A585 Windy Harbour to Skippool Improvement Scheme

TR010035

5.2 Flood Risk Assessment Part 1

APFP Regulation 5(2)(e)

Planning Act 2008

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

Volume 5

October 2018

Page Left Intentionally Blank

Infrastructure Planning

Planning Act 2008

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

A585 Windy Harbour to Skippool Improvement Scheme
Development Consent Order 201[ ]

FLOOD RISK ASSESSMENT PART 1

Regulation Number:	Regulation 5(2)(e)
Planning Inspectorate Scheme Reference	TR010035
Application Document Reference	TR010035/APP/5.2
Author:	A585 Windy Harbour to Skippool Improvement Scheme Project Team, Highways England

Version	Date	Status of Version
Rev 0	October 2018	DCO submission

Page Left Intentionally Blank

CONTENTS

PART 2

LIST OF TABLES

1 EXECUTIVE SUMMARY

1.1.1 This report documents the approach taken to assess sources of flood risk to the A585 Windy Harbour to Skippool Improvement Scheme ("the Scheme") and to quantify any flood risk impacts of the proposals. The Scheme is located to the south of the estuary of the River Wyre and crosses a number of tributaries of the Wyre, including the main river Main Dyke and Horsebridge Dyke, as well as several ordinary watercourses.

1.1.2 The EA Flood Map for Planning (Rivers and Sea) shows that the majority of the Scheme is located in Flood Zone 1. However, a small portion of the Scheme is located in Flood Zone 3 (when the presence of flood defences is ignored, land with a 1 in 100 (1%) or greater chance of flooding each year from rivers; or with a 1 in 200 (0.5%) or greater chance of flooding each year from the sea). Flood defences, comprising raised walls/embankments and flap gates, are present and these provide protection against fluvial and tidal flooding.

1.1.3 With regard to flood risk vulnerability, the Scheme is classified as Essential Infrastructure. The location of this type of development is deemed appropriate in Flood Zones 1, 2 and 3, subject to satisfaction of the National Planning Policy Framework Exception Test in Zone 3. Environmental assessments have demonstrated the wider sustainability benefits of the Scheme, satisfying part 1 of the Exception Test. The findings of this assessment help demonstrate that, within the design constraints of tying into the existing road network at each end, the Scheme would in the majority be flood free over its development lifetime and that the Scheme would make a contribution to reducing flood risk overall (Exception Test Part 2).

1.1.4 The assessment has considered flood risk from a range of possible sources, namely river flooding, flooding from tides, surface water and groundwater flooding, as well as flooding from reservoirs, canals and other artificial sources. The assessment has used published data sources, as well as the results of bespoke hydraulic and hydrological modelling studies to quantify river and tidal flood risk. Consultation with the Environment Agency and Lead Local Flood Authority has been ongoing during the preparation of this report and assessment methodologies have been agreed with the Environment Agency.

1.1.5 The assessment has concluded that there is limited risk of flooding from groundwater and artificial sources. Land within the study area is also, mostly, at very low risk of surface water flooding. Implementation of a suitable surface water drainage strategy would manage rainfall runoff to ensure that the risk from surface water flooding would not increase across the Scheme. A suitable drainage design would be implemented to ensure that there would be no increase in surface water run-off from the Scheme to the local land drainage system and that there would be no increase in third party flood risk from this source.

1.1.6 Rivers and the tidal Wyre have been identified as the primary sources of flood risk to the Scheme, warranting detailed assessment. A linked 1D2D model of the Horsebridge Dyke and Main Dyke was developed to quantify baseline fluvial flood risk and to enable an assessment of the potential impacts of the Scheme on this baseline status. The model represents open channel and culverted reaches of these watercourses, as well as key hydraulic structures and their floodplains.

1.1.7 Model results have demonstrated that the Scheme is not at risk of fluvial flooding from the Main Dyke or the Horsebridge Dyke. Modelled design events have included a range up to and including the 1% (1 in 100) annual chance flood, inclusive of 70% uplift in peak flow as an allowance for climate change.

1.1.8 Incorporating the Scheme into the model demonstrates that replacing the existing Skippool Bridge culverts with a 12.5m clear span bridge significantly reduces upstream flood extents in all modelled events. The flow regimes of these watercourses are subject to tide locking when high water levels in the Wyre Estuary prevent them from freely discharging. Tide locked conditions have also been modelled and results demonstrate that the Scheme is not at risk of flooding. Furthermore, the Scheme does not increase flood risk to third parties during a tide locked scenario.

1.1.9 The preferred construction methodology for the Scheme necessitates that the road embankment is built before work to increase the capacity of the A585 crossing of the Main Dyke is commenced. Modelling of this scenario indicates that only minor increases in flood levels and extents would occur during smaller, more commonplace events and that these increases are constrained to open fields, rather than impacting any existing property or infrastructure. These effects would be mitigated through design, by provision of compensatory storage on the right bank of the Main Dyke immediately to the north of the A586.

1.1.10 A qualitative assessment of flood risk from the Pool Foot Creek, which is crossed by the Scheme towards its eastern end, also indicates that the Scheme would not be at risk of fluvial flooding from this source.

1.1.11 An Environment Agency 2D only model of the River Wyre Estuary was enhanced and used to assess both the risk of tidal flooding to the Scheme and any change in tidal flood risk to third parties resulting from the Scheme, assuming that existing flood defences on the Wyre remain in place. Model results show that immediately east of Skippool Junction the Scheme is at risk of tidal flooding during a 0.5% AEP event with and without an allowance for climate change. When climate change is considered baseline flood risk depths in the order of 700mm are predicted locally. There are significant design constraints linked to the Scheme having to tie in to the existing road network, to protecting this small part of the Scheme from flooding during this extreme event. It is considered that there is no practicable mitigation to protect the Scheme that would not cause detriment to flood risk on third party land. With the Scheme in place, during the 0.5% AEP event there is a small localised benefit in terms of a reduction in flood risk to a small area of existing residential development to the south east of Skippool Junction. When climate change allowance is included the Scheme is predicted to increase baseline flood depths locally by up to 10cm. Although baseline flood depths are increased, changes in flood extents are negligible due to the nature of the topography. The increase in the context of baseline floodwater depths of up to 1m is relatively small.

1.1.12 Residual tidal flood risk would be managed through notifying road users via appropriate signage and social media, giving warnings, and where necessary enforcing road closures, implemented using intelligence provided by the Environment Agency flood warning service. This commitment is included in the Record of Environmental Actions and Commitments (document reference T010035/APP/7.3).

1.1.13 This FRA has been reviewed by the Environment Agency. The comments received and initial responses to them are detailed in Appendix F.

2 INTRODUCTION

2.1 Background

2.1.1 Arcadis Consulting (UK) Ltd (Arcadis) has been commissioned by Highways England (HE) to undertake a Flood Risk Assessment (FRA) to inform the design and Environmental Impact Assessment (EIA) of the proposed A585 Windy Harbour to Skippool Improvement Scheme, in Lancashire (hereinafter referred to as the Scheme). The Scheme is described in Section 2.2.

2.1.2 The Environment Agency (EA) Flood Map shows that parts of the alignment of the Scheme are located in Flood Zone 3 (high probability of flooding). In line with the requirements of the National Networks National Policy Statement (NN NPS)[1] and the supporting National Planning Policy Framework (NPPF)[2], all proposals for new development in Flood Zone 3 should be accompanied by a site-specific FRA.

2.1.3 This report documents the approach taken to assess sources of flood risk to the Scheme and to quantify any flood risk impacts of the proposals. The findings of the assessment have both informed Scheme design and flood risk mitigation requirements.

2.2 Scope of Works

2.2.1 The agreed scope of works comprises the following tasks:

- Consult with the EA and Lancashire County Council, in their role as Lead Local Flood Authority (LLFA), to obtain baseline flood risk information, including the EA 1D hydraulic models of the Main Dyke and Horsebridge Dyke and the 2D tidal model of the River Wyre
- Appraise relevant documents and data (e.g. Strategic Flood Risk Assessment, Local Flood Risk Management Plan, EA Product 4 Data Pack)
- Use existing information to qualitatively assess flood risk from surface water, groundwater and artificial sources
- Update existing EA models of the Main Dyke and Horsebridge Dyke to produce a linked 1D/2D domain hydraulic model and update the design flow hydrology for subject watercourses for input into model
- Use the model to define baseline flood risk in the study area from fluvial flood events, including the tide locked scenario
- Enhance the existing EA Wyre tidal model to include watercourse and structure details in the vicinity of the Scheme and use the model to define baseline flood risk in the study area from tidal flooding
- Incorporate the proposed Scheme into the river and tidal models in order to quantify any flood risk impacts and mitigation requirements both during construction and on completion of the Scheme
- Prepare an FRA report to illustrate the findings of the study

[1] *National Networks National Planning Statement (Department for Transport, 2014)*
[2] *National Planning Policy Framework (Communities and Local Government, 2018)*

2.3 Terminology

2.3.1 Flood risk is a product of both the likelihood and consequences of flooding. Throughout this report, flood events are defined according to their likelihood of occurrence. Floods are described according to an 'annual chance', meaning the chance of a particular flood occurring in any 1 year. This is directly linked to the probability of a flood. For example, a flood with an annual chance of 1 in 100 (a 1 in 100 chance of occurring in any 1 year on average), has an annual exceedance probability (AEP) of 1%.

2.4 Limitations

2.4.1 This report has been informed by a number of data sources which Arcadis believe to be trustworthy. However, Arcadis is unable to guarantee the accuracy of information provided by others. The report is based on information available at the time of writing. Further details regarding the modelling assumptions and limitations are included in Section 7.7.

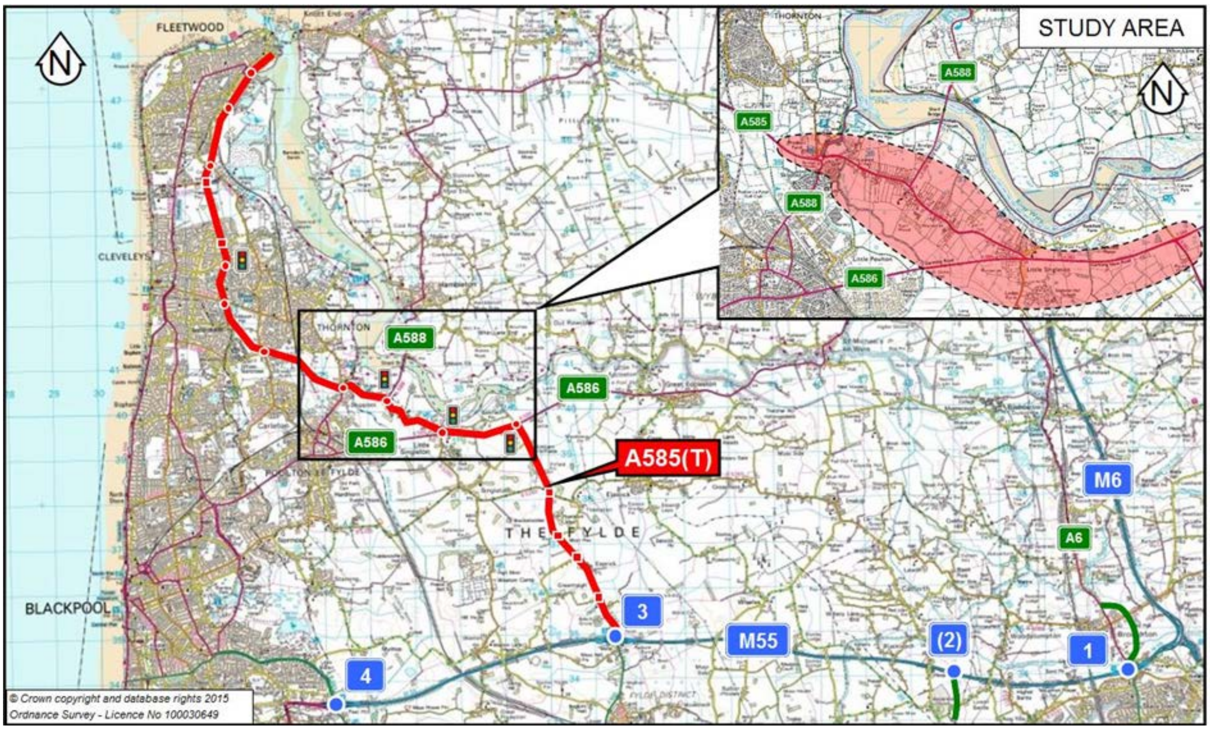
3 BACKGROUND

3.1 Site Location

3.1.1 The A585 is a single carriageway trunk road, which provides the only viable access from the motorway network, in particular the M6 and M55, into Fleetwood and surrounding urban areas in west Lancashire. As a result, the A585 suffers from congestion, in particular during peak travel times. The congestion is particularly severe at the A585/A586 signalised junction (Little Singleton) and the A585/A588 signalised junction (Shard Road).

3.1.2 The Government's Autumn Statement in 2014[3] identified the need for an Improvement Scheme along the A585 between Windy Harbour and Skippool to ameliorate the impact of traffic on the route between these 2 locations, illustrated in Figure 1.

