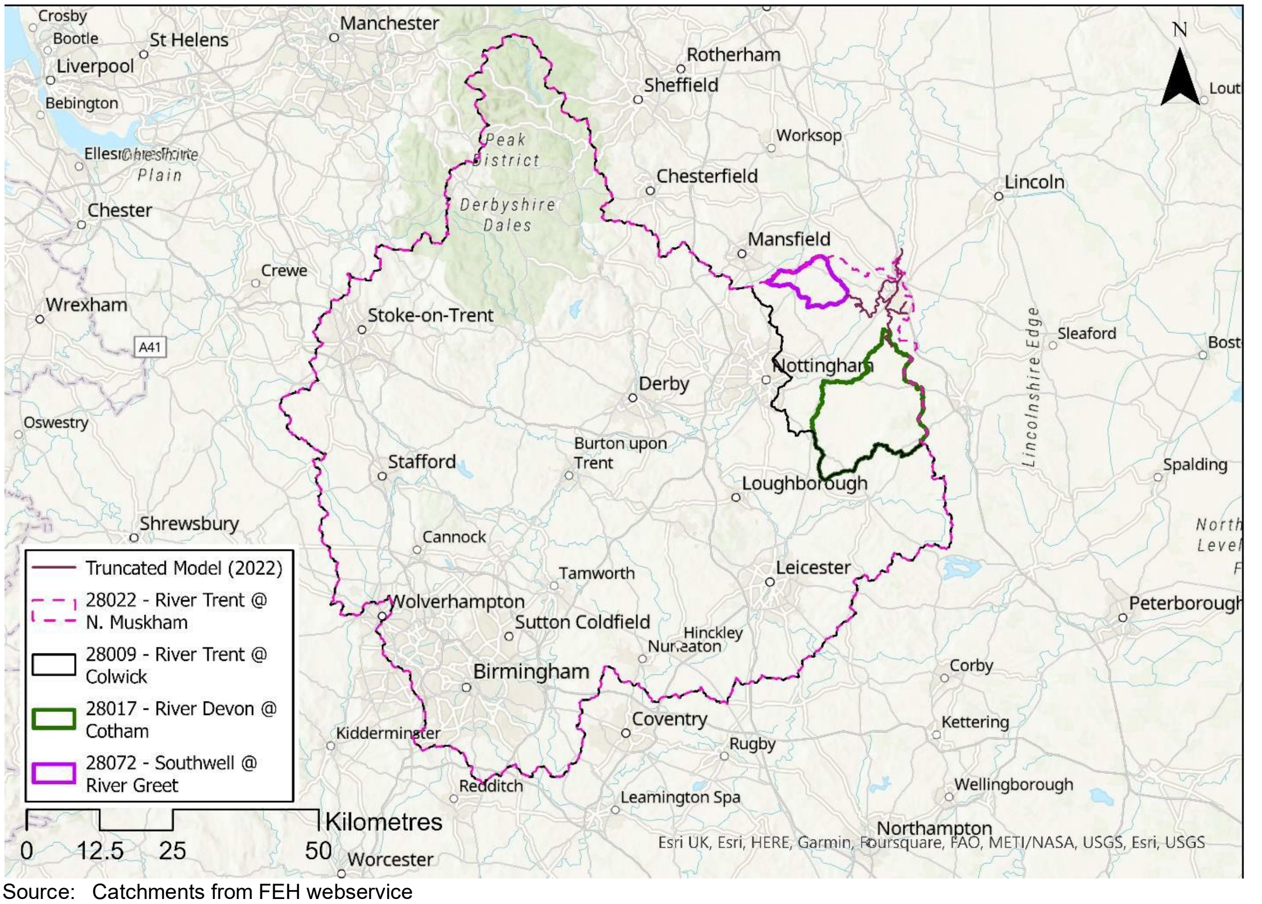
[2] BGS 2022. GeoIndex Onshore. https://mapapps2.bgs.ac.uk/geoindex/home.html?_ga=2.238421760.1868831349.1660551391-1935774792.1660551391. Accessed 02/08/22.

Table 4.1: Gauging stations

Watercourse	Station name	Gauging authority number	NRFA number	Catchment area (km²)	Type (rated / ultrasonic / level)	Start of record and end if station closed
River Trent	Colwick	4009	28009	7,486	Velocity area station	01/1958-present
River Trent	Farndon	4071	-	7,767	Level	10/1999-present
River Trent	North Muskham	4022	28022	8,231	Ultrasonic	09/1966-present
River Greet	Southwell	4072	28072	58.5	Crump Flat V weir	01/1974-present
River Devon	Cotham	4017	28017	284	Velocity area station	01/1966-12/2003

The catchments associated with each gauge are shown in Figure 4.3. This figure also displays the key reservoirs noted as unusual catchment features.

Figure 4.3: Gauging station catchments



Source: Catchments from FEH webservice

4.5 Data available at each flow gauging station

Station name	Start and end of NRFA flood peak record	Update for this study?	OK for QMED?	OK for pooling?	Data quality check needed?	Other comments on station and flow data quality
Colwick	01/09/1958 - 06/05/2022	Yes	Yes	Yes	No	Gauged above QMED and beyond AMAX3. Good fit to gaugings across stage range. The AMAX series reported by the NRFA is supplemented with historic AMAX entries from 1884 to 1954 as derived by Black & Veatch (2005).
North Muskham	01/09/1966 - 06/05/2022	No	Yes	Yes	No	Well rated up to the level of the highest recorded floods. Since 1996 the upstream gauge appears to be performing well and flows bypassing the gauge are small.
Southwell	11/12/1974 - 06/05/2022	No	No	No	Yes	Not listed as a Peak Flow rated gauge on the NRFA; however, it has been used in past studies and has been provided for this commission without any cautionary notes. The NRFA reports uncertainty at high flows but also that a drowned flow rating was established by high flow gauging in June 2007 and the full period of record was reprocessed.
Cotham	01/1966 - 12/2003	No	No	No	No	Became level-only in April 1978 due to unreliable rating. Rating underestimates flows throughout the range. No gaugings above bankfull.

4.6 Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available?	Source of data	Details
Check flow gauging's	No	-	-	No rating reviews are proposed under the current scope of work.
Historical flood data	Yes	Yes	Environment Agency	Flood extent data and aerial imagery for observed flood events during November 2012, November 2019, February 2020 and January 2021 (see Annex C).
Flow or river level data for events	Yes	Yes	Environment Agency	Flow data and river level data has been provided for the stations listed in Section 2.4.
Rainfall data for events	Yes	Yes	Environment Agency	15-minute rainfall data has been provided for the following rain gauges: Calverton - 118464 Lambley TBR - 118209 Staythorpe - 120693 Waltham on the Wolds - 113261
Potential evaporation data	No	-	-	-
Results from previous studies	Yes	Yes	Environment Agency	River Trent and Tributaries at Newark Study - Halcrow, 2011 River Greet Strategic Flood Risk Mapping - 2008 Fluvial Trent Strategy - Black and Veatch, 2005
Other data or information	No	-	-	No abstraction data is available for the catchment. Due to the size of the River Trent abstraction impact will be negligible and not influence results.

4.7 Hydrological understanding of catchment

Conceptual model

Only fluvial flooding has been considered in this study.

The main area of interest to the study is in the vicinity of the A46 between Farndon Junction and Winthorpe Junction.

Flooding at Farndon is predominantly from the River Trent while further downstream at Newark, flooding may also result from the River Devon, Middle Beck, Sodbridge Drain, Lowfield Drain, Car Dyke and Dogge Dyke.

Flooding is expected to occur as result of peak flows exceeding channel capacity and/or the combination of flood peaks in the contributing tributaries coinciding with flood peaks in the receiving River Trent.

Unusual catchment features

The flow regime of the River Trent at North Muskham is subject to substantial flow modifications owing to imports and abstractions. Limited information has been provided on these, so the full extent of the impact of imports and abstractions cannot be quantified in this study and will be treated as an assumption. The impact of abstractions is considered captured in observed data, but it is also noted that they would have little influence within the catchment during a high flow event.

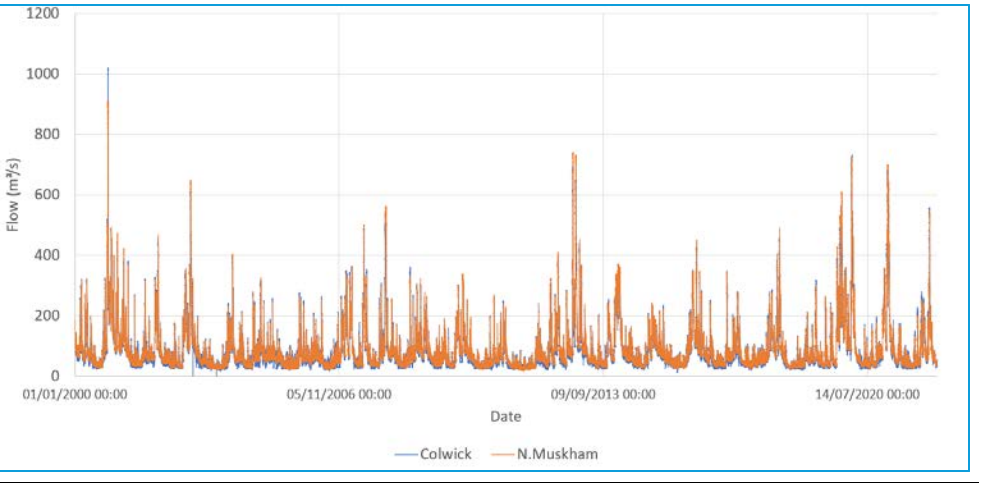
Reservoir(s) in the catchment will have limited effect on runoff at North Muskham. This is supported by the indicated FEH FARL value of 0.95.

Plots of flow data and interpretation

The flow series at Colwick and North Muskham (from January 2000 to May 2022) is plotted below (Figure 4.4). The Figure illustrates that peak flow at downstream North Muskham can be less than the corresponding event peak flow at upstream Colwick.

AMAX 1 was observed in November 2000, this is the biggest event on record and is >250m ^{3}/s than any other peak flood event. The majority of flow events are below 600m ^{3}/s, with general trends showing the winter months result in higher flood events. This is expected based on the catchment location and seasonality across the UK. There are four peaks relatively close together, since 2020, showing the regularity of higher flood flows has increased, but they do not compare to the AMAX 1.

Figure 4.4: Flow series at Colwick and North Muskham



Plots of flood peak data and interpretation

River Trent at Colwick

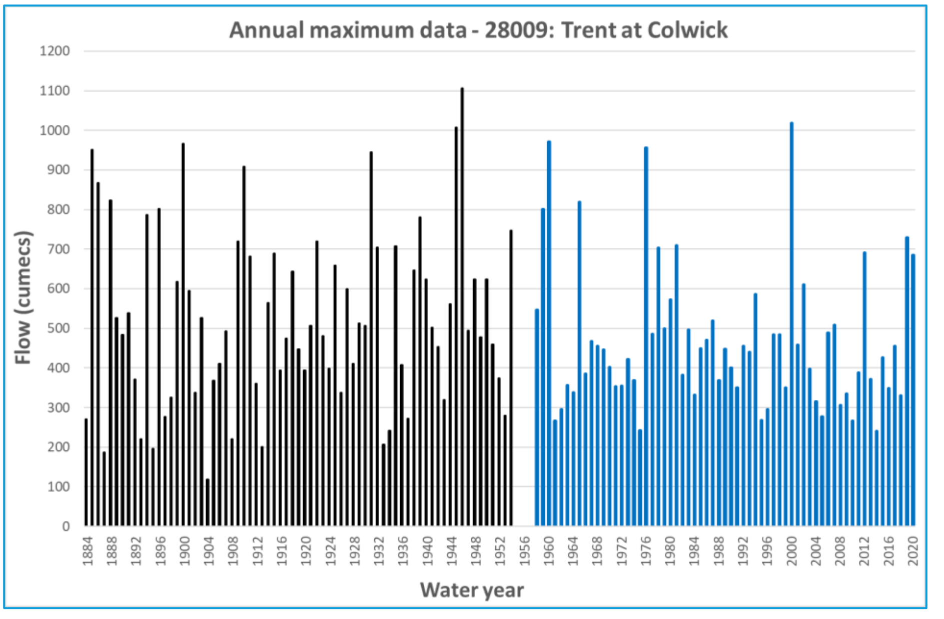
The station has 134-years of AMAX data, shown in Figure 4.5. There is missing data for water years 1955-1957 (inclusive) and 18 days in 1970.

The water year with the lowest AMAX (119m^3/s) on record is 1904. The water year with the highest AMAX on record is 1946 (1,107m ^{3}/s) followed by 2000 (1,019m^3/s) and 1945 (1,007m^3/s).

The historic AMAX series from 1884 -1954 is shown in black while the AMAX series as reported by the NRFA (1958 – 2020) is shown in blue.

Few events occur over 1000m^3/s, with flood peaks occurring approximately every 20 years.

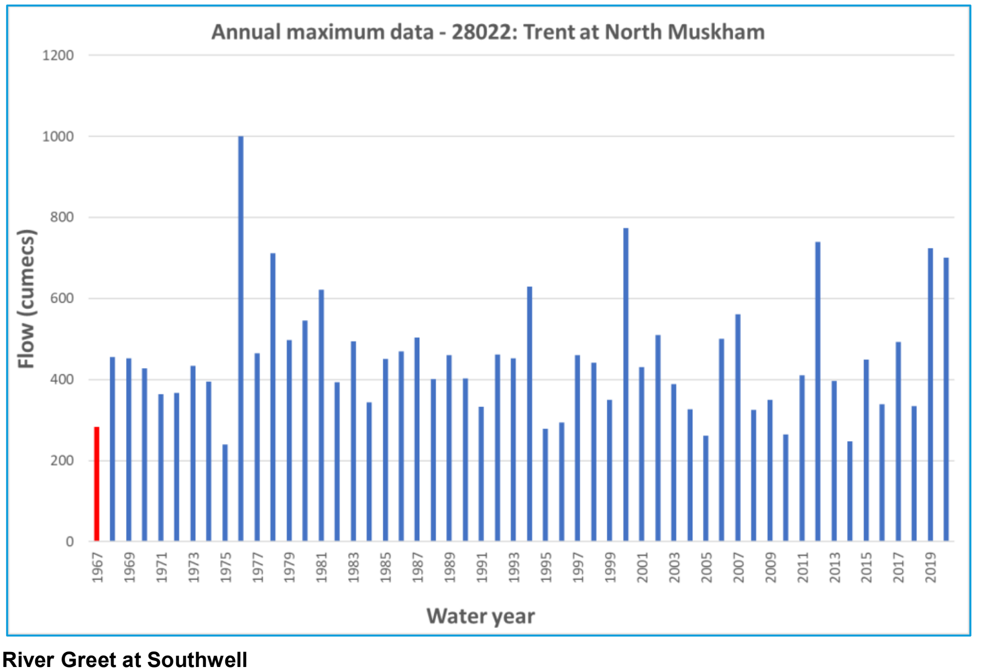
Figure 4.5: Annual Maximum data – Trent at Colwick



River Trent at North Muskham

The station has 53-years of useable gauged data (water years 1968 to 2020, inclusive), shown in Figure 4.6. Water year 1967 (shaded red) is rejected by the NRFA because it does not cover a full water year. There are also 32 missing days in 1973.

The smallest AMAX event (239m^3/s) on record is water year 1975 and the largest AMAX event recorded is 1976 (1,000m^3/s) followed by 2000 (774m^3/s) and 2012 (740m^3/s). No real trend is seen in the AMAX peaks for the Trent at North Muskham, although there have been an increase in number of peaks above 600m^3/s sinve 2011, compared to the 10-15 years prior.

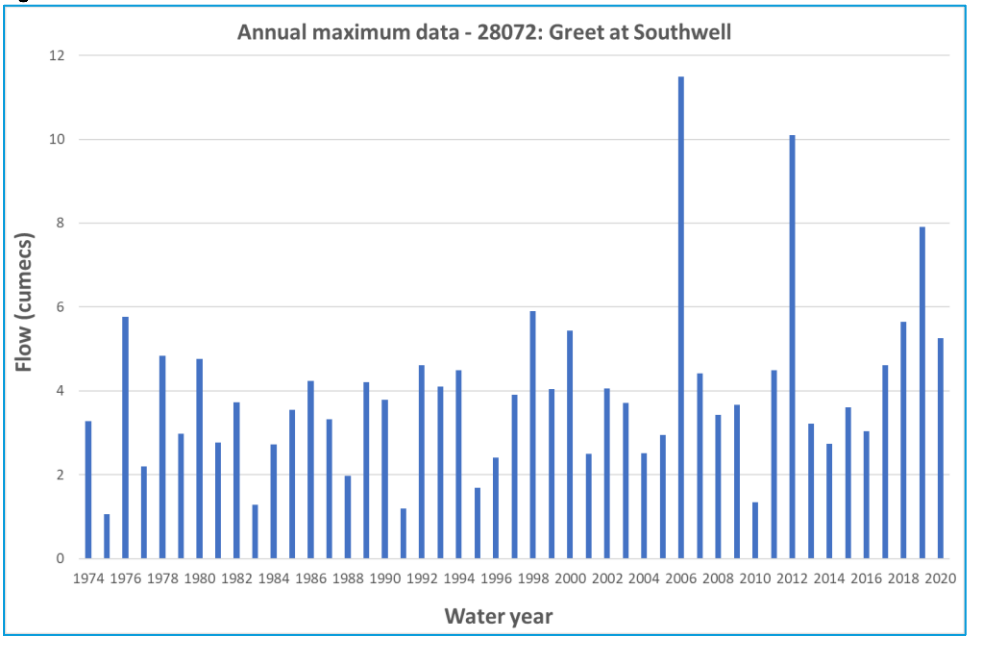


River Greet at Southwell

The station has 47-years of gauged data (water years 1974 to 2020, inclusive), shown in Figure 4.7. The water year with the lowest AMAX (1.1m^3/s) on record is 1976. The water year with the highest AMAX on record is 2006 (11.5m^3/s) followed by 2012 (10.1m^3/s) and 2019 (7.9m^3/s).

The flood peaks mostly remain below 6m^3/s. All three largest AMAX events occur since 2000, suggesting an increase in overall extreme event flood peaks.

Figure 4.7: Annual Maximum data – Greet at Southwell

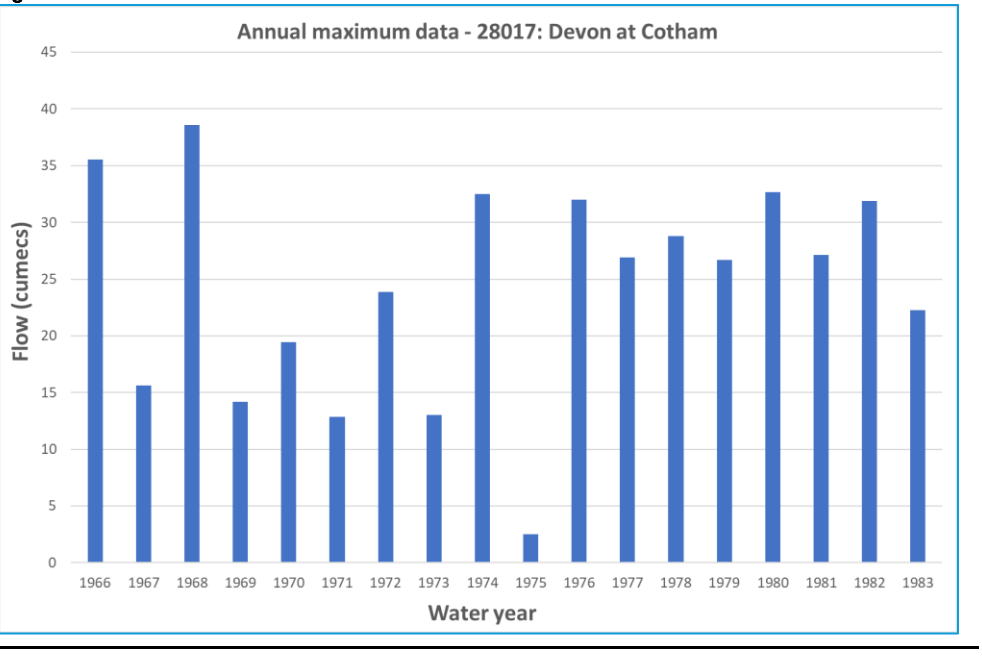


River Devon at Cotham

The station has 18-years of gauged data, shown in Figure 4.8. The water year with the lowest AMAX (2.5m ^{3}/s) on record is 1975. The water year with the highest AMAX on record is 1968 (38.6m^3/s) followed by 1966 (35.6m^3/s) and 1980 (32.7m^3/s).

The data is fairly uniform, expect a low peak in 1975.

Figure 4.8: Annual maximum data – Devon at Cotham



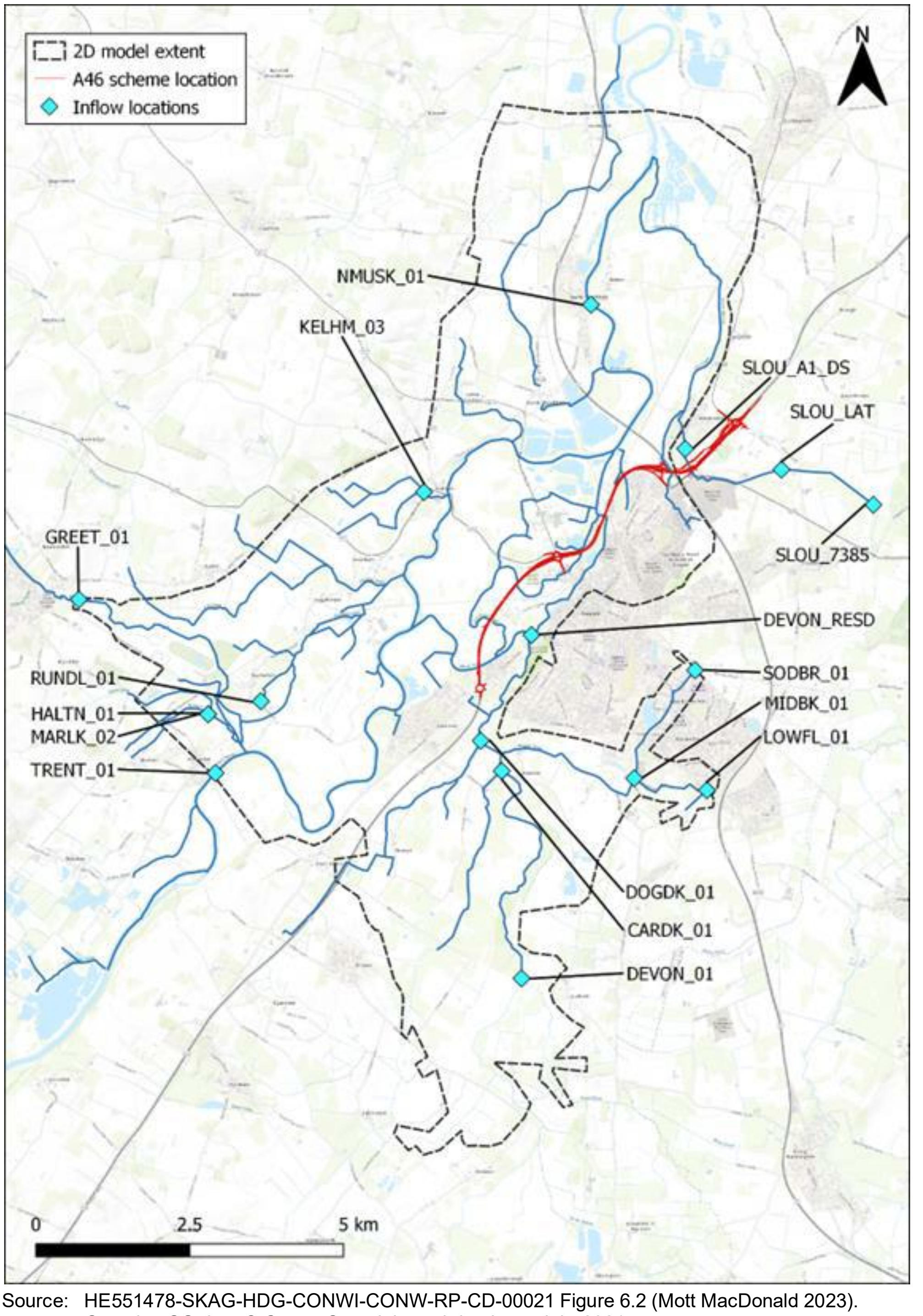
4.8 Initial choice of approach

Is FEH appropriate?	Yes, in general the standard application of FEH methods is appropriate. However, for the River Trent, it is unlikely that a suitable pooling group could be established due to the lack of stations contained within the NRFA Peak Flows Database which are similar in size. Similarly, the FEH QMED regression equation was developed from data on 602 catchments, with the largest catchment used in the development of the equation being 4590km² which is significantly smaller than the River Trent at Colwick (7486km²) or North Muskham (8231km²).
Initial choice of method(s) and reasons **How will hydrograph shapes be derived if needed?** **Will the catchment be split into sub-catchments? If so, how?**	**Gauged Locations:** The initial approach is to update the flood frequency understanding at the gauged locations for which, with the exception of the Devon at Cotham, FEH Statistical methods are considered most appropriate. Typical flood hydrographs have been derived for the gauged model inflows based on standardised event hydrographs observed at the respective gauge, this is further discussed in Section 7. **River Devon:** For the River Devon and its sub-catchments, Halcrow (2011) undertook event modelling within the ReFH Calibration Tool to derive optimised parameters of Tp, Cmax, BL and BR. The gauge at Cotham is no longer operational following its closure in 2003. In undertaking the calibration, Halcrow (2011) made use of events up to September 2002. It is not considered of much benefit to re-visit the event analysis due to no further recent events being available to use in the assessment, but also because the ReFH Calibration tool itself has not undergone any revision since the assessment by Halcrow. Instead, for the Devon and its sub-catchments, it is proposed to adopt the optimised parameters reported by the Halcrow study within ReFH2.3. **Ungauged Locations:** For the ungauged watercourses that are being explicitly modelled, there will be a need for inflow hydrographs. At all ungauged locations, the hybrid method will be used, where the ReFH2.3 hydrographs will be adopted and the design hydrographs scaled to the preferred flows based on the FEH Statistical combined flows matrix. The tributaries will be scaled so the combined model inflow to the model will reproduce the required design event peak flow on the River Trent. The catchment will be split into sub-catchments based on the adopted inflow locations within the hydraulic model. These can be seen in Figure 4.9.
Software to be used	FEH Web Service [3] / WINFAP 5[4] / ReFH2.3 / Flood Modeller Pro

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

[4] WINFAP 5 © Wallingford HydroSolutions Limited 2022.

Figure 4.9: Model inflow locations used to define subcatchments



Source: HE551478-SKAG-HDG-CONWI-CONW-RP-CD-00021 Figure 6.2 (Mott MacDonald 2023). Contains OS data © Crown Copyright and database right 2021

5 Joint probability

Reassessment of the dependency between the gauged watercourses within the study area has been undertaken to derive appropriate AEPs / return periods for applying to the tributaries when modelling the required design events on the Trent.

The Environment Agency Multivariate Event Modeller (MEM) tool[5] allows estimation of the joint probability of extreme events in combinations of up to 10 variables. The tool is based on the approach of Heffernan and Tawn (2004).

A joint probability analysis is undertaken using the Multivariate Event Modeller (MEM) tool to determine AEP (%) flood flows in the River Devon and River Greet tributary inflows that combine to produce a 1% AEP (100-year return period) flood within the receiving River Trent.

A full summary of the analysis undertaken can be found in Annex B, Section B.3.

Based on approx. 12-years of DMF data and a 50,000-year simulated event set, for modelling the 1% AEP (100-year return period) in the Trent, the adopted corresponding AEP to model in the River Devon is the 4% AEP (25-year return period), as presented in Table 5.1.

Table 5.1: Joint probability

Colwick	Southwell	Cotham
Target AEP (%) [Return-Period Years]	**Corresponding Tributary AEP (%) [Return-Period Years]**	
50% [2-year]	50% [2-year]	50% [2-year]
20% [5-year]	50% [2-year]	50% [2-year]
10% [10-year]	50% [2-year]	50% [2-year]
5% [20-year]	50% [2-year]	20% [5-year]
4% [25-year]	50% [2-year]	20% [5-year]
3.3% [30-year]	50% [2-year]	10% [10-year]
2% [50-year]	20% [5-year]	10% [10-year]
1.3% [75-year]	10% [10-year]	5% [20-year]
1% [100-year]	**10% [10-year]**	**4% [25-year]**
0.5% [200-year]	10% [10-year]	2% [50-year]
0.1% [1000-year]	4% [25-year]	2% [50-year]

[5] The MEM is a demonstration tool disseminated by the Environment Agency that allows analysis of multivariate joint probability problems in more than 3 variables. The tool was designed by JBA Consulting and Lancaster University and is based on the statistical approach outlined by Heffernan and Tawn (2004).

6 Locations where flood estimates required

The table below lists the locations of subject sites. An example of changed areas is provided in Annex F.

6.1 Summary of subject sites

Site code	Type of estimate L: lumped catchment S: Sub-catchment	Watercourse	Name or description of site	Easting	Northing	AREA on FEH CD-ROM (km^2)	Revised AREA if altered
Gauging Stations							
Station 28009	L	Trent	Colwick Station 28009	462050	339900	7466	7486
Station 28022 (TRENT_02)	L	Trent	North Muskham Station 28022	480150	360050	8209	8231
Station 28072 (GREET_01)	L	Greet	Southwell Station 28072	471050	354150	59.9	58.5
Station 28017	L	Devon	Cotham Station 28017	478700	347550	341	284
Model Inflows (shown in Figure 4.9)							
TRENT_01	L	Trent	Upstream model extent	473818	351120	-	7683
TRENT_RESD	S	Trent	Residual catchment flow	-	-	-	27.1
GREET_01	L	Greet	Upstream extent	471050	354150	59.9	58.5
DEVON_01	L	Devon	Upstream extent	478650	347500	270.5	271
DEVON_RESD	S	Devon	Residual catchment flow	-	-	-	34.0
SODBR_01		Sodbridge Drain	Upstream extent	481610	352900	-	3.48
LOWFL_01		Lowfield Drain	Upstream extent	481910	350840	-	0.78
MIDBK_01	L	Middle Beck	Confluence with Sodbridge	480620	351040	6.43	3.31
CARDK_01	L	Car Dyke	Confluence with Devon	477530	348340	60.4	65.1
DOGDK_01	L	Dogge Dyke	Confluence with Devon	476619	349464	2.13	5.73
MARLK_01	L	Marlock Dyke	Confluence with Beck Dyke	473734	352073	2.30	3.51
HALTN_01	L	Halloughton (Beck Dyke)	Confluence with Marlock Dyke	473752	352110	12.5	12.7
RUNDL_01	L	Rundell Dyke	Confluence with Trent	476836	354338	32.8	33.2
KELHM_01	L	Unnamed Kelham	Upstream of confluence with KELHM_02	477191	355696	-	2.35
KELHM_02	L	Unnamed Kelham	Upstream of confluence with KELHM_01	477153	355781	-	2.09
OLDTR_01	L	Old Trent Dyke	Upstream of A617	478436	354512	-	0.81
OLDTR_RESD	S	Old Trent Dyke	Residual catchment flow	-	-	-	2.35
CRANK_01	S	Unnamed Crankley Point (west)	Existing A46	480288	355649	-	0.12

Site code	Type of estimate L: lumped catchment S: Sub-catchment	Watercourse	Name or description of site	Easting	Northing	AREA on FEH CD-ROM (km^2)	Revised AREA if altered
CRANK_02	S	Unnamed Crankley Point (east)	Existing A46	480471	355954	-	0.31
WINTH_01	L	Unnamed Winthorpe	Downstream of A46	481449	356396	3.20	9.94
NMUSK_01	L	North Muskham	Confluence with Trent	480138	357701	-	1.99
Target Flows							
TRENT_02	L	Trent	North Muskham Station 28022	480150	360050	8209	8231
DEVON_02	L	Devon	Confluence with Trent	478950	353370		383
OLDTR_02	L	Old Trent Dyke	Confluence with Trent	478391	353029	1.62	3.15

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

Catchment descriptors which have been changed from the FEH values and/or manually calculated are shown in **bold text.** Altered areas are provided in table 5.1 above.

Site code	FARL	PROPWET	BFIHOST	BFIHOST19	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	URBEXT 2000	FPEXT
TRENT_01	0.94	0.31	0.505	0.497	96.6	53.7	760	**0.110**	0.12
TRENT_02	-	-	-	-	-	-	-	-	-
GREET_01	0.98	0.27	0.623	0.599	8.78	44.0	656	**0.042**	0.11
DEVON_01	0.98	0.27	0.382	0.392	20.1	28.1	592	**0.014**	0.25
DEVON_02	-	-	-	-	-	-	-	-	-
SODBR_01	**0.82**	0.27	0.391	0.434	**1.98**	10.5	568	**0.120**	0.52
LOWFL_01	**1.00**	0.27	0.391	0.434	**0.87**	10.5	568	**0.069**	0.52
MIDBK_01	**0.89**	0.27	0.391	0.434	**1.93**	10.5	568	**0.164**	0.52
CARDK_01	0.99	0.27	0.439	0.422	**9.86**	13.8	586	**0.037**	0.34
DOGDK_01	1.00	0.27	0.400	0.381	2.66	18.6	587	**0.001**	0.32
MARLK_01	1.00	0.27	0.381	0.360	**1.99**	29.8	628	**0.013**	0.16
HALTN_01	1.00	0.27	0.381	0.360	5.79	29.8	628	**0.000**	0.16
RUNDL_01	1.00	0.27	0.437	0.422	8.14	28.3	613	**0.015**	0.21
KELHM_01	0.98	0.27	0.531	0.515	**1.60**	28.0	596	**0.009**	0.41
KELHM_02	**1.00**	0.27	0.531	0.515	**1.50**	28.0	596	**0.007**	0.41
OLDTR_01	**0.77**	0.27	0.671	0.727	**0.89**	6.00	582	**0.056**	0.89
OLDTR_02	**0.93**	0.27	0.671	0.727	**1.88**	6.00	582	**0.029**	0.89
CRANK_01	**1.00**	0.27	0.532	0.534	**0.63**	12.3	576	**0.081**	0.31
CRANK_02	**1.00**	0.27	0.532	0.534	**0.63**	12.3	576	**0.081**	0.31
WINTH_01	1.00	0.27	0.580	0.642	**3.52**	12.3	574	**0.032**	0.31
NMUSK_01	**0.83**	0.27	0.671	0.727	**1.46**	6.00	582	**0.029**	0.89

6.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes	Catchment boundaries obtained from the FEH Web Service have been checked based on 2m LiDAR data (resampled to 10m) and a flow tracing algorithm within a GIS application and against the surface water network as depicted on Ordnance Survey (OS) mapping. Catchment areas that have been revised are documented in Section 6.1.
Record how other catchment descriptors were checked and describe any changes.	Where catchment area was updated, the appropriateness of the FEH descriptor DPLBAR was investigated using equation 7.1, presented in FEH Volume 5. Where appropriate, the FEH descriptor FARL was updated using equations 4.1 to 4.4 in FEH Volume 5. Where catchment area was updated or manually delineated, URBEXT values have been calculated based on the urban extent as shown on OS 50k mapping and using equations 5.2 and 5.4 as presented in the Joint Defra/EA R&D Technical Report FD1919/TR[6]. Note the BFIHOST19 catchment descriptor has been used in all calculations.
Source of URBEXT	URBEXT2000, manually calculated based on URBAN 50k where appropriate.
Method for updating of URBEXT	FEH values of URBEXT2000 are updated to the current year (2022) based on the CPRE formula from Technical Report FD1919/TR.

[6] A C Bayliss, K B Black, A Fava-Verde & T R Kjeldsen (2006). URBEXT2000 – A new FEH catchment descriptor. R&D Technical Report FD1919/TR.

7 Statistical method

7.1 Application of Statistical method

What is the purpose of applying this method?	The FEH statistical method is the preferential choice for the main River Trent and other input catchments for this assessment given that: • There is a very good availability of gauged data within the catchment • The length of record available at sites (notably gauges on the River Trent) is generally long • The size and scale of the catchments which are to be assessed have a moderate to very large catchment area. This includes the River Trent, which is approximately 7500km ^{2} at Colwick and over 8000km ^{2} at North Muskham. Rainfall runoff approaches may potentially result in an overestimate of flow for these catchments. • The Trent has a wide, extensive floodplain and extensive upstream features (such as flood risk alleviation schemes, offline storage/ lake features. Flood flow estimates derived by the FEH statistical method will, where appropriate, be compared against flood flow estimates derived by the ReFH2 rainfall-runoff method.

7.2 Overview of estimation of QMED at each subject site

Site code	QMED (rural) from CDs (m³/s)	Final method	Data transfer: NRFA numbers for donor sites used (see 6.3)	Data transfer: Distance between centroids d_{ij} (km)	Data transfer: Moderated QMED adjustment factor, (A/B)[a]	Data transfer: If more than one donor: Weight	Data transfer: If more than one donor: Weighted ave. adjustment	Urban adjust-ment factor UAF for CDs	Final estimate of QMED (m³/s) after donor and urban adjustment
Gauging Stations									
Station 28009	536	AM	28009	-	0.756	-	-	1.133	459
Station 28022 (TRENT_02)	563	-	-	-	0.749*	-	-	1.125	475
Station 28072 (GREET_01)	4.71	AM	28072	-	0.741	-	-	1.064	3.71
Station 28017	25.0	DT	28024 30005 31023 31025 31026 31010	17.11 17.71 21.70 27.89 29.27 32.94	-	0.327 0.323 0.298 0.263 0.256 0.238	1.229	1.013	31.1
Other FEPs									
TRENT_01	548	AM	28009	-	0.756	-	-	1.133	463
TRENT_02	563	-	-	-	0.749*	-	-	1.125	475
GREET_01	4.71	AM	28072	-	0.741	-	-	1.064	3.71
DEVON_01	24.0	DT	28024 30005 31023 31025 31026 31010	17.11 17.71 21.70 27.89 29.27 32.94	-	0.327 0.323 0.298 0.263 0.256 0.238	1.229	1.013	29.9
DEVON_02	31.4							1.022	39.5
SODBR_01	0.25	CD	-	-	-	-	1.150	1.121	0.32
LOWFL_01	0.14	CD	-	-	-	-	1.150	1.069	0.17
MIDBK_01	0.32	CD	3005	28.36	-	0.261	1.150	1.168	0.43

Site code	QMED (rural) from CDs (m³/s)	Final method	Data transfer: NRFA numbers for donor sites used (see 6.3)	Distance between centroids d_{ij} (km)	Moderated QMED adjustment factor, (A/B)[a]	If more than one donor: Weight	Weighted ave. adjustment	Urban adjustment factor UAF for CDs	Final estimate of QMED (m³/s) after donor and urban adjustment
			31023	29.88		0.253			
			30014	34.43		0.231			
			28024	35.71		0.225			
			29009	38.06		0.215			
			31026	45.07		0.187			
			3005	25.92		0.274			
			28024	27.31		0.266			
			31023	29.11	-	0.257			
CARDK_01	6.69	CD	30014	38.13		0.214	1.208	1.039	8.40
			31025	38.19		0.214			
			31026	39.42		0.209			
DOGDK_01	0.97	CD	-	-	-	-	1.103	1.001	1.07
MARLK_01	0.81	CD	-	-	-	-	1.069	1.012	0.88
			3005	34.15		0.232			
			28024	35.75		0.225			
HALTN_01	2.42	CD	31023	37.00	-	0.219	1.069	1.000	2.59
			28055	40.63		0.204			
			30014	44.61		0.188			
			29009	45.48		0.185			
			3005	36.34		0.222			
			31023	38.65		0.212			
RUNDL_01	4.40	CD	28024	39.96	-	0.207	1.077	1.016	4.82
			29009	39.96		0.207			
			29004	41.90		0.199			
			28055	44.15		0.190			
KELHM_01	0.31	CD	3005	34.07		0.233		1.011	0.34
			31023	36.07		0.224			
			29009	38.07	-	0.215	1.103		
			28024	39.11	-	0.210			
KELHM_02	0. 30	CD	29004	39.99		0.207		1.009	0.33
			30014	41.36		0.201			
OLDTR_01	0.02	CD	-	-	-	-	1.103	1.098	0.03
OLDTR_02	0.14	CD	-	-	-	-	1.103	1.050	0.16
CRANK_01	-	DT	-	-	-	-	1.103	1.105	0.02
CRANK_02	-	DT	-	-	-	-	1.103	1.105	0.06
WINTH_01	0.63	CD	-	-	-	-	1.103	1.045	0.73
NMUSK_01	0.06	CD	-	-	-	-	1.103	1.051	0.08

Are the values of QMED spatially consistent?	Yes; where relevant, QMED increases sensibly with downstream distance.
Method used for urban adjustment for subject and donor sites	WINFAP v4[7]

Parameters used for WINFAP v4 urban adjustment if applicable		
Impervious fraction for built-up areas, IF	Percentage runoff for impervious surfaces, PR_{imp}	Method for calculating fractional urban cover, URBAN
0.3	70%	From updated URBEXT2000

[7] Wallingford HydroSolutions (2016). WINFAP 4 Urban adjustment procedures.

Site code	QMED (rural) from CDs (m³/s)	Final method	Data transfer			If more than one donor		Urban adjust-ment factor UAF for CDs	Final estimate of QMED (m³/s) after donor and urban adjustment
			NRFA numbers for donor sites used (see 6.3)	Distance between centroids d_{ij} (km)	Moderated QMED adjustment factor, $(A/B)^a$	Weight	Weighted ave. adjustment		

Notes

Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer (with urban adjustment); CD – Catchment descriptors alone (with urban adjustment);

The QMED adjustment factor A/B for each donor site is moderated using the power term, a, which is a function of the distance between the centroids of the subject catchment and the donor catchment. The final estimate of QMED is $(A/B)^a$ times the initial (rural) estimate from catchment descriptors.

7.3 Search for donor sites for QMED

Comment on potential donor sites	**River Trent** QMED at Colwick is derived directly from the 134-years of station data. For deriving QMED at downstream North Muskham, the Black & Veatch Study multiplied the QMED estimate derived at Colwick (based on the period of record 1884 – 2000) by a factor of 1.016 to account for flood growth. This factor was derived by the ratio of QMED estimates for the two locations as obtained for the common period of records 1968 to 2000. Based on the same approach this study found an increase of less than 1%. Investigating the events where there is an increase in flow at North Muskham, relative to Colwick gives an increase of 3.5%. However, there are instances where flow is less at North Muskham relative to Colwick. In 66% of coincident events flows are greater and in 34% flows are less. QMED is derived at North Muskham based on a flood growth rate of +3.5%. If an increase of 3.5% is assumed resulting from an increased area of 745km² (i.e. the difference in catchment area between Colwick and North Muskham) then for an increase of 197km² (i.e., the difference in catchment area at Colwick and the upstream model inflow), 26.5% of the difference in flow estimated between North Muskham and Colwick can be applied to the Colwick flow estimates to derive the upstream model inflow. **Greet at Southwell (Station 28072)** QMED at Southwell is derived directly from the 47-years of station data (water years 1974 to 2020, inclusive). **Devon at Cotham (Station 28017)** The NRFA states that this site is not suitable for QMED or pooling as the rating underestimates flows throughout the range. Based on the station data at Cotham, QMED is calculated as 26.8m³/s which yields an adjustment of 1.04. As the rating is reported to underestimate flows throughout the range the estimate of QMED (as derived from the data) is considered to be underestimated. Adopting the six geographically closest stations gives an adjustment of 1.229 which gives a final QMED at Cotham of 31.1m³/s. **Ungauged Locations** At those ungauged flow estimation points, QMED adjustment is based on a weighted adjustment derived from the six geographically closest sites as given by WINFAP.

7.4 QMED adjustment for urbanisation

Subject and donor sites were adjusted for urban expansion to 2023 using the Urban Expansion Factor (UEF) formula[8]:

URBEXT2000

$$UEF = 0.7851 + 0.2124 \tan^{-1}\{(Year - 1967.5)/20.32\}$$

The UEF was calculated as 1.044.

[8] Environment Agency (2022) LIT11832 Version 4: Flood Estimation Guidelines

An estimate of the updated urban area in catchment for each site and donor was then required to deurbanise. This was derived by multiplying the updated URBEXT2000 descriptor by 1.567 to estimate URBAN50k (the proportion of urban area within the catchment). Using these updated URBAN50k (urban) values, the Urban Adjustment Factors (UAF) were calculated. These were then used to update QMED to factor in the updated Urban value, as shown in Table 7.1.

Table 7.1: URBEXT2000 updates and QMED urban adjustment

Site/donor	Area (km^2)	URBEXT2000	Updated URBEXT2000 (URBEXT2000*1.044)	Urban	UAF	QMED after urban adjustment (m^3/s)
Station 28009	7486	0.105	0.110	0.172	1.134	593
Station 28072	58.5	0.040	0.042	0.065	1.064	4.57
Station 28017	284	0.013	0.014	0.021	1.013	25.9
Station 28022	8231	0.099	0.104	0.163	1.125	622
TRENT_01	7683	0.105	0.110	0.172	1.134	606
TRENT_02	27.1	-	-	-	-	-
GREET_01	58.5	0.040	0.037	0.042	1.064	4.57
DEVON_01	271	0.013	0.016	0.014	1.013	24.9
DEVON_02	34.0	0.022	0.024	0.023	1.022	32.0
SODBR_01	3.48	0.120	0.093	0.120	1.121	0.31
LOWFL_01	0.78	0.069	0.054	0.069	1.069	0.17
MIDBK_01	3.31	0.164	0.127	0.164	1.168	0.42
CARDK_01	65.1	0.0354	0.034	0.037	1.039	6.64
DOGDK_01	5.73	0.001	0.011	0.001	1.001	0.92
MARLK_01	3.51	0.013	0.010	0.013	1.012	0.78
HALTN_01	12.7	0.000	0.006	0.000	1.000	2.31
RUNDL_01	33.2	0.014	0.010	0.015	1.016	4.30
KELHM_01	2.35	0.009	0.007	0.009	1.011	0.29
KELHM_02	2.09	0.007	0.005	0.007	1.009	0.28
OLDTR_01	0.81	0.056	0.043	0.056	1.098	0.03
OLDTR_02	2.35	0.029	0.022	0.029	1.050	0.18
CRANK_01	0.12	0.081	0.063	0.081	1.105	0.07
CRANK_02	0.31	-	0.081	0.127	-	-
WINTH_01	9.94	0.032	0.027	0.032	1.045	0.83
NMUSK_01	1.99	0.054	0.042	0.054	1.095	0.09

7.5 Donor sites chosen and QMED adjustment factors

For the River Trent at Colwick QMED is derived directly from the station AMAX record (based on the 134-years of station data). Similarly for the River Greet, QMED is estimated directly from the gauged data as despite the cautionary remarks provided by the NRFA, the station has 47 years of data, has undergone a rating review in 2007 and it would be remiss to not use the data.

For the Devon at Cotham an adjustment of 1.229 is adopted, which is based on the six geographically closest stations.

QMED at North Muskham is derived by increasing the QMED estimate at upstream Colwick by 3.5% which is based on the average increase in coincident events (where flow at North Muskham is shown to increase relative to Colwick).

For ungauged flow estimation points, QMED adjustment is based on a weighted adjustment derived from the six geographically closest sites. This is presented in Table 7.2.

Table 7.2: QMED adjustment factors

NRFA no.	Method (AM or POT)	Adjustment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjustment ratio (A/B)
28009	AM	No	459	607	0.756
28022	AM	No	475	634	0.749
28072	AM	No	3.71	5.01	0.741
28017	AM	No	-	25.3	1.229

7.6 Derivation of pooling groups

It is unlikely that a suitable pooling group could be established for the River Trent due to the lack of stations contained within the NRFA Peak Flows Database which are similar in catchment size. Hence, it is proposed to continue to adopt a single-site approach and to derive a common flood frequency curve to be applied at both Colwick and North Muskham. A single-site growth curve has been derived from the combined (134-years) historic and present-day AMAX series at Colwick and from the present-day (53-year) record at North Muskham.

Following submission of the proposed hydrological approach to the Environment Agency for comment, the Environment Agency's representative, JBA Consulting, requested that a weighted average growth curve, based on sample size, be investigated. Hence, also derived is a weighted growth curve based on both station's records, weighted by the period of record available at each respective gauge.

For the River Greet at Southwell, while not listed as a Peak Flow rated gauge on the NRFA, its data has been used in past studies and has been provided for this commission without any cautionary notes.

The NRFA reports uncertainty at high flows but also that a drowned flow rating was established by high flow gauging in June 2007 and the full period of record was reprocessed. The adopted growth curve is based on single site analysis as the enhanced single site and pooling analyses estimate the largest AMAX event in June 2007 as having a return period of approximately 200-years (based on a record of only 47-years). The single site analysis estimates the largest AMAX event as having a return period of approximately 100-years and is hence preferred so as not to underestimate the 1% AEP (100-year return period) design event at Southwell.

For the Devon at Cotham, the adopted growth curve is based on a pooled analysis due to the cautionary comments with regards to the station's data. The initial pooling group was strongly heterogeneous and formed largely by stations having significantly higher BFIHOST values than the Devon catchment.

Research by Formetta et al., (2018) found BFIHOST and flood seasonality to improve homogeneity of pooling-groups and provide a more accurate estimate of the growth curve than the current FEH pooling method. The pooling group for the River Devon is hence formed from stations which are similar in respect to BFIHOST19 and flood seasonality as well as AREA, SAAR, FARL and FPEXT.

There are 14 no. small ungauged catchments with catchment areas ranging from <0.5km² to >10km². A separate pooling group has been derived, using the similarity distance measure for small catchments. However, as small catchments are underrepresented in the NRFA Peak Flow Database, the final adopted group is inevitably made up of catchments larger than the subject sites themselves.

The changes to pooling groups are shown in Table 7.3. The original and final pooling group comparisons can be seen in Annex D.

Table 7.3: Derivation of pooling groups

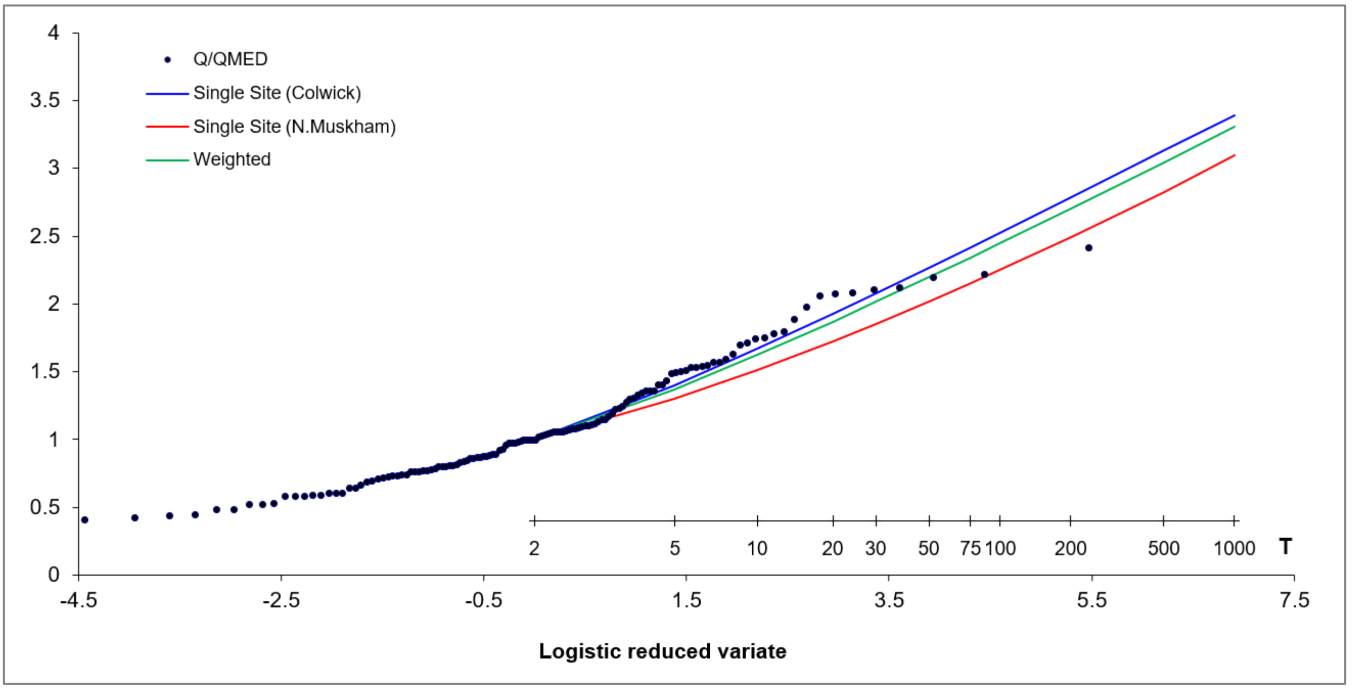
Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged?	Changes made to default pooling group, with reasons	Rural weighted average L-moments
Colwick	N/A	Yes	N/A, Single-site derived growth curve	L-CV: 0.227 L-Skew: 0.178
N.Muskham	N/A	Yes	N/A, Single-site derived growth curve	L-CV: 0.172 L-Skew: 0.214
Greet at Southwell	GREET_01	Yes	N/A, Single-site derived growth curve	L-CV: 0.259 L-Skew: 0.210
Devon at Cotham	DEVON_01	No	**Removed:** 54016, 33019, 54020, 27087, 204001, 33029, 33011 and 54041 all removed as BFIHOST or SAAR is too high. **Added:** 33005, 37010, 25005, 31005, 43009, 28024, 35008 and 36005 to increase total number of station years.	L-CV: 0.267 L-Skew: 0.167
Small catchments	MIDBK_01	No	**Removed:** 27073, 26016, 26014, 33054 on account of SPRHOST <20% 7011 as <8-years of AMAX data. **Added:** 27010, 24007, 37016 and 30004 to increase total number of station years.	L-CV: 0.297 L-Skew: 0.187

Note: Pooling groups were derived using the procedures from Science Report SC050050 (2008).

7.7 Flood growth curves - River Trent

Flood growth curves derived from single-site analysis at Colwick and North Muskham are shown below in Figure 7.1. Note that the AMAX events shown are those recorded at Colwick. Also shown is a weighted growth curve derived based on the respective stations' periods of record.

Figure 7.1: Flood growth curves – River Trent



The estimated rarity of the five largest AMAX events is tabulated in Table 7.4, based on the single-site derived growth curve at Colwick and the weighted growth curve. The largest AMAX entry for water year 1946 is estimated as having a return period of approximately 75-years or 88-years, based on the single-site derived curve and the weighted curve, respectively.

The derived growth curves presented show that estimates appear reasonable. As the upper curve exceeds the top 2 ranked AMAX events for higher magnitude events which the design assessment will focus on (such as the 100 year event), flows are unlikely to be underestimated. This provides confidence that estimates can be considered to be of a reasonable level of conservatism for subsequent application to the project flood model.

Table 7.4: Five largest AMAX events - Colwick

AMAX Event (water year)	AMAX Peak (m^3/s)	Single-site (Colwick)	Weighted
1946	1107	~75-yr	~88-yr
2000	1019	~45-yr	~55-yr
1945	1007	~42-yr	~50-yr
1960	972	~35-yr	~40-yr
1976	957	~30-yr	~38-yr

AMAX events recorded in water years 1976 and 2000 represent coincident events at both stations.

The largest AMAX event at North Muskham is recorded in 1976. Based on the single-site derived growth curve the estimated event rarity is approximately 65-years and the estimated rarity based on the weighted growth curve approximately 40-years. This compares with an estimate of event rarity for the 1976 AMAX event at Colwick of 38-years which is consistent. Based on the flood frequency analysis, it is observed that the AMAX event in water year 2000, registers as a lesser magnitude flood than at upstream Colwick, having an estimated return period of approximately 10-years to 15-years.

Table 7.5: Three largest AMAX events – North Muskham

AMAX Event (water year)	AMAX Peak (m^3/s)	Single-site (N.Muskham)	Weighted
1976	1000	~65-yr	~40-yr
2000	774	~15-yr	~10-yr

AMAX Event (water year)	AMAX Peak (m^3/s)	Single-site (N.Muskham)	Weighted
2012	740	~12-yr	<10-yr

The weighted growth curve is adopted as a common growth curve for applying at Colwick and North Muskham. The weighted growth curve gives more weighting to the Colwick single-site analysis due to the significantly longer period of record at Colwick relative to North Muskham. The weighted growth curve plots steeper than the single-site derived growth curve at North Muskham and hence avoids under estimating event rarity at that station.

7.8 Derivation of flood growth curves at subject sites

Site code	Method	If P, ESS or J, name of pooling group	Distribution used and reason for choice	Note any urban adjustment or permeable adjustment	Parameters of distribution	Growth factor for 1% AEP
TRENT_01 TRENT_02	SS (weighted)	-	The GEV distribution was adopted rather than the FEH recommended GL distribution as when plotted on a flood frequency plot was shown to provide a better fit to the (Colwick) station AMAX data, as shown within the Annex to this report.	N/A	**Trent (Colwick)** Location: 0.872 Scale: 0.349 Shape: -0.013 **Trent (N.Muskham)** Location: 0.912 Scale: 0.239 Shape: -0.060 **Weighted** Location: 0.883 Scale: 0.318 Shape: -0.026	2.45
GREET_01 RUNDL_01	SS	Greet at Southwell	GL, FEH recommended distribution for UK flood data. GL distribution also shown to plot closer to GL curve on L-Moment ratio diagram.	N/A	Location: 1.00 Scale: 0.264 Shape:-0.210	3.04
DEVON_01 DEVON_02 CARDK_01	P	Devon at Cotham	GL shown as best fitting distribution as indicated by z-value within WINFAP	Urban adjustment	Location: 1.00 Scale: 0.272 Shape: -0.170	2.90
SODBR_01 LOWFL_01 MIDBK_01 DOGDK_01 MARLK_01 HALTN_01 RUNDL_01 KELHM_01 KELHM_02 KELHM_03 OLDTR_01 OLDTR_02	P	Small Catchments	GL shown as best fitting distribution as indicated by z-value within WINFAP	No adjustment	Location: 1.00 Scale: 0.307 Shape: -0.187	3.24

Site code	Method	If P, ESS or J, name of pooling group	Distribution used and reason for choice	Note any urban adjustment or permeable adjustment	Parameters of distribution	Growth factor for 1% AEP
CRANK_01						
CRANK_02						
WINTH_01						
NMUSK_01						

Notes

Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis

Urban adjustments are all carried out using the method of Kjeldsen (2010).

Growth curves were derived using the procedures from Science Report SC050050 (2008).

7.9 Flood estimates from the statistical method

Site code	Flood peak (m^3/s) for the following return periods (in years)											
	2	5	10	20	25	30	50	75	100	100 CC	200	1000
	Flood peak (m^3/s) for the following AEP (%) events											
	50	20	10	5	4	3.3	2	1.3	1	1 CC	0.5	0.1
Model Inflows												
TRENT_01	463	635	752	867	904	933	1018	1085	1134	1576	1252	1534
TRENT_RESD	1.61	2.21	2.62	3.02	3.15	3.25	3.54	3.78	3.95	5.49	4.36	5.34
GREET_01	3.71	5.25	6.29	7.37	7.73	8.03	8.91	9.64	10.2	14.2	11.6	15.4
DEVON_01	29.9	42.6	51.5	60.9	64.1	66.8	74.7	81.4	86.4	120	100	137
DEVON_RESD	4.67	6.66	8.06	9.53	10.0	10.5	11.7	12.7	13.5	18.8	15.6	21.4
SODBR_01	0.32	0.48	0.59	0.71	0.75	0.79	0.89	0.98	1.04	1.45	1.22	1.72
LOWFL_01	0.17	0.26	0.31	0.38	0.40	0.42	0.47	0.52	0.56	0.77	0.65	0.92
MIDBK_01	0.43	0.64	0.80	0.96	1.01	1.06	1.20	1.31	1.40	1.95	1.64	2.31
CARDK_01	8.40	11.97	14.48	17.1	18.0	18.8	21.0	22.9	24.3	33.8	28.0	38.4
DOGDK_01	1.07	1.58	1.95	2.35	2.49	2.60	2.94	3.23	3.45	4.80	4.03	5.69
MARLK_01	0.88	1.24	1.49	1.75	1.83	1.90	2.11	2.28	2.41	3.35	2.75	3.65
HALTN_01	2.59	3.66	4.39	5.14	5.39	5.60	6.21	6.73	7.11	9.88	8.09	10.8
RUNDL_01	4.82	6.81	8.17	9.57	10.0	10.4	11.6	12.5	13.2	18.4	15.1	20.0
KELHM_01	0.34	0.51	0.62	0.75	0.80	0.83	0.94	1.03	1.10	1.53	1.29	1.82
KELHM_02	0.33	0.49	0.61	0.73	0.77	0.81	0.91	1.00	1.07	1.49	1.25	1.76
OLDTR_01	0.03	0.04	0.05	0.06	0.06	0.06	0.07	0.08	0.09	0.12	0.10	0.14
OLDTR_RESD	0.13	0.20	0.24	0.29	0.31	0.32	0.37	0.40	0.43	0.60	0.50	0.71
CRANK_01	0.023	0.034	0.042	0.051	0.054	0.056	0.063	0.070	0.074	0.103	0.087	0.122
CRANK_02	0.056	0.084	0.103	0.124	0.131	0.138	0.155	0.171	0.182	0.254	0.213	0.301
WINTH_01	0.73	1.08	1.33	1.60	1.70	1.77	2.01	2.20	2.35	3.27	2.75	3.88
NMUSK_01	0.08	0.11	0.14	0.17	0.18	0.18	0.21	0.23	0.25	0.34	0.29	0.40
Target Flows												
TRENT_02	475	652	772	889	927	957	1044	1113	1163	1617	1284	1573
DEVON_02	4.67	6.66	8.06	9.53	10.0	10.5	11.7	12.7	13.5	18.8	15.6	21.4
OLDTR_02	0.16	0.24	0.29	0.35	0.37	0.39	0.44	0.48	0.52	0.72	0.60	0.85

8 Revitalised flood hydrograph 2 (ReFH2) method

8.1 Application of ReFH2 method

What is the purpose of applying this method?	ReFH2.3 is used to: • derive design hydrographs for those ungauged locations; • provide lumped estimates at all locations where flood estimates are required, for the purpose of: • deriving the ratio of the 0.1% AEP (1000-year return period) over the 1% AEP (100-year return period) flow; and • providing flood estimates for comparison with those derived by the FEH statistical method.

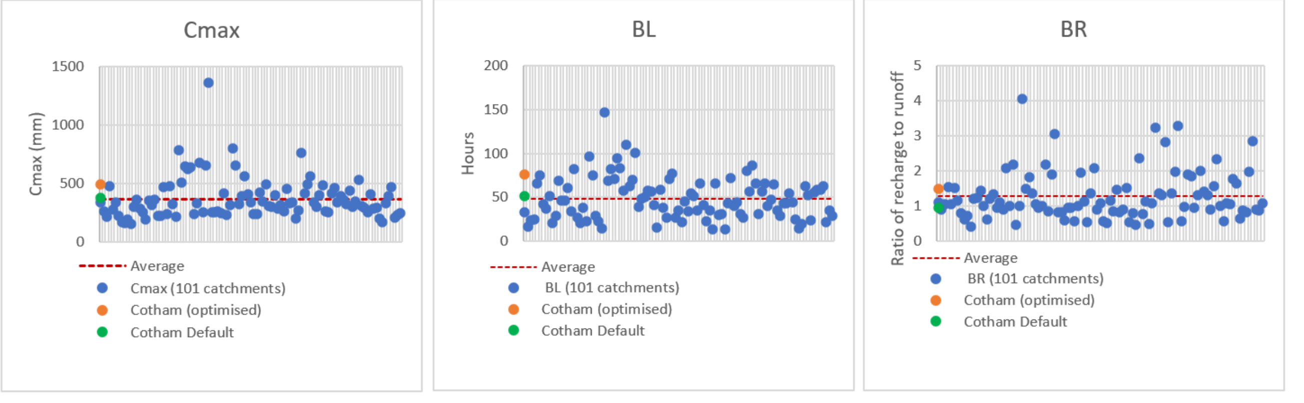
8.2 Parameters for ReFH2 model

Values shown in **bold** have been modified from the default values obtained from FEH catchment descriptors. The FEH13 DDF model has been used.

Site code	Tp_{rural} (hours)	Tp_{urban} (hours)	C_{max} (mm)	PR_{imp} % runoff for impermeable surfaces	BL (hours)	BR (2-yr)
TRENT_01	-	-	-	-	-	-
GREET_01	8.88	6.66	555	70	66.4	2.20
DEVON_01	**14.8**	**14.8**	**491**	70	**75.6**	**1.50**
DEVON_RESD	9.42	7.07	**614**	70	**56.7**	**1.61**
DEVON_02*	20.1	15.1	**614**	70	**56.7**	**1.61**
SODBR_01	5.63	4.22	**509**	70	**30.6**	**1.97**
LOWFL_01	4.31	3.23	**509**	70	**28.9**	**1.95**
MIDBK_01	5.61	4.21	361	70	38.5	1.88
CARDK_01	13.7	10.3	564	70	66.2	1.89
DOGDK_01	5.89	4.42	520	70	46.5	1.42
MARLK_01	4.30	3.22	298	70	35.3	1.19
HALTN_01	7.92	5.94	298	70	44.5	1.19
RUNDL_01	9.78	7.34	350	70	52.8	1.81
KELHM_01	4.98	3.74	446	70	46.0	2.77
KELHM_02	4.98	3.74	446	70	46.0	2.77
OLDTR_01	6.92	5.19	773	70	53.3	2.62
OLDTR_02*	6.92	5.19	773	70	53.3	2.62
CRANK_01	2.95	2.21	468	70	34.8	2.63
CRANK_02	2.95	2.21	468	70	34.8	2.63
WINTH_01	7.89	5.91	620	70	56.7	2.27
NMUSK_01	5.99	4.49	773	70	50.5	2.62
TRENT_02	-	-	-	-	-	-

ReFH2 parameters for the River Devon and its sub-catchments have transposed from event modelling within the ReFH Calibration Tool undertaken by Halcrow in 2011. The optimised values of Cmax, BL and BR are shown for the River Devon below in Figure 8.1. Also shown are optimised parameter values at 101 gauging stations. The optimised parameter values adopted for the River Devon are shown to increase from the default values for all three parameters and are shown to be slightly greater than the average values obtained from 101 sites.

Figure 8.1: Optimised values – River Devon



8.3 Design events for ReFH2 method: Lumped catchments

Based on the URBEXT values, the winter storm profile rainfall depths have been applied in ReFH2.3. The critical storm duration has been presented as 48.1 hours, based on the key characteristics of the River Trent. This has been assumed to be appropriate based on the extensive analysis previously undertaken by the Halcrow 2011 study.

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)
TRENT_01	Urban	-	-
GREET_01	Urban	Winter	15.0
DEVON_01	Urban	Winter	48.1
DEVON_02*	Urban	Winter	48.1
SODBR_01	Urban	Winter	48.1
LOWFL_01	Urban	Winter	48.1
MIDBK_01	Urban	Winter	48.1
CARDK_01	Urban	Winter	48.1
DOGDK_01	Urban	Winter	48.1
MARLK_01	Urban	Winter	13.0
HALTN_01	Urban	Winter	13.0
RUNDL_01	Urban	Winter	15.0
KELHM_01	Urban	Winter	7.5
KELHM_02	Urban	Winter	7.5
OLDTR_01	Urban	Winter	11.0
OLDTR_02*	Urban	Winter	11.0
CRANK_01	Urban	Winter	4.5
CRANK_02	Urban	Winter	4.5
WINTH_01	Urban	Winter	13.0
NMUSK_01	Urban	Winter	9.0
TRENT_02	Urban	-	-

8.4 Design events for ReFH2 method: Sub-catchments and intervening areas

Site code	Season of design event	Storm duration (hours)	Storm area for ARF (if not catchment area)	Reason for selecting storm
DEVON_01	Winter	48.1	383	Determined, by means of hydraulic modelling, to be the critical duration by Halcrow (2011)
DEVON_02*				
SODBR_01				
LOWFL_01				
MIDBK_01				
CARDK_01				
DOGDK_01				

8.5 Flood estimates from the ReFH2 method

Site code	Flood peak (m^3/s) for the following return periods (in years)											
	2	5	10	20	25	30	50	75	100	100 CC	200	1000
	Flood peak (m^3/s) for the following AEP (%) events											
	50	20	10	5	4	3.3	2	1.3	1	1 CC	0.5	0.1
Model Inflows												
TRENT_01	-	-	-	-	-	-	-	-	-	-	-	-
TRENT_RESD	-	-	-	-	-	-	-	-	-	-	-	-
GREET_01	5.31	6.95	8.23	9.70	10.2	10.7	12.2	13.5	14.6	21.7	17.7	26.4
DEVON_01	39.7	48.6	56.1	65.2	68.5	71.4	80.1	87.6	93.2	130	107	142
DEVON_RESD	6.21	7.59	8.74	10.1	10.6	11.1	12.4	13.5	14.4	19.9	16.5	21.6
SODBR_01	0.67	0.87	1.03	1.23	1.30	1.36	1.54	1.69	1.81	2.57	2.10	2.83
LOWFL_01	0.16	0.21	0.25	0.30	0.32	0.33	0.38	0.41	0.44	0.63	0.51	0.69
MIDBK_01	0.59	0.78	0.94	1.12	1.19	1.25	1.43	1.58	1.69	2.46	1.99	2.72
CARDK_01	9.28	11.3	12.9	14.8	15.5	16.1	18.0	19.7	21.0	29.1	24.3	32.6
DOGDK_01	1.20	1.48	1.71	1.98	2.07	2.16	2.41	2.64	2.82	3.95	3.28	4.45
MARLK_01	1.14	1.50	1.78	2.09	2.20	2.30	2.60	2.89	3.11	4.52	3.72	5.47
HALTN_01	2.82	3.66	4.32	5.06	5.34	5.58	6.32	7.01	7.56	10.9	9.07	13.3
RUNDL_01	5.27	6.86	8.10	9.51	10.0	10.5	11.8	13.1	14.1	20.4	16.9	24.5
KELHM_01	0.39	0.53	0.64	0.76	0.81	0.84	0.96	1.07	1.15	1.68	1.40	2.12
KELHM_02	0.35	0.47	0.57	0.68	0.72	0.75	0.86	0.95	1.03	1.50	1.24	1.89
OLDTR_01	0.05	0.06	0.08	0.10	0.10	0.11	0.12	0.14	0.15	0.23	0.19	0.29
OLDTR_RESD	0.13	0.19	0.23	0.28	0.30	0.31	0.36	0.41	0.44	0.68	0.55	0.85
CRANK_01	0.026	0.037	0.046	0.055	0.058	0.061	0.070	0.077	0.083	0.121	0.100	0.153
CRANK_02	0.064	0.092	0.112	0.135	0.143	0.150	0.171	0.190	0.205	0.298	0.246	0.377
WINTH_01	0.73	1.00	1.23	1.49	1.58	1.66	1.92	2.16	2.35	3.53	2.87	4.36
NMUSK_01	0.13	0.18	0.23	0.27	0.29	0.31	0.35	0.40	0.43	0.65	0.53	0.83
Target Flows												
TRENT_02	-	-	-	-	-	-	-	-	-	-	-	-
DEVON_02	52.0	63.2	72.6	83.8	87.9	91.4	102	111	118	162	135	176
OLDTR_02	0.18	0.25	0.31	0.37	0.40	0.42	0.49	0.55	0.60	0.91	0.74	1.15

9 Discussion and summary of results

9.1 Comparison of results from different methods

Site code	Ratio of peak flow to FEH Statistical peak					
	Return period 2 years / 50% AEP			Return period 100 years / 1% AEP		
	ReFH2.3	FEH Stat.	Ratio	ReFH2.3	FEH Stat.	Ratio
Model Inflows						
TRENT_01	-	463	**-**	-	1134	**-**
GREET_01	5.31	3.71	**1.43**	14.6	10.2	**1.44**
DEVON_01	39.7	29.9	**1.33**	93.2	86.4	**1.08**
DEVON_RESD	6.21	4.67	**1.33**	14.4	13.5	**1.06**
SODBR_01	0.67	0.32	**2.06**	1.81	1.04	**1.73**
LOWFL_01	0.16	0.17	**0.94**	0.44	0.56	**0.80**
MIDBK_01	0.59	0.43	**1.36**	1.69	1.40	**1.21**
CARDK_01	9.28	8.40	**1.11**	21.0	24.3	**0.86**
DOGDK_01	1.20	1.07	**1.12**	2.82	3.45	**0.82**
MARLK_01	1.14	0.88	**1.30**	3.11	2.41	**1.29**
HALTN_01	2.82	2.59	**1.09**	7.56	7.11	**1.06**
RUNDL_01	5.27	4.82	**1.09**	14.1	13.2	**1.07**
KELHM_01	0.39	0.34	**1.15**	1.15	1.10	**1.05**
KELHM_02	0.35	0.33	**1.06**	1.03	1.07	**0.96**
OLDTR_01	0.05	0.03	**1.72**	0.15	0.09	**1.78**
OLDTR_RESD	0.13	0.13	**1.00**	0.44	0.43	**1.04**
CRANK_01	0.026	0.023	**1.13**	0.083	0.074	**1.12**
CRANK_02	0.064	0.056	**1.13**	0.205	0.182	**1.12**
WINTH_01	0.73	0.73	**1.00**	2.35	2.35	**1.00**
NMUSK_01	0.13	0.08	**1.74**	0.43	0.25	**2.05**
Target Flows						
TRENT_02	-	475	**-**	-	1163	**-**
DEVON_02	52.0	39.5	**1.32**	118	114	**1.03**
OLDTR_02	0.18	0.16	**1.12**	0.60	0.52	**1.16**

9.2 Final choice of method

Choice of method and reasons	At all gauged locations and for Car Dyke, flow estimates as derived by the FEH statistical method are adopted. This approach has been chosen given that: The FEH statistical method for catchments of this scale is considered preferential. The catchments of interest contain extensive floodplain and complex attenuation features (such as flood alleviation schemes). The use of a rainfall runoff approach alone may lead to an overestimation of flows. It is assumed that the flood record used captures the complexity of this flooding within the gauged data; and The method makes use of gauged data and local information. This provides confidence in estimate flows and favours this approach; The estimate of the 0.1% AEP (1000-year return period) event is derived by multiplying the FEH statistical 1% AEP (100-year return period) flow estimate by the ratio of the ReFH2.3 0.1% AEP flow estimate over the ReFH2.3 1% AEP flow estimate. For all other locations, the flow estimates as derived by the ReFH2.3 method are adopted.
How will the flows be applied to a hydraulic model?	During the course of hydraulic modelling the tributary inflows will be scaled so that the combined inflow to the model reproduces the required design event peak flow on the River Trent. This will be reported in the hydraulic modelling reporting and is not discussed further here.