Figure 1: Site Location Plan (Contains Ordnance Survey data © Crown copyright and database right 2016)



3.2 Proposed Development

3.2.1 The general arrangement of the Scheme is shown on document 2.5 (document reference TR010035/APP/2.5). The A585 Windy Harbour to Skippool Improvement Scheme ("the Scheme") consists of:

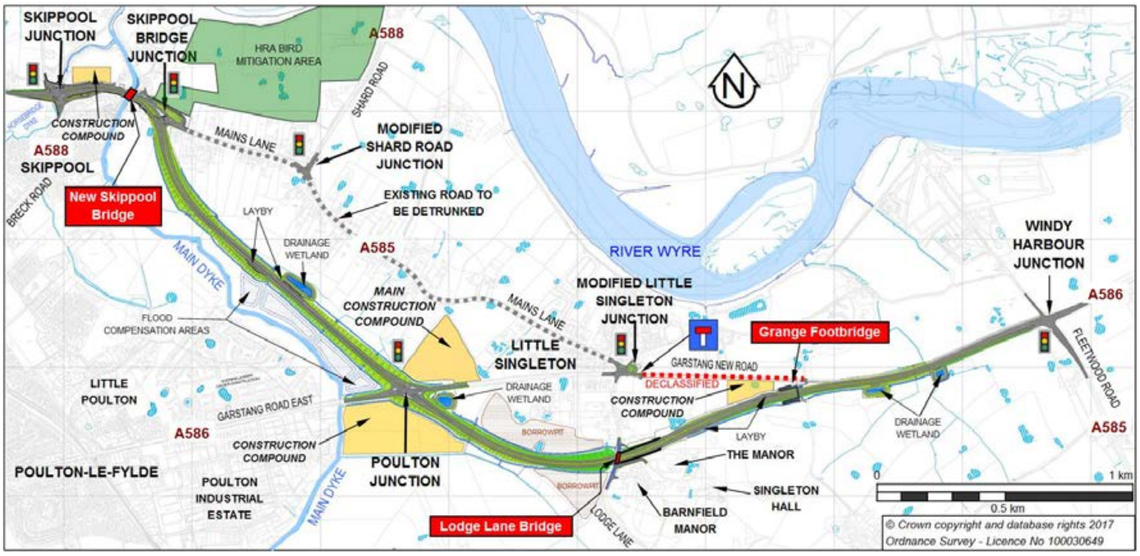
- A 4.85km (3 miles) long dual 2-lane carriageway bypass from Windy Harbour Junction to the Skippool Junction
- Four new junctions including: conversion of Skippool Junction to a traffic signal-controlled crossroads with A588 Breck Road and B5412 Skippool Road; Skippool Bridge Junction in the form of a 3-arm traffic signal-controlled junction

[3] https://www.gov.uk/government/topical-events/autumn-statement-2014

with the existing Mains Lane; Poulton Junction in the form of a signal-controlled crossroads connecting the new bypass to A586 Garstang Road East and modification to Little Singleton Junction (also known as Five Lane Ends) to accommodate U-turning traffic including buses. Between Skippool Bridge Junction and Poulton Junction the bypass is on embankment. East of Poulton Junction through to east of Lodge Lane the bypass is mostly in cutting

- Three new major structures including: replacement of Skippool Bridge; Lodge Lane Bridge and Grange Footbridge
- Alterations to the existing road network on completion of the bypass include: detrunking the A585 between Skippool Bridge Junction and the end of Garstang New Road east of Little Singleton; applying a reduction in speed limit to 30mph and providing a combined footway/cycleway along Mains Lane between Shard Road Junction and Little Singleton; altering Garstang New Road east of Little Singleton to allow restricted access to farmers' fields and provide a shared footway/cycleway route between Windy Harbour Junction and Little Singleton; applying a reduced speed limit of 30mph along Garstang Road East between the proposed Poulton Junction and Little Singleton and upgrading the lighting along Mains Lane and Garstang Road East

Figure 2: Scheme Proposals and Constraints (Contains Ordnance Survey data © Crown copyright and database right 2017)



3.3 Catchment Description

3.3.1 The Scheme is located to the south of the estuary of the River Wyre, as illustrated in Figure 3. The River Wyre is designated by the EA as Main River and, rising in the Forest of Bowland in central Lancashire, follows a southerly then westerly flow path, becoming tidally influenced below the weir at St Michael's. The tidally influenced reach of the river drains a catchment area of approximately 320km^2 and the river discharges into the Irish Sea at Fleetwood.

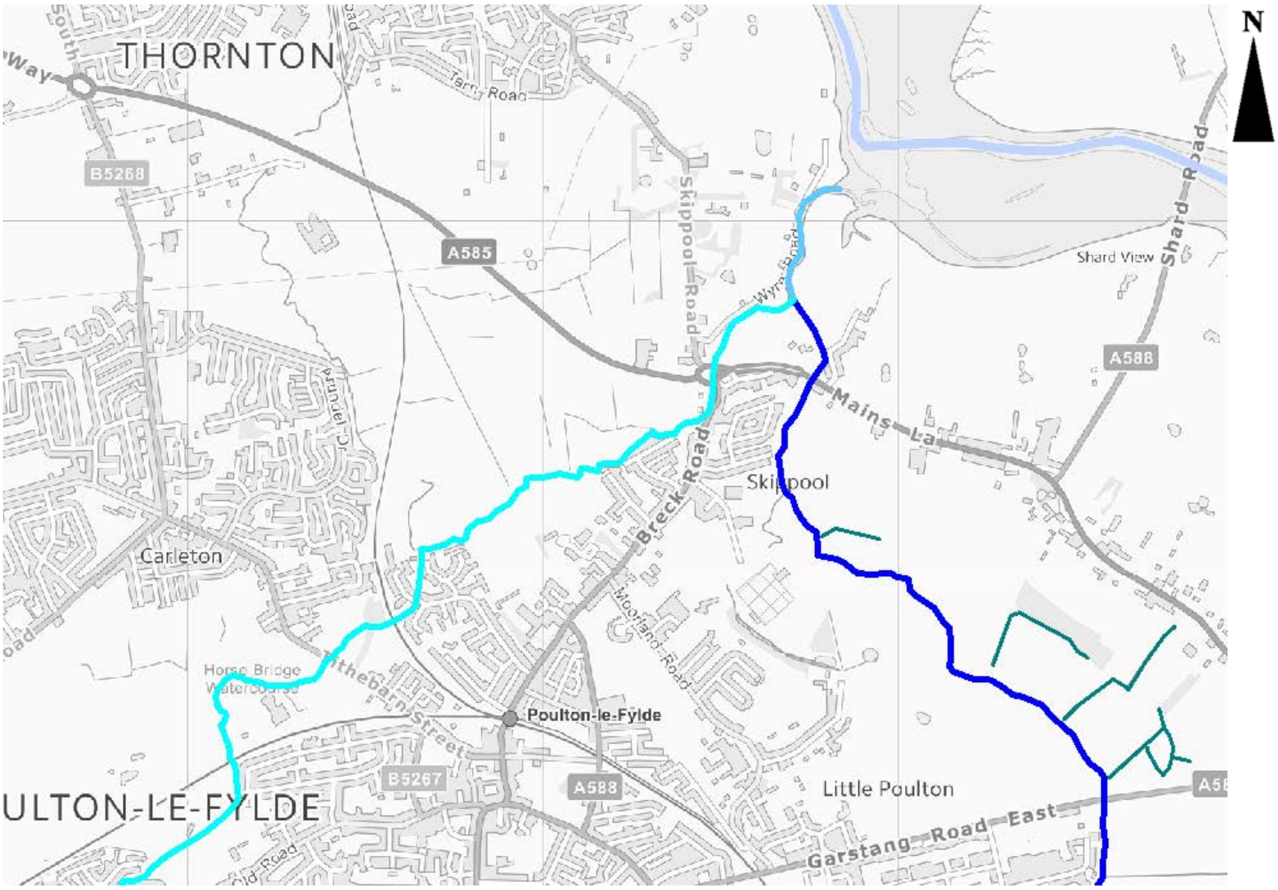
3.3.2 Tributaries of the Wyre are crossed by the Scheme. The Main Dyke is not a naturally occurring watercourse having been constructed to aid drainage of neighbouring farmland in the 18th or 19th Century. The Main Dyke is approximately 10.6km in length and drains into the Wyre via the Skippool Creek (see Figure 3), with gates operated to limit the upstream propagation of the tide. This watercourse is a designated Main River and has a catchment extending from Marton Mere in Blackpool covering an area of approximately 30km^2. The watercourse has a very limited gradient and during dry weather periods localised ponding of water can be observed throughout its length. The Dyke is also reported to be subject to siltation and vegetation overgrowth, and the hydraulic regime is generally controlled by a relatively large number of road and rail crossings of varying length and geometry[4].

3.3.3 The Horsebridge Dyke also drains to the Skippool Creek / Wyre estuary via a flap valve structure. The Horsebridge Dyke is designated as a Main River and drains a total catchment area of approximately 10km^2.

3.3.4 To the east of the Little Singleton Junction, the Scheme crosses an unnamed stream that discharges to the Wyre downstream of Bankfield Farm. This watercourse, known as the Pool Foot Creek, drains a catchment area of approximately 1.6km^2 and has a flapped outfall to the Wyre, in the form of a flood gate that is integrated into a headwall for a farm access track that crosses the creek.

3.3.5 Upstream of the A585, a network of small land drainage ditches cross open fields to the east of the Main Dyke, discharging into the Main Dyke.

Figure 3: Watercourses (Contains Ordnance Survey data © Crown copyright and database right 2017)



Geology and Soils

---

4 *River Wyre, River Brock, Main Dyke & Horsebridge Dyke Flood Risk Mapping Investigation (Atkins, 2003)*

3.3.6 With reference to public data provided by the British Geological Survey (BGS) Geology of Britain Viewer[5], the bedrock geology underlying the Scheme comprises the Sidmouth Mudstone Formation. The superficial geology consists primarily of Devonian Till, with small areas of Tidal Flat Deposits along Garstang New Road and in the vicinity of Skippool roundabout.

3.3.7 The Soilscapes Viewer[6] characterises the dominant soils in the study area as slightly acid loamy and clayey soils with impeded drainage. To the east of the Scheme, along Garstang New Road, there are also small areas of slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils. There are also areas of loamy and clayey soils of coastal flats with naturally high groundwater.

Topography and Land Use

3.3.8 Within the study area the general topography grades towards the Wyre Estuary. Existing ground levels are lowest towards the western end of the Scheme, around Skippool, at around 5m Above Ordnance Datum (AOD), with a general increase in elevation to the east towards Garstang New Road (approximately 12m AOD) and Little Singleton (approximately 20m A0D). Land use is a mixture of urban development and agriculture.

3.4 Flood History and Defences

Flood History

3.4.1 The British Hydrological Society (BHS) Chronology of British Hydrological Events web site[7] is a public repository for hydrological facts. It attempts to provide as much material as possible so that the spatial extent of flood events, and their relative severity, can be assessed. A search of the website has been undertaken and no records of flooding local to the Scheme have been identified.

3.4.2 Consultation with the EA has highlighted that there has been historical flooding downstream of Skippool Bridge associated with the Main Dyke, however no further details have been provided.

3.4.3 Anecdotal flooding information was also collected during a public consultation event in September 2016, with a number of local residents referring to flooding along the Main Dyke being severe and extending quite far south. It was also reported that flooding has much reduced since the new tidal gates were installed, but a lack of maintenance of the Main Dyke in certain reaches was highlighted as a concern.

3.4.4 The joint Lancashire and Blackpool Local Flood Risk Management Strategy[8] has been reviewed and highlights that in the low-lying areas of west Lancashire, the risk of flooding is predominantly linked to the capacity of the drainage networks, including piped networks in urban areas and open drainage ditches in both urban and rural areas. In the lowest lying areas near the coast high tides and storm surges can increase water levels in channels and cause drainage systems to stop discharging to the sea. However, the report does not identify any historical flooding incidents having occurred in the area of the Scheme.

[5] *Geology of Britain Viewer (British Geological Survey, 2016). Accessed via http://mapapps.bgs.ac.uk/geologyofbritain/home.html*
[6] *Soilscapes map viewer (Cranfield Soil and Agrifood Institute, 2016) Accessed via http://www.landis.org.uk/soilscapes/*
[7] *Chronology of British Hydrological Events (British Hydrological Society, 2016). Accessed via http://cbhe.hydrology.org.uk/*
[8] *Lancashire and Blackpool Local Flood Risk Management Strategy (Lancashire County Council & Blackpool Council, 2013)*

3.4.5 The SFRA[9] documents a flood event dating to winter 1998 when a large tree bough jammed in the tidal door on the Main Dyke and a road gully discharging to the Main Dyke was also without a flap as the casing had corroded. During this event there was flooding of the A585 carriageway, the garage/service station adjacent to Skippool Bridge and the gardens of properties in the local area.

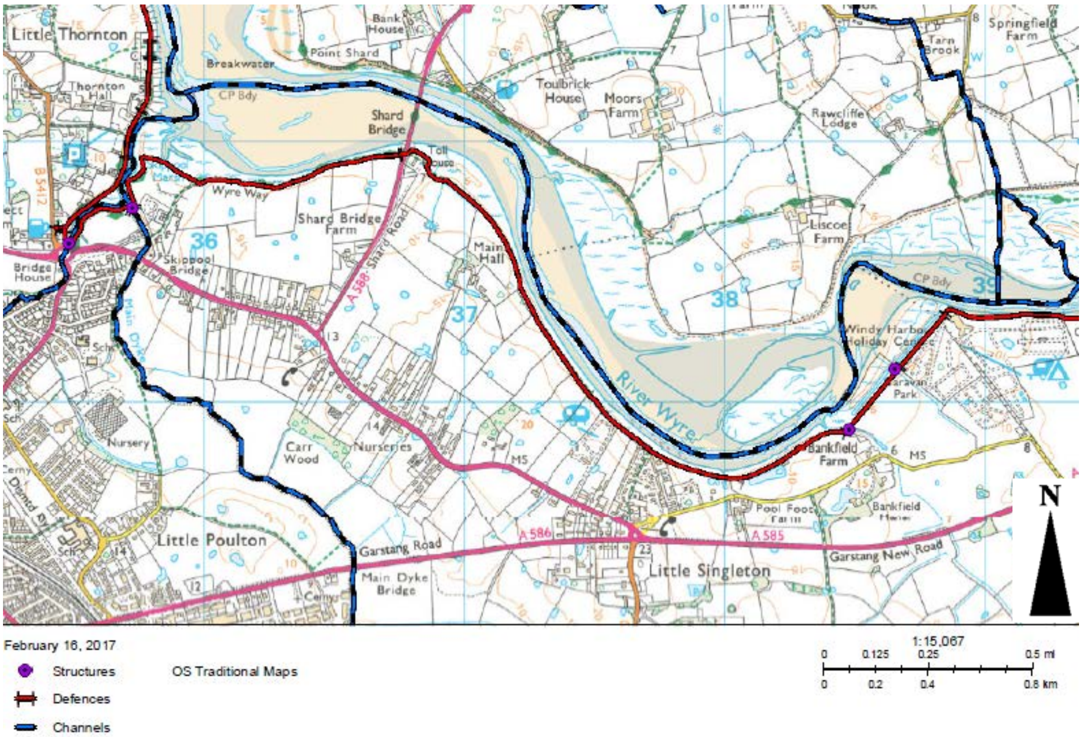
3.4.6 During public consultation events, held in September 2016, the issue of flooding of agricultural land adjacent to the Main Dyke was raised, with it reported that adjacent fields are prone to accumulating standing water during the winter months, due to waterlogged soil conditions. Further to the east, a landowner in the vicinity of the Pool Foot Creek reported that during periods of substantial rainfall combined with a high tide, his lower fields adjacent to the Wyre Estuary can experience flooding due to tide locking of the watercourse.

Defences

3.4.7 Information on local flood defences has been collected from the EA and from a FRA report prepared for a proposed residential development scheme in the Main Dyke catchment, off Garstang Road East in Poulton-le-Fylde[10]. Flood defences providing protection against fluvial and tidal flooding are illustrated in Figure 4 and described below.

[9] *Strategic Flood Risk Assessment (Wyre Council, 2007)*
[10] *Garstang Road East Flood Risk Assessment and Drainage Strategy (Ironside Farrar Limited, 2015)*

Figure 4 Location of EA Flood Defences (supplied by the EA, data request ref CL5227)



Fluvial Defences

3.4.8 Defences are present along the Main Dyke downstream of the Skippool Tidal Sluice (see below). Upstream of this point, the Main Dyke between the downstream tidal gates and the A585 crossing at Skippool Bridge is defended by earth embankments (not shown in the EA Defence database). Crest levels on the left bank (west side) of the watercourse are at approximately 5.2m AOD and are similar on the east side, with a low point at Old Mains Lane, 70m downstream of the A585 on the right bank (5.1m AOD).

3.4.9 The Skippool Tidal Sluice, illustrated in Figure 5, has been recently upgraded and is designed to reduce the impact of a storm surge in the Wyre Estuary propagating up the Main Dyke during a significant tidal event. The level of the top of the tidal gates, as recorded in the EA Defence database, is 5.21mAOD. However, inspection of point cloud LiDAR data gives a parapet level across the structure of 6.6mAOD.

Figure 5: Tidal Gates at Main Dyke Outfall to Wyre Estuary (Source: Arcadis, 2017)

3.4.10 Upstream of the A585 bridge there are no continuous defences alongside Main Dyke. Neighbouring fields and properties are vulnerable to flooding if the water levels exceed around 5m AOD. Small wooden doors on the upstream side of the existing A585 bridge (as shown in Figure 6) are now virtually obsolete as the new flap gates downstream control the downstream levels.

Figure 6: Tidal Gates at existing A585 Bridge (Source: Arcadis, 2017)

3.4.11 The Horsebridge Dyke passes beneath the A585 at Skippool roundabout via the Skippool Clough culvert. The EA Horsebridge Dyke hydraulic model states that this culvert has a diameter of 1.7m. However, survey data obtained as part of the A585 Scheme indicates that the first 20.7m of the culvert has a diameter of 1.6m and the following 43.8m run has a diameter of 1.52m. A final 1.6m diameter section 21m in length discharges to Skippool Creek via a flap valve, illustrated in Figure 7. This provides protection against tides propagating upstream.

Figure 7: Skippool Clough Culvert (Source Arcadis, 2017)

Tidal Defences

3.4.12 Raised defences along the Wyre Estuary were built or improved in the 1980s. In the study area, defences comprise flood walls and embankments which are maintained by the EA. Review of the EA's asset database for the area shows that the Standard of Protection (SoP) offered by these structures ranges from 25 years in the immediate vicinity of the Main Dyke and Horsebridge Dyke, to 50 years at the Windy Harbour Holiday Park some 3.5km to the east. Located in Sub-area 5 (Wyre Urban), the EA Catchment Flood Management Plan sets out a preferred policy of continued maintenance of existing defences and major assets to their current standard, taking action to improve them to an appropriate standard where they fail to meet target conditions.

4 NATIONAL POLICY STATEMENT FOR NATIONAL NETWORKS

4.1 General

4.1.1 The National Networks National Policy Statement (NN NPS)[11] sets out the need for and Government's policies to deliver Nationally Significant Infrastructure projects (NSIPs) on the national road and rail networks in England.

4.1.2 With regard to flood risk and surface water drainage, the NN NPS supports the National Planning Policy Framework (NPPF)[2] and its accompanying Planning Practice Guidance (PPGNPPF)[12]. Paragraphs 5.92 to 5.94 explain that essential transport infrastructure is permissible in areas of high flood risk, subject to satisfaction of the NPPF Exception Test. An objective of the NN NPS is for schemes to contribute towards reducing the risk of flooding, stating that considerations should include design standards for drainage systems, interactions with floodplains and watercourses and maintenance standards. Applications for all projects in Flood Zones 2 and 3 and projects of 1 hectare or greater in Flood Zone 1, should be accompanied by a FRA. Projects should adhere to any national standards for Sustainable Drainage Systems (SuDS).

4.1.3 Projects should be subject to a detailed FRA that considers all sources of flood risk. The FRA should be informed by consultation with the EA and relevant LLFA. The FRA should also be informed by the results of any hydrological and hydraulic modelling undertaken to define baseline flood risk, quantify any impacts on this baseline, and to inform the design of any necessary flood risk management measures. A drainage strategy should also be prepared that centres on the application of SuDS, appropriate to local conditions, to manage surface water runoff.

4.1.4 Early adoption of, and adherence to, the principles set out in the NN NPS with respect to flood risk, can ensure that detailed designs and plans for transport schemes take due account of the importance of flood risk and the need for appropriate mitigation, if required.

4.2 The Sequential and Exception Tests

4.2.1 The NPPF identifies 4 Flood Zone classifications, detailed in Table 1.

Table 1 : Flood Zones (Source: PPGNPPF (2014), Table 1)

Flood Zone	Annual Probability of Flooding (%)
1. Low Probability	Fluvial and Tidal <0.1% AEP
2. Medium Probability	Fluvial 0.1-1.0% AEP Tidal 0.1-0.5% AEP
3a. High Probability	Fluvial > 1% AEP Tidal > 0.5% AEP

[11] *National Policy Statement for National Networks December (Department for Transport, 2014)*
[12] *Flood Risk and Coastal Change Planning Practice Guidance (Ministry of Housing, Communities and Local Government, 2014) Accessed via https://www.gov.uk/guidance/flood-risk-and-coastal-change*

Flood Zone	Annual Probability of Flooding (%)
3b. The Functional Floodplain	Fluvial and Tidal > 5.0% AEP * Starting point for consideration. LPAs should identify Functional Floodplain, which should not be defined solely by rigid probability parameters

4.2.2 The NPPF specifies that the suitability of all new development in relation to flood risk should be assessed by applying the Sequential Test. This Test should be used to demonstrate that there are no reasonably available sites in areas with a lower probability of flooding that would be appropriate to the type of development proposed. The NPPF provides guidance on the suitability of each land use classification in relation to each of the Flood Zones as summarised in Table 2.

Table 2: Flood Risk Vulnerability Classification (Source: PPGNPPF Table 3)

Flood Zone	Essential Infrastructure	Water Compatible	Highly Vulnerable	More Vulnerable	Less Vulnerable
Zone 1	✓	✓	✓	✓	✓
Zone 2	✓	✓	Exception Test required	✓	✓
Zone 3a	Exception Test required	✓	×	Exception Test required	✓
Zone 3b	Exception Test required	✓	×	×	×
Key: ✓ Development is appropriate × Development should not be permitted					

4.3 EA Flood Zone Categorisation and Development Flood Risk Vulnerability Classification

4.3.1 The EA Flood Map for Planning (Rivers and Sea)[13] (provided in Appendix A) shows that the majority of the Scheme is located in Flood Zone 1. However, a small portion of the Scheme is located in Flood Zone 3 (when the presence of flood defences are ignored, land with a 1 in 100 (1%) or greater chance of flooding each year from rivers; or with a 1 in 200 (0.5%) or greater chance of flooding each year from the sea). With regard to flood risk vulnerability, the Scheme is classified as Essential Infrastructure. The location of this type of development is deemed appropriate in Flood Zones 1, 2 and 3, subject to satisfaction of the NPPF Exception Test in Zone 3.

[13] Environment Agency. Flood Map for Planning. Accessed via http://maps.environment-agency.gov.uk/wiybv/

4.4 Application of the Sequential Test and Exception Test

Sequential Test

4.4.1 The aim of the Sequential Test is to steer development to areas of lowest flood risk and should demonstrate that alternative locations in areas of lower flood risk have been considered first. Three route corridors were considered during optioneering stages of the project, online, southern and northern corridors. Five options were identified for the southern corridor, while 2 options were identified for both the northern and online corridors. A total of 9 options were therefore considered.

4.4.2 During the options stage, Environmental Assessment Reports (EARs) were prepared which assessed the options in accordance with the Design Manual for Roads and Bridges Volume 11 (DMRB). The EARs provided an assessment of air quality, cultural heritage, landscape effects, noise, biodiversity, geology and soils, road drainage and the water environment, people and communities and materials. The conclusions of the assessments within the EARs informed sifting workshops to determine a preferred route. Through this process it is demonstrated that the Scheme has thoroughly considered alternatives in line with the requirements of the Sequential Test.

Exception Test

4.4.3 The Scheme provides the greatest potential to unlock growth potential in the area, offers the best journey times and is considered to improve the overall experience for road users. Environmental assessments undertaken to date have also demonstrated the wider sustainability benefits of the Scheme, satisfying part 1 of the Exception Test.

4.4.4 The findings of this FRA help demonstrate that the development would be safe for its lifetime and that the Scheme would make a contribution to reducing flood risk overall (Exception Test Part 2).

4.4.5 Therefore, it is asserted that the Scheme passes the Exception Test.

5 POTENTIAL SOURCES OF FLOODING

5.1.1 In line with best practice, this section of the FRA considers flood risk from the range of possible sources listed in Table 3.

Table 3: Sources of Flooding

Source of Flooding	Description
1. Flooding from rivers (Fluvial)	Floodwater originating from a nearby watercourse when the amount of water exceeds the channel capacity of that watercourse
2. Flooding from the sea (Coastal)	High tides, storm surges and wave action, often acting in combination, flooding low-lying coastal land
3. Flooding from groundwater	Flooding caused when groundwater levels rise above ground level following prolonged rainfall
4. Flooding from land (Surface Water)	Flooding caused by intense rainfall exceeding the available infiltration and/or drainage capacity of the ground
5. Flooding from reservoirs, canals and other artificial sources	Failure of infrastructure that retains or transmits water or controls its flow

5.2 Fluvial

5.2.1 As indicated by the EA Flood Map for Planning, and confirmed through EA consultation, the Scheme crosses land that is considered at high risk of flooding from rivers (Flood Zone 3). This source of flood risk has therefore been assessed in detail using bespoke hydraulic and hydrological modelling. The assessment methodologies and results are summarised in Sections 6 and 7, with further information provided in Appendices A, B, C and D.

5.3 Coastal

5.3.1 The study area is defended from regular direct inundation from the Wyre Estuary by EA maintained, raised flood defences, described in Section 2.4.2, and areas of higher ground along the estuary frontage. Information supplied by the EA as part of their Product 4 Data Pack indicates that the existing alignment of the A585 is at risk of tidal flooding during a 0.5% AEP event (plus climate change) in 3 locations; Skippool Junction, alongside the Main Dyke between Garstang Road and Mains Lane, and west of the Windy Harbour Junction (near Pool Foot Creek). In order to refine the assessment of tidal flood risk, the Wyre Tidal Model was obtained from the EA. Further discussion on tidal flood risk is included in Section 0.

5.3.2 The tidal nature of the Wyre is also an influence on the flow regimes of the Main Dyke, the Horsebridge Dyke and the Pool Foot Creek and is consequently a factor in defining fluvial flood risk to the proposed Scheme. The interaction between fluvial and tidal flood risk sources has therefore been considered in this assessment by representing a tidal boundary condition in the fluvial hydraulic model. Further details are provided in Section 0.

5.4 Groundwater

5.4.1 Groundwater flooding occurs when groundwater rises to the ground surface. This may happen during winter and/or after prolonged or heavy rain storms. Ground investigations have included monitoring of groundwater levels at 17 locations across the study area during the period between January and July 2018.

5.4.2 The data collected confirms the presence of a shallow water table within the superficial deposits. Across the study area groundwater levels were found to vary from 0.1m below ground level (bgl) to 6.1m bgl, with an average level of 2.4m bgl. Local to the proposed Lodge Lane cutting an average groundwater level of 3m bgl was recorded, with levels ranging between 1m bgl and 6m bgl. The groundwater level around the Main Dyke was recorded at approximately 1m bgl and is likely to be in hydraulic connection with the Main Dyke through the quaternary tidal flat deposits.