9.3 Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	For the River Trent, the study has adopted an AMAX series supplemented with historic AMAX entries from 1884 to 1954 as derived by Black & Veatch (2005). The study assumes: ● the catchment and watercourse have been largely unchanged since the historic data recorded in the late 19th and early 20th century. ● all large floods have been identified during the historic review. For the River Devon, parameters optimised from the Halcrow 2011 study have been used. This study assumes the parameters remain the best available estimate and have not been updated due to the extensive study carried out previously. The study has derived the 0.1% AEP (1000-year return period) growth factors based on a rainfall runoff approach and assumes confidence is greater in rainfall growth curves than in flood growth curves for longer return periods.
Discuss any particular limitations	Confidence in design (and event) flow estimates in the ungauged tributary watercourses is limited by the absence of gauged data. However, the impact and influence of this limitation on the overall conclusions of the assessment is deemed small as: - These catchments are small and, when compared to the River Trent, are not the main contributor or significantly influence flood conditions which may impact the scheme. The update to ReFH2.3 software reduces user input on calibration of parameters. Therefore, no tests have been carried out to compare the River Devon and it's subcatchments. For modelling the event inflows, catchment rainfall has been derived and used within ReFH2 to derive the event hydrograph(s).
Provide information on the uncertainty in the design peak flow estimates and the methodology used	Uncertainty in the flow estimates is reported in Section 6.6.
Comment on the suitability of the results for future studies	The study has made use of the latest Environment Agency Flood Estimation Guidelines [9] and the latest recommended software and methodologies to update the hydrological analysis which was undertaken in 2011 by Halcrow. The hydrological analysis presented herein is derived for the purpose of meeting the scope of the A46 Newark Bypass study. Reported flow estimates should not be relied upon for other studies.

[9] Environment Agency (2022). Flood Estimation Guidelines: LIT 11832 Published: 07/07/2022

9.4 Checks

Are the results consistent, for example at confluences?

On the main River Trent, flows increase with downstream distance.

What do the results imply regarding the return periods / frequency of floods during the period of record?

AMAX events recorded in water years 1976 and 2000 represent coincident events at both stations located on the River Trent.

The largest AMAX event at North Muskham is recorded in 1976. Based on the weighted growth curve, the estimated event rarity is approximately 40-years. This compares with an estimate of event rarity for the 1976 AMAX event at Colwick of 38-years which is generally agreeable. Based on the flood frequency analysis, it is observed that the AMAX event in water year 2000, registers as a lesser magnitude flood than at upstream Colwick, having an estimated return period of approximately 10-years to 15-years.

What is the range of 100-year / 1% AEP growth factors? Is this realistic?

2.31 – 3.35
Growth factors fall within the ratios of 2.1- 4.0 as outlined and recommended as suitable by the EA's guidance

If 1000-year / 0.1% AEP flows have been derived, what is the range of ratios for 1000-year / 0.1% AEP flow over 100-year / 1% AEP flow?

1.75 – 1.92

How do the results compare to the hydraulic model?

The application of inflows to the model cannot be directly compared to the hydraulic model, due to the routing component which has been utilised and the active floodplain component. This cannot be quantified within the hydrology.

How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.

Site	Mott MacDonald (2022)	Halcrow (2011)
	1% AEP	1% AEP
Colwick (28009)	1124	1200
N. Muskham (28022)	1163	1220
Devon US	86.4	85.1
Devon Lateral	14.4	16.5
Sodbridge	1.81	0.61
Lowfield Drain	0.44	0.30
Middle Beck	1.69	3.6
Car Dyke	24.3	19.7
Dogg Dyke	2.82	1.24
Greet @ Southwell	11.3	9.4

For Trent at Colwick the estimate of the 1% AEP has reduced by 6.5% compared to the estimate reported by Halcrow (2011), while at North Muskham the estimate of the 1% AEP has reduced by 4.8%.

For the River Devon, flows estimated under the current commission are generally comparable to those estimated previously; however, for the Devon sub-catchments, flows are shown to disagree due to differences in calculated catchment area.

The current study has derived and checked catchment boundaries based on high resolution LiDAR data and a flow tracing algorithm within a GIS application.

The inflow hydrology concluded by this assessment is deemed to be preferential given that:

- **The study utilises the latest gauged data, use of up to date methodology and follows the latest guidance at the time of writing;**
- **The updated flow estimates demonstrate that there is consistency across both studies. This is expected given the lack of significant recent flood events since 2011 which may influence changes in the understanding of flooding on the River Trent at this location;**
- **The latest hydrology utilises an enhanced level of assessment, particularly when reviewing joint probability.**

The QMED and 1% AEP specific discharge (l/s/ha) has been derived and is presented in Table 9.1.

Table 9.1: Specific discharge

Site	QMED specific discharge (l/s/ha)	1% AEP specific discharge (l/s/ha)
Station 28009	0.61	0.00
Station 28072	0.63	0.39
Station 28017	1.09	0.00
Station 28022	0.58	0.00
TRENT_01	-	-
GREET_01	0.63	0.39
DEVON_01	1.10	0.13
DEVON_02	1.03	0.09
SODBR_01	0.93	10.69
LOWFL_01	2.19	47.59
MIDBK_01	1.31	11.24
CARDK_01	1.29	0.54
DOGDK_01	1.86	6.23
MARLK_01	1.03	0.09
HALTN_01	2.05	2.74
RUNDL_01	1.45	1.05
KELHM_01	1.45	15.21
KELHM_02	1.58	17.08
OLDTR_01	0.33	44.24
OLDTR_02	0.50	11.33
CRANK_01	1.84	82.69
WINTH_01	0.73	3.59
NMUSK_01	0.38	17.95

Final results

Site code	Flood peak (m^3/s) for the following return periods (in years)											
	2	5	10	20	25	30	50	75	100	100 CC	200	1000
	Flood peak (m^3/s) for the following AEP (%) events											
	50	20	10	5	4	3.3	2	1.3	1	1 CC	0.5	0.1
Model Inflows												
TRENT_01	463	635	752	867	904	933	1018	1085	1134	1576	1252	2007
TRENT_RESD	1.61	2.21	2.62	3.02	3.15	3.25	3.54	3.78	3.95	5.49	4.36	9.87
GREET_01	3.71	5.25	6.29	7.37	7.73	8.03	8.91	9.64	10.2	14.2	11.6	18.4
DEVON_01	29.9	42.6	51.5	60.9	64.1	66.8	74.7	81.4	86.4	120	100	132
DEVON_RESD	6.21	7.59	8.74	10.1	10.6	11.1	12.4	13.5	14.4	19.9	16.5	21.6
SODBR_01	0.67	0.87	1.03	1.23	1.30	1.36	1.54	1.69	1.81	2.57	2.10	2.83
LOWFL_01	0.16	0.21	0.25	0.30	0.32	0.33	0.38	0.41	0.44	0.63	0.51	0.69
MIDBK_01	0.59	0.78	0.94	1.12	1.19	1.25	1.43	1.58	1.69	2.46	1.99	2.72
CARDK_01	8.40	12.0	14.5	17.1	18.0	18.8	21.0	22.9	24.3	33.8	28.0	38.4
DOGDK_01	1.20	1.48	1.71	1.98	2.07	2.16	2.41	2.64	2.82	3.95	3.28	4.45
MARLK_01	1.14	1.50	1.78	2.09	2.20	2.30	2.60	2.89	3.11	4.32	3.72	5.47
HALTN_01	2.82	3.66	4.32	5.06	5.34	5.58	6.32	7.01	7.56	10.5	9.07	13.3
RUNDL_01	5.27	6.86	8.10	9.51	10.0	10.5	11.8	13.1	14.1	19.6	16.9	24.5
KELHM_01	0.39	0.53	0.64	0.76	0.81	0.84	0.96	1.07	1.15	1.60	1.40	2.12
KELHM_02	0.35	0.47	0.57	0.68	0.72	0.75	0.86	0.95	1.03	1.43	1.24	1.89

Site code	Flood peak (m^3/s) for the following return periods (in years)											
	2	5	10	20	25	30	50	75	100	100 CC	200	1000
	Flood peak (m^3/s) for the following AEP (%) events											
	50	20	10	5	4	3.3	2	1.3	1	1 CC	0.5	0.1
OLDTR_01	0.046	0.064	0.079	0.096	0.102	0.107	0.124	0.140	0.153	0.213	0.189	0.294
OLDTR_RESD	0.13	0.19	0.23	0.28	0.30	0.31	0.36	0.41	0.44	0.62	0.55	0.85
CRANK_01	0.026	0.037	0.046	0.055	0.058	0.061	0.070	0.077	0.083	0.121	0.100	0.153
CRANK_02	0.064	0.092	0.112	0.135	0.143	0.150	0.171	0.190	0.205	0.298	0.246	0.377
WINTH_01	0.73	1.00	1.23	1.49	1.58	1.66	1.92	2.16	2.35	3.26	2.87	4.36
NMUSK_01	0.13	0.18	0.23	0.27	0.29	0.31	0.35	0.40	0.43	0.60	0.53	0.83
Target Flows												
TRENT_02	475	652	772	889	927	957	1044	1113	1163	1617	1284	2059
DEVON_02	39.5	56.3	68.1	80.5	84.7	88.3	99	108	114	159	132	181
OLDTR_02	0.18	0.25	0.31	0.37	0.40	0.42	0.49	0.55	0.60	0.91	0.74	1.15

9.5 Uncertainty bounds

Table 9.2 reports the 95% confidence bounds for the FEH statistical flow estimates at key FEPs. Quantifying uncertainty in design flows estimated from the ReFH2.3 method is not straightforward and is beyond the scope of this study.

The factorial standard errors from ReFH2 are comparable to those observed for the FEH pooled statistical method and hence the degree of uncertainty may be considered to be similar.

Table 9.2: Uncertainty bounds

Site code	Flood peak (m^3/s) for the following return periods (in years)							
	2		20		100		200	
	Flood peak (m^3/s) for the following AEP (%) events							
	50		5		1		0.5	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
FEH Statistical Estimates								
TRENT_01	463	463	802	966	986	1366	1054	1558
GREET_01	3.18	4.24	6.07	8.67	8.00	12.4	8.86	14.3
DEVON_01	15.2	58.8	30.4	122	42.3	177	47.8	207
TRENT_02	475	475	823	991	1011	1401	1081	1598

A. FEH Catchment Descriptors

A.1 Updated catchment descriptor values

Table A.1 presents the original updated FARL, DPLBAR and UBREXT2000 values for the catchments where changes have been made (Section 5.2).

Table A.1: Initial catchment descriptors

Site code	FARL	DPLBAR (km)	URBEXT 2000
TRENT_01	0.94	96.6	0.105
TRENT_02	-	-	-
GREET_01	0.98	8.78	0.04
DEVON_01	0.98	20.1	0.038
DEVON_02	0.982	25.64	0.022
SODBR_01	0.91	1.91	0.145
LOWFL_01	0.94	1.21	0.107
MIDBK_01	0.94	2.54	0.245
CARDK_01	0.99	9.52	0.03
DOGDK_01	1	2.66	0.006
MARLK_01	1	2.43	0.019
HALTN_01	1	5.79	0.006
RUNDL_01	1	8.14	0.0144
KELHM_01	0.98	1.65	0.019
KELHM_02	0.98	1.69	0.006
OLDTR_01	0.74	0.89	0.057
OLDTR_02	0.92	2.55	0.006
CRANK_01	1	0.63	0.101
CRANK_02	-	-	-
WINTH_01	1	3.52	0.019
NMUSK_01	0.95	129.7	0.104

B. Hydrological boundaries

The subsequent sections discuss the process involved in deriving hydrological (fluvial) boundaries for the purpose of the hydraulic modelling.

B.1 Design hydrographs

B.1.1 River Trent

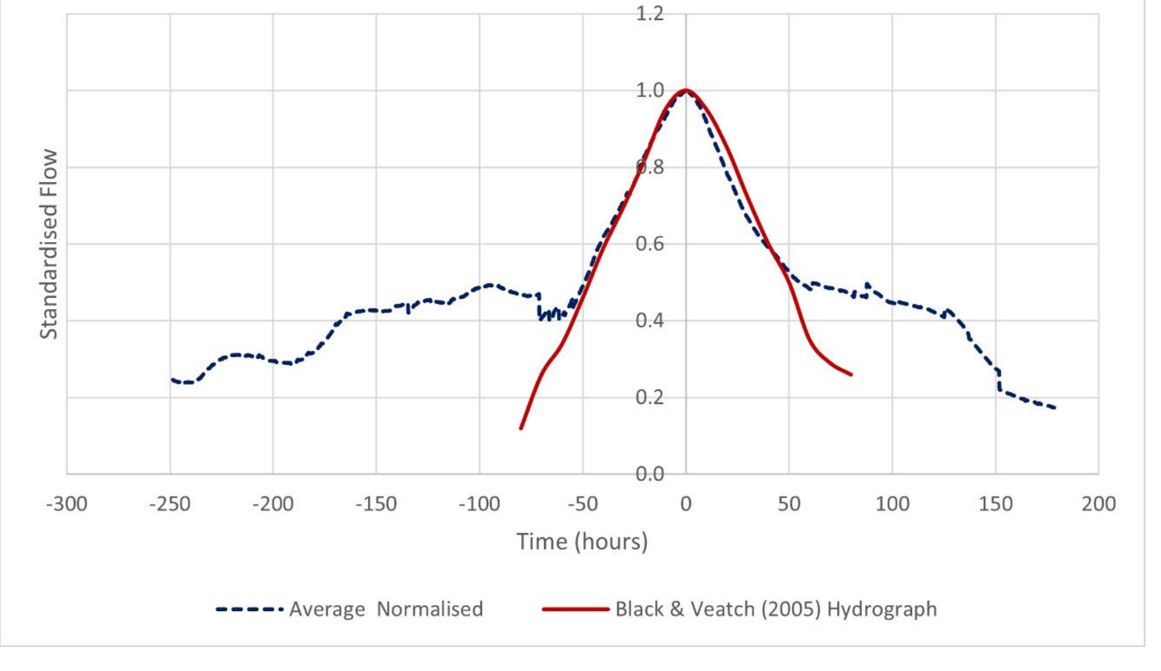
An average design hydrograph shape has been determined for the River Trent at Colwick based on eight observed event flood hydrographs which were standardised by the observed peak flow. The eight events are shown in Table B.2 alongside their rank within the present-day AMAX series i.e., 1958 – present. Some events (such as AMAX rank 2 and 5) have not been included due to the multiple peaks observed, meaning these are of limited suitability for the method of analysis.

Table B.2: Observed AMAX event against ranking – River Trent

AMAX Event	Rank in Present-Day AMAX Series
11/12/1965	4
26/02/1977	3
30/12/1978	8
01/01/1982	7
08/11/2000	1
31/12/2002	11
27/11/2012	9
18/02/2020	6

The average hydrograph shape obtained from the eight events tabulated above is compared in Figure B.1 against the average hydrograph shape as derived by the Black & Veatch Study. Based on this, there appears no justification for updating the existing hydrograph for the River Trent.

Figure B.1: Average hydrograph shape – River Trent



B.1.2 River Greet

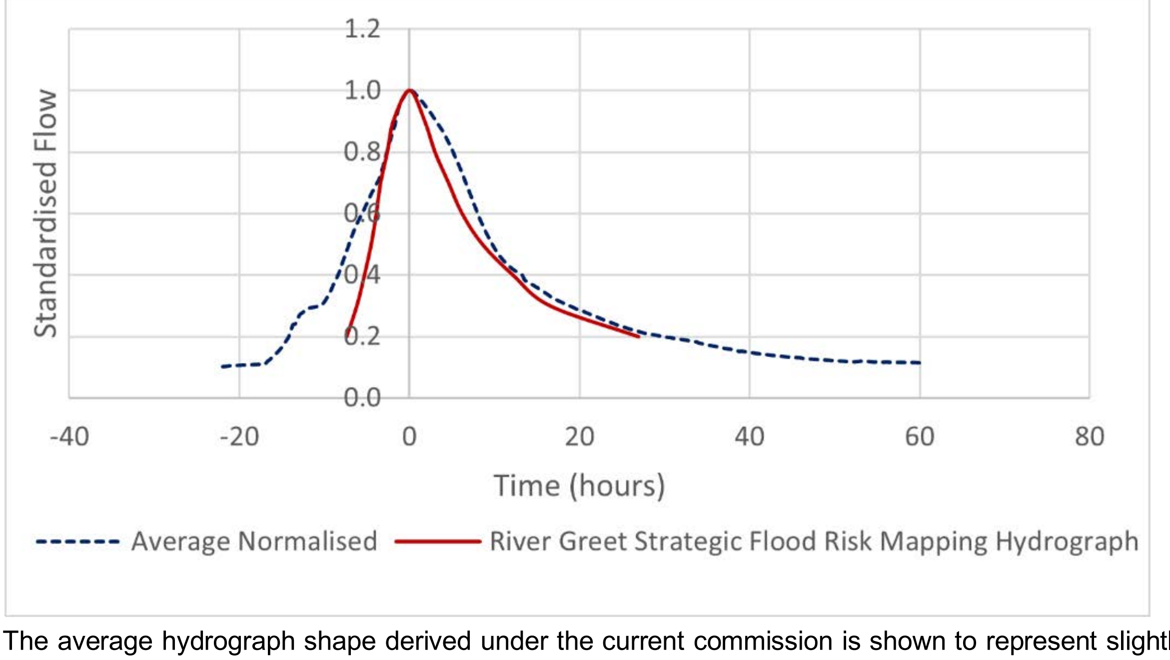
An average design hydrograph shape has been determined for the River Greet at Southwell based on the top eight observed event flood hydrographs. The eight events are tabulated in Table B.3 alongside their rank within the AMAX series.

Table B.3: Observed AMAX event against ranking – River Greet

AMAX Event	Rank in Present-Day AMAX Series
25/02/1977	5
16/01/1999	4
06/11/2000	7
25/06/2007	1
23/07/2013	2
13/06/2019	6
16/02/2020	3
23/12/2020	8

The average hydrograph shape obtained from the eight events tabulated above is compared in Figure B.2 below against the average hydrograph shape as derived by the River Greet Strategic Flood Risk Mapping study (2008).

Figure B.2: Average hydrograph shape – River Greet



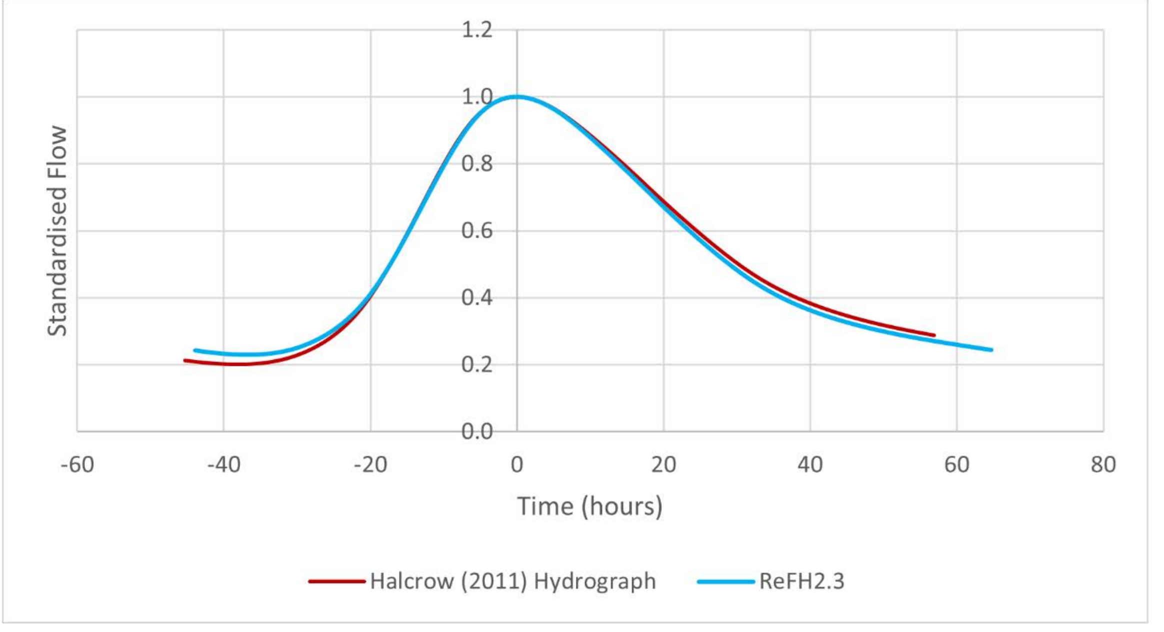
The average hydrograph shape derived under the current commission is shown to represent slightly more volume than that derived during the River Greet Strategic Flood Risk Mapping Study (2008); this results from the inclusion of recent flood events including June 2019, February 2020 and December 2020. The average hydrograph shape obtained under the current commission is adopted as the design hydrograph shape representing the River Greet inflow.

9.5.1 River Devon

For the River Devon at Cotham, only river level data has been provided due to no reliable rating existing for the gauge. Halcrow (2011) derived a design hydrograph for the River Devon within ReFH based on event analysis undertaken at the Cotham gauge to adjust the ReFH design parameters. The adopted storm duration of 48 hours was determined as the critical duration as identified by hydraulic modelling. The resulting hydrographs were then scaled to reconcile with the FEH statistical estimates.

The hydrograph shape derived by Halcrow (2011) is standardised by its peak flow and compared against a standardised design hydrograph derived within ReFH2 (v2.3) adopting the same parameters and 48 hour storm duration as derived by Halcrow. This is shown in Figure B.3.

Figure B.3: Comparison of hydrograph shapes (2011 study vs this study)

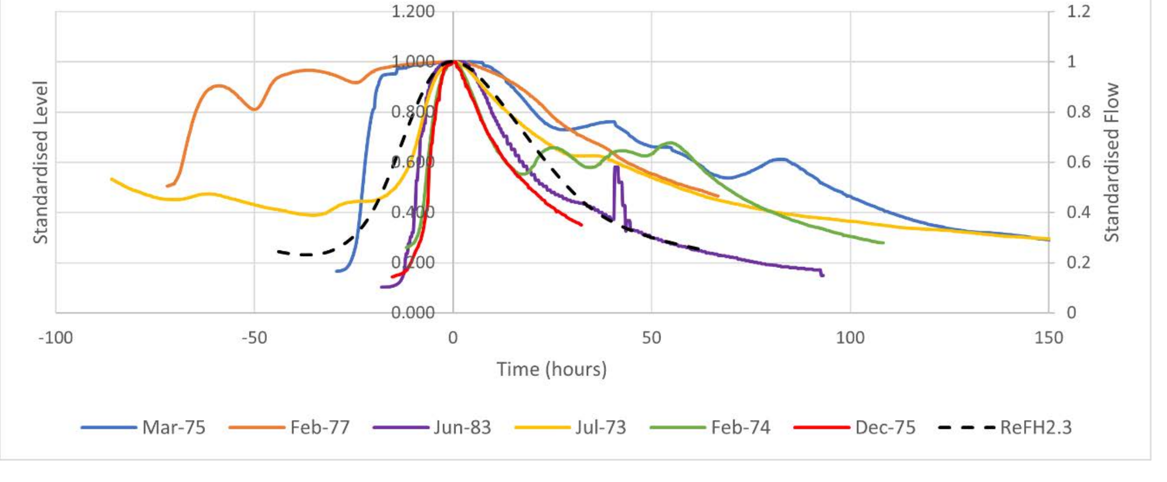


The design hydrograph shapes derived in ReFH1 and ReFH2.3 are shown to be very similar. Both hydrographs have been derived based on parameter optimisation (Tp, Cmax, BL and BR) using observed events at the Cotham gauge and a storm duration of 48-hours.

As ReFH2.3 represents the latest advancement of the ReFH model, the hydrograph produced in ReFH2.3, and shown above, is adopted as the design hydrograph shape for representing the River Devon.

The appropriateness of the adopted design hydrograph, in terms of its shape and width (duration), is assessed in Figure B.4 against standardised (level) hydrographs for a selection of the largest AMAX events at Devon at Cotham. While the level hydrographs are not strictly comparable due to the difference in the units of measurement, comparing the standardised hydrographs does allow consideration such as typical hydrograph width and shape to be determined. Based on the comparison, it is considered the adopted design hydrograph representing the River Devon inflow is generally representative of the typical flood hydrograph.

Figure B.4: Standardised level hydrograph comparison – River Devon



B.1.3 Small ungauged watercourses

For those ungauged inflows, design hydrographs are derived within ReFH2.3.

B.2 Flood peak timing

Halcrow (2011) reported that the River Devon peaks, on average, 20 hours before the River Trent, and that the River Greet on average peaks 30 hours before the River Trent.

Based on a comparison of concurrent AMAX entries for the Trent at Colwick and Devon at Cotham, the Devon is shown to peak on average 33 hours before the Trent. It should be noted that this is based on five events only and a comparison using the POT series at either gauge gives an average difference of 15 hours however this is based on 11 events only. A simple average of the two yields a 24-hour difference, slightly higher than the 20-hour figure reported by Halcrow (2011).

For the River Greet, comparison of 20 concurrent AMAX events, shows the Greet to peak on average 36 hours before the River Trent and based on a comparison of 128 concurrent events in the POT series at either gauge gives an average difference of 32 hours. These figures are slightly higher than the Halcrow (2011) value of 30 hours.

In both catchments the analysis broadly confirms the Halcrow (2011) values and the latter are retained for this study.

B.3 Hydrological dependency

B.3.1 Background

To assess the dependence between flood flows in the River Trent occurring in conjunction with flood flows in the contributing tributaries, the Halcrow (2011) study determined dependence based on comparing ranked POT series for the available period of record and concluded that it would be reasonable (although conservative) to assume an equal return period on the River Trent and all tributaries.

Based on an empirical investigation of concurrent AMAX events it appears the assumption of equal return periods in the tributaries to that in the main River Trent does not hold true and such assumptions are considered unduly conservative.

As an example, the 26 February 1977 event on the Trent at Colwick (with a peak flow of 957m³/s) is estimated as having a return period of ~38-years based on the flood frequency understanding presented herein. The corresponding concurrent peak flow in the Devon is 32.0m³/s which is approximately equivalent to the estimate of the 2-year event on the Devon at Cotham. The corresponding concurrent peak flow in the Greet is 5.58 m³/s which is approximately equivalent to the estimate of the 7-year event on the Greet at Southwell.

Similarly, the 08 November 2000 event on the Trent at Colwick (with a peak flow of 1019m³/s) registers as approximately a 55-year event while the corresponding concurrent peak flow in the Greet at Southwell (5.43m³/s) registers as having a return period of approximately 5 years.

Reassessment of the dependency between the gauged watercourses within the study area has been undertaken to derive appropriate AEPs / return periods for applying to the tributaries when modelling the required design events on the Trent.

B.3.2 Assessment

The Environment Agency Multivariate Event Modeller (MEM) tool [10] allows estimation of the joint probability of extreme events in combinations of up to 10 variables. The tool is based on the approach of Heffernan and Tawn (2004).

A joint probability analysis is undertaken using the Multivariate Event Modeller (MEM) tool to determine AEP (%) flood flows in the River Devon and River Greet tributary inflows that combine to produce a 1% AEP (100-year return period) flood within the receiving River Trent.

[10] The MEM is a demonstration tool disseminated by the Environment Agency that allows analysis of multivariate joint probability problems in more than 3 variables. The tool was designed by JBA Consulting and Lancaster University and is based on the statistical approach outlined by Heffernan and Tawn (2004).

Dependence structure

The first step in creating the joint probability model is to fit a set of relationships between each pair of variables. The second step is to simulate a large random sample of extreme events, using the model to extrapolate beyond the range of the data.

A 50,000-year event set was simulated and the automatically determined marginal parameters (based on the generalised Pareto Distribution to Peaks Over Threshold Data) were used in the analysis.

Joint probability design scenarios for the following AEPs have been derived 50% (2-year), 20% (5-year), 10% (10-year), 5% (20-year), 4% (25-year), 3.3% (30-year), 2% (50-year), 1.3% (75-year), 1% (100-year), 0.5% (200-year) and 0.1% (1000-year).

There are any number of potential combinations of probabilities that could produce the joint probability design scenarios and different combinations are output by the MEM tool.

The combinations in the resulting joint probability matrix could be simulated in the hydraulic model to determine the joint probability scenario that generated the most severe flooding event. However, with numerous possible combinations and given the scope of the work is to model the 1% AEP (100-year return period) event in the main River Trent, the approach has instead been to determine the estimate of the 1% AEP (100-year return period) flow at Colwick based on the adopted daily mean flow (DMF) data for each concurrent period of record at Cotham and Southwell, and to determine the corresponding event rarity based on the estimated flow at Southwell to create the joint exceedance.

The combined joint probability for peak flows coinciding at Colwick and Cotham, and Colwick and Southwell, are assessed independently due to the period of record at the gauges not extending over the same time period, i.e., the period of record at all three gauges are not concurrent**.**

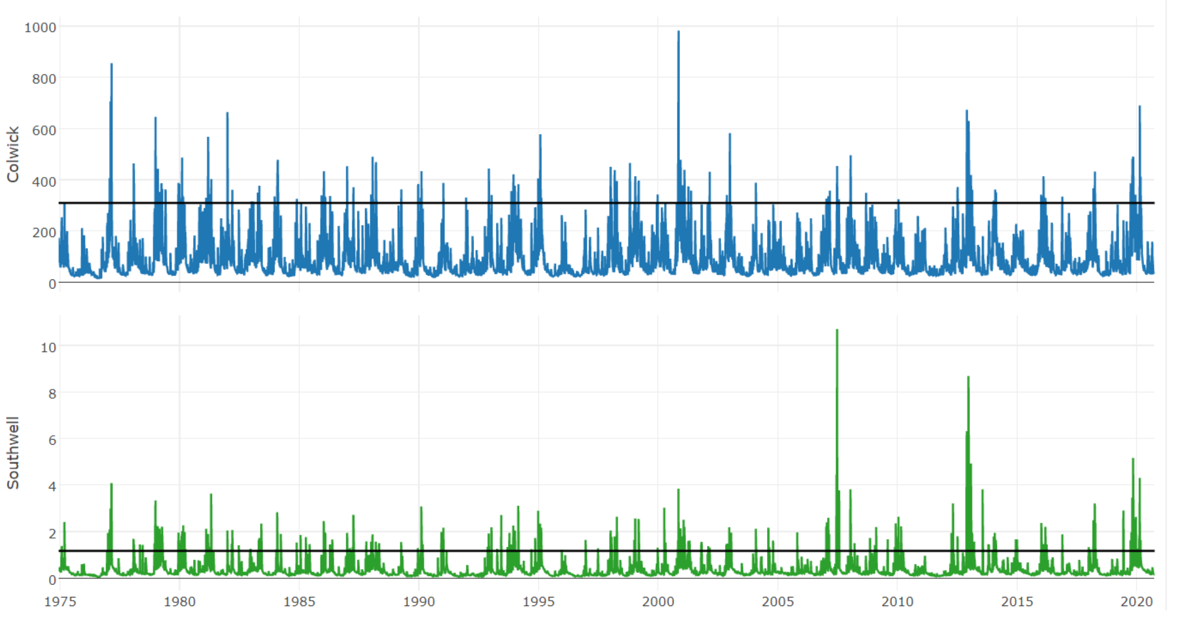
B.3.2.1 Colwick-Southwell

Data

The data were checked for missing values at both gauges. Over the common period of record, there were no missing data and the concurrent periods of record (11/12/1974 - 30/09/2020) were directly used in the joint probability analysis.

The daily mean flow is plotted below in Figure B.5.

Figure B.5: Time series of daily mean data for Colwick and Southwell (black lines indicate the 97.5th percentile threshold used in analysis)



It is observed that while some of the largest peaks do occur together, this is not consistently the case. The Chi estimate for Colwick and Southwell is 0.29, indicating that extreme events at Colwick and Southwell are unlikely to occur together.

Summary statistics for event

The MEM outputs identified that of the concurrent input data, (45.8 years) there were a total of 98 independent peak events that exceeded the 97.5th percentile flow for Colwick and 162 for Southwell. These statistics have been used by the MEM tool in the subsequent analysis to determine and calculate the joint probability of corresponding flood return periods .

Results

Based on approx. 46-years of data and a 50,000-year simulated event set, for modelling the 1% AEP (100-year return period) in the River Trent the adopted corresponding AEP to model in the River Greet is estimated to be the 10% AEP (10-year return period).

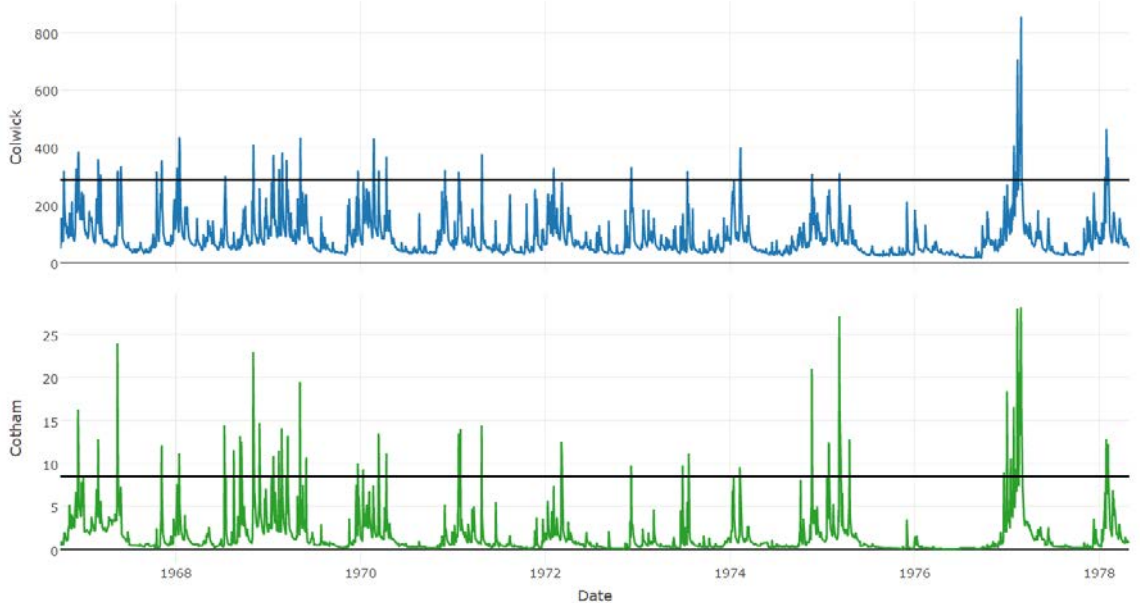
B.3.2.2 Colwick-Cotham

Data

Daily mean flows at Colwick and Cotham are available for the concurrent period 01/10/1966 to 30/04/1978. The data were checked for missing values. At Cotham there are eight days of missing data between 01/10/1966 - 05/12/1973 and 32 days of missing data between 13/12/1973 - 30/04/1976. The missing data has been infilled by simple interpolation. The period of missing data does not exclude extremes and hence the simple method of interpolation is considered appropriate.

Daily mean flow values were extracted for the two gauges and is plotted below in Figure B.6.

Figure B.6: Time series of daily mean data for Colwick and Cotham (black lines indicate the 97.5 th percentile threshold used in analysis)



The Chi estimate for Colwick and Cotham is 0.43; this value is higher than for Colwick/Southwell but still indicates that extreme events at Colwick and Cotham are unlikely to occur together.

Summary statistics for event

Using the MEM tool identified that, over the 11.6 years of concurrent data there were a total of 32 independent peak events that exceeded the 97.5th percentile flow for Colwick and 37 for Southwell. These statistics have been used by the MEM tool in the subsequent analysis to determine and calculate the joint probability of corresponding flood return periods.

Results

Based on approx. 12-years of DMF data and a 50,000-year simulated event set, for modelling the 1% AEP (100-year return period) in the Trent, the adopted corresponding AEP to model in the River Devon is the 4% AEP (25-year return period), as presented in Table B.4.

Table B.4: Joint probability

Colwick	Southwell	Cotham
Target AEP (%) [Return-Period Years]	**Corresponding Tributary AEP (%) [Return-Period Years]**	
50% [2-year]	50% [2-year]	50% [2-year]
20% [5-year]	50% [2-year]	50% [2-year]
10% [10-year]	50% [2-year]	50% [2-year]
5% [20-year]	50% [2-year]	20% [5-year]
4% [25-year]	50% [2-year]	20% [5-year]
3.3% [30-year]	50% [2-year]	10% [10-year]
2% [50-year]	20% [5-year]	10% [10-year]
1.3% [75-year]	10% [10-year]	5% [20-year]
1% [100-year]	**10% [10-year]**	**4% [25-year]**
0.5% [200-year]	10% [10-year]	2% [50-year]
0.1% [1000-year]	4% [25-year]	2% [50-year]

B.3.2.3 Ungauged Inflows

For the remaining ungauged inflows, the corresponding AEP event to apply when modelling the 1% AEP (100-year return period) in the River Trent is initially based on the corresponding AEPs applied to the River Greet at Southwell. The Chi estimate for Colwick and Southwell is less than is estimated for Colwick and Cotham and hence, extreme events at Colwick and Southwell are less likely to occur together than at Colwick and Cotham. The catchment area of the River Greet at Southwell is 58.5km² and whilst still greater than the majority of the ungauged catchments considered in the study, is less so than the Devon at Cotham which drains a catchment area of 284km².

During the course of hydraulic modelling the main river and tributary inflows will be scaled so that the combined inflow to the model reproduces the required design event peak flow on the River Trent. This will be reported in the hydraulic modelling reporting and is not discussed further here.

C. Event hydrology (model calibration)

For the purpose of calibration and verification of the hydraulic model, there is a requirement for deriving event hydrology.

C.1 Event Selection

Flood extent data and aerial imagery for observed flood events has been provided by the Environment Agency for the purpose of the study. The flood extents have been provided in ESRI Shapefile format and are reported to have been digitised from a number of different sources. Data has been provided for fluvial events on the River Trent for 27 – 28 November 2012, 16 November 2019, 18 - 19 February 2020 and 22 - 23 January 2021. The estimated event rarity is tabulated below in Table C.5.

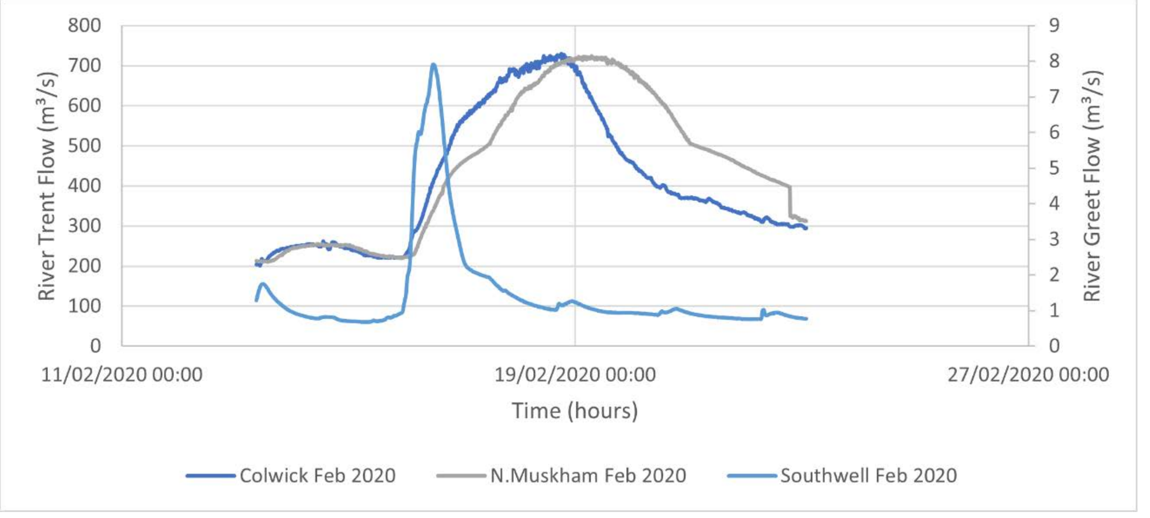
Table C.5: Estimated rarity of flood extent data provided

River Trent (Colwick)			River Greet (Southwel)		
Date	**Peak Flow (m^3/s)**	**Estimated Rarity AEP % [Return Period Years]**	**Date**	**Peak Flow (m^3/s)**	**Estimated Rarity AEP % [Return Period Years]**
27/11/2012	692	12.5% AEP [8-years]	25/11/2012	9.91	1.7% AEP [58-years]
15/11/2019	490	33.3% AEP [~3-years]	15/11/2019	6.64	8.3% AEP [12-years]
18/02/2020	730	11.1% AEP [9-years]	16/02/2020	7.91	4.5% AEP [22-years]
22/01/2021	686	14.3% AEP [7-years]	14/01/2021	4.00	33.3% AEP [3-years]

February 2020

The largest of the four events on the River Trent at Colwick is the 18 February 2020 event. The event is estimated as having a 11.1% AEP (9-year return period). The corresponding peak flow on the River Greet is estimated as having a 4.5% AEP (22-year return period). The River Greet is shown to peak some 54 hours before the flood peak in the River Trent, at Colwick. The peak flow at downstream North Muskham occurs 13 hours after the peak flow registered at Colwick and registers a lesser peak flow of 724 m^3/s, compared to 730 m^3/s at Colwick. The flood extent of the February 2020 event is shown to inundate the A46 carriageway between NGR SK 78758 54238 and SK 80173 55384 (flood extents are shown in the Annex to this document).

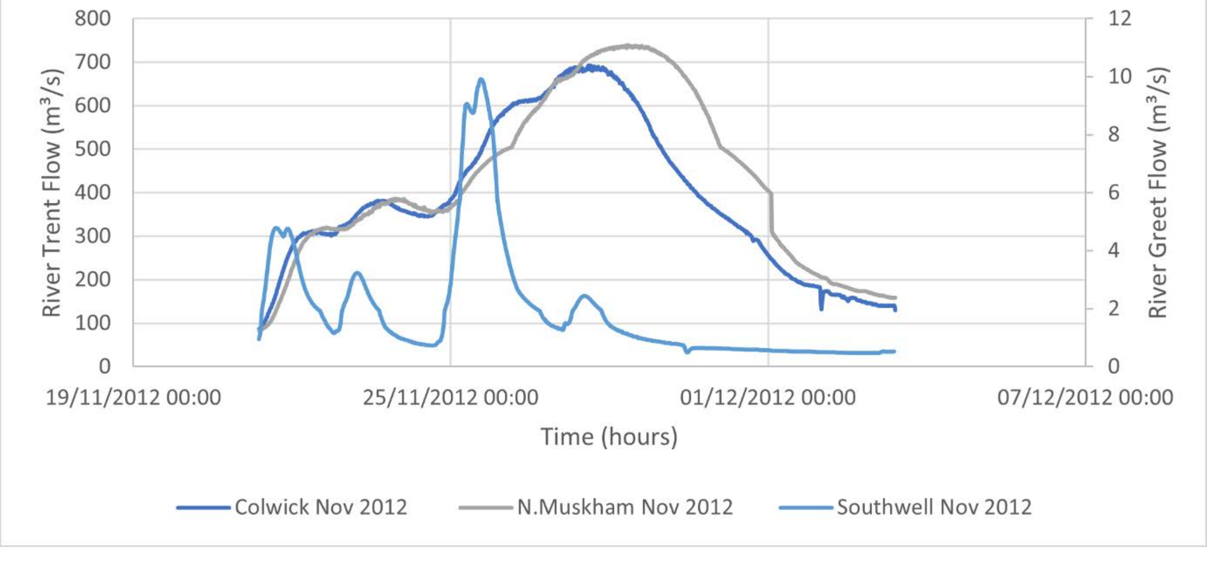
Figure C.7: February 2020 flood hydrograph



November 2012

The second largest of the four events on the River Trent at Colwick is the 27 November 2012 event. The event is estimated as having a 12.5% AEP (8-year return period). The corresponding peak flow on the River Greet is estimated as having a 1.7% AEP (58-year return period). The River Greet is shown to peak some 49 hours before the flood peak in the River Trent, at Colwick. The peak flow at downstream North Muskham occurs 17.5 hours after the peak flow registered at Colwick. The flood extent of the November 2012 event is shown to inundate the A46cal carriageway between NGR SK 78100 52884 and SK 78219 53490; and between SK 78696 54166 and SK 79199 54573. Between the two areas of inundation there are pockets of flood water over the A46 carriageway.

Figure C.8: November 2012 flood hydrograph

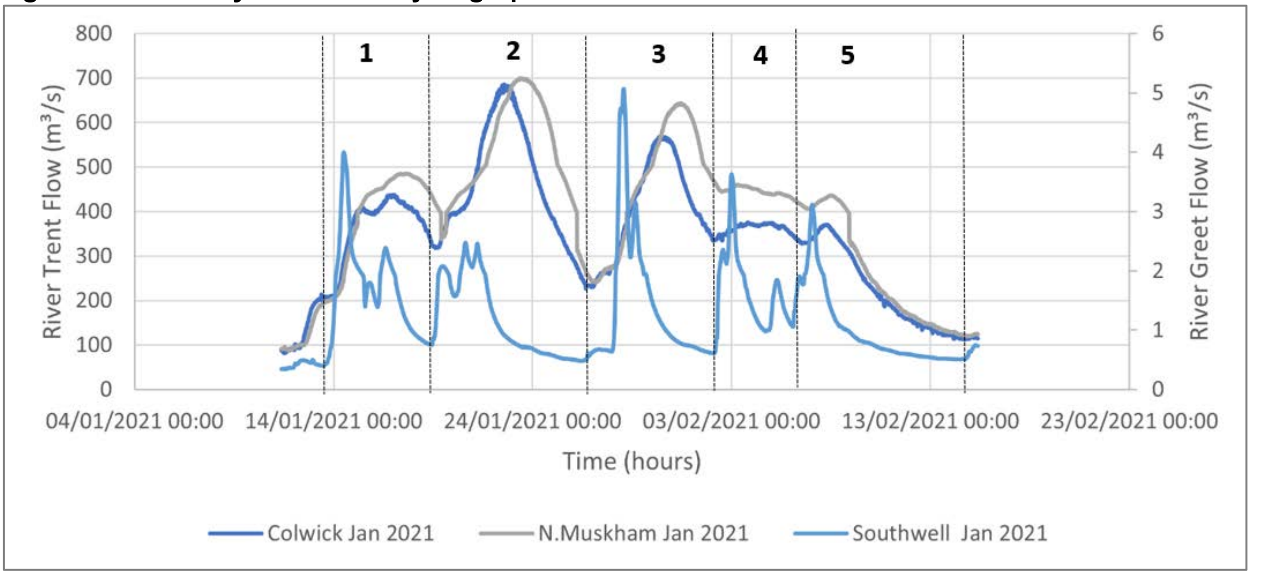


January 2021

The January 2021 event is the third largest of the four events considered. On the River Trent at Colwick, the event is estimated as having a 14% AEP (7-year return period). The peak flow at downstream North Muskham occurs 19 hours after the peak flow at Colwick.

The January 2021 flood event results from a succession of storm events and can be viewed as having five distinct peaks. The corresponding peak flow on the River Greet, taken as flood peak number two, occurs approximately 47 hours before the flood peak on the Trent and is estimated as having a <50% AEP% (<2-year return period). Flood peaks number one and number three on the River Greet are shown to be greater and are estimated as having a 33% AEP (3-year return period) or approximately 20% AEP (5-year return period), however these occur 8 days before and 6 days after the main flood peak in the River Trent, respectively. The January 2021 event is perhaps not a great candidate for calibrating or verifying the model due to the complexity in river response resulting from the succession of storms.

Figure C.9: January 2021 flood hydrograph



November 2019

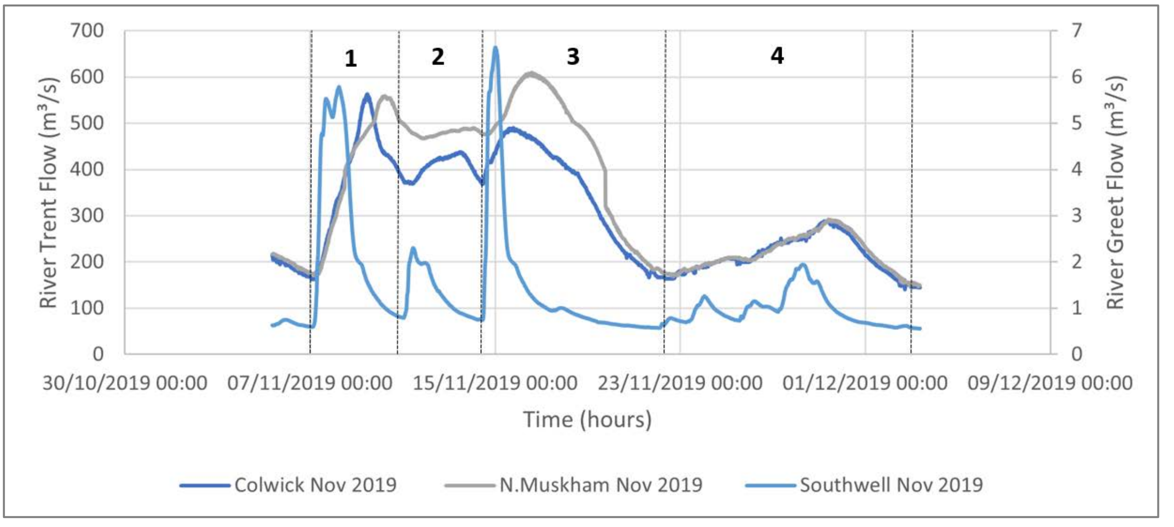
The November 2019 event is the smallest of the four events considered. The November 2019 flood event results from a succession of storm events and can be viewed as having four distinct peaks.

On the River Trent, flood peak number three is taken to represent the main peak however flood peak number one, for the Trent at Colwick is shown to be greater than the preceeding peaks while at North Muskham flood peak number three represents the largest peak flow. Flood peak number three, at downstream North Muskham, occurs 19 hours after the peak flow at Colwick. Flood peak number three on the River Trent is estimated as having approximately a 33% AEP (3-return period).

The corresponding peak flow on the River Greet occurs 19 hours before the flood peak on the Trent at Colwick and with a peak flow of 6.64 m³/s is estimated as having a 8.3% AEP (12-year return period).

The flood extent of the November 2019 event is shown as pockets of inundation rather than widespread flooding.

Figure C.10: November 2019 flood hydrograph



D. Supporting Information

The subsequent sections present supporting information used in the analyses or made reference to in the reporting.

D.1 Flood frequency analysis

D.1.1 Station AMAX series

Table D.6: River Trent at Colwick

Water Year	Date / Time	Peak Flow (m^3/s)
1884		271
1885		951
1886		867
1887		186
1888		823
1889		527
1890		484
1891		538
1892		371
1893		221
1894		787
1895		196
1896		802
1897		276
1898		325
1899		618
1900		967
1901		595
1902		338
1903		527
1904		119
1905		368
1906		410
1907		493
1908		221
1909		720
1910		908
1911		681
1912		360
1913		200
1914		565
1915		689
1916		394
1917		475
1918		643
1919		447
1920		394
1921		506

Water Year	Date / Time	Peak Flow (m³/s)
1922		720
1923		481
1924		399
1925		658
1926		337
1927		600
1928		410
1929		512
1930		506
1931		945
1932		704
1933		206
1934		241
1935		708
1936		407
1937		272
1938		646
1939		780
1940		624
1941		502
1942		453
1943		319
1944		561
1945		1007
1946		1107
1947		495
1948		624
1949		477
1950		624
1951		459
1952		374
1953		279
1954		747
1955		Missing
1956		Missing
1957		Missing
1958	23/01/1959 00:00	547
1959	31/01/1960 00:00	801
1960	05/12/1960 00:00	972
1961	12/01/1962 00:00	266
1962	31/03/1963 00:00	296
1963	15/03/1964 00:00	356
1964	24/03/1965 00:00	338
1965	11/12/1965 00:00	819
1966	12/12/1966 00:00	385
1967	15/01/1968 00:00	468
1968	08/05/1969 00:00	456
1969	23/02/1970 03:15	446

Water Year	Date / Time	Peak Flow (m³/s)
1970	25/04/1971 20:15	402
1971	04/02/1972 11:15	353
1972	07/12/1972 17:30	355
1973	12/02/1974 15:30	422
1974	11/03/1975 06:00	369
1975	03/12/1975 00:45	243
1976	26/02/1977 08:30	957
1977	30/01/1978 14:45	486
1978	30/12/1978 11:30	703
1979	09/02/1980 12:45	500
1980	12/03/1981 16:45	572
1981	01/01/1982 21:45	710
1982	03/05/1983 22:30	382
1983	08/02/1984 06:00	496
1984	24/11/1984 16:00	332
1985	12/01/1986 12:30	450
1986	02/01/1987 04:30	470
1987	26/01/1988 04:00	520
1988	07/04/1989 20:45	369
1989	09/02/1990 13:30	448
1990	11/01/1991 02:00	401
1991	23/12/1991 03:15	351
1992	04/12/1992 18:45	456
1993	14/12/1993 15:00	440
1994	30/01/1995 00:00	587
1995	23/12/1995 20:30	268
1996	21/12/1996 00:30	296
1997	08/03/1998 11:45	484
1998	29/10/1998 03:00	484
1999	25/12/1999 19:45	351
2000	08/11/2000 12:30	1019
2001	27/02/2002 13:30	459
2002	31/12/2002 17:30	610
2003	01/02/2004 22:15	397
2004	24/10/2004 07:45	315
2005	25/10/2005 18:45	277
2006	27/06/2007 02:45	489
2007	17/01/2008 18:15	508
2008	14/12/2008 11:15	306
2009	17/01/2010 09:00	335
2010	09/11/2010 23:30	267
2011	07/07/2012 18:30	389
2012	27/11/2012 14:30	692
2013	02/02/2014 02:00	372
2014	13/12/2014 07:15	241
2015	10/02/2016 01:00	426
2016	22/11/2016 21:00	349
2017	04/04/2018 12:15	456

Water Year	Date / Time	Peak Flow (m³/s)
2018	01/10/2019 08:45	330
2019	18/02/2020 18:15	730
2020	22/01/2021 13:45	686

Table D.7: River Trent at North Muskham

Water Year	Date / Time	Peak Flow (m³/s)
1968	08/05/1969 00:00	456
1969	23/02/1970 00:00	453
1970	26/04/1971 00:00	428
1971	04/02/1972 00:00	363
1972	18/07/1973 02:00	366
1973	13/02/1974 05:00	434
1974	11/03/1975 15:45	394
1975	03/12/1975 05:00	239
1976	27/02/1977 03:30	1000
1977	30/01/1978 22:30	465
1978	31/12/1978 10:15	712
1979	10/02/1980 08:45	498
1980	13/03/1981 14:00	545
1981	02/01/1982 19:15	621
1982	04/05/1983 03:15	393
1983	09/02/1984 05:30	495
1984	25/11/1984 02:00	344
1985	13/01/1986 02:30	450
1986	02/01/1987 14:30	469
1987	26/01/1988 19:15	504
1988	08/04/1989 02:45	402
1989	10/02/1990 01:45	460
1990	11/01/1991 12:30	403
1991	23/12/1991 13:15	333
1992	05/12/1992 06:30	462
1993	15/12/1993 03:15	453
1994	30/01/1995 13:15	629
1995	24/12/1995 01:45	279
1996	21/12/1996 04:15	294
1997	06/01/1998 23:15	459
1998	30/10/1998 09:15	442
1999	26/12/1999 05:00	350
2000	09/11/2000 10:00	774
2001	27/02/2002 19:45	431
2002	01/01/2003 16:30	509
2003	01/02/2004 23:30	389
2004	24/10/2004 15:30	326
2005	26/10/2005 06:15	262
2006	27/06/2007 22:00	500
2007	23/01/2008 02:15	562

Water Year	Date / Time	Peak Flow (m³/s)
2008	15/12/2008 02:15	326
2009	18/01/2010 02:15	349
2010	10/11/2010 03:15	265
2011	08/07/2012 05:30	410
2012	28/11/2012 08:00	740
2013	03/02/2014 04:00	396
2014	13/12/2014 11:45	247
2015	10/02/2016 15:30	450
2016	23/11/2016 08:15	339
2017	05/04/2018 03:30	492
2018	01/10/2019 03:15	334
2019	19/02/2020 07:00	724
2020	23/01/2021 08:45	700

Table D.8: River Devon at Cotham

Water Year	Date / Time	Peak Flow (m³/s)
1966	15/05/1967 00:00	35.6
1967	06/11/1967 00:00	15.6
1968	02/11/1968 00:00	38.6
1969	13/03/1970 00:00	14.2
1970	23/01/1971 00:00	19.4
1971	05/03/1972 00:00	12.8
1972	22/07/1973 16:30	23.9
1973	10/02/1974 00:15	13.1
1974	10/03/1975 11:00	32.5
1975	02/12/1975 13:00	2.5
1976	26/02/1977 06:15	32.0
1977	06/05/1978 00:00	26.9
1978	01/02/1979 00:00	28.8
1979	18/02/1980 00:00	26.7
1980	27/04/1981 00:00	32.7
1981	30/12/1981 00:00	27.2
1982	01/06/1983 19:15	31.9
1983	24/03/1984 00:00	22.3

Table D.9: River Greet at Southwell

Water Year	Date / Time	Peak Flow (m³/s)
1974	09/03/1975 16:45	3.28
1975	02/10/1975 23:00	1.06
1976	25/02/1977 16:45	5.77
1977	28/01/1978 18:45	2.19
1978	29/12/1978 15:15	4.83
1979	26/02/1980 00:15	2.97
1980	26/04/1981 22:30	4.76
1981	30/12/1981 23:45	2.76
1982	23/04/1983 03:30	3.72
1983	02/08/1984 18:15	1.28
1984	21/01/1985 19:15	2.72

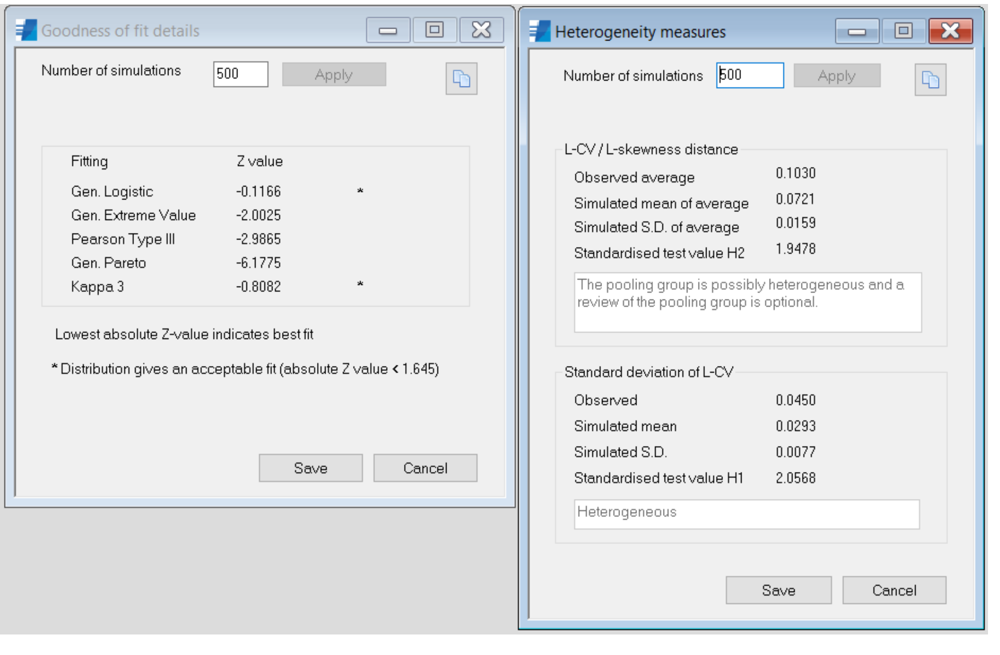
Water Year	Date / Time	Peak Flow (m³/s)
1985	10/01/1986 12:45	3.55
1986	07/04/1987 18:15	4.23
1987	21/10/1987 07:45	3.32
1988	07/04/1989 07:30	1.97
1989	08/02/1990 03:30	4.21
1990	10/01/1991 03:45	3.78
1991	26/09/1992 07:45	1.20
1992	11/06/1993 21:00	4.61
1993	26/02/1994 20:00	4.10
1994	26/01/1995 00:30	4.49
1995	22/12/1995 15:45	1.69
1996	20/12/1996 04:45	2.40
1997	10/04/1998 12:45	3.90
1998	16/01/1999 05:15	5.90
1999	03/04/2000 19:00	4.04
2000	06/11/2000 09:15	5.43
2001	26/10/2001 20:45	2.49
2002	22/12/2002 08:15	4.05
2003	10/08/2004 08:15	3.71
2004	22/10/2004 01:00	2.51
2005	24/10/2005 13:30	2.94
2006	25/06/2007 18:15	11.5
2007	16/01/2008 03:00	4.41
2008	07/08/2009 07:45	3.42
2009	16/01/2010 16:00	3.66
2010	26/02/2011 12:30	1.35
2011	29/04/2012 18:15	4.49
2012	23/07/2013 21:00	10.1
2013	09/01/2014 09:15	3.22
2014	12/12/2014 09:45	2.73
2015	09/03/2016 13:30	3.61
2016	21/11/2016 21:45	3.04
2017	02/04/2018 16:30	4.61
2018	13/06/2019 05:30	5.64
2019	16/02/2020 12:00	7.91
2020	23/12/2020 22:15	5.25

D.1.2 Pooling groups

Table D.10: Devon at Cotham

Station	Distance (SDM)	Years of data	L-CV	L-SKEW	Discordancy
40005 (Beult @ Stilebridge)	0.763	59	0.239	0.200	1.76
22006 (Blyth @ Hartford Bridge)	1.506	60	0.318	0.289	0.56
33005 (Bedford Ouse @ Thornborough Mill)	1.595	28	0.178	-0.112	1.92
37010 (Blackwater @ Appleford Bridge)	1.675	58	0.287	0.203	0.34
25005 (Leven @ Leven Bridge)	1.694	47	0.244	0.272	0.75
31005 (Welland @ Tixover)	1.759	57	0.291	0.255	0.18
43009 (Stour @ Hammoon)	1.771	52	0.186	0.102	1.10
28024 (Wreake @ Syston Mill)	1.864	52	0.318	0.305	1.46
35008 (Gipping @ Stowmarket)	2.000	55	0.294	0.050	1.21
36005 (Brett @ Hadleigh)	2.074	58	0.297	0.090	0.73

Figure D.11: Growth curve and L-moment details for Devon at Cotham pooling

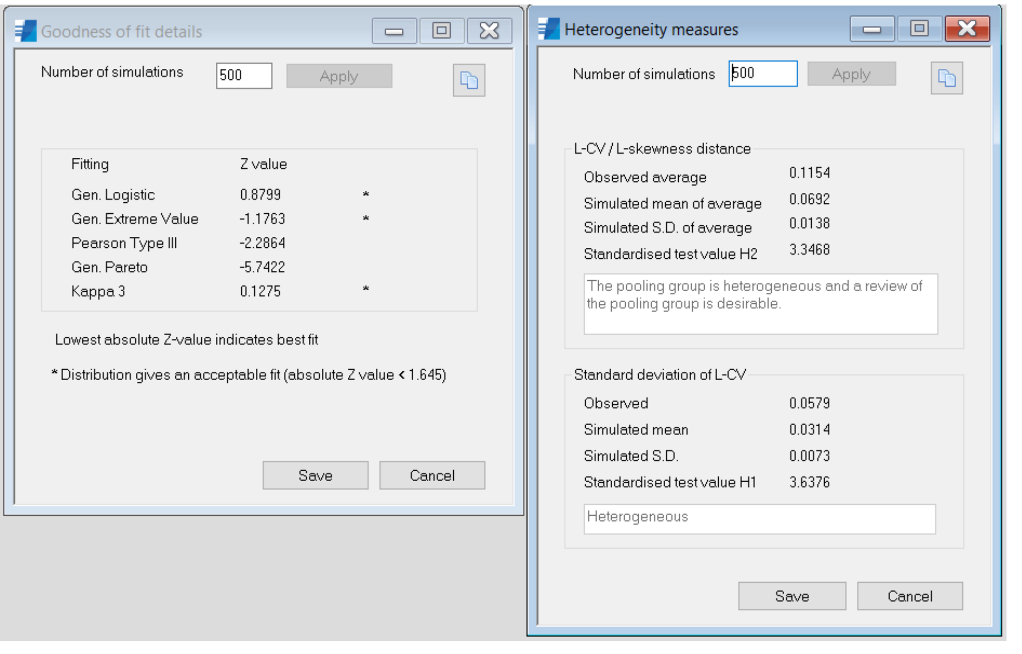


D.1.3 Small (ungauged) catchments

Table D.11: Small catchment pooling group

Station	Distance (SDM)	Years of data	L-CV	L-SKEW	Discordancy
36010 (Bumpstead Brook @ Broad Green)	1.156	53	0.377	0.173	0.75
27051 (Crimple @ Burn Bridge)	1.187	48	0.219	0.146	0.59
25019 (Leven @ Easby)	1.279	42	0.338	0.386	1.25
36004 (Chad Brook @ Long Melford)	1.631	53	0.304	0.167	0.64
39033 (Winterbourne Stream @ Bagnor)	1.683	58	0.342	0.383	1.50
36003 (Box @ Polstead)	1.722	60	0.314	0.088	0.52
36007 (Belchamp Brook @ Bardfield Bridge)	1.743	55	0.378	0.112	1.55
27010 (Hodge Beck @ Bransdale Weir)	1.797	41	0.224	0.293	1.03
24007 (Browney @ Lanchester)	1.815	15	0.222	0.212	1.86
37016 (Pant @ Copford Hall)	1.818	55	0.287	0.104	0.25
30004 (Lymn @ Partney Mill)	1.849	58	0.224	0.030	1.07

Figure D.12: Growth curve and L-moment details for small catchments



D.1.4 Single Site Analysis

Figure D.13: River Trent at Colwick – Flood Frequency Plot

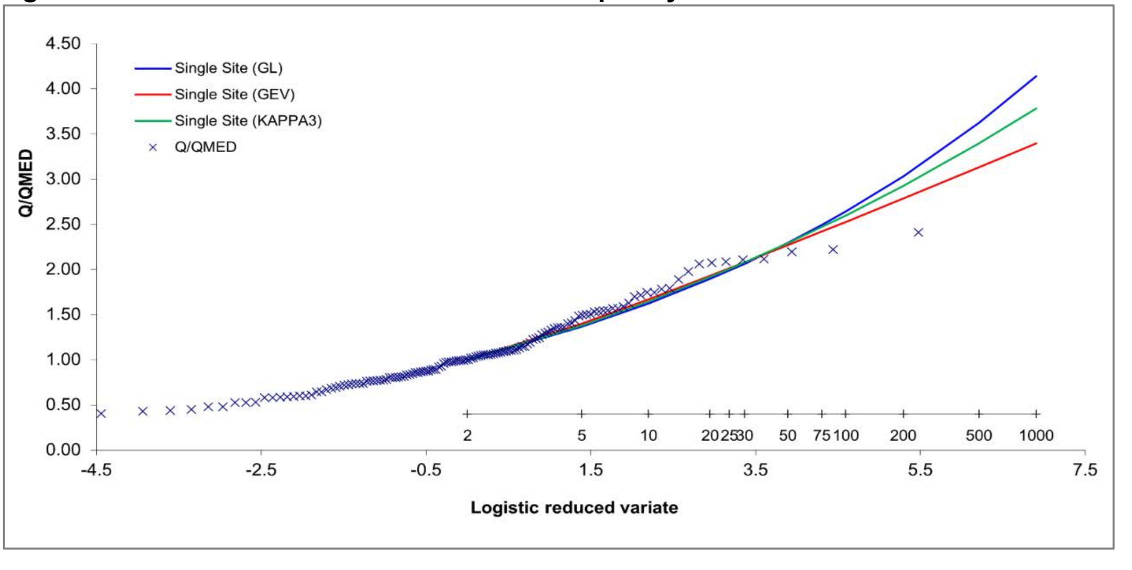


Figure D.14: River Trent at Colwick – L-Moment Ratio Diagram

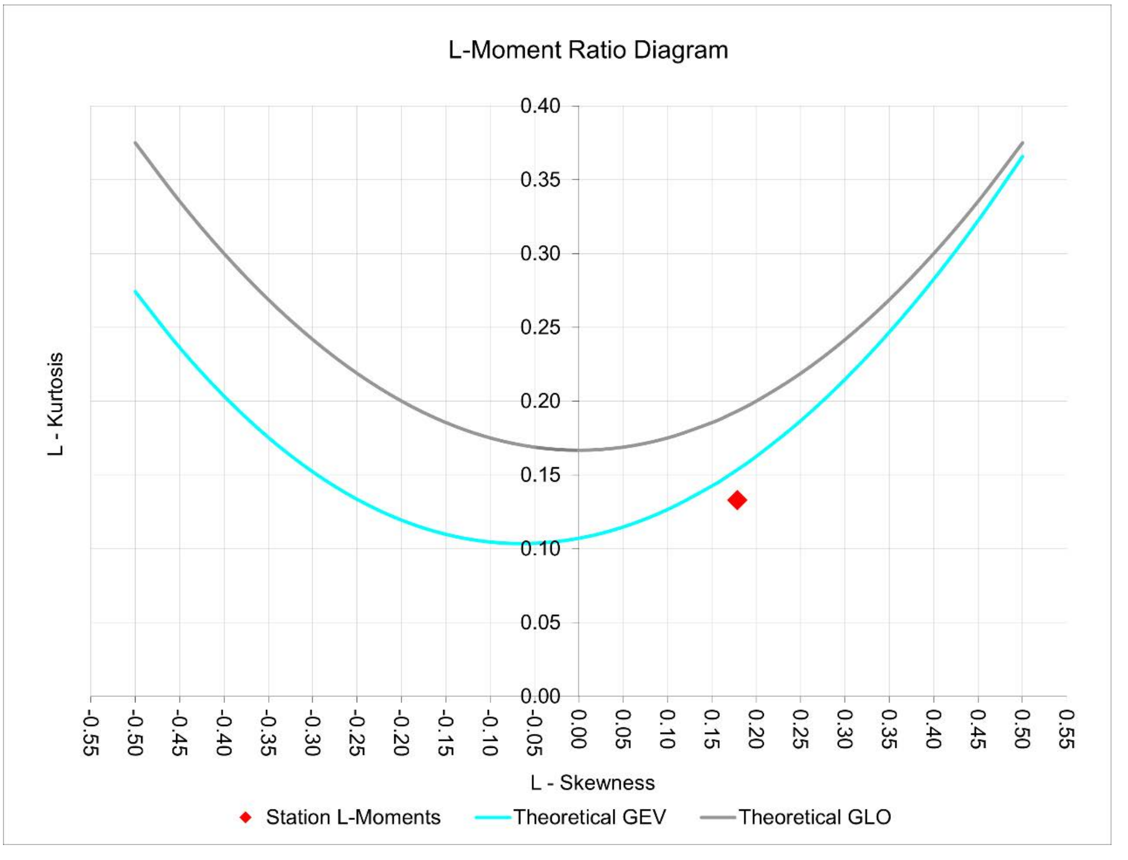


Figure D.15: River Greet at Southwell – Flood Frequency Plot

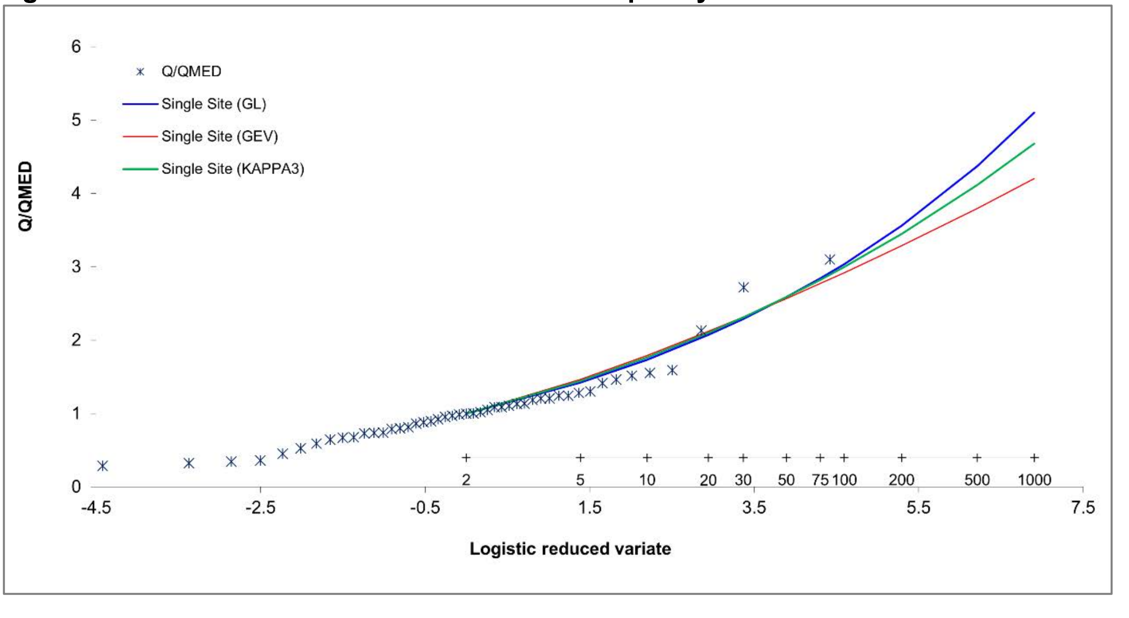
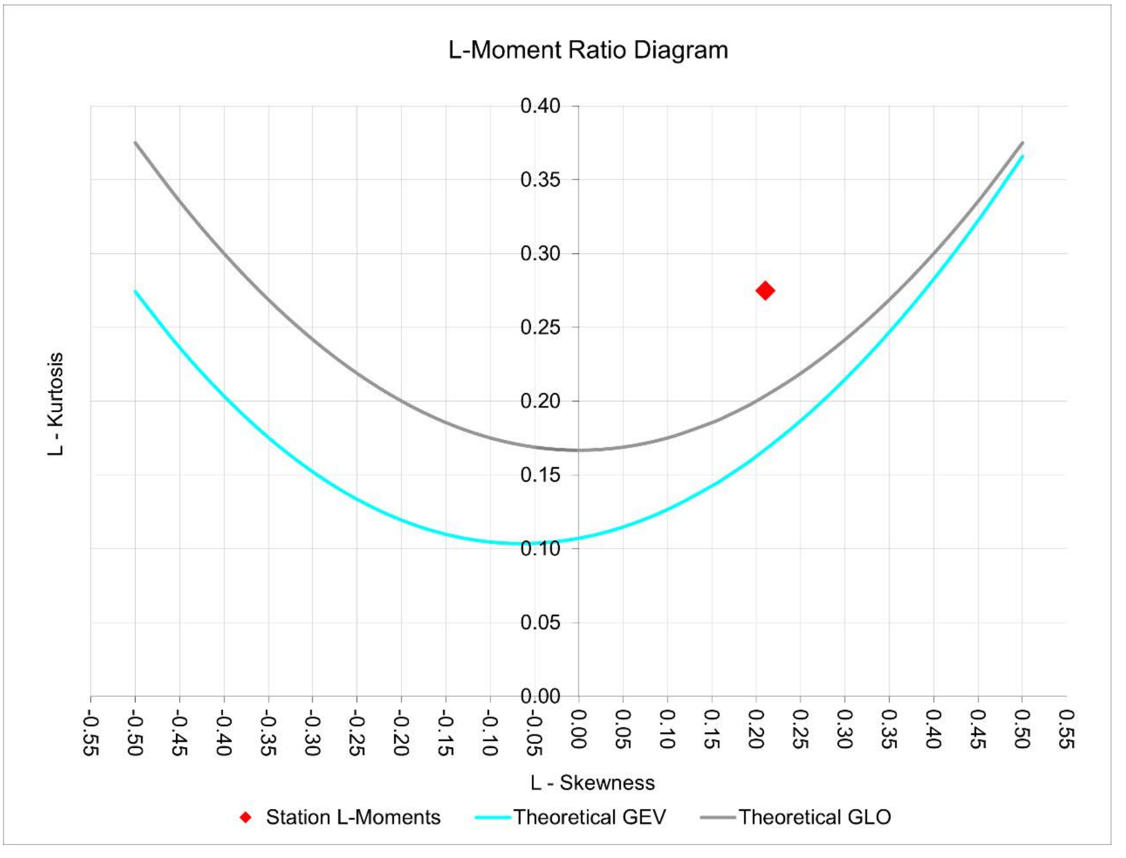