5.4.3 BGS mapping[14] is also available that defines groundwater flood risk susceptibility into 3 categories:

- Limited potential for groundwater flooding to occur
- Potential for groundwater flooding of assets located below the ground surface
- Potential for groundwater flooding to occur at the surface

5.4.4 The mapping shows that the majority of the Scheme is classified as having limited potential for groundwater flooding to occur at the surface. The majority of the superficial deposits comprises a secondary aquifer undifferentiated, meaning the strata is generally of low permeability, but with local potential for small scale water supply where more permeable layers are locally encountered. Within the area of Lodge Lane a small area of a secondary A aquifer is mapped which indicates more water bearing potential, but this is limited in extent.

5.4.5 The Scheme includes a section of relatively deep cutting at Lodge Lane (up to 8.6m deep) and the investigations undertaken to date indicate the potential for groundwater seepage into the cutting. A retaining wall is proposed to minimise groundwater ingress and the results from a programme of geotechnical surveys would inform the next stage of the Scheme design and identify any further measures necessary to control groundwater. **Therefore through detailed Scheme design, groundwater flooding as a source of risk to the Scheme would be mitigated and any measures necessary to ensure no increase in groundwater flood risk on third party lands would be incorporated**.

5.5 Surface Water

Existing Drainage Regime – Land Drainage

5.5.1 Within the area directly affected by the Scheme proposals, land is predominantly agricultural. Fields either side of the Main Dyke either drain directly into the watercourse, perpendicular to the contours, or via a network of field boundary ditches. Sub-surface mole drains may also be present to assist with draining the land. Anecdotal evidence indicates that fields adjacent to the Main Dyke are prone

[14] *BGS (2015) Risk of flooding from groundwater maps accessed via* http://www.bgs.ac.uk/research/groundwater/flooding/home.html

to waterlogging and standing water during wet winter periods.

5.5.2 Existing (greenfield) rates of runoff have been calculated using current best practice methodologies, as set out in the EA Flood Estimation Guidelines[15]. These are summarised in Table 4.

Table 4: Greenfield Runoff Rate Calculations

Event AEP	Greenfield Runoff Rate (l/s/ha)
50%	4.8
20%	6.3
3.33%	9.3
1%	11.9

Existing Drainage Regime – Highway Drainage

5.5.3 The existing highway drainage regime has been characterised using records from Highways England's HADDMS inventory system and by inspection during a site walkover. Findings indicate that the highway is generally served by a system of gullies and carrier drains in the road verges. Outfalls discharge to the Skippool Clough Culvert, the Horsebridge Dyke, the Main Dyke (both directly and indirectly via a number of drainage ditches) and to the watercourse named the Pool Foot Creek.

5.5.4 The existing highway drainage infrastructure is subject to routine maintenance and in September 2015 a major scheme of works was undertaken along the A585 between Skippool roundabout and the Singleton junction to clean and make repairs to the drainage system.

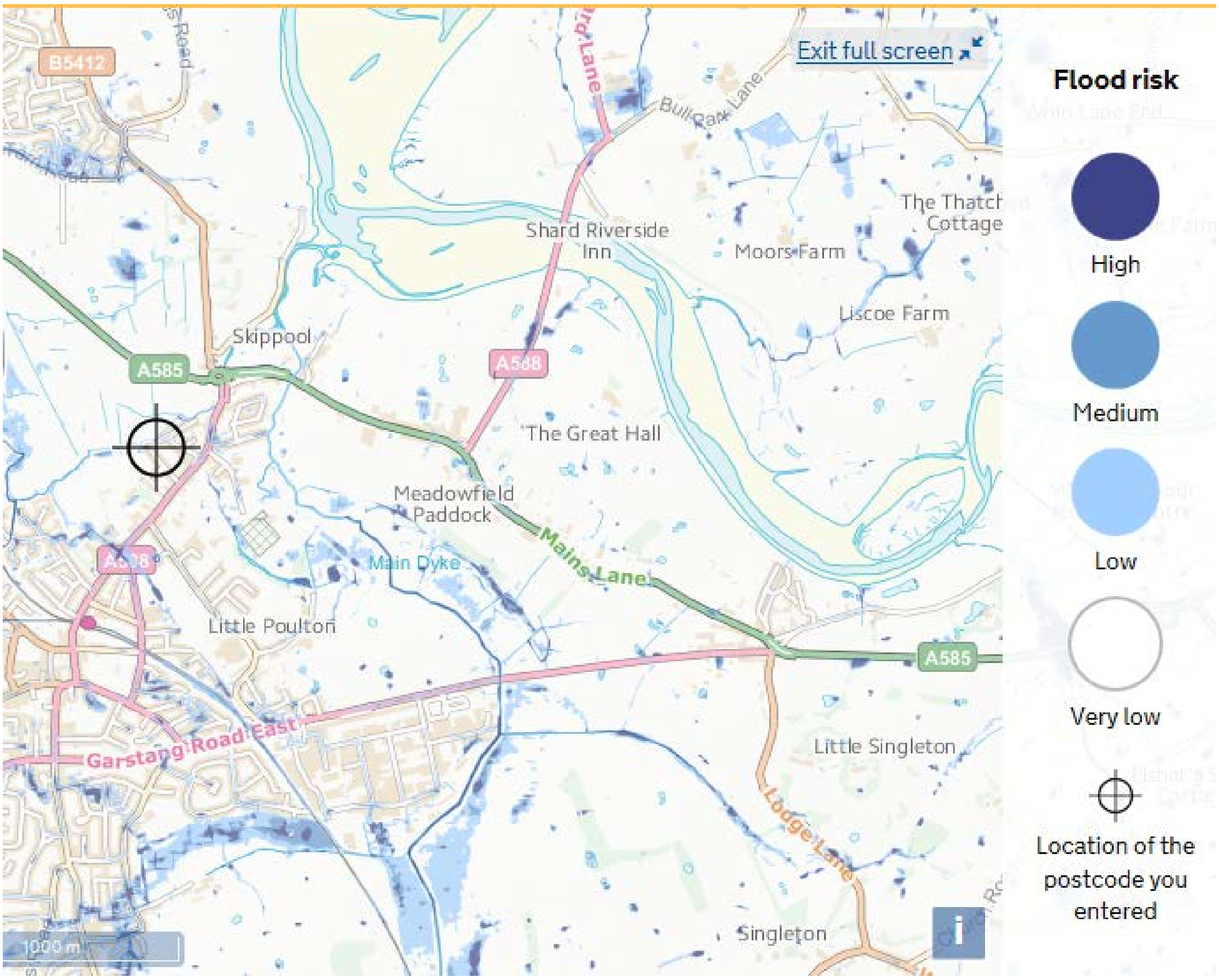
Existing Surface Water Flood Risk

5.5.5 The risk of flooding from surface water is defined by EA mapping[16] , reproduced in Figure 8, as very low (land assessed as having a less than 0.1% AEP of flooding from this source) along the majority of the existing alignment of the A585 between Skippool and Windy Harbour.

5.5.6 There are localised areas at high risk (greater than 3.3% AEP), for example, an area that spans the existing A585 alignment near Bankfield Manor.

[15] *Environment Agency (2015) Flood Estimation Guidelines*
[16] *Environment Agency. Risk of flooding from surface waters. Accessed online via https://flood-warning-information.service.gov.uk/long-term-flood-risk/*

Figure 8 EA Surface Water Flood Map (© Crown copyright and database rights 2017 OS 100024198)



5.5.7 The Scheme is therefore mostly at very low risk of surface water flooding however areas of agricultural land in the Main Dyke valley are reported to be prone to waterlogging during the winter months in response to prolonged periods of wet weather, co-incident with high tides.

Proposed Surface Water Management Strategy

Policy Requirements

5.5.8 The NPPF stipulates that development should be safe from flooding during its lifetime, should not cause any flood risk detriment and where possible should make a contribution to reducing flood risk in its local catchment. As the Scheme involves construction of built development on existing greenfield land, changing the existing land drainage regime, management of surface water runoff from the highway is key to satisfying these requirements of the NPPF.

5.5.9 Standards for highway drainage design are set out in HD33/16 Design of Highway Drainage Systems[17]. These standards stipulate that peak discharge rates must be

[17] Highways England, 2016 http://www.standardsforhighways.co.uk/ha/standards/dmrb/vol4/section2/hd3316.pdf

controlled and appropriate attenuation storage provided within the system to accommodate the design 1% AEP storm, inclusive of an allowance for climate change. The consequences of exceedance during storms with a magnitude in excess of the 1% AEP must also be considered.

Drainage Proposals

5.5.10 The Scheme would introduce impermeable land cover and has the potential to impact on the current land drainage regime. To ensure that the Scheme does not impact on flood risk from this source a drainage strategy has been developed (Appendix E). The Strategy is summarised below.

The road would be drained:

- At junctions by combined kerb and drainage units/gully pots discharging to carrier pipes
- Along the bypass by concrete "V" channels discharging to carrier pipes
- Along the bypass where it is in cutting by filter drains
- On Lodge Lane (side road) by gully pots.

5.5.11 These systems would discharge to the Main Dyke, Horsebridge Dyke (under Skippool Junction) and Pool Foot Creek. Where existing outfalls are being re-used, their existing discharge rate would be maintained and at all new outfalls discharge rates would be restricted to greenfield. To achieve this, storage and orifice plate flow controls would be provided. Storage would take the form of oversized pipes or wetlands where there is adequate space to provide them. Where the water quality of the receiving waterbody could be affected, treatment systems would be included, and provision would also be made for containment in the event of an accidental spillage. All proposed outfalls to existing watercourses would be installed with flap valves to prevent flooding of the drainage networks under tide locked conditions.

5.5.12 **Surface water flood risk would therefore be managed through design such that the risk of flooding from this source is assessed as low.**

5.6 Artificial Sources

5.6.1 The EA's maximum extent of flooding from reservoirs[18] does not extend into the area of the Scheme. A review of OS mapping highlights that there are no canals or bodies of stored water located in the vicinity of the Scheme. **It is therefore considered that the risk of flooding from artificial sources is negligible**.

[18] *Environment Agency. Risk of flooding from reservoirs. Accessed online via https://flood-warning-information.service.gov.uk/long-term-flood-risk/*

6 ASSESSMENT METHODOLOGY – FLUVIAL AND TIDAL FLOOD RISK

6.1 General

6.1.1 This section outlines the methodology that was adopted in order to quantify:

- The extent of flooding from the Main Dyke and the Horsebridge Dyke, accounting for the influence of the tidal regime of the Wyre Estuary. To meet this requirement a linked Flood Modeller Pro (FMP) -TUFLOW (1D2D) hydraulic model has been constructed
- The extent of flooding from the tidal River Wyre. To meet this requirement, an existing EA TUFLOW (2D only) model has been refined

6.2 Consultation and Data Collection

6.2.1 The study has been informed by:

- 1m resolution LiDAR data
- Ordnance Survey mapping
- Consultation with the EA
- Horsebridge Dyke and Main Dyke Hydraulic Model and Reporting, Atkins, 2003
- River Wyre Tidal Model, JBA, 2015
- EA Flood Product 4 Fluvial and Tidal Mapping for Skippool Roundabout, EA, 2015.
- Existing Skippool Bridge Survey, Arcadis, 2016
- Existing Skippool Roundabout Culvert Survey, Arcadis, 2016
- Satellite Imagery, Google, 2016
- Scheme design drawings

6.3 Hydrology

6.3.1 A hydrological assessment was undertaken to derive design flow hydrographs for the Main Dyke, Horsebridge Dyke and its tributary, using current best practice Flood Estimation Handbook (FEH) methodologies[15]. Design flood hydrographs have been produced for the 50%, 20%, 10%, 5%, 2%, 1.33%, 1%, 1% plus 30%, 35% and 70% Climate Change (CC) allowances and 0.1% events.

6.3.2 Full details of the analysis are provided in the Flood Calculation Record in Appendix C and the results are briefly summarised below. The EA has been consulted regarding the acceptability of these flow estimates and have confirmed (See Appendix A) that the design flows are appropriate for use in this FRA.

6.3.3 Catchments draining to the flow estimation points assessed are illustrated in Figure 9 and a summary of the adopted flow estimates are provided in Table 5.

Figure 9 Catchments Draining to Flow Estimation Points ((Contains OS data © Crown copyright [and database right] (2016))

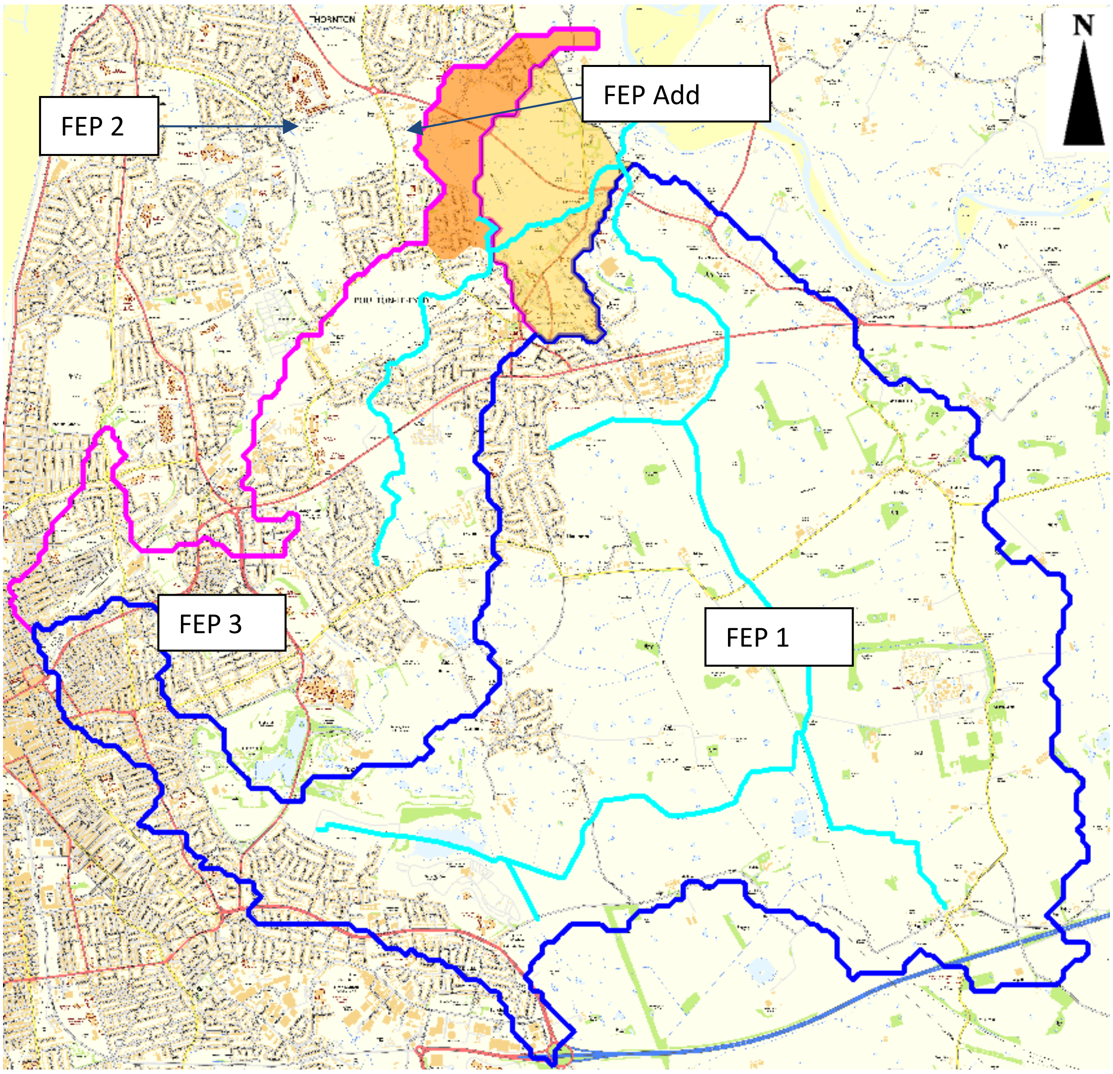


Table 5: Summary of design flow estimates (m³/s)

Event AEP	Flow Estimation Point			
	FEP1[a]	FEP2[b]	FEP3[c]	Add[d]
50%	11.23	0.95	6.61	1.03
20%	15.16	1.23	12.28	1.36
10%	17.48	1.47	14.58	1.61
5%	19.54	1.72	17.13	1.88
2%	21.95	2.13	21.24	2.30
1.33%	23.22	2.34	23.20	2.52
1%	23.60	2.50	24.79	2.70

Event AEP	Flow Estimation Point			
	FEP1[a]	FEP2[b]	FEP3[c]	Add[d]
1% plus 30% CC	30.68	3.25	32.23	3.51
1% plus 35% CC	31.86	3.38	33.47	3.64
1% plus 70% CC	40.12	4.25	42.14	4.59
0.1% year	28.20	4.30	42.32	4.79

6.3.4 Where a – Main Dyke to confluence with the Horsebridge Dyke; b – unnamed tributary of the Horsebridge Dyke; c – Horsebridge Dyke to confluence with the Main Dyke; d – direct catchment draining to the Horsebridge Dyke downstream of the Main Dyke confluence.

6.3.5 Adopted flows are those derived from the FEH Statistical method for FEP1 and from the urban extension to the Revitalised Flood Hydrograph (ReFH) model for the other FEPs, due to the degree of urban development in their catchments.

6.4 Baseline Fluvial Hydraulic Modelling

6.4.1 A linked 1D-2D hydraulic model for the Horsebridge Dyke and the Main Dyke based upon existing EA 1D only models for both watercourses has been constructed. This revised 1D-2D model has been used to establish a baseline for flood risk in the study area and to understand the impacts of the Scheme on surrounding flood risk.

Existing Model Review

6.4.2 Arcadis undertook a comprehensive review of the existing EA 1D only Horsebridge Dyke and Main Dyke models, this review is available in Appendix B. A summary of key issues identified as part of the review is provided in Table 6.

Table 6: Model Review Key Findings.

Item	Description of Issue
ISIS Panel Markers	Panel Markers need to be added at changes in section slope. At the moment, they seem to be in line with left and right banks. This is creating jumps in the conveyance curve. In addition, several of the bank markers have been incorrectly placed.
Cross section geometry	Glass walling and minor levees in the model cross sections need to be removed by creating a 1D-2D linked model.
Model Schematisation	The model should be converted to a linked 1D-2D model in order to improve the modelling of floodplain flows.

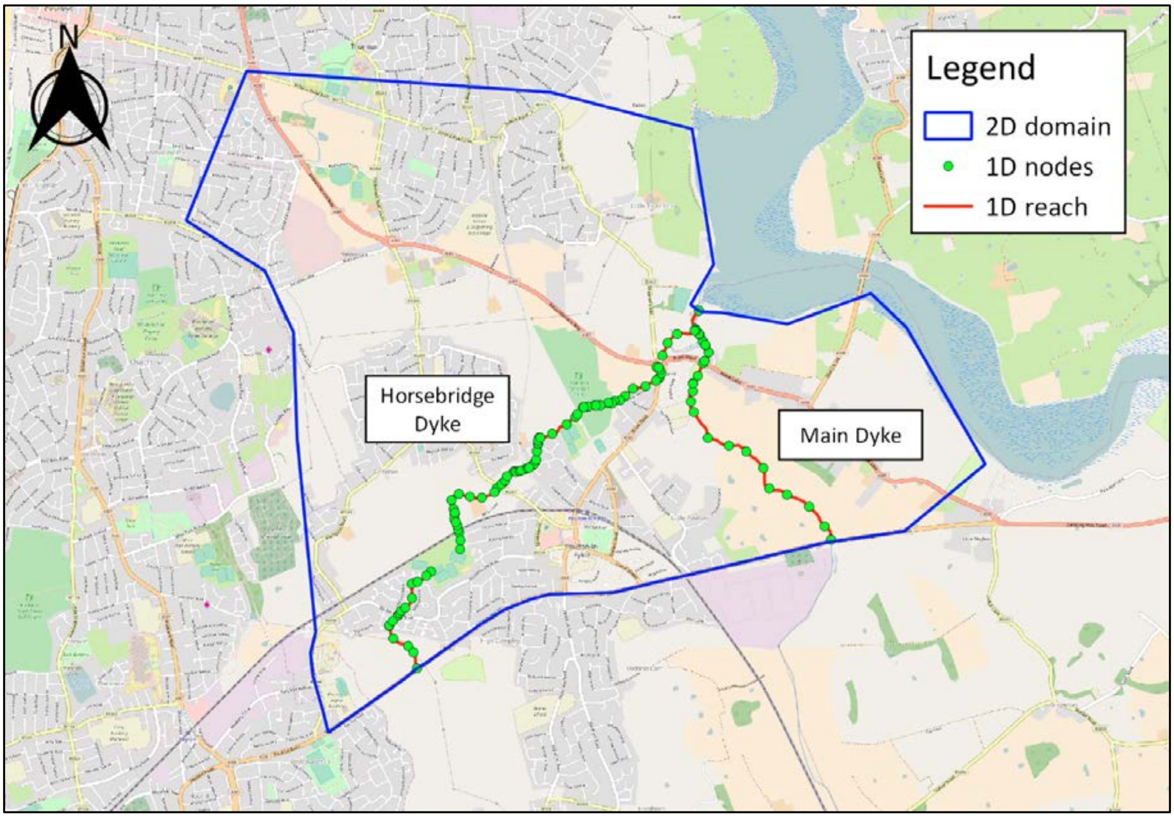
Item	Description of Issue
Model Schematisation	The Main Dyke model should be linked to the Horsebridge Dyke model to assess the interaction between the 2 watercourses dynamically. This would impact on the backwater effects at the A585 bridge and on the combined floodplain to the south of the A585.
Model Schematisation	The spill unit representing the overtopping flows need to be added for the Mains Lane culvert and the bridge near the pumping station.
Model Schematisation	The 2 USPBR bridge units in the model need to be changed to Arch Bridges as this unit is hydraulically more appropriate for the situation being modelled.
Roughness	Channel roughness needs review, justification (with survey photos) and amending.
Downstream Boundary	A detailed hydrological review is required to ensure that the latest estimation methods are considered. This review would also identify whether a single lumped inflow is appropriate or whether additional point / lateral inflows are required.
Model Schematisation	The A585 crossing of the Main Dyke is 373m upstream of the model downstream boundary. Sensitivity testing carried out on the downstream boundary indicated that effects of this are significant at the existing A585 bridge. The same HT (stage time) boundary was used as a downstream boundary for all the design events. This represents 24 hours of tidal data which has been extracted from a 'typical' spring tide cycle. Given that this analysis was carried out 13 years ago, it is recommended that further analysis is carried out to re-project the tide levels to the current day. Additional discussion with the EA is recommended to ensure that the most appropriate combinations of inflow and tide boundaries are being used. It is highlighted that the peak fluvial inflow currently coincides with the lowest tidal level.

6.4.3 The recommended improvements have been implemented, as described below.

1D Domain

6.4.4 To facilitate assessment of the proposed works, the 2 EA 1D models of the Horsebridge Dyke and Main Dyke have been improved and combined into a 1D-2D linked model. The model has been run using TUFLOW version 2016-03-AD-iSP-w64 and Flood Modeller Pro Version 4.2. Figure 10 shows the overall schematisation of the model.

Figure 10: Hydraulic Model Schematisation (Contains Ordnance Survey data © Crown copyright and database right 2017)



Structures

6.4.5 The structure improvements identified in Table 6 have been applied. Structures were verified using the latest available survey data, satellite imagery and photography where available. Those that have been modified so that the overtopping routes are modelled in 2D in order to provide more accurate floodplain extents are listed below:

HBRD02_3006A	HRBD02_1318
HRBD02_2591	HRBD02_0838
HRBD02_2236	HRBD02_0152
HRBD02_1641	HRBD02_0078
HRBD02_1464	MAIN02_0230
HRBD02_1409	

6.4.6 Additional modifications were made to the key tidal structures at the downstream ends of both the Horsebridge Dyke and Main Dyke to incorporate the flapped outfalls which are present.

6.4.7 The EA defence database records the crest level of the Skippool tidal flaps as 5.21mAOD. However, inspection of point cloud LiDAR combined with aerial photography and a site inspection indicated that the top of the wall was in fact higher and ties into higher ground on the left and right banks (Figure 11). Therefore, the crest elevation for the purposes of the modelling was taken to be 6.6mAOD.

Figure 11: Wall across the top of Skippool Tidal Flaps tying into higher ground beyond (Arcadis 2018)

Geometry

6.4.8 The 2 watercourses within the study area have been modified by trimming cross sections to end at the bank top and creating 1D-2D HX links along the channel edges. The upstream end of the Horsebridge Dyke was extended 100m upstream (node HRBD02_3444) to utilise the existing Garstang Road embankment as an effective 2D model boundary.

6.4.9 The 2D model orientation has been set to approximately 45 degrees in order to be perpendicular to the predominant direction of floodplain flow.

Roughness

6.4.10 Roughness values for the FMP channels included in the supplied model were updated, these updates were informed by photographs taken in 2002 supplied with the existing model report. These photographs were only available in areas where structures had been surveyed however, so are limited.

Initial Conditions

6.4.11 1D initial conditions were supplied by a Flood Modeller initial conditions file (IIC), these were generated during a steady state run.

Boundaries

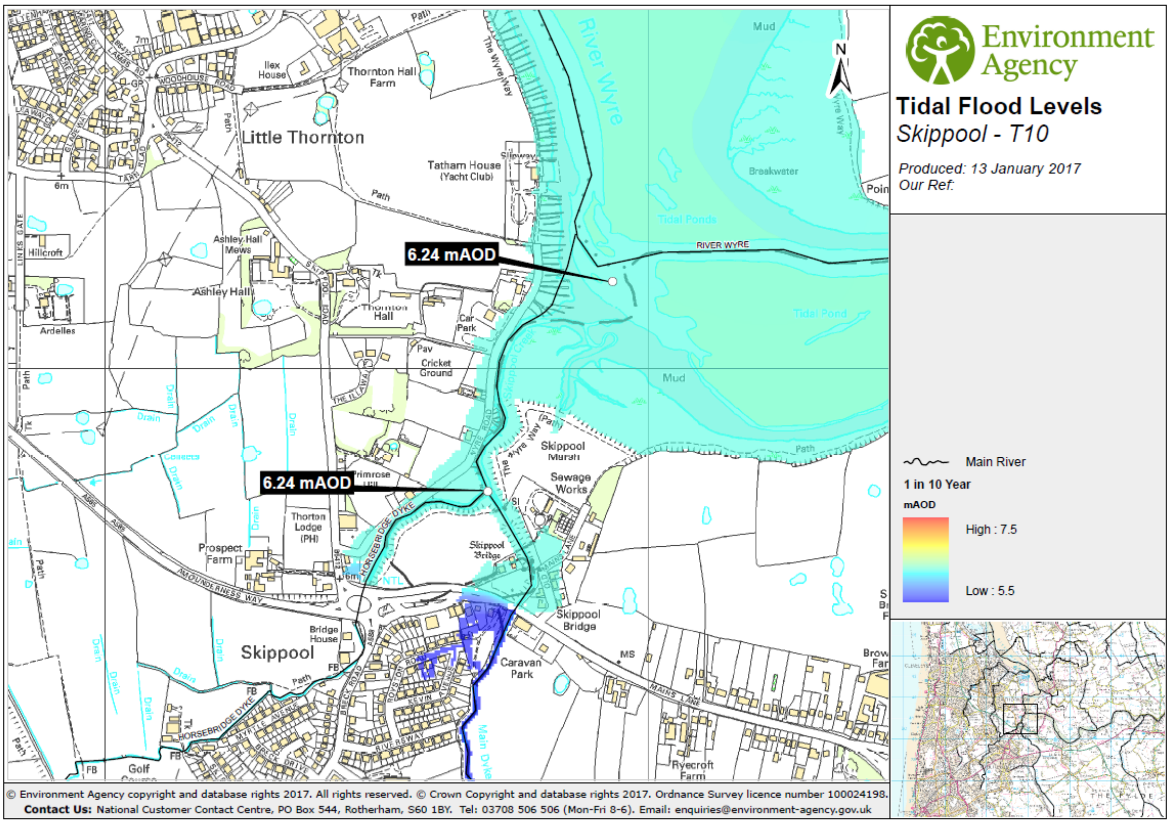
6.4.12 Point inflows are applied to the upstream of the Main Dyke, the Horsebridge Dyke and to represent a small tributary on the left bank of the Horsebridge Dyke at Shirley Heights / The Oaks. Inflows from the intervening catchments are applied to the 1D model as lateral inflows. These fluvial inflows have been generated as detailed in the FEH Calculation Record provided in Appendix C. The 1D model downstream boundary occurs where the Main Dyke joins the tidal River Wyre and is represented using a stage time (HT) boundary unit. Tidal boundaries were derived specifically for this study using the methodology set out below.