Figure D.16: River Greet at Southwell – L-Moment Ratio Diagram



D.2 Observed flood data

D.2.1 Flood extents of calibration events

Figure D.17: February 2020 flood extent

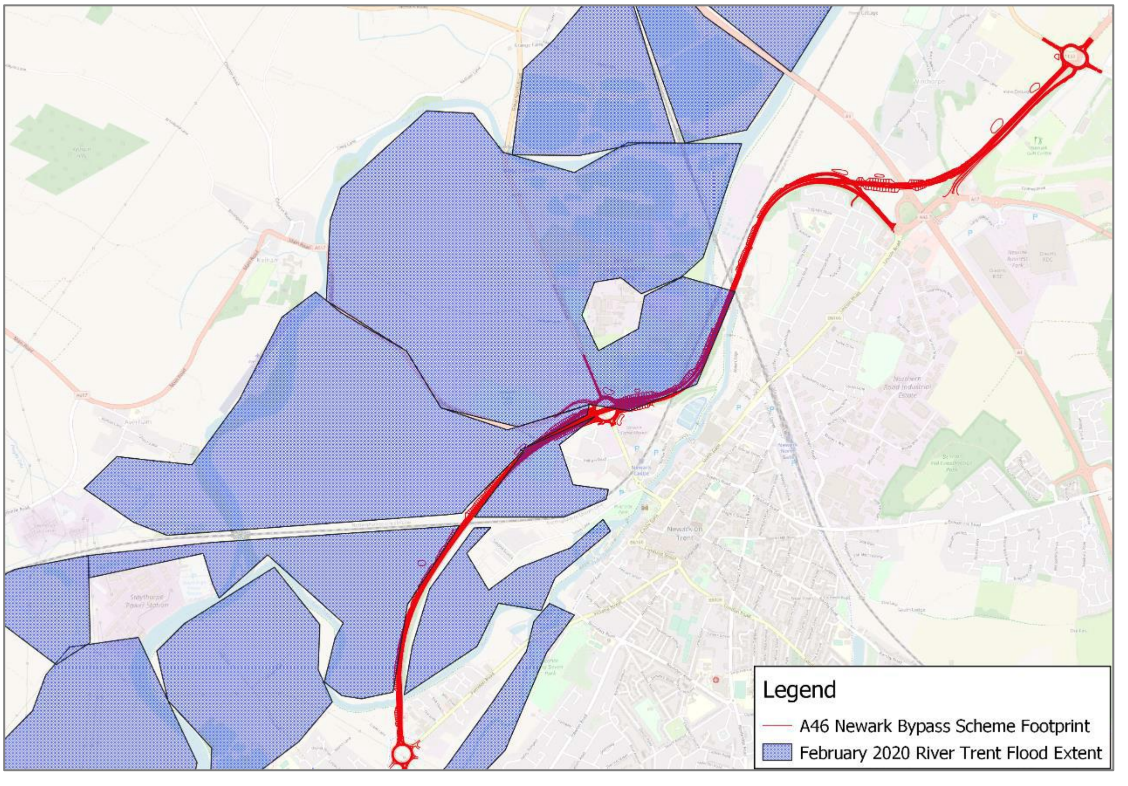


Figure D.18: Photograph taken on 19 February 2020 at 09:34:59

Source: Obliques_S20_064_200219_093459_LowRes

Figure D.19: November 2012 flood extent

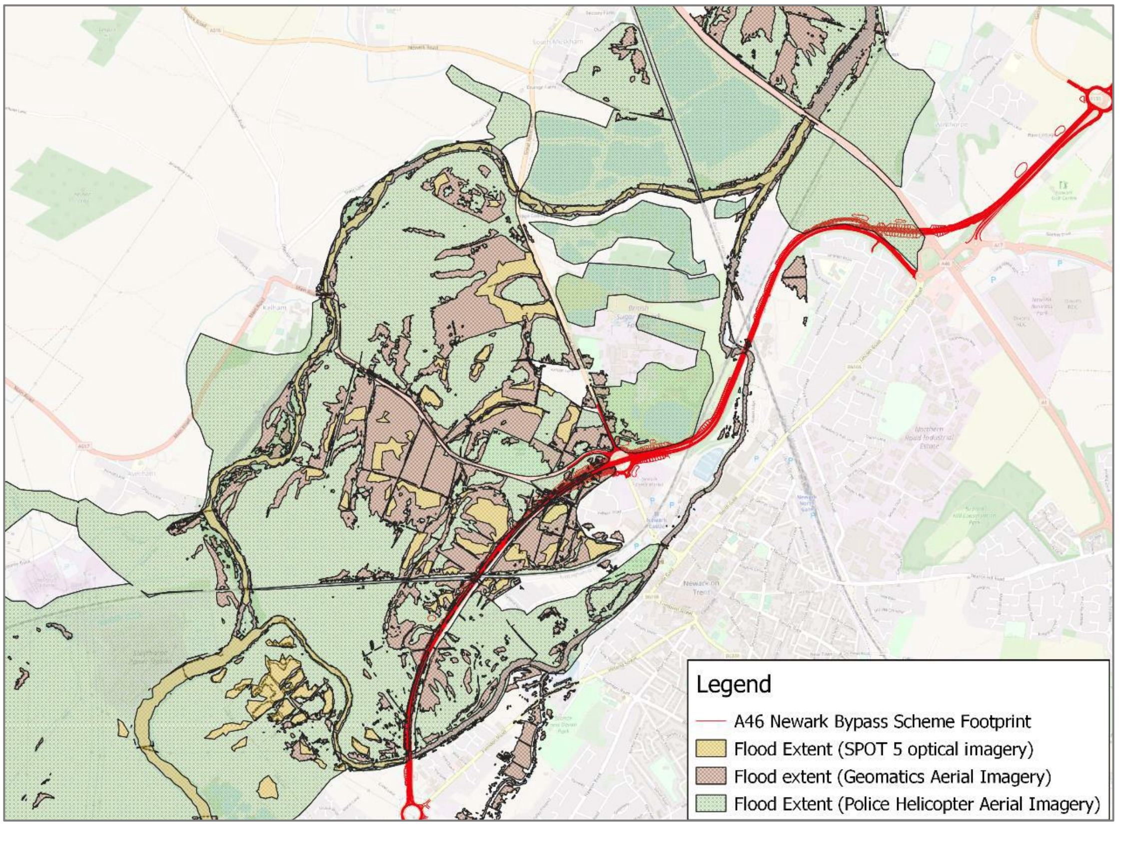


Figure D.20: Photograph taken on 29 November 2012 at 15:13:00

Figure D.21: January 2021 flood extent

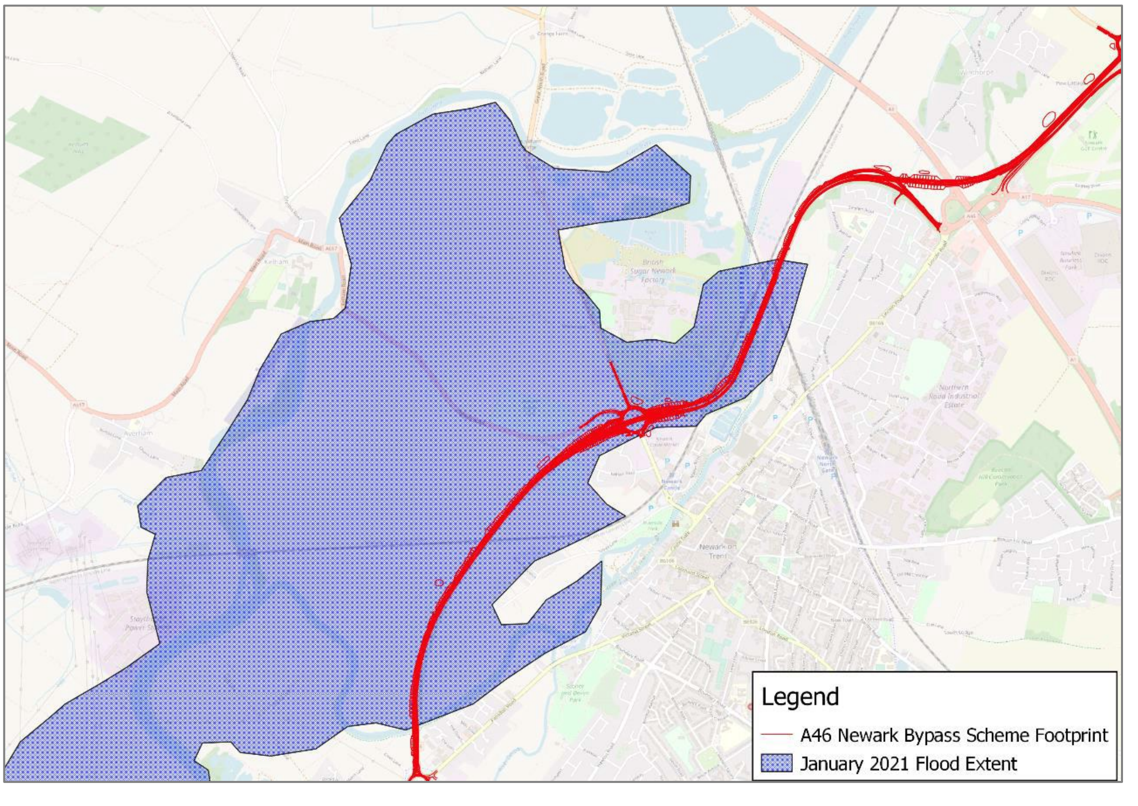
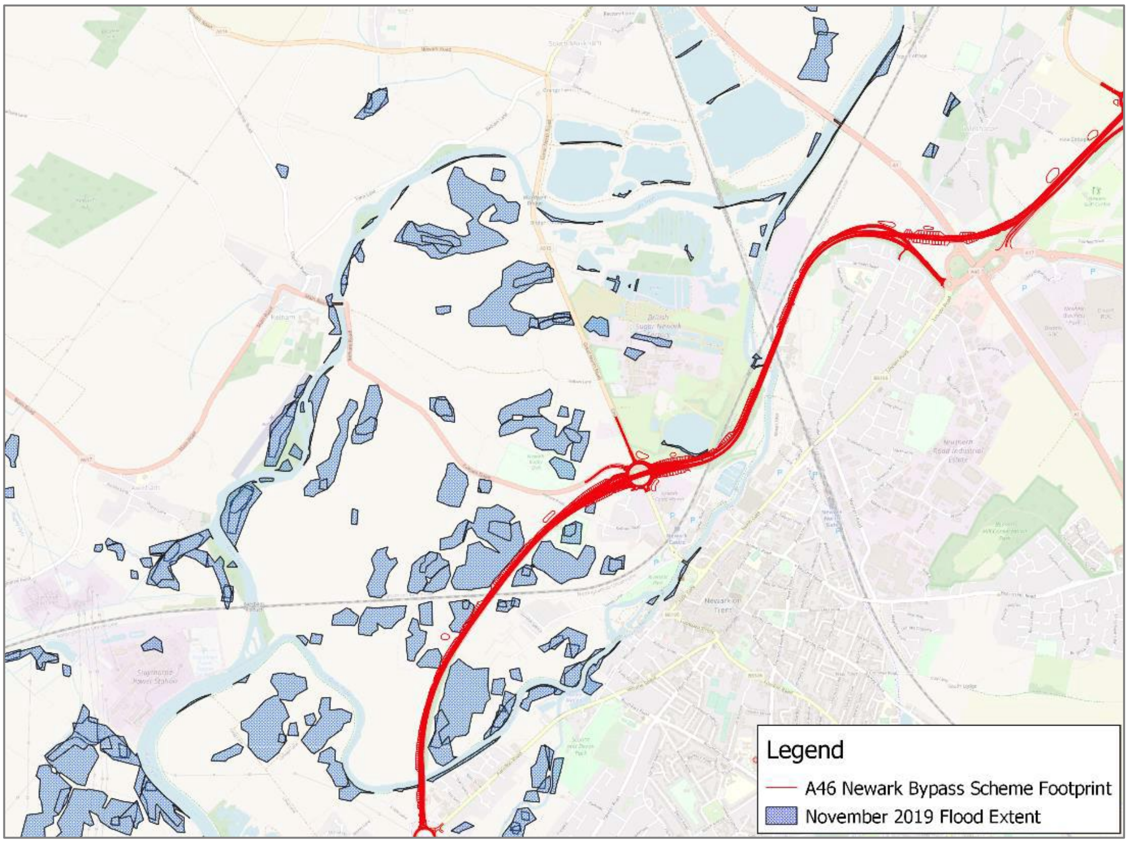


Figure D.22: Photograph taken on 24 January 2021 at 08:43:48

Source: Obliques_S21_012_20210124_084348 Tolney Lane_Sugar Factory_lowres

Figure D.23: November 2019 flood extent (no photographs)



E. Pooling group derivation

This section presents the original and final pooling groups used for the FEH Statistical method.

Table E.12: Devon at Cotham – initial group

Station	Distance (SDM)	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT2000	BFIHOST19
54016 (Roden @ Rodington)	0.424	51	10.858	0.203	0.205	0.418	0.416	2.242	261.942	693	0.221	0.981	0.013	0.587
33019 (Thet @ Melford Bridge)	0.72	57	7.33	0.251	0.253	0.104	0.101	0.118	311.37	620	0.19	0.932	0.014	0.729
40005 (Beult @ Stilebridge)	0.763	59	37.911	0.239	0.241	0.2	0.197	1.381	278.048	691	0.184	0.992	0.015	0.328
54020 (Perry @ Yeaton)	0.959	57	10.59	0.144	0.146	0.009	0.007	1.061	188.077	739	0.19	0.954	0.014	0.61
27087 (Derwent @ Low Marishes)	1.083	31	14.68	0.158	0.158	0.217	0.216	0.301	475.938	741	0.188	0.996	0.01	0.662
22006 (Blyth @ Hartford Bridge)	1.506	60	52.591	0.318	0.32	0.289	0.287	1.183	273.673	696	0.115	0.99	0.009	0.344
204001 (Bush @ Seneirl Bridge)	1.527	48	62.534	0.085	0.086	0.158	0.157	1.554	298.983	1116	0.164	0.992	0.003	0.394
33029 (Stringside @ Whitebridge)	1.531	54	2.722	0.248	0.248	-0.081	-0.082	1.082	95.412	628	0.226	0.991	0.007	0.879
33011 (Little Ouse @ County Bridge Euston)	1.561	59	3.928	0.312	0.314	-0.018	-0.019	0.993	129.345	596	0.146	0.985	0.008	0.688
54041 (Tern @ Eaton upon Tern)	1.566	42	12.444	0.187	0.189	0.109	0.107	0.085	193.485	719	0.119	0.954	0.015	0.604

Table E.13: Devon at Cotham – final

Station	Distance (SDM)	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT2000	BFIHOST19
40005 (Beult @ Stilebridge)	0.763	59	37.911	0.239	0.241	0.200	0.197	1.76	278	691	0.184	0.992	0.015	0.328
22006 (Blyth @ Hartford Bridge)	1.506	60	52.591	0.318	0.32	0.289	0.287	0.56	274	696	0.115	0.990	0.009	0.344
33005 (Bedford Ouse @ Thornborough Mill)	1.595	28	21.8	0.178	0.18	-0.112	-0.113	1.92	388	655	0.111	0.983	0.014	0.466
37010 (Blackwater @ Appleford Bridge)	1.675	58	13.15	0.287	0.291	0.203	0.198	0.34	249	572	0.098	0.991	0.026	0.461
25005 (Leven @ Leven Bridge)	1.694	47	43.32	0.244	0.246	0.272	0.270	0.75	194	726	0.107	0.994	0.014	0.369
31005 (Welland @ Tixover)	1.759	57	37.24	0.291	0.293	0.255	0.253	0.18	420	636	0.098	0.971	0.013	0.352
43009 (Stour @ Hammoon)	1.771	52	111.3	0.186	0.187	0.102	0.100	1.10	519	849	0.123	0.992	0.010	0.434
28024 (Wreake @ Syston Mill)	1.864	52	34.45	0.318	0.323	0.305	0.301	1.46	417	634	0.088	0.953	0.022	0.388

Station	Distance (SDM)	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT2000	BFIHOST19
35008 (Gipping @ Stowmarket)	2.000	55	14.7	0.294	0.299	0.050	0.046	1.21	126	577	0.099	0.996	0.028	0.395
36005 (Brett @ Hadleigh)	2.074	58	11	0.297	0.298	0.090	0.088	0.73	156	580	0.076	0.994	0.009	0.411

Table E.14: Small catchments – initial group

Station	Distance (SDM)	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 2000	BFIHOS T19
27073 (Brompton Beck @ Snainton Ings)	0.706	40	0.816	0.214	0.215	0.02	0.019	0.695	8.06	721	0.237	1.00	0.008	0.81
26016 (Gypsey Race @ Kirby Grindalythe)	1.089	23	0.101	0.312	0.312	0.258	0.258	0.133	15.85	757	0.03	1.00	0.000	0.93
36010 (Bumpstead Brook @ Broad Green)	1.156	53	7.5	0.377	0.379	0.173	0.172	0.677	27.582	588	0.045	1.00	0.007	0.37
27051 (Crimple	1.187	48	4.544	0.219	0.22	0.146	0.145	1.228	8.172	855	0.013	1.00	0.006	0.33

Station	Distance (SDM)	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 2000	BFIHOS T19
@ Burn Bridge)														
25019 (Leven @ Easby)	1.279	42	5.384	0.338	0.339	0.386	0.385	0.874	15.088	830	0.019	1.00	0.004	0.50
26014 (Water Forlornes @ Driffield)	1.451	22	0.431	0.298	0.299	0.12	0.119	1.042	32.415	721	0.016	1.00	0.007	0.92
36004 (Chad Brook @ Long Melford)	1.631	53	4.938	0.304	0.305	0.167	0.166	0.724	50.328	589	0.065	1.00	0.006	0.46
39033 (Winterbourne Stream @ Bagnor)	1.683	58	0.401	0.342	0.342	0.383	0.382	1.506	45.312	717	0.033	1.00	0.001	0.81
33054 (Babingley @ Castle Rising)	1.688	44	1.132	0.204	0.205	0.069	0.068	0.713	48.53	686	0.118	0.94	0.005	0.90
7011 (Black Burn @ Pluscarden Abbey)	1.703	7	5.205	0.544	0.544	0.571	0.571	2.495	36.375	808	0.041	0.98	0.001	0.66
36003 (Box @ Polstead)	1.722	60	3.875	0.314	0.317	0.088	0.086	0.727	56.72	566	0.093	0.99	0.012	0.55

Station	Distance (SDM)	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 2000	BFIHOS T19
36007 (Belchamp Brook @ Bardfield Bridge)	1.743	55	4.63	0.378	0.378	0.112	0.111	1.187	58.16	560	0.079	1.00	0.004	0.53

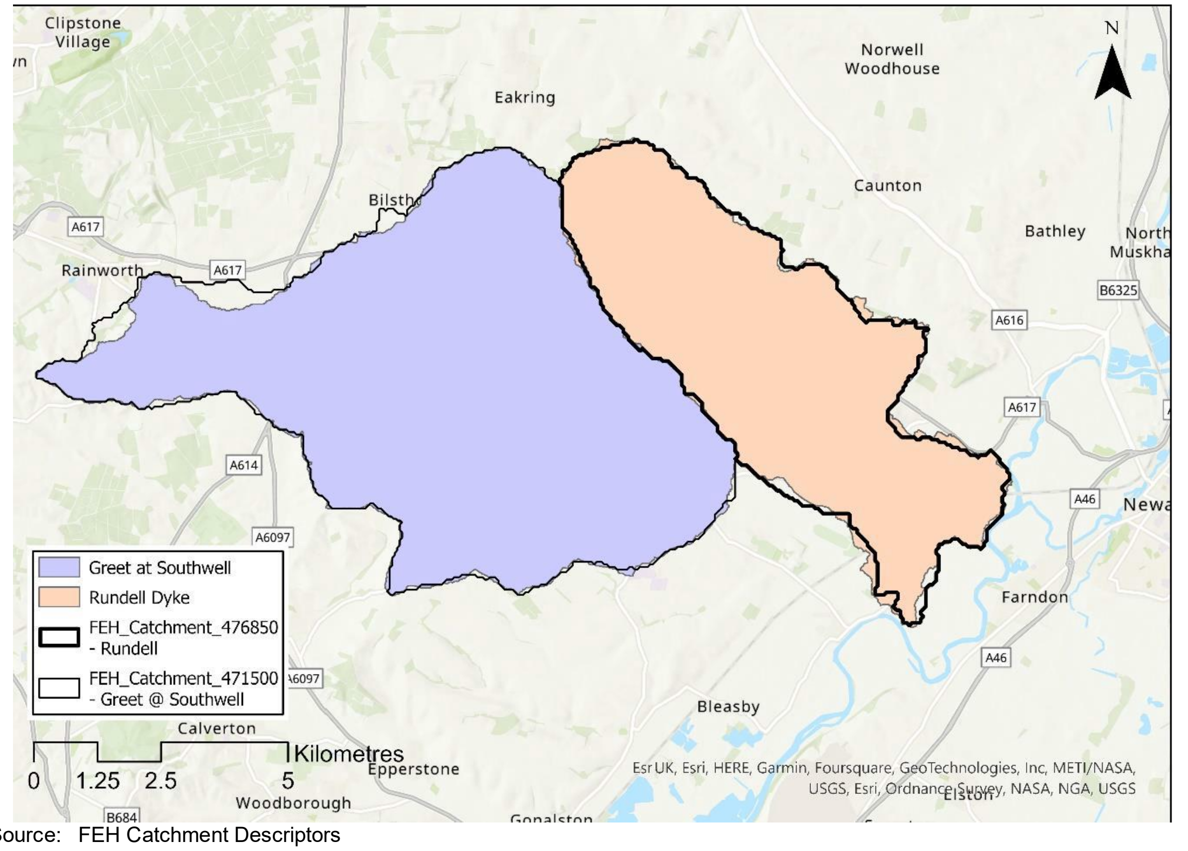
Table E.15: Small catchments - final

Station	Distance (SDM)	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 2000	BFIHOS T19
36010 (Bumpstead Brook @ Broad Green)	1.156	53	7.5	0.377	0.379	0.173	0.172	0.75	27.582	588	0.045	1	0.007	0.368
27051 (Crimple @ Burn Bridge)	1.187	48	4.544	0.219	0.22	0.146	0.145	0.59	8.172	855	0.013	1	0.006	0.329
25019 (Leven @ Easby)	1.279	42	5.384	0.338	0.339	0.386	0.385	1.25	15.088	830	0.019	1	0.004	0.495
36004 (Chad Brook @ Long Melford)	1.631	53	4.938	0.304	0.305	0.167	0.166	0.64	50.328	589	0.065	1	0.006	0.456
39033 (Winterbourne Stream @ Bagnor)	1.683	58	0.401	0.342	0.342	0.383	0.382	1.50	45.312	717	0.033	1	0.001	0.812

Station	Distance (SDM)	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 2000	BFIHOS T19
36003 (Box @ Polstead)	1.722	60	3.875	0.314	0.317	0.088	0.086	0.52	56.72	566	0.093	0.99	0.012	0.549
36007 (Belchamp Brook @ Bardfield Bridge)	1.743	55	4.63	0.378	0.378	0.112	0.111	1.55	58.16	560	0.079	1	0.004	0.529
27010 (Hodge Beck @ Bransdale Weir)	1.797	41	9.42	0.224	0.224	0.293	0.293	1.03	18.82	987	0.009	1	0.001	0.303
24007 (Browney @ Lanchester)	1.815	15	10.981	0.222	0.222	0.212	0.211	1.86	44.67	797	0.015	1	0.001	0.353
37016 (Pant @ Copford Hall)	1.818	55	7.47	0.287	0.289	0.104	0.103	0.25	63.8	588	0.069	1	0.009	0.385
30004 (Lymn @ Partney Mill)	1.849	58	7.184	0.224	0.225	0.030	0.029	1.07	60.087	686	0.06	0.98	0.006	0.529

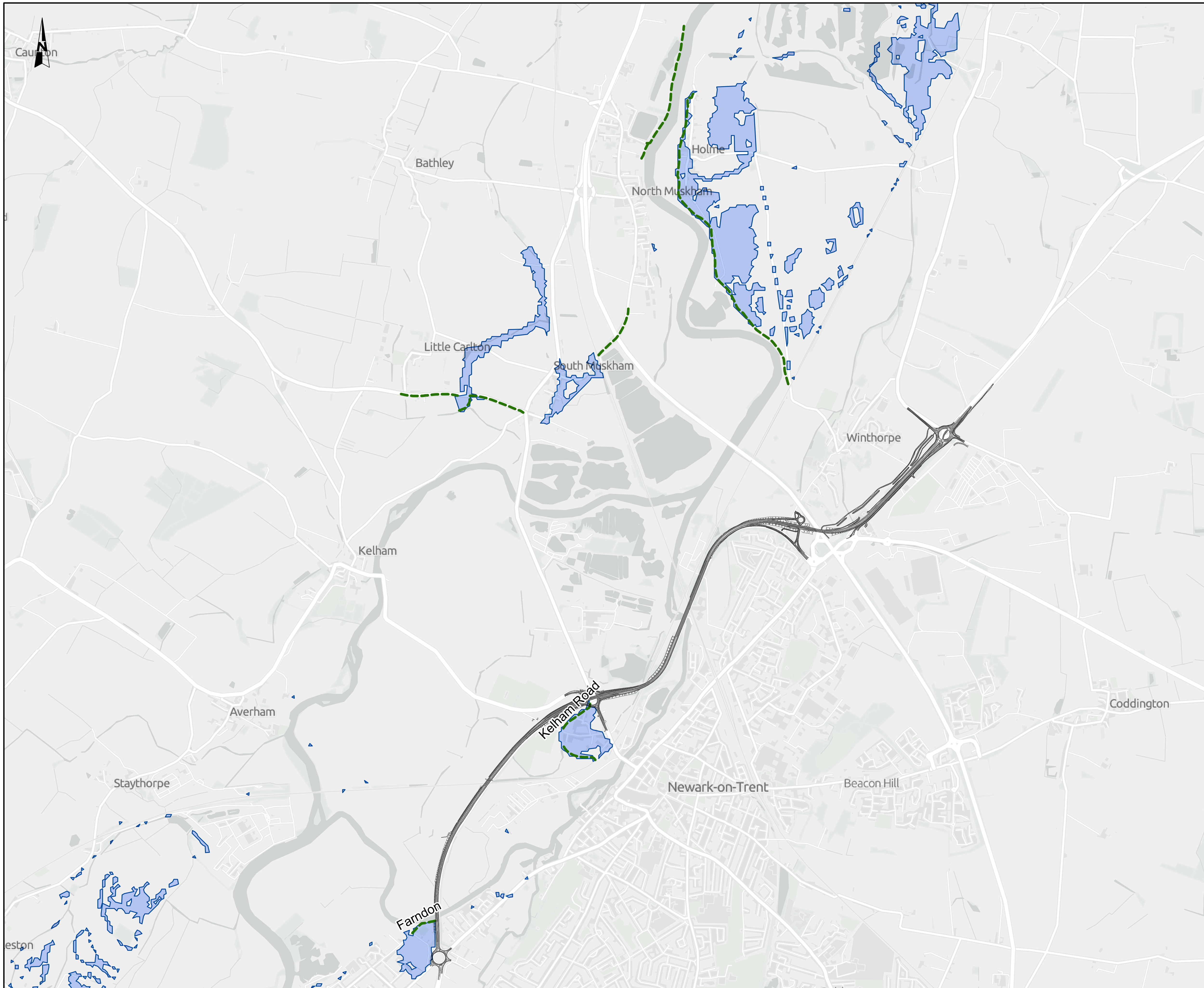
F. FEH descriptor changes – area example

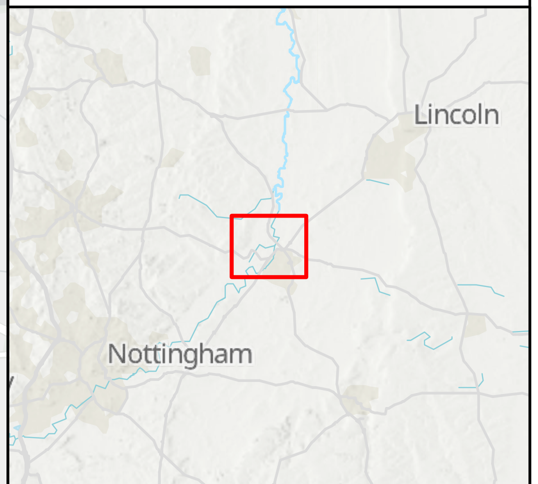
Figure F.24: Example of changed areas



Source: FEH Catchment Descriptors

C. Flood Risk Assessment Maps





NOTES

Source
Flood defence/Area benefiting from flood defence © Environment Agency copyright and/or database right 2023. All rights reserved.

Service Layer Credits
Contains OS data © Crown Copyright and database right 2023
Contains data from OS Zoomstack

KEY TO SYMBOLS

- Scheme alignment
- Flood defence
- Area benefiting from flood defence

C01	08/12/23	DCO APPLICATION	DT	OE	HF
REV.	DATE	AMENDMENT DETAILS	ORIG	CHK'D	APP'D

CLIENT
national highways

PURPOSE OF ISSUE
DCO APPLICATION

DEVELOPMENT CONSENT ORDER NUMBER
TR010065

PROJECT TITLE
A46 NEWARK BYPASS

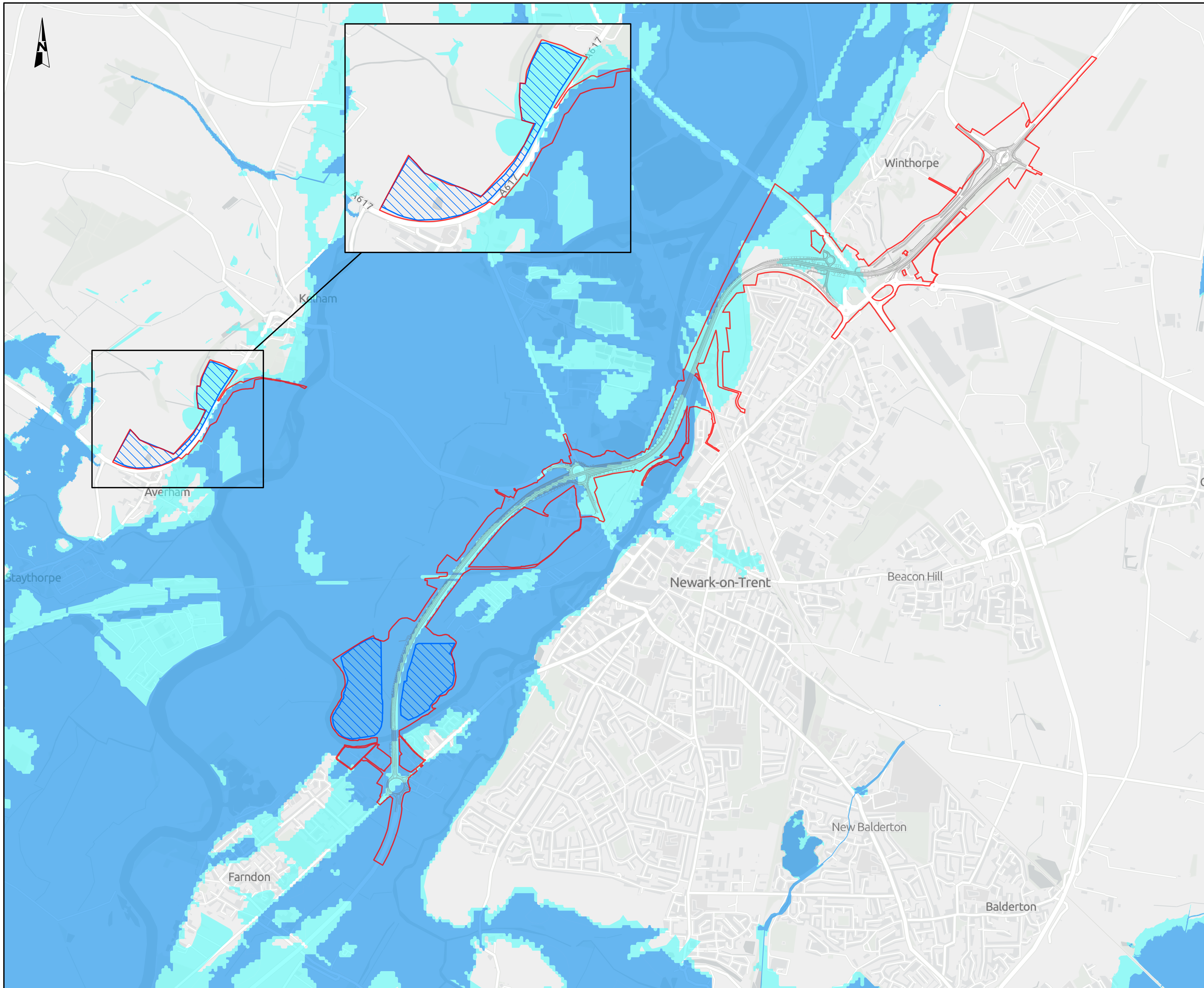
DRAWING TITLE
Appendix C.1
Flood Defence

ORIGINAL SIZE A3 SCALE 1:30,000

DRAWING NUMBER

HE PIN	ORIGINATOR	VOLUME		PROJECT REF NO.
HE551478	SKAG	EWE		HE551478
CONWI_CONW	DR	LE	00004	REVISION C01
LOCATION	TYPE	ROLE	NUMBER	

0 1,000 2,000 Metres

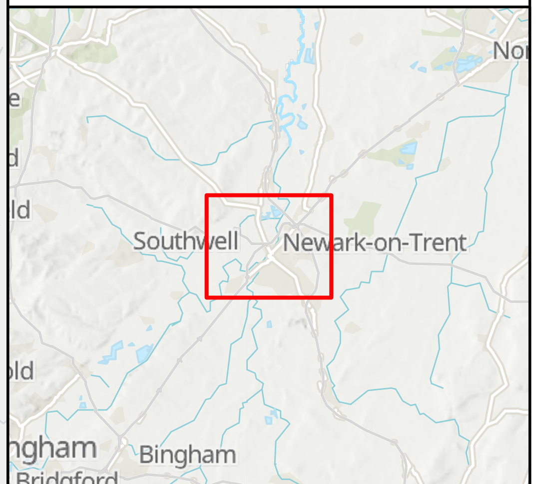


NOTES

Source
Flood Zone Data © Environment Agency copyright and/or database right. © Crown copyright and database rights 2023.
Service Layer Credits
Contains OS data © Crown Copyright and database right 2023
Contains data from OS Zoomstack

KEY TO SYMBOLS

- Order Limits
- Scheme alignment
- Floodplain Compensation Area
- Flood Zone 3
- Flood Zone 2



REV.	DATE	AMENDMENT DETAILS	ORIG	CHK'D	APP'D
C01	08/12/23	DCO APPLICATION	DT	OE	HF

CLIENT
national highways

PURPOSE OF ISSUE
DCO APPLICATION

DEVELOPMENT CONSENT ORDER NUMBER
TR010065

PROJECT TITLE
A46 NEWARK BYPASS

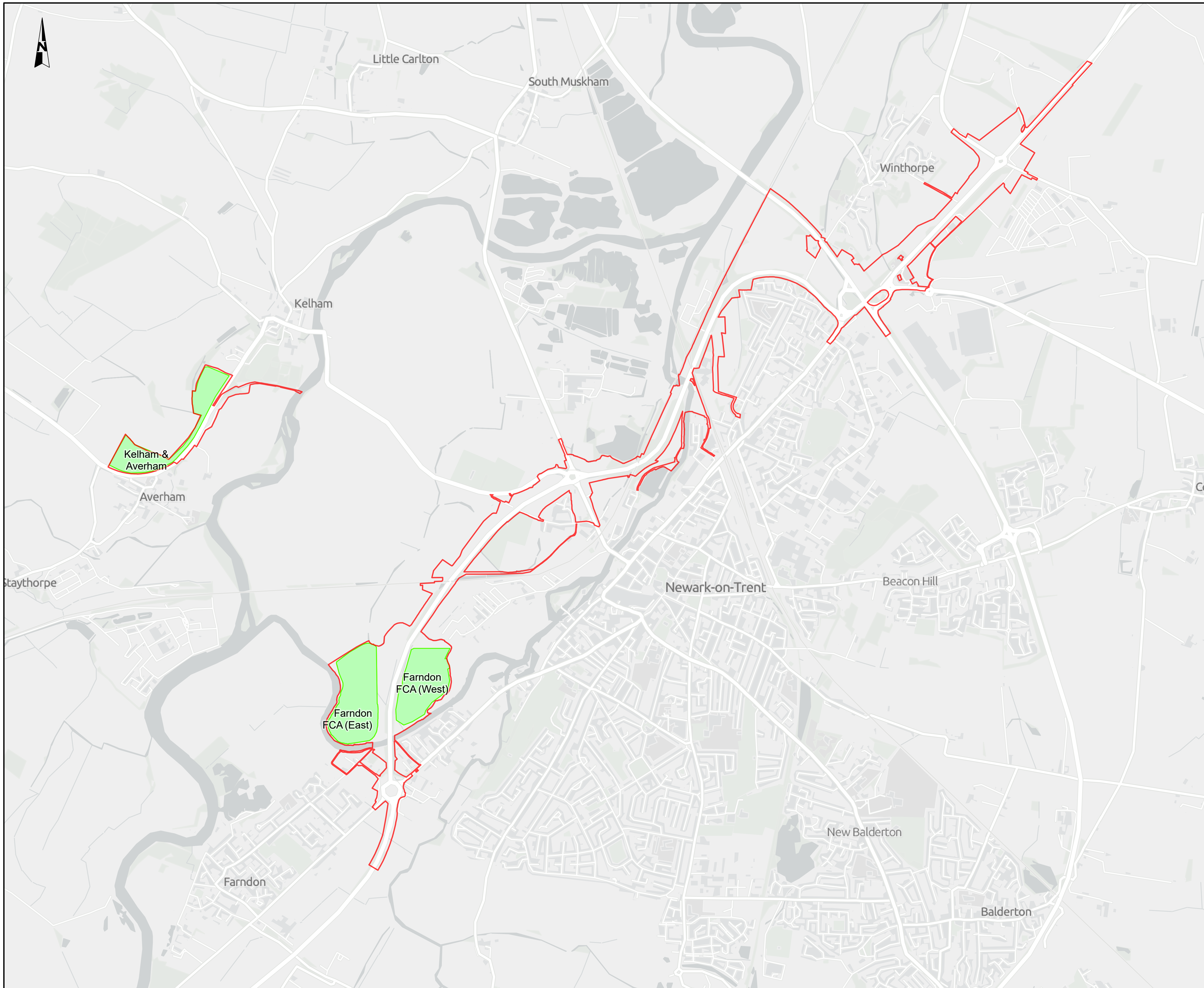
DRAWING TITLE
Appendix C.2
Flood Risk

ORIGINAL SIZE A3
SCALE 1:25,000

DRAWING NUMBER
HE PIN HE551478 | ORIGINATOR SKAG | VOLUME EWE
LOCATION CONWI_CONW | TYPE DR | ROLE LE | NUMBER 00005

PROJECT REF NO. HE551478
REVISION C01

0 1,000 2,000 Metres

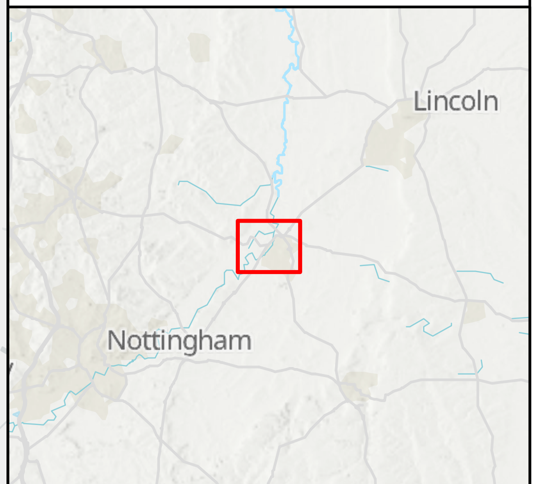


NOTES

Service Layer Credits
Contains OS data © Crown Copyright and database right 2023
Contains data from OS Zoomstack

KEY TO SYMBOLS

- Order Limits
- Floodplain Compensation Area



C01	08/12/23	DCO APPLICATION	DT	OE	HF
REV.	DATE	AMENDMENT DETAILS	ORIG	CHK'D	APP'D

CLIENT

national highways

PURPOSE OF ISSUE
DCO APPLICATION

DEVELOPMENT CONSENT ORDER NUMBER
TR010065

PROJECT TITLE
A46 NEWARK BYPASS

DRAWING TITLE
Appendix C.3
Floodplain Compensation Areas

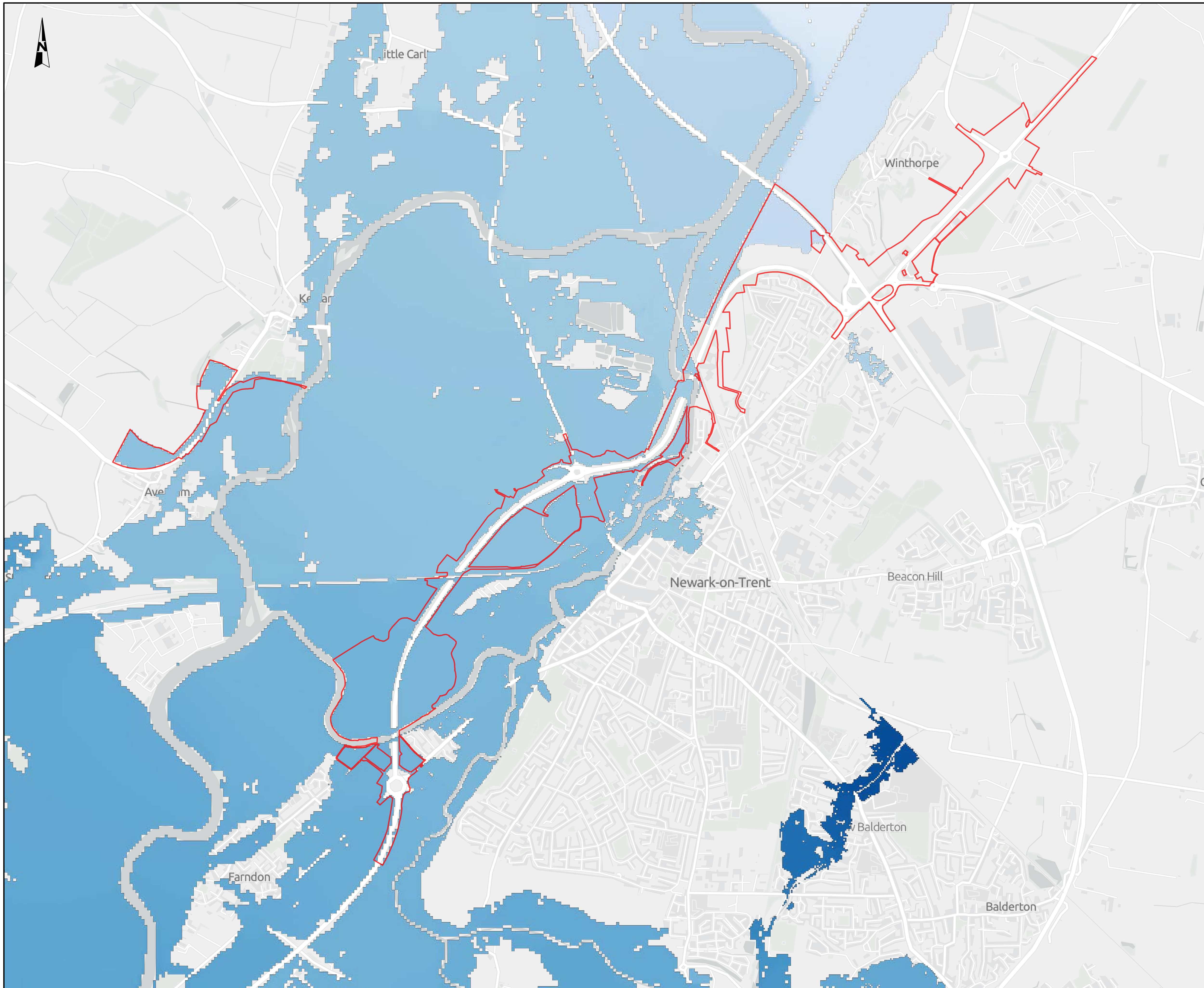
ORIGINAL SIZE A3 SCALE 1:25,000

DRAWING NUMBER
HE PIN | ORIGINATOR | VOLUME
HE551478 SKAG EWE
CONWI_CONW DR LE 00006
LOCATION | TYPE | ROLE | NUMBER

PROJECT REF NO. HE551478

REVISION C01

Metres
0 1,000 2,000



NOTES

Service Layer Credits
Contains OS data © Crown Copyright and database right 2023
Contains data from OS Zoomstack

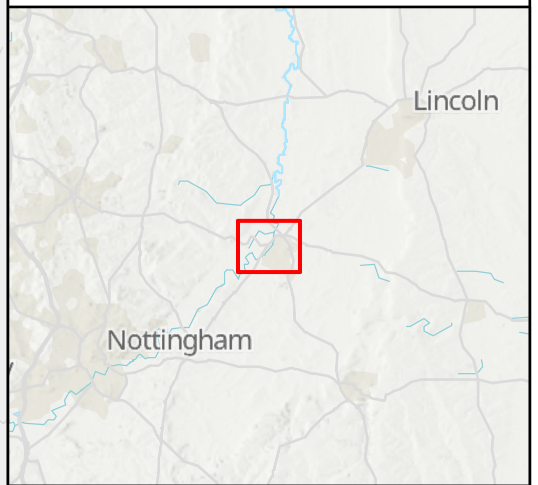
KEY TO SYMBOLS

Order Limits

Flood Max Elevation (mAOD) Proposed Scheme 1%AEP+CC

21.56m

1.55m



REV.	DATE	AMENDMENT DETAILS	ORIG	CHK'D	APP'D
C01	08/12/23	DCO APPLICATION	DT	OE	HF

CLIENT

national highways

PURPOSE OF ISSUE

DCO APPLICATION

DEVELOPMENT CONSENT ORDER NUMBER

TR010065

PROJECT TITLE

A46 NEWARK BYPASS

DRAWING TITLE

Appendix C.4
Hydraulic Model Flood Extents (1%AEP+CC)

ORIGINAL SIZE A3

SCALE 1:25,000

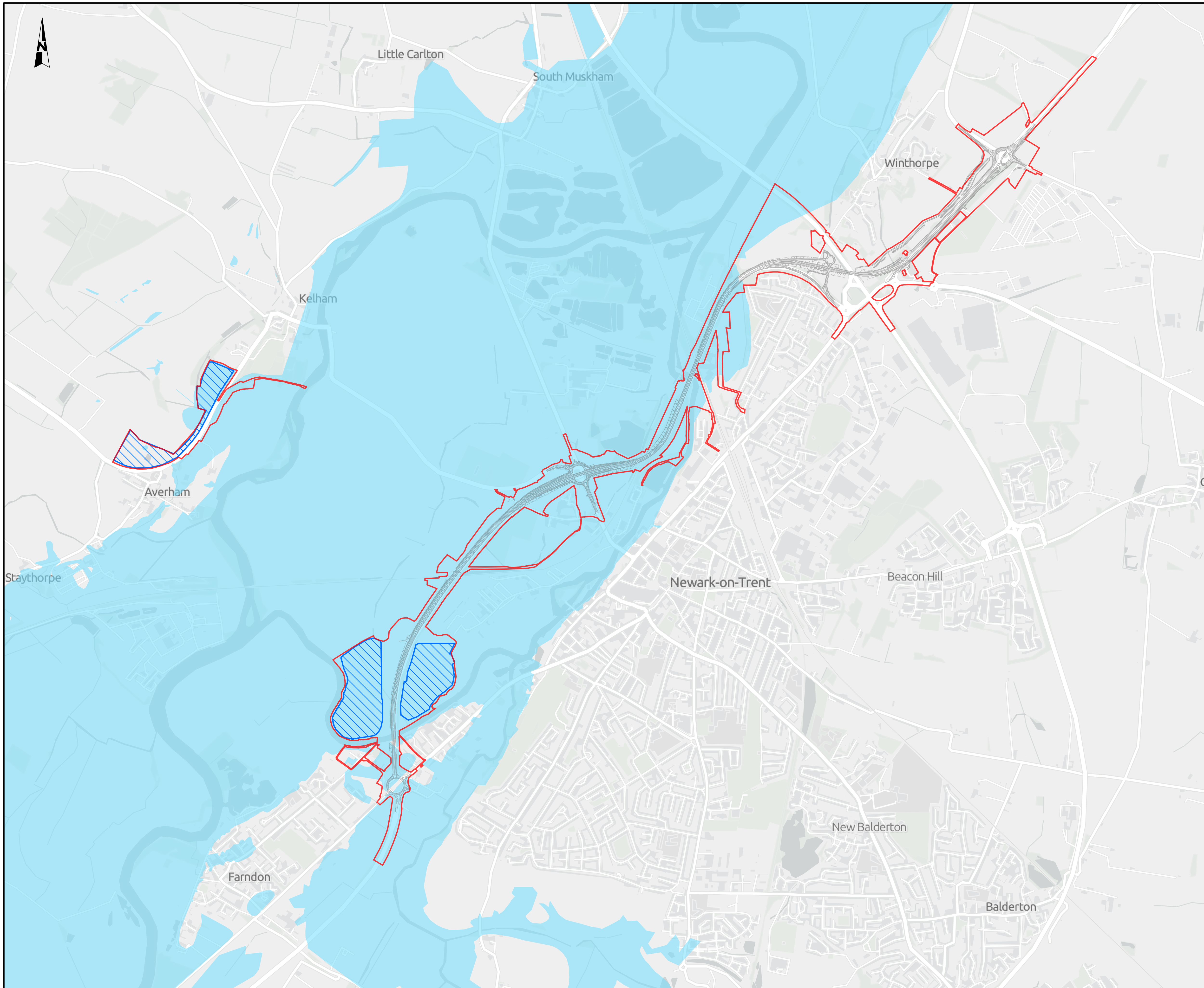
DRAWING NUMBER

HE PIN HE551478 | ORIGINATOR SKAG | VOLUME EWE

LOCATION CONWI_CONW | TYPE DR | ROLE LE | NUMBER 00007

PROJECT REF NO. HE551478

REVISION C01

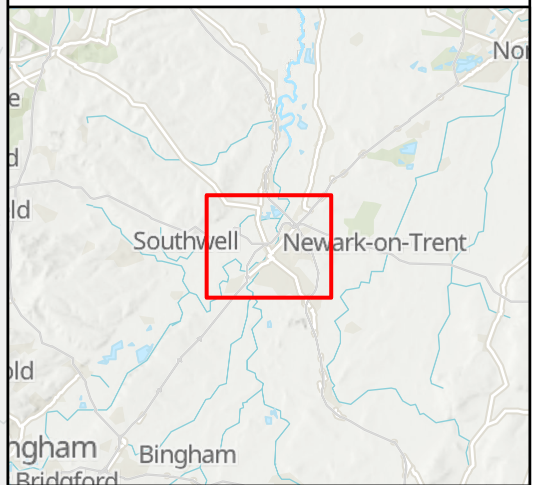


NOTES

Source
Historic Flood Risk Data © Environment Agency copyright and/or database right. © Crown copyright and database rights 2023.
Service Layer Credits
Contains OS data © Crown Copyright and database right 2023
Contains data from OS Zoomstack

KEY TO SYMBOLS

- Order Limits
- Scheme alignment
- Floodplain Compensation Area
- Historic flood risk



REV.	DATE	AMENDMENT DETAILS	ORIG	CHK'D	APP'D
C01	08/12/23	DCO APPLICATION	DT	OE	HF

CLIENT
national highways

PURPOSE OF ISSUE
DCO APPLICATION

DEVELOPMENT CONSENT ORDER NUMBER
TR010065

PROJECT TITLE
A46 NEWARK BYPASS

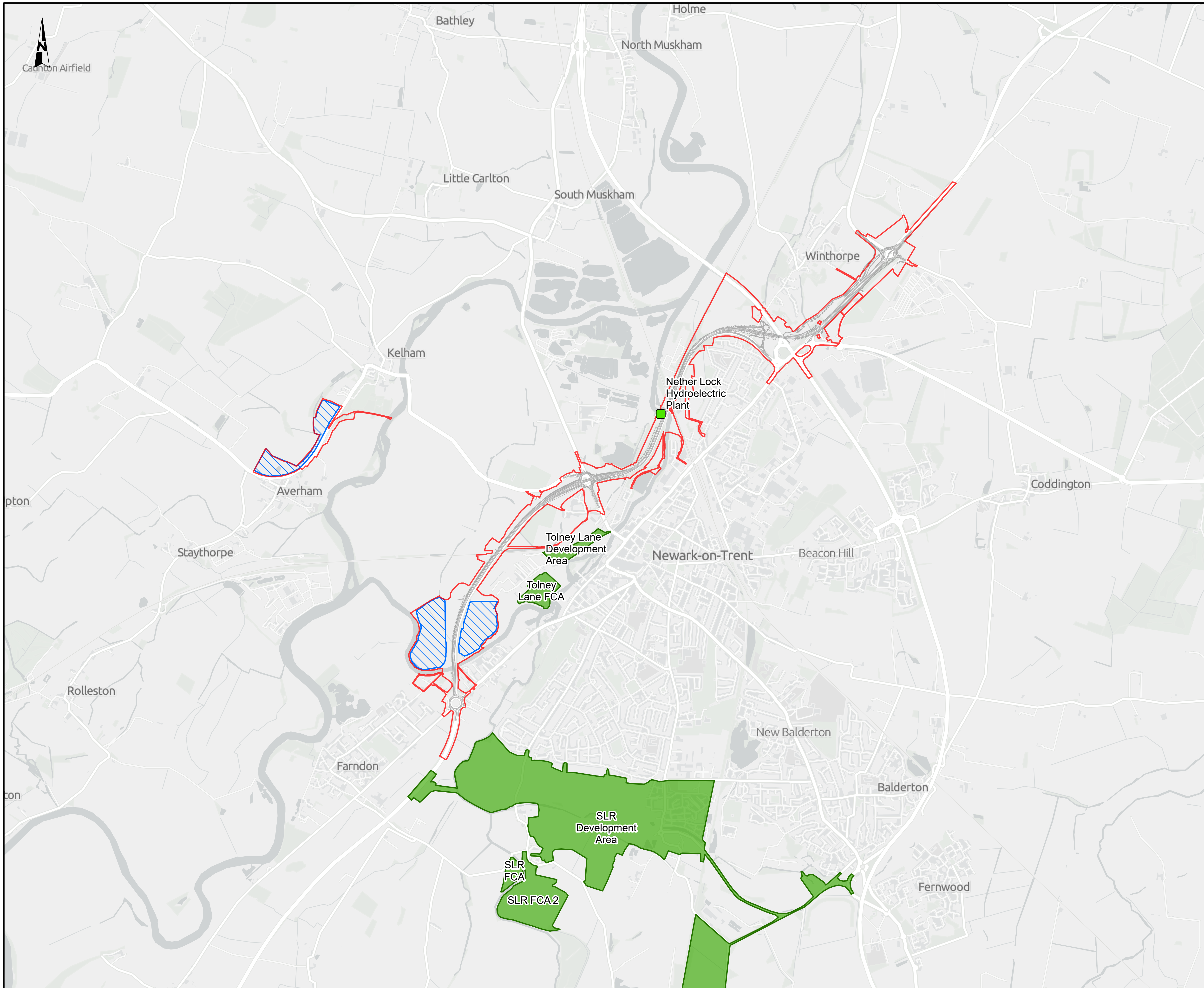
DRAWING TITLE
Appendix C.5
Historic Flood Risk

ORIGINAL SIZE A3 SCALE 1:25,000

DRAWING NUMBER
HE PIN HE551478 | ORIGINATOR SKAG | VOLUME EWE
LOCATION CONWI_CONW | TYPE DR | ROLE LE | NUMBER 00009

PROJECT REF NO. HE551478
REVISION C01

0 1,000 2,000 Metres

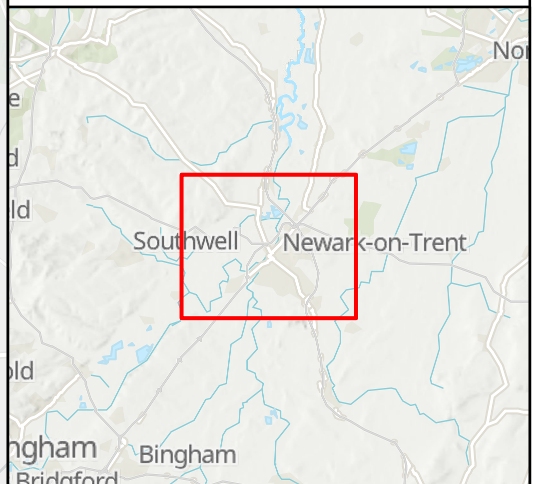


NOTES

Source
Flood Zone Data © Environment Agency copyright and/or database right 2020. All rights reserved.
Service Layer Credits
Contains OS data © Crown Copyright and database right 2023
Contains data from OS Zoomstack

KEY TO SYMBOLS

- Order Limits
- Scheme alignment
- Floodplain Compensation Area
- Nether Lock hydroelectric scheme
- Southern Link Road and Tolney Lane scheme



REV.	DATE	AMENDMENT DETAILS	ORIG	CHK'D	APP'D
C01	08/12/23	DCO APPLICATION	DT	OE	HF

CLIENT
national highways

PURPOSE OF ISSUE
DCO APPLICATION

DEVELOPMENT CONSENT ORDER NUMBER
TR010065

PROJECT TITLE
A46 NEWARK BYPASS

DRAWING TITLE
Appendix C.6
Other Schemes

ORIGINAL SIZE A3
SCALE 1:35,000

DRAWING NUMBER
HE PIN HE551478 | ORIGINATOR SKAG | VOLUME EWE
LOCATION CONWI_CONW | TYPE DR | ROLE LE | NUMBER 00010

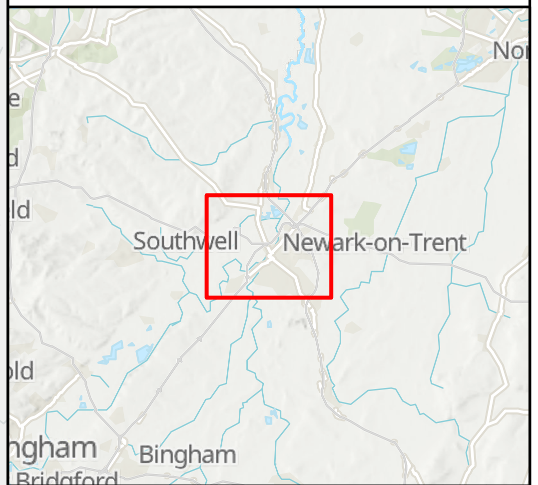
PROJECT REF NO. HE551478
REVISION C01

NOTES

Source
Reservoir flood extent © Environment Agency copyright and/or database right. © Crown copyright and database rights 2023.
Service Layer Credits
Contains OS data © Crown Copyright and database right 2023
Contains data from OS Zoomstack

KEY TO SYMBOLS

- Order Limits
- Scheme alignment
- Floodplain Compensation Area
- Reservoir flood extent



REV.	DATE	AMENDMENT DETAILS	ORIG	CHK'D	APP'D
C01	08/12/23	DCO APPLICATION	DT	OE	HF

CLIENT

national highways

PURPOSE OF ISSUE
DCO APPLICATION

DEVELOPMENT CONSENT ORDER NUMBER
TR010065

PROJECT TITLE
A46 NEWARK BYPASS

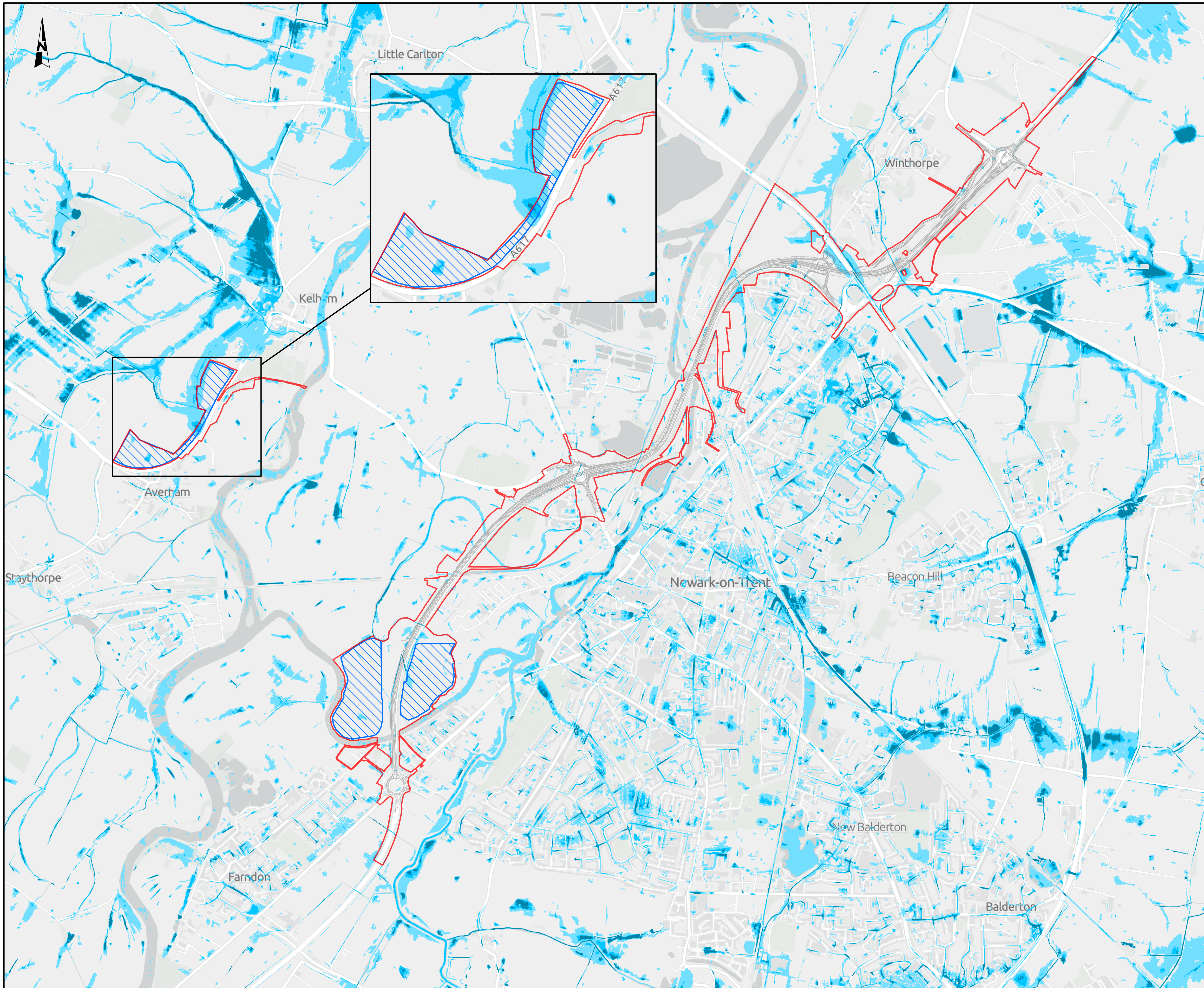
DRAWING TITLE
Appendix C.7
Reservoir Flood Risk

ORIGINAL SIZE A3 SCALE 1:25,000

DRAWING NUMBER
HE PIN | ORIGINATOR | VOLUME
HE551478 SKAG EWE
CONWI_CONW DR LE 00011
LOCATION | TYPE | ROLE | NUMBER

PROJECT REF NO. HE551478
REVISION C01

0 1,000 2,000 Metres



NOTES

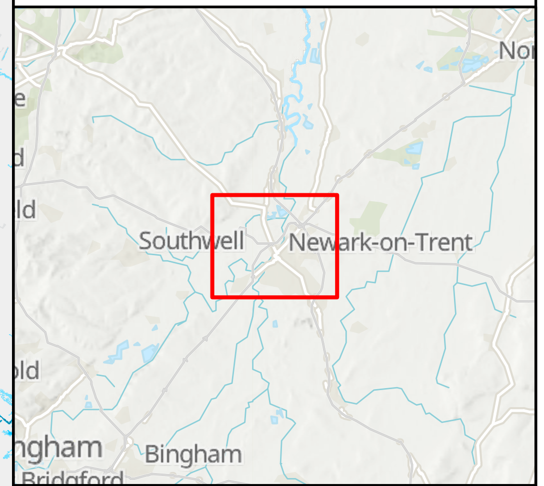
Source
Risk of Flooding from Surface Water © Environment Agency copyright and/or database right 2023. All rights reserved.
Service Layer Credits
Contains OS data © Crown Copyright and database right 2023
Contains data from OS Zoomstack

KEY TO SYMBOLS

- Order Limits
- Scheme alignment
- Floodplain Compensation Area

Risk of Flooding from Surface Water

- 30 year extent
- 100 year extent
- 1000 year extent



REV.	DATE	AMENDMENT DETAILS	ORIG	CHK'D	APP'D
C01	08/12/23	DCO APPLICATION	DT	OE	HF

CLIENT
national highways

PURPOSE OF ISSUE
DCO APPLICATION

DEVELOPMENT CONSENT ORDER NUMBER
TR010065

PROJECT TITLE
A46 NEWARK BYPASS

DRAWING TITLE
Appendix C.8
Surface Water Flood Risk

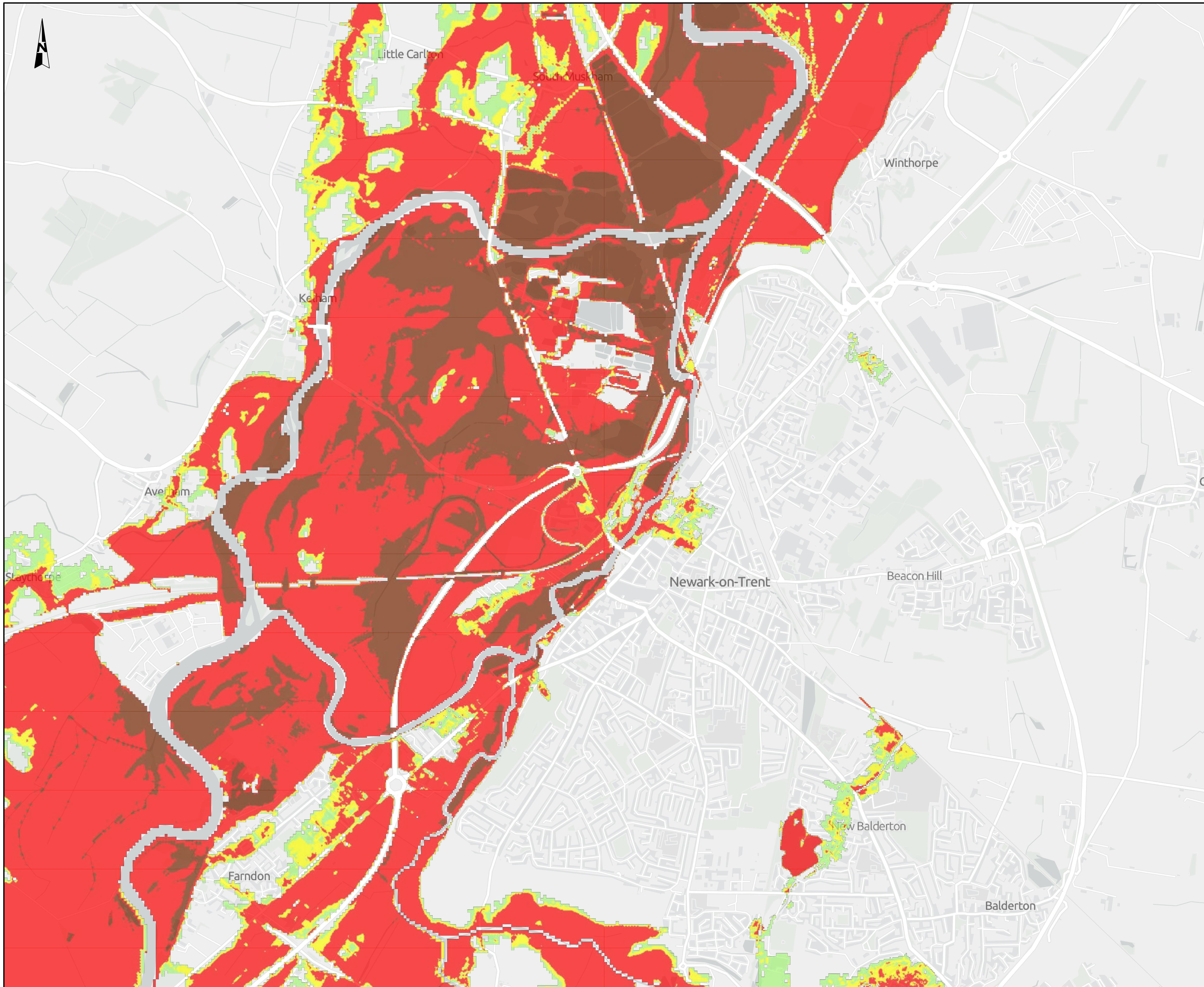
ORIGINAL SIZE A3 SCALE 1:25,000

DRAWING NUMBER
HE PIN HE551478 | ORIGINATOR SKAG | VOLUME EWE
LOCATION CONWI_CONW | TYPE DR | ROLE LE | NUMBER 00012

PROJECT REF NO. HE551478

REVISION C01

0 1,000 2,000 Metres



0 | 1,000 | 2,000 Metres

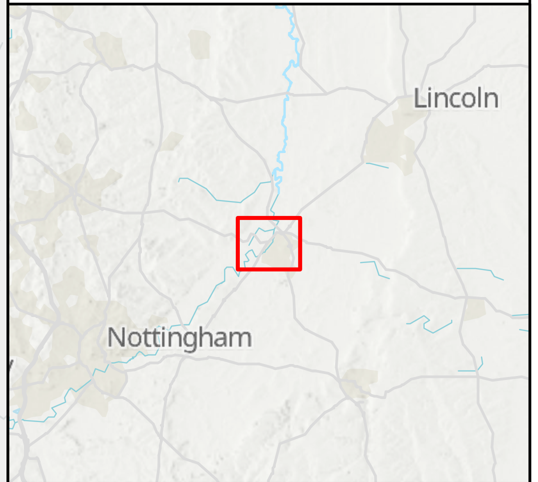
NOTES

Service Layer Credits
Contains OS data © Crown Copyright and database right 2023
Contains data from OS Zoomstack

KEY TO SYMBOLS

Flood hazard

- 0 = No hazard (H <= 0)
- 1 = Low hazard (H <= 0.75)
- 2 = Moderate hazard (H <= 1.25)
- 3 = Significant hazard (H <= 2.5)
- 4 = Extreme hazard (H > 2.5)



REV.	DATE	AMENDMENT DETAILS	ORIG	CHK'D	APP'D
C01	08/12/23	DCO APPLICATION	DT	OE	HF

CLIENT
national highways

PURPOSE OF ISSUE
DCO APPLICATION

DEVELOPMENT CONSENT ORDER NUMBER
TR010065

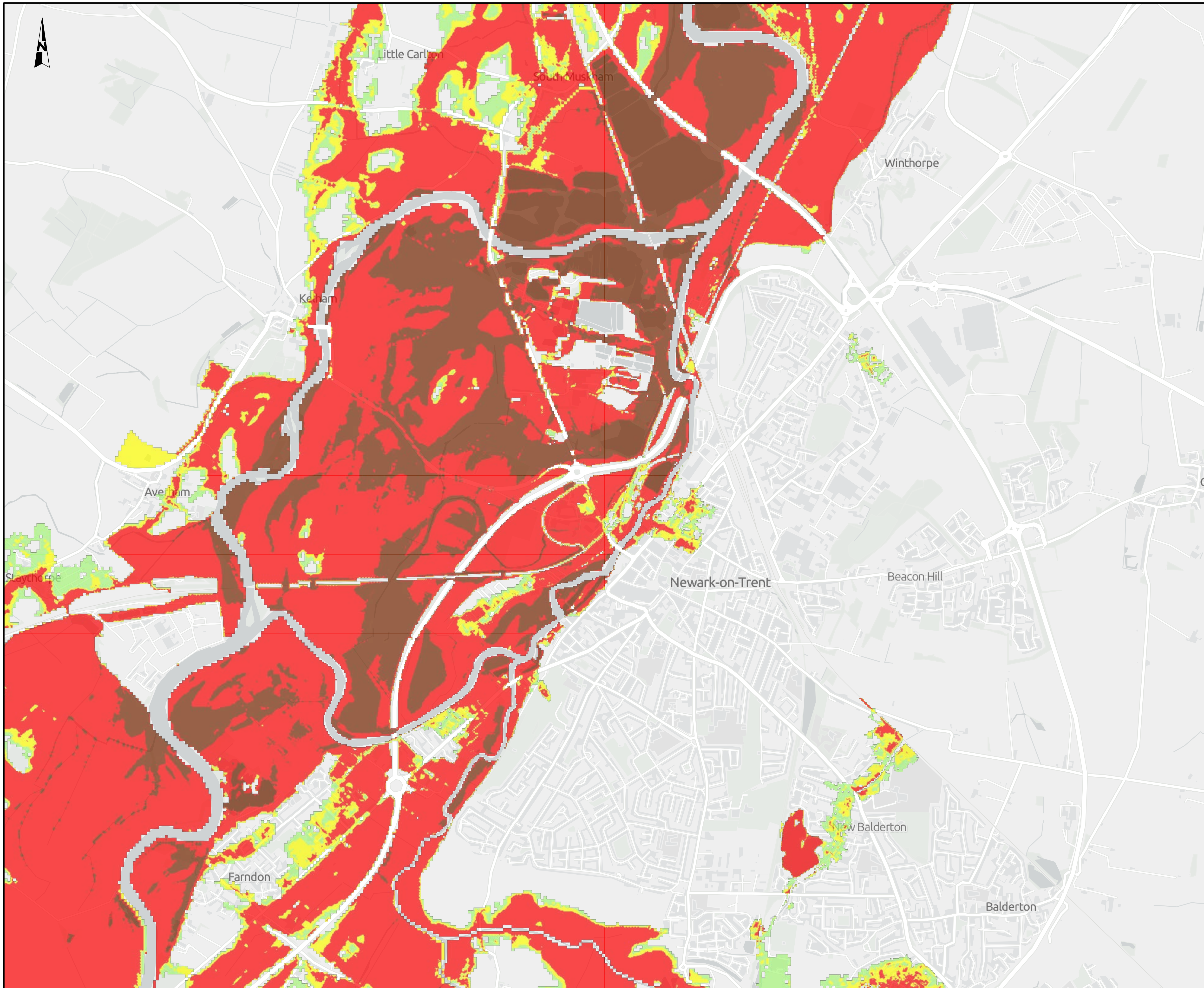
PROJECT TITLE
A46 NEWARK BYPASS

DRAWING TITLE
Appendix C.9
Flood Hazard Mapping 1%AEP+CC Event

ORIGINAL SIZE A3 | SCALE 1:25,000

DRAWING NUMBER
HE PIN: HE551478 | ORIGINATOR: SKAG | VOLUME: EWE
LOCATION: CONWI_CONW | TYPE: DR | ROLE: LE | NUMBER: 00013