6.4.13 Tidal water levels were extracted at the mouth of the River Wyre (Lat 53.93, Lon -3.01) from the MIKE21 Global Tidal Model[19], which has a resolution of 0.125º x 0.125º. The Global Tidal Model includes 10 harmonic constituents, Semidiurnal: M2, S2, K2, N2, Diurnal: S1, K1, O1, P1, Q1 and Shallow Water: M4. A tidal curve was extracted from this data which has the closest peak value to mean high water spring (MHWS).

6.4.14 High tidal levels in the Wyre would close the flaps on the outfalls which would otherwise enable the Horsebridge Dyke and Main Dyke to discharge into the estuary. This is referred to as 'tide locking'. In order to make an assessment of the impact of 'tide locking' on water levels in the Main Dyke and Horsebridge Dyke, tidal analysis was carried out to generate tidal curves at the fluvial model downstream boundary, as described below.

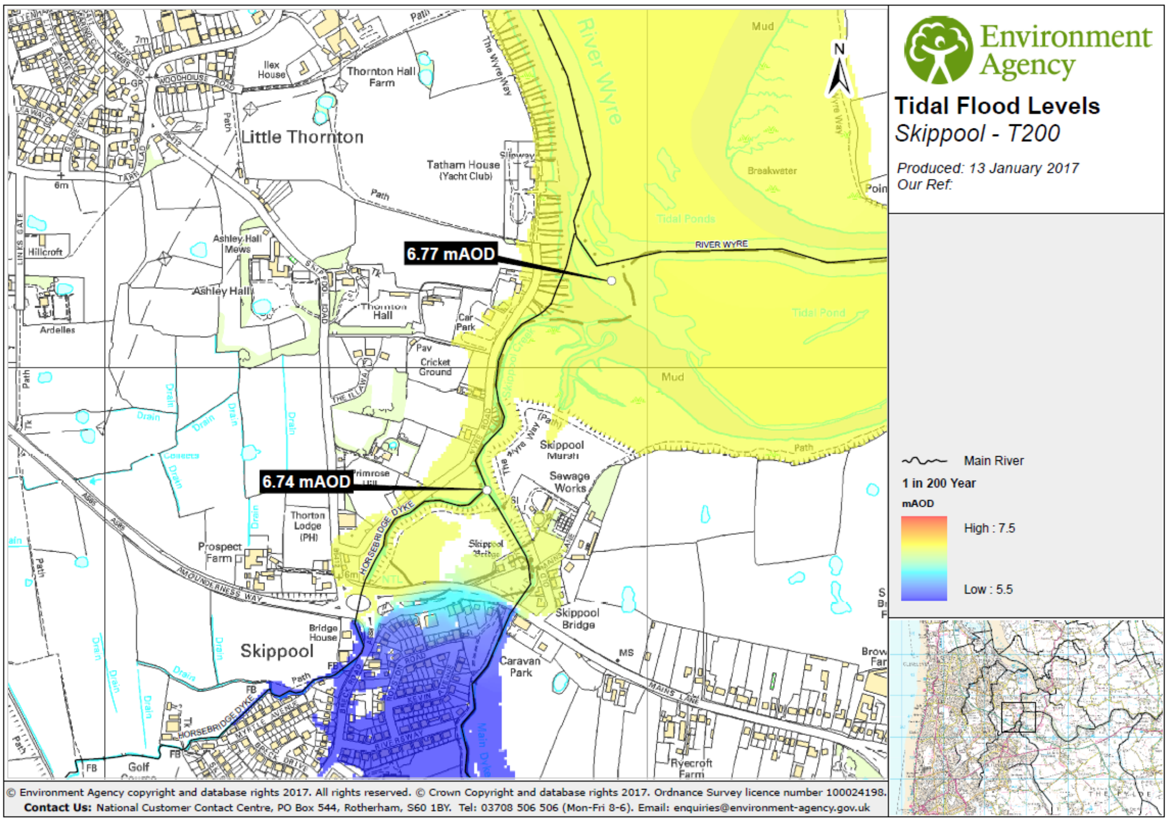
6.4.15 Water levels for the 10% AEP and 0.5% AEP events at locations within the estuary towards Skippool were supplied by the EA and are shown in Figure 12 and Figure 13 respectively. Values from the offshore positions labelled in Figure 12 and Figure 13 were used to derive tidal curves.

Figure 12: 10% AEP water levels in the Wyre Estuary (Supplied by the EA. OS licence: 100024198)



[19] http://www.dhigroup.com/download/mike-by-dhi-tools/coastandseatools/global-tide-model

Figure 13: 0.5% AEP water levels in the Wyre Estuary (Supplied by the EA, OS licence: 100024198)



6.4.16 Tidal curves were generated for the 10% AEP and 0.5% AEP events at 3 climate epochs: 2016 (present day), 2069 and 2115. The event water levels are referenced to a base year of 2014[20] and uplifted to the desired climate epoch using UKCP09 medium emissions scenario 95th percentile sea level rise figures.

6.4.17 The EA practical guidance[21] for generating a storm tide curve using the return period water levels is followed. For this process, the closest available surge curve data was obtained for Heysham from the EA Coastal Flood Boundary (CFB) dataset. Tidal data from the Heysham tide gauge was processed to identify a base astronomical tide between highest astronomical tide (HAT) and mean high water spring (MHWS).

6.4.18 The 3 components of the design tide curve (extreme sea level, base astronomical tide curve and surge shape) were then combined to produce the resultant design tide curve, where the peak in astronomical tide and surge shape are set to coincide at the same time. Figure 14 and Figure 15 show the design tide curves for 2016 10% AEP and 0.5% AEP events respectively.

[20] *JBA Consulting, (2015). North West Region – Lancashire tidal areas benefitting from defences revisited. Final Model Development Report.*

[21] *Environment Agency, (2011). Coastal flood boundary conditions for UK mainland and islands. Project: SC060064/TR4: Practical guidance design sea levels*

Figure 14: Design Tide Curve for a 2016 10% AEP Event

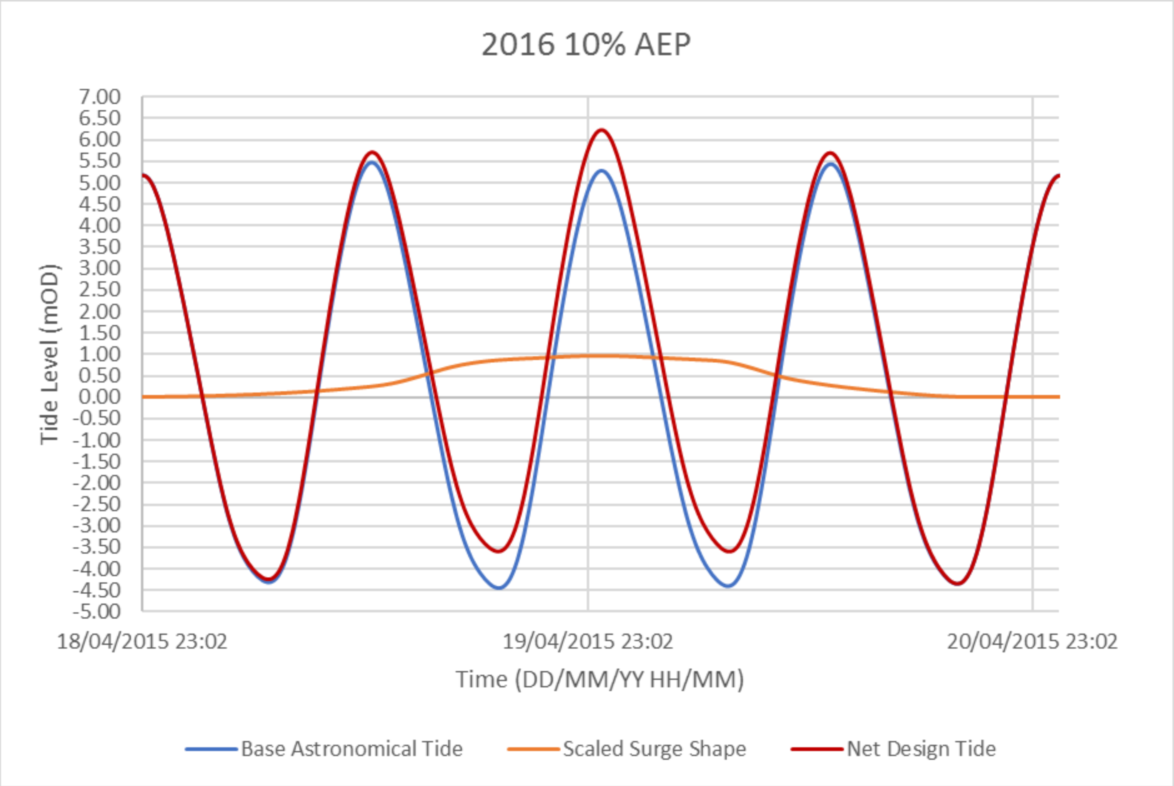
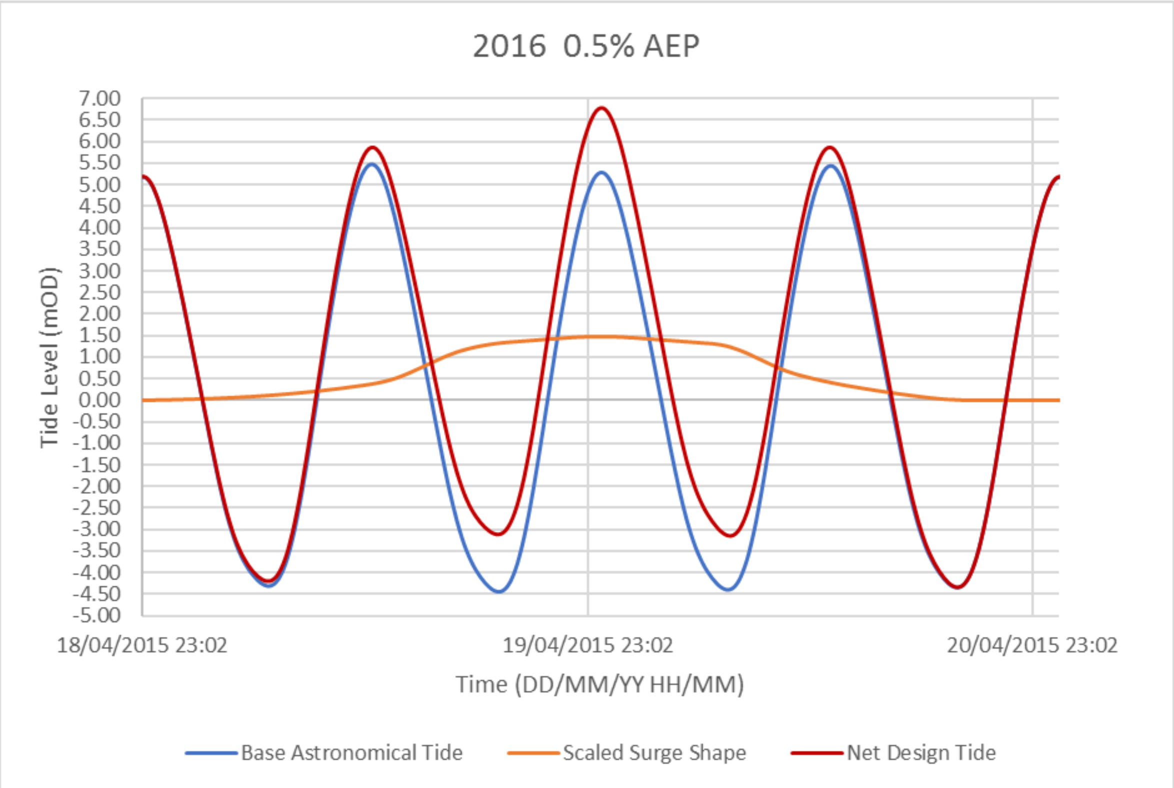


Figure 15: Design Tide Curve for a 2016 0.5% AEP Event



6.4.19 Further details on how these tidal curves were used to assess the impact of tide locking is given in Section 7.2.

2D Domain

Geometry

6.4.20 The baseline DTM utilises a combined tile set of 1M LiDAR (surveyed November 2010), this elevation data is read directly into the model as an ASCII grid file. The TUFLOW grid is created using a cell size of 4m orientated at approximately 45 degrees from a north south line in order to better capture the flow pathways in the vicinity of the A585 scheme.

6.4.21 A TUFLOW Z shape (2d_zsh_main_dyke_correction_01.SHP) was added into the 2D domain on the left bank of the Main Dyke behind The Breck Primary School, where the LiDAR had been incorrectly filtered resulting in a ‘hole’ in the DTM.

6.4.22 Four drainage ditches on the right bank of the Main Dyke were enforced using 2d_fcsh as these allow flood water from the Main Dyke to propagate north east towards Mains Lane.

6.4.23 Where structures were large enough to justify a spilling mechanism within the 2D domain, usually at large roads, spill levels based on LiDAR derived road deck levels were ‘stamped’ using Z shapes in order to correctly modify flow pathways.

6.4.24 Two culverts beneath the Poulton and Wyre railway line on the floodplain to the north of Horsebridge Dyke were represented using 2d_zsh to ensure that flood flows could pass through the embankment rather than incorrectly constraining flood extents.

6.4.25 The tidal defences as detailed in Section 0 were schematised using Z shapes with elevation data being derived from the EA’s provided asset record for the structures. As discussed in Section 0, the crest level of the Skippool Tidal Gates was updated to 6.6mAOD.

Roughness

6.4.26 Ordnance Survey MasterMap data supplied in October 2016 was used to generate a new 2D roughness layer; 13 surface types were identified within the model domain and standard roughness values assigned accordingly. Additional roughness patches were added to cover the fields along the banks of the Main Dyke between Mains Lane and Garstang Road in order to reflect the undulating and overgrown nature of the ground as identified on Google aerial mapping, but which was not accurately represented by the MasterMap data. A similar methodology was applied to the left and right banks of the Horsebridge Dyke immediately upstream of Tithebarn Street. In both locations, application of a slightly higher, and more representative roughness coefficient also helped to stabilise the model during larger flood events.

1D-2D Links

6.4.27 Links between the 1D domain and the 2D domain have been schematised using HX lines, digitised along channel bank tops. The 1D cross sections connect to 2 TUFLOW grid cells and supply a water level across the banks. In order to achieve model stability, Z point elevations have been added to the 2D domain which match the 1D cross section bank heights along the HX lines.

6.5 Baseline Tidal Modelling

Supplied River Wyre Model

6.5.1 The River Wyre tidal model (defended and undefended) was developed by JBA Consulting and submitted to the EA in 2015. This model was supplied to Arcadis for use in this FRA. Results from the JBA modelling were used to assess the defended and undefended flood risk to the Scheme in the vicinity of Pool Foot Creek, whereas results from the enhanced tidal model (see below) were used to assess the flood risk to the Scheme as it crosses the Main Dyke floodplain. This decision was made as the interaction between the Scheme and the tidal flood extents is very minimal at Pool Foot Creek compared to the interaction across the Main Dyke floodplain.

Tidal Model Enhancements

6.5.2 The supplied tidal model was reviewed as part of this FRA and it was noted that, for the most part, channels and structures in the vicinity of the Scheme were not modelled explicitly in the tidal model. Whilst this is acceptable for the purposes for which the tidal model was developed, in order to assess in more detail the impact of the Scheme on tidal flood risk, a number of enhancements were made, as described in Table 7. For stability reasons, the following structures were modelled as 2d_lfcsh rather than ESTRY culverts:

- Skippool Clough culvert on the Horsebridge Dyke
- Minor crossing of the Main Dyke behind Kevin Avenue
- Proposed A585 crossing of the Main Dyke

6.5.3 Small bridges and culverts on the Horsebridge Dyke were removed from the model entirely. This approach was considered acceptable as the structures were small and conveyed only a minor proportion of flows when compared to the Wyre tidal flood flows.

Table 7: Tidal Model Enhancements

Model File	Description	Data Source
2d_fcsh_Model_Wyre_Channel_040	Defines Main Dyke channel Horsebridge Dyke channel	Minimum bed elevation from FMP 1D model channel cross sections
2d_srf_Model_Wyre_Channel_040	Storage Reduction Factor applied to Main Dyke and Horsebridge Dyke channels	Channel section widths from FMP 1D model
1d_nwk_Model_Wyre_Culverts_034	Structures on the Main Dyke and Horsebridge Dyke	FMP 1D model

Model File	Description	Data Source
2d_zsh_tidal_defences_026	Tidal defences along Skippool Creek and Wyre estuary	EA Asset Database, as modelled in linked 1D2D model
2d_zsh_main_dyke_correction_038	Smooths out DTM on left bank of Main Dyke, behind Brockfield School	LiDAR
2d_zsh_DTM_Stability_004	Smooths out DTM on left bank of Main Dyke, downstream of Mains Lane	LiDAR
2d_zsh_Bridge_Patch_040	Bridge Decks which had been filtered from LiDAR data	FMP 1D model spill levels / LiDAR
2d_po_Model_Wyre_043	Plot Output lines to record flow in 2D channels	N/A
2d_mat_Model_Wyre_Stability_025	Roughness patches to improve model stability	Aerial Mapping / Engineering judgment
2d_mat_Model_Wyre_001	Base roughness	MasterMap
2d_fcsh_main_dyke_P_15 2d_fcsh_main_dyke_L_15	Field Drains	LiDAR
2d_srf_main_dyke_15	Storage Reduction Factor for field drains	LiDAR
2d_bc_Model_Wyre_Culverts_034	Link between 2D channel and structures on the Main Dyke and Horsebridge Dyke	FMP Model / LiDAR

Model File	Description	Data Source
2d_zsh_Road_Crest_042 2d_zsh_Road_Central_Reservation_042	Elevations of the Scheme central reservation and road around Skippool Junction	CAD files from design team

6.5.4 Tidal boundary conditions were left unchanged from the supplied model. The 0.5% AEP was assessed as this event is used to define Flood Zone 3 when referring to tidal flooding. A climate change scenario was assessed which was based on the medium emission 95th percentile UKCP09 scenario for the year 2115[20]. A baseflow was applied to the Main Dyke and Horsebridge Dyke to aid model stability.

6.6 Option Modelling (Fluvial and Tidal Models)

6.6.1 The Scheme, as illustrated in Figure 2, has been assessed. The Scheme would impact both the Main Dyke floodplain and the existing A585 crossing of the Main Dyke at Skippool Bridge. Changes to both the 1D and 2D domains were made to represent this. The following elements of the Scheme were schematisation in the option flood models:

- Proposed Skippool Bridge Main Dyke crossing (1D domain)
- Proposed A585 embankment (2D domain)
- Proposed wetland area (2D domain)

6.6.2 In addition, it has been identified that the Skippool Clough culvert on the Horsebridge Dyke needs remedial work and that this should be carried out at the same time as the Scheme. At this stage, the modelling has not been updated to assess these works as a final decision on the design of a replacement culvert has not been made. However, the replacement is likely to maintain similar dimensions and alignment as the existing structure. It is therefore considered that the new culvert would largely maintain the flood risk baseline on the Horsebridge Dyke.

Proposed Skippool Bridge (1D Domain)

6.6.3 The proposals include a change from the existing 2 1.8m diameter circular culverts to a 12.5m wide clear span bridge with a minimum soffit level of 5.0mAOD.

6.6.4 In the fluvial model, the proposals have been represented in 1D using a USPR bridge unit. The channel cross sections immediately upstream and downstream of the bridge were updated to accommodate the new bridge and to ensure that conveyance through the widened structure was maximised. Overtopping onto the road has been modelled using FMP spill units set at the elevation of the bridge deck which are linked to TUFLOW HX boundaries. The levels along the new A585 are enforced via the application of a 2D surface model and 2d_zsh (Section 0).

6.6.5 In the tidal model, the existing crossing is modelled as an ESTRY double barrelled circular culvert, 1.8m in diameter. The proposed crossing is modelled using a 2d_lfcsh which represents a single rectangular culvert, 12.5m wide with a soffit level of 5.0mAOD.

Proposed A585 Embankment (2D Domain)

6.6.6 A surface model in ASCII format was created as shown in Figure 16; this was read into the 2D domains of both the fluvial and tidal models within the geometry control file.

Figure 16: Scheme Alignment Surface Model Elevations (wetland area shown in green) (© OpenStreetMap contributors)

6.6.7 Four new culverts have been added to the model to convey flood waters along the ditches described in Section 0. These culverts would be constructed of plastic and hence a Manning's n roughness coefficient of 0.01 has been applied. The same model file has been used to represent the culverts in the fluvial and tidal models.

6.6.8 In addition, a wetland area, included in the design to attenuate and treat discharges of highway runoff, has been enforced in the fluvial and tidal models using a TUFLOW generated TIN.

7 MODELLING RESULTS

7.1 Fluvial Flooding

7.1.1 Eleven design events have been assessed as part of this FRA; 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1.33% AEP, 1% AEP, and 0.1% AEP fluvial floods, all in combination with a MHWS tidal condition. Climate change was assessed by adding 30%, 35% and 70% to the 1% AEP flows.

7.1.2 Baseline flood extents are shown in Appendix D, Figures D1 – D11. Results demonstrate that although the Scheme is proposed in an area currently predicted to be at risk of flooding, by increasing the capacity of the existing A585 crossing as part of the Scheme proposals, upstream flood extents are reduced. Therefore the Scheme is not at risk of flooding for any of the design events assessed.

7.1.3 Difference grids which show the impact of the Scheme on flood extents and levels are shown in Appendix D, Figures D12 to D22. These show that the Scheme proposals reduce flood depths and extents upstream of the A585 for all modelled events. There are increases in flood levels downstream of the A585 and upstream of the Skippool tidal gates resulting from additional water passing through the A585 bridge which cannot then pass as rapidly through the tidal gates. However, flood extents are not increased as a result. The increase in flood levels extends upstream on the Horsebridge Dyke between the A585 and the Main Dyke confluence during the 1% AEP plus 70% for climate change event.

7.1.4 An assessment was carried out to ensure that the proposed development was not at increased risk of flooding over its lifetime due to climate change, this used the 3 climate change scenarios as described in Section 3 for the 1% AEP event: +30%, +35% and +70% fluvial inflows. Figures D8, D9 and D10 in Appendix D show that for all allowances assessed the Scheme is not predicted to be inundated.

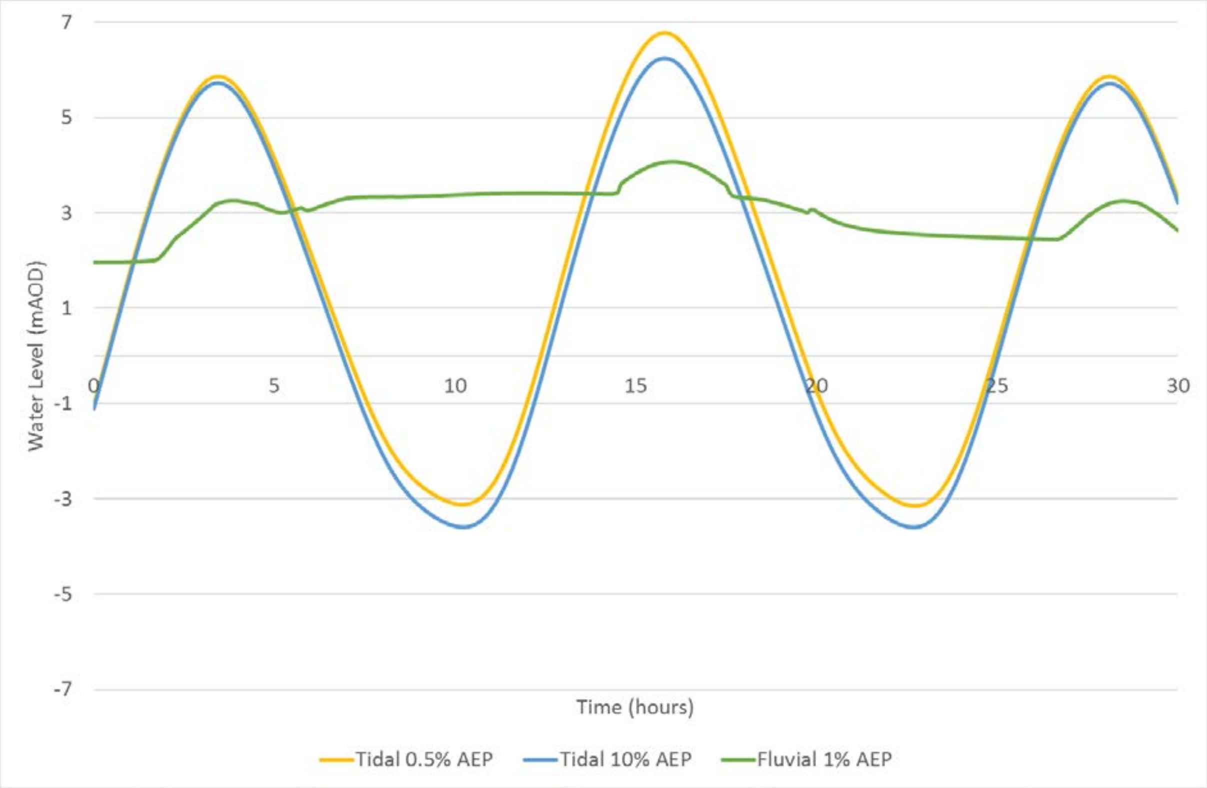
7.2 Impact of Tide Locking on Fluvial Flood Levels

Methodology

7.2.1 The EA has requested that the impact of the tide locking of the outfalls on the Horsebridge Dyke and Main Dyke be assessed. Tide locking of the outfalls is predicted to occur when water levels in the Wyre rise above the water levels on the upstream side of these outfalls. The EA originally requested that this should be assessed by applying the design 10% AEP and 0.5% AEP tide levels at the downstream boundary. Given that these predicted water levels are in the order of 6.5mAOD, compared to the Mean High Water Springs (MHWS) level of around 3.5mAOD, significant model stability issues were encountered when applying these design levels.