PROJECT REF NO. HE551478
REVISION C01



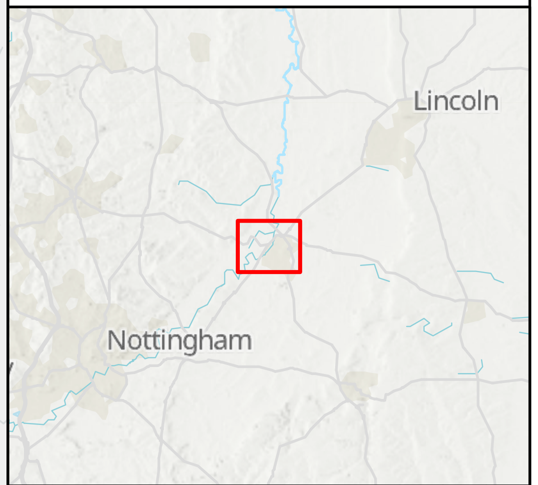
NOTES

Service Layer Credits

KEY TO SYMBOLS

Flood hazard

- 0 = No hazard (H <= 0)
- 1 = Low hazard (H <= 0.75)
- 2 = Moderate hazard (H <= 1.25)
- 3 = Significant hazard (H <= 2.5)
- 4 = Extreme hazard (H > 2.5)



REV.	DATE	AMENDMENT DETAILS	ORIG	CHK'D	APP'D
C01	08/12/23	DCO APPLICATION	DT	OE	HF

CLIENT

national highways

PURPOSE OF ISSUE

DCO APPLICATION

DEVELOPMENT CONSENT ORDER NUMBER

TR010065

PROJECT TITLE

A46 NEWARK BYPASS

DRAWING TITLE

Appendix C.10
Post-Scheme Flood Hazard Mapping 1%AEP+CC Event

ORIGINAL SIZE A3 SCALE 1:25,000

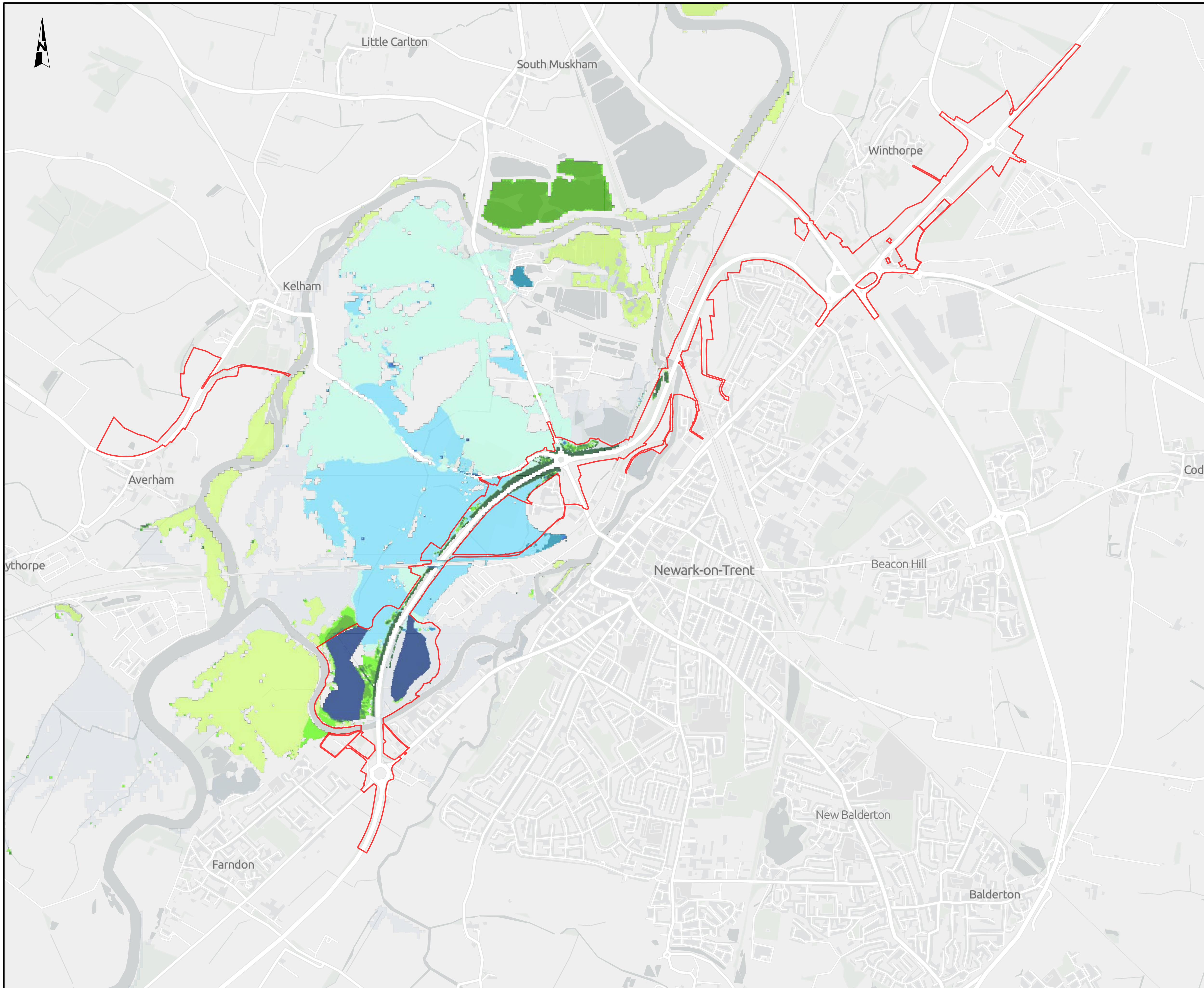
DRAWING NUMBER

HE PIN	ORIGINATOR	VOLUME
HE551478	SKAG	EWE

LOCATION	TYPE	ROLE	NUMBER
CONWI_CONW	DR	LE	00014

PROJECT REF NO. HE551478

REVISION C01



NOTES

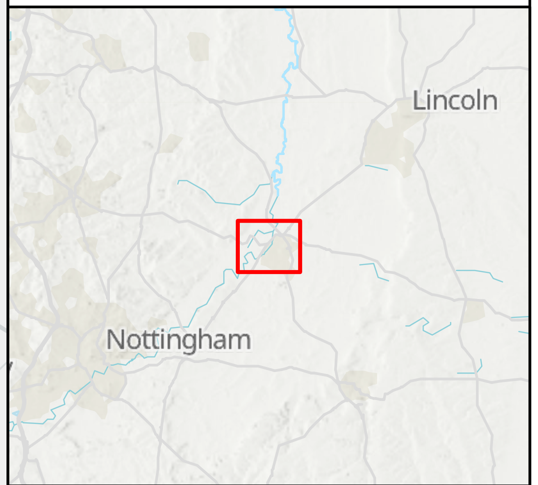
Service Layer Credits
Contains OS data © Crown Copyright and database right 2023
Contains data from OS Zoomstack

KEY TO SYMBOLS

Order Limits

Depth difference (m)

- ≤ -0.15
- -0.15 - -0.1
- -0.1 - -0.05
- -0.05 - -0.01
- -0.01 - -0.05
- -0.05 - 0.005
- 0.005 - 0.01
- 0.01 - 0.05
- 0.05 - 0.1
- 0.1 - 0.15
- >0.15



REV.	DATE	AMENDMENT DETAILS	ORIG	CHK'D	APP'D
C01	08/12/23	DCO APPLICATION	MH	OE	HF

CLIENT

national highways

PURPOSE OF ISSUE: DCO APPLICATION

DEVELOPMENT CONSENT ORDER NUMBER: TR010065

PROJECT TITLE: A46 NEWARK BYPASS

DRAWING TITLE: Appendix C.11
50%AEP Flood Depth Difference (scheme-baseline)

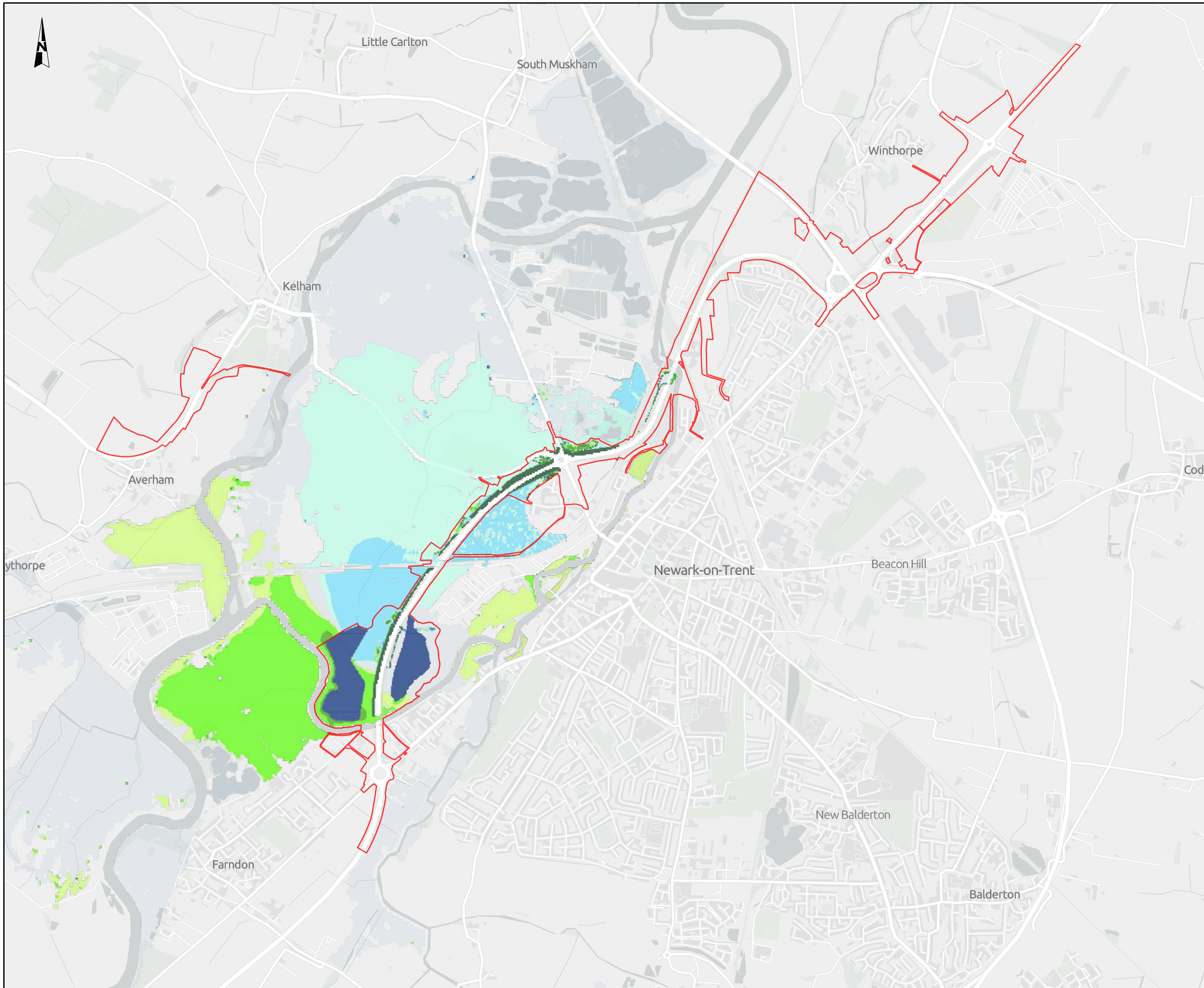
ORIGINAL SIZE: A3 SCALE: 1:25,000

DRAWING NUMBER
HE PIN: HE551478 | ORIGINATOR: SKAG | VOLUME: EWE
LOCATION: CONWI_CONW | TYPE: DR | ROLE: LE | NUMBER: 00021

PROJECT REF NO.: HE551478

REVISION: C01

0 1,000 2,000 Metres



NOTES

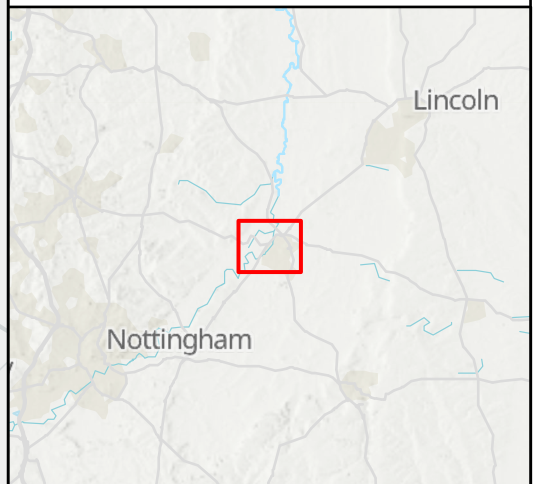
Service Layer Credits
Contains OS data © Crown Copyright and database right 2023
Contains data from OS Zoomstack

KEY TO SYMBOLS

Order Limits

Depth difference (m)

- ≤ -0.15
- -0.15 - -0.1
- -0.1 - -0.05
- -0.05 - -0.01
- -0.01 - -0.05
- -0.05 - 0.005
- 0.005 - 0.01
- 0.01 - 0.05
- 0.05 - 0.1
- 0.1 - 0.15
- >0.15



REV.	DATE	AMENDMENT DETAILS	ORIG	CHK'D	APP'D
C01	08/12/23	DCO APPLICATION	MH	OE	HF

CLIENT
national highways

PURPOSE OF ISSUE
DCO APPLICATION

DEVELOPMENT CONSENT ORDER NUMBER
TR010065

PROJECT TITLE
A46 NEWARK BYPASS

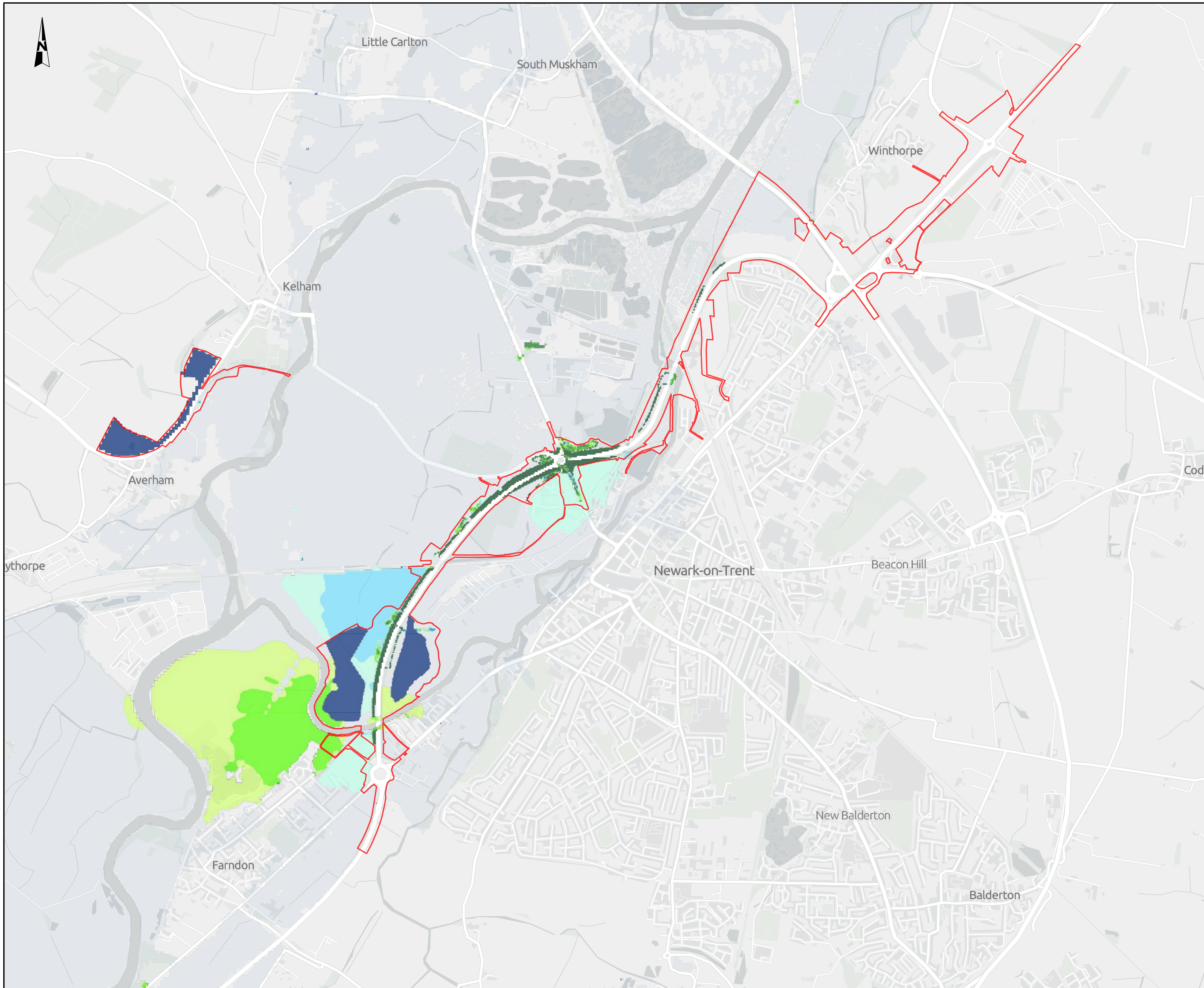
DRAWING TITLE
Appendix C.12
20%AEP Flood Depth Difference (scheme-baseline)

ORIGINAL SIZE A3 SCALE 1:25,000

DRAWING NUMBER
HE PIN | ORIGINATOR | VOLUME
HE551478 SKAG EWE
CONWI_CONW DR LE 00022
LOCATION | TYPE | ROLE | NUMBER

PROJECT REF NO. HE551478
REVISION C01

0 1,000 2,000 Metres



0 1,000 2,000 Metres

NOTES

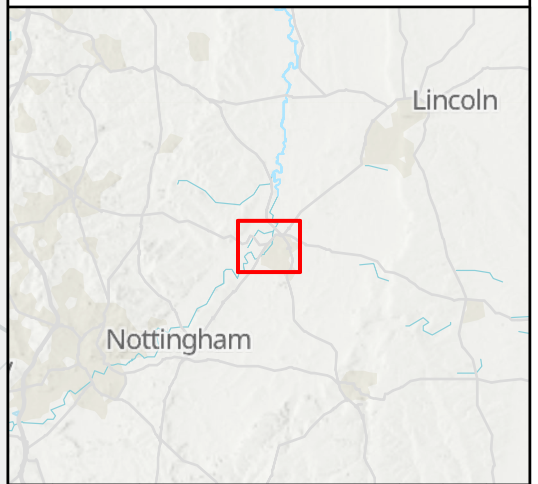
Service Layer Credits
Contains OS data © Crown Copyright and database right 2023
Contains data from OS Zoomstack

KEY TO SYMBOLS

Order Limits

Depth difference (m)

- ≤ -0.15
- -0.15 - -0.1
- -0.1 - -0.05
- -0.05 - -0.01
- -0.01 - -0.05
- -0.05 - 0.005
- 0.005 - 0.01
- 0.01 - 0.05
- 0.05 - 0.1
- 0.1 - 0.15
- >0.15



REV.	DATE	AMENDMENT DETAILS	ORIG	CHK'D	APP'D
C01	08/12/23	DCO APPLICATION	MH	OE	HF

CLIENT
national highways

PURPOSE OF ISSUE
DCO APPLICATION

DEVELOPMENT CONSENT ORDER NUMBER
TR010065

PROJECT TITLE
A46 NEWARK BYPASS

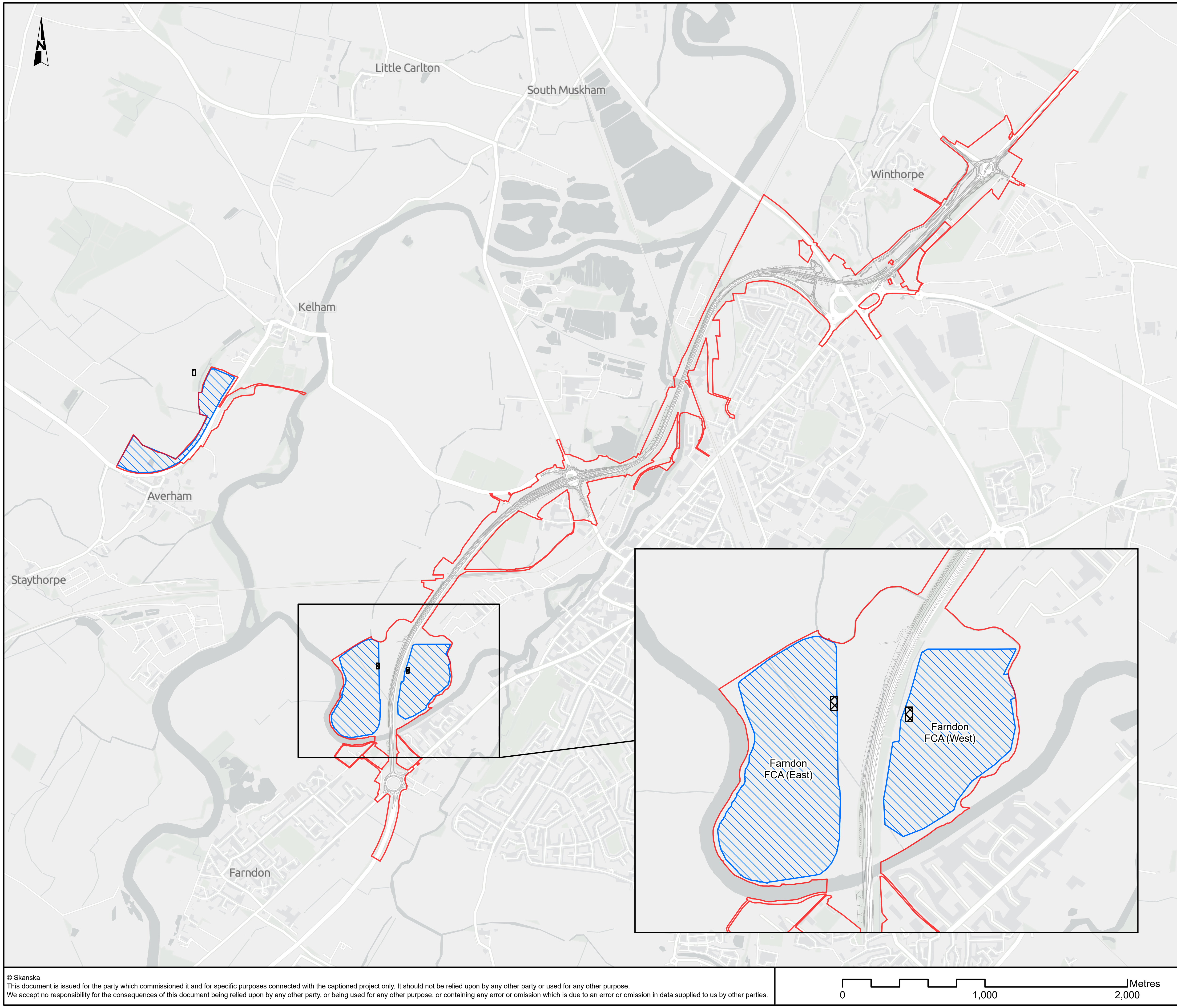
DRAWING TITLE
Appendix C.13
1%AEP+CC Flood Depth Difference (scheme-baseline)

ORIGINAL SIZE A3 SCALE 1:25,000

DRAWING NUMBER
HE PIN HE551478 | ORIGINATOR SKAG | VOLUME EWE
LOCATION CONWI_CONW | TYPE DR | ROLE LE | NUMBER 00023

PROJECT REF NO. HE551478

REVISION C01

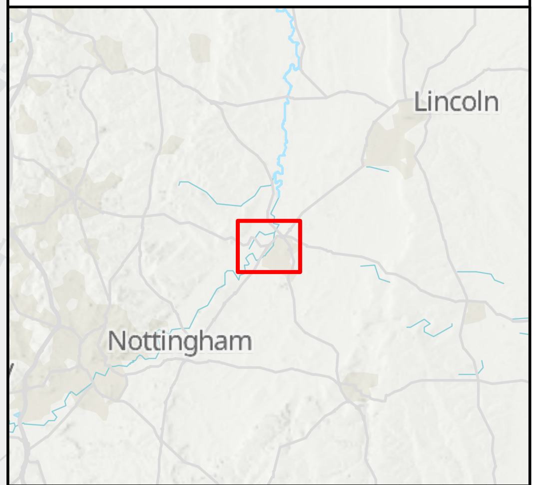


NOTES

Source
Flood Compensation Area Data modelled by Mott MacDonald, 2023.
Service Layer Credits
Contains OS data © Crown Copyright and database right 2023
Contains data from OS Zoomstack

KEY TO SYMBOLS

- Order Limits
- Floodplain Compensation Area (FCA)
- Scheme alignment
- Stockpile



REV.	DATE	AMENDMENT DETAILS	ORIG	CHK'D	APP'D
C01	08/12/23	DCO APPLICATION	MH	OE	HF

CLIENT
national highways

PURPOSE OF ISSUE
DCO APPLICATION

DEVELOPMENT CONSENT ORDER NUMBER
TR010065

PROJECT TITLE
A46 NEWARK BYPASS

DRAWING TITLE
Figure 2.5
Stockpile Locations at Farndon FCAs

ORIGINAL SIZE A3 SCALE 1:25,000

DRAWING NUMBER
HE PIN | ORIGINATOR | VOLUME
HE551478 SKAG EWE
CONWI_CONW DR LE 00024
LOCATION | TYPE | ROLE | NUMBER

PROJECT REF NO.
HE551478

REVISION
C01

D.A46 - Third-Party Volume Impact Assessment: HE551478-SKAG-HDG-CONWI_CONW-TN-CD-00005

Contents

1 Introduction

1.1 Overview

1.1.1 The A46 Newark Bypass Scheme (hereafter referred to as the 'Scheme') passes through the floodplain of the River Trent, a hydrologically active environment, with evidence of the floodplain being inundated at least once a year. Attenuation basins to accommodate surplus rainfall are proposed within the floodplain, as a means of preventing flooding. Details of these features are set out in Appendix 13.4 (Drainage Strategy Report) of the Environmental Statement Appendices **(TR010065/APP/6.3).**

1.1.2 This volume impact assessment has been developed to support both the Flood Risk Assessment and the Drainage Strategy, which form Appendices 13.2 and 13.4 of the Environmental Statement Appendices **(TR010065/APP/6.3**) respectively, for the application for Development Consent for the Scheme in accordance with the requirements of the National Policy Statement for National Networks (NPSNN) (Department for Transport, 2014) and the National Planning Policy Framework (Department for Levelling Up, Housing and Communities, 2023).

1.2 Purpose of the report

1.2.1 The purpose of this report is to demonstrate that a relaxation in the lead local flood authority's (LLFA) requirement for drainage attenuation of the 1 in 100 year event plus climate change allowance is appropriate due to the floodplain conditions adjacent to the Scheme. In this context, attenuation is the control of storm water runoff from the road to replicate the equivalent flow from a greenfield. The climate change allowance is an uplift on the estimated storm water flows from the Scheme's drainage system. This report has been prepared in consultation with the LLFA (Nottinghamshire County Council (NCC)) as discussed in paragraph 1.3.2.

1.3 Correspondence

1.3.1 Drainage and Flood Management Steering Group meetings have been held regularly (at least every two months) to ensure key stakeholders, including the Environment Agency (EA), NCC as the LLFA, the River Trent and Lindsey Marsh Internal Drainage Board (LMDB) and the Canals and Rivers Trust (CRT) are kept updated.

1.3.2 During the 6th steering group meeting, held on the 30 November 2022 (meeting minutes ref: HE551478-SKAG-HDG-CONWI_CONW-MI-CD-

00014, see Appendix A) in discussion between the lead local flood authority and the Applicant it was proposed to only attenuate surface water flows up to the 1 in 30 year storm event plus a climate change allowance (+ 40%). During the meeting, NCC agreed that such a principle could be explored, and any proposals would need to be qualified with a volume impact assessment (this report). Confirmation that this principle could be explored was provided in writing by NCC on the 22 March 2023 (see record of email in Appendix A).

1.3.3 On the 20 July 2023 during further detailed correspondence with the EA, it was proposed that the Farndon East borrow pit area would be utilised as attenuation to offset, by displacement, the exceedance volume for events above the 1 in 30-year storm (+ climate change) up to the 1 in 100 year (+ climate change %) which cannot be managed in the borrow pits or their landscaped area. This volume would approximately be 4,000 m^3 – 12,000 m^3.

1.3.4 This borrow pit wetland area would drain via the proposed de-culverted land drain, with flow control, across the A46 and into the Old Trent Dyke via an existing retained drain. All the above proposed is located within the DCO Order Limit.

1.4 Principles of approach

1.4.1 The alternative application in storage requirements has been proposed because a considerable part of the land surrounding the Scheme is located within Flood Zones 2 and 3 and has been designated as agricultural land. The reasons for allowing this change have been listed below:

- During a pluvial event above the 1 in 30 year pluvial storm event, exceedance would flow into the surrounding land. As the land is expected to flood regularly from fluvial events, it has only been utilised for agricultural purposes. It is therefore reasonable to allow the exceedance volume to flow into this land before draining into the receiving watercourse.
- If a storm event above the 1 in 30 year (+ climate change %) occurs at the same time as a fluvial flood event the additional volume would lead to a negligible increase in fluvial flood levels.
- Residential and commercial areas are located above and outside of the floodplain and existing flood defences are also in place.
- As the highway is raised on an embankment there is no risk of the highway being flooded during this event.
- Any additional volume discharged into the receiving watercourses would have a minimal impact downstream.

1.4.2 Current Design Manual for Roads and Bridges (DMRB) guidance requires all surface water run-off generated on the highway during a 1 in 100 year storm event (+ climate change %), to be attenuated before it is discharged. It is proposed that this is stepped down, and surface water attenuated for the 1 in 30 year storm event (+ climate change %), with the additional run-off generated during larger storm events managed within the surrounding floodplain.

1.4.3 A key difference between the pluvial and fluvial flood events is that pluvial events have a much smaller catchment area and volumetric flow rate and would therefore drain quicker than a fluvial event, which has a catchment area and volumetric flow rate several magnitudes larger.

1.5 Management of Exceedance Flows

1.5.1 In the event of a basin overtopping (for storm events above the 1 in 30 + climate change % for basins within the floodplain and above the 1 in 100 year event (+ climate change %) outside the floodplain, exceedance would either flow directly into the nearest watercourse or be controlled with the surrounding land before discharging to the receiving watercourse.

1.5.2 Where exceedance run-off is managed within the topography, the run-off would discharge via the land drain. Where exceedance flows to the nearest watercourse a spillway would be engineered into the bund to control the flow direction to the receiving watercourse. By dispersing the water over a large flow path and reducing the flow's energy we can mitigate rutting and potentially reduce its flow rate into the receiving watercourse.

1.5.3 Drawing reference: HE551478-SKAG-HDG-CONWI_CONW-DR-CD-00010 illustrates the flow routes exceedance flows would take when basins overtop. As this document assesses the overtopping of basins designed to store the 1 in 30 year storm event (+ climate change %) it also covers the management of exceedance flows for larger storm event's up to and including the 1 in 100 year storm events (+ climate change %).

2 The scheme

2.1 Scheme context

2.1.1 In March 2020, the Department for Transport's (DfT) Road Investment Strategy 2 included a commitment for National Highways to improve the A46 'Trans-Midlands Trade Corridor' between the M5 and the Humber Ports, to create a continuous dual carriageway from Lincoln to Warwick.

2.1.2 The A46 forms part of the strategic Trans-Midlands Trade Corridor between the M5 in the south-west and the Humber Ports in the northeast. The improvements to the A46 corridor are detailed within the DfT's Road Investment Strategy 2 as a mechanism for underpinning the wider economic transformation of the country. RIS2 makes a commitment to create a continuous dual carriageway from Lincoln to Warwick.

2.1.3 The stretch of A46 between the Farndon roundabout to the west of Newark-on-Trent, and the A1, to the east of Newark-on-Trent, is the last remaining stretch of single carriageway between the M1 and A1 and consequently queuing traffic is a regular occurrence, often impacting journey time reliability.

2.1.4 The preferred route announcement (PRA) for the Scheme was made in February 2022. The option presented at PRA has been developed to form the preliminary design of the Scheme. This preliminary design forms the application for DCO. The preliminary design determines the route, location, general layout, components etc. of the Scheme and is the basis on which the more detailed designs are progressed.

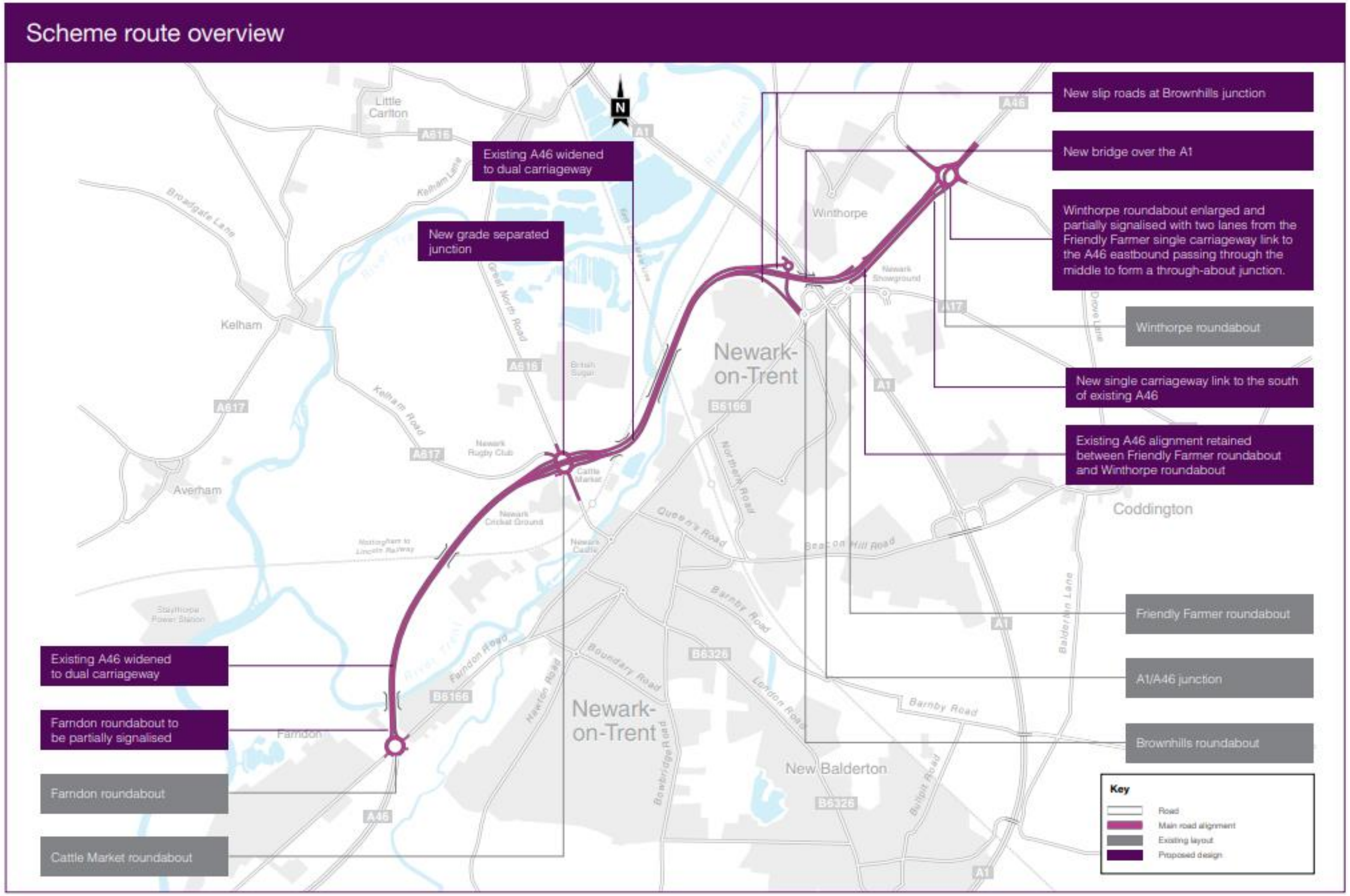
2.1.5 Further details on the need for the Scheme are contained within the Case for the Scheme **(TR010065/APP/7.1).**

2.2 Scheme location

2.2.1 The Scheme would provide a dual carriageway on the A46 between Farndon and Winthorpe in Nottinghamshire. The Farndon roundabout is located at the southern extent of the Scheme where the B6166 Farndon Road joins the A46.

2.2.2 The Winthorpe roundabout is located at the northern extent where the A1133 joins the A46. Along its route, it crosses the A617 and the B6326, at the Cattle Market junction, and the A1 between the Friendly Farmer and Brownhills roundabouts. Figure 1 below shows the location of the Scheme. Further details can also be found on the Location Plan **(TR010065/APP/2.1)** which shows the Scheme in its wider geographical context.

Figure 2-1: Scheme location



2.2.3 The Scheme would be situated within the county boundary of NCC and within the administrative boundary of Newark and Sherwood District Council.

2.2.4 The Scheme crosses the River Trent twice, the Nottingham to Lincoln railway line twice, and the East Coast Main Line once.

2.2.5 The existing A46, currently a single carriageway, is elevated on embankments due to the low-lying floodplain of the River Trent. This floodplain is located to the west of the A46 for the majority of the affected length, along with a section at the southern end on the eastern side of the A46. Several roundabouts form key junctions along the route, linking local A roads. Road infrastructure is softened by roadside vegetation in places and the River Trent is a strong natural influence within an otherwise built-up landscape. To the north of the A46, farmland dominates, interspersed with small-scale settlements. To the south of the A46, the town of Newark-on-Trent forms a notable urban settlement.

2.3 Scheme aims and objectives

2.3.1 Scheme-specific objectives have been used to develop the proposed Scheme design which are set out below:

Safety	Improving safety through Scheme design to reduce collisions for all users of the A46 Scheme.
Congestion	Improve journey time and journey time reliability along the A46 and its junctions between Farndon and Winthorpe, including all approaches and A1 slip roads.
Connectivity	Accommodate economic growth in Newark-on-Trent and the wider area by improving its strategic and local connectivity.
Environment	Deliver better environmental outcomes by achieving a net gain in biodiversity and improve noise levels at Noise Important Areas along the A46 between Farndon and Winthorpe roundabouts.
Customer	Build an inclusive Scheme which improves facilities for cyclists, walkers and other vulnerable users where existing routes are affected.

2.4 Scheme description

2.4.1 The section of the A46 that is to be upgraded is approximately 6.5 kilometres in length. The Scheme comprises on-line widening for the majority of its length between Farndon roundabout and the A1. A new section of offline dual carriageway is proposed between the western and eastern sides of the A1 before the new dual carriageway ties into the existing A46 to the west of Winthorpe roundabout. The widening works include earthwork widening along the existing embankments, and new structures where the route crosses the railway lines, River Trent, the A1 and local roads.

2.4.2 For information on the river and ordinary watercourse crossings please refer to Appendix 13.2 Flood Risk Assessment of the Environmental Statement **(TR010065/APP/6.3).**

2.4.3 The Scheme consists of the following principal elements:

- Widening of the existing A46 to a dual carriageway for a distance of 6.5 kilometres to provide two traffic lanes in both directions.
- Partial signalisation of Farndon roundabout at the southern extents of the Scheme.
- A new grade separated junction at Cattle Market junction with the A46 elevated to pass over the roundabout. A larger roundabout beneath the A46 to provide increased capacity.
- A new off-line section to bypass the existing Brownhills roundabout and Friendly Farmer roundabout.
- A new grade separated northbound exit slip to a new roundabout providing local access, with a two-way link road on the southern arm to connect with the existing Brownhills roundabout.
- A two-way parallel link road from Friendly Farmer to Winthorpe roundabout to the southern side of the existing dual carriageway.
- A new bridge structure across the existing A1, located to the north of the existing bridge.
- An upgraded roundabout with partial signal controls at Winthorpe roundabout.
- Improvements to walker, cyclist and horse-rider (WCH) facilities through safer, enhanced routes.
- Three areas have been identified for floodplain compensation which are being referred to as the Kelham and Averham floodplain compensation areas (FCA), Farndon West FCA and Farndon East FCA. In addition, the Farndon East and Farndon West FCA would also be used as a borrow pit to support the creation of embankments required for the Scheme.
- Drainage features including attenuation basins.
- Environmental mitigation including landscape planting.
- Associated accommodation works and maintenance access tracks.

2.4.4 Details of how the Scheme meets the objectives of the Scheme can be found in the Case for the Scheme **(TR010065/APP/7.1)**.

3 Assessment methodology

3.1 Overview

3.1.1 An assessment was required to demonstrate that the unattenuated exceedance run-off from extreme events, above the 1 in 30 year storm event (+ climate change %), would have a negligible material impact on nearby properties and land during the following events.

3.1.2 To fully account for the risk this may pose, the impact of the attenuation change was compared to both the 1 in 100 year pluvial storm event as well as combined pluvial and fluvial events. This would therefore account for the impact during a storm event as well as the rare occasion that a storm event occurs at the same time as the river flooding.

3.1.3 Pluvial flooding (also referred to as surface water flooding) occurs when the volume of rainfall exceeds the capacity of the drainage systems or the ground in which to absorb it. This excess water typically flows overland, ponding in natural or man-made low-lying areas.

3.1.4 Fluvial flooding (also referred to as watercourse flooding) occurs when the water level in a river, lake or stream rises and overflows onto the neighbouring land during times of excess rainfall.

3.2 Pluvial assessment

1 in 100 year pluvial event (only)

3.2.1 In this assessment the overtopped exceedance is assessed against the surrounding topography to determine overland flow routes. Spillways and flow routes are indicated on drawing ref HE551478-SKAG-HDG-CONWI_CONW-DR-CD-00010.

3.3 Pluvial - fluvial combined event assessment

Joint 1 in 100 year pluvial event and various fluvial flood event

- This includes the combined 1 in 100 year pluvial event and the following fluvial events;
  - 1 in 2 year fluvial flood event
  - 1 in 30 year fluvial flood event
  - 1 in 100 year fluvial flood event

3.3.1 All the above events make an allowance for climate change, 40% for storm events and 39% for fluvial events.

3.3.2 For these assessments a table of calculations has been provided demonstrating the affect the additional volume would have on flood event.

3.3.3 It should be noted that the probability of peak fluvial flood levels and a pluvial flood levels coinciding is extremely low. Therefore, this impact assessment considers an extreme event scenario.

4 Pluvial event assessment

4.1 Topographic review

4.1.1 The topography of the land surrounding the attenuation basins has been assessed and overland flow paths determined. A suitable spillway location has been set for each basin, shown in Appendix B. No land outside of the DCO Order Limit would be crossed to get to the watercourse.

4.1.2 Where the surrounding topography directs water back to the basin exceedance would flow into the land drain around the perimeter of the basin and to its respective receiving watercourse. No land outside of the DCO Order Limit would be crossed to get to the watercourse.

4.2 Overflow volume and flow rate calculations

4.2.1 An approximation of the exceedance volumes for each attenuation basin located within the floodplain would be calculated. This would be done using the most up-to-date drainage schematics and catchment areas.

4.2.2 The total discharge volumes for the 1 in 100 year event (+CC%) would be subtracted from the 1 in 30 year event (+CC%) to provide the unattenuated volume of run-off that would overtop the basin and flow to the receiving watercourse via an overland flow-path that would stay within the boundary limits.

4.2.3 The volume run-off calculator from the Micro Drainage Source Control module was used to determine the storage volume which have been included in table 1 below.

Table 1: Storage volumed calculated on Micro Drainage

Basin	Area (sqm)	Area (ha)	QBAR	Q30 (+40%)	Q100 (+40%)	Exceedance Volume (cubic m)	Outflow Rate (l/s)
1	15311.00	1.53	4.29	1184	1932	748	35.5
2	9880.00	0.99	2.77	765	1250	485	36
3	16200.00	1.62	4.54	1238	2021	783	38.3
4	8050.00	0.81	2.25	621	1013	392	21
5	5975.00	0.60	1.67	464	757	293	16

6	14925.00	1.49	4.18	1162	1895	733	36.8
7	15500.00	1.55	4.34	1202	1960	758	37.3
8	30100.00	3.01	8.43	2323	3791	1468	65
9	5303.00	0.53	1.48	410	669	259	14.5

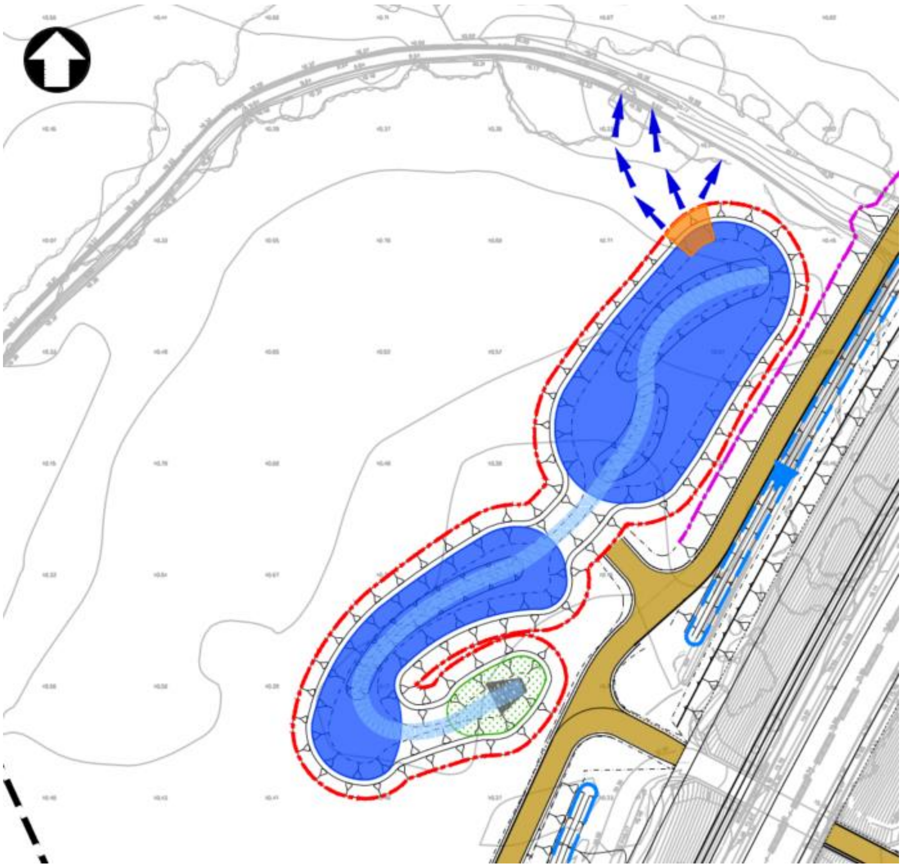
4.3 Flow paths and informal storage areas

4.3.1 When a basin overtops, the controlled exceedance would flow via an erosion-protected flow path, engineered to flow naturally via the existing topography into the closest part of the receiving watercourse.

4.3.2 Overland flow paths for each basin within the floodplain have been provided on drawings in Appendix B of this document HE551478-SKAG-HDG-CONWI_CONW-DR-CD-00010 and HE551478-SKAG-HDG-CONWI_CONW-DR-CD-00020.

4.3.3 These plans include exceedance management routes for the basins outside the floodplain in the event of basins overtopping due consecutive storm events or failure due to lack of maintenance. The drawing has been included in Appendix B for review.

Figure 4-1: Example overland flow plan showing spillway in orange and flow path in blue



5 Combined pluvial - fluvial event assessment

5.1 Reviewing impact on flood levels for combined events

5.1.1 The calculated unattenuated discharge volumes are added to their respective flood zones to determine a worst-case level increase.

5.1.2 The flood zone boundaries are then reviewed wherever the flood zone extends over or near third-party land.

5.2 Topographic review

5.2.1 Physical barriers such as the railways and the A46 itself impact flood levels and the flow of water. For the combined assessment the floodplain would be divided into zones based on the physical barriers as well as flow structures present across the Scheme within the floodplain.

5.2.2 The Scheme has been divided into the below sections based on the physical barriers, which affect the floodplain, such as the railways. Figure 3-1 presents the flood zones as well as approximate flood levels.

Figure 5-1: Flood Zones and respective 1 in 100 year modelled flood levels

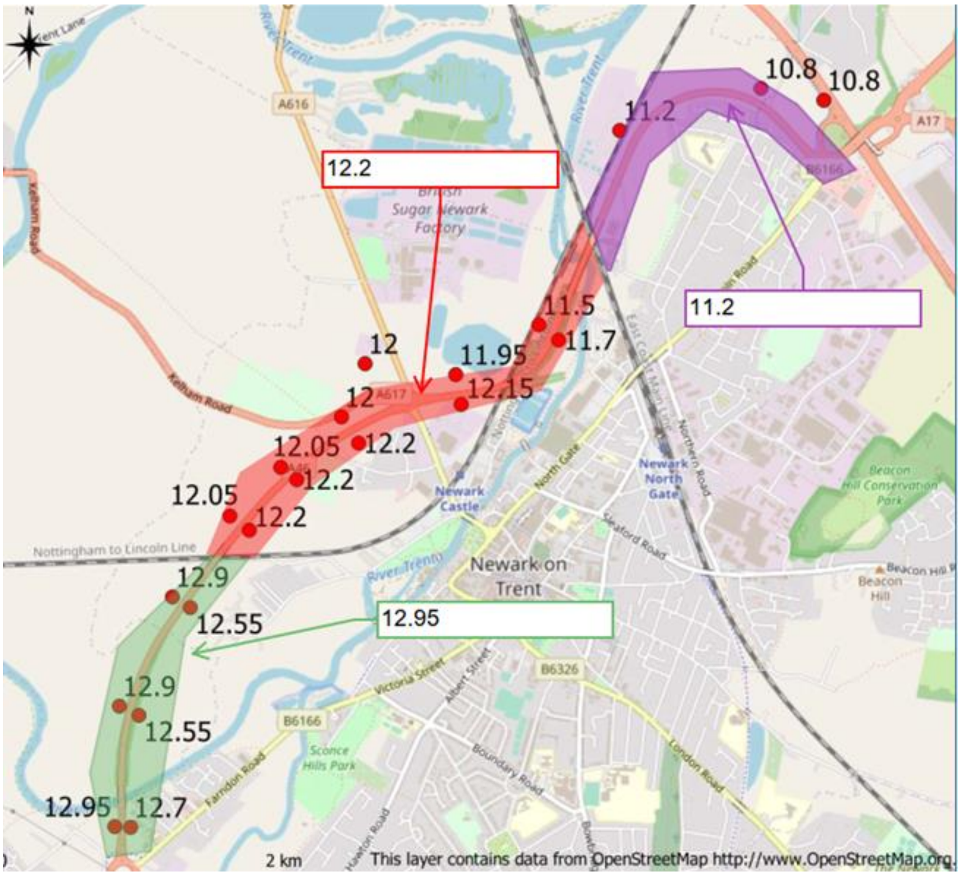


Figure 5-2: Green flood zone

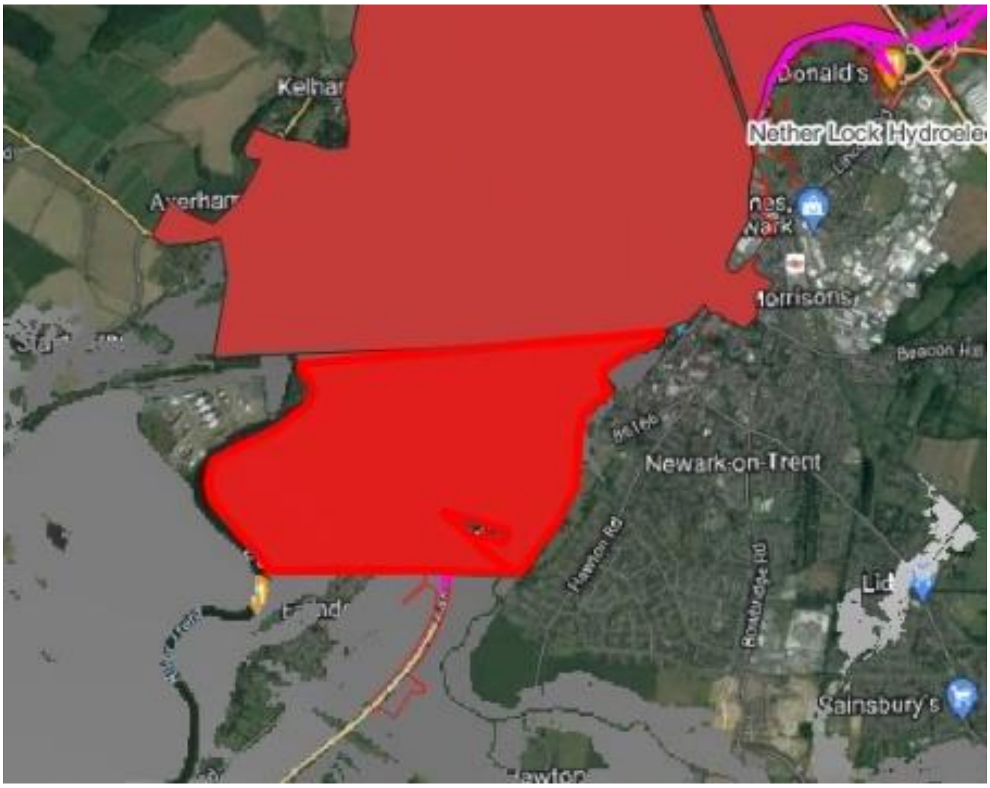


Figure 5-3: Red flood zone

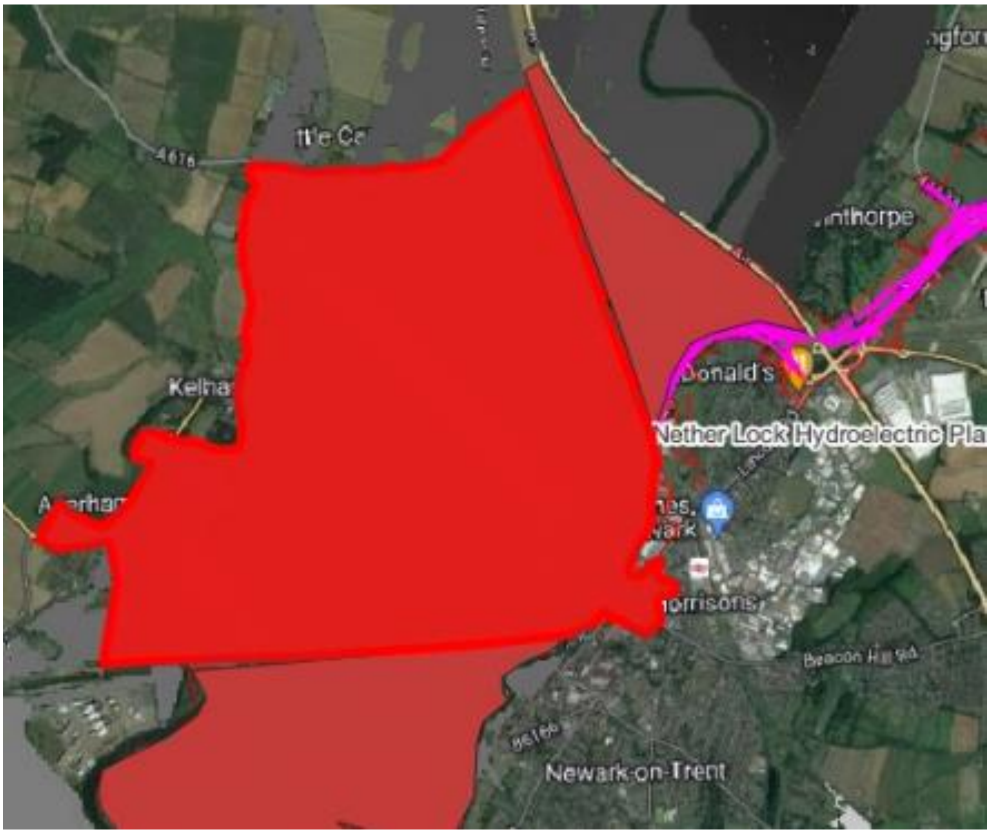


Figure 5-4: Purple flood zone

5.3 Combined event volume calculations

5.3.1 The following table outlines the calculations made for the impact assessment and the resulting impact on fluvial flood levels for the 1 in 100 year storm event. Table 2 below has been colour coded to match the indicated flood zones in Figure 1.

Table 2: Impact assessment calculations

Basin	Total Volume - 1 in 100 year (+40% CC) (m3)	Total Volume - 1 in 30 year (+20% CC) (m3)	Unattenuated Volume (m3)	Total Volume in Zone (m3)	Safety Factor +20% (m3)	Available Floodplain Area (m2)	Additional Flood Depth(m)	Existing Flood Levels (m)	Impacted Flood Levels (m)
1	4447	3033	1414						
2	2546	1734	812						
3	1627	1112	515	2741	3290	3169079	0.001	12.90	12.90
4	1258	860	399						
5	1548	1058	490						
6	3529	2414	1114						
7	3436	2351	1085						
8	7393	5061	2332						
9	1835	1254	581	6001	7201	9251390	0.001	12.20	12.20
11	2685	1835	850						
12	5584	3821	1763	2613	2115	1191819	0.002	11.20	11.20

6 Conclusion

6.1 Mitigation

6.1.1 It has been proposed that the Farndon East borrow pit area would be utilised as attenuation in pluvial only events to offset the exceedance volume for events above the 1 in 30 year storm (+ 40% climate change allowance) up to the 1 in 100 year (+ 40% climate change allowance) which cannot be managed in the wetland basins or the landscaped area.

6.1.2 This area would outfall via a flow control device limited to the 1 in 100 year discharge rate into a de-culverted land drain which would flow north-west through the A46 into the Old Trent Dyke. This volume displacement would counteract the additional volume discharged.

6.1.3 Additionally, further displacement has been included in design to ensure that all attenuation basins would discharge at QBAR (mean annual flood) greenfield run-off rates rather than like-for-like greenfield run-off rates. Storm events above the QBAR event (including the 1 in 30 and 1 in 100 year events) would therefore discharge at a rate that is much lower than natural greenfield run-off rates for the equivalent event.

6.1.4 The results of the impact assessments have been discussed below using the same colour zones from Figures 5-2 to 5-4 and Table 2.

6.2 Pluvial event assessment

6.2.1 The pluvial event assessment found that, with the provision of a spillway and an overland flow path there is an extremely low risk to both residential and commercial areas if only up to the 1 in 30 year storm event (+ 40% climate change allowance) is attenuated. Appendix B provides evidence of exceedance routes for attenuation basins within the floodplain.

6.2.2 The exceedance volume from storm events above the 1 in 30 year storm event (+ 40% climate change allowance) would be offset by the provision of additional storage within the Farndon East borrow pit area. This volume would be available for use when the river is not in flood i.e. no fluvial flooding.

6.3 Combined fluvial and pluvial event assessment

Green zone

6.3.1 Critical areas within the green flood zone (as shown in figure 5-2) include the Tolney Lane Road residential area. As the area is already within flood zone 3 and partially within flood zone 2, based on the topography of the area the indicated 1 millimetre increase in flood levels would have a negligible impact on the existing flood risk. There would also be minimal impact on properties at Mill Gate Road in comparison to the existing flood risk.

6.3.2 Based on this, the change of attenuation requirements from the 1 in 100 year (+ 40% climate change allowance) to the 1 in 30 year (+ 40% climate change allowance) would have no material impact within the green zone (as shown in figure 5-2).

Red zone

6.3.3 Within the red areas (as shown in figure 5-3) the flood plain extends up to North Gate Road. As the resulting flood level increase is only 1 millimetre there would be a negligible increase in flood levels.

6.3.4 Based on this, the change of attenuation requirements from the 1 in 100 year (+ 40 climate change allowance) to the 1 in 30 year (+ 40 climate change allowance) would have no material impact within the green zone (as shown in figure 5-2).

Purple zone

6.3.5 The topography within the area around Basins 11 and 12 indicates an increase in flood plain levels of 2 millimetres. This increase shall be negligible over the existing flood risk in this area.

6.3.6 Based on this, the change of attenuation requirements from the 1 in 100 year (+ 40% climate change allowance) to the 1 in 30 year (+ 40% climate change allowance) would have no material impact within the purple zone (as shown in figure 5-4).

6.4 Pollution dilution

6.4.1 Surface water run-off generated on the highway’s surface would be conveyed to the conveyance swales, which will treat the run-off and remove pollutants. In the event of a fluvial flood event that inundated the swales in the floodplain, pollutants within the highway run-off water would be diluted to acceptable levels within the flood water. See the Highways England Water Risk Assessment Tool (HEWRAT) at Appendix 13.3 of the Environmental Statement **(TR010065/APP/6.3).**

A. Record of meetings

[redacted] water attenuation

Importance: High

Hi [redacted]

It was good speaking with you earlier today to gain further reassurance on the proposals for surface water attenuation. In the absence of Harvey, Sarah in the flood risk team has now provided an updated response which will supersede the previous response issued further down the email chain.

The Environment Agency (EA) had raised concerns that surface water exceedance flow routing and volumes had not been presented or assessed for comment as part of the consultation process. Whilst Nottinghamshire County Council as the Lead Local Flood Authority are responsible for managing and regulating surface water flood risk, the EA has a strategic overview of all forms of flood risk. The EA recognises that the proposed scheme is located in an area of complex flood risk and that the timings and mechanisms of flooding vary depending on the source.

The applicant has now proposed an expanded surface water attenuation scheme which attenuates surface water flows from the proposed A46 road scheme up to the 1 in 100 year + climate change storm event, as requested. This is achieved through a system of attenuation basins using borrow pits which will be excavated as part of the road scheme. We have been assured that the borrow pits will have the required capacity to attenuate the full amount of surface water (rainfall) generated in a 1 in 100 year + climate change storm event. The exact plans of how these borrow pit attenuation basins will be hydrologically linked and designed will be drawn up at a later stage as the project progresses.

The surface water stored in the borrow pits will drain through an existing drainage channel which passes under the A46 into the Old Trent Dyke to the North East. This drainage channel will have a new headwall installed and a flow control device fitted. We are assured that overall the surface water drainage scheme will attenuate all the additional surface water generated by the road scheme (up to the 1 in 100 year + climate change storm event) and will not discharge additional flows into the drainage channel or surrounding land owned by third parties. We are therefore reassured that the finished scheme will not increase flood risk elsewhere and will therefore be compliant with the NPPF allaying our previous concerns. Please continue to consult the Environment Agency on the plans for the design and operation of the surface water attenuation scheme so we can ensure that it will fulfil these objectives.

I hope this is sufficient in allowing you to submit by the noon deadline however should you require any further discussion please feel free to contact me.

If you are satisfied with the above response please could you confirm by way of reply to this email.

Many thanks

[redacted]t
Sustainable Places Team
East Midlands Area

[redacted]
Environment Agency, Trentside Offices, Scarrington Road, West Bridgford, Nottingham NG2 5FA
[redacted]

[redacted]

From [redacted]
Sent: 13 July 2023 16:52
[redacted]
Subject: A46 progress Environment Agency

[redacted]

Hello - In response to your latest email and to prepare for the meeting on Monday, we have made the adjustments to the Drainage Strategy as below.

To satisfy the ***- National Planning Policy Framework requirement to not increase flood risk elsewhere during the surface water DFE by Consider whether the Borrow Pits site can be incorporated in the overall flood risk strategy to offer attenuation or flood compensation.***
Would do so by attenuating the volume of exceedance in the Farndon east borrow pit area.

The proposed amendment -
Drainage Strategy Section 4 - Application of storage requirements and third-party impact assessment

1. It has been proposed that the Farndon east borrow pit area, would be utilised as attenuation to offset the exceedance volume for events above the 1 in 30 year storm (+CC) up to the 1 in 100 year (+CC) which can't be managed in the wetland basins or the landscaped area.
2. This area would outfall via a flow control device limited to the 1 in 100 year discharge rate into a deculverted land drain which will flow north-west through the A46 into the Old Trent Dyke. This volume displacement should counteract the additional volume discharged.
3. Additionally further displacement has been included in that all attenuation basins will discharge at QBAR greenfield run-off rates rather than like-for-like greenfield run-off rates. Storm events above the QBAR event (includes the 1 in 30 and 1 in 100 year events) will therefore be discharging at a rate much lower than natural greenfield run-off rates for the equivalent event.

[redacted]

From: [redacted]
Sent: 12 July 2023 22:37
[redacted]
Subject: RE: A46 progress Environment Agency

Hi [redacted]

Having spoken with Harvey before he went on annual leave he issued me with the below updated response which I hope helps.

The Environment Agency (EA) raised concerns that surface water exceedance flow routing and volumes had not been presented or assessed for comment as part of the consultation process. Whilst Nottinghamshire County Council as the Lead Local Flood Authority are responsible for managing and regulating surface water flood risk, the EA has a strategic overview of all forms of flood risk. The EA recognises that the proposed scheme is located in an area of complex flood risk and that the timings and mechanisms of flooding vary depending on the source.

The proposals include designing surface water attenuation basins to contain up the 1 in 30 year (plus 40% climate change allowance (CC)) event. The design flood event (DFE) detailed within planning practice guidance (PPG) is the 1 in 100 year (plus 40% CC), meaning the proposals are not compliant with PPG. It is essential that the consequences of failing to comply with PPG are fully understood.

The design team have now produced a Volume Impact Assessment including plans indicating the route which exceedance surface water flows will take during the 1 in 100 year (plus 40% CC). Surface water will overtop the attenuation ponds via a formalised weir and flow into the surrounding landscape. It is interpreted that this exceedance flow will leave the proposed order limits and enter third party land during the surface water DFE as defined by PPG. In the event of a widespread surface water DFE occurring, covering the entire order limits, a total volume of 5,919m3 will flow onto the surrounding landscape, being greater than 2 Olympic sized swimming pools of surface water.

Whilst the plans are welcomed, the detail that is presented acts to strengthen the EA's concerns over the proposed surface water drainage strategy.

Is it acknowledged that most of the land impacted falls within Flood Zone 3, but this is associated with fluvial flood risk from the locally dominant River Trent. The proposals may have the effect of increasing the complexity of flooding to the adjacent land by increasing its risk of surface water flooding.

The EA strongly disagrees with the surface water design assumption that during a surface water DFE at this particular location, the River Trent will be in flood. The River Trent at Newark has a large catchment and there is a typical warning time of multiple days. Surface water flood risk is flashier and can occur with little warning.

It is recommended that the applicant consider further:

The off-site impacts from the surface water exceedance flows. Whilst we have been provided flow routes, they are local to the attenuation ponds areas. Where does the water ultimately end up? Some appear to flow into the Old Trent Dyke or directly into the River Trent, but others just onto land.

Consider seeking permission from 3rd party landowners (if relevant), to increase their risk of surface water flooding.

Consider whether the Borrow Pits site can be incorporated in the overall flood risk strategy to offer attenuation or flood compensation.

In summary, the plans demonstrate that the proposals fail to comply with National Planning Policy Framework requirement to not increase flood risk elsewhere during the surface water DFE. The scheme will result in more surface water entering the Old Trent Dyke and River Trent during the DFE. Whilst it is unlikely that the proposals will result in a change of flood hazard to any vulnerable receptor, the EA are concerned by the cumulative effect of such development proposals.

I hope this helps. I am happy to discuss this further if required however if I do need input from Harvey I am afraid he is now on annual leave until the 1st August 2023.

Many thanks

[redacted]

Environment Agency, Trentside Offices, Scarrington Road, West Bridgford, Nottingham NG2 5FA
[redacted]

[redacted]

[redacted]
Subject: A46 progress Environment Agency

[redacted]

Thankyou – Harvey called yesterday which was very helpful for us, we discussed in some detail , some of the issues regarding the complexities of the scheme and how the A46: Kelham & Averham Floodplain Compensation Area Technical Note marries with the Drainage Strategy and how to utilize the Borrow Pits site.

I explained that the Barrow Pits site and the additional potential of attenuating a proportion of the existing catchment of the A46 was / has been considered as a potential use for these site, this may be worth being a key focus for the meeting

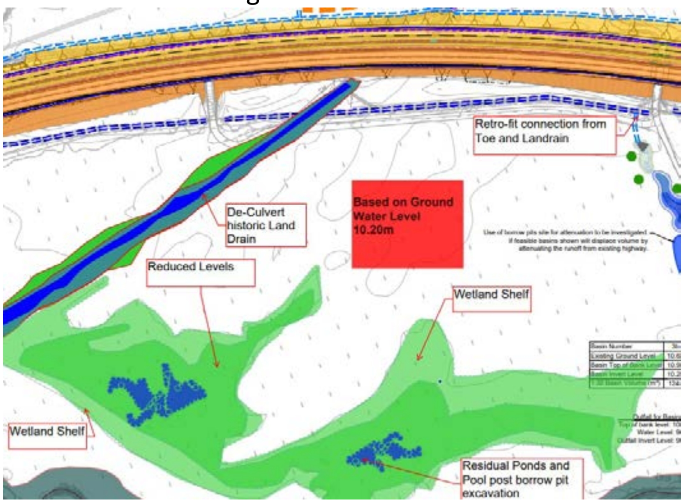


Figure 1 - Concept

17th July 2023 at 11am would suit, yes please.

[redacted]
Civil Infrastructure Engineer

From: [redacted]
Sent: 12 July 2023 07:34

[redacted]

From: [redacted]
Sent: 05 July 2023 12:34
[redacted]
Subject: A46 progress

Hello all,

Apologies for the blanket email but I am trying to establish which elements of the project you are now waiting for a response on from us. I think it might be useful to have a quick Teams meeting with just me from the EA so I can establish progress and deadlines.

I propose covering the following;

- Volume Impact Assessment – [redacted] has stated he believes he has now responded to everything for this but I need to check this.

- Drainage Basis of Design – is there any other information required (flood risk, biodiversity, fisheries and groundwater)?
- Fish protection and biodiversity for pre and during development – is any more information required?

Other points to cover

- Disapplication of permit requirements
- Statement of common ground

Do you think a quick meeting would be useful? If so could you suggest a date and time we can organise this or would you like me to suggest a time this week that we can dial in?

Many thanks

[redacted]

Environment Agency, Trentside Offices, Scarrington Road, West Bridgford, Nottingham NG2 5FA
[redacted]

[redacted]

Information in this message may be confidential and may be legally privileged. If you have received this message by mistake, please notify the sender immediately, delete it and do not copy it to anyone else. We have checked this email and its attachments for viruses. But you should still check any attachment before opening it. We may have to make this message and any reply to it public if asked to under the Freedom of Information Act, Data Protection Act or for litigation. Email messages and attachments sent to or from any Environment Agency address may also be accessed by someone other than the sender or recipient, for business purposes.
Information in this message may be confidential and may be legally privileged. If you have received this message by mistake, please notify the sender immediately, delete it and do not copy it to anyone else. We have checked this email and its attachments for viruses. But you should still check any attachment before opening it. We may have to make this message and any reply to it public if asked to under the Freedom of Information Act, Data Protection Act or for litigation. Email messages and attachments sent to or from any Environment Agency address may also be accessed by someone other than the sender or recipient, for business purposes.
Information in this message may be confidential and may be legally privileged. If you have received this message by mistake, please notify the sender immediately, delete it and do not copy it to anyone else. We have checked this email and its attachments for viruses. But you should still check any attachment before opening it. We may have to make this message and any reply to it public if asked to under the Freedom of Information Act, Data Protection Act or for litigation. Email messages and attachments sent to or from any Environment Agency address may also be accessed by someone other than the sender or recipient, for business purposes.

[redacted]

Sent: 03 April 2023 12:20
To: [redacted]
Subject: RE: A46 - Drainage Strategy and Volume Impact Assessment

Caution: This is an external email and has a suspicious subject or content. Please take care when clicking links or opening attachments. When in doubt, contact your IT Department

Hi [redacted]

Below sets out our standard surface water drainage conditions. Hope these help

- Demonstrate that the development will use SuDS throughout the site as a primary means of surface water management and that design is in accordance with CIRIA C753 and NPPF Paragraph 169.
- Limit the discharge generated by all rainfall events up to the 100 year plus 40% (climate change) critical rain storm to QBar rates for the developable area.
- Provide detailed design (plans, network details, calculations and supporting summary documentation) in support of any surface water drainage scheme, including details on any attenuation system, the outfall arrangements and any private drainage assets.

  Calculations should demonstrate the performance of the designed system for a range of return periods and storm durations inclusive of the 1 in 1 year, 1 in 30 year and 1 in 100 year plus climate change return periods.

  - No surcharge shown in a 1 in 1 year.
  - No flooding shown in a 1 in 30 year.
  - For all exceedance to be contained within the site boundary without flooding properties in a 100 year plus 40% storm.
- Evidence to demonstrate the viability (e.g Condition, Capacity and positive onward connection) of any receiving watercourse to accept and convey all surface water from the site.
- Details of STW approval for connections to existing network and any adoption of site drainage infrastructure.
- Evidence of approval for drainage infrastructure crossing third party land where applicable.
- Provide a surface water management plan demonstrating how surface water flows will be managed during construction to ensure no increase in flood risk off site.

Evidence of how the on-site surface water drainage systems shall be maintained and managed after completion and for the lifetime of the development to ensure long term effectiveness.

regards

[redacted]ood Risk Management
Place Department - Nottinghamshire County Council

County Hall, West Bridgford, Nottingham NG2 7QP
[redacted]

[redacted] | flood.team@nottscc.gov.uk | www.nottinghamshire.gov.uk

Flood Risk Management Team, Nottinghamshire County Council,
County Hall, Loughborough Road, West Bridgford, Nottingham, NG2 7QP

Nottinghamshire
County Council

From: [redacted]
Sent: 03 April 2023 12:07
To: [redacted]
Subject: RE: A46 - Drainage Strategy and Volume Impact Assessment

Hi [redacted]

As discussed over the phone please can you send over a copy of NCC's standard planning requirements,

Kind Regards,

[redacted]

From [redacted]
Sent: 22 March 2023 12:37
[redacted]
Subject: RE: A46 - Drainage Strategy and Volume Impact Assessment

> **Caution:** This is an external email and has a suspicious subject or content. Please take care when clicking links or opening attachments. When in doubt, contact your IT Department

Hi [redacted]

Thanks for that info, I'm happy to confirm that we would consider a relaxing of the 100yr attenuation subject to the proposals having no significant detrimental impacts on the surrounding areas.

Best regards

[redacted]
Principal Officer – Flood Risk Management
Place Department - Nottinghamshire County Council
County Hall, West Bridgford, Nottingham NG2 7QP
0115 9774473

[redacted] | flood.team@nottscc.gov.uk | www.nottinghamshire.gov.uk

Flood Risk Management Team, Nottinghamshire County Council,
County Hall, Loughborough Road, West Bridgford, Nottingham, NG2 7QP

Nottinghamshire County Council

[redacted]

To: [redacted]

Subject: A46 - Drainage Strategy and Volume Impact Assessment

Hi [redacted]

Please see linked below our latest revisions of the A46 schemes drainage strategy drawings which we are issuing ahead of the formal issue, for information/consultation, we will reissue formally in the following days,

[redacted]

The latest update includes additional schematics for the capture system (gullies, kerb drains) as well as a general detailed pass on the design,

We have discussed the principle of relaxing the 1 in 100 year attenuation requirements for the strategy previously but have nothing in writing to confirm this. Please can you confirm the acceptability of the principle, stated below, so we can begin work on the impact assessment,

Notthinghamshire County Council are willing to consider the relaxation of the 1 in 100 year attenuation requirement down to the 1 in 30 year (+CC) on the condition that an impact assessment is carried out and it is proven that no third-party properties or land are seriously impacted by the relaxation.

Kind Regards,

[redacted]
Flood Risk Management Engineer
[redacted]

M M
MOTT MACDONALD

[redacted]

Website | Twitter | LinkedIn | Facebook | Instagram | YouTube

[redacted]

Record of meeting

Project title	A46 Newark Bypass

Subject	A46 Newark Bypass – Drainage and Flood Management Steering Group meeting #6
Location	TEAMS
Date/time of meeting	30/11/2022, 10:00
Project number	100103345
Attendees	[redacted]
Apologies	
Recorded by	
Distribution	Internal

Item	Discussed	Action
1 *Introductions, H&S*	OE Introductions and agenda	
2. Public Engagement	[redacted] present the consultation so far and [redacted] urages everyone to participate with feedback.	
3. Future developments	[redacted] Introduction to all existing schemes near the [redacted]6 bypass.	
3.1 Tolney lane scheme	[redacted] he modelling done for the scheme is 10yrs old. It is a catchment level model. It was refined for	[redacted] Share project brief and potential

[redacted]

Item	Discussed	Action
	the location but the modelling being done for A46 bypass could be used to support this scheme.	locations for flood compensation with MM
	[redacted] The model used for this scheme was not QA'ed [redacted] EA would like the A46 bypass model to be used to assess the Tolney Lane scheme options.	
	[redacted] otes A46 bypass model methodology has [redacted] een shared with the EA already.	
	[redacted] highlights the benefits for all parties by [redacted] ning the objectives of the two schemes.	
	[redacted] Council will have their own programme. When [redacted] plan moves forward, we can look at how long it will take for the Tolney lane to be delivered. It needs to be delivered as soon as possible (funding and impacts being assessed) but it is a priority of the council. A 2-5yrs timeline was suggested.	
	[redacted] orking towards delivering the Tolney lane scheme in the next 3 yrs. There is some scope to shorten this programme.	
3.2 Newark Southern Link Road (SLR) scheme	[redacted] dertook an assessment of the SLR report at this stage. SLR scheme elements are located primarily within functional floodplain of River Devon and include 3x roundabouts, two bridges (River Devon bridge and a flood alleviation bridge) and a replacement culvert structure on the Mill Burn necessitated by the raising of Hawton Road). The bridge located over the River Devon has an effective span of 100m and reported to have been designed to have a minimum 600mm freeboard under the modelled 1% AEP plus (20%) climate change allowance event. Other scheme elements include seven compensation areas and additional mitigation (River Devon channel widening, etc). In terms of cumulative impacts of the SLR scheme and the A46 bypass, it is not considered there would be an adverse material impact to flood risk. Proposed works associated with the Newark Bypass are minimal in the River Devon floodplain and are primarily within the functional floodplain of the River Trent. The SLR modelling results suggest there is a surplus of storage within the Devon floodplain locally when compared to baseline. While the SLR modelling results did show increased water levels >30mm at ten properties, given the overland distance and local topography it is not considered likely that works associated with the Newark Bypass scheme would further impact upon water levels in this area. We will assess in detail over the course of the hydraulic modelling for the scheme but currently	

[redacted]

Item	Discussed	Action
	[redacted] do not expect the SLR scheme to have a material impact to the A46 scheme	
	[redacted] points out the ground levels near SLR are above the Newark bypass levels and thus based on ground levels alone it is unlikely to directly impact on the A46 scheme.	
	[redacted] advised no major comments or concerns at this stage.	
	[redacted] brief technical note which summarises our assessment is being prepared and will be shared for [redacted] to formally review and advise.	[redacted] Share with [redacted] a short technical note to explain why the SLR model will not be incorporated in the A46 bypass model
4. Survey update	[redacted] More detail required and topographic survey starting on site next week. MW confirms surveyors are starting on site next week.	
5. Hydraulic modelling update	[redacted] provides hydraulic modelling progress so far.	
	[redacted] interim model being used just as a tool to give us a feel of flood levels to help generate draft results. This will inform design as it matures. The model is running with the scheme with the compensation areas. Results will be available shortly. Once certainty on quality is obtained, results will be shared.	
6. Floodplain Comp, Update	[redacted] we are hoping to reduce the size of compensation needed in the burrow pit site. At Kelham we are negotiating with landowners potential locations. The connectivity with the River Trent includes widening of the channel, which could act as flood compensation as well, which we are assessing. The new proposed embankment for the road will consume some low lawing ground levels, and we are hoping to compensate this too. Once we have modelling results, we will know what hydraulic connectivity is possible and we will assess if the proposed areas will be able to compensate adequately. [redacted] urther screening analysis is required and 3 areas are the most favourable, i.e., will achieve more direct compensation. Where possible, we aim to provide direct compensation. [redacted] or reference 17 or 18 sites were assessed ally as potential FCAs for the scheme.	
7. Water quality monitoring strategy	[redacted] Comparison point for the monitoring before and during construction. 12 points around the area were selected during a site visit. The type of monitoring will be in situ (temperature, visual inspection, sending samples to laboratory for analysis).	

[redacted]

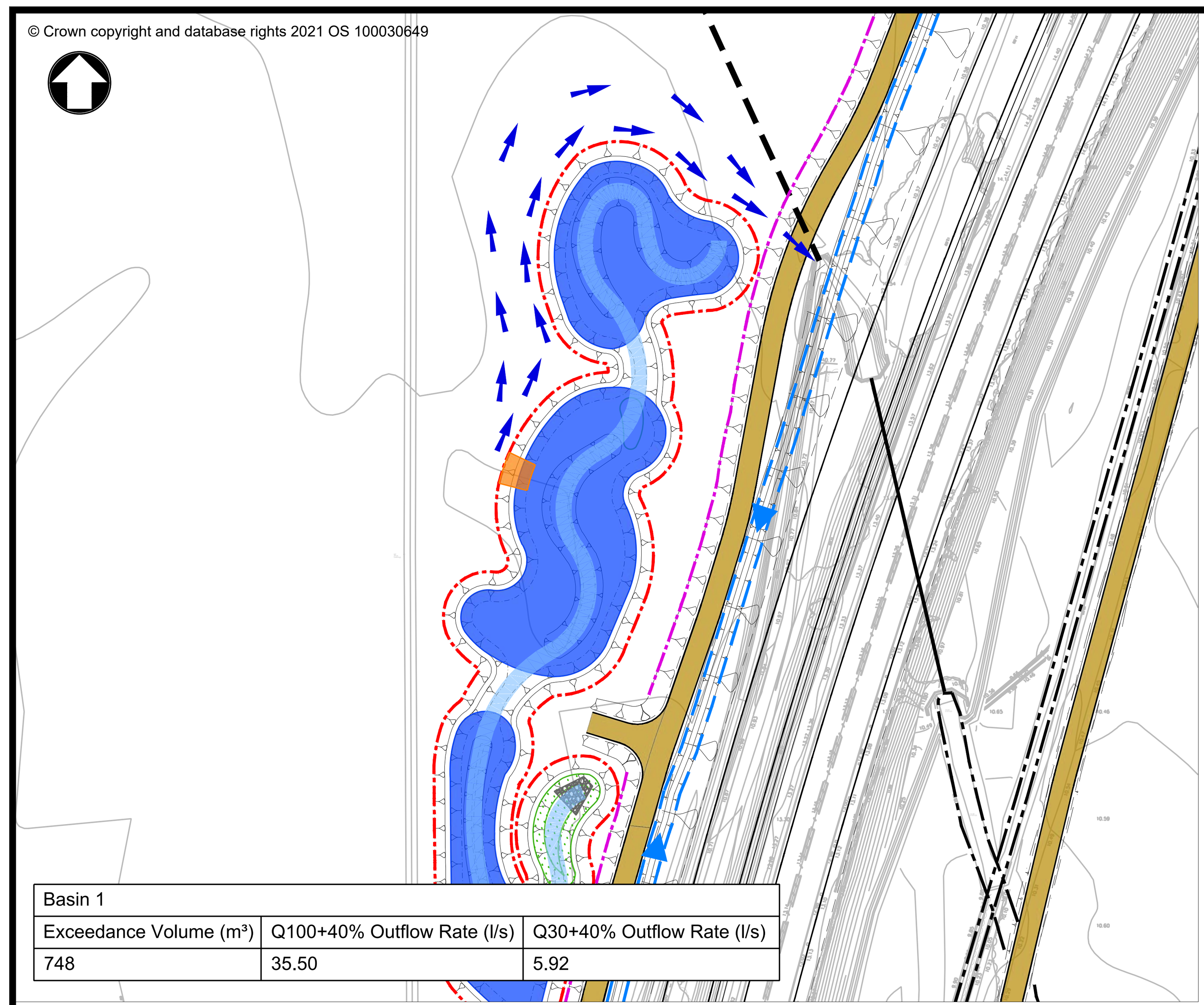
Item	Discussed	Action
	The outcomes will inform the drainage design. Two Local Natures Reserves (Farndon Ponds LNR and Devon Pastures LNR) were scoped out of the environmental assessment, as follows: - Farndon Ponds LNR is located approximately 1.51 upstream of the closest point of the proposed scheme, therefore the proposed scheme is not considered to have a suitable pathway to the LNR and can be scoped out. - Devon Pasture LNR is located on the River Devon, and is downstream of the proposed scheme, but upstream of the confluence between the River Devon and River Trent. Therefore, the LNR is considered to be at a suitable distance for any contaminants to have dispersed and there not to be a credible pathway (contaminants are not anticipated to travel upstream between the confluence of the two rivers, and the site location). As such, Devon Pasture LNR can also be scoped out.	[redacted]o share sketches of locations of LNR to enable to EA to confirm agreement with the approach.
	[redacted] ould like to take a look at the water quality monitoring strategy in more detail.	[redacted] to provide proposed strategy report
8. Drainage update - Attenuation basins	[redacted] Presents a proposed attenuation basin which is the floodplain. Part of the pond will have permanent water where there will be water treatment. The remaining area is overflow area, which was initially targeting 1 in 100yr flood levels however this may be stepped down to the 1 in 30 once an assessment of the impacts has demonstrated no impact on third-parties. The toe swale was design to be protected against the 1 in 20yr so it is protected from inundation by most fluvial events. This will ensure pollutants do not leak into the floodplain. The toe swale conveys to the attenuation basin. The basins have some flood resilience as the invert level of the basin were raised slightly. Design strategy will be issued shortly for comments.	[redacted] Share drainage strategy
	[redacted] entioned no need to attenuate 1 in 100yr flows. Because this can relaxed based on the normal flooding frequency (1 in 2yrs) in this area [redacted]e will assess the impact of this. [redacted] in such a big catchment, there is some attenuation, so the timing for flood could be later, so needs some consideration. [redacted]the current flood frequency for the floodplain is 1 in 2yr.	[redacted] Produce plan on how assessment will be done on impacts of the reduced surface water storage requirements will have.

[redacted]

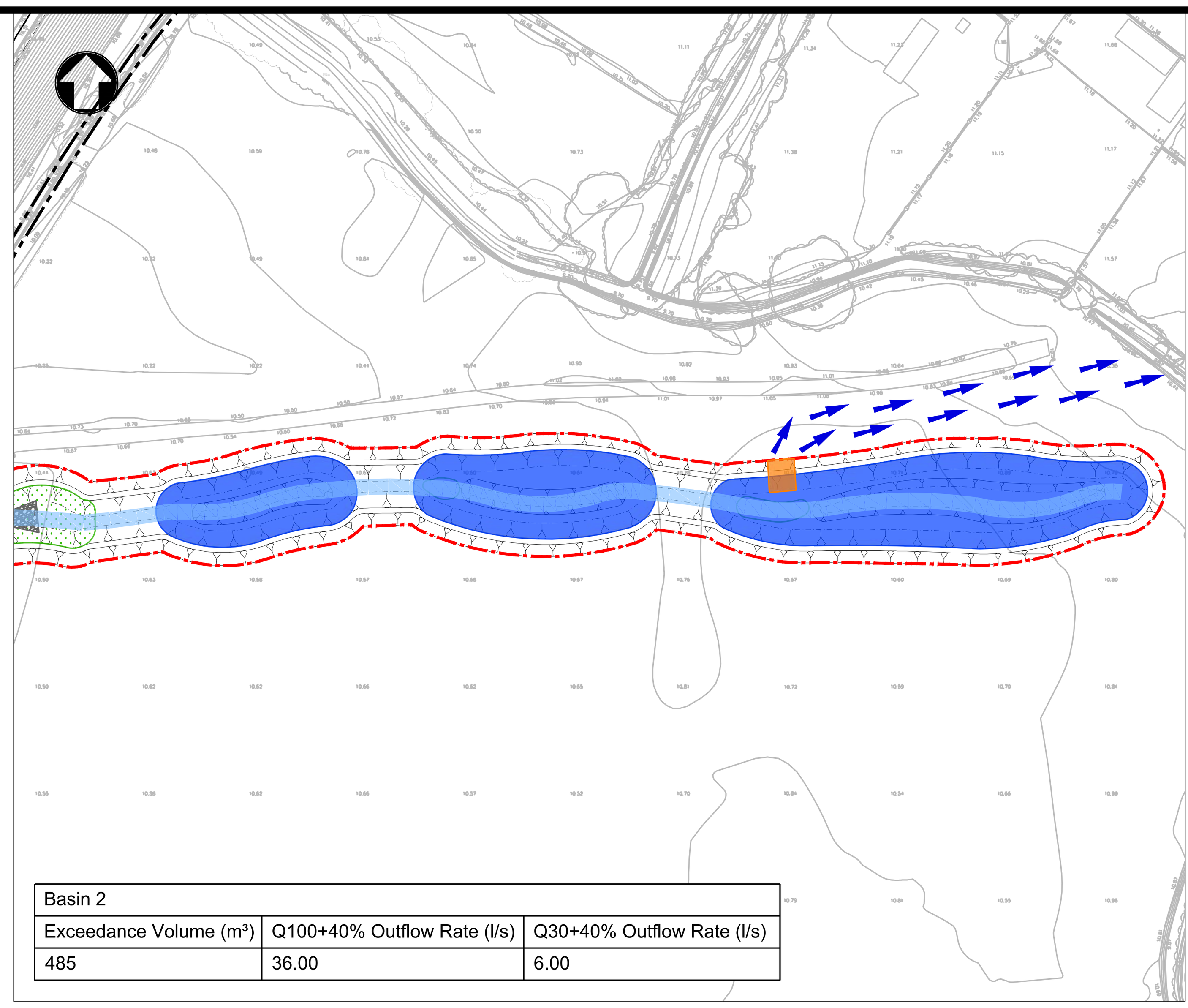
Item	Discussed	Action
	[redacted] raises a concern due to infiltration of pollutants [redacted]he ground. [redacted] hydrocarbons cannot leach to the soil, so there will be a lining, depending on the actual level of contaminants [redacted] he amount of lining will be based on predicted level of contaminants. [redacted]The toe swale will be sufficiently above flood [redacted]el. The drainage system is being design to 1 in 20yr flood levels. JBn 1 in 2yr flood event: no inundation of the drainage infrastructure.	
		[redacted] Organise the next steering group meeting to continue our collaborative work

B. Volume impact assessment plan

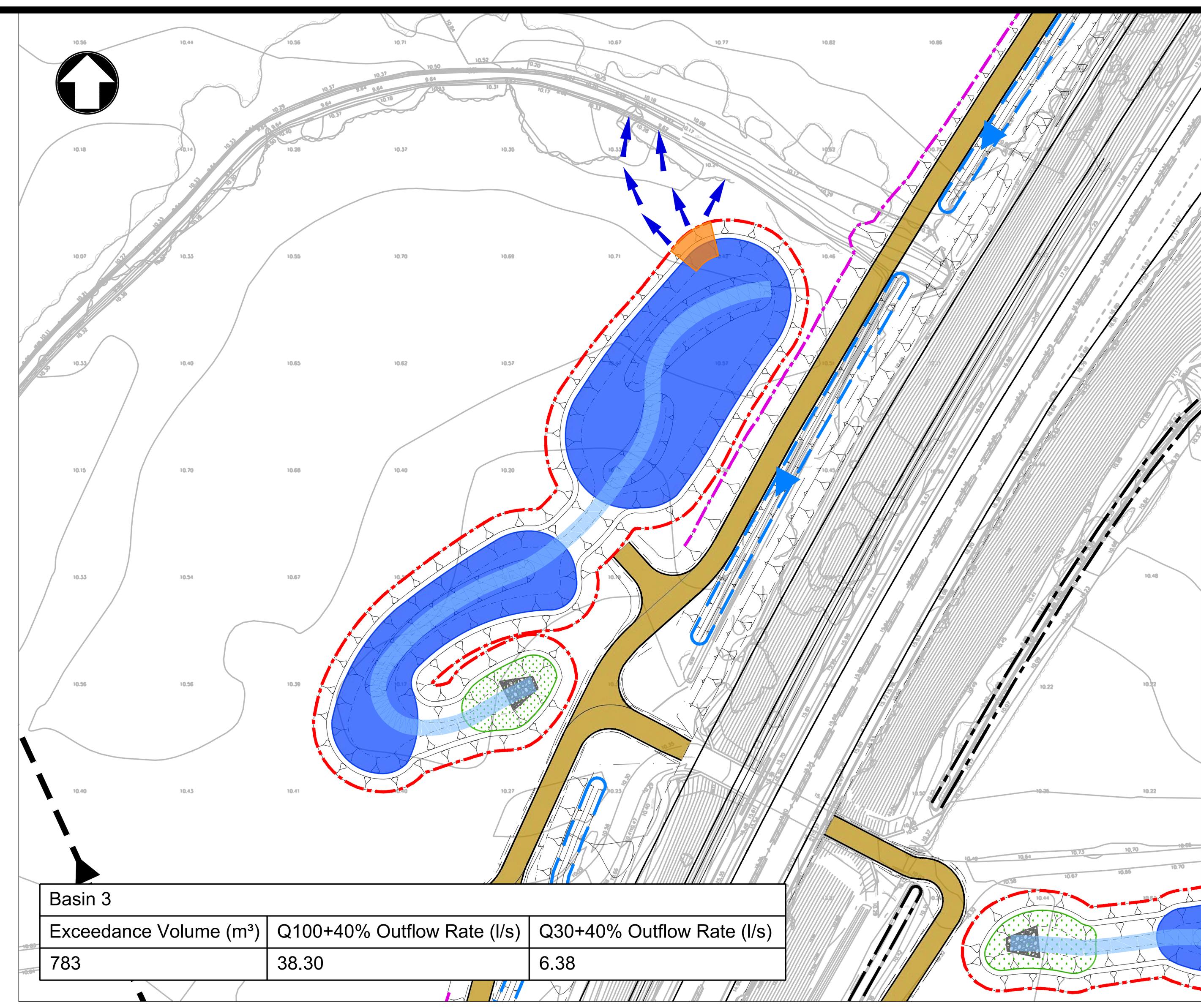
© Crown copyright and database rights 2021 OS 100030649



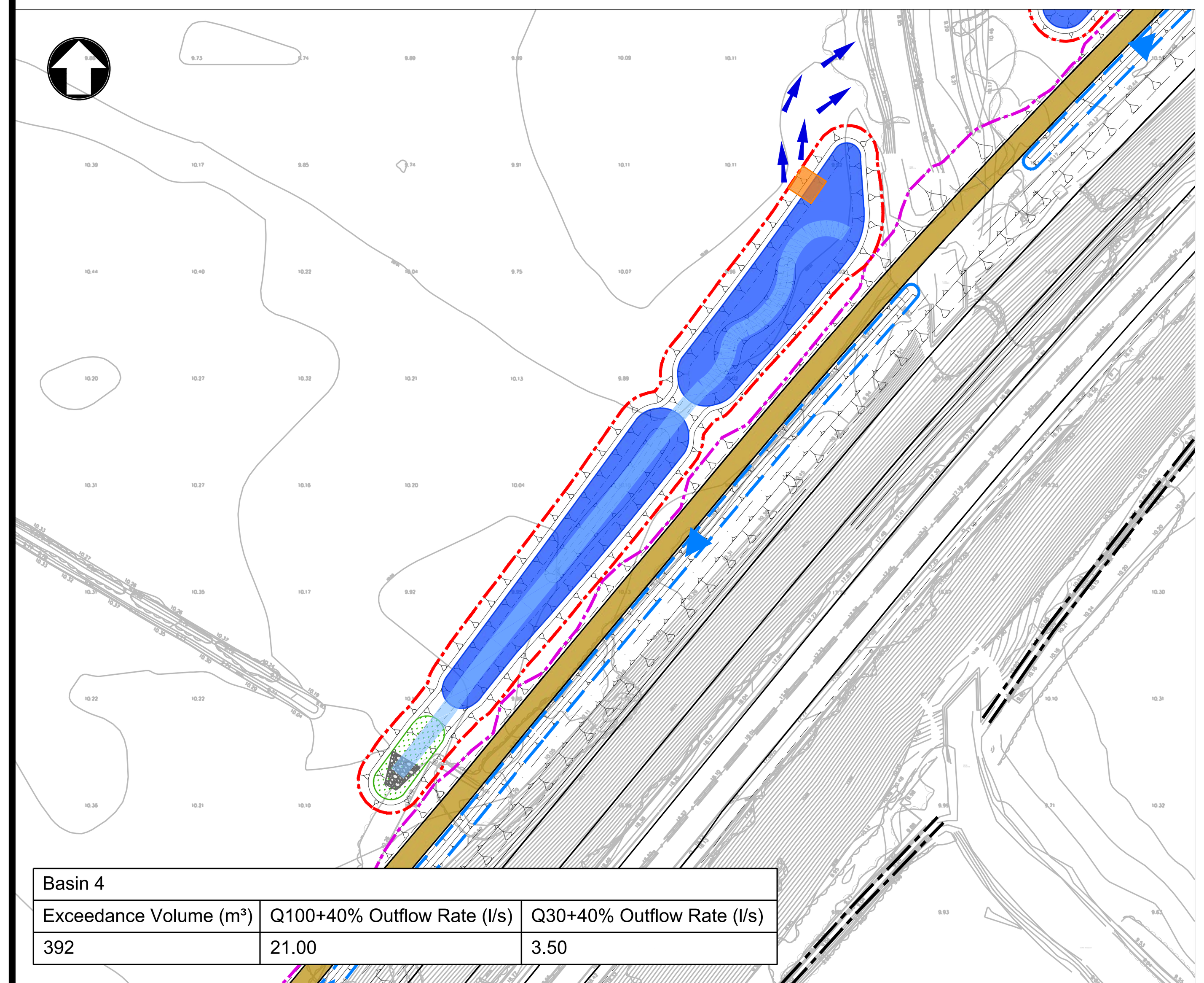
Basin 1		
Exceedance Volume (m³)	Q100+40% Outflow Rate (l/s)	Q30+40% Outflow Rate (l/s)
748	35.50	5.92



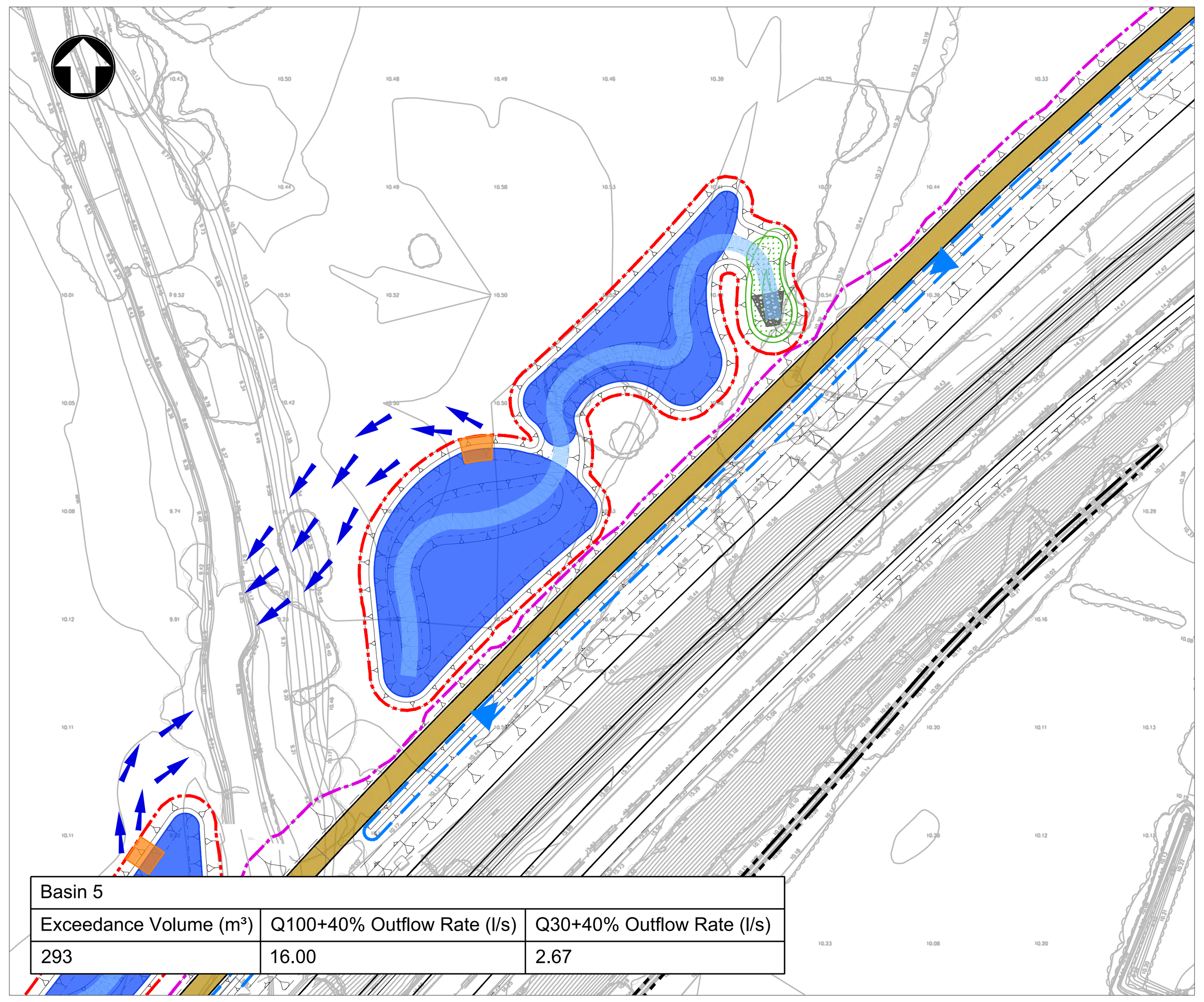
Basin 2		
Exceedance Volume (m³)	Q100+40% Outflow Rate (l/s)	Q30+40% Outflow Rate (l/s)
485	36.00	6.00



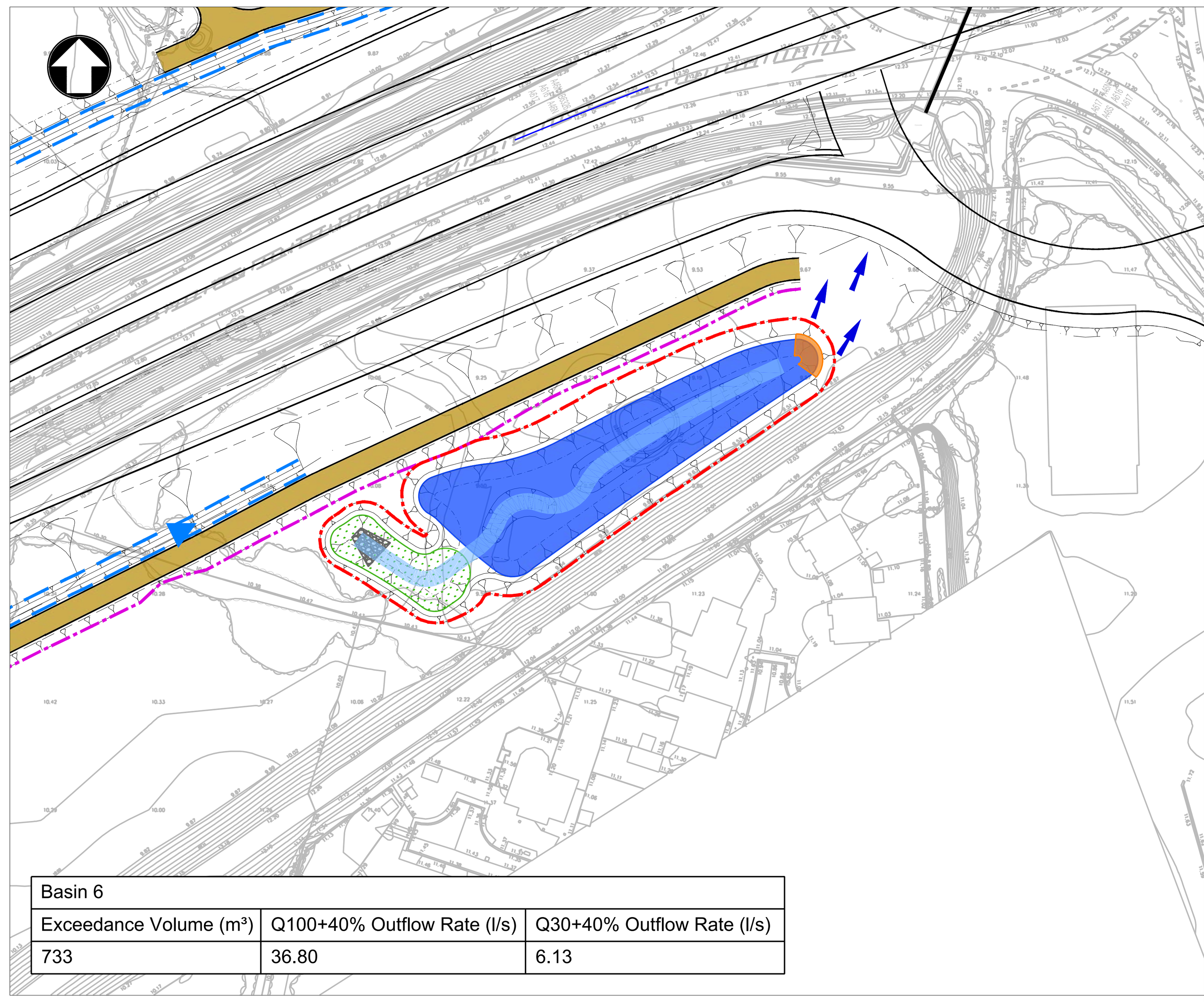
Basin 3		
Exceedance Volume (m³)	Q100+40% Outflow Rate (l/s)	Q30+40% Outflow Rate (l/s)
783	38.30	6.38



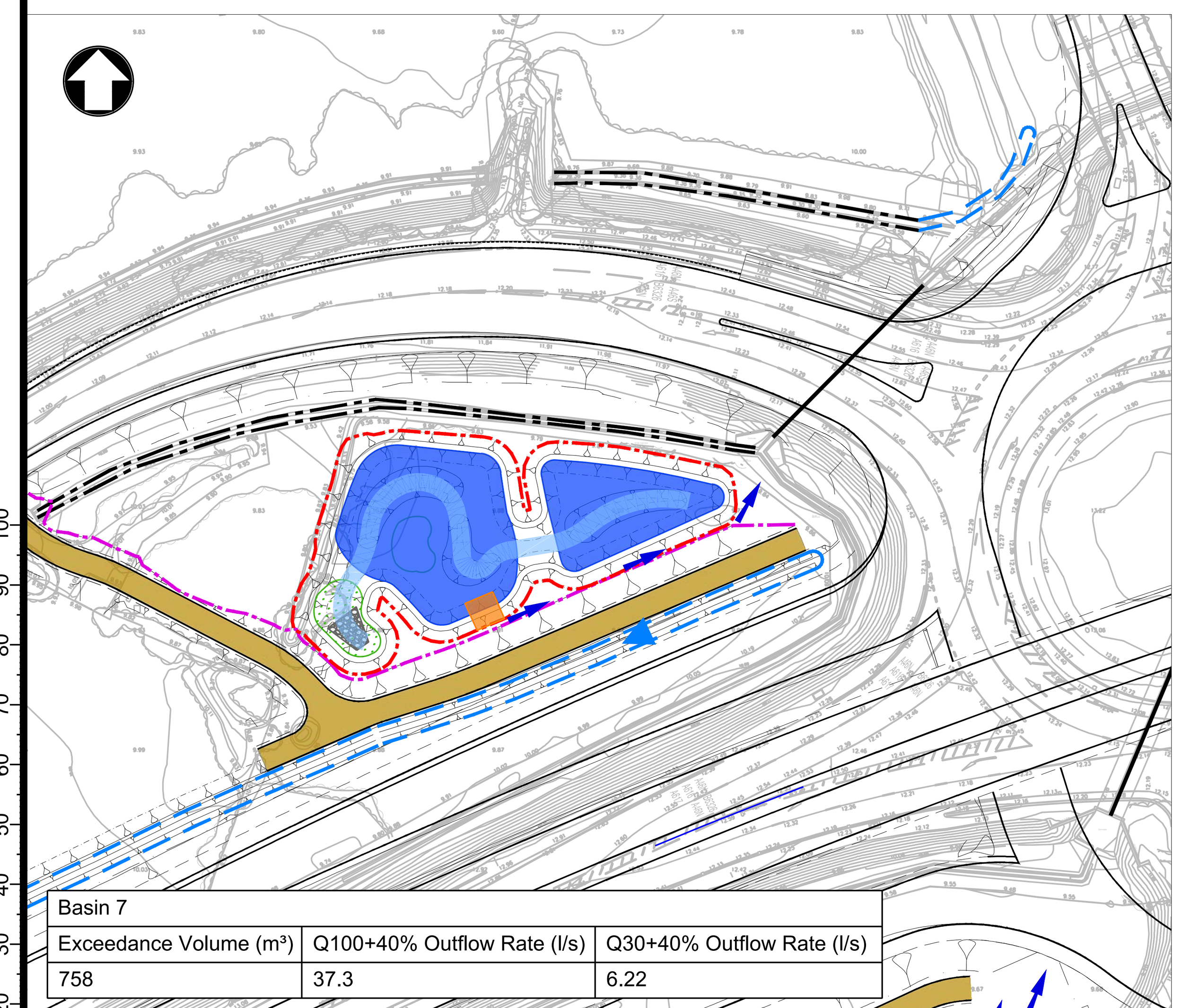
Basin 4		
Exceedance Volume (m³)	Q100+40% Outflow Rate (l/s)	Q30+40% Outflow Rate (l/s)
392	21.00	3.50



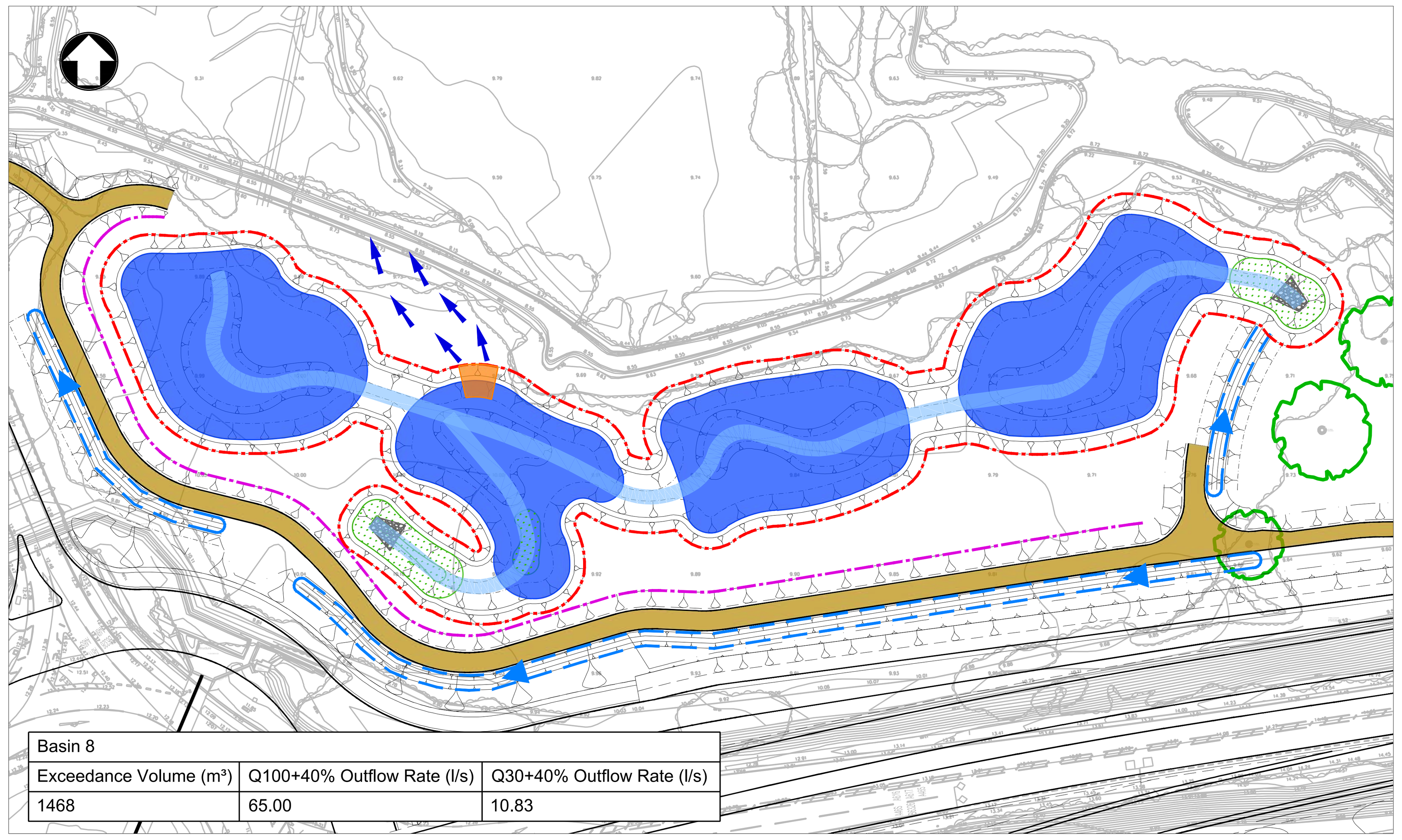
Basin 5		
Exceedance Volume (m³)	Q100+40% Outflow Rate (l/s)	Q30+40% Outflow Rate (l/s)
293	16.00	2.67



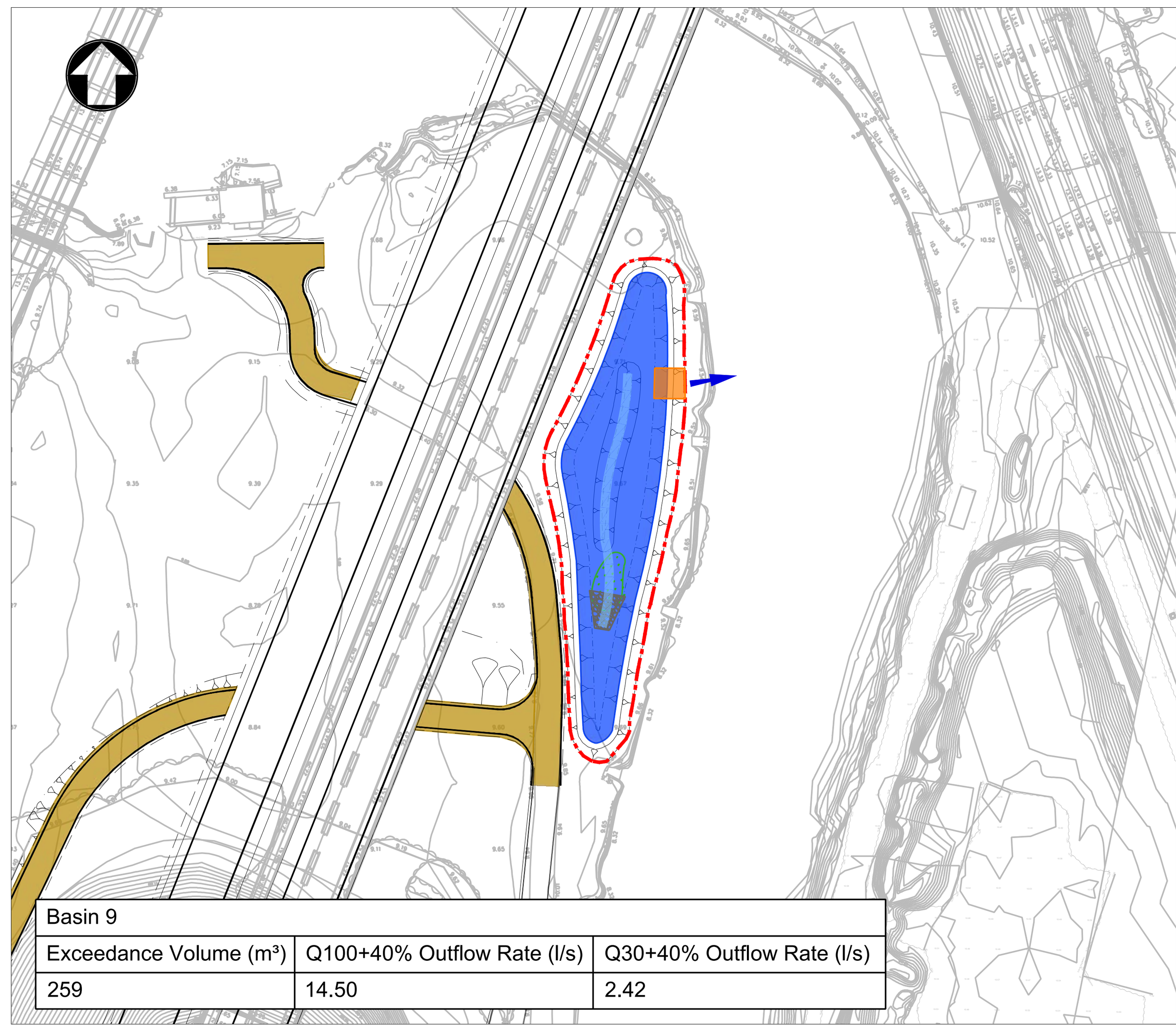
Basin 6		
Exceedance Volume (m³)	Q100+40% Outflow Rate (l/s)	Q30+40% Outflow Rate (l/s)
733	36.80	6.13



Basin 7		
Exceedance Volume (m³)	Q100+40% Outflow Rate (l/s)	Q30+40% Outflow Rate (l/s)
758	37.3	6.22



Basin 8		
Exceedance Volume (m³)	Q100+40% Outflow Rate (l/s)	Q30+40% Outflow Rate (l/s)
1468	65.00	10.83



Basin 9		
Exceedance Volume (m³)	Q100+40% Outflow Rate (l/s)	Q30+40% Outflow Rate (l/s)
259	14.50	2.42

1:1000 0 50m 100m

Notes

Key
- Main basin
- Pond
- Basin forebay
- Flow paths
- Rockblanket
- Proposed swale/ditch
- Existing swale/ditch to remain
- Access and Maintenance Track (includes cutoff drain)
- Land drain for basin
- Toe drain for maintenance track
- 5m wide spillway for basin
- Spill route to outfall/watercourse

REV.	DATE	AMENDMENT DETAILS	ORIG	CHK'D	APP'D
P01	06/07/23	First Issue	RB	GT	---

[redacted]

Client: national highways

Drawing Status: Suitable for Information | Status: S2

Project Title: A46 Newark Bypass

Drawing Title: A46 Newark Bypass
Volume Impact Assessment Plan

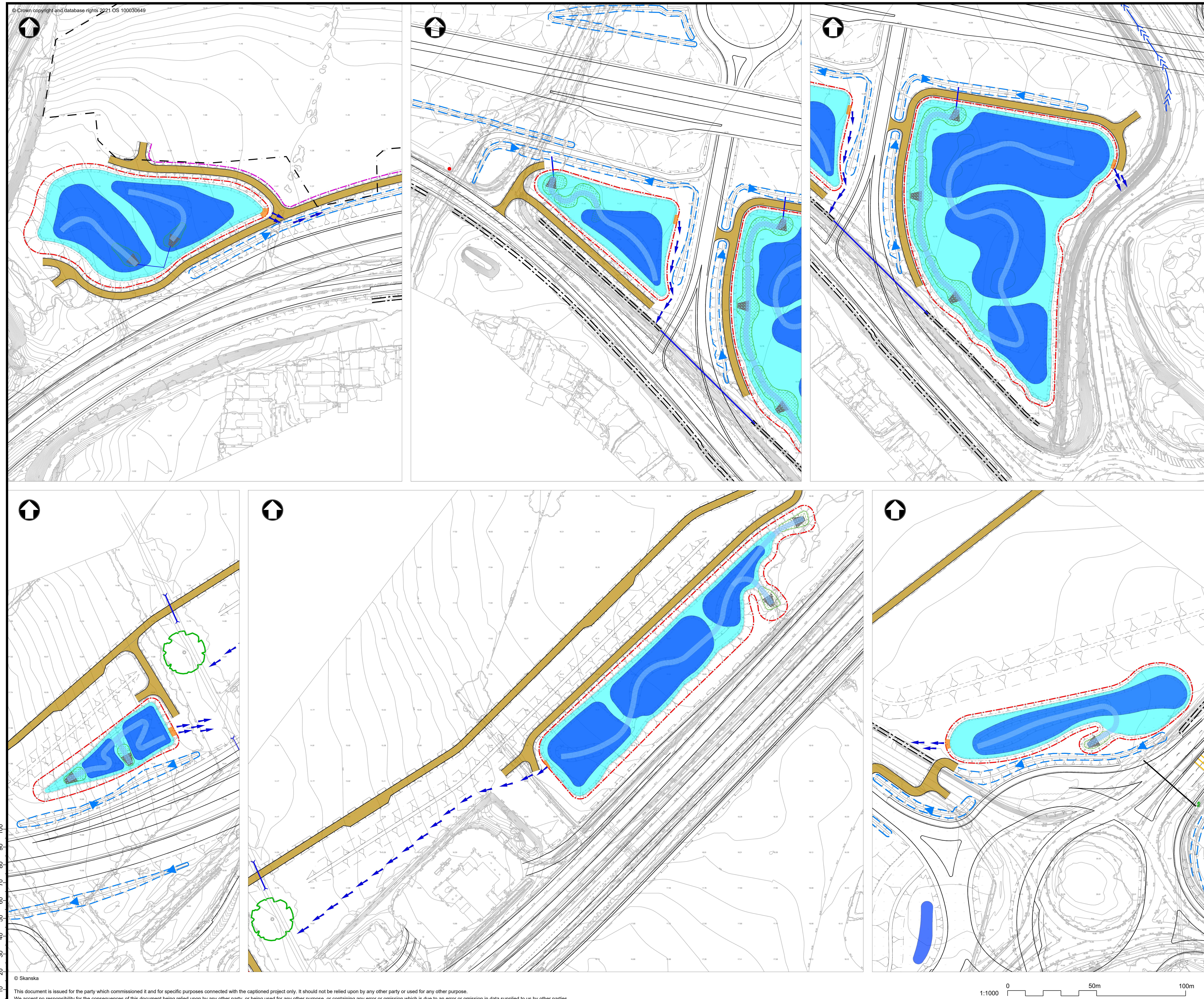
Scale	Designed	Drawn	Checked	Approved
1:1000	[redacted]			---
Original Size: A1	Date: 06/07/23	Date: 06/07/23	Date: 06/07/23	Date: ---

Drawing Number: HE PIN | Originator | Volume
HE551478 - SKAG - HDG -
CONWI_CONW - DR - CD - 00010

Project Ref. No.: HE551478

Revision: P01

[redacted]



Notes

Key

- Main basin
- Pond
- Basin forebay
- Flow paths
- Rockblanket
- Proposed swale/ditch
- Existing swale/ditch to remain
- Access and Maintenance Track (includes cutoff drain)
- Land drain for basin
- Toe drain for maintenance track
- 5m wide spillway for basin
- Spill route to outfall/watercourse

REV.	DATE	AMENDMENT DETAILS	ORIG	CHK'D	APP'D
P01	14/09/23	First Issue	RB	GT	---

[redacted]

national highways

Drawing Status	Status
Suitable for Information	S2

Project Title
A46 Newark Bypass

Drawing Title
A46 Newark Bypass
Volume Impact Assessment Plan
Basins Outside of Floodplain

Scale	Designed	Drawn	Checked	Approved
1:1000	[redacted]			---
Original Size				Date
A1	14/09/23	14/09/23	14/09/23	---

Drawing Number
HE PIN | Originator | Volume
HE551478 - SKAG - HDG -
CONWI_CONW - DR - CD - 00020

Project Ref. No.
HE551478

Revision
P01

[redacted]

E. A46 – Drainage Impact Assessment Email Correspondence

[redacted]

Subject: HIGH IMPORTANCE - RE: A46 progress Environment Agency - surface water attenuation

Importance: High

Hi [redacted] ,

It was good speaking with you earlier today to gain further reassurance on the proposals for surface water attenuation. In the absence of Harvey, Sarah in the flood risk team has now provided an updated response which will supersede the previous response issued further down the email chain.

The Environment Agency (EA) had raised concerns that surface water exceedance flow routing and volumes had not been presented or assessed for comment as part of the consultation process. Whilst Nottinghamshire County Council as the Lead Local Flood Authority are responsible for managing and regulating surface water flood risk, the EA has a strategic overview of all forms of flood risk. The EA recognises that the proposed scheme is located in an area of complex flood risk and that the timings and mechanisms of flooding vary depending on the source.

The applicant has now proposed an expanded surface water attenuation scheme which attenuates surface water flows from the proposed A46 road scheme up to the 1 in 100 year + climate change storm event, as requested. This is achieved through a system of attenuation basins using borrow pits which will be excavated as part of the road scheme. We have been assured that the borrow pits will have the required capacity to attenuate the full amount of surface water (rainfall) generated in a 1 in 100 year + climate change storm event. The exact plans of how these borrow pit attenuation basins will be hydrologically linked and designed will be drawn up at a later stage as the project progresses.

The surface water stored in the borrow pits will drain through an existing drainage channel which passes under the A46 into the Old Trent Dyke to the North East. This drainage channel will have a new headwall installed and a flow control device fitted. We are assured that overall the surface water drainage scheme will attenuate all the additional surface water generated by the road scheme (up to the 1 in 100 year + climate change storm event) and will not discharge additional flows into the drainage channel or surrounding land owned by third parties. We are therefore reassured that the finished scheme will not increase flood risk elsewhere and will therefore be compliant with the NPPF allaying our previous concerns. Please continue to consult the Environment Agency on the plans for the design and operation of the surface water attenuation scheme so we can ensure that it will fulfil these objectives.

I hope this is sufficient in allowing you to submit by the noon deadline however should you require any further discussion please feel free to contact me.

If you are satisfied with the above response please could you confirm by way of reply to this email.

Many thanks

[redacted]

Sustainable Places Team
East Midlands Area

[redacted] environment-agency.gov.uk
ency, Trentside Offices, Scarrington Road, West Bridgford, Nottingham NG2 5FA
External 020 3025 3833
Internal 30253833

I am dyslexic, expect creative thinking and creative spelling but if my email has any errors which make it unclear, please do give me a call

[redacted]
Sent: 13 July 2023 16:52
To [redacted]
Subject: A46 progress Environment Agency

[redacted]
Hello - In response to your latest email and to prepare for the meeting on Monday, we have made the adjustments to the Drainage Strategy as below.

To satisfy the ***- National Planning Policy Framework requirement to not increase flood risk elsewhere during the surface water DFE by Consider whether the Borrow Pits site can be incorporated in the overall flood risk strategy to offer attenuation or flood compensation.***
Would do so by attenuating the volume of exceedance in the Farndon east borrow pit area.

The proposed amendment -
Drainage Strategy Section 4 - Application of storage requirements and third-party impact assessment

1. It has been proposed that the Farndon east borrow pit area, would be utilised as attenuation to offset the exceedance volume for events above the 1 in 30 year storm (+CC) up to the 1 in 100 year (+CC) which can't be managed in the wetland basins or the landscaped area.
2. This area would outfall via a flow control device limited to the 1 in 100 year discharge rate into a deculverted land drain which will flow north-west through the A46 into the Old Trent Dyke. This volume displacement should counteract the additional volume discharged.
3. Additionally further displacement has been included in that all attenuation basins will discharge at QBAR greenfield run-off rates rather than like-for-like greenfield run-off rates. Storm events above the QBAR event (includes the 1 in 30 and 1 in 100 year events) will therefore be discharging at a rate much lower than natural greenfield run-off rates for the equivalent event.

[redacted]
Technical Specialist
Civil Infrastructure Engineer

From: [redacted]
Sent: 12 July 2023 22:37
[redacted]
Subject: RE: A46 progress Environment Agency

Hi ,

Having spoken with Harvey before he went on annual leave he issued me with the below updated response which I hope helps.

The Environment Agency (EA) raised concerns that surface water exceedance flow routing and volumes had not been presented or assessed for comment as part of the consultation process. Whilst Nottinghamshire County Council as the Lead Local Flood Authority are responsible for managing and regulating surface water flood risk, the EA has a strategic overview of all forms of flood risk. The EA recognises that the proposed scheme is located in an area of complex flood risk and that the timings and mechanisms of flooding vary depending on the source.

The proposals include designing surface water attenuation basins to contain up the 1 in 30 year (plus 40% climate change allowance (CC)) event. The design flood event (DFE) detailed within planning practice guidance (PPG) is the 1 in 100 year (plus 40% CC), meaning the proposals are not compliant with PPG. It is essential that the consequences of failing to comply with PPG are fully understood.

The design team have now produced a Volume Impact Assessment including plans indicating the route which exceedance surface water flows will take during the 1 in 100 year (plus 40% CC). Surface water will overtop the attenuation ponds via a formalised weir and flow into the surrounding landscape. It is interpreted that this exceedance flow will leave the proposed order limits and enter third party land during the surface water DFE as defined by PPG. In the event of a widespread surface water DFE occurring, covering the entire order limits, a total volume of 5,919m3 will flow onto the surrounding landscape, being greater than 2 Olympic sized swimming pools of surface water.

Whilst the plans are welcomed, the detail that is presented acts to strengthen the EA's concerns over the proposed surface water drainage strategy.

Is it acknowledged that most of the land impacted falls within Flood Zone 3, but this is associated with fluvial flood risk from the locally dominant River Trent. The proposals may have the effect of increasing the complexity of flooding to the adjacent land by increasing its risk of surface water flooding.

The EA strongly disagrees with the surface water design assumption that during a surface water DFE at this particular location, the River Trent will be in flood. The River Trent at Newark has a large catchment and there is a typical warning time of multiple days. Surface water flood risk is flashier and can occur with little warning.

It is recommended that the applicant consider further:

The off-site impacts from the surface water exceedance flows. Whilst we have been provided flow routes, they are local to the attenuation ponds areas. Where does the water ultimately end up? Some appear to flow into the Old Trent Dyke or directly into the River Trent, but others just onto land.

Consider seeking permission from 3rd party landowners (if relevant), to increase their risk of surface water flooding.

Consider whether the Borrow Pits site can be incorporated in the overall flood risk strategy to offer attenuation or flood compensation.

In summary, the plans demonstrate that the proposals fail to comply with National Planning Policy Framework requirement to not increase flood risk elsewhere during the surface water DFE. The scheme will result in more surface water entering the Old Trent Dyke and River Trent during the DFE. Whilst it is unlikely that the proposals will result in a change of flood hazard to any vulnerable receptor, the EA are concerned by the cumulative effect of such development proposals.

I hope this helps. I am happy to discuss this further if required however if I do need input from Harvey I am afraid he is now on annual leave until the 1st August 2023.

Many thanks

[redacted]st
Sustainable Places Team
East Midlands Area
[redacted]
Environment Agency, Trentside Offices, Scarrington Road, West Bridgford, Nottingham NG2 5FA
External 020 3025 3833
Internal 30253833

I am dyslexic, expect creative thinking and creative spelling but if my email has any errors which make it unclear, please do give me a call

---

[redacted]
Subject: A46 progress Environment Agency

,

Thankyou – Harvey called yesterday which was very helpful for us, we discussed in some detail , some of the issues regarding the complexities of the scheme and how the A46: Kelham & Averham Floodplain Compensation Area Technical Note marries with the Drainage Strategy and how to utilize the Borrow Pits site.

I explained that the Barrow Pits site and the additional potential of attenuating a proportion of the existing catchment of the A46 was / has been considered as a potential use for these site, this may be worth being a key focus for the meeting

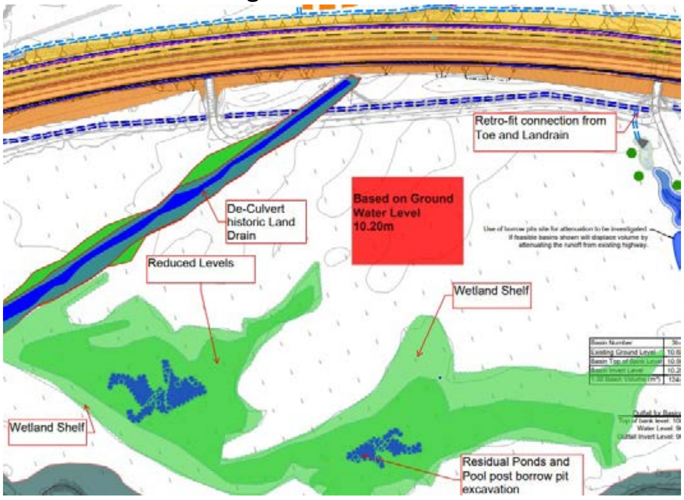


Figure 1 - Concept

17th July 2023 at 11am would suit, yes please.

[redacted]eer

From: [redacted]@environment-agency.gov.uk>
Sent: 12 July 2023 07:34

[redacted]

From: [redacted] environment-agency.gov.uk>
Sent: [redacted]
Subject: A46 progress

Hello all,

Apologies for the blanket email but I am trying to establish which elements of the project you are now waiting for a response on from us. I think it might be useful to have a quick Teams meeting with just me from the EA so I can establish progress and deadlines.

I propose covering the following;

- Volume Impact Assessment – Harvey has stated he believes he has now responded to everything for this but I need to check this.

- Drainage Basis of Design – is there any other information required (flood risk, biodiversity, fisheries and groundwater)?
- Fish protection and biodiversity for pre and during development – is any more information required?

Other points to cover

- Disapplication of permit requirements
- Statement of common ground

Do you think a quick meeting would be useful? If so could you suggest a date and time we can organise this or would you like me to suggest a time this week that we can dial in?

Many thanks

[redacted]
Planning Specialist
Sustainable Places Team
East Midlands Area
[redacted] environment-agency.gov.uk
[redacted]ency, Trentside Offices, Scarrington Road, West Bridgford, Nottingham NG2 5FA
[redacted]

[redacted]

Information in this message may be confidential and may be legally privileged. If you have received this message by mistake, please notify the sender immediately, delete it and do not copy it to anyone else. We have checked this email and its attachments for viruses. But you should still check any attachment before opening it. We may have to make this message and any reply to it public if asked to under the Freedom of Information Act, Data Protection Act or for litigation. Email messages and attachments sent to or from any Environment Agency address may also be accessed by someone other than the sender or recipient, for business purposes.
Information in this message may be confidential and may be legally privileged. If you have received this message by mistake, please notify the sender immediately, delete it and do not copy it to anyone else. We have checked this email and its attachments for viruses. But you should still check any attachment before opening it. We may have to make this message and any reply to it public if asked to under the Freedom of Information Act, Data Protection Act or for litigation. Email messages and attachments sent to or from any Environment Agency address may also be accessed by someone other than the sender or recipient, for business purposes.
Information in this message may be confidential and may be legally privileged. If you have received this message by mistake, please notify the sender immediately, delete it and do not copy it to anyone else. We have checked this email and its attachments for viruses. But you should still check any attachment before opening it. We may have to make this message and any reply to it public if asked to under the Freedom of Information Act, Data Protection Act or for litigation. Email messages and attachments sent to or from any Environment Agency address may also be accessed by someone other than the sender or recipient, for business purposes.

[redacted]

From: [redacted]@nottscc.gov.uk>
Sent:
To: [redacted]
Subject: RE: A46 - Drainage Strategy and Volume Impact Assessment

Hi [redacted]

Below sets out our standard surface water drainage conditions. Hope these help

- Demonstrate that the development will use SuDS throughout the site as a primary means of surface water management and that design is in accordance with CIRIA C753 and NPPF Paragraph 169.
- Limit the discharge generated by all rainfall events up to the 100 year plus 40% (climate change) critical rain storm to QBar rates for the developable area.
- Provide detailed design (plans, network details, calculations and supporting summary documentation) in support of any surface water drainage scheme, including details on any attenuation system, the outfall arrangements and any private drainage assets.

  Calculations should demonstrate the performance of the designed system for a range of return periods and storm durations inclusive of the 1 in 1 year, 1 in 30 year and 1 in 100 year plus climate change return periods.
  - No surcharge shown in a 1 in 1 year.
  - No flooding shown in a 1 in 30 year.
  - For all exceedance to be contained within the site boundary without flooding properties in a 100 year plus 40% storm.
- Evidence to demonstrate the viability (e.g Condition, Capacity and positive onward connection) of any receiving watercourse to accept and convey all surface water from the site.
- Details of STW approval for connections to existing network and any adoption of site drainage infrastructure.
- Evidence of approval for drainage infrastructure crossing third party land where applicable.
- Provide a surface water management plan demonstrating how surface water flows will be managed during construction to ensure no increase in flood risk off site.

Evidence of how the on-site surface water drainage systems shall be maintained and managed after completion and for the lifetime of the development to ensure long term effectiveness.

regards

Principal Officer – Flood Risk Management
Place Department - Nottinghamshire County Council

County Hall, West Bridgford, Nottingham NG2 7QP
[redacted]

[redacted] | flood.team@nottscc.gov.uk | www.nottinghamshire.gov.uk

Flood Risk Management Team, Nottinghamshire County Council,
County Hall, Loughborough Road, West Bridgford, Nottingham, NG2 7QP

Nottinghamshire County Council

From:
Sent: 03 April 2023 12:07
To: [redacted]
Subject: RE: A46 - Drainage Strategy and Volume Impact Assessment

Hi ,

As discussed over the phone please can you send over a copy of NCC's standard planning requirements,

Kind Regards,

[redacted]
Flood Risk Management Engineer

From: [redacted]
Sent: 22 March 2023 12:37
[redacted]
Subject: RE: A46 - Drainage Strategy and Volume Impact Assessment

Caution: This is an external email and has a suspicious subject or content. Please take care when clicking links or opening attachments. When in doubt, contact your IT Department

Hi

Thanks for that info, I'm happy to confirm that we would consider a relaxing of the 100yr attenuation subject to the proposals having no significant detrimental impacts on the surrounding areas.

Best regards
[redacted]
Principal Officer – Flood Risk Management
Place Department - Nottinghamshire County Council
County Hall, West Bridgford, Nottingham NG2 7QP
0115 9774473

@nottscc.gov.uk | flood.team@nottscc.gov.uk | www.nottinghamshire.gov.uk

Flood Risk Management Team, Nottinghamshire County Council,
County Hall, Loughborough Road, West Bridgford, Nottingham, NG2 7QP

From: [redacted]
Sent: 22 [redacted]
To: [redacted]
Subject: A46 - Drainage Strategy and Volume Impact Assessment

Hi ,

Please see linked below our latest revisions of the A46 schemes drainage strategy drawings which we are issuing ahead of the formal issue, for information/consultation, we will reissue formally in the following days,

[redacted]

The latest update includes additional schematics for the capture system (gullies, kerb drains) as well as a general detailed pass on the design,

We have discussed the principle of relaxing the 1 in 100 year attenuation requirements for the strategy previously but have nothing in writing to confirm this. Please can you confirm the acceptability of the principle, stated below, so we can begin work on the impact assessment,

Notthinghamshire County Council are willing to consider the relaxation of the 1 in 100 year attenuation requirement down to the 1 in 30 year (+CC) on the condition that an impact assessment is carried out and it is proven that no third-party properties or land are seriously impacted by the relaxation.

Kind Regards,

[redacted]
BEng Civil Engineering with Sustainability
Flood Risk Management Engineer
[redacted]

MOTT MACDONALD

[redacted]

[redacted]

Record of meeting

Project title	A46 Newark Bypass

Subject	A46 Newark Bypass – Drainage and Flood Management Steering Group meeting #6
Location	TEAMS
Date/time of meeting	30/11/2022, 10:00
Project number	100103345
Attendees	[redacted]
Apologies	[redacted]
Recorded by	[redacted]
Distribution	Internal

Item	Discussed	Action
1 *Introductions, H&S*	[redacted] introductions and agenda	
2. Public Engagement	[redacted] present the consultation so far and [redacted]ourages everyone to participate with feedback.	
3. Future developments	[redacted] introduction to all existing schemes near the A46 bypass.	
3.1 Tolney lane scheme	[redacted] The modelling done for the scheme is 10yrs It is a catchment level model. It was refined for	[redacted] Share project brief and potential

[redacted]

Item	**Discussed**	**Action**
	the location but the modelling being done for A46 bypass could be used to support this scheme.	locations for flood compensation with [redacted]
	[redacted] he model used for this scheme was not QA'ed and EA would like the A46 bypass model to be [redacted]d to assess the Tolney Lane scheme options.	
	[redacted]notes A46 bypass model methodology has [redacted]n shared with the EA already.	
	[redacted]highlights the benefits for all parties by a[redacted]ning the objectives of the two schemes.	
	[redacted]Council will have their own programme. When the plan moves forward, we can look at how long it will take for the Tolney lane to be delivered. It needs to be delivered as soon as possible (funding and impacts being assessed) but it is a priority of the council. A 2-5yrs timeline was suggested.	
	[redacted] working towards delivering the Tolney lane scheme in the next 3 yrs. There is some scope to [redacted]orten this programme.	
3.2 Newark Southern Link Road (SLR) scheme	[redacted] undertook an assessment of the SLR report at [redacted]s stage. SLR scheme elements are located primarily within functional floodplain of River Devon and include 3x roundabouts, two bridges (River Devon bridge and a flood alleviation bridge) and a replacement culvert structure on the Mill Burn necessitated by the raising of Hawton Road). The bridge located over the River Devon has an effective span of 100m and reported to have been designed to have a minimum 600mm freeboard under the modelled 1% AEP plus (20%) climate change allowance event. Other scheme elements include seven compensation areas and additional mitigation (River Devon channel widening, etc). In terms of cumulative impacts of the SLR scheme and the A46 bypass, it is not considered there would be an adverse material impact to flood risk. Proposed works associated with the Newark Bypass are minimal in the River Devon floodplain and are primarily within the functional floodplain of the River Trent. The SLR modelling results suggest there is a surplus of storage within the Devon floodplain locally when compared to baseline. While the SLR modelling results did show increased water levels >30mm at ten properties, given the overland distance and local topography it is not considered likely that works associated with the Newark Bypass scheme would further impact upon water levels in this area. We will assess in detail over the course of the hydraulic modelling for the scheme but currently	

[redacted]

Item	**Discussed**	**Action**
	do not expect the SLR scheme to have a material impact to the A46 scheme	
	[redacted] points out the ground levels near SLR are above the Newark bypass levels and thus based on ground levels alone it is unlikely to directly impact on the A46 scheme.	
	[redacted] advised no major comments or concerns at this [redacted]ge.	
	[redacted] A brief technical note which summarises our [redacted]sessment is being prepared and will be shared for [redacted]o formally review and advise.	[redacted] Share with [redacted] a short technical note to explain why the SLR model will not be incorporated in the A46 bypass model
4. Survey update	[redacted] More detail required and topographic survey starting on site next week. MW confirms surveyors are starting on site next week.	
5. Hydraulic modelling update	[redacted] provides hydraulic modelling progress so far.	
	[redacted] interim model being used just as a tool to give us a feel of flood levels to help generate draft results. This will inform design as it matures. The model is running with the scheme with the compensation areas. Results will be available shortly. Once certainty on quality is obtained, results will be shared.	
6. Floodplain Comp, Update	we are hoping to reduce the size of compensation needed in the burrow pit site. At Kelham we are negotiating with landowners potential locations. The connectivity with the River Trent includes widening of the channel, which could act as flood compensation as well, which we are assessing. The new proposed embankment for the road will consume some low lawing ground levels, and we are hoping to compensate this too. Once we have modelling results, we will know what hydraulic connectivity is possible and we will assess if the proposed areas will be able to compensate adequately. OE Further screening analysis is required and these 3 areas are the most favourable, i.e., will achieve more direct compensation. Where possible, we aim to provide direct compensation. [redacted] For reference 17 or 18 sites were assessed [redacted]ially as potential FCAs for the scheme.	
7. Water quality monitoring strategy	Comparison point for the monitoring before and during construction. 12 points around the area were selected during a site visit. The type of monitoring will be in situ (temperature, visual inspection, sending samples to laboratory for analysis).	

[redacted]

Item	Discussed	Action
	The outcomes will inform the drainage design. Two Local Natures Reserves (Farndon Ponds LNR and Devon Pastures LNR) were scoped out of the environmental assessment, as follows: - Farndon Ponds LNR is located approximately 1.51 upstream of the closest point of the proposed scheme, therefore the proposed scheme is not considered to have a suitable pathway to the LNR and can be scoped out. - Devon Pasture LNR is located on the River Devon, and is downstream of the proposed scheme, but upstream of the confluence between the River Devon and River Trent. Therefore, the LNR is considered to be at a suitable distance for any contaminants to have dispersed and there not to be a credible pathway (contaminants are not anticipated to travel upstream between the confluence of the two rivers, and the site location). As such, Devon Pasture LNR can also be scoped	RB to share sketches of locations of LNR to enable to EA to confirm agreement with the approach.
	[redacted] ould like to take a look at the water quality monitoring strategy in more detail.	[redacted] to provide proposed strategy report
8. Drainage update - Attenuation basins	Presents a proposed attenuation basin which is in the floodplain. Part of the pond will have permanent water where there will be water treatment. The remaining area is overflow area, which was initially targeting 1 in 100yr flood levels however this may be stepped down to the 1 in 30 once an assessment of the impacts has demonstrated no impact on third-parties. The toe swale was design to be protected against the 1 in 20yr so it is protected from inundation by most fluvial events. This will ensure pollutants do not leak into the floodplain. The toe swale conveys to the attenuation basin. The basins have some flood resilience as the invert level of the basin were raised slightly. Design strategy will be issued shortly for comments.	[redacted] Share drainage strategy
	[redacted] Mentioned no need to attenuate 1 in 100yr s. Because this can relaxed based on the normal flooding frequency (1 in 2yrs) in this area [redacted] we will assess the impact of this. : in such a big catchment, there is some attenuation, so the timing for flood could be later, so needs some consideration. [redacted] the current flood frequency for the floodplain is 1 2yr.	Produce plan on how assessment will be done on impacts of the reduced surface water storage requirements will have.

[redacted]

Item	Discussed	Action
	[redacted]aises a concern due to infiltration of pollutants [redacted]e ground. [redacted]hydrocarbons cannot leach to the soil, so there will be a lining, depending on the actual level of contaminants. The amount of lining will be based on predicted level of contaminants. [redacted]he toe swale will be sufficiently above flood [redacted]el. The drainage system is being design to 1 in 20yr flood levels. [redacted] 1 in 2yr flood event: no inundation of the [redacted]inage infrastructure.	
		[redacted] Organise the next steering group meeting to continue our collaborative work

F.A46 Newark Trent 2023 Temporary Works Fluvial Hydraulic Modelling Technical Report: HE551478-SKAG-HDG-CONWI_CONW-TN-CD-00007

Contents

1 Introduction

1.1 Background

1.1.1 The Delivery Integrated Partnership (DIP) A46 Newark Bypass Scheme entails the development of Section 7 of the A46 that spans between Farndon Junction and Winthorpe Junction. The Scheme aims to upgrade an existing single carriageway road in Newark-on-Trent to a dual carriageway.

1.1.2 The Delivery Integrated Partnership consisting of Skanska and Mott MacDonald are currently in the Stage 3 design phase for the Scheme. Mott MacDonald has been commissioned by National Highways to undertake the Flood Risk Assessment (FRA) in support of the PCF Stage 3 and Stage 5 design phases of the Scheme.

1.1.3 This report outlines the temporary works hydraulic modelling study that has been undertaken to quantify the risk of flooding arising from temporary works structures. It has been produced in addition to the Hydraulic Modelling Technical Report[1].

1.2 Scope

1.2.1 The aim of this hydraulic modelling study is to provide an understanding of the impact of the temporary works elements on fluvial flood risk. The requirements were agreed with the Environment Agency (EA) and are as follows:

- Incorporate agreed temporary works elements with the permanent works hydraulic model. The temporary works elements incorporate compounds, working platforms, haul roads, temporary culverts and Bailey Bridge embankments.
- Assess the impact on fluvial flood risk for the 3.33% and 1% Annual Exceedance Probability (AEP) events.
- Assess the impact of the addition of stockpiles at flood compensation areas (FCAs) during the 3.33% AEP event.
- Quantify the impact of flood risk to receptors.

1.3 Environment Agency engagement

1.3.1 Prior to undertaking hydraulic modelling, the assumptions in this document were discussed with the Environment Agency[2] (EA).

[1] Hydraulic Modelling Technical Report (HE551478-SKAG-HDG-CONWI_CONW-RP-CD-00021)

[2] MS Teams meeting 'A46 Temporary Works Discussion' 2024-04-18 (HE551478-SKAG-HDG-CONWI_CONW-MI-CD-00020)

1.3.2 The following points were agreed with the EA during the A46 Temporary Works Discussion on 18 April 2023:

- Temporary works should be designed to the 3.33% (1 in 30 year) Annual Exceedance Probability (AEP) event.
- Sensitivity testing of flood risk to the presence of stockpiles should be undertaken against the 3.33% AEP event.
- Sensitivity testing of flood risk due to the overall temporary works elements should be undertaken against the 1% (1 in 100 year) AEP event.

2 Methodology

2.1.1 Temporary works elements were incorporated into the permanent works modelling of the A46 Newark Bypass. Further details on the permanent works hydraulic modelling methodology are provided in the Hydraulic Modelling Technical Report[1].

2.2 Temporary works structures

2.2.1 The following sections describe the temporary works structures and any assumptions made of their representation during the hydraulic modelling assessment. A summary of modelling assumptions is provided in Table 2-1.

Haul roads

2.2.2 Haul roads would have a 0.7m average thickness above the topographic ground level, and an average width of 8.0m.

2.2.3 Temporary culverts would be constructed below haul roads. These are discussed further in Section 2.4.

Working platforms

2.2.4 Working platforms would have a 1.2m average thickness above the existing topographic ground levels.

2.2.5 The working platform south of the River Trent at Nether Lock will have two 20m-wide gaps between piers. This is discussed further in Section 2.3

Compounds

2.2.6 Three compounds have been included in the hydraulic modelling assessment. All other compounds have been excluded as they are either located within the footprint of a working platform and are therefore represented more conservatively, or are located within Flood Zone 1.

2.2.7 The base of the compounds would have an average thickness of 0.3m above topographic ground level. Compound cabins would be raised and would not impede flow. Plant that is stored in compounds would be relocated upon flood warning.

Modelling assumptions: temporary works structures

2.2.8 Modelling assumptions discussed in the above section are summarised in Table 2-1.

Table 2-1 Modelling assumptions – temporary works structures

Structure	**Assumptions**
Haul roads	Average thickness of 0.7m applied by uplifting ground levels from the project model LiDAR. Average width of 10m applied to ensure that the 8m wide haul roads are represented in the model's 10m cell size. This provides a slightly conservative estimate of flood risk.
Working platforms	Average thickness of 1.2m applied by uplifting ground levels from the project model LiDAR. Uplifted areas were generally flat in the LiDAR and therefore appropriate platform volumes were modelled.
Compounds	Average thickness of 0.3m applied by uplifting ground levels from the project model LiDAR. The uplifted areas were generally flat in the LiDAR and therefore appropriate compound volumes were modelled.

2.3 Waterbodies and crossings

Slough Dyke

2.3.1 A Self-Propelled Modular Transporter (SPMT) would be required to carry bridge materials into position. This requires temporary culverting of the Slough Dyke watercourse with a gravel overlay atop the culvert to enable the SPMT to cross. The culvert would be in place for one to two months. It would be approximately 50 to 100m long and would have a 1m² cross-sectional area opening.

2.3.2 The temporary Slough Dyke culvert was not included in this hydraulic modelling assessment due to its very short time frame of use and the reduced chance of flooding coinciding with the use of the culvert.

Nether Lock vicinity: Bailey bridge and platform

2.3.3 A temporary Bailey bridge would be in place for the duration of the works which is estimated to be approximately two to three years. Figure 2-1 presents the location of the temporary Bailey bridge.

2.3.4 The bridge would be held in place either side of the River Trent by reinforced soil embankments with concrete platforms of 0.3m thickness above the topographic ground level. The embankments would form the ramp to the bridge and would be perpendicular to the

River Trent flow. Figure 2-2 presents the Bailey Bridge embankments. This could restrict flow in the River Trent, therefore the embankments have been included in this hydraulic modelling assessment. The bridge itself was not incorporated in the hydraulic modelling assessment given that there is at least 1m of freeboard at the embankments during the 3.33% AEP event. It was therefore assumed that the water level would not reach the bridge level.

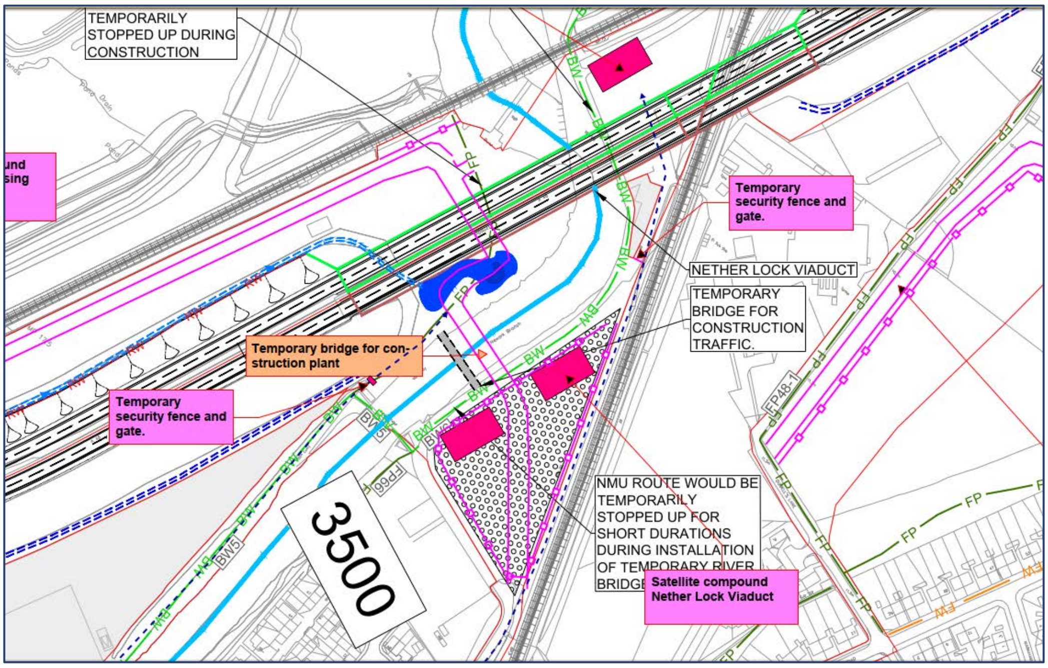
2.3.5 Components of the Bailey bridge embankments are as follows:

- The embankments would reach the bridge soffit at approximately 12.5mAOD.
- The embankments would be 8m wide but would widen to 15m at the bridge with a gradient of 1:10.
- On the western bank, the embankment would be 30m long.
- On the eastern bank, the embankment would be 20m long.

2.3.6 The Bailey bridge embankments have been represented with a width of 20m at the bridge instead of 15m to ensure that the embankments are represented in the model's 10m cell size. This provides a more conservative estimate of flood risk.

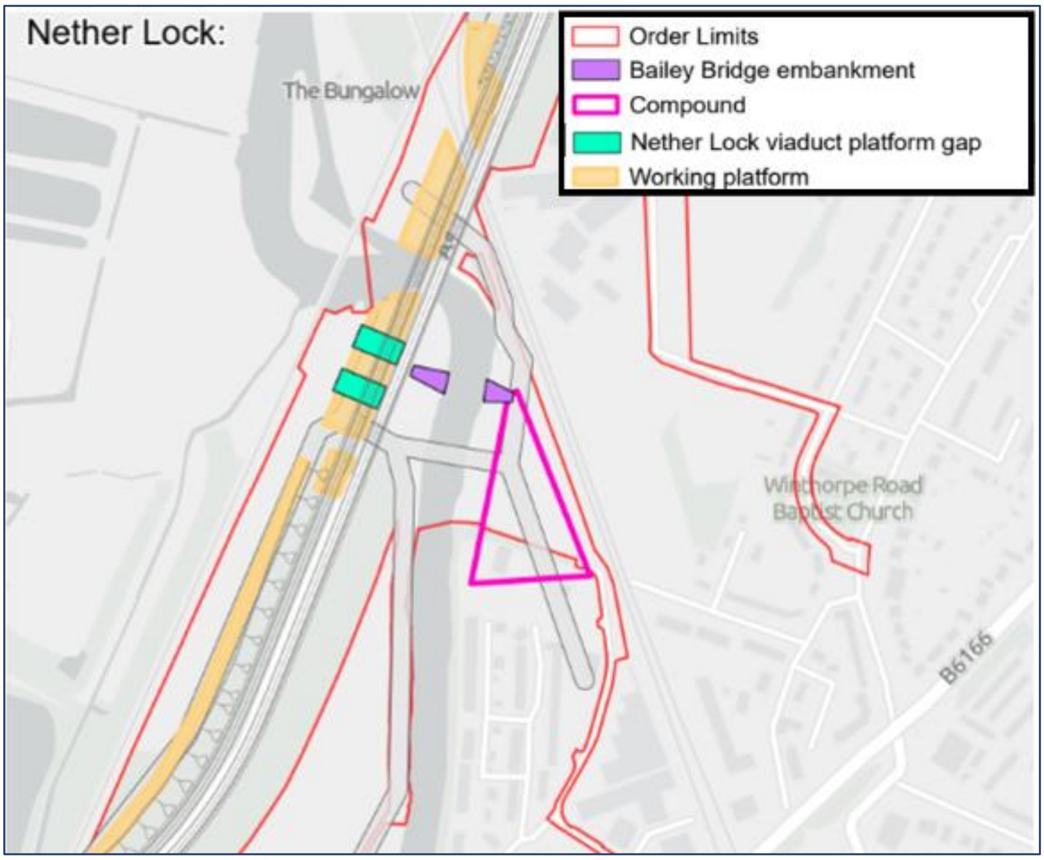
2.3.7 The working platform south of the River Trent at Nether Lock will have two 20m-wide gaps between piers as shown in Figure 2-2. These gaps are required as to they provide flow pathways from east to west, as mitigation against potential upstream flood impact to residential receptors. It is vital that these gaps are maintained open, that they are reinforced due to potentially high flood depths of up to 1.9m in a 3.33%AEP event, and that flow paths are unimpeded to the east and west of the gaps. Due to the sensitivity of upstream receptors to gap width between piers, further sensitivity testing is recommended at Detailed Design.

Figure 2-1: Location of temporary Bailey bridge (Construction Design Strategy)



Source: Contains OS data © Crown Copyright and database rights 2023.

Figure 2-2 Temporary works structures at Nether Lock



Source: Contains OS data © Crown Copyright and database rights 2023.

Nottingham to Lincoln West Railway

2.3.8 There is a disconnected waterbody to the north of the Notts to Lincs railway line and to the west of the A46. This would be infilled with gravel during the construction phase and a working platform would sit atop the infill. Platform locations are presented in Figure 2-3.

2.3.9 Although this waterbody is not hydraulically connected in normal conditions, the arches of the A46 crossing the Notts to Lincs railway line provide flow conveyance in flood conditions. Both arches (north and south of the railway) would be completely blocked by working platforms to the west sitting 1.2m above the ground level.

Figure 2-3: Working platform locations at the Notts to Lincs railway line

Source: Map data ©2023 Google Satellite. Markup by Mott MacDonald.

Modelling assumptions: waterbodies and crossings

2.3.10 Modelling assumptions of the temporary works waterbodies and crossings discussed in this section are summarised in Table 2-2.

Table 2-2: Modelling assumptions – waterbodies and crossings

Structure	Modelling assumptions
Slough Dyke	Not included in model due to very temporary nature of culvert.
Bailey bridge embankments	Western bank: 30m long, 8m wide, widening to 15m at the bridge, with a gradient of 1:10. Eastern bank: 20m long, 8m wide, widening to 15m wide at the bridge, with a gradient of 1:10. The embankment is represented with a width of 20m at the bridge to ensure it is represented within the model's 10m cell size. This provides a more conservative estimate of flood risk.
Platform gaps at Nether Lock	The two 20m gaps between piers are oblique to the model grid, and are therefore modelled as 20m to 33m wide openings to ensure representation within the model's 10m cell size.
Nottingham to Lincoln West Railway Crossing	Working platforms north and south of the railway line. An average thickness of 1.2m applied by uplifting existing or infilled ground levels from the project model LiDAR.

2.4 Haul road culverts

Locations

2.4.1 Haul roads may provide a barrier to flow pathways through the existing A46 culverts. Haul road culverts are therefore required to provide onward conveyance of flow through the existing A46 culverts.

2.4.2 The existing A46 culverts and their haul road counterparts are summarised in Table 2-3. Haul road culvert dimensions, unless otherwise specified in Table 2-3, would be approximately 10m long and 1m² cross-sectional area (a larger cross-sectional area than the existing culverts). Suitable haul road culvert inverts were inferred from the project LiDAR or were retained from the existing A46 culverts where direct links were made between structures.

2.4.3 Four existing culverts have been identified in Table 2-3 as requiring a haul-road counterpart. Figure 2-4 presents a schematic of the four identified haul road culvert locations in relation to the existing A46 culverts.

2.4.4 Existing A46 culverts typically discharge to adjacent ditches. Where a ditch is not present (e.g., Pipe Culvert No. 5), an excavated trench would be required to prevent new preferential flow paths developing in the zone between existing culverts and haul road culverts.

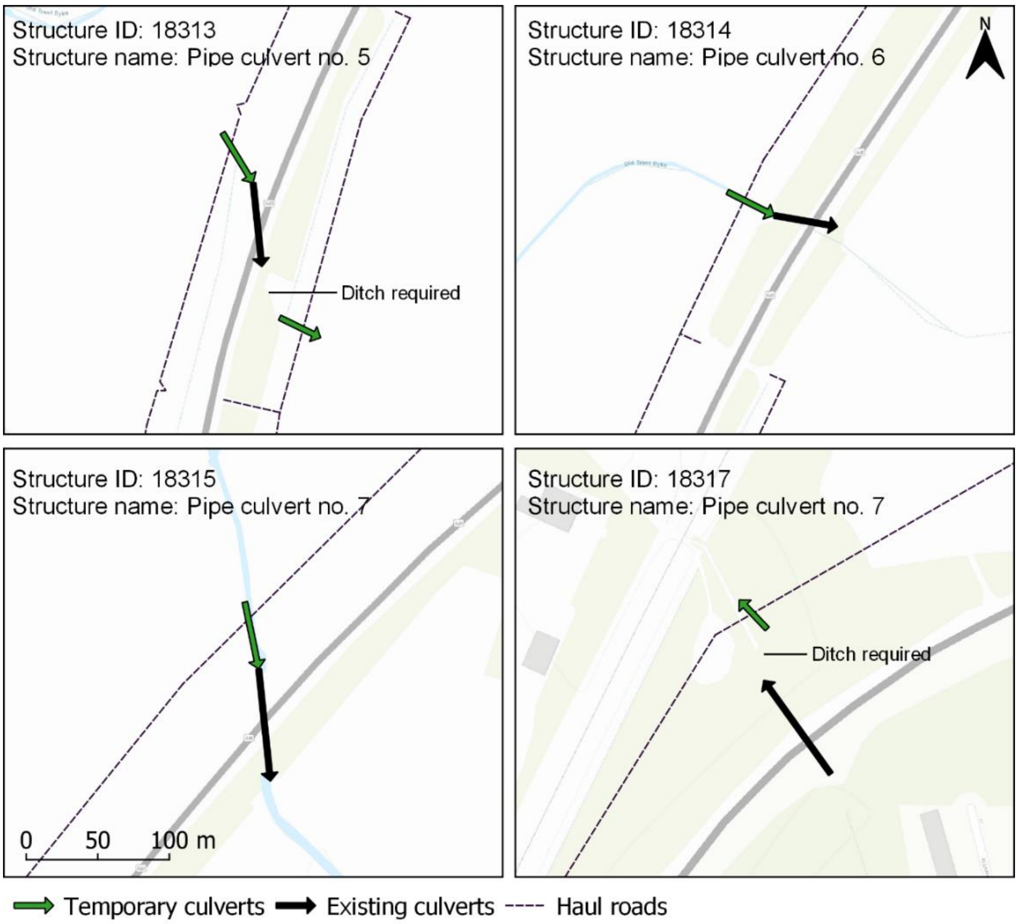
2.4.5 As indicated in Section 2.2, it is assumed for modelling purposes that haul roads are an average 0.7m thickness above topographic ground level. Haul road thickness would vary in reality and may be negligible at some locations. For example, at structure 18307 Farm Access (B2), and structure 18546 Sewage Work Underpass, the top of the haul road would be no higher than the invert levels of the underpasses.

Table 2-3: Existing A46 culverts and their haul road equivalents

Structure ID	Structure Name	Include Haul Road culvert equivalent in Temp Works model?	Reason	BNG Coordinates	
				X	Y
18303	Windmill	No	No haul road at this location.	478100	352851
18305	Flood Relief Culvert	No	No haul road at this location. Culvert extension for permanent works would be built first.	479362	354654
18307	Farm Access (B2)	No	Haul road would be at existing invert level.	478234	353524
18311	Notts-Lincoln Rly West	No	No haul road at this location.	478513	353947
18313	Pipe Culvert No. 5	**Yes**	Two haul road culverts required, one east and one west. There are no ditches at this location - an excavated trench is required to join the existing A46 and haul road culverts.	478162	353354
18314	Pipe Culvert No. 6	**Yes**	One haul road culvert required at the west.	478282	353610
18315	Pipe Culvert No. 7	**Yes**	Two 1.7m² (1.5m diameter) haul road culverts required to the north.	478718	354200
18316	Pipe Culvert No. 12	No	Haul road goes over existing culvert and does not block it.	479780	354720
18317	Pipe Culvert No. 16	**Yes**	One haul road culvert required to the north.	480459	355972
18318	Pipe Culvert No. 17	No	Culvert would not be impeded by temporary works as it is located a sufficient distance away.	481160	355780
18324	Winthorpe Road Subway	No	Subway would remain open and would not be impeded by a haul road.	480930	356000
18545	Notts-	No	Platform and haul road are above	479800	354740

Structure ID	Structure Name	Include Haul Road culvert equivalent in Temp Works model?	Reason	BNG Coordinates	
				X	Y
	Lincoln Rly East		culvert.		
18546	Sewage Work Access	No	Haul road would be at existing invert level.	480280	355650
27622	Farndon Underpass	No	No haul road at this location.	478100	352600
18335	Nether Lock Viaduct	No	Platforms are modelled. No obstruction to River Trent flows otherwise.	480130	355280
18334	Nether Lock Viaduct Rail	No	Platforms are modelled. No obstruction to River Trent flows otherwise.	480170	355390
6992	Bleach House Culvert	No	Culvert extensions built first. There is no temporary culvert at this location.	481550	356050

Figure 2-4 Haul road culvert locations



Source: Contains OS data © Crown Copyright and database rights 2023.

Modelling assumptions: haul road culverts

2.4.6 Haul road culvert modelling assumptions are summarised below:

1. There are no surveyed levels for the temporary culvert inverts. Suitable levels have been inferred from the project LiDAR which is at a 2m resolution and was flown in 2020. At temporary culvert invert locations within channels, the channel bed is well defined by the LiDAR and this was taken as the invert level. At all locations, there is minimal vegetation cover to cause obstruction to LiDAR.
2. Most temporary culverts were modelled in close proximity to the inverts of the existing culverts due to the proximity of the haul roads to the Scheme. This was managed by applying ‘pit’ structures at the interfaces between culverts to allow flood water to spill to the surface. This enables the representation of the interaction that would occur between two separate culvert structures.
3. Where temporary culverts are located at a sufficient distance from an existing culvert, temporary drainage ditches have been modelled and would be required to aid flow conveyance.

2.5 Stockpiles

Excavation at Farndon and Kelham Flood Compensation Areas

2.5.1 Stockpiles would be typically transient in nature and would be quickly depleted during ongoing construction. Stockpile volumes would contribute largely to embankments in permanent works.

2.5.2 Excavation at Farndon and Kelham would occur early in the construction sequence. The resulting stockpiles at Farndon and Kelham may potentially provide a barrier to flow in a flood event.

2.5.3 It is understood that there is potential for stockpiling north of Brownhills, in an area located entirely within Flood Zone 1. However, it may not be practical to haul material from the excavation areas at Farndon and Kelham to Brownhills, and then back again when required for construction. Therefore, it is assumed that stockpiles would occur at Farndon and Kelham and their impact on flooding during the 3.33% AEP event has been assessed.

Modelling assumptions: stockpiles

2.5.4 Sensitivity testing of stockpiles at the Farndon and Kelham FCAs as a barrier to flow during the 3.33% AEP event is required. For simplicity and conservatism, sensitivity testing of stockpiles assumes that stockpile volume is additional to the total (temporary and permanent) earthworks volume.

2.5.5 It is assumed that there may be up to three stockpiles across the Farndon and Kelham areas. Two stockpiles are assumed to be located at Farndon, and one at Kelham. Stockpiles are assumed to be 40m long, 20m wide and 10m high and all three were incorporated in the model.

2.5.6 Stockpile locations at Farndon have been selected for modelling purposes only. Stockpile footprint size will be the same during construction, but locations may vary from these indicative locations shown in Figure 3-1.

2.5.7 The permanent works model includes the Scheme with FCA mitigation, and therefore assumes the FCA areas to be already excavated. At Kelham, for simplicity of modelling, the stockpile has been located outside the FCA in order to conservatively model a maximum stockpile topographic profile above ground level. During construction, however, phasing of excavation activities means that stockpiling will be located within the FCA.

2.5.8 Preliminary modelling indicated that the Kelham FCA would not be completely inundated during a 3.33% AEP event and therefore there is flexibility in the location and orientation of a stockpile in this area.

2.6 Other works

2.6.1 The following are additional elements that have been considered in the assessment of temporary works flood risk.

Piling, sheet piling and scaffolding

2.6.2 Sheet piling would be within the footprint of working platforms. There is no additional sheet piling expected, and none that might extend above ground level and impact flood risk. Therefore, the temporary works hydraulic model does not consider sheet piling.

2.6.3 Scaffolding would be in place around piers and would provide little cross-sectional impediment to flow. Scaffold decks are expected to be above the 3.33% AEP event flood level. Therefore, the temporary works hydraulic model does not consider scaffolding.

Drainage

2.6.4 During temporary works, existing drainage would be maintained to perform as currently.

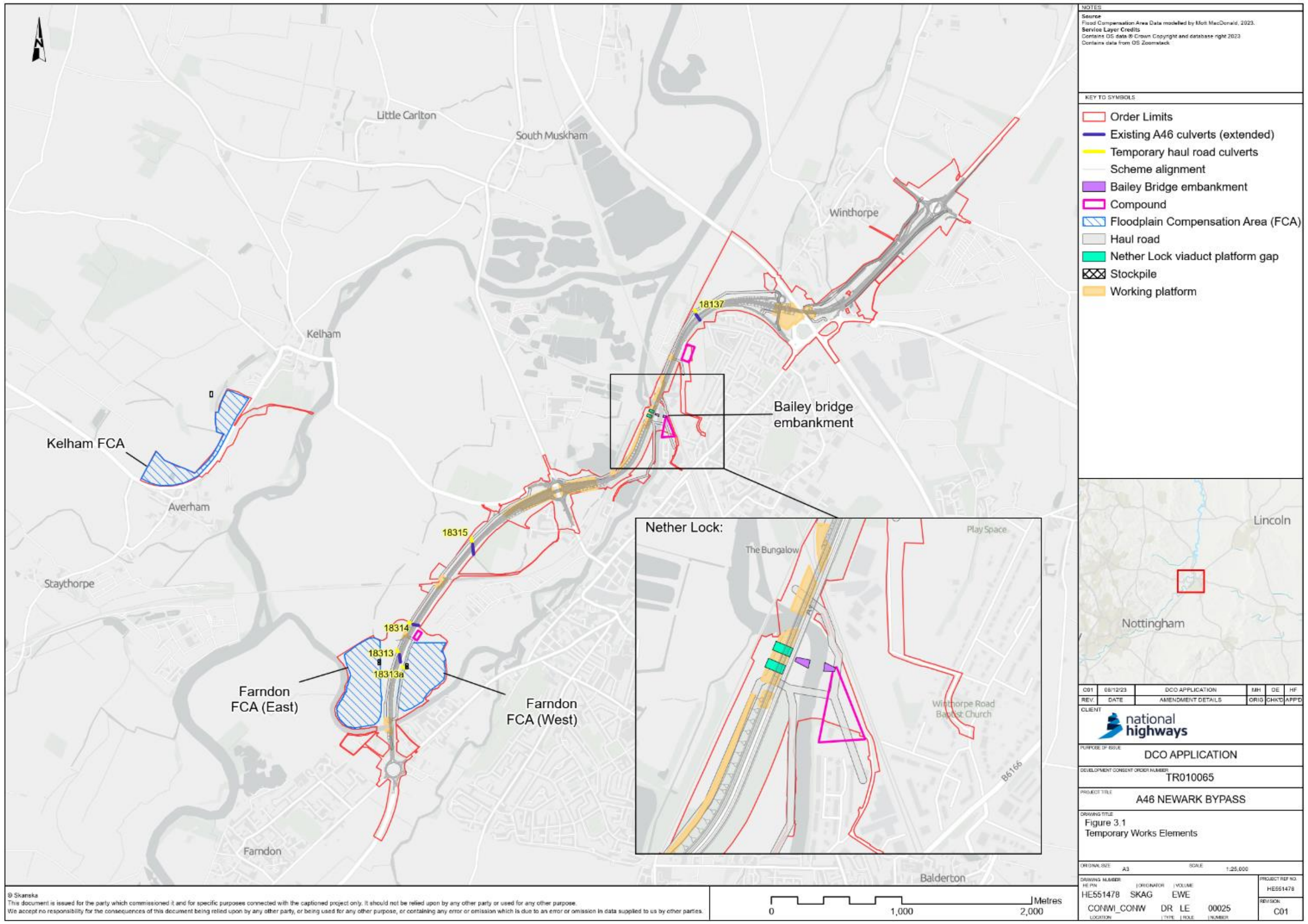
2.6.5 Sequencing for permanent works drainage (e.g., ditches and swales) is expected to manage drainage and would not increase flood risk. Therefore, the temporary works hydraulic model does not consider drainage.

3 Modelling methodology

3.1.1 Temporary works structures were incorporated into the permanent works hydraulic model alongside the Scheme design and FCAs, thus ensuring a conservative assessment of the impacts. The permanent works methodology is provided in the Hydraulic Modelling Technical Report [1].

3.1.2 The representation of temporary works structures was based on the assumptions summarised in the above sections and involved the addition of 2d_zsh layers to the model. Figure 3-1 presents a schematic of the temporary works elements.

Figure 3-1 Temporary works elements



Source: Contains OS data © Crown Copyright and database rights 2023.
<u>Note: stockpile locations are indicative as discussed in Section 2.5, and actual locations may slightly differ from those shown.</u>

4 Results

4.1.1 The below section outlines the results of the temporary works hydraulic modelling assessment. The impact of the structures on flood depths and A46 culvert peak flows is summarised for the 3.33% and 1% AEP events, and the addition of stockpiles during the 3.33% AEP. Comparisons are made to the baseline results, summarised in Section 6 of the Hydraulic Modelling Technical Report[1].

4.2 The 3.33% AEP event

Flood depths

4.2.1 Figure 4-1 presents the depth differences across the floodplain with the addition of the Scheme and temporary works elements for the 3.33% AEP event compared to baseline conditions.

4.2.2

Location	Observed change	Cause of change	Receptors impacted by >0.01m change of depth due to Scheme and temporary works	Approximate Scheme and temporary works flood depths at affected receptors (m)
A	Decrease in flood depths by up to 0.15m along the locations of haul roads. Consistent across the length of the Scheme.	The decrease in flood depth is due to the uplift of haul roads by 0.7m from the project LiDAR. The residual flood depth difference stems from the resultant displacement of flood waters due to haul roads and the Scheme embankment.	None	No receptors affected
B	Increase in flood depths by up to 0.05m to the west of the Scheme and localised increases up to 0.1m upstream of the underpass beneath the Notts to Lincs railway line.	Working platforms at the Notts to Lincs railway crossing and at the south of the Scheme obstruct flow pathways from west to east. This leads to the backing up of flood waters upstream of the working platforms. Flow on the floodplain can only reach the east via existing and temporary culverts, and the Windmill Viaduct. A greater volume of flow now moves northwards	None	No receptors affected

Location	Observed change	Cause of change	Receptors impacted by >0.01m change of depth due to Scheme and temporary works	Approximate Scheme and temporary works flood depths at affected receptors (m)
		through the floodplain.		
C	Increase in depths across the western floodplain between Kelham Road and Great North Road up to 0.02m. Note increases on the margin of the extent typically below 0.01m.	Movement of flood waters from west to east is restricted by working platforms and haul roads along the Scheme. This restriction leads to a slight increase in depths across the western floodplain as flood waters build up.	Five receptors between Kelham Road and Great North Road Approximate increases between 0.01 and 0.015m	0.01 – 0.90
D	Decrease in flood depths to the south east of the Scheme up to 0.05m.	Restricted movement of flood waters from west to east leads to an increase in depths to the west (location B) and a comparable decrease to the east. Decrease in flood depths to the east of the Scheme, including Tolney Lane caravan park, where flood depths would decrease by up to 0.01m when compared to the baseline. Farndon FCA to the east (location H) also provides attenuation of flood waters.	No increase in flood risk.	No increase in flood risk
E	Decrease of up to 0.1m to the east of the Scheme behind the Kelham Road flood defence. No receptors are impacted.			
F	Decrease in depths up to 0.05m to the west of the new Bailey bridge embankment.	The combined impact of the Bailey bridge embankment, working platforms and haul roads at this location slightly restrict flows from east to west. Flow is still able to move westwards via the two 20m gaps between piers at the platform. The slight restriction to flow causes flood waters to back up behind the working platform and increase depths upstream to Kings Waterside & Marina.	No increase in flood risk.	No receptors affected
G	Localised increase up to 0.05m upstream of the embankment. Note that depth increases are typically below 0.02m.		Two receptors at Kings Waterside & Marina Approximate increases of 0.02m	2.20

Location	Observed change	Cause of change	Receptors impacted by >0.01m change of depth due to Scheme and temporary works	Approximate Scheme and temporary works flood depths at affected receptors (m)
		Freeboard at Bailey bridge embankment: 1.85m		
H	Increased depths over 1m in the Farndon FCAs.	The FCAs provide flood storage which results in increased depths where ground levels have been lowered for this purpose.	None	No receptors affected
I	Decrease in flood depths in the range of 0.005m to 0.01m on the south west floodplain.	The Farndon FCA to the west provides locally improved conveyance of flood waters. This decreases depths on the floodplain.	None	No receptors affected
J	Increased depths between 0.1m and 0.3m in the Kelham FCA	The Kelham FCA provides attenuation of flood waters. Connected to the floodplain via culverts.	None	No receptors affected

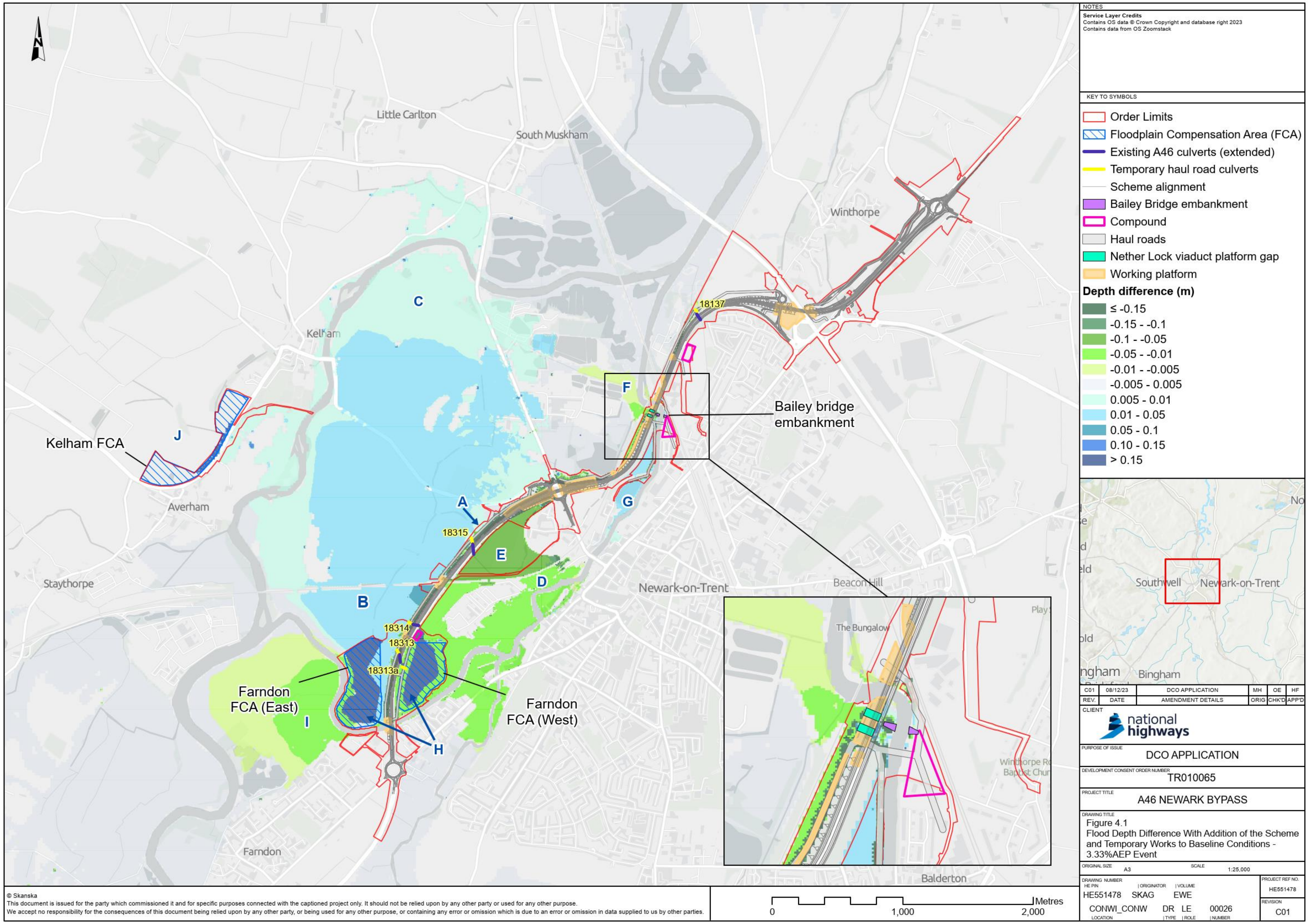
4.2.3 summarises the changes in depths and outlines the causes at specific locations. The number of high sensitivity receptors is provided for each location where the combined permanent and temporary works would cause an increase in flood risk.

Culvert peak flows

4.2.4 The locations of the existing culverts where haul road culverts have been incorporated are presented in Figure 4-1. The impact on peak flows conveyed through the existing A46 culverts where haul road culverts have been incorporated are summarised in Table 4-2.

4.2.5 Baseline peak flows have been compared against those during the Scheme with FCA mitigation, and with the addition of the temporary works. This enables the isolation of the impact of the temporary works from the Scheme on peak flows.

Figure 4-1: Flood depth difference with addition of the Scheme and temporary works structures to baseline conditions - 3.33% AEP event



Source: Contains OS data © Crown Copyright and database rights 2023.

Table 4-1 Summary of observed flood depth changes - 3.33% AEP event

Location	Observed change	Cause of change	Receptors impacted by >0.01m change of depth due to Scheme and temporary works	Approximate Scheme and temporary works flood depths at affected receptors (m)
A	Decrease in flood depths by up to 0.15m along the locations of haul roads. Consistent across the length of the Scheme.	The decrease in flood depth is due to the uplift of haul roads by 0.7m from the project LiDAR. The residual flood depth difference stems from the resultant displacement of flood waters due to haul roads and the Scheme embankment.	None	No receptors affected
B	Increase in flood depths by up to 0.05m to the west of the Scheme and localised increases up to 0.1m upstream of the underpass beneath the Notts to Lincs railway line.	Working platforms at the Notts to Lincs railway crossing and at the south of the Scheme obstruct flow pathways from west to east. This leads to the backing up of flood waters upstream of the working platforms. Flow on the floodplain can only reach the east via existing and temporary culverts, and the Windmill Viaduct. A greater volume of flow now moves northwards through the floodplain.	None	No receptors affected
C	Increase in depths across the western floodplain between Kelham Road and Great North Road up to 0.02m. Note increases on the margin of the extent typically below 0.01m.	Movement of flood waters from west to east is restricted by working platforms and haul roads along the Scheme. This restriction leads to a slight increase in depths across the western floodplain as flood waters build up.	Five receptors between Kelham Road and Great North Road Approximate increases between 0.01 and 0.015m	0.01 – 0.90
D	Decrease in flood depths to the south east of the Scheme up to 0.05m.		No increase in flood risk.	No increase in flood risk

<table>
<tr><th>Location</th><th>Observed change</th><th>Cause of change</th><th>Receptors impacted by >0.01m change of depth due to Scheme and temporary works</th><th>Approximate Scheme and temporary works flood depths at affected receptors (m)</th></tr>
<tr><td>E</td><td>Decrease of up to 0.1m to the east of the Scheme behind the Kelham Road flood defence. No receptors are impacted.</td><td>Restricted movement of flood waters from west to east leads to an increase in depths to the west (location B) and a comparable decrease to the east. Decrease in flood depths to the east of the Scheme, including Tolney Lane caravan park, where flood depths would decrease by up to 0.01m when compared to the baseline. Farndon FCA to the east (location H) also provides attenuation of flood waters.</td><td></td><td></td></tr>
<tr><td>F</td><td>Decrease in depths up to 0.05m to the west of the new Bailey bridge embankment.</td><td rowspan="2">The combined impact of the Bailey bridge embankment, working platforms and haul roads at this location slightly restrict flows from east to west. Flow is still able to move westwards via the two 20m gaps between piers at the platform. The slight restriction to flow causes flood waters to back up behind the working platform and increase depths upstream to Kings Waterside & Marina.

Freeboard at Bailey bridge embankment: 1.85m</td><td>No increase in flood risk.</td><td>No receptors affected</td></tr>
<tr><td>G</td><td>Localised increase up to 0.05m upstream of the embankment. Note that depth increases are typically below 0.02m.</td><td>Two receptors at Kings Waterside & Marina

Approximate increases of 0.02m</td><td>2.20</td></tr>
<tr><td>H</td><td>Increased depths over 1m in the Farndon FCAs.</td><td>The FCAs provide flood storage which results in increased depths where ground levels have been lowered for this purpose.</td><td>None</td><td>No receptors affected</td></tr>
<tr><td>I</td><td>Decrease in flood depths in the range of 0.005m to 0.01m on the south west floodplain.</td><td>The Farndon FCA to the west provides locally improved conveyance of flood waters. This decreases depths on the floodplain.</td><td>None</td><td>No receptors affected</td></tr>
<tr><td>J</td><td>Increased depths between 0.1m and 0.3m in the Kelham FCA</td><td>The Kelham FCA provides attenuation of flood waters. Connected to the floodplain via culverts.</td><td>None</td><td>No receptors affected</td></tr>
</table>

Table 4-2: Summary of existing A46 culvert peak flow changes - 3.33% AEP event

Structure ID	Structure name		Peak flow (m^3/s)			Difference (baseline vs temporary works) (m^3/s)	Cause of change
			Baseline	Scheme with FCA mitigation	Temporary works		
18313	Pipe culvert No. 5	Negative Peak	-1.89	-1.82	-1.09	-0.80	Between 20 and 30 hours model simulation time, there is a negative flow spike in the culvert. This is attributed to flow reaching the downstream end of the culvert first, resulting in a backwater effect before flows entering the upstream of the culvert become greater at around 50 hours. There is a decrease of 0.8m^3/s in the magnitude of negative flow from the baseline with the addition of the temporary works which is due to the haul roads restricting flow on the eastern floodplain which reduces the backwater effect. There is an increase of 0.17m^3/s in the positive peak flow from the baseline with addition of the temporary works due to an increase in depths to the west of the Scheme which leads to a greater volume of flow conveyed east due to a more positive gradient. Less flow is conveyed with the addition of the temporary works than in the Scheme with FCA mitigation, as the haul road slightly restricts the culvert entrance.
		Positive Peak	1.00	1.14	1.17	0.17	
18314	Pipe Culvert No. 6	Negative Peak	-2.08	-2.20	-2.06	-0.02	There is a negative flow spike as observed at Culvert 18313. Addition of the temporary works results in an increase of 0.48m^3/s from the baseline due to increased depths to the west of the Scheme leading to more flow being conveyed. The increase in flow has no significant flood risk impact downstream as flood depths are reduced compared with baseline conditions.
		Positive Peak	0.96	1.12	1.42	0.48	
18315	Pipe Culvert No. 7	Positive Peak	6.47	5.84	9.00	2.53	An overall increase of 2.53 m^3/s from the baseline due to increase in depths to the west of the Scheme. More flow is conveyed with the addition of temporary works due

							to greater flood depths upstream of the culvert. Also, a higher volume of flow is conveyed to this culvert from the south due to the obstruction of the Notts to Lincs railway line crossing (as seen at Location B). No significant impact downstream as flood depths are reduced.
18317	Pipe Culvert No. 16	n/a	0.00	0.00	0.00	0.00	Flow does not reach the culvert inlet during the 3.33% AEP event. Flapped outfall prevents reverse flow through the structure.

Summary

- The Scheme, with the addition of temporary works structures, would increase flood depths to the west of the Scheme by between 0.01 and 0.05m. Depths would decrease to the east of the scheme by between 0.05 and 1.0m.
- The increase in depths to the west arises from the displacement of flood waters by the Scheme and temporary haul roads. This is further affected by the working platforms at the Notts to Lincs West railway crossing and the crossing of the River Trent by working platforms. The working platforms obstruct flow pathways that are present during baseline conditions. Flow can only move eastwards via the existing and temporary culverts, and therefore more flow moves northwards through the floodplain and over the Notts to Lincs railway line (from area B to C). This results in a decrease in flood depths to the east of the Scheme.
- Near Nether Lock, the Bailey bridge embankments, a working platform and haul roads slightly obstruct flow to the west of the Scheme. Flow is not completely blocked, however, as two 20m gaps between piers will allow flow from east to west, to mitigate potential impacts to vulnerable upstream receptors. The slight restriction to flow in this area however causes an increase in flood depths by between 0.02 and 0.05m near the embankments, and this increase extends upstream to the Kings Waterside & Marina.
- At the Bailey bridge embankment, there is a freeboard of 1.85m.
- The impact on existing culvert peak flows is not considered to be significant. The addition of temporary culverts would ensure that flow is still able to reach the existing culverts where this might otherwise be prevented by haul roads.
- The addition of the temporary works would increase flood depths by up to 0.015m to five receptors on the western floodplain between Kelham Road and Great North Road (location C).
- Upstream of the Bailey Bridge embankment (location G), temporary works would increase flood depths by up to 0.05m, effecting two receptors (houseboats) at Kings Waterside & Marina.
- The increases in flood depths at the identified receptors are less than 0.05m and are therefore considered a minor impact. This is discussed in further detail in Section 9 of the Flood Risk Assessment[3].

[3] Flood Risk Assessment HE551478-SKAG-HDG-CONWI_CONW-RP-CD-00022

4.3 The 3.33% AEP event with stockpiles

Flood depths

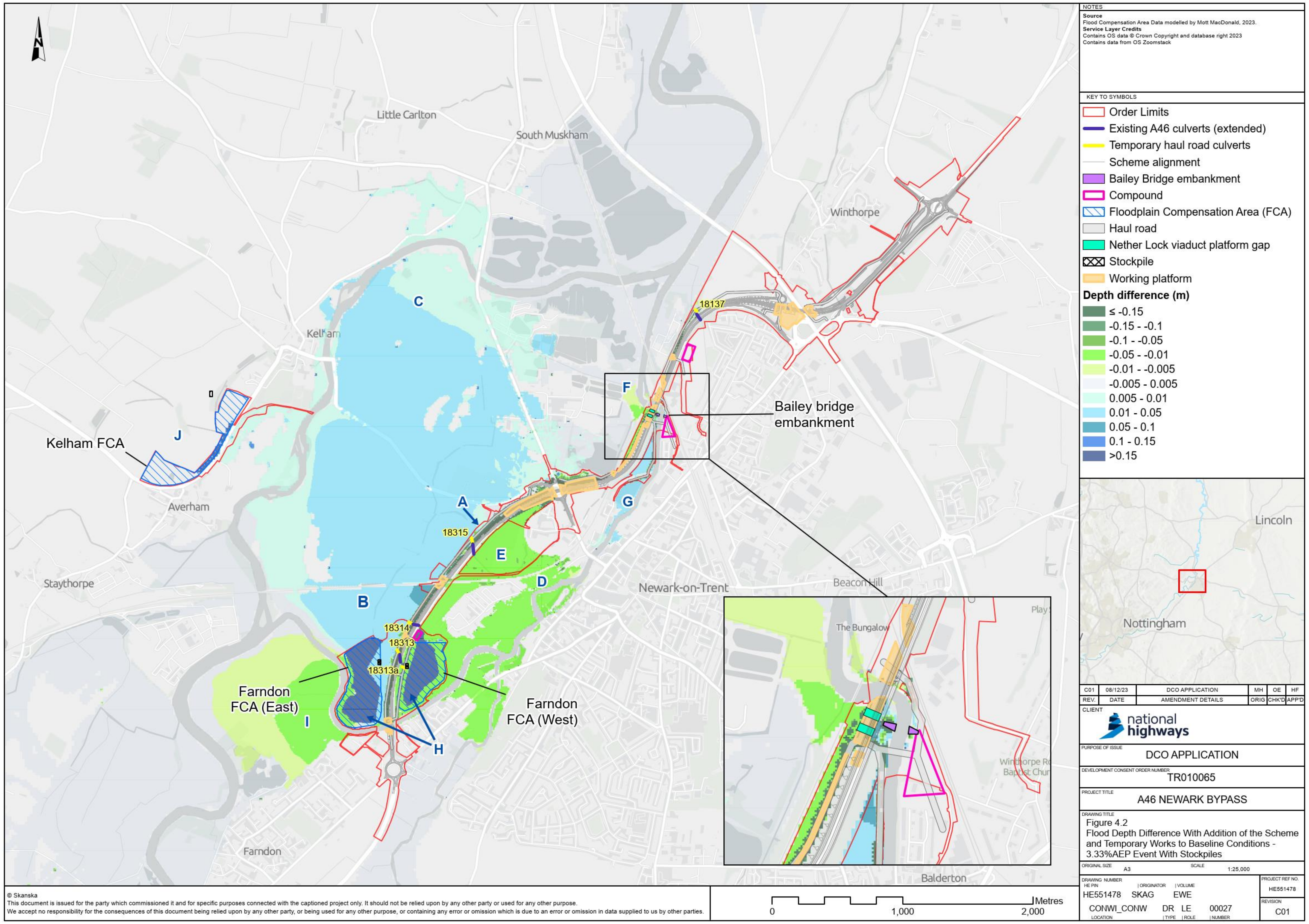
4.3.1 As part of sensitivity testing, the addition of stockpiles alongside temporary works at the Farndon FCAs has been assessed during the 3.33% AEP event. Figure 4-2 presents the difference in depths compared to baseline conditions. The changes observed with the addition of stockpiles are generally consistent with those of the 3.33% AEP event without stockpiles. Certain areas however overly represent the influence of stockpiles, and this is caused by model oscillations, which are discussed in the Hydraulic Model technical Report. Additional model tests described in the Hydraulic Model Technical Report indicate that when the main driver of model oscillations (a railway underpass) is removed from the model, results for the 3.33%AEP event with and without stockpiles are similar. Table 4-3 summarises the changes.

Culvert peak flows

4.3.2 The impact on peak flows conveyed through the existing A46 culverts where haul road culverts have been incorporated are summarised in Table 4-4 for the 3.33% AEP event with the addition of stockpiles.

4.3.3 The culvert peak flows with the addition of the stockpiles to the temporary works has been compared to those predicted without the addition of stockpiles. This enabled the isolation of the effects of the stockpiles on culvert peak flows arising from the stockpiles.

Figure 4-2: Flood depth difference with addition of the Scheme and temporary works structures to baseline conditions - 3.33% AEP event with stockpiles



Source: Contains OS data © Crown Copyright and database rights 2023.

Note: stockpile locations are indicative as discussed in Section 2.5, and actual locations may slightly differ from those shown.

Table 4-3: Summary of observed flood depth changes - 3.33% AEP event with stockpiles

Location	Observed change	Cause of change
A	As observed during the 3.33% AEP event without stockpiles.	
B	As observed during the 3.33% AEP event without stockpiles.	
C	Whilst similar to the 3.33% AEP event temporary works without stockpiles results, the influence of the stockpiles is overly represented in this area. The increase in the extent of the flood depth increases of up to 0.05m between Kelham Road and Great North Road is attributed to model oscillations which are referenced in further detail in the Hydraulic Model Technical Report.	
D	As observed during the 3.33% AEP event without stockpiles.	
E	This area overly represents the influence of stockpiles. Flood depth decreases of up to 0.05m is attributed to model oscillations which are referenced in further detail in the Hydraulic Model Technical Report.	
F	As observed during the 3.33% AEP event without stockpiles.	
G	As observed during the 3.33% AEP event without stockpiles, although the extent where depth increases by between 0.01 and 0.05m extends slightly further upstream to Brewers Wharf on the east bank of the River Trent, potentially impacting 16 residential receptors However, similar to Areas C and E above, this area overly represents the influence of stockpiles. Increased upstream flood extents, compared to the 3.33% AEP event without stockpiles, are considered unlikely to be directly related to stockpiles, and are attributed to model oscillations which are referenced in further detail in the Hydraulic Model Technical Report. Additional model tests described in the Hydraulic Model Technical Report indicate that when the main driver of model oscillations (a railway underpass) is removed from the model, the flood extents and flood depth differences at Brewer's Wharf are more similar to the 3.33% AEP with stockpiles scenario. Residual minor differences in flood extents and depths in this area are not considered to be directly attributable to stockpiles.	
H	As observed during the 3.33% AEP event without stockpiles.	
I	As observed during the 3.33% AEP event without stockpiles.	
J	As observed during the 3.33% AEP event without stockpiles.	

Table 4-4 Summary of existing A46 culvert peak flow changes – 3.33% AEP event with stockpiles

Structure ID	Structure name		**Peak flow (m^3/s)**		**Difference (without vs with stockpiles) (m^3/s)**	**Cause of change**
			Temporary works without stockpiles	**Temporary works with stockpiles**		
18313	Pipe culvert No. 5	Negative peak	-1.09	-1.08	+0.01	Negligible change in peak flows in the culvert, and a small increase of 0.01m^3/s in the negative peak. No impact on flood risk.
		Positive peak	1.17	1.17	0.00	
18314	Pipe culvert No. 6	Negative peak	-2.06	-2.04	+0.02	Small increase of 0.05m^3/s in the positive flow as the stockpile upstream of the culvert displaces flood waters and slightly increases depths, conveying more flow through the culvert. No increase in flood risk.
		Positive peak	1.42	1.47	+0.05	
18315	Pipe culvert No. 7	Positive peak	9.00	8.00	-1.00	A reduction of 1.0m3/s in the positive peak flow attributed to model oscillations in area E (Table 4-3). No impact on flood risk.
18317	Pipe culvert No. 16	n/a	0.00	0.00	0.00	Flows do not reach this culvert. The flapped outfall prevents reverse flow.

Summary

- The flood risk impacts of the presence of stockpiles at the Farndon FCA areas during the 3.33% AEP event are broadly similar to those observed without stockpiles.
- Depth differences observed in areas C, E, G with the addition of stockpiles compared to the 3.33%AEP without stockpiles, are attributed to model oscillations which are discussed in further detail in the Hydraulic Modelling Technical Report. These depth differences are considered unlikely to be caused by the introduction of stockpiles alone to the model.
- At structure 18315, there is a reduction of $1m^3/s$ in the peak flow, which is also likely due to flood level oscillations at area E .
- The addition of stockpiles results in small changes in culvert peak flows at structures 18313 and 18314. These changes are attributed to the displacement of flood waters due to the stockpiles leading to a higher volume of flow conveyed through the culverts. These changes have no impact on flood risk downstream of the culverts.

4.4 The 1% AEP event

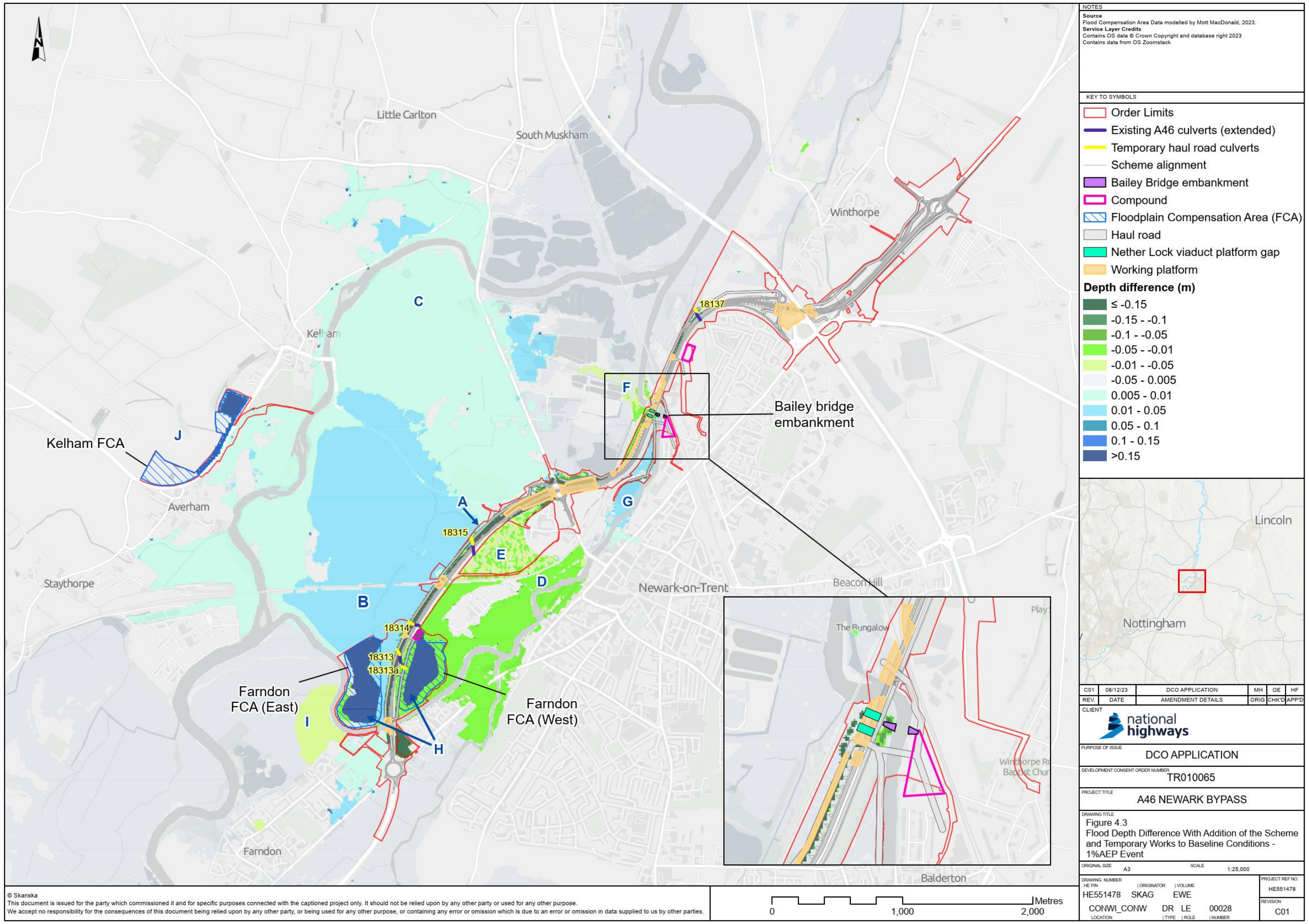
Flood depths

4.4.1 The impact of the combined permanent and temporary works elements on flood risk during the 1% AEP event has also been assessed as part of sensitivity testing. Figure 4-3 presents the depth differences in comparison to the baseline conditions for the 1% AEP event. The changes observed are broadly consistent with those of the 3.33% AEP event. Any additional changes are described in Table 4-5.

Culvert peak flows

4.4.2 The impact on peak flows conveyed through the existing A46 culverts where haul road culverts have been assessed are summarised in Table 4-6

Figure 4-3: Flood depth difference with addition of the Scheme and temporary works structures to baseline conditions - 1% AEP event



Source: Contains OS data © Crown Copyright and database rights 2023.

Table 4-5 Summary of observed flood depth changes - 1% AEP event

Location	Observed change	Cause of change	Receptors impacted by >0.01m change of depth due to Scheme and temporary works	Approximate Scheme and temporary works flood depths at affected receptors (m)
A	As observed during the 3.33% AEP event.		None	No receptors affected
B	As observed during the 3.33% AEP event.		None	No receptors affected
C	Depth increase across western floodplain between Kelham Road and Great North Road up to 0.01m. Margins of extent near Kelham Road see depth increases up to 0.02m.	Movement of flood waters from west to east is restricted by working platforms and haul roads along the Scheme. This restriction leads to a slight increase in depths across the western floodplain as flood waters build up.	One dwelling. Approximate increase of 0.01m	0.55
D	Decrease in flood depths to the south east of the Scheme up to 0.05m.	There is greater overtopping from the River Trent to the east of the Scheme during higher order events. Therefore, the impact of temporary works reducing depths to the east is less significant.	No increase in flood risk.	No increase in flood risk.
E	For the 1% AEP, there is up to 0.01m depth decrease compared to the baseline.			
F	Freeboard at Bailey bridge embankment: 1.46m As observed during the 3.33% AEP event.			
G	One additional receptor compared to 3.33% AEP event subject to flood depth increase between 0.01 and 0.05m.	Increased flooding due to higher AEP event	Two receptors at Kings Marina, similar to the 3.33% AEP event. The additional residential receptor is at Mather Road (west bank of River Trent). Approximate increase of 0.01m.	0.30 – 2.00
H	As observed during the 3.33% AEP event.		None	No receptors affected

Location	Observed change	Cause of change	Receptors impacted by >0.01m change of depth due to Scheme and temporary works	Approximate Scheme and temporary works flood depths at affected receptors (m)
I	General increase in depths to the south of area I, of up to 0.01m and localised increase up to 0.10m in the Farndon area. 50 receptors subject to flood depth increase between 0.01 and 0.05m.	Working platforms at the A46 crossing of the River Trent at Windmill Viaduct obstruct flow movement to the east. This results in the backing up of flood waters and increasing depths. The compound located at Farndon Roundabout also displaces flood waters	50 dwellings. Increases between 0.01 and 0.05m	0.05 – 0.35
J	Further increase in flood extent inside Kelham FCA. Flood depth increases up to 0.5m.	Increased flooding due to higher AEP event.	None	No receptors affected

Table 4-6 Summary of existing A46 culvert peak flow changes -1% AEP event

			Peak flow (m^3/s)				
Structure ID	**Structure name**		**Baseline**	**Scheme with FCA mitigation**	**Temporary works**	**Difference (baseline vs temporary works) (m^3/s)**	**Cause of change**
18313	Pipe culvert No. 5	Negative Peak	-1.88	-1.81	-1.11	-0.77	Negative flow spike as observed in the 3.33% event.
		Positive Peak	1.05	1.16	1.19	0.14	An overall increase of 0.14m^3/s from the baseline due to an increase in depths to the west of the Scheme leading to a greater volume of flow conveyed east. There is a small increase of 0.03m^3/s with the addition of the temporary works however there is no impact on flood risk. Consistent with the 3.33% AEP event observations.
18314	Pipe Culvert No. 6	Negative Peak	-2.07	-2.19	-2.06	-0.01	Negative flow spike as observed in 3.33% AEP event.
		Positive Peak	1.02	1.14	1.53	0.51	An overall increase of 0.51m^3/s from the baseline due to an increase in depths to the west of the Scheme. A further increase with addition of temporary works due to greater flood depths upstream of the culvert resulting from haul road displacement. Negligible impact downstream as flood depths are reduced compared with baseline conditions. Consistent with the 3.33% AEP event observations.
18315	Pipe Culvert No. 7	Positive Peak	6.93	6.16	10.54	3.61	An overall increase of 3.61m^3/s from the baseline due to an increase in flood depths to the west of the Scheme. A further increase with addition of temporary works due to greater flood depths upstream of the culvert. Also, a higher volume of flow is conveyed to this culvert from the south due to the obstruction of the Notts to Lincs railway line crossing (as seen at Location B). This increase as a result of the temporary works does not increase flood risk, as flood depths downstream are lower than the baseline.

							Consistent with the 3.33% AEP event observations.
18317	Pipe Culvert No. 16	n/a	0.00	0.00	0.00	0.00	As observed during the 3.33% AEP event.

Summary

- The impacts of temporary works structures on flood depths during the 1% AEP event are generally consistent with those observed during the 3.33% AEP event.
- To the east of the Scheme (location E), the decrease in depths is more significant during the 3.33% AEP event. Flood depths in this area are impacted by overtopping from the River Trent to the east of the Scheme during the 1% AEP event. The impact on flood risk from the temporary works is therefore less apparent.
- To the west of the Scheme (location C), there would be an increase in flood depths of approximately 0.01m to one dwelling on the floodplain following addition of temporary works elements. This is lower than the five receptors impacted during the 3.33% AEP event due to more widespread flooding causing a localised reduction in the amount that the flood depth changes in this area.
- Upstream of the Bailey bridge embankment (location G), three residential receptors would be impacted by increased flood depths, which is one more than the two impacted during the 3.33% AEP event.
- At the Bailey bridge embankment, there is a freeboard of 1.41m.
- South of location I, there are localised increases in depths due to working platforms at the A46 crossing of the River Trent at Windmill Viaduct and the compound at Farndon Roundabout. There would be an increase in flood depths by between 0.01 and 0.05m to 50 “highly sensitive” receptors arising from the temporary works.
- Overall, there would be a minor impact to a total of 53 “highly sensitive” receptors arising from the combined permanent and temporary works during the 1% AEP event.
- The impact on peak flows through the existing culverts is generally consistent with those observed during the 3.33% AEP. The results demonstrate that flows are still able to reach the culverts in locations where this might otherwise be prevented by haul roads.
- The greatest change in culvert peak flow compared to the baseline is predicted to be at structure 18315. This increase is attributed to a higher volume of flow being conveyed north on the western floodplain due to blockage by the scheme. This is increased further with addition of the temporary works as the haul road provides some blockage at the inlet of the culvert. This impact does not affect flood risk, however, and flood depths downstream in location E are predicted to be lower than in the baseline.

Conclusions

4.4.3 Changes in flood depth as a result of the combined permanent and temporary works elements have been compared to baseline depths. Inclusion of the scheme with the temporary works provides a conservative assessment of flood risk impact of the temporary works.

4.4.4 During the 3.33% AEP event, the combined permanent and temporary works elements would lead to an increase in flood depths of between 0.01 and 0.05m to the west of the Scheme, and a decrease of between 0.05m and 0.1m to the east. This is attributed to the displacement of flood waters by the Scheme and temporary haul roads. This is also a result of the blockage of existing flow paths west to east at the Notts to Lincs West railway crossing and where the A46 crosses the River Trent at Windmill Viaduct.

4.4.5 A total of seven “high sensitivity” receptors in on the western floodplain and upstream of the Bailey bridge embankment would be subject to an increase in flood depths of between 0.01 and 0.05m during the 3.33% AEP event due to the combined permanent and temporary works. This is considered a minor impact and is discussed in further detail in Section 9 of the Flood Risk Assessment[4].

4.4.6 The addition of stockpiles at the Farndon FCA would lead to similar impacts on depth differences observed during the 3.33% AEP. However model oscillations lead to an over-representation in some areas of the effect of stockpiles in the 3.33% AEP, when compared to the 3.33%AEP event without stockpiles. The overall conclusions in relation to flood risk are expected to remain the same as those without stockpiles.

4.4.7 The impacts during the 1% AEP are consistent with those of the 3.33% AEP event but on a larger scale due to the increased magnitude of flooding. A total of 50 “high sensitivity” receptors on the western floodplain, upstream of the Bailey bridge embankment, and near Farndon Roundabout would be subject to increases in flood depths of between 0.01 and 0.05m due to the Scheme and temporary works.

4.4.8 Changes in peak flow rates through the existing culverts are not considered to have a significant effect. The results demonstrate that the addition of temporary culverts would ensure that flows continue to reach existing culverts in locations where this would otherwise be prevented by haul roads. In instances where peak flows are changed as a result of temporary works elements, no detrimental flood risk impacts arise.

[4] Flood Risk Assessment HE551478-SKAG-HDG-CONWI_CONW-RP-CD-00022

G. Floodplain Compensation Areas – RAG Matrix

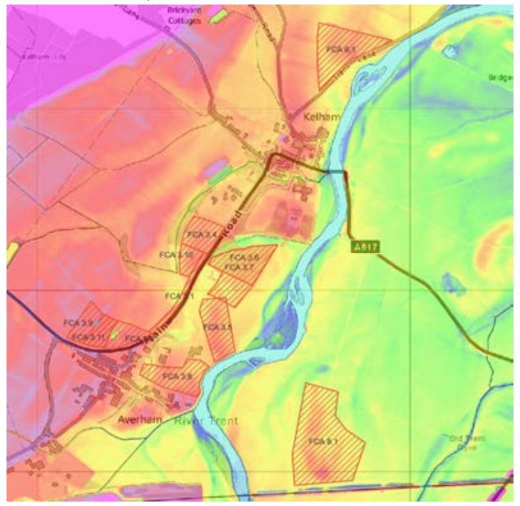
Floodplain Compensation Areas RAG Screening

This screening matrix identifies sites in the study area that were screened as potentially suitable for utilisation as Floodplain Compensation Areas. It identifies the sites that have been taken forward as part of the Scheme (edged in bold black). The screening process and factors that determined the selection of the sites selected as Flood Compensation Areas as part of the Scheme are described in Section 3.3 of the Flood Risk Assessment [ES Appendix 13.2] and Chapter 3 (Assessment of Alternatives) of the Environmental Statement (TR010065/APP/6.1 .

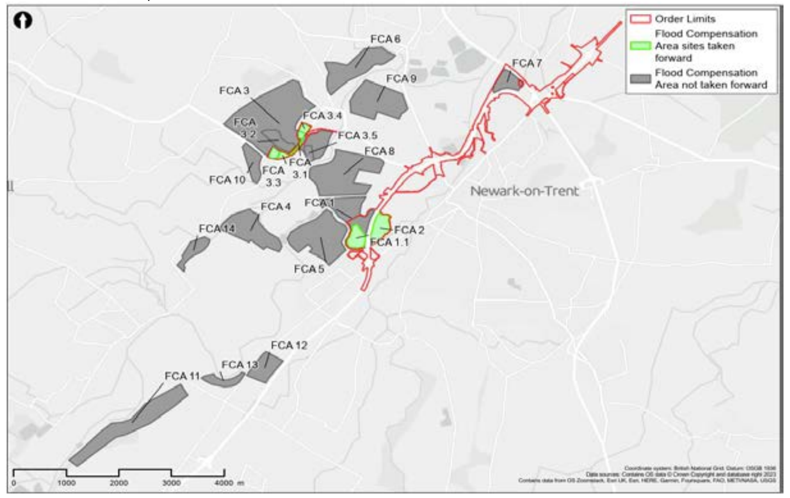
Factors	Description	FCA 1	FCA 1.1	FCA 1.2	FCA 2	FCA 3	FCA 3.1	FCA 3.2	FCA 3.3	FCA 3.4	FCA3.5	FCA 3.6	FCA 3.7	FCA 3.8
Location description	N/A	Farndon Borrow Pits	Farndon Borrow Pits Proposal A	Farndon Borrow Pits Proposal B	Farndon Borrow Pits East	Kelham Overall	Kelham Site	Kelham Site	Kelham Site	Kelham Site	Kelham Airfield site	Kelham Airfield site 2	Kelham Airfield site 3	Averham Site
Floodplain Compensation Levels available (approx.)	Relevant elevations available in mAOD	9.6-11.4	9.6-11.4	10.6-12.0	9.6-11.4	10.8-12.2	10.8-12.2	10.8-12.2	10.8-12.2	10.8-12.2	9.6-12.2	9.6-12.2	9.6-12.2	10.8-12.2
Hydraulic Connectivity	Connectivity to River Trent & A46 scheme													
Planning Applications on the site	According to Newark and Sherwood online map													
Ecology														
Ecology - Arb	Arboriculturist sites which have been surveyed													
Archaeology	Archaeology findings													
Land Usage	Vulnerability classification of the receptors													
Land Availability	Future planning and likely need for land													
Utilities	Utility clashes/diversions - desktop based assessment													
Land Contamination	Contaminated land risk assessment													
Groundwater	High groundwater levels													
Geotech	Suitable gradient for cutting slopes													
Change in Flood Risk	Change in risk													
Public Right of Way crossings	Can Public Right of Way cross the land be easily rerouted.	No	No	No	No	yes	yes	no	no	no	no	no	no	no
Within DCO Consulted Area?	Yes/No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Conclusion														

Factors	Description	FCA 3.9	FCA 3.10	FCA 3.11	FCA 4	FCA 5	FCA 6	FCA 7	FCA 8	FCA 9	FCA 10	FCA 11	FCA 12	FCA 13	FCA 14	FCA 6.1	FCA 8.1
Location description	N/A	Kelham Additional Area	Kelham land south of conservation area	Kelham Additional Area 2	Staythorpe South	North of Farndon	Kelham Trent Lane	Brownhills Junction	Tarmac South	Tarmac North	Staythorpe North	RAF Syerston Trent Lane	Stokes Hall 1	Stokes Hall 2	Rolleston	Kelham Trent Lane Reduced	Tarmac South Reduced
Floodplain Compensation Levels available (approx.)	Relevant elevations available in mAOD	10.8-12.2	10.8-12.2	10.8-12.2	9.8-11.4	9.6-11.8	9.6 - 12.6	9.6-9.9	9.6-13.0	9.6-10.0	9.8-12.5	11.0-13.0	11.0-13.0	11.0-13.0	11.0-13.0	9.6 - 12.6	9.6-13.0
Hydraulic Connectivity	Connectivity to River Trent & A46 scheme																
Planning Applications on the site	According to Newark and Sherwood online map																
Ecology																	
Ecology - Arb	Arboriculturist sites which have been surveyed																
Archaeology	Archaeology findings																
Land Usage	Vulnerability classification of the receptors																
Land Availability	Future planning and likely need for land																
Utilities	Utility clashes/diversions - desktop based assessment																
Land Contamination	Contaminated land risk assessment																
Groundwater	High groundwater levels																
Geotech	Suitable gradient for cutting slopes																
Change in Flood Risk	Change in risk																
Public Right of Way crossings	Can Public Right of Way cross the land be easily rerouted.	no	no	no	yes	yes	yes	no	no	no	no	yes	no	no	yes	no	no
Within DCO Consulted Area?	Yes/No	Yes	Yes	Yes	No	No	No	Yes	No	No	No	No	No	No	No	No	No
Conclusion																	

Kelham & Averham map:



Wider site selection map:



Key to the RAG Matrix:

- Site unsuitable
- Site is potentialy or definitely unsuitable depending on costing and/or suitability of more appropriate sites
- Solution may require mitigation/civil engineering considerations
- Considered suitable
- Considered suitable and taken forward as part of the Scheme

Justification for incomplete rows:

Ecology-Arb	Not all sites were surveyed outside of the statutory consultation boundary of the scheme.
Archaeology	Not all sites were surveyed outside of the statutory consultation boundary of the scheme.
Land Availability	Where other factors prevent use of the site, this factor was not investigated due to risk of unnecessarily causing inconvenience to landowners.
Utilities	Utilities information was not requested where other factors prevented the use of the site.
Land Contamination	Not all sites were surveyed outside of the statutory consultation boundary of the scheme.
Groundwater	Not all sites were surveyed outside of the statutory consultation boundary of the scheme.

H. Hydraulic Modelling Technical Note

Contents

Figures

Tables

Executive summary

This technical note provides information regarding additional hydraulic modelling and analysis carried out to supplement the details provided in Appendix 13.2 Flood Risk Assessment of the Environmental Statement Appendices [APP-177]. The technical note also provides details to support the responses to the Relevant Representations [RR-020] from the Environment Agency, specifically discussing the issues raised in EAFR-001, EAFR-002, EAFR-007 and EAFR-009.

In assessment of fluvial flood risk impacts to and from the A46 Newark Bypass (the “Scheme”), the Flood Risk Assessment (FRA) [APP-177] considers that fluvial flood risk impacts in the 1% AEP plus climate change event from the Scheme with flood risk mitigations (the Mitigated Scheme) to sensitive receptors are negligible, in accordance with Design Manual for Roads and Bridges guidance. This technical note aims to improve the understanding of the flood risk impacts at receptors resulting from the Scheme, for the 1% AEP plus climate change event and also for the modelled lower magnitude events. Many of these impacts are very small in magnitude, with changes in flood depths in the hydraulic model results of the order of a few millimetres.

Sources of uncertainty in the hydraulic modelling results are discussed, noting that model uncertainties occur for all models and have a potential magnitude that is comparable to or greater than the very small changes in flood depth assessed in this technical note.

Within this technical note, model results are presented and discussed for the baseline and Scheme (permanent works) scenarios, and the return period events assessed for the Scheme. All presented impacts to receptors in the 1% AEP plus climate change event are negligible. This is discussed further in Section 3.5.

The Design Manual for Roads and Bridges guidance defines a change in peak flood level of +/- 10mm as having a "negligible" impact. The Environment Agency agrees with this assumption, observing[1] that a 10mm change in flood depth falls within model tolerance.

Sensitivity testing has been undertaken at Windmill Viaduct for the 1% AEP plus climate change event. Sensitivity testing was also undertaken at Fosse Road and Tolney Lane for lower magnitude events. **This sensitivity testing demonstrates that the Mitigated Scheme does not result in any increases in flood depths greater than 10mm at vulnerable receptors, for any modelled flood event**. Sensitivity tests discussed in this technical note are additional to, and independent of, any sensitivity testing discussed in Appendix A of the FRA [APP-177].

The conclusions of the FRA [APP-177] and the significance of effect for fluvial flood risk presented within Chapter 13 Road Drainage and the Water Environment of the Environmental Statement [APP-057] and the assessment presented within Appendix 13.1 Water Framework Directive Compliance Assessment of the Environmental Statement Appendices [APP-176] are unchanged by the additional sensitivity testing

[1] In EAFR-002 of Environment Agency Written Representations for Deadline 2 [REP2-043]

results presented within this technical note. All increases in flood levels presented for all modelled events are “negligible” as the increases in depth at vulnerable receptors are less than 10mm, in accordance with Design Manual for Roads and Bridges guidance and are therefore considered acceptable by the Applicant.

1. Introduction

1.1 Background

1.1.1 The Scheme comprises the development of a stretch of the A46 between Farndon Junction and Winthorpe Junction. The Scheme aims to upgrade an existing single carriageway road in Newark-on-Trent to a dual carriageway.

1.1.2 The Scheme requires the construction of a new carriageway that will be located alongside the existing carriageway. These associated works will require new junctions and features such as utilities, drainages, public rights of way and accesses, which will include environmental mitigation work.

1.1.3 As a part of the application for development consent, the Applicant has assessed the potential changes to flood risk due to the Scheme, to enable mitigation measures to be prepared as part of the Scheme design that comply with National Planning Policy Framework requirements. This assessment is presented in the FRA [APP-177] .

1.1.4 This technical note provides details to support the responses to the Relevant Representations [RR-020] from the Environment Agency, specifically discussing the issues raised in EAFR-001, EAFR-002, EAFR-007 and EAFR-009. Section 1.4 outlines how the sections of this technical note relate to the specific Relevant Representations.

1.1.5 In assessment of fluvial flood risk impacts to and from the Scheme, the FRA [APP-177] considers that fluvial flood risk impacts in the 1% AEP plus climate change event (the design event) from the Mitigated Scheme to sensitive receptors are “negligible”, in accordance with Design Manual for Roads and Bridges (DMRB) LA 113[2] and LA 104[3] guidance. Additional hydraulic modelling and analysis has been undertaken to help to respond to the Relevant Representations and therefore to supplement the details provided in the FRA [APP-177]. This additional modelling and analysis consisted of targeted sensitivity tests, using the hydraulic model to improve the understanding of flood risk impacts at specific receptors for specific events.

1.1.6 An additional technical note has been issued on the Floodplain Compensation Areas [REP3-035] in addition to this note, which provides further detail on the design and assessment of the floodplain compensation areas that form part of the Scheme.

1.2 List of terms used

1.2.1 The following terms are used throughout this technical note and are defined here for ease of reference:

[2] National Highways (2019) DMRB LA 113 – Road drainage and the water environment, Revision 1 [online] available at: LA 113 - Road drainage and the water environment (standardsforhighways.co.uk). LA 113 - Road drainage and the water environment (standardsforhighways.co.uk);

[3] National Highways (2020) DMRB LA 014 – Environmental assessment and monitoring, Revision 1 [online] available at: LA 104 - Environmental assessment and monitoring (standardsforhighways.co.uk). LA 104 - Environmental assessment and monitoring

- **Original model –** this was the hydraulic model developed and used to support the FRA [APP-177].
- **Sensitivity tests –** these are tests that have been undertaken using the original model as a base. The tests involve the enforcement of features in the model at specific locations to provide greater understanding of the modelled flood risk during specific flood events.
- **Baseline scenario** – this is the scenario representing the river and floodplain under the existing 'baseline' conditions prior to the development of the Scheme. Sensitivity tests have been undertaken on both baseline and Scheme scenarios in the hydraulic model in order to produce comparable results. Therefore, the baseline scenario reflects the model enforcements made in the sensitivity tests and consequently differs from the original model.
- **Mitigated Scheme –** this term was used in the FRA [APP-177] to refer to the representation of the Scheme in the hydraulic model that includes the mitigation measures that are part of the DCO application. In sensitivity tests, comparisons are made between the Mitigated Scheme and the baseline, both of which have the same local model enforcements, unless noted otherwise.
- **Enforced/enforcements –** these terms have been used throughout this technical note to refer to the model amendments, including ground features and structures, made as part of the sensitivity testing. The sensitivity tests are discussed in further detail in Section 3 for the 1% AEP plus climate change event, and in Appendix B for the 1% and 5% AEP events.
- **Receptor vulnerability –** the FRA [APP-177] considers receptor sensitivity according to the DMRB guidelines. These broadly align with flood risk vulnerability classifications provided in Annex 3 of the National Planning Policy Framework (NPPF)[4]. For this technical note, receptor vulnerability is expressed according to the NPPF classifications which are: Essential Infrastructure, Highly Vulnerable, More Vulnerable, Less Vulnerable and Water Compatible.
- **Flood hazard –** this term is used throughout the technical note to describe the potential risk to receptors. The hydraulic model outputs flood hazard classifications which align with those described in the Environment Agency "Flood Risks to People"[5] documentation. Modelled peak velocities and depths are used to classify areas of flooding as Low, Moderate, Significant or Extreme degree of hazard.

---

[4] National Planning Policy Framework - Annex 3: Flood risk vulnerability classification - Guidance - GOV.UK (www.gov.uk)

[5] Environment Agency (2006) Flood Risks to People, available at: https://assets.publishing.service.gov.uk/media/602bbc768fa8f50383c41f80/Flood_risks_to_people_-_Phase_2_The_flood_risks_to_people_methodology_technical_report.pdf

1.3 Use of the National Receptor Database in the assessment of potential flood risk impacts

1.3.1 The Environment Agency National Receptor Database (NRD)[6] classifies receptors according to Multi-Coloured Manual (MCM) codes[7], class codes and class descriptions. The NRD contains point location information on properties such as their address and the type of property use. The NRD does not provide information about non-property-based receptors such as transport networks and environmental designations.

1.3.2 Due to licensing restrictions, the NRD is not widely accessible to the public as it relies on Ordnance Survey data, which is subject to restrictions regarding its release as open data. However, summary information derived from the NRD is included in various Environment Agency publications and reports. Therefore, both this technical note and the FRA [APP-177] only provide summary information from the analysis of NRD data.

1.3.3 For the purposes of this technical note, NRD class descriptions have been used to assign NPPF vulnerabilities, where possible, to all receptors within the study area. The tabulated NPPF vulnerability classification for each NRD class description is provided in Appendix A of this technical note.

1.3.4 However, not all NRD receptors have class descriptions. Specifically, any receptors with an MCM code of '999' lack class description information. Consequently, for all receptors with an MCM code of '999', aerial imagery was assessed to assign a probable land-use type and therefore vulnerability. The qualifier 'Low confidence' was added to the NPPF vulnerability for these receptors, e.g. "More Vulnerable (Low Confidence)" and "Less Vulnerable (Low Confidence)".

1.3.5 Although the NRD is very useful in assessing flood risk to receptors across the modelled area, there are potential sources of error in the location and classification of individual receptors. The NRD is a snapshot at a given moment in time, informed by underlying Ordnance Survey receptor address data and topology. Any inaccuracies noted in the review of NRD receptors are flagged in the relevant sections of this technical note.

1.4 Structure of the technical note

1.4.1 This technical note provides details and a narrative on the flood risk impacts arising from the Scheme. The document has been split into the following sections:

- **Section 2 – Modelling uncertainty:** A discussion of the uncertainties in the hydraulic modelling results that are important context for the consideration of flood risk impacts predicted by the model.

  This section contains discussion points that are relevant for the responses for the Environment Agency Relevant Representations being considered in this technical note.

[6] Environment Agency (2014) NRD2014 Guidance Version 1, September 2015

[7] FHRC (2024) The Handbook MCM online (accessed Dec 2024)

- **Section 3 – Receptor impacts for the design event**: This section summarises the flood depth differences at receptors for the Mitigated Scheme versus baseline scenarios using the NRD and the NPPF receptor classifications for the 1% AEP plus climate change event.

  This section provides information supporting the responses for EAFR-001 and EAFR-002 [RR-020].
- **Section 4 – Slough Dyke realignment:** This section documents a sensitivity test in relation to the Slough Dyke realignment.

  This is relevant to the response for EAFR-007 [RR-020].

- **Section 5 – Climate change allowances applied in the hydraulic model:** This section discusses the assessment of a credible maximum river flow climate change scenario that was included in the FRA [APP-177].

  This section provides information to support the response for EAFR-009 [RR-020].

- **Appendix A – NRD to NPPF receptor vulnerabilities:** This section presents the methodology for assigning NPPF flood risk vulnerabilities to all receptors within the study area to inform the detailed receptor analysis.

- **Appendix B – Receptor analysis for low magnitude events:** This section summarises the flood depth differences at receptors for the Mitigated Scheme versus baseline scenarios using the NRD and NPPF receptor classifications for events of lower magnitude than the 1% AEP plus climate change event. These are the 50%, 20%, 5%, 3.33% and 1% AEP events.

  This section provides information to support the response for EAFR-001 and EAFR-002 [RR-020].

1.5 Policy context, guidance and guidelines

1.5.1 Guidance, standards, and best practice have been followed in the FRA (APP-177) and within this document, with particular reference to:

- DMRB LA 113 - Road drainage and the water environment[2]
- DMRB LA 104 - Environmental assessment and monitoring[3]
- National Planning Policy Framework (NPPF)[8]
- Planning Practice Guidance: Flood risk and coastal change[9]

[8] Ministry of Housing, Communities and Local Government (2012): National Planning Policy Framework. Available at National Planning Policy Framework - Guidance - GOV.UK (www.gov.uk)

[9] Department for Levelling Up (2022) Planning Policy Guidance: Flood risk and coastal change [online] Available at: Flood risk and coastal change - GOV.UK (www.gov.uk)

- Nationally Significant Infrastructure Projects: Advice on the Water Framework Directive[10]

1.5.2 The FRA [APP-177] has been developed in accordance with DMRB LA 113 and LA 104 guidelines. DRMB provides guidance tables on receptor sensitivity, magnitude of impact and significance of effect[11].

1.5.3 Guidance on receptor sensitivity which is provided within Table 3.70 of the DRMB LA 113, broadly aligns with NPPF receptor vulnerability classifications[4], and examples of both are provided in Table 4.2 of the FRA [APP-177].

1.5.4 Of particular relevance to the assessment of impacts to receptors within the FRA [APP-177], Table 3.71 of DRMB LA 113 specifies a change in peak flood level of +/- 10mm to be a "negligible" impact. The Environment Agency agrees with this assumption [REP2-043] observing that a 10mm change in flood depth falls within model tolerance.

1.5.5 In accordance with DMRB guidance therefore, Tables 13-9 and 13-10 of Environmental Statement Chapter 13 Road Drainage and the Water Environment [APP-057] demonstrates that the Scheme would not result in significant adverse effects in terms of fluvial flood risk during both construction and operation. These tables have been reviewed in light of the modelling updates within this technical note and it is considered that the conclusions of Chapter 13 Road Drainage and the Water Environment of the Environmental Statement [APP-057] and Appendix 13.1 Water Framework Directive Compliance Assessment of the Environmental Statement Appendices [APP-176] are unchanged.

[10] Planning Inspectorate (2024), Nationally Significant Infrastructure Projects: Advice on the Water Framework Directive, available online at Nationally Significant Infrastructure Projects: Advice on the Water Framework Directive - GOV.UK, accessed January 2025.

[11] Receptor sensitivity and magnitude of impact tables are provided in DMRB LA 113 Table 3.70 and Table 3.71, respectively. The significance of effect table is provided in DMRB LA 104 Table 3.8.1.

2. Modelling uncertainty

2.1 Introduction

2.1.1 This section provides an overview of the sources of modelling uncertainty that need to be understood in the context of the hydraulic modelling undertaken to support the FRA [APP-177].

2.1.2 The discussion on model uncertainty is important for background context as the flood depth differences discussed in this technical note are very small in magnitude and are often smaller than modelling uncertainties for this this type of complex 1D-2D linked model.

2.2 Sources of modelling uncertainty

2.2.1 Two sources of modelling uncertainties that are relevant to this technical note are the modelling setup and in the behavior of the numerical solver.

2.2.2 Uncertainties in modelling setup include model inputs and model configuration. Model inputs, such as survey data, LiDAR, inflows and design geometry are data that are incorporated into the modelling relatively unchanged from various sources and all come with some level of error. However, the errors in these data are typically accepted on the basis that the best available data has been used for the model development.

2.2.3 During the development of a hydraulic model, there are occasions when decisions must be made regarding the best way to incorporate the input data into the model configuration. This may require interpretation of survey data, combining conflicting geometry sources, adapting design details for representation inside the model's numerical mesh and enforcing ground features and structure elevations.

2.2.4 In the development of the original hydraulic model, a conservative approach was used for decisions on the model representation in order that it captured the worst-case impact. This technical note revisits locations where a conservative approach was initially taken and refines them with a modified approach for proposed structures and other surface topographical features that might affect flow paths or flood risk.

2.2.5 The large scale and complexity of the linked watercourse and floodplain components of this model are relevant in relation to this point. The large area represented meant the decisions had to be made on the level of resolution in the model. While the model provides an appropriate tool for evaluating the Scheme, uncertainties arise from inevitable modelling choices such as the selection of the grid cell size(s). This, in turn, limits the level of detail in assessing localised flood risk impacts as the grid size governs the approaches for the representation of ground features and structures in the model.

2.2.6 Modelling uncertainties due to numerical solver behaviour can arise due to poor convergence, threshold condition impacts and localised flow conditions that do not fit comfortably inside the limitations of the computational model solver's numerical schemes (for TUFLOW, this would include conditions such as fast, deep flows which stretch the assumption that a 2D shallow water equation is applicable).

2.2.7 Numerical solver uncertainties generally have a lesser impact on the flood risk outputs of hydraulic models than model input and configuration uncertainties. However, they are relevant to this technical note because they can cause localised fluctuations and water level differences in areas away from the parts of the model that have been updated with the Scheme geometry and where the flood risk would otherwise be independent of the Mitigated Scheme.

2.3 Modelling tolerance

2.3.1 The consequence of numerical solver uncertainty, which may stem from solver approach or convergence difficulties, is that the Flood Modeller and TUFLOW hydraulic modelling software will undertake multiple iterations to converge to within a specified tolerance in water level, or to minimise mass balance error.

2.3.2 Flood Modeller has a default tolerance of 0.01m (10mm) in water level and, according to the Environment Agency report SC120002, “Benchmarking the latest generation of 2D hydraulic packages” (2013), TUFLOW exhibits differences in water level compared to other packages of between 0.01m (10mm) and 0.05m (50mm), or up to 10% of the water depth. It may therefore be expected that there is an inherent level of uncertainty in model outputs. It should be noted that the DMRB guidance adopts a pragmatic approach by defining a change in peak flood level of +/- 10mm as having a "negligible" impact. The Environment Agency agrees with this assumption [REP2-043], observing that a 10mm change in flood depth falls within model tolerance.

2.3.3 It should be noted that where convergence difficulties arise, oscillations may be induced in the water surface, even though the model is achieving a desired level of mass balance. There would therefore be areas over which the baseline and Mitigated Scheme model scenarios exhibit such oscillations differently and comparing their peak water levels will expose the effect tolerances as a striped or dappled pattern in the depth comparison figures.

2.4 FRA [APP-177] model proving

2.4.1 Hydraulic modelling was used to support the flood risk assessment of the Mitigated Scheme (FRA [APP-177]). The hydraulic modelling included sensitivity testing to understand the impact of assumptions, including changes in hydraulic roughness, adjustments to inflows, blockages applied to structures and adjustments to weir coefficients. The model was subsequently calibrated and was then signed off by the Environment Agency (email correspondence with Paul Goldsmith, 1 February 2024) with regards to its technical function.

2.4.2 As discussed in the FRA [APP-177], modelling instabilities have been observed by way of localised velocity and depth fluctuations in the modelling results in locations away from the area of interest. However, these numerical uncertainties were deemed in the FRA [APP-177] not to reflect flood risk changes due to the Scheme.

2.5 Additional sensitivity testing

2.5.1 This technical note focusses on how sensitive flood risk impacts at specific enforcement points are to changes in the representation of components within the original hydraulic model.

2.5.2 Sensitivity testing was undertaken on the 1% AEP plus climate change event (the design event) to further investigate flood risk increases at specific locations. These consist of alternative representations of design details at:

- Windmill Viaduct, discussed in Section 3, undertaken to assess flood risk impacts to receptors where the original model predicts increases greater than 0.01m (10mm).
- Slough Dyke, discussed in Section 4, undertaken to determine what impact the realignment of the Slough Dyke watercourse would have on predicted flood risk.

2.5.3 Additional sensitivity testing was also undertaken for the 1% AEP and 5% AEP flood events to assess flood risk impacts to receptors where the original model predicts increases greater than 0.01m (10mm). These tests consisted of the following:

- Tolney Lane, discussed in Appendix B4, undertaken to assess flood risk impacts for the 5% AEP event.
- Fosse Road, discussed in Appendix B6, undertaken to assess flood risk impacts for the 1% AEP event.

2.5.4 The outcomes of the sensitivity tests demonstrate that the Scheme has a negligible impact on flood risk for the design event (1% AEP plus climate change event) and all modelled lower magnitude flood events.

2.6 Summary

2.6.1 This technical note details the flood depth increases at receptors in the Mitigated Scheme and assesses the potential reasons for these increases through sensitivity testing for the design event (1% AEP plus climate change event) and all modelled lower magnitude flood events.

2.6.2 The presentation and analysis of flood risk impacts below 0.01m (10mm) helps to provide a fuller picture of the model results when considering the impact of the Mitigated Scheme on flood risk. It should be noted that increases in flood depths less than 0.01m (10mm) are considered “negligible” impacts in accordance with DMRB guidance. The Environment Agency agrees with this assumption [REP2-043], observing that a 10mm change in flood depth falls within model tolerance.

2.6.3 The sensitivity testing consisted of enforcements to ground features and structures in the original hydraulic model at specific locations. The objective of the sensitivity testing was to assess whether predicted flood risk impacts to specific receptors in the model could be reduced or removed. It is important to note that while enforcements in the model representation have been made, these adjustments are only intended to test the model’s sensitivities and the predicted impacts on receptors.

3. Design event analysis – 1% AEP plus climate change

3.1 Introduction

3.1.1 To provide further context on the Scheme's approach to passing the Exception Test, this section of the technical note provides further analysis on the Scheme design event, in addition to that provided in the FRA [APP-177]. It looks at receptor impacts at locations 4 (Windmill Viaduct), 11 (Cattle Market roundabout) and 8 (Embankment on floodplain between Kelham Road and Nottingham to Lincoln railway line) in further detail to expand upon information provided in the FRA [APP-177].

3.1.2 DMRB guidance defines a change in peak flood level of +/- 10mm as having a "negligible" impact. The Environment Agency agrees with this assumption [REP2-043], observing that a 10mm change in flood depth falls within model tolerance.

3.1.3 Section 3.5 looks at receptor impacts in further detail for the design event in line with DMRB guidance.

3.1.4 Receptor impacts for lower magnitude flood events were also analysed and details are provided in Appendix B of this technical note.

3.2 Windmill Viaduct

3.2.1 Original model

3.2.1.1 In the 1% AEP plus climate change event, flood depth increases between 0.005m and 0.01m (5mm-10mm) are predicted west of Windmill Viaduct[12] on the right bank of the River Trent (Figure 1). Despite the predicted increase in flood depths, the flood hazard classification is not predicted to change between the baseline and Mitigated Scheme, remaining "Significant" (Figure 2 and Figure 3). Furthermore, changes in peak flood level less than 10mm such as at this location are considered "negligible" impacts in accordance with DMRB guidance.

3.2.1.2 The increase in depth west of Windmill Viaduct is caused by the representation of its extension on the right bank of the River Trent in the Mitigated Scheme model scenario. The representation of the embankment footprint in the original Mitigated Scheme model was conservatively estimated. Although the change in peak flood level at this location is considered 'negligible', sensitivity testing of the embankment footprint was undertaken to determine if a more detailed representation affected the assessment, and this is discussed further in Section 3.2.2.

[12] Windmill Viaduct is marked as Location 4 in Figure 8.1 of in Chapter 6.3 Environmental Statement - Appendix 13.2 Flood Risk Assessment (APP-177)

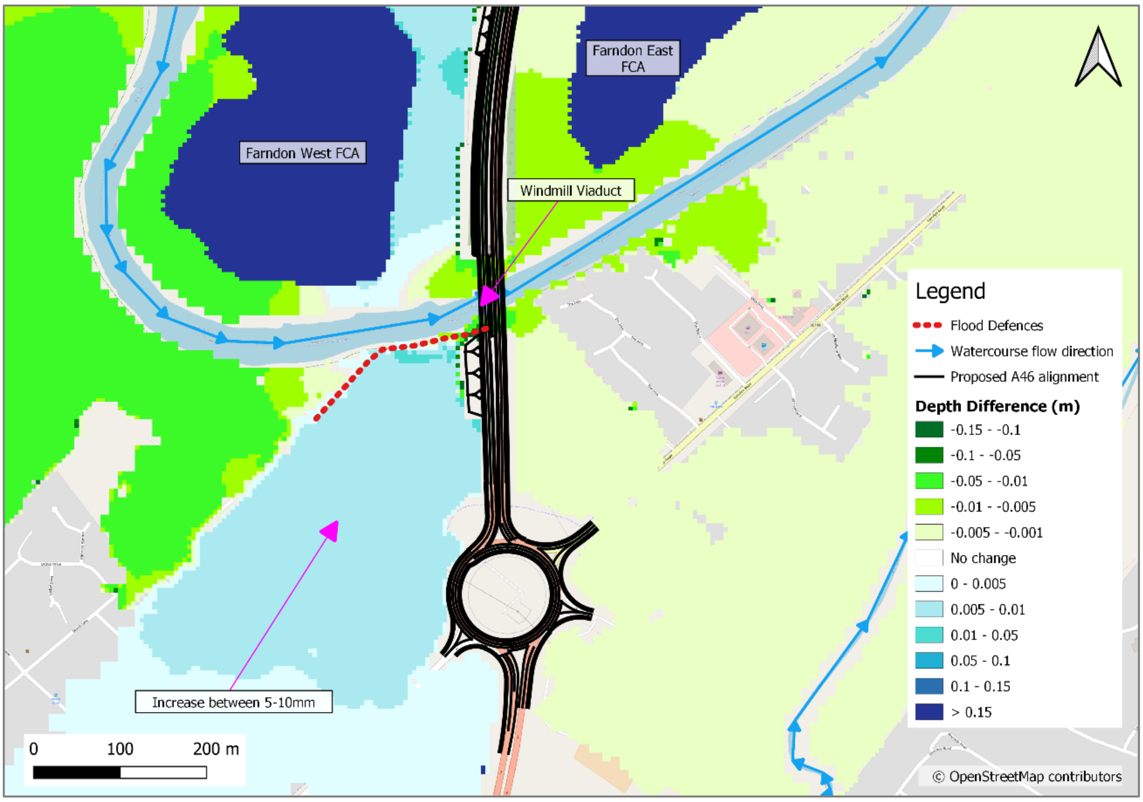


Figure 1: 1% AEP plus climate change. Windmill viaduct. Flood depth differences. Mitigated Scheme versus baseline. Original model.

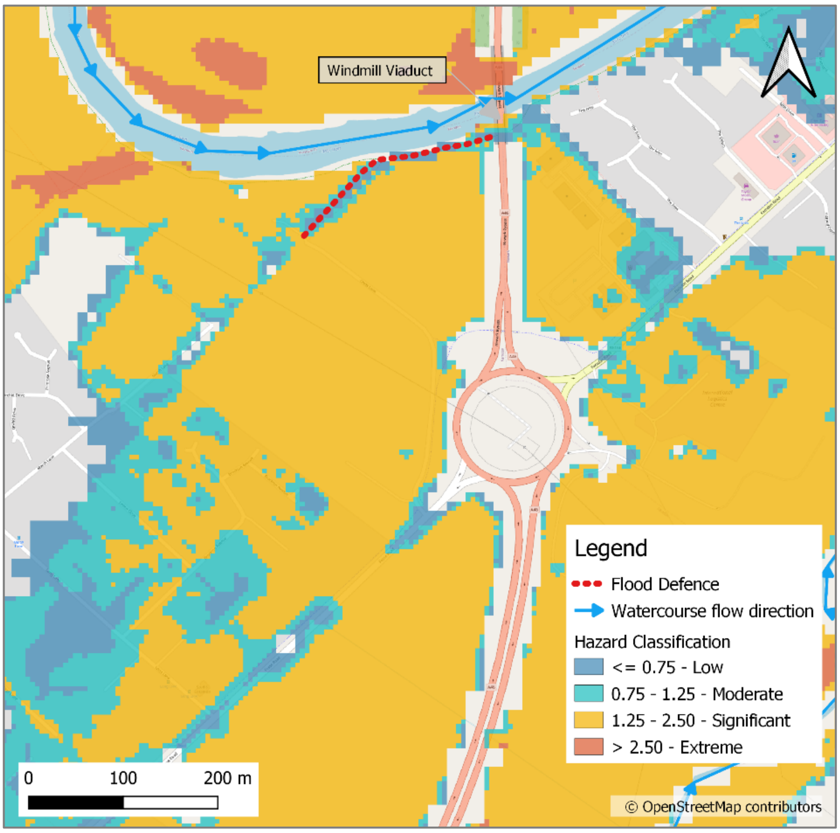


Figure 2: 1%AEP plus climate change. Windmill viaduct. Flood hazard. Original baseline.

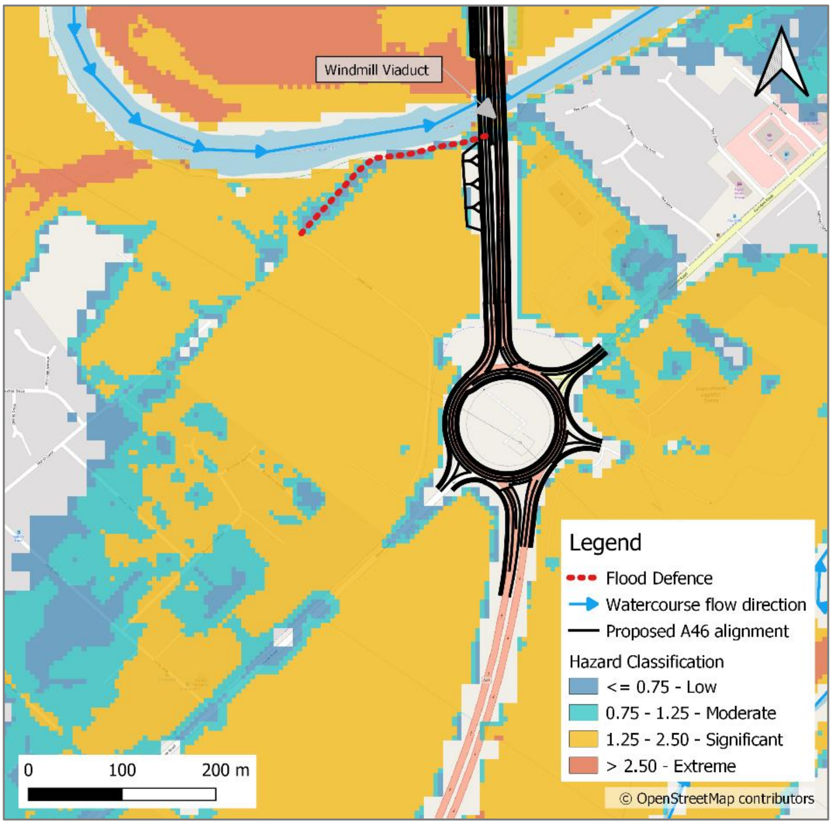


Figure 3: 1%AEP plus climate change. Windmill viaduct. Flood hazard. Mitigated Scheme.

3.2.2 Sensitivity testing

3.2.2.1 In the original model, a conservative approach was taken with respect to the representation of the embankment, in order to provide a conservative estimate of peak water levels in the floodplain. In the sensitivity test, the elevation of four $10m^2$ grid cells at the northern end of the embankment was reduced, which allowed a small but significant increase in conveyance beneath the viaduct on the right bank of the River Trent, bringing the water levels and flows through the viaduct back towards baseline conditions. This test indicates the sensitivity of the model to the adjustment of just four grid cells in this area.

3.2.2.2 As a result of the modified representation of the Scheme embankment and abutment, sensitivity testing demonstrates that the area south of Windmill Viaduct now shows flood depth differences less than 0.002m (2mm) compared to the baseline (Figure 5, with Figure 4 enabling direct comparison with the depth differences from the original model as shown in Figure 1). The area of depth increase has also reduced. Detailed analysis of the results of this sensitivity test is provided in Section 3.5.

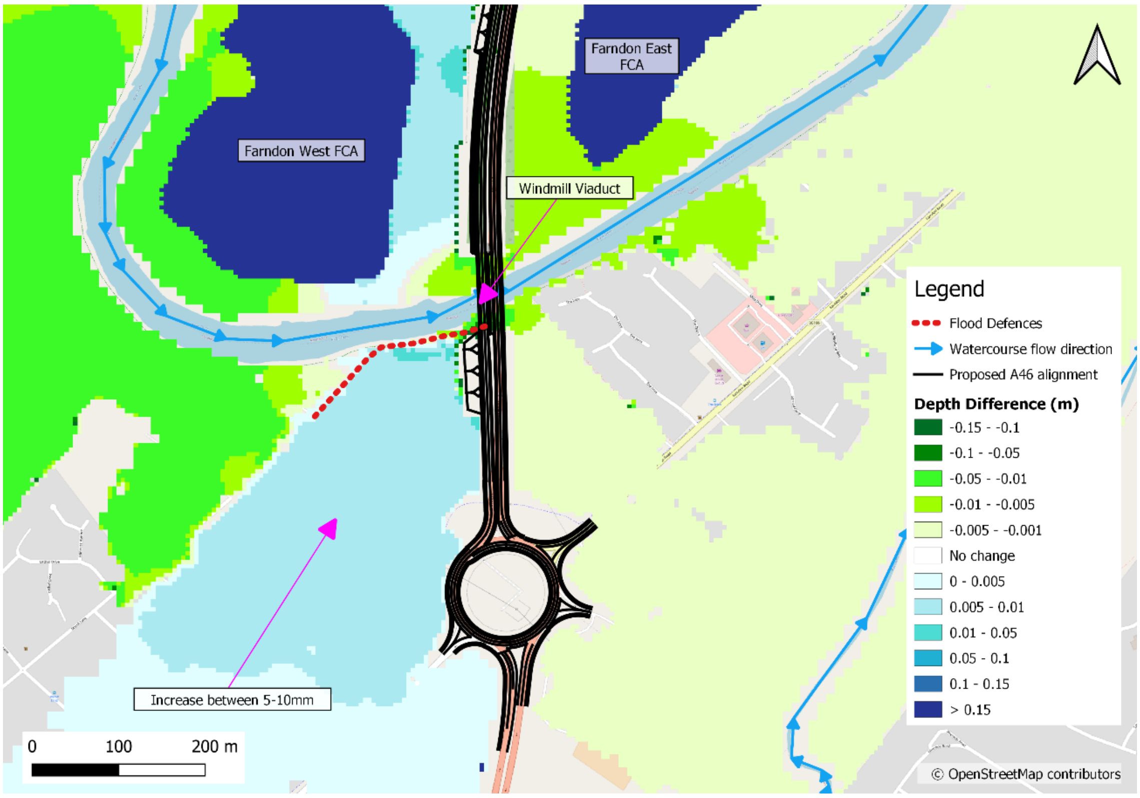


Figure 4: 1% AEP plus climate change. Windmill viaduct. Flood depth differences. Mitigated Scheme versus baseline. Original model. (this is a duplication of the depth differences shown in Figure 1 for ease of comparison with Figure 5)

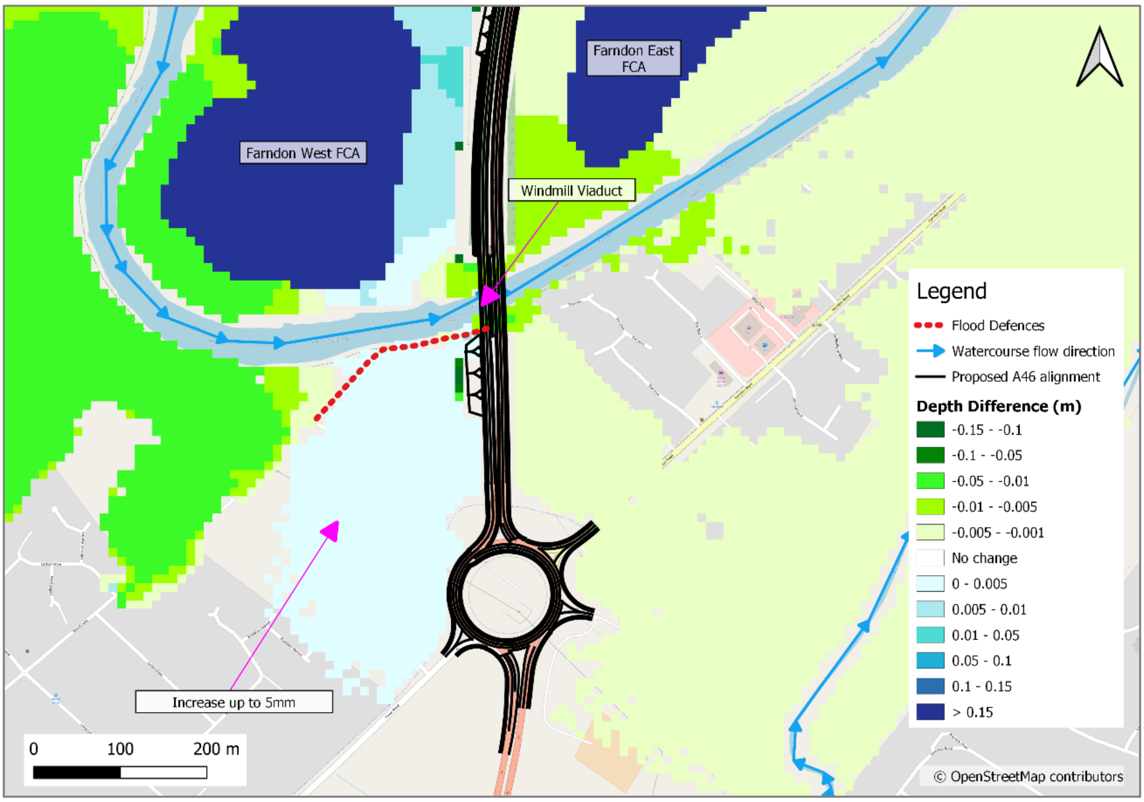


Figure 5: 1% AEP plus climate change. Windmill viaduct. Flood depth differences. Sensitivity test.

3.3 South of Cattle Market roundabout

3.3.1 Figure 6 presents the change in flood depths in the area south of Cattle Market roundabout. The FRA [APP-177] notes an increase in water levels up to 0.02m (20mm) in the vicinity of Cattle Market[13]. However, this increase affects a localised area to the north-east and does not impact any vulnerable receptors.

3.3.2 Depth increases south of Cattle Market roundabout are less than 0.01m (10mm), averaging 0.006m (6mm). This increase is considered a "negligible" impact in accordance with DMRB guidance. Baseline flood depths in this area are up to 3m for this event and the baseline flood hazard classification in the area is "Significant". The flood hazard classification is unchanged by the Mitigated Scheme as shown in Figure 7 and Figure 8.

3.3.3 No additional sensitivity tests were undertaken for this location as the design representation of the Scheme in the original model is considered appropriate. The design representation cannot therefore reasonably be modified for sensitivity testing. Nevertheless, flood depth differences within this area resulting from the Mitigated Scheme are considered a "negligible" impact in accordance with DMRB guidance.

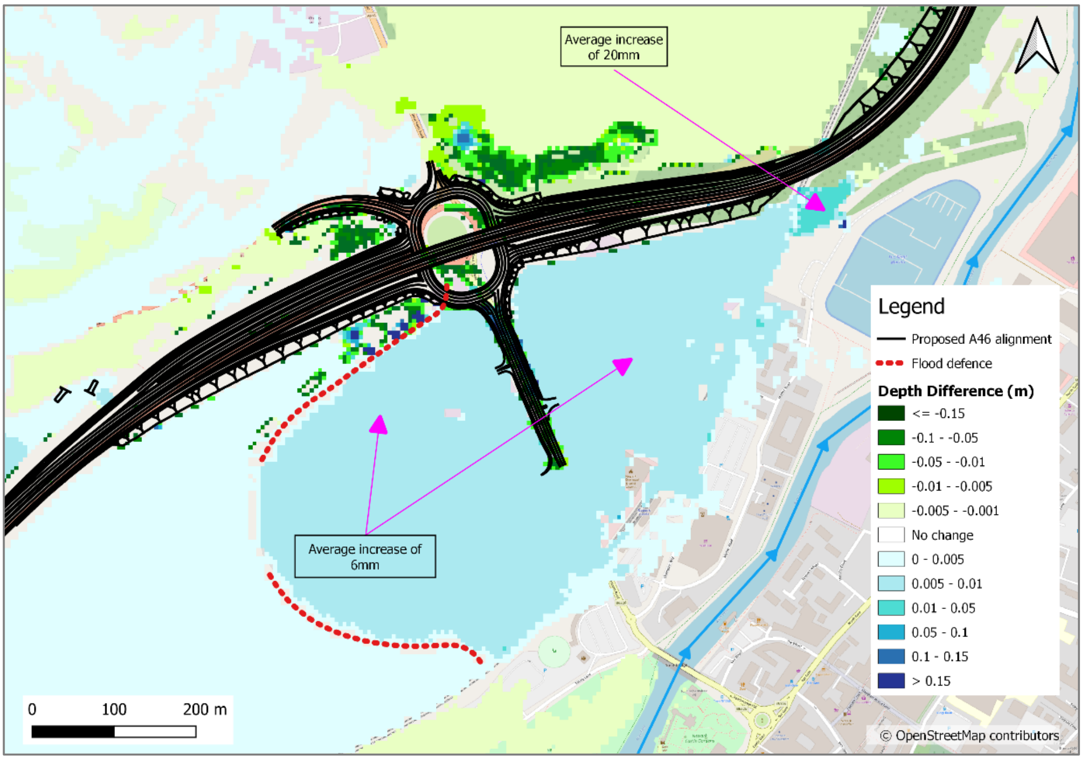


Figure 6: 1%AEP plus climate change. Flood depth differences. Mitigated Scheme versus baseline. Original model.

[13] The area south of Cattle Market roundabout is marked as Location 11 in Figure 8.1 of in Chapter 6.3 Environmental Statement - Appendix 13.2 Flood Risk Assessment (APP-177)

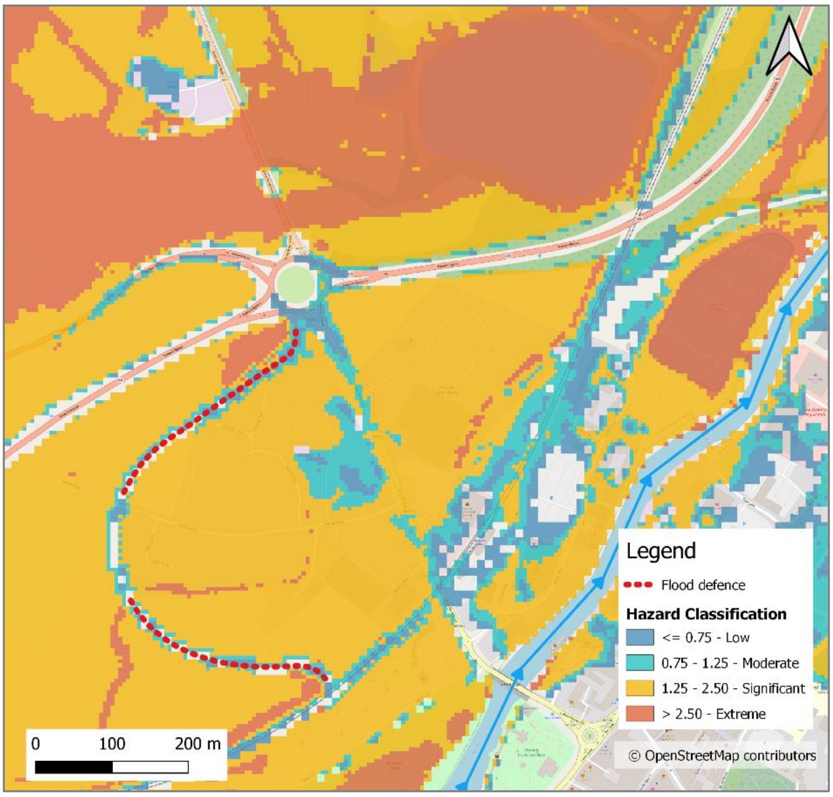


Figure 7: 1%AEP plus climate change. Cattle Market roundabout. Flood hazard. Original baseline.

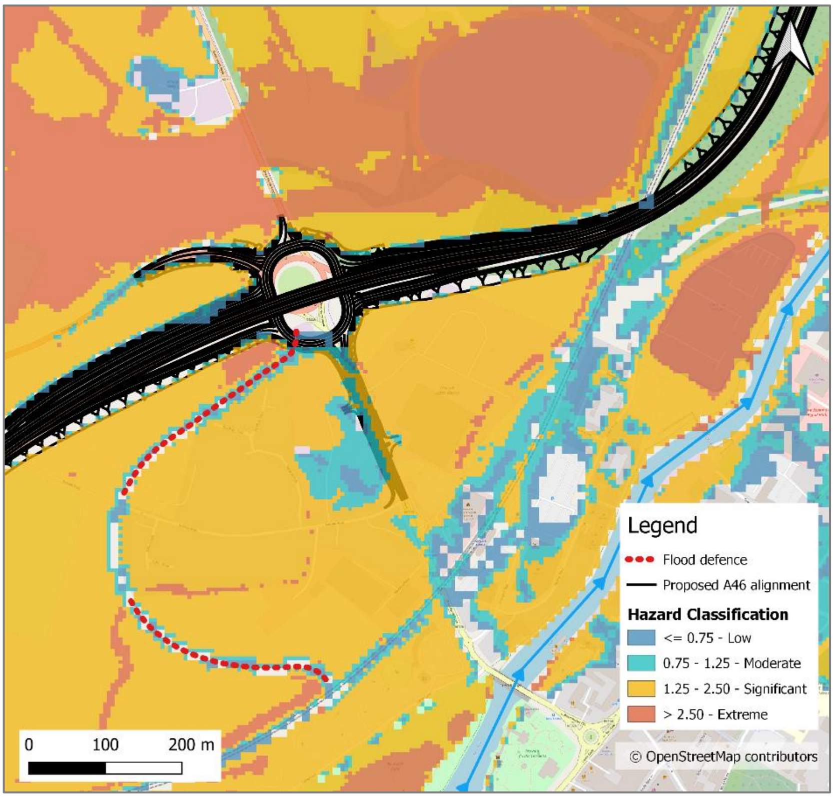


Figure 8: 1%AEP plus climate change. Cattle Market roundabout. Flood hazard. Mitigated Scheme.

3.4 Embankment on floodplain between Kelham Road and Nottingham to Lincoln railway line

3.4.1 The FRA [APP-177] notes that the water level at the base of the new embankment between Kelham Road and the Nottingham to Lincoln railway line[14] has a localised increase of up to 0.086m (86mm) from the baseline. It is important to note that this increase represents only one modelled 10m grid cell as shown in Figure 9. Elsewhere, flood depth increases are generally less than 0.01m (10mm), and decreases are also observed nearby, as shown in green in Figure 9. Changes in peak flood level less than 0.01m (10mm) are considered a "negligible" impact, in accordance with DMRB guidance.

3.4.2 There are no vulnerable receptors at this location, and the wider area is predominantly agricultural.

3.4.3 No additional sensitivity tests were undertaken for this location due to the absence of vulnerable receptors.

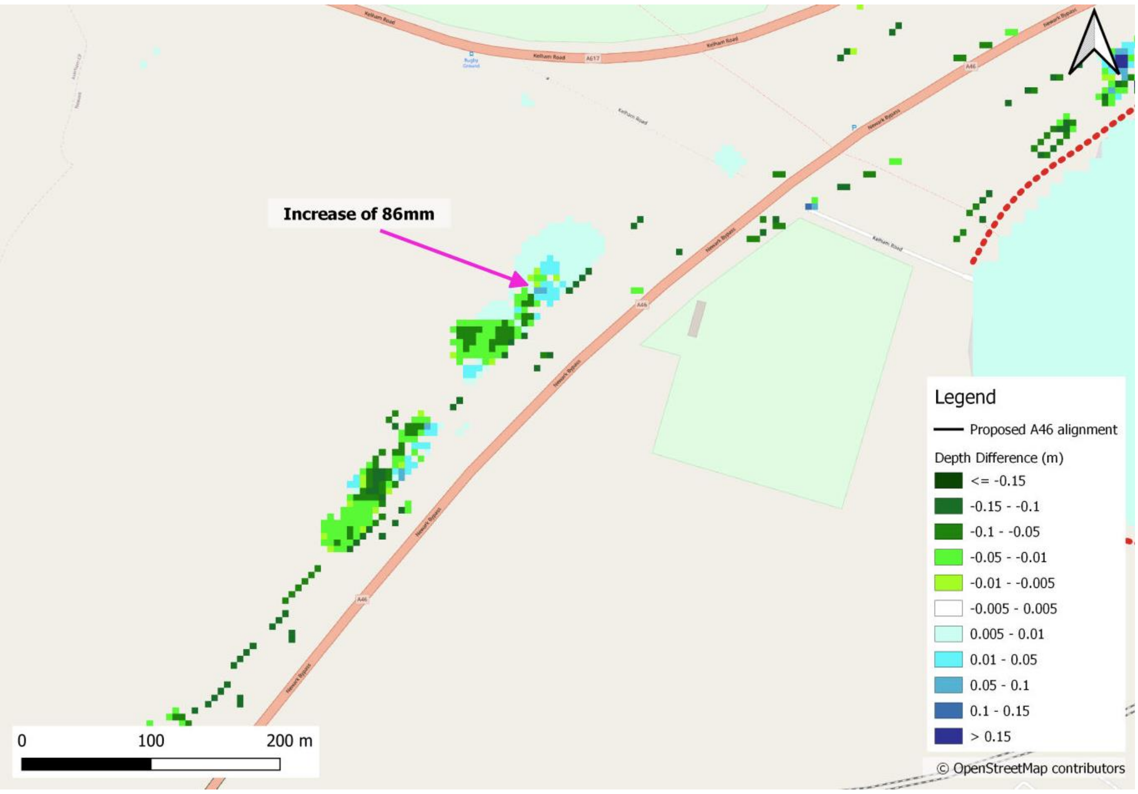


Figure 9: 1%AEP plus climate change. Flood depth differences. Mitigated Scheme versus baseline. Original model.

[14] The embankment between Kelham Road and Nottingham to Lincoln railway line, is marked as Location 8 in Figure 8.1 of in Chapter 6.3 Environmental Statement - Appendix 13.2 Flood Risk Assessment (APP-177)

3.5 Design event receptor analysis

3.5.1 Introduction

3.5.1.1 This section provides further detail on the changes in flood depths at receptors arising from the Mitigated Scheme for the 1% AEP event plus climate change, drawing on results of the sensitivity testing undertaken at Windmill Viaduct outlined in Section 3.2.2.

3.5.1.2 Table 1 summarises the results for the original hydraulic model. Table 2 summarises the results of the sensitivity test at Windmill Viaduct. The total numbers of receptors with increases or decreases in flood depth exclude “Water Compatible” receptors, (as identified in Appendix A of this technical note,) which by their nature are resilient to minor changes in flood level.

3.5.2 Original model

3.5.2.1 A comparison between the Baseline and Mitigated Scheme scenarios for the original model (Table 1) indicates that flood depths at 1,619 receptors are predicted to decrease, whilst they are predicted to increase at 1,058 receptors. Receptors with a predicted increase are summarised as follows:

- Seven “Essential Infrastructure” receptors with flood depth increases less than 0.01m (10mm) as outlined in the following points. Note that the flood hazard is not predicted to change at any of these receptors due to the Mitigated Scheme.
    - One electricity sub-station at the model boundary 5km north of the Scheme which shows a flood depth difference of 0.0004m (0.4mm) on top of a baseline depth of 0.08m (80mm).
    - One electricity sub-station at South Muskham 1.5km north of the Scheme which shows depth differences of 0.0001m (0.1mm) on top of a baseline flood depth of 0.92m (920mm).
    - One electricity sub-station located south of Cattle Market roundabout just off the Great North Road which shows a depth difference of 0.007m (7mm) on top of baseline flood depths of 0.27m (270mm).
    - Two electricity sub-stations located south of Windmill viaduct near Fosse Road which show depth differences of less than 0.002m (2mm) on top of baseline flood depths exceeding 0.26m (260mm).
    - One sewage pumping station located south of Windmill viaduct near Fosse Road which shows a flood depth difference of 0.001m (1mm) on top of a baseline flood depth of 0.90m (900mm).
    - One wind turbine, however the physical location of the turbine as observed on satellite imagery is approximately 250m from the assigned NRD receptor location, and no depth differences are observed at this location in this event.
- Seven “Highly Vulnerable” receptors with flood depth increases of less than 0.01m (10mm) as outlined in the following points. Note that the flood hazard is not predicted to change at any of these receptors due to the Scheme.
    - Two telecommunications cabinets with depth differences less than 0.007m (7mm) on top of baseline flood depths of greater than 0.05m (50mm).

    - Five telecommunications infrastructure, including a cabinet and a mast with depth increases of less than 0.001m (1mm), where baseline flood depths are up 0.64m (640mm).
- 171 "More Vulnerable" receptors with flood depth increases between 0.005 to 0.01m (5mm-10mm) as below.
    - 123 receptors are located south of Cattle Market roundabout. The average depth increase at the Cattle Market roundabout receptors is 0.006m (6mm) on top of an average baseline depth of 0.965m (965mm). Note that the flood hazard is not predicted to change at any of these receptors due to the Scheme.
    - 48 receptors are located upstream of Windmill Viaduct near Fosse Road, where the average depth increase is 0.006m (6mm) on top of an average baseline depth of 0.44m (440mm). Note that the flood hazard is not predicted to change at the majority of these receptors due to the Scheme, aside from at four receptors where it increases from either "Low" to "Moderate" or "Moderate" to "Low".
- 25 "More Vulnerable (Low Confidence)" receptors with flood depth increases between 0.005m and 0.01m (5mm-10mm) as below. Flood depth increases for these receptors are identical to those discussed for "More Vulnerable" receptors for this event;
    - 12 receptors are located south of Cattle Market roundabout.
    - 13 receptors are located upstream of Windmill Viaduct near Fosse Road.

3.5.2.2 Note that the above increases in flood depths are less than 10mm and are therefore considered "negligible" impacts in accordance with DMRB guidance. No "More Vulnerable", "Highly Vulnerable" or "Essential Infrastructure" receptors show flood depth increases of greater than 0.01m (10mm).

3.5.2.3 There are flood depth increases greater than 0.01m (10mm) at two "Less Vulnerable" receptors. These are the Farndon West and East FCAs. This change is expected, as the FCAs are designed to fill up and store water within the floodplain.

3.5.2.4 The model predicts that there would generally be no change in the flood hazard at receptors where an increase in flood depth is predicted, with the exception of four receptors upstream of Windmill Viaduct. The sensitivity of the receptors at this location have been assessed further and the outcomes are discussed in Section 3.5.3.

3.5.3 Sensitivity testing

3.5.3.1 A sensitivity test was undertaken on the 1% plus climate change event which involved amendments to the abutment and embankment representation in the Mitigated Scheme model, as discussed in Section 3.2.2. The purpose of this test was to determine whether flood depth changes at the 48 receptors upstream of Windmill Viaduct were sensitive to these amendments. The baseline for this sensitivity test was that of the original model.

3.5.3.2 The outcomes of the sensitivity test, presented in Table 2, are as follows:

- As per the original model, no “More Vulnerable”, “Highly Vulnerable” or “Essential Infrastructure” receptors show flood depth increases of greater than 0.01m (10mm).
- The number of “More Vulnerable” receptors with an increase between 0.005m to 0.010m (5mm-10mm) has reduced by 27 from 171 to 144. Following the sensitivity test, there are no longer any “More Vulnerable” receptors where depth increases above 5mm are predicted upstream of Windmill Viaduct.
- The number of receptors showing depth differences greater than 2mm has reduced, with smaller depth changes now predicted following the sensitivity test.
- Seven “Essential Infrastructure” locations with flood depth increases less than 0.01m (10mm), six of which are electricity sub-stations:
  - One at the model boundary 5km north of the Scheme which shows a flood depth difference of 0.0004m (0.4mm) on top of a baseline depth of 0.08m (80mm).
  - Two in South Muskham over 1.5km from the Scheme showing maximum depth differences of between 0.0003m to 0.0004m (0.3-0.4mm) on top of baseline flood depths between 0.57m to 0.92m (570mm-920mm).
  - One in North Muskham over 2km from the Scheme which shows maximum depth differences of 0.0001m (0.1mm) on top of a baseline flood depth of up to 0.83m (830mm).
  - One south of Cattle Market roundabout just off the Great North Road which shows a depth difference of 0.007m (7mm) on top of baseline flood depths of 0.27m (270mm).
  - One located 800m from the sewage works at Quibells Lane which shows a depth difference of 0.0001m (0.1mm) on top of baseline flood depths of 1.62m (1,620mm).
  - The remaining “Essential Infrastructure” receptor is a wind turbine according to the NRD. However, the physical location of the turbine as observed on satellite imagery is approximately 250m from the assigned NRD receptor location, and no depth differences are observed at this location in this event.
- Six "Highly Vulnerable" receptors:
  - Four telecommunications cabinets with depth differences ranging from 0.0004m to 0.0081m (0.4mm-8mm), on top of baseline flood depths of 0.03m to 0.29m (30-290mm).
  - One phone mast, with a flood depth difference of 0.0007m (0.7mm) on top of baseline flood depth of 0.19m (190mm).
  - One caravan at Tolney Lane, which sees an increase of flood depths of 0.0005m (0.5mm) on top of baseline flood depths of 0.50m (500mm). The baseline flood hazard classification at this location is “Significant” and does not change as a result of the Scheme or the sensitivity test.

3.5.3.3 For the majority of receptors other than those itemised below, the hazard classification for receptors in the sensitivity test does not change compared to the baseline.

- Hazard decrease from "Moderate" to "Low" at three "More Vulnerable" receptors.
- Hazard decrease from "Significant" to "Moderate" at one "More Vulnerable" and one "Less Vulnerable (Low Confidence)" receptors.
- Hazard increase from "Low" to "Moderate" at one "Less Vulnerable" receptor.
- Hazard increase from "Significant" to "Extreme" at water features Farndon East FCA and Farndon West FCA. Since the FCAs are designed to fill up and store water within the floodplain, this is expected.

3.5.4 Summary

3.5.4.1 During the 1% AEP event plus climate change, reductions in flood depth are predicted at 1,619 receptors. Furthermore, the Scheme is not predicted to cause increases in flood depths above 0.01m (10mm) at any "Essential Infrastructure", "Highly Vulnerable", "More Vulnerable", "More Vulnerable (Low Confidence)", or "Less Vulnerable (Low Confidence)". Increases greater than 0.01m (10mm) are predicted at two "Less Vulnerable" receptors, however these are the Farndon West and East FCAs and are expected. Therefore, the flood risk impacts arising due to the Scheme during the 1% AEP plus climate change event are considered "negligible" in accordance with the DMRB guidance.

3.5.4.2 The original model predicts depth increases between 5mm and 10mm at 171 "More Vulnerable" receptors, 123 of these are located south of Cattle Market roundabout and 48 are located south of Windmill Viaduct. Although increases of less than 0.01m (10mm) are considered a 'negligible' impact in accordance with DMRB guidance, sensitivity testing of the model at Windmill Viaduct was undertaken to better understand the increases at these receptors.

3.5.4.3 Amendments to the Windmill Viaduct Scheme embankment in the sensitivity model involved a modified representation of the Scheme embankment and abutment taking into consideration the 10m model grid size. This amendment led to a reduction in the number of "More Vulnerable" properties from 171 to 144 where a depth increase is predicted.

3.5.4.4 As a result of the amendments to the Scheme embankment at Windmill Viaduct, no "More Vulnerable" receptors upstream of Windmill Viaduct show a depth increase greater than 0.005m (5mm) or an increase in flood hazard.

3.5.4.5 The remaining 144 "More Vulnerable" receptors with a predicted depth increase between 0.005m to 0.01m (5 – 10mm) are all located south of Cattle Market roundabout, and the average predicted depth increase is 0.006m (6mm). Furthermore, flood hazard is not predicted to change at these receptors as a result of the Scheme. It should be noted that these increases are considered a "negligible" impact in accordance with the DMRB guidance and are on top of an average baseline depth of 0.965m (965mm) and are therefore considered acceptable by the Applicant.

Table 1: 1% AEP plus climate change. Flood depths differences. Mitigated Scheme versus baseline. Original model

	Count of receptors with change in depth							
NPPF Class	**<0mm**	**0-1mm**	**1-2mm**	**2-3mm**	**3-4mm**	**4-5mm**	**5-10mm**	**>10mm**
Essential Infrastructure	11	3	2	1	0	0	1	0
Highly Vulnerable	90	5	0	0	0	0	2	0
More Vulnerable	940	265	101	73	30	51	171	0
More Vulnerable (Low Confidence)	236	109	16	13	5	3	25	0
Less Vulnerable	234	46	11	6	1	0	44	2
Less Vulnerable (Low Confidence)	108	53	1	1	0	0	17	0
Water Compatible	213	54	7	4	0	1	10	0
Total number with decrease (excluding water compatible)								**1619**
Total number with increase (excluding water compatible)								**1058**

Table 2: 1% AEP plus climate change. Flood depth differences. Mitigated Scheme versus baseline. Windmill Viaduct sensitivity test.

	Count of receptors with change in depth							
NPPF Class	**<0mm**	**0-1mm**	**1-2mm**	**2-3mm**	**3-4mm**	**4-5mm**	**5-10mm**	**>10mm**
Essential Infrastructure	10	5	1	0	0	0	1	0
Highly Vulnerable	91	4	0	0	0	0	2	0
More Vulnerable	804	315	16	2	5	3	144	0
More Vulnerable (Low Confidence)	216	126	10	0	0	0	12	0
Less Vulnerable	191	56	7	4	3	0	39	2
Less Vulnerable (Low Confidence)	94	55	6	1	0	0	12	0
Water Compatible	141	70	5	1	3	1	9	0
Total number with decrease (excluding water compatible)								**1406**
Total number with increase (excluding water compatible)								**831**

4. Slough Dyke realignment

4.1.1 The Slough Dyke watercourse is a designated Environment Agency Main River, a River WFD Waterbody (Slough Dyke Catchment (tributary of Trent) (GB104028053111)) and is a tributary of the River Trent. Realignment of the watercourse is proposed at the location where it crosses the Scheme alignment near Brownhills Junction.

4.1.2 The realignment would move the existing watercourse by approximately 7m to 8m to the east to be aligned closer to the A1 highway. A schematic of the Slough Dyke realignment is shown in Figure 10. Details of the cross-section plan can be found in TR010065/APP/2.6 “Engineering Plans and Sections Part 6 - Structures General Arrangements APP-14”, Sheet 12.

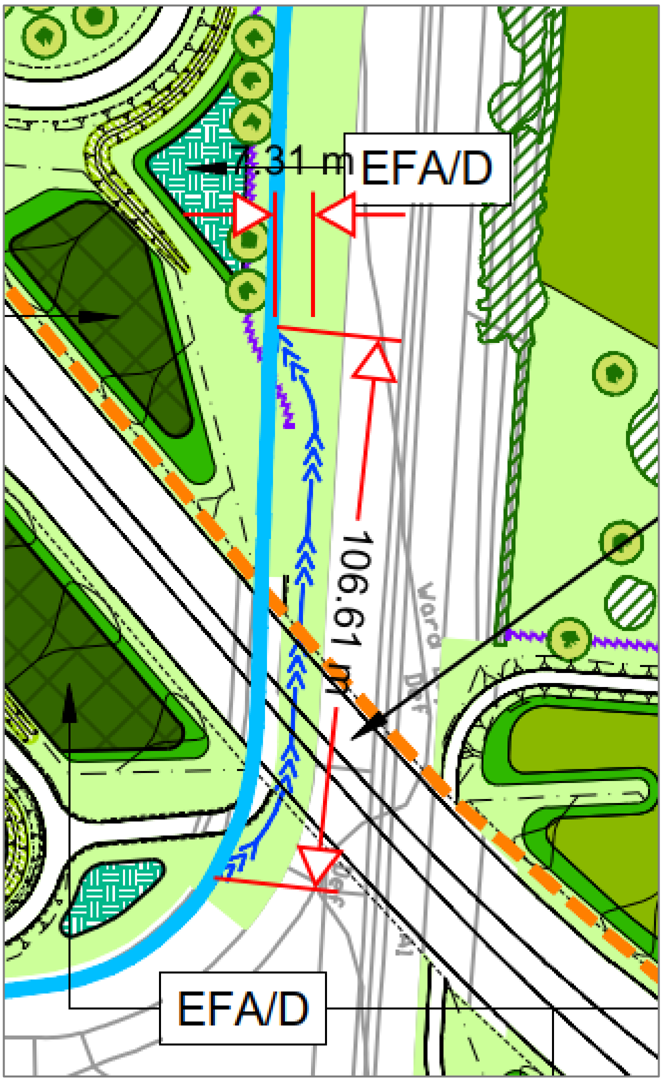


Figure 10: Slough Dyke realignment – extract from AS-007 (General Arrangement Plans) Sheet 25005

4.1.3 The existing channel cross-section shape would be retained and is not expected to change the current hydraulics or risk of flooding in the local area. The realignment was therefore not included in the original model.

4.1.4 For this technical note, sensitivity testing of the realignment has been undertaken to assess any potential change in flood risk due to the representation of the

Slough Dyke realignment. Enforcements to the hydraulic model for sensitivity testing consisted of:

- Increasing the channel length by 33m.
- Shifting the channel to the east by 8 to 10m.

4.1.5 The hydraulic model results for the 1% AEP plus climate change event demonstrate changes in peak water level of up to 0.015m (15mm) immediately upstream of the realigned section of Slough Dyke (Figure 11) within the channel. However, this has no impact on flood depths on the floodplain. It has therefore been demonstrated that the Slough Dyke realignment representation would not increase the risk of flooding. In addition, the significance of effect for fluvial flood risk presented within Chapter 13 Road Drainage and the Water Environment of the Environmental Statement [APP-057], and the assessment presented within Appendix 13.1 Water Framework Directive Compliance Assessment of the Environmental Statement Appendices [APP-176] are unchanged.

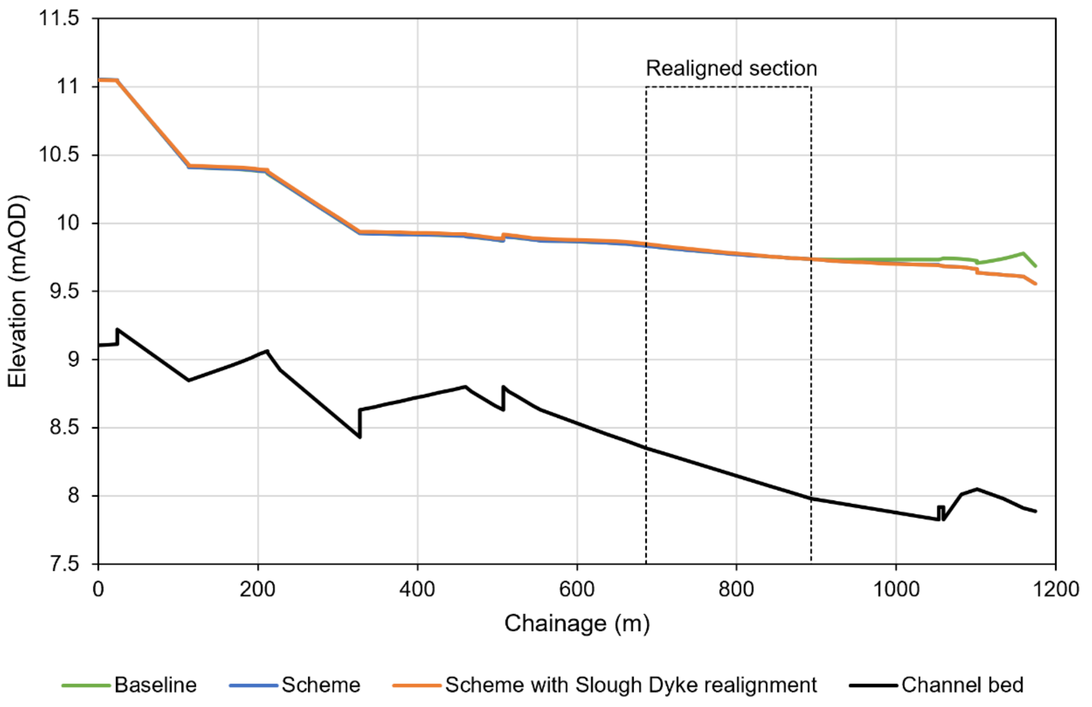


Figure 11: Comparison of peak water levels through Slough Dyke with and without realignment

5. Climate change allowances applied in the hydraulic model

5.1.1 The use of the hydraulic model for the assessment of the flood risk for the baseline and Mitigated Scheme scenarios for the FRA [APP-177] included consideration of a credible maximum climate change scenario (H++).

5.1.2 The design flood event assessed for the Mitigated Scheme was the 1% AEP plus climate change event, using the higher central allowance of 39% for the 2080s epoch (Section 8 of the FRA [APP-177]).

5.1.3 However, the credible maximum climate change scenario was also assessed. The event assessed was the 0.5% AEP plus the upper end climate change allowance of 62%. As discussed in Section 7.2 of the FRA [APP-177], this event was selected as the 'check event' required for assessment in the DMRB document CD356[15]. The 0.1% AEP event was used as a proxy event for the 0.5% plus 62% climate change uplift.

5.1.4 Table 3 shows the peak flows applied in the model for the major and dominant fluvial inflow from the Upper River Trent ('TRENT 01'). It can be seen from the table that the peak flow for the 0.5% AEP plus 62% climate change event (2028m^3/s) is within 1% of the peak flow for the 0.1% AEP event (2007m^3/s) and therefore is a suitable proxy event as discussed in the FRA [APP-177].

Table 3: Peak flows for model inflows from the Upper River Trent catchment

	Flood peak (m^3/s) for the following AEP (%) events												
	50	**20**	**10**	**5**	**4**	**3.3**	**2**	**1.3**	**1**	**1 plus 39% climate change**	**0.5**	**0.5 plus 62% climate change**	**0.1**
TRENT 01	463	635	752	867	904	933	1018	1085	1134	1576	1252	2028	2007

5.1.5 The deck levels of the bridges and the elevations of the road surface for the main carriageway of the Scheme are preset, as the nature of the Scheme is a widening of an existing road rather than the construction of a new road. The analysis presented in the FRA [APP-177] shows that the main carriageway of the Scheme is not at flood risk for the 0.5% AEP plus 62% climate change event and therefore the Scheme is resilient to a credible maximum climate change scenario.

5.1.6 Some of the ancillary road connections to the Scheme, including Cattle Market roundabout for example, are at lower elevations than the rest of the Scheme as they tie in with existing sections of highway which are not to be altered as part of the Scheme and thus are not applicable for flood resilience.

[15] Design Manual for Roads and Bridges, CD 356 Design of highway structures for hydraulic action, Revision 1, Highways England, March 2020

Appendix A - NRD to NPPF receptor vulnerabilities

NRD class descriptions have been used to assign NPPF flood risk vulnerabilities, where possible, to all receptors within the study area. NPPF receptor vulnerability is described in Annex 3: Flood risk vulnerability classification[4]. The table that was used to convert NRD class descriptions to NPPF vulnerabilities is provided in Table 4, and includes the following assumptions:

- Any points in the NRD where “Housetype” is "office" and “Floorlevel” is "dB" (definite basement) are assigned as "Less Vulnerable".
- Any points in the NRD where “Housetype” is "flat" and “Floorlevel” is "dB" are assigned as "Highly Vulnerable".
- The flood risk vulnerability classification mandates that essential utility infrastructure be categorised as “Essential Infrastructure”. Although there are 77 electricity sub-stations in the Study area, most of these are smaller sub-stations serving residential areas.
- Any points in the NRD labelled as “Caravan” are considered “Highly Vulnerable”, regardless of whether the caravan is permanent or temporary. Please note that the NRD may not have identified all caravans.

Table 4: Lookup table for mapping of NRD class descriptions to NPPF vulnerability

NRD Class Description	***NPPF vulnerability***
Electricity Sub-Station Power Station / Energy Production Water / Waste Water / Sewage Treatment Works	Essential Infrastructure
Ambulance Station Army Caravan Emergency / Rescue Service Fire Station Telecommunication	Highly Vulnerable
Boarding / Guest House / Bed And Breakfast / Youth Hostel Care / Nursing Home Children’s Nursery / Crèche College Detached Dwelling General Practice Surgery / Clinic Health Care Services Health Centre Holiday / Campsite Holiday Let/Accommodation/Short-Term Let Other Than CH01 Hotel/Motel Landfill Medical Preparatory / First / Primary / Infant / Junior / Middle School Primary School Public House / Bar / Nightclub Residential Residential Institution Secondary / High School Self-Contained Flat (Includes Maisonette / Apartment) Semi-Detached Sheltered Accommodation Terraced Waste Management	More Vulnerable
Activity / Leisure / Sports Centre Agricultural	Less Vulnerable

Agricultural - Applicable to land in farm ownership and not run as a separate business enterprise Allotment Amenity - Open areas not attracting visitors Amusements Ancillary Building Animal Centre Animal Services Bank / Financial Service Bingo Hall / Cinema / Conference / Exhibition Centre / Theatre / Concert Hall Builders' Yard Bus / Coach Station Car / Coach / Commercial Vehicle / Taxi Parking / Park And Ride Site Central Government Service Church Church Hall / Religious Meeting Place / Hall Cinema Commercial Community Service Centre / Office Community Services Crane / Hoist / Winch / Material Elevator Dentist Equestrian Factory/Manufacturing Farm / Non-Residential Associated Building Fast Food Outlet / Takeaway (Hot / Cold) Football Facility Forestry Garage Grab / Skip / Other Industrial Waste Machinery / Discharging Grazing Land Hopper / Silo / Cistern / Tank Horticulture Indoor / Outdoor Leisure / Sporting Activity / Centre Industrial Applicable to manufacturing, engineering, maintenance, storage / wholesale distribution and extraction sites Industrial Support Job Centre Land Law Court Leisure - Applicable to recreational sites and enterprises Library Local Government Service Manufacturing Market (Indoor / Outdoor) Mineral / Ore Working / Quarry / Mine Museum / Gallery Office Office / Work Studio Other Licensed Premise / Vendor Park Permanent Crop / Crop Rotation Petrol Filling Station Place Of Worship Playground Police Box / Kiosk Police Training Post Office Public / Village Hall / Other Community Facility Public Car Parking Public Park / Garden Racquet Sports Facility Railway Asset Recreational / Social Club Recycling Site Restaurant / Cafeteria Retail Retail Service Agent Servicing Garage Shop / Showroom Station / Interchange / Terminal / Halt Steel Works	

Theatre Vehicle Storage Vet / Animal Medical Treatment Warehouse / Store / Storage Depot Wholesale Distribution Workshop / Light Industrial Chimney / Flue Other Educational Establishment Water Sports Facility Transport Transport Track / Way Transport Related Infrastructure Underground Feature Castle / Historic Ruin Development Site Development Dual Use	
Advertising Hoarding Bus Shelter Cemetery / Crematorium / Graveyard. In Current Use. Channel / Conveyor / Conduit / Pipe House Boat Lake / Reservoir Maintained Amenity Land Marina Memorial / Market Cross Monument Mooring Named Pond Object of Interest Open Space Other Utility Use Parent Shell PO Box Postal Box Property Shell Public Convenience Pump House / Pumping Station / Water Tower (water compatible) Static Water Street Record Telephone Box Tourist Information Signage Traffic Information Signage Unused Land Utility Vacant / Derelict Land Verge / Central Reservation	Water Compatible

Appendix B - Receptor analysis for low magnitude events

B1. Introduction

This Appendix summarises the flood depth differences at receptors for the Mitigated Scheme versus baseline scenarios for lower magnitude events than the 1% AEP plus climate change event. The analysis uses the same methodology as used for the 1% AEP plus climate change analysis in Section 3 of this technical note.

The summary tables present the total numbers of receptors with increases or decreases in flood depth. The totals exclude “Water Compatible” receptors, as identified in Appendix A, which by their nature are resilient to minor changes in flood level.

DMRB guidance sets out flood depth thresholds only for the 1% AEP plus climate change event. Therefore, for the smaller events reported in Appendix B these thresholds (and subsequent conclusions of significance of effect) are provided for context only. Changes in peak flood level less than 0.01m (10mm) are still considered a "negligible" impact, in accordance with the DMRB guidance. The Environment Agency agrees with this assumption (REP2-043), observing that a 10mm change in flood depth falls within model tolerance. However, for the purpose of reporting, all depth increases above 0.001m (1mm) have been reported in the summary tables.

B2. 50% AEP event (2-year return period event)

A comparison between the baseline and Mitigated Scheme scenarios for the original model (Table 5) indicates that 14 receptors are predicted to decrease in flood depths, whilst 15 receptors are predicted to increase.

No flood depth increases above 0.01m (10mm) are predicted at any “Essential Infrastructure”, “Highly Vulnerable”, “More Vulnerable”, “More Vulnerable (Low Confidence)”, or “Less Vulnerable (Low Confidence)” receptors.

For vulnerable receptors, predicted increases smaller than 0.01m (10mm) and therefore considered “negligible” impacts are summarised as follows :

- One “Essential Infrastructure” receptor with a flood depth increase of less than 0.002m (2mm) compared to the baseline.
    - This is a wind turbine. However, the physical location of the turbine as observed on satellite imagery appears to be approximately 250m from the assigned NRD receptor point, and no depth differences are observed at this location.
- Three “Highly Vulnerable” receptors with flood depth differences of less than 0.005m (5mm) on top of baseline flood depths between 0.045m and 0.10m (45mm-100mm).
- Three “More Vulnerable (Low Confidence)” receptors with flood depth increases of less than 0.01m (10mm) on top of baseline flood depths between 0.02m and 0.47m (20mm-470mm).Eight “Less Vulnerable” receptors with flood depth

increases of greater than 0.005m (5mm) include the cricket club, the rugby club, five greenfield locations, and one hopper located 1.2km north of the Scheme, with baseline flood depths between 0.02m and 0.79m (20mm-790mm).

- Four "Less Vulnerable" receptors where increases in flood depths greater than 0.01m (10mm) are predicted, one of these being an increase of 0.031m (31mm) at the cricket club, and the remaining three being greenfield sites. It should be noted that at the cricket club, the baseline depth is 0.40m (400mm), and there would be no change in flood hazard due to the Scheme.

The model predicts that the Scheme would not change the flood hazard classification at most receptors other than those below:

- Increase from "Low" to "Significant" at one "Less Vulnerable" receptor at the Farndon West FCA. This change is expected, as the FCA is designed to fill up and store water within the floodplain. There is no change at the Farndon East FCA as the hazard rating is already "Significant".
- Decrease from "Significant" to "Moderate" at one "Less Vulnerable" receptor at agricultural land near Cattle Market roundabout.

B2.1 Summary - 50% AEP

During the 50% AEP event, reductions in flood depths are predicted at 14 receptors. The Scheme is not predicted to cause increases in flood depths above 0.01m (10mm) at any "Essential Infrastructure", "Highly Vulnerable", "More Vulnerable", "More Vulnerable (Low Confidence)", or "Less Vulnerable (Low Confidence)" receptors.

There are four "Less Vulnerable" receptors with increases above 0.01m (10mm) due to the Mitigated Scheme, one of which is the cricket club, which has a predicted increase of 0.031m (31mm) on top of a baseline depth of 0.4m (400mm). The Mitigated Scheme model predicts no change in flood hazard at this receptor. The remaining impacted "Less Vulnerable" receptors are the two FCAs and a greenfield site.

Table 5: 50% AEP. Flood depth differences. Mitigated Scheme versus baseline. Original model.

	Count of receptors with change in depth							
NPPF Class	**<0mm**	**0-1mm**	**1-2mm**	**2-3mm**	**3-4mm**	**4-5mm**	**5-10mm**	**>10mm**
Essential Infrastructure	0	0	1	0	0	0	0	0
Highly Vulnerable	0	0	0	1	0	2	0	0
More Vulnerable	0	0	0	0	0	0	0	0
More Vulnerable (Low Confidence)	0	0	0	0	0	1	2	0
Less Vulnerable	14	0	0	0	0	0	4	4
Less Vulnerable (Low Confidence)	0	0	0	0	0	0	0	0
Water Compatible	54	0	0	3	5	0	9	1
Total number with decrease (excluding water compatible)								**14**
Total number with increase (excluding water compatible)								**15**

B3. 20% AEP event (5-year return period event)

A comparison between baseline and Mitigated Scheme scenarios for the original model (Table 6) indicates that 44 receptors are predicted to decrease in flood depths, whilst 36 receptors are predicted to increase.

No flood depth increases above 0.01m (10mm) are predicted at any “Essential Infrastructure”, “Highly Vulnerable”, “More Vulnerable”, “More Vulnerable (Low Confidence)”, or “Less Vulnerable (Low Confidence)” receptors.

For vulnerable receptors, predicted increases smaller than 0.01m (10mm) and therefore considered “negligible” impacts are summarised as follows :

- Two “Essential Infrastructure” receptors with flood depth increases less than 1mm on top of baseline flood depths between 0.20m and 0.77m (200-770mm).
  - One is a wind turbine according to the NRD. However, the physical location of the turbine, as observed on satellite imagery is approximately 250m from the assigned NRD receptor location, and no depth differences are observed at this location.
  - One is an electricity sub-station 1.2km northwest of the Scheme where the baseline flood depth is already 0.77m (770mm).
- Four “Highly Vulnerable” receptors with flood depth differences of less than 0.005m (5mm) on top of baseline depths of up to 0.35m (350mm). These receptors are caravans in the western end of the Tolney Lane area adjacent to Old Trent Dyke. Flood hazard is not predicted to change at these receptors.
- One “More Vulnerable” receptor and one “More Vulnerable (Low Confidence)” receptor at Tolney Lane with flood depth differences greater than 0.005m (5mm). Flood hazard is not predicted to change at these receptors.
  - At the “More Vulnerable” receptor, the predicted flood depth increase of 0.006m (6mm) is on top of a baseline depth of 0.14m (140mm). However, upon close inspection of the results, the respective depths in the baseline and Mitigated Scheme scenarios both show minor numerical fluctuations in this area at the peak of up to 0.005m (5mm), indicating that the modelled depth increases in this area are a result of modelling uncertainty (see Section 2) rather than a material flood risk impact.
  - Based on aerial imagery, the receptor marked as “More Vulnerable (Low Confidence)” appears unlikely to be a “More Vulnerable” residential dwelling.

- Seven “Less Vulnerable” receptors with flood depth increases of greater than 0.005m (5mm) include the cricket club, the rugby club, and five greenfield locations with baseline flood depths between 0.30m and 1.20m (300mm-1200mm). Flood hazard is not predicted to change at these receptors, aside from one which is agricultural land and is predicted to increase from “Moderate” to “Significant”.
- Three “Less Vulnerable (Low Confidence)” receptors with flood depth increases of greater than 0.005m (5mm), including the rugby club, one at the British Sugar Factory 750m north of the Scheme, and one at agricultural land 150m west of

the Scheme. Flood hazard is not predicted to change at these receptors, aside from one which is located at the British Sugar Factory and is predicted to increase from “Low” to “Moderate”.

B3.1 Summary – 20% AEP

During the 20% AEP event, reductions in flood depths are predicted at 44 receptors. The Mitigated Scheme is not predicted to increase flood depths above 0.01m (10mm) at any “Essential Infrastructure”, “Highly Vulnerable”, “More Vulnerable”, “More Vulnerable (Low Confidence)” or “Less Vulnerable (Low Confidence)” receptors.

There is one “More Vulnerable” receptor at Tolney Lane where an increase of 0.006m (6mm) is predicted. It should be noted that this is on top of a baseline depth of 0.14m (140mm) with no predicted change in flood hazard and is considered a “negligible” impact.

There are three “Less Vulnerable (Low Confidence)” receptors with increases greater than 0.01m (10mm). One of these is the cricket club, with an increase of 0.012m (12mm) on top of a baseline depth of 0.7m (700mm). Note that flood hazard is not predicted to change. The remaining two receptors are the Farndon West and East FCAs, which are designed to fill.

Table 6: 20% AEP. Flood depth differences. Mitigated Scheme versus baseline. Original model.

	Count of receptors with change in depth							
NPPF Class	**<0mm**	**0-1mm**	**1-2mm**	**2-3mm**	**3-4mm**	**4-5mm**	**5-10mm**	**>10mm**
Essential Infrastructure	0	2	0	0	0	0	0	0
Highly Vulnerable	0	0	0	1	0	3	0	0
More Vulnerable	4	4	0	1	0	0	1	0
More Vulnerable (Low Confidence)	9	2	0	1	0	0	4	0
Less Vulnerable	30	3	0	2	0	0	4	3
Less Vulnerable (Low Confidence)	1	0	0	2	0	0	3	0
Water Compatible	78	2	0	4	1	1	3	8
Total number with decrease (excluding water compatible)								**44**
Total number with increase (excluding water compatible								**36**

B4. 5% AEP event (20-year return period event)

A comparison between the baseline and Mitigated Scheme scenarios for the original model indicates that 201 receptors are predicted to decrease in flood depths, whilst 69 receptors are expected to increase.

No flood depth increases above 0.01m (10mm) are predicted at any “Essential Infrastructure”, “Highly Vulnerable”, or “Less Vulnerable (Low Confidence)” receptors. The model predicts that the Scheme would not change the flood hazard classification at most receptors, decreasing flood hazard at four receptors and increasing it at five.

Predicted increases smaller than 0.01m (10mm) and therefore considered “negligible” impacts are summarised as follows:

- One “Essential Infrastructure” receptor with a flood depth increase of less than 0.001m (1mm). This is an electricity sub-station located 800m northwest of the Scheme, where baseline depths are 0.65m (650mm). Flood hazard is not predicted to change at this receptor.

The model predicts flood depth increases above 0.01m (10mm), however investigation of model results indicates that changes in flood level at their locations are sensitive to model inputs. This is discussed further in Sections B4.1 and B4.2 of this Appendix. The receptors with predicted increases above 0.01m (10mm) are summarised as follows:

- Three “Less Vulnerable” with an increase greater than 0.01m (10mm), two of which are located within the Farndon East and West FCAs. This change is expected, as the FCA is designed to fill up and store water within the floodplain. The remaining “Less Vulnerable” receptor is the cricket club, where a depth increase of 0.025m (25mm) is predicted on top of a baseline depth of 0.98m (980mm), though flood hazard is not predicted to change and remains “Significant”.
- Three “More Vulnerable” receptors and two “More Vulnerable (Low Confidence)” receptors with flood depths of greater than 0.01m (10mm) and less than 0.02m (20mm) on top of baseline depths between 0.045m and 0.40m (45-400mm). These receptors are located at Tolney Lane. Flood hazard is not predicted to change at these receptors. It is noted that these receptors at Tolney Lane are sensitive to local drainage and access infrastructure for the Nottingham to Lincoln railway line, and this is discussed further in Sections B4.1 and B4.2 of this Appendix.
- One “Less Vulnerable” receptor which is not predicted to flood in the baseline is now predicted to flood due to the Scheme, this is the Riverside Car Park. The hazard classification at this location due to the Scheme is “Low”. The flood depths due to the Scheme at this location range between 0.0075m to 0.05m (7.5-50mm). This is discussed further in Sections B4.1 and B4.2 of this Appendix.

B4.1 5% AEP receptors at Tolney Lane

The predicted increases greater than 0.01m (10mm) at the three “More Vulnerable” and two “More Vulnerable (Low Confidence)” receptors are located to the south of an existing opening beneath the Nottingham to Lincoln railway line near the Tolney Lane area. This location is shown in Figure 12. It should be noted that a depth increase greater than 0.01m (10mm) does not occur at this location for any other modelled flood event.

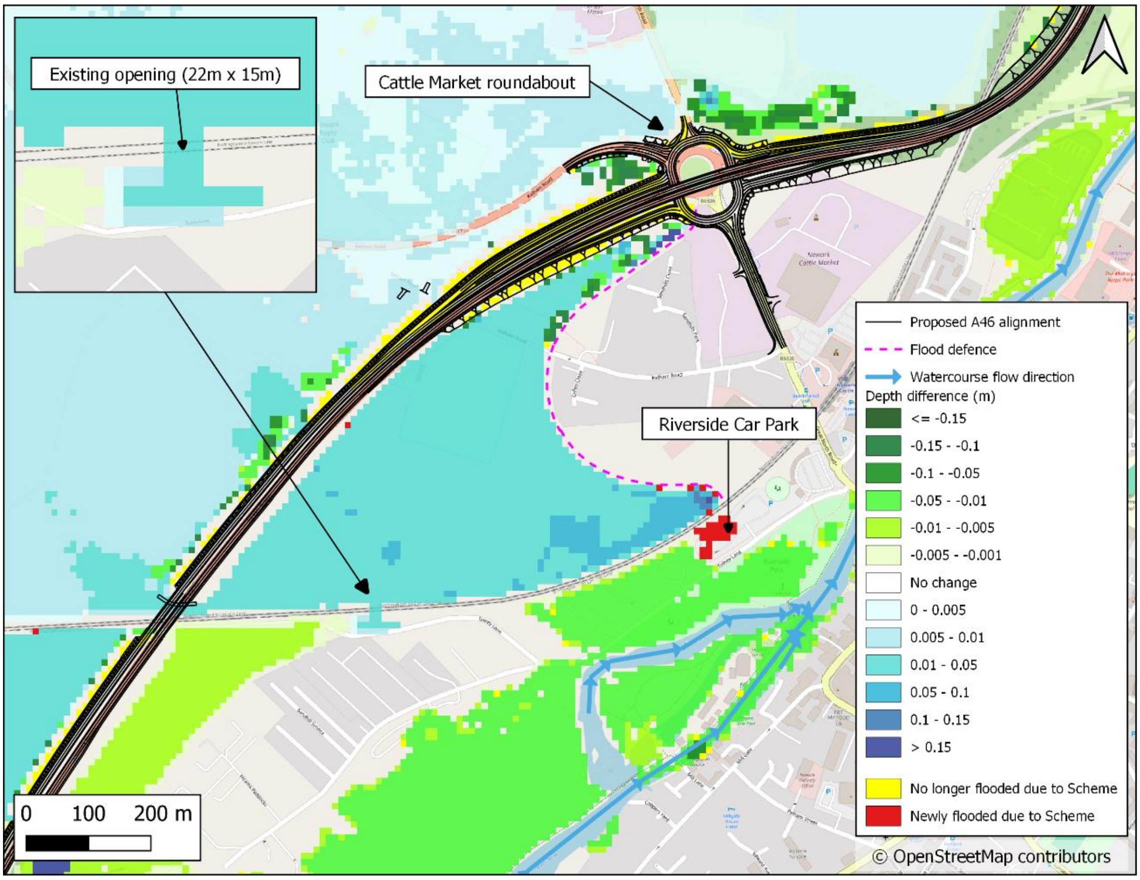


Figure 12: 5% AEP. Tolney Lane. Flood depth differences. Mitigated Scheme versus baseline. Original model.

5.1.7 The existing opening beneath the Nottingham to Lincoln railway line was inaccessible during a site visit in December 2024, and therefore the condition of the structure is unknown. Due to the size of the opening, it has been incorporated in the baseline and Mitigated Scheme models as a clear opening in the ground model which enables a conservative estimate of flow through the area, and ultimately a conservative estimate of flood risk at receptors.

5.1.8 Further investigation into the flow mechanisms at Tolney Lane and the surrounding area were undertaken for the 5% AEP event, given that this is the only event where flood depth increases above 0.01m (10mm) are predicted at this location. A schematic of the flow mechanisms in this area is shown in Figure 13 and a description is given below:

- (1) Flow enters the area behind the Kelham Road flood defence from the western floodplain via the opening beneath the A46 where it crosses the Nottingham to Lincoln railway line (1a), and an existing culvert (1b). The flow direction is west to east at this point.
- (2) Due to the Scheme embankment to the north, there is an increase in water level behind the Kelham Road flood defence in comparison to the baseline. In the area behind the Kelham Road flood defence, flow generally circulates

behind the bund. Flow is directed north towards culvert beneath Cattle Market roundabout (2), as well as to the east towards an existing culvert beneath the Nottingham to Lincoln railway line (3).

- (3) Flow moves eastwards through the area behind the Kelham Road flood defence and leaves the area via an existing culvert beneath the Nottingham to Lincoln railway line to the east where it then reaches an existing ditch or trackway that runs parallel to the Riverside way car park in a south westerly direction. The condition of this ditch or trackway is unknown, a photo of the structure is included in Figure 14 below, with the structure showing localised pluvial flooding at the time of the site visit.

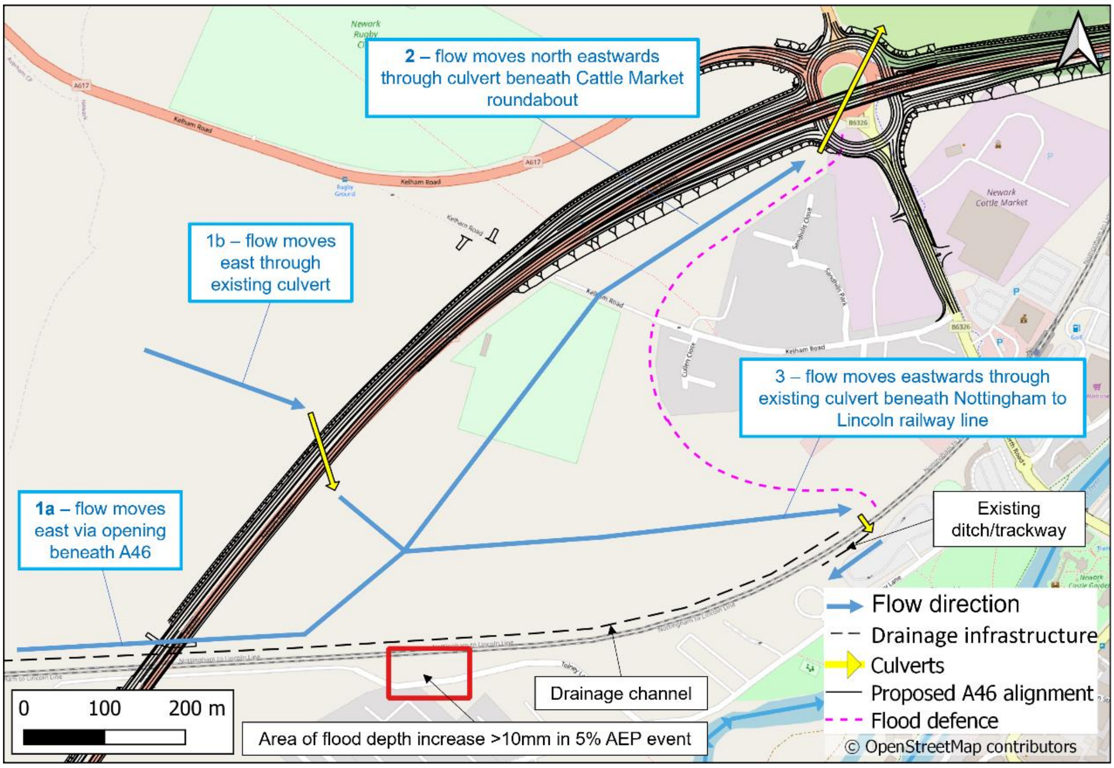


Figure 13: Schematic of flow mechanisms in area near Tolney Lane

Figure 14: Photo of the existing culvert to east and the associated ditch or trackway. Source: Skanska, 16/01/2025.

5.1.1 The representation of several elements in this region of the model has been reviewed and modified as part of sensitivity testing of this model area. This is discussed in section B4.2 of this Appendix.

B4.2 Sensitivity testing

5.1.2 The sensitivity test consisted of the following modifications to key model elements near the Tolney Lane area:

- **Eastern culvert beneath Nottingham to Lincoln railway line:** surveyed culvert invert levels were enforced, enabling smoother conveyance of flow through the culvert and out of the area behind the Kelham Road flood defence bund.
- **Enforcement of the existing ditch or trackway to the south of the eastern culvert:** this feature was not captured in the survey, therefore LiDAR levels were used. A 50% constriction was applied to prevent overestimation of the flow area in the model. This ultimately provides a more conservative model set up for assessing flood risk at Tolney Lane.
- **Enforcement of an existing drainage channel running parallel to the north of the Nottingham to Lincoln railway line:** surveyed levels were enforced, and it should be noted that the surveyed elevations are assumed to be the water surface elevations in the drainage channel rather than the invert. This means that the representation of the drainage channel is conservative.

5.1.3 Results of the sensitivity test demonstrate that with the modifications to key elements given above, there are no depth increases due to the Scheme greater than 0.01m (10mm) near Tolney Lane. The flood depth change following the sensitivity test are shown in Figure 15.

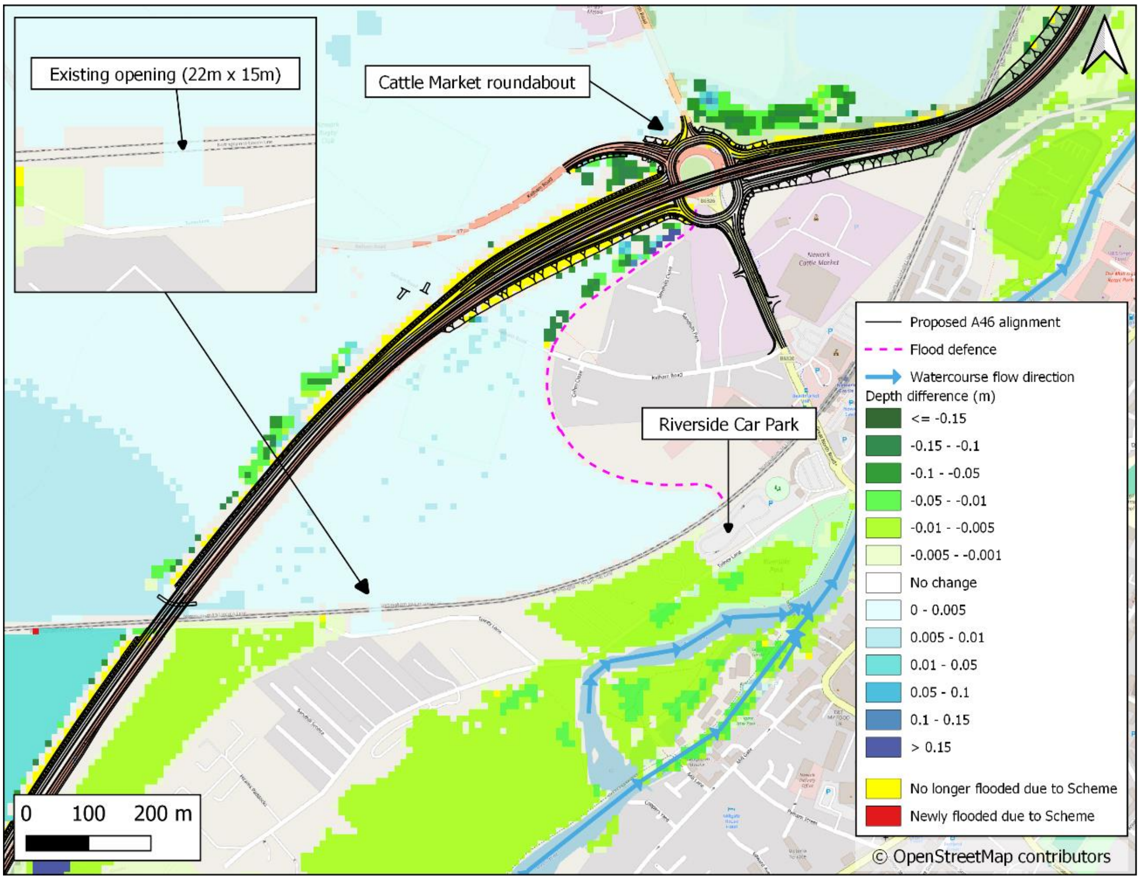


Figure 15: 5% AEP. Tolney Lane. Flood depth differences. Mitigated Scheme versus baseline. Sensitivity model.

5.1.1 The sensitivity test shows no increases in flood depth greater than 0.01m (10mm) at any “Essential Infrastructure”, “Highly Vulnerable”, “More Vulnerable”, “More Vulnerable (Low Confidence)”, or “Less Vulnerable (Low Confidence)” receptors. Flood depth increases at the cricket club have reduced to less than 0.01m (10mm), and the Riverside Car Park is no longer predicted to flood as a result of the Mitigated Scheme. The only predicted flood depth increases above 0.01m (10mm) are the “Less Vulnerable” FCAs which are designed to fill up and store water within the floodplain .

B4.3 Summary

The original model predicts that flood depths would increase by more than 0.01m (10mm) at five “More Vulnerable” or “More Vulnerable (Low Confidence)” receptors at Tolney Lane. An increase greater than 10mm is also predicted at the “Less Vulnerable” cricket club. No change in flood hazard is predicted at these receptors.

Sensitivity testing was undertaken to determine if these increases were sensitive to local drainage and access infrastructure for the Nottingham-Lincoln railway line, near the Tolney Lane area. The sensitivity test at Tolney Lane shows no flood depth increases greater than 0.01m (10mm), other than at two “Less Vulnerable” receptors, which are the Farndon West and East FCAs, as expected.

Table 7 presents the receptor analysis for the 5% AEP event for the original model, and Table 8 presents the receptor analysis incorporating the sensitivity test.

Table 7: 5% AEP. Flood depth differences. Mitigated Scheme versus baseline. Original model.

	Count of receptors with change in depth							
NPPF Class	**<0mm**	**0-1mm**	**1-2mm**	**2-3mm**	**3-4mm**	**4-5mm**	**5-10mm**	**>10mm**
Essential Infrastructure	3	1	0	0	0	0	0	0
Highly Vulnerable	37	0	0	0	0	0	0	0
More Vulnerable	56	2	0	3	2	1	0	3
More Vulnerable (Low Confidence)	35	12	2	1	2	2	2	2
Less Vulnerable	53	12	1	1	0	1	5	4
Less Vulnerable (Low Confidence)	17	1	0	3	1	3	2	0
Water Compatible	81	16	2	3	10	1	4	0
Total number with decrease (excluding water compatible)								**101**
Total number with increase (excluding water compatible								**68**

Table 8: 5% AEP. Flood depth differences. Mitigated Scheme versus baseline. Sensitivity model.

	Count of receptors with change in depth							
NPPF Class	**<0mm**	**0-1mm**	**1-2mm**	**2-3mm**	**3-4mm**	**4-5mm**	**5-10mm**	**>10mm**
Essential Infrastructure	1	1	0	0	0	0	0	0
Highly Vulnerable	48	0	0	0	0	0	0	0
More Vulnerable	38	1	3	1	3	1	0	0
More Vulnerable (Low Confidence)	25	4	2	3	3	0	0	0
Less Vulnerable	40	1	2	1	3	3	0	2
Less Vulnerable (Low Confidence)	10	0	4	0	5	0	0	0
Water Compatible	70	1	14	1	4	1	0	0
Total number with decrease (excluding water compatible)								**162**
Total number with increase (excluding water compatible								**43**

B5. 3.33% AEP event (30-year return period event)

A comparison between the baseline and Mitigated Scheme scenarios for the original model (Table 9) indicates that 265 receptors are predicted to decrease in flood depth, whilst 73 are predicted to increase.

No flood depth increases above 0.01m (10mm) are predicted at any “Essential Infrastructure”, “Highly Vulnerable”, “More Vulnerable”, “More Vulnerable (Low Confidence)”, or “Less Vulnerable (Low Confidence)” receptors.

Predicted increases smaller than 0.01m (10mm) and therefore considered “negligible” impacts are summarised as follows for vulnerable receptors:

- Three “Essential Infrastructure” receptors with increases less than 0.001m (1mm), all of which are electricity sub-stations. Two of the sub-stations are at the model boundary 2.5km southeast of the Scheme, the third is located 1.5km north of the Scheme. Baseline flood depths across the three locations ranges from 0.37m (370mm) to 0.79m (790mm), and flood hazard is not predicted to change.
- Two “Less Vulnerable” receptors with increases above 0.01 (10mm). These are the Farndon West and East FCAs. This change is expected, as the FCA is designed to fill up and store water within the floodplain.

B5.1 Summary – 3.33% AEP

During the 3.33% AEP event, reductions in flood depths are predicted at 265 receptors. The Scheme is not predicted to increase flood depths to any receptors above 0.01m (10mm), aside from two “Less Vulnerable” receptors which are the Farndon West and East FCAs as expected. In addition to this, there are no instances of increased hazard due to the Mitigated Scheme.

Table 9: 3.33% AEP. Flood depth differences. Mitigated Scheme versus baseline. Original model.

	Count of receptors with change in depth							
NPPF Class	**<0mm**	**0-1mm**	**1-2mm**	**2-3mm**	**3-4mm**	**4-5mm**	**5-10mm**	**>10mm**
Essential Infrastructure	2	3	0	0	0	0	0	0
Highly Vulnerable	49	0	0	0	0	0	0	0
More Vulnerable	71	10	3	3	2	1	0	0
More Vulnerable (Low Confidence)	50	12	5	2	3	1	0	0
Less Vulnerable	71	5	2	1	4	0	2	2
Less Vulnerable (Low Confidence)	22	1	5	1	5	0	0	0
Water Compatible	98	8	10	2	5	0	0	0
Total number with decrease (excluding water compatible)								**265**
Total number with increase (excluding water compatible								**73**

B6. 1% AEP event (100-year return period event)

A comparison between baseline and Mitigated Scheme scenarios for the original model indicates that 644 receptors are predicted to decrease in flood depth, whilst 306 receptors are predicted to increase.

Predicted increases smaller than 0.01m (10mm) and therefore considered "negligible" impacts are summarised as follows:

- One "Essential Infrastructure" receptor. This is a sewage pumping station near Fosse Road with an increase of 0.004m (4mm) on top of a baseline flood depth of 0.6m (600mm). Flood hazard is not predicted to change.
- Five "Highly Vulnerable" receptors with increases up to 0.002m (2mm). Two of these are caravans at Tolney Lane, with increases of 2mm on top of baseline depths of 0.1m (100mm), the remaining three are telecommunications phone masts with increases of less than 0.002m (2mm) on top of baseline depths of 0.27m (270mm).

The model predicts flood depth increases above 0.01m (10mm), however investigation of model results indicates that changes in flood level at their locations are sensitive to model configuration. This is discussed further in Sections B6.1 and B6.2 of this Appendix. The receptors with predicted increases above 0.01m (10mm) are summarised as follows:

- One "Essential Infrastructure" receptor. This is an electricity sub-station near Fosse Road with an increase of 0.027m (27mm) on top of a baseline flood depth of 0.22m (220mm). Flood hazard is not predicted to change.
- 36 "More Vulnerable" receptors, all of which are located near Fosse Road, 300m southwest of Farndon Roundabout, and are attributed to modelling uncertainties. Impacts at Fosse Road are discussed further in sections B6.1 and B6.2 of this Appendix. It should be noted that except for two receptors, flood hazard is not predicted to change; the two "More Vulnerable" residential properties show an increase in flood hazard classification from "Low" to "Moderate". However, this is reflective only of the NRD point position at the centroid of the properties. The overall hazard across the wider area is "Moderate".
- Two of the 36 "More Vulnerable" receptors near Fosse Road are not predicted to flood in the baseline and are now predicted to flood due to the Scheme, these are dwellings at Village Close. The hazard classification at these receptors with the Scheme is "Low". The flood depth with the Scheme is up to 0.021m (21mm) at these properties.
- Five "More Vulnerable (Low Confidence)" receptors located near Fosse Road 300m southwest of Farndon Roundabout. Flood hazard is not predicted to change at these receptors.
- Three "Less Vulnerable" receptors, two of which are the Farndon West and East FCAs, and the third is a showroom at Fosse Road. At the showroom, a depth increase of 0.027m (27mm) is predicted on top of a baseline depth of 0.310m (310mm), and the flood hazard is not predicted to change.

B6.1 1% AEP receptors at Fosse Road

In the vicinity of Fosse Road, flood depth increases greater than 0.01m (10mm) are observed in the original model (Figure 16). One “Essential Infrastructure” receptor, and all “More Vulnerable” and “More Vulnerable (Low Confidence)” receptors with an increase above 0.01m (10mm) in the 1% AEP event are located in this area.

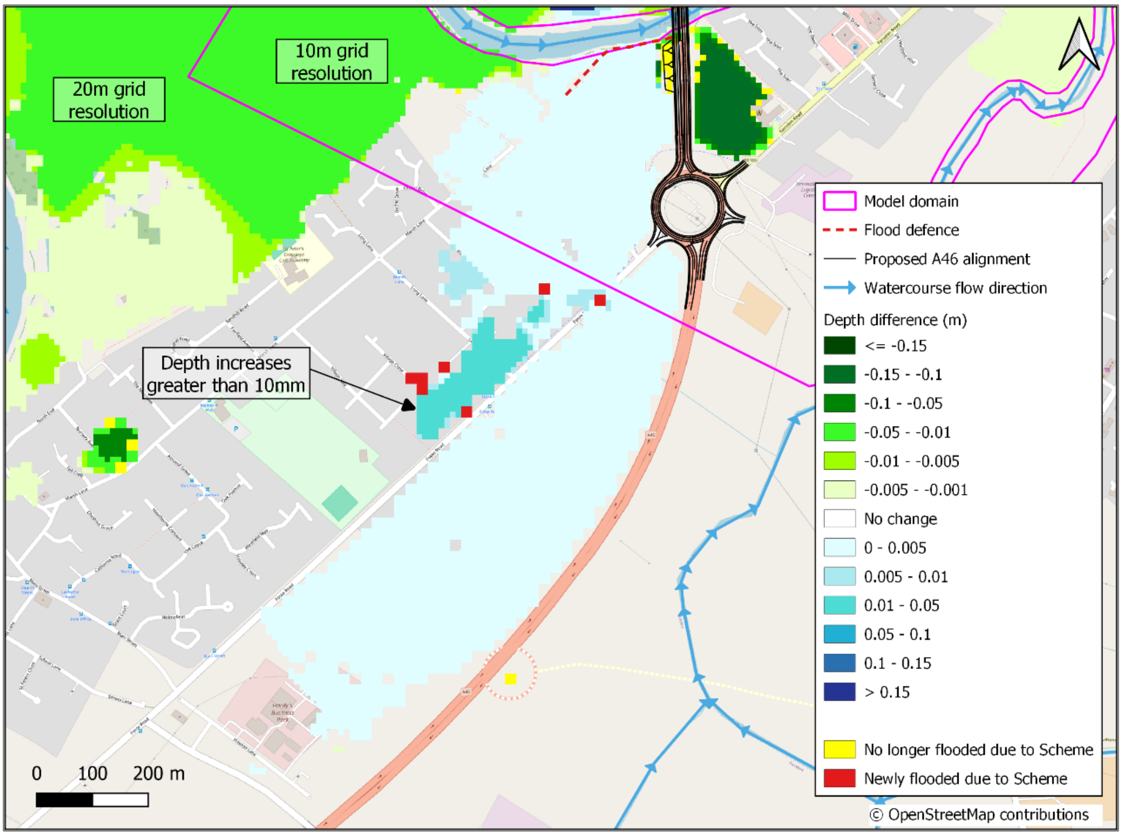


Figure 16: 1% AEP. Fosse Road. Flood depth differences. Mitigated Scheme versus baseline. Original model.

A review of model grid cells at this location indicates that this impact can be attributed to modelling uncertainties arising from the selection of grid cell size(s), as discussed in Section 2.2. Figure 16 shows the transition from a 10m grid resolution, representing the Scheme, to a 20m grid resolution beyond the Scheme boundary. The area of flood depth increase at Fosse Road is outside of the Scheme boundary, and the grid size transition occurs approximately 150m north of this area, resulting in edge effects at the model domain boundary.

Sensitivity testing of the model domain boundary locations has been undertaken to further investigate this area of flood depth increase and is discussed in section B6.2 of this Appendix.

B6.2 Sensitivity testing

As the area of flood depth increase greater than 0.01m (10mm) in the vicinity of Fosse Road is limited to the 1% AEP event only, sensitivity testing was undertaken for this event. The sensitivity test combined the modified representation of the Scheme embankment and abutment at Windmill Viaduct as discussed in Section 3.2, with modifications to the model domain boundaries.

The original model domain boundary and the model domain boundary modified as part of the sensitivity test are shown in Figure 17. This boundary marks the change in grid resolution from 10m to 20m. For the sensitivity test, the ground model in the Fosse Road area is represented at a higher (10m) resolution.

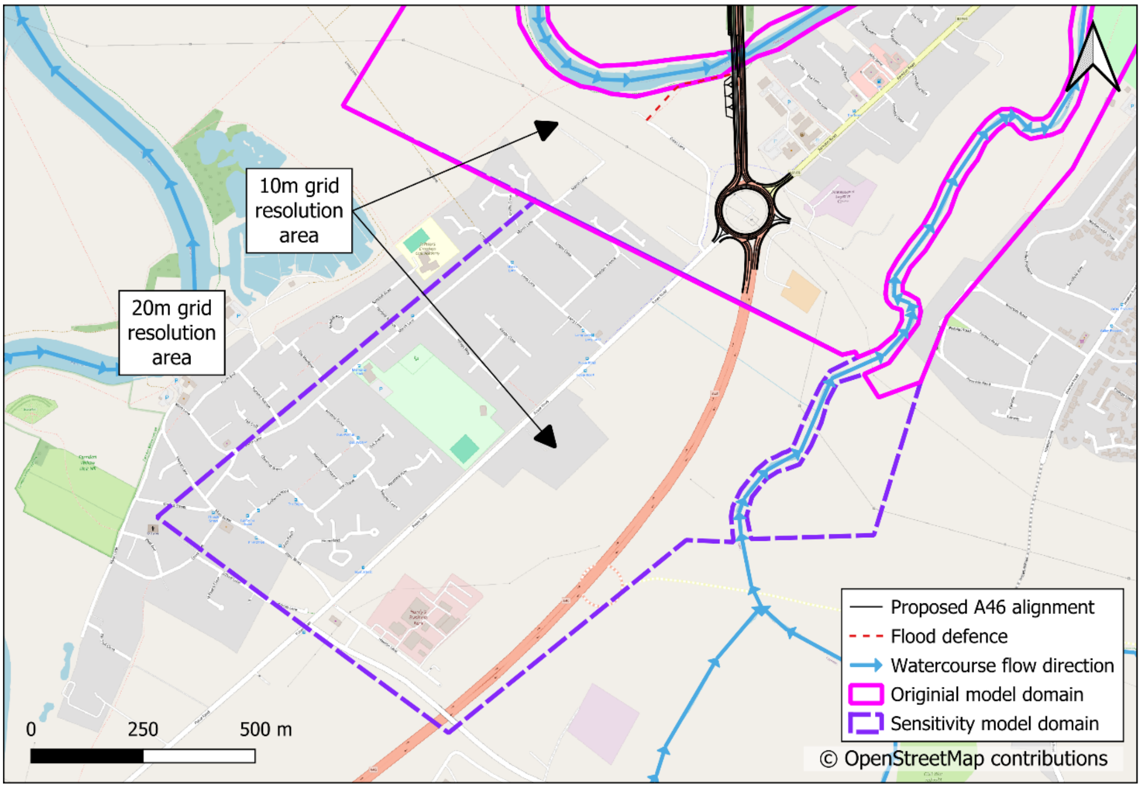


Figure 17: Original 10m model domain (pink solid line) and its extension further south in the sensitivity model (purple dashed line)

Flood depth changes near Fosse Road following the sensitivity test are shown in Figure 18. The sensitivity model does not predict any increases in flood depth greater than 0.01m (10mm) at any “Essential Infrastructure”, “Highly Vulnerable”, “More Vulnerable”, “More Vulnerable (Low Confidence)”, or “Less Vulnerable (Low Confidence)” receptors. The only predicted increases above 0.01m (10mm) are at the “Less Vulnerable” FCAs as expected.

There are three instances of new flooding, shown by red cells in Figure 18, with flood depths ranging between 0.001m to 0.02m (1mm to 20mm). These are located at the edges of the Farndon Recreation Ground and do not impact any vulnerable receptors.

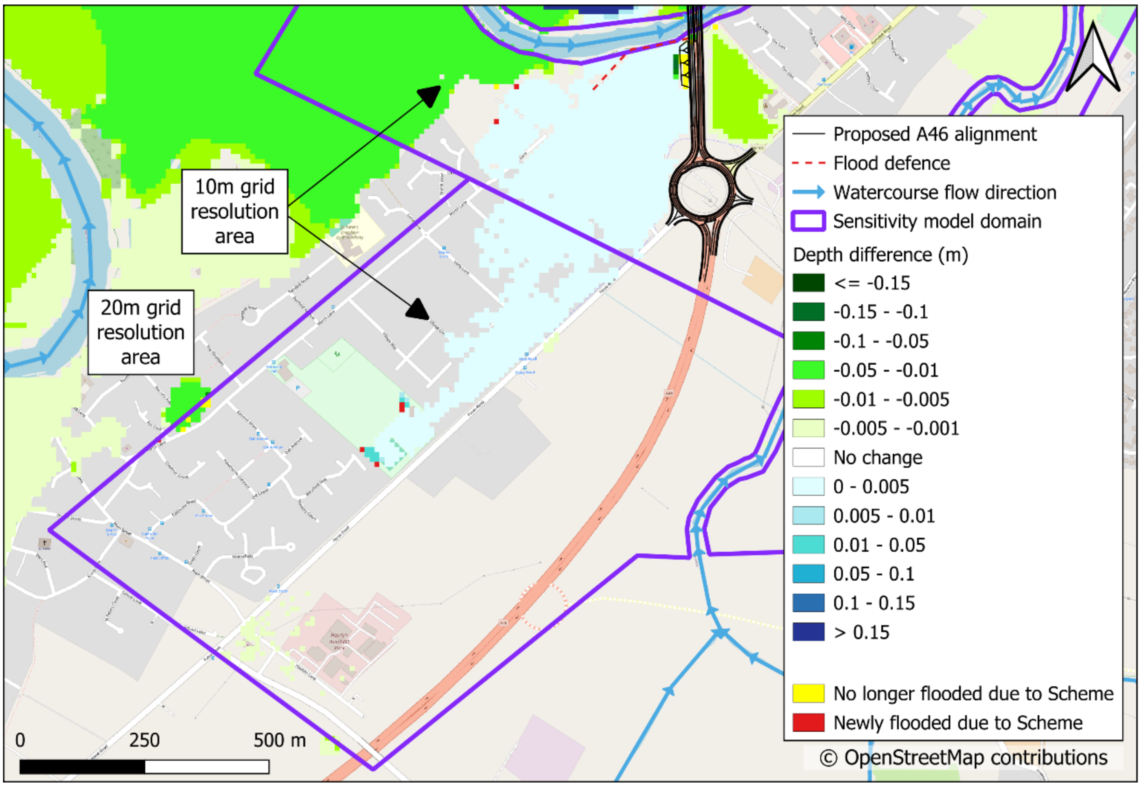


Figure 18: 1% AEP. Fosse Road. Flood depth differences. Mitigated Scheme versus baseline. Sensitivity model.

B6.3 Summary – 1% AEP

The original model predicts that flood depths would increase by more than 0.01m (10mm) at one “Essential Infrastructure”, 36 “More Vulnerable”, five “More Vulnerable (Low Confidence)” and three “Less Vulnerable” receptors in the Fosse Road area. Flood hazard is not predicted to increase at these receptors.

Sensitivity testing was undertaken to determine if these increases were sensitive to model inputs near Fosse Road. For the sensitivity test, modifications were made to Scheme embankment and abutment at Windmill Viaduct, together with adjustments to the location of the model domain boundary. As a result, there are no flood depth increases greater than 0.01m (10mm), aside from at two “Less Vulnerable” receptors at Farndon West and East FCAs, as expected.

Figure 10 presents the receptor analysis for the 5% AEP event for the original model, and Figure 11 presents the receptor analysis incorporating the sensitivity test.

Table 10: 1% AEP. Flood depth differences. Mitigated Scheme versus baseline. Original model.

	Count of receptors with change in depth							
NPPF Class	**<0mm**	**0-1mm**	**1-2mm**	**2-3mm**	**3-4mm**	**4-5mm**	**5-10mm**	**>10mm**
Essential Infrastructure	9	0	0	0	1	0	0	1
Highly Vulnerable	63	2	3	0	0	0	0	0
More Vulnerable	220	14	20	9	49	40	17	36
More Vulnerable (Low Confidence)	106	18	10	6	4	19	4	5
Less Vulnerable	166	4	5	1	3	9	0	3
Less Vulnerable (Low Confidence)	80	5	10	1	2	5	0	0
Water Compatible	141	7	7	2	0	0	0	3
Total number with decrease (excluding water compatible)								**644**
Total number with increase (excluding water compatible								**306**

Table 11: 1% AEP. Flood depth differences. Mitigated Scheme versus baseline. Sensitivity model.

	Count of receptors with change in depth							
NPPF Class	**<0mm**	**0-1mm**	**1-2mm**	**2-3mm**	**3-4mm**	**4-5mm**	**5-10mm**	**>10mm**
Essential Infrastructure	4	0	1	0	0	0	0	0
Highly Vulnerable	61	1	0	0	0	0	0	0
More Vulnerable	174	57	101	4	1	0	0	0
More Vulnerable (Low Confidence)	66	31	18	1	0	0	0	0
Less Vulnerable	123	7	10	1	0	0	0	2
Less Vulnerable (Low Confidence)	44	8	13	1	0	0	0	0
Water Compatible	100	8	8	1	0	0	0	0
Total number with decrease (excluding water compatible)								**472**
Total number with increase (excluding water compatible								**257**

I. Floodplain Compensation Areas Technical Note

Contents

Figures

Tables

1 Introduction

1.1.1 The A46 Newark Bypass (the "Scheme") entails the development of a stretch of the A46 that spans between Farndon Junction and Winthorpe Junction. The Scheme aims to upgrade an existing single carriageway road in Newark-on-Trent to a dual carriageway.

1.1.2 The Scheme requires the construction of a new carriageway that will run alongside the existing carriageway. These associated works will require new junctions and features such as utilities, drainage, public rights of way and accesses, which will include significant environmental mitigation work.

1.1.3 The Scheme is currently in Examination of the application for development consent. As a part of this, the Environment Agency, through a Relevant Representation, has requested additional information on the Floodplain Compensation Areas (FCAs).

1.1.4 The document provides additional information on the following points in the Environment Agency's Relevant Representation [EAFR-004]:

- Details of the exact volumes of floodplain lost due to the development.
- Details of how the volume lost is mitigated in the flood risk mitigation design.

1.1.5 This Technical Note is intended to be read in conjunction with, and is therefore an Appendix of, this Appendix 13.2 (Flood Risk Assessment) (the "Scheme FRA"), which provides justification for the location of the FCAs, hydraulic modelling to demonstrate effectiveness of the FCAs and descriptions of the infrastructure required to facilitate them.

2 FCA assessment

2.1 Assessment of floodplain loss

2.1.1 The FCA calculations have been carried out in accordance with CIRIA guidance document C624[1]. Following selection of the preferred route corridor and as part of the Scheme design process, the requirement for floodplain compensation was reduced where possible, for example by implementing steeper embankment slopes that reduced the Scheme's encroachment on the floodplain.

2.1.2 The floodplain volume loss (in 0.2m bands) detailed in the rest of this report is calculated from the Scheme design following completion of the preliminary Scheme design process. The design volume was calculated using a 3D CAD model of the Scheme. This model combined the highways model with conservative preliminary 3D representations of other elements not captured in that model. This created a 3D model for use in flood risk mitigation design. The additional elements captured outside of the initial 3D CAD model of the highway consist of raised drainage elements, additional earthworks and permanent access tracks.

2.1.3 Due to variation in peak fluvial flood levels along the length of the Scheme, the Scheme is split into three areas (see Figure 1) for the purposes of floodplain compensation design, with volumetric analysis undertaken for each section using the different design peak fluvial flood levels. These three areas are defined by the Railway Nottingham to Lincoln Line, the East Coast Main Line and A1 embankments, which cross the floodplain and result in the backing up of flood water. The peak fluvial flood levels were taken from early Scheme assessment and were set as 12.95mAOD, 12.20mAOD and 11.20mAOD for the green, red and purple shaded areas, respectively. These levels are still considered appropriate for demonstrating varying peak flood levels along the length of the Scheme.

2.1.4 For each 0.2m increment level between 8.6mAOD to 13mAOD, the volume lost in the floodplain (as taken by the Scheme design) was calculated from the 3D CAD model. This could also be described as the floodplain storage capacity lost in the floodplain. The cumulative volume loss for all aspects is presented in Figure 2.

2.1.5 Of particular interest is the volume of floodplain lost between 8.6-10.2mAOD due to this being below the typical water level of the River Trent, and therefore challenging to mitigate due to the need to drain any FCA into the River Trent. Analysis of the existing ground indicates that these lower elevations are valid, as the existing ground is drained by Internal Drainage Board (IDB) governed dykes that outfall into the River Trent several kilometres downstream.

[1] CIRIA, C624 - Development and flood risk, London 2004

2.1.6 In addition to the below volumes in Figure 2, temporary works volumes add an increase at each level band. These increases are shown in Figure 7.

Figure 1 - Road section split (maximum flood levels shown). Source: Open Street Maps

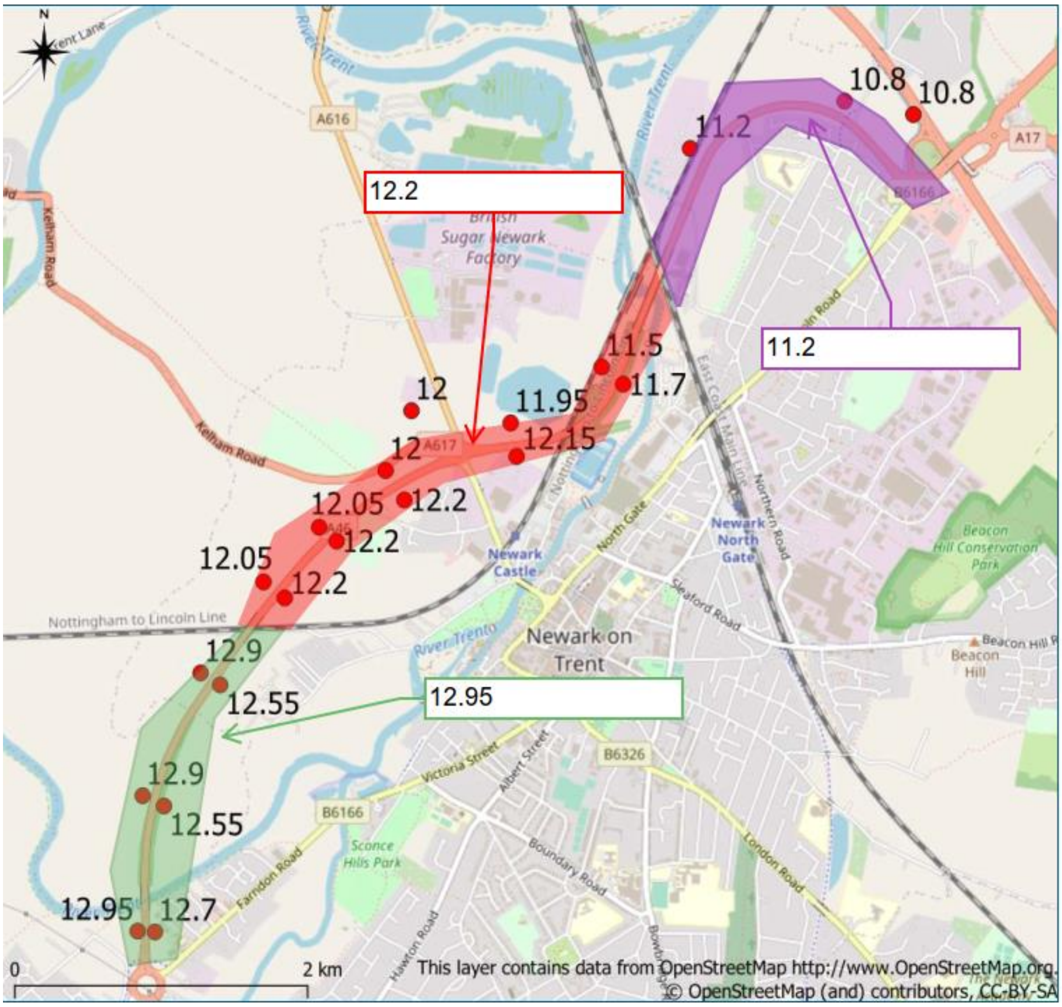
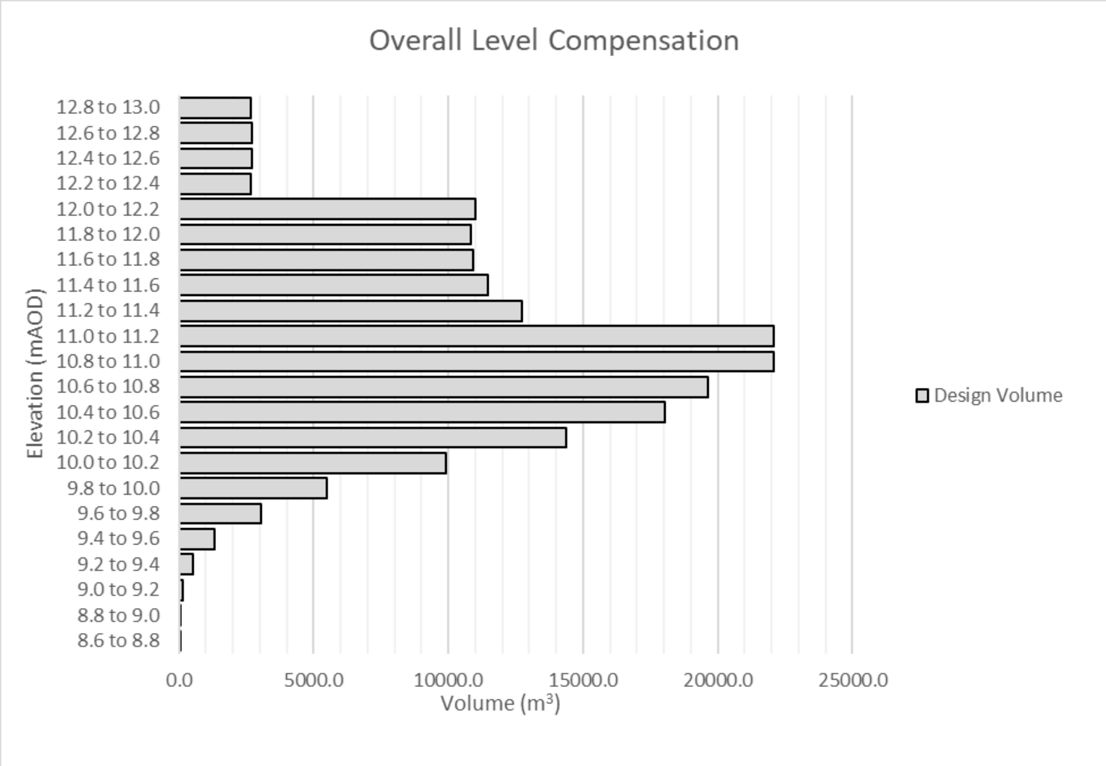


Figure 2 - Volume of floodplain loss



2.2 FCA Sites proposed in Development Consent Order

2.2.1 The rest of this Technical Note looks at the FCAs taken forward to the Examination of the application for development consent and how they provide flood risk mitigation.

2.2.2 Figure 7 sets out the potential elevation ranges available at the three sites taken forwards. All but one (Kelham & Averham) of the FCAs are located within the existing floodplain, due to their proximity to the Scheme. Close proximity is considered best practice for FCA design, as the floodplain lost and floodplain compensation can be hydraulically linked in a consistent way with the source of fluvial flooding. This also provides the additional carbon saving of providing winnable material for construction of the Scheme embankments adjacent to the Scheme itself, reducing construction traffic and the associated carbon cost.

2.2.3 Between 8.6-9.6mAOD, the floodplain compensation requirement (total inc. temporary case 5500m^3, permanent case 2200m^3) is expected to be met by a combination of aspects of the Scheme design, outlined as follows:

- Landscape grading and the drainage cut-off ditches needed for the proposed access tracks in the Farndon area, which will largely replace the existing drainage cut-off ditches of the Newark bypass. This can only be confirmed at Detailed Design.
- Indirect compensation at Farndon East FCA, demonstrated in Figure 7 in light yellow. Floodplain compensation will only be available at these

elevations when groundwater levels allow, in a similar way to the lowest elevations of the floodplain in the baseline scenario which are subject to flooding from groundwater emergence.

Table 1 - Tabulated Existing Ground Elevation Data (mAOD)*

Site	NGR	Max Ground Elevation	Min Ground Elevation	Average Ground Elevation
Farndon West FCA	SK 77885 53388	11.27	9.39	11.22
Farndon East FCA	SK 78373 53270	11.32	9.91	10.75
Kelham and Averham FCA	SK 76350 55280	15.56	10.18	12.82

* The tabulated max levels shown in Table 1 are absolute maximums. Based on the negligible volumes available close to the max levels, the rest of the document refers to level bands where it is considered reasonable for floodplain compensation to be provided at the referenced site.

Farndon sites

2.2.4 Levels at both sites vary between approximately 10.0 and 11.6mAOD, with the Farndon West site providing greater volumes at the upper end of this range. By maintaining the existing bank of the River Trent, the Farndon sites are capable of providing floodplain compensation below the mean water level of the River Trent. The indicative areas of the FCAs are shown in Figure 3. Water is conveyed to these sites when the River Trent banks are overtopped.

2.2.5 GIS polygons of the two Farndon FCA sites to serve as floodplain compensation were assessed. The volumetric capacity of these sites in 0.2m increments is detailed in Table 2 at the end of this technical note. Whilst the Farndon sites can cater for a large portion of the floodplain compensation required, the volume necessary between 11.5-13.0mAOD would need to be provided elsewhere.

Farndon West FCA

2.2.6 For Farndon West FCA, the minimum elevation of the northernmost portion near the tie-in to the Old Trent Dyke is 10.5mAOD which is the existing ground level; the excavation levels for other areas range between 10.5-11.6mAOD. There will be an average change in elevation for FCA purposes of approximately 0.5m comparing with existing ground levels. The mechanism for flooding of the site is by overtopping of the River Trent bank adjacent to the FCA, which is unchanged from the existing flood mechanism.

2.2.7 The connection to the Old Trent Dyke for flood water conveyance following a flood will be enabled through flooding through a channel to the left bank of the watercourse, which will also enable fish passage as discussed in the Farndon FCA Fish Escape Design Technical Note, contained in Appendix G of the Habitat Regulations Assessment [REP5-075]. This approach was chosen to ensure that the proposed area can make maximum use of the land and mimic existing flood flow paths, whilst also not generating a fluvial bypass of the existing River Trent channel.

2.2.8 Currently, a 1:1000 gradient is proposed from south to north through the site, however detailed design of the wetland and floodplain grazing marsh that sit within the footprint of the FCA will likely result in a more effective conveyance mechanism.

Farndon East FCA

2.2.9 Farndon East FCA is to provide indirect compensation to floodplain lost between 8.6-9.6mAOD, when low groundwater levels make this appropriate. Direct compensation is provided at the site between 9.6-11.0mAOD. The mechanism for flooding of the site is by overtopping of the River Trent bank adjacent to the FCA, which is unchanged from the existing flood mechanism.

2.2.10 A connection to the Old Trent Dyke to enable flood water conveyance following a flood will be enabled through a shallow passage to the left bank of the watercourse, which will also enable fish passage as discussed in the Farndon FCA Fish Escape Design Technical Note contained in Appendix G of the Habitat Regulations Assessment [REP5-075]. This approach was chosen to ensure that the proposed area can make maximum use of the land and mimic existing flood flow paths, whilst also not generating a new flood flow path from the River Trent through breaking the high left bank of the river.

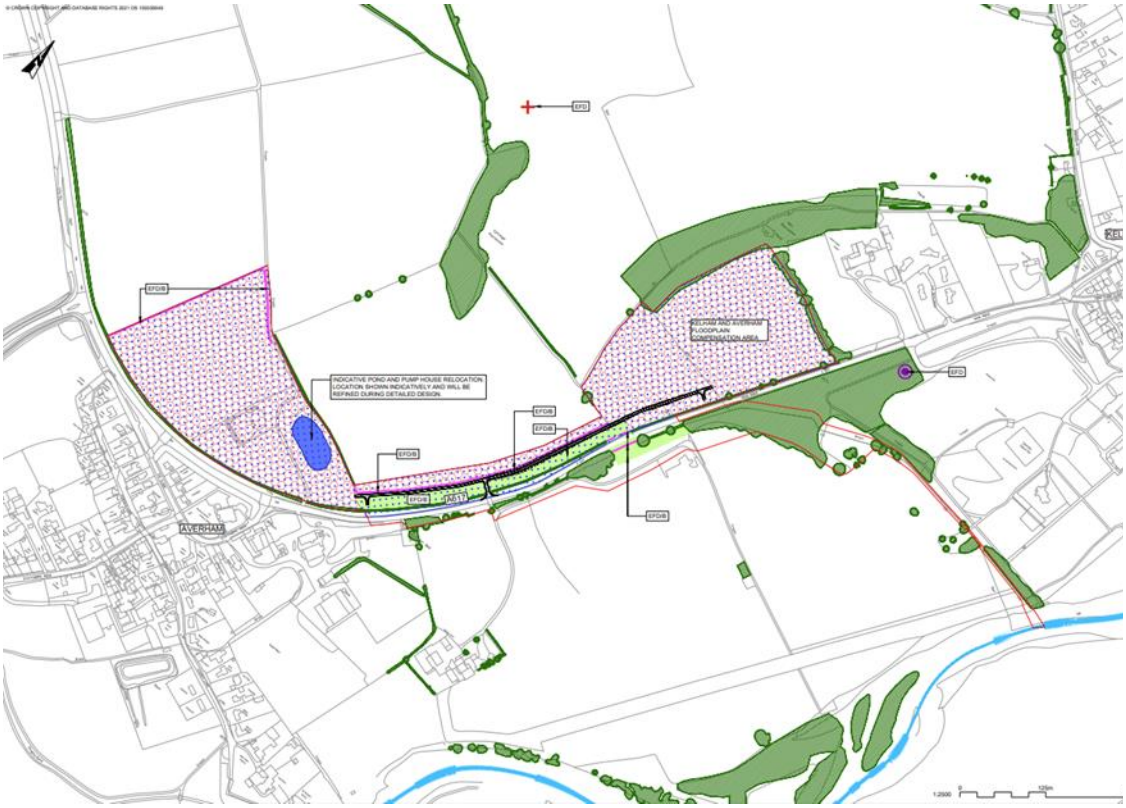
2.2.11 Due to the dual use of the site as a borrow pit, this FCA site will be a permanent groundwater fed lake, that will have a maximum crest level of 9.6mAOD.

Figure 3 - Farndon West and Farndon East FCA's. Source: Environmental Masterplan [AS-026]

Kelham and Averham FCA site

2.2.12 This site provides level-for-level floodplain compensation at the higher elevations required, in an area outside of the existing floodplain. The A617 road is the edge of the existing floodplain and the flooding mechanism proposed for the Kelham & Averham FCA is for the field ditch running along the south side the A617 to be connected to the FCA site via a series of culverts beneath the road. During a flood event, conveyance will be achieved via a combination of ditch flow and overland flow across the floodplain between the A617 and the River Trent.

Figure 4 - Kelham & Averham FCA. Source: Environmental Masterplan [AS-026]



2.2.13 Figure *7* and Table 2 at the end of this technical note demonstrate that the proposed FCA can meet the requirements of the upper elevation volume-for-volume and level-for-level compensation.

2.2.14 The site is intended to achieve floodplain compensation for volume lost in level bands between 11.4-13.0mAOD, predominately serving the highlighted green and red sections of the embankment shown in Figure 1. As flood levels do not reach above 12.4mAOD at the site for events up to the design event, elevation bands between 12.4-13.0mAOD are to be compensated indirectly at elevations between 11.6-12.4mAOD.

3 Hydraulic modelling

3.1 Overall context

3.1.1 The Scheme is not able to provide direct floodplain compensation for all elevations at all areas of the Scheme (see Figure 1). This is due to two main factors. Firstly, the floodplain is split into three areas (as shown in Figure 1) which have limited hydraulic connectivity between them due to flood water backing up behind the Railway Nottingham to Lincoln Line, the East Coast Main Line and A1 embankments. Secondly, there is a lack of suitable land in each section area to achieve flood volume mitigation at all elevations.

3.1.2 Hydraulic modelling of the Scheme was undertaken that included the FCAs to demonstrate their effectiveness. This hydraulic modelling is described in detail in the Hydraulic Modelling Technical Report (Appendix A of the Flood Risk Assessment [APP-177]). The design of the FCAs was incorporated into the hydraulic model to assess the connectivity of the FCAs with the floodplain, as well as to assess the impact of the FCAs in mitigating the peak water level and volume increase due to the Scheme. The outcomes of this assessment are discussed in the Scheme FRA, demonstrating that the FCAs have suitable connectivity to the floodplain.

3.1.3 Further to the Hydraulic Modelling Technical Report contained in Appendix A of the Flood Risk Assessment [APP-177], an additional Hydraulic Modelling Technical Note is provided in Appendix H of this Flood Risk Assessment , that provides further detail on modelling tolerances and other sensitivity tests.

3.2 FCA sensitivity test

3.2.1 Prior to the Examination (but post-Development Consent Order submission), the Environment Agency requested[2] that a targeted FCA sensitivity test be undertaken to establish if increasing the size of the FCAs resulted in substantial benefit to receptors. This could potentially address Environment Agency comments regarding the impacts to receptors in general, which are addressed in the Hydraulic Modelling Technical Note (Appendix H of this Flood Risk Assessment. Farndon West FCA was chosen for the sensitivity test as Farndon East FCA fills the suitable land it is constrained by, and Kelham & Averham FCA is intended to mitigate elevation bands that are higher than the elevations of many of the receptors in the floodplain.

3.2.2 Figure 5 and Figure 6 show the results of a sensitivity test that specifically looks at increasing the size of Farndon West FCA by 20%, to

[2] Meeting held between the Applicant and Environment Agency 05/09/2024

establish whether an appreciable benefit to flood risk could be achieved with a reasonably sized increase to the FCA volumes reported in Table 2. The addition to Farndon West FCA was implemented in the hydraulic model with the same approach as the rest of the FCA, extending to the north of the site outlined in the Scheme FRA. The figures show the difference between the Scheme FRA model outputs and the sensitivity model with increased FCA size. The sensitivity tests demonstrate that decreases in flood depths are less than 0.005m (5mm).

3.2.3 In Figure 5 for the 50% AEP event, areas of flood depth reduction are largely in agricultural land. These areas flood to average depths of 0.2m and 0.8m, west and east of the existing A46 respectively, in the baseline scenario, the sensitivity test and the Scheme with mitigation. Therefore, a reduction of up to 0.005m (5mm) is not considered to be an appreciable benefit, when considering the vulnerability of the receptors. It is acknowledged that a single low vulnerability receptor at Newark Ransome and Marles Cricket Club would experience a 5mm reduction in flood depth if the FCA is increased in size. However, this benefit is not considered proportionate to the increase in works required to achieve this, when the receptor would be flooded to a flood depth of over 0.4m (400mm) in this case. Note that outside the area of floodplain shown, impacts are within the modelling tolerance range of 0.01m (10mm).

3.2.4 In Figure 6, agricultural areas where benefit is shown in the 1% AEP plus climate change event, already substantially benefit in the Scheme with mitigation. Therefore, increasing the size of the FCA is not considered to have an appreciable benefit to the applicable agricultural receptors, as the decrease in depths is only expected to be an additional 0.002m (2mm) at the receptors. Note that outside the area of floodplain shown in Figure 6, impacts are within the modelling tolerance range of 0.01m (10mm).

3.2.5 The sensitivity test therefore demonstrates that increasing the size of Farndon West FCA would not assist in materially reducing flood risk to receptors in the floodplain.

Figure 5 - 50% AEP sensitivity test depth difference map

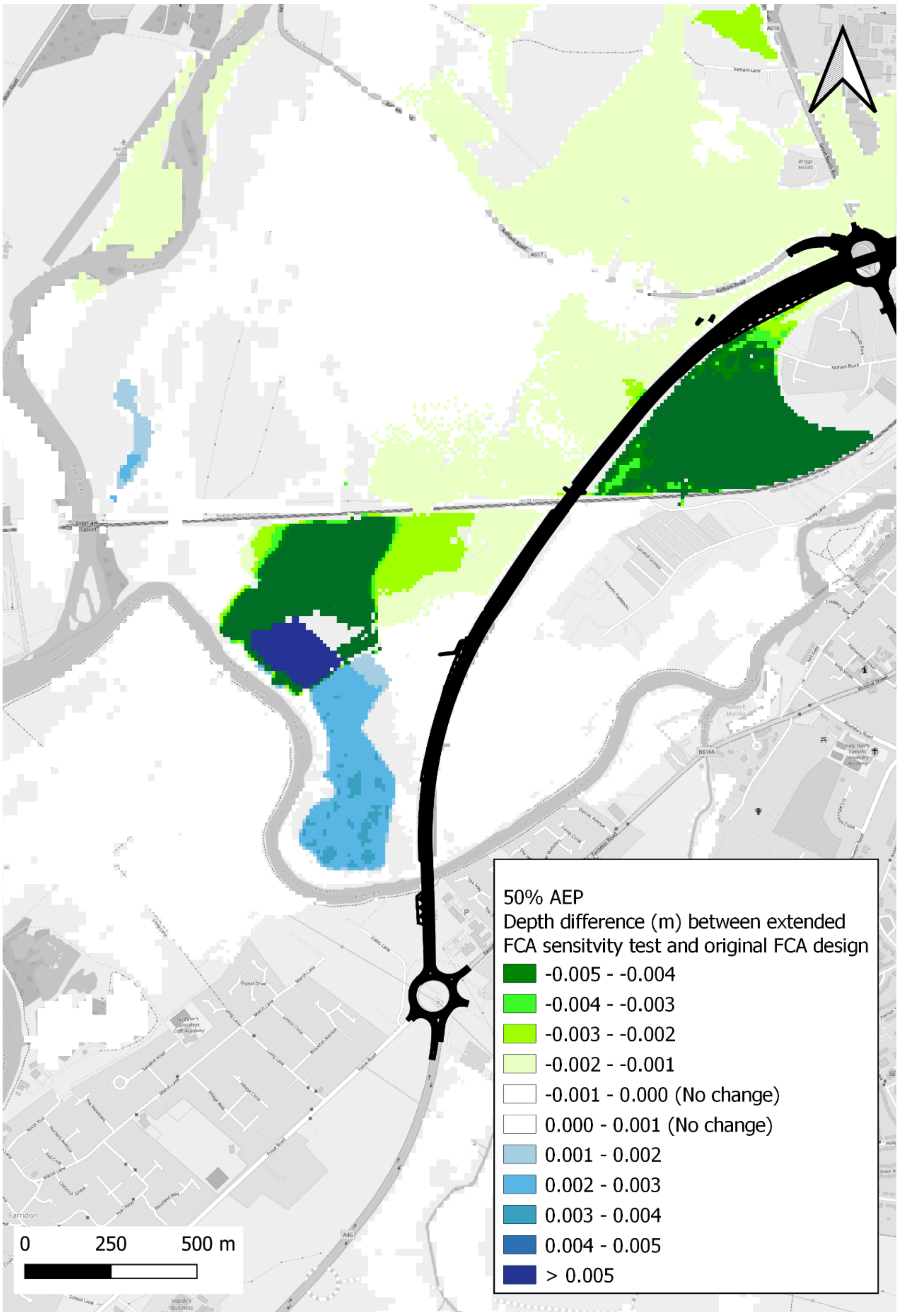
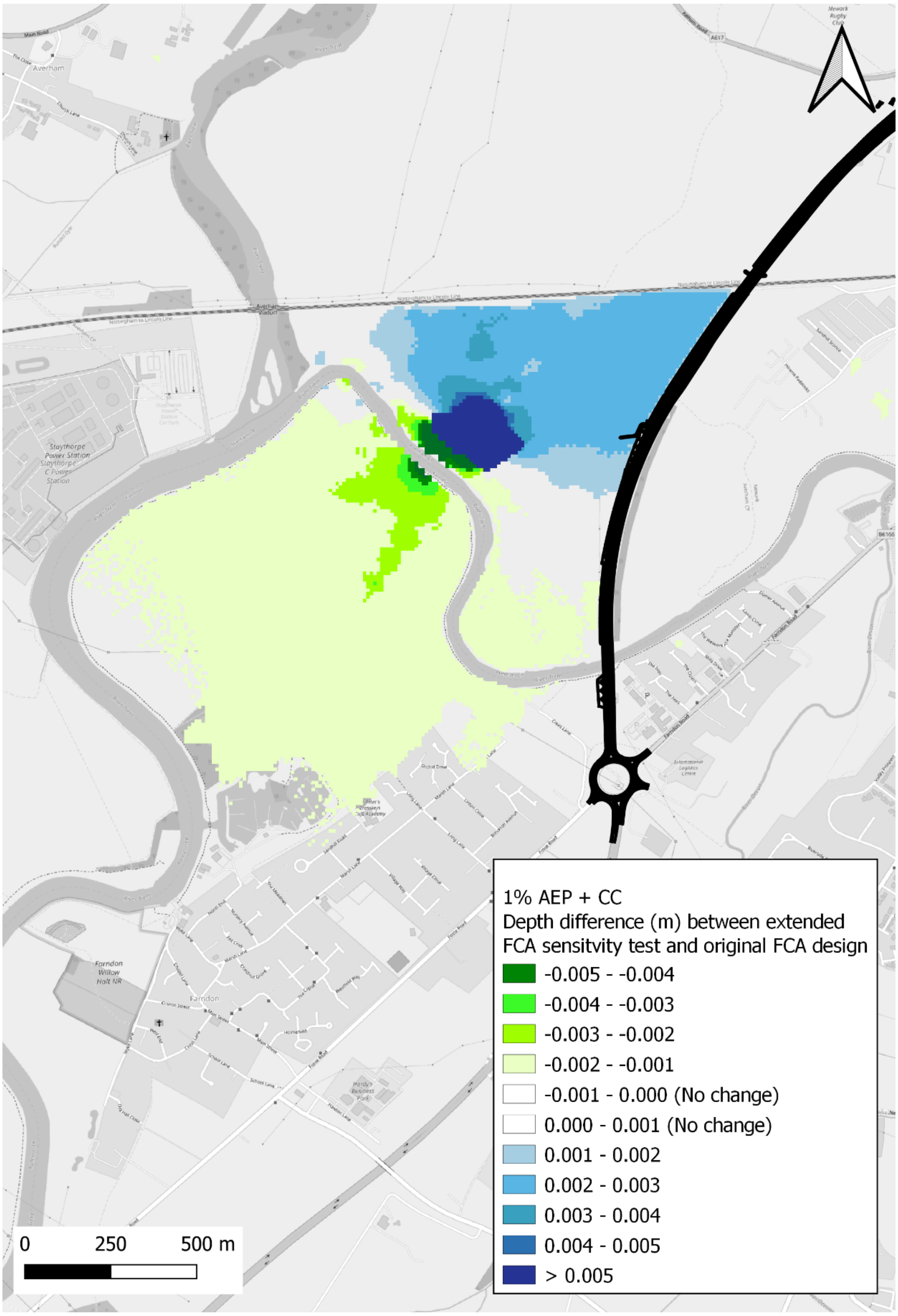


Figure 6 - 1% AEP+CC sensitivity test depth difference map



3.3 Kelham & Averham FCA Culvert Crossings

3.3.1 In the Flood Risk Assessment for the Scheme [APP-177] the Kelham & Averham FCA is described as having a crossing between the A617 and an access track that runs the length of an interconnecting ditch between two larger FCA areas.

3.3.2 At detailed design, it is anticipated that an additional crossing may be required between the A617 and the access track, to facilitate landowner access to farmland. Both crossings would require culverts for flow conveyance. Hydraulic model sensitivity testing therefore conservatively considers both potential culverted crossings between the A617 and the access track.

3.3.3 A culvert beneath the A617 was previously included in the Scheme hydraulic model, and therefore the hydraulic model sensitivity tests consider a total of three sets of culverts (both proposed culverted crossings and the Scheme A617 culvert) relevant to Kelham & Averham FCA flow conveyance. All three sets of culverts are modelled with the same invert levels. Each culvert is represented as having five 60mm diameter pipes.

3.3.4 For both the 3.33% AEP and the 1% AEP plus 39% climate change events, with the inclusion of the three sets of culverts, there is minimal change in the time that the Kelham and Averham FCA fills up and draws down, when compared to the baseline. Depth differences for both events, between the Scheme plus culverts and the baseline, are negligible (less than 10mm) at vulnerable receptors.

3.3.5 Sensitivity testing was also undertaken for a 75% blockage scenario at all three sets of culverts for the 1% AEP plus 39% climate change event. The blockages result in a slight reduction in flow in this event when compared to the Scheme, resulting in a 10mm depth reduction in the southern end of the Kelham and Averham FCA. Depth differences in this event for the blockage scenario compared to the Scheme are negligible (less than 10mm) at vulnerable receptors.

4 Conclusion

4.1.1 Figure 7 details the floodplain volume lost and the associated compensatory excavation volumes available at the Farndon FCA sites (shown in Figure 3) and Kelham & Averham FCA (shown in Figure 4), at 0.2m increments. The addition of temporary works volumes as shown does not exceed FCA capacity where direct compensation can be provided. Floodplain compensation at lower elevations (8.6-9.6m AOD) is to be achieved through replacement access track cutoff ditches, landscaping and the groundwater fed lake in Farndon East FCA, as volumes are relatively minor.

4.1.2 This Technical Note demonstrates the viability of the Farndon East, Farndon West and Kelham & Averham FCAs for floodplain compensation in a multi-site approach, to provide the required floodplain compensation for the Scheme, in support of the FRA. Sensitivity testing demonstrates that increasing the size of Farndon West FCA would not assist in appreciably reducing flood risk to receptors in the floodplain. Sensitivity testing also indicates that the addition of culverts beneath crossings at Kelham and Averham FCA would not materially impact flow conveyance and would have a negligible impact on flood risk to vulnerable receptors.

Figure 7. Graphical representation of Farndon and Kelham & Averham sites storage potential. Light yellow indicates additional Farndon East FCA volume

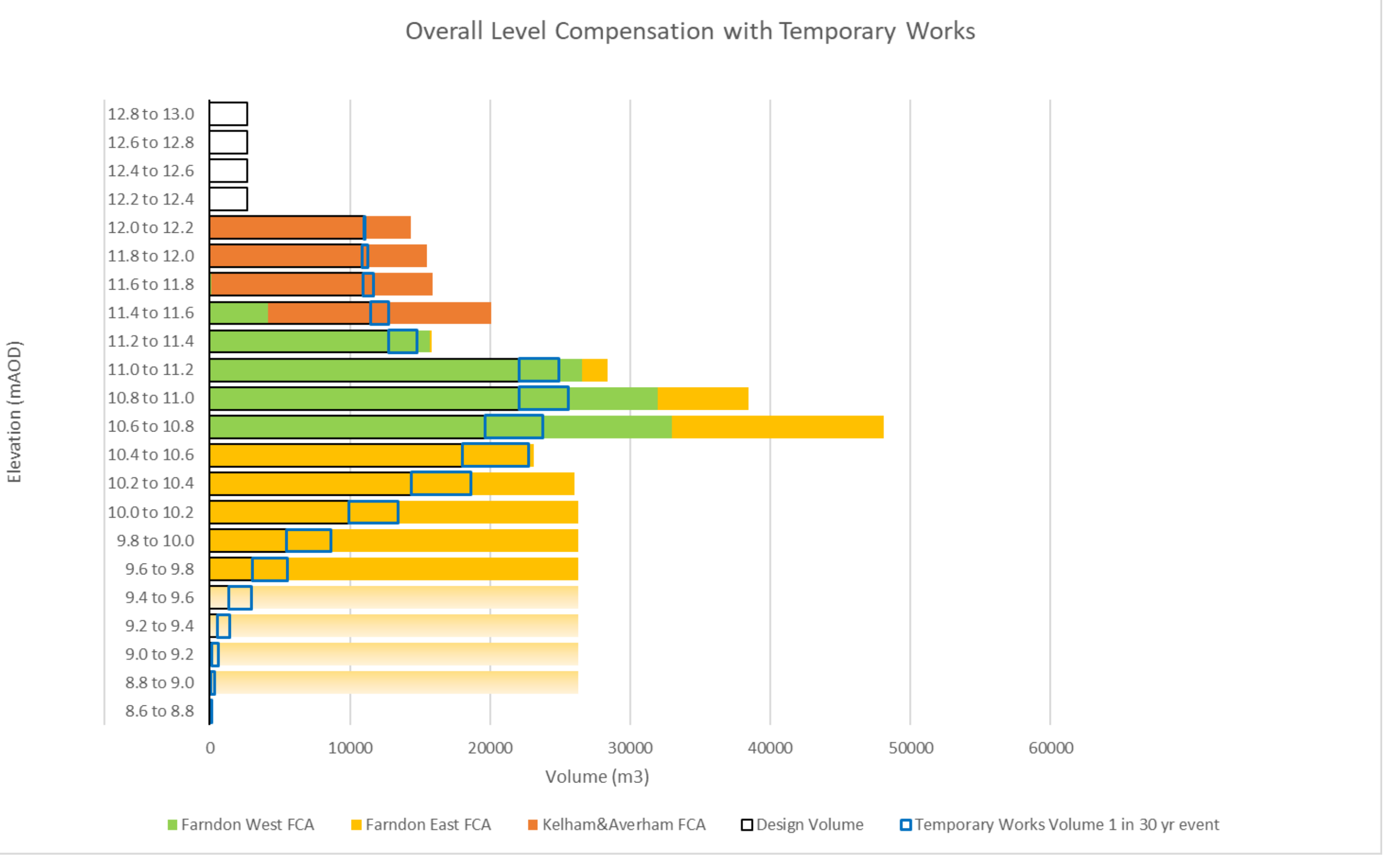


Table 2 - Floodplain Compensation Potential at FCA sites

Level (at top of layer)	Stage 3 Floodplain Loss	Farndon West FCA	Farndon East FCA	Kelham & Averham FCA
	Loss	**Gain**	**Gain**	**Gain**
mAOD	m^3	m^3	m^3	m^3
8.4-8.6	0			
8.6-8.8	59.3			
8.8-9.0	67.1	0*	**	
9.0-9.2	162.8	0*	**	
9.2-9.4	510.9	0*	**	
9.4-9.6	1338.9	0*	**	
9.6-9.8	3032.8	0*	26265	
9.8-10.0	5478.2	0*	26265	
10.0-10.2	9922.4	0*	26265	
10.2-10.4	14388.8	0*	26026	
10.4-10.6	18045.6	0*	23103	
10.6-10.8	19625.8	32955	15143	
10.8-11.0	22060.1	31933	6533	
11.0-11.2	22081.9	26593	1812	
11.2-11.4	12738.0	15718	131	
11.4-11.6	11483.9	4175	0	15,877
11.6-11.8	10931.2	93	0	15,785
11.8-12.0	10848.2	0	0	15,506
12.0-12.2	11011.0	0	0	14,351
12.2-12.4	2663.3	0	0	0
12.4-12.6	2694.2	0	0	0
12.6-12.8	2692.9	0	0	0
12.8-13.0	2659.9	0	0	0
Totals	**184,497**	**111,467**	**151,544**	**61,519**

Legend

Level band lower than the drain down watercourse invert level	(yellow)
Above flood level at site location, levels compensated indirectly – see section 2.2	(peach)
FCA design levels	(green)

*Levels not calculated due to geomorphological risks with implementation

**Compensation provided within deep lake, which may be inundated with groundwater due to seasonal variation