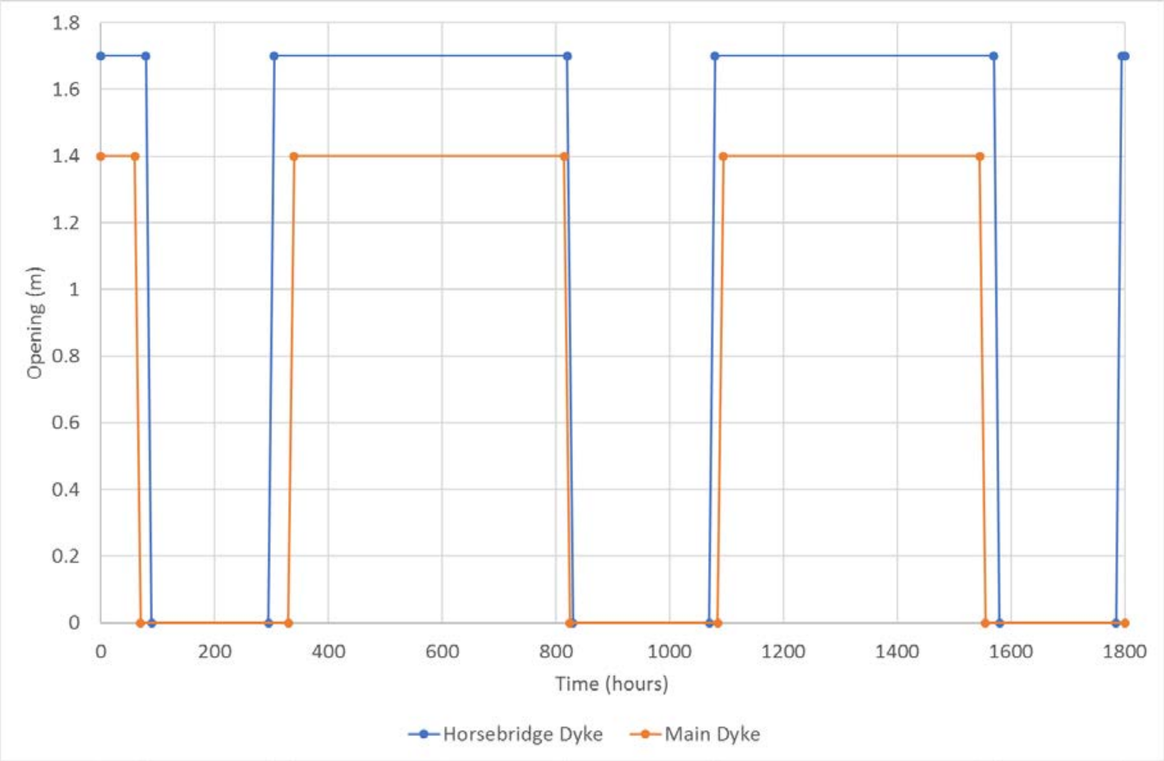
7.2.2 To model the impacts of this tide locking on upstream water levels in the Horsebridge Dyke and Main Dyke, the existing model structures (flapped outfalls) were replaced with sluice units controlled with time based rules. The rules were set to close the sluice at the times when the tide levels from the 10% AEP and 0.5% AEP events in the Wyre would be high enough to prevent the Horsebridge Dyke and Main Dyke discharging to the Wyre. The closure time was defined by comparing the predicted upstream water levels in the Horsebridge Dyke / Main Dyke with the predicted tidal levels in the Wyre. Due to the gradient of the tidal curve, a negligible difference was observed between the predicted closure time for the 10% AEP and the 0.5% AEP events (Figure 17).

Figure 17: Main Dyke Tidal (downstream of flaps) and Fluvial (upstream of flaps) Levels



7.2.3 The rules in the sluice units were defined with a time base profile which forces the sluice to shut for the duration of the high tide, as shown in Figure 18. In each case, a 10 minute closure and opening time was applied for model stability.

Figure 18: Main Dyke and Horsebridge Dyke Sluice Opening Profiles

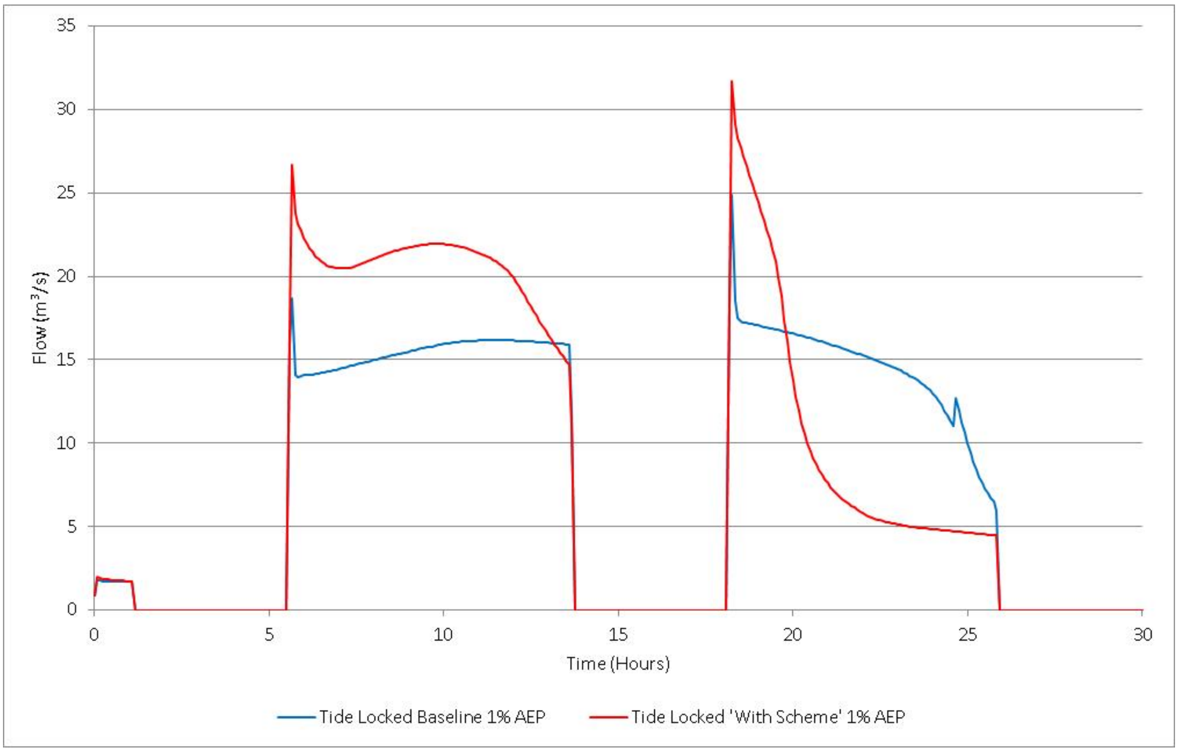


7.2.4 In total, 22 tide locking model runs were carried out to assess the impacts for the baseline and with Scheme conditions for all eleven design events.

Tide Locking Results

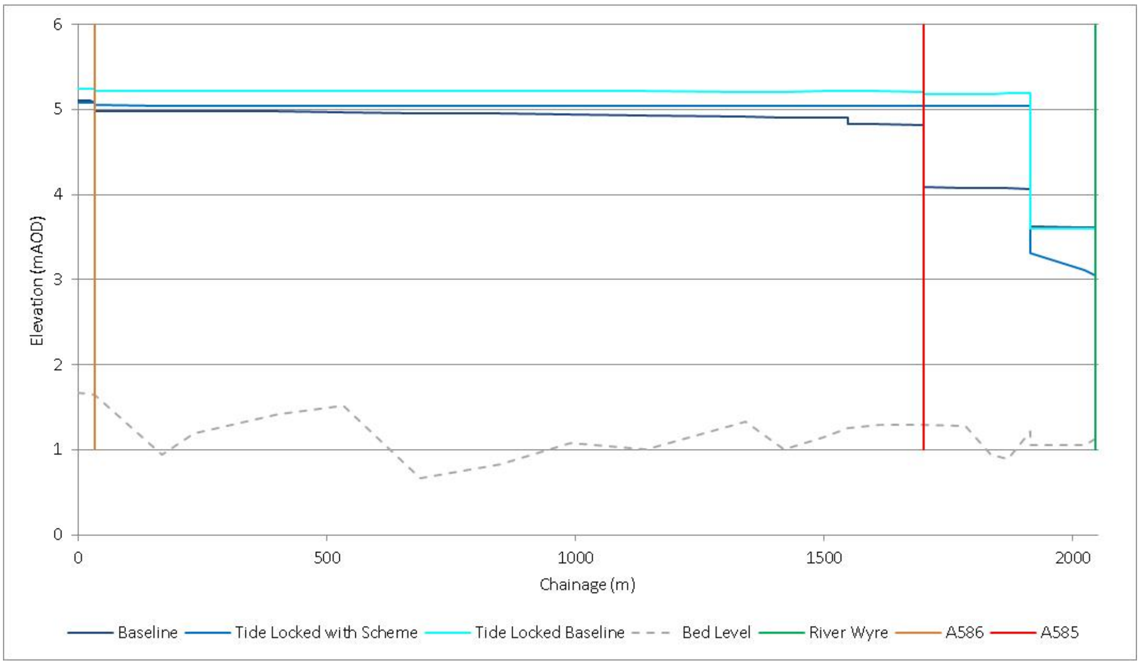
7.2.5 The results from the 22 modelled runs are discussed below. Section 7.1 identifies that the replacement of the existing culverts at the A585 crossing (Skippool Bridge) with a clear span bridge has a significant impact on flood extents along the Main Dyke. Figure 19 shows flows through the tide locked sluice for the 1% AEP baseline and option model runs. It illustrates that the proposed structure allows greater flow through the tidal flaps once the sluice has reopened following a drop in tidal levels in the Wyre. An increase in flow through the tidal gates allows the reach upstream of the Main Dyke flaps to drain down faster.

Figure 19: Main Dyke Tidal Flap Flow Hydrograph



7.2.6 Figure 20 shows the water level profile along the Main Dyke for the 1% AEP tide locked baseline, 1% AEP tide locked ‘with Scheme’ and the 1% AEP MWHS baseline. The tide locking mechanism is shown to increase water levels by a maximum of 1.12m immediately upstream of the tidal flaps for the baseline scenario. When comparing the 2 tide locked scenarios, water levels are an average of 160mm lower for the ‘with Scheme’ run. Water levels remain unchanged for the Horsebridge Dyke from the tide locked ‘with Scheme’ run when compared against the tide locked baseline.

Figure 20: Main Dyke: Impact of Tide Locking



7.2.7 Impacts on the Scheme during a tide locked scenario have been reviewed for all design events assessed. The flood extents for baseline and 'with Scheme' models are included in Appendix D Figures D34 to D44. The results indicate that the Scheme is not at risk of fluvial flooding during any of the modelled tide locked scenarios. The flood waters do not overtop the proposed Scheme embankment or the proposed Scheme crossing of the Main Dyke.

7.2.8 These figures also demonstrate that during the tide locked scenario, flood extents are reduced for the 'with Scheme' model and hence, the Scheme does not have a detrimental impact on flood risk to the surrounding area.

7.3 Tidal Model Flood Extents

7.3.1 Baseline modelled flood extents are shown in Appendix D, Figures D45 and D46, and demonstrate that the Scheme is at risk of flooding immediately to the east of Skippool Junction. During the 0.5% AEP event, the existing A585 is overtopped in the second tidal cycle. When adding an allowance for climate change, the A585 is overtopped in both the first and second tidal cycles.

7.3.2 Difference grids which show the impact of the Scheme on flood extents and levels are included in Appendix D, Figures D47 and D48. These show that the Scheme proposals increase flood depths on the Horsebridge Dyke by up to 6cm during the 0.5% AEP. However, a developed area of land at Kevin Avenue and Royston Road that is predicted to be at risk of flooding in the baseline is removed from the floodplain when the Scheme is in place. Less floodplain upstream on the Main Dyke is also predicted in the option model.

7.3.3 During the 0.5% AEP inclusive of an allowance for climate change, the impacts of the Scheme are more widespread; flood depths on the Main Dyke and the Horsebridge Dyke are increased by up to 10cm. Although depths are increased, changes in flood extents are negligible and the benefit in terms of a reduced risk of flooding at Kevin Avenue and Royston Road is maintained.

7.3.4 The key mechanisms driving the changes in flood depths along the Main Dyke are an increase in flows through the widened A585 bridge and, during the 0.5% AEP inclusive of an allowance for climate change, the expansion of baseline flooding into the area in which the Scheme embankment is proposed with the resulting displacement of floodwater.

7.3.5 The key mechanism driving the changes in flood depths along the Horsebridge Dyke is also the increased flood flows on the Main Dyke through the widened A585 crossing. This in turn increases flood levels on the Main Dyke and restricts the volume of flow which can pass from the Horsebridge Dyke into the Main Dyke. Consequently, flood levels increase in the Horsebridge Dyke and a small increase in floodplain flood depths is observed.

7.4 Implication of Results for the Scheme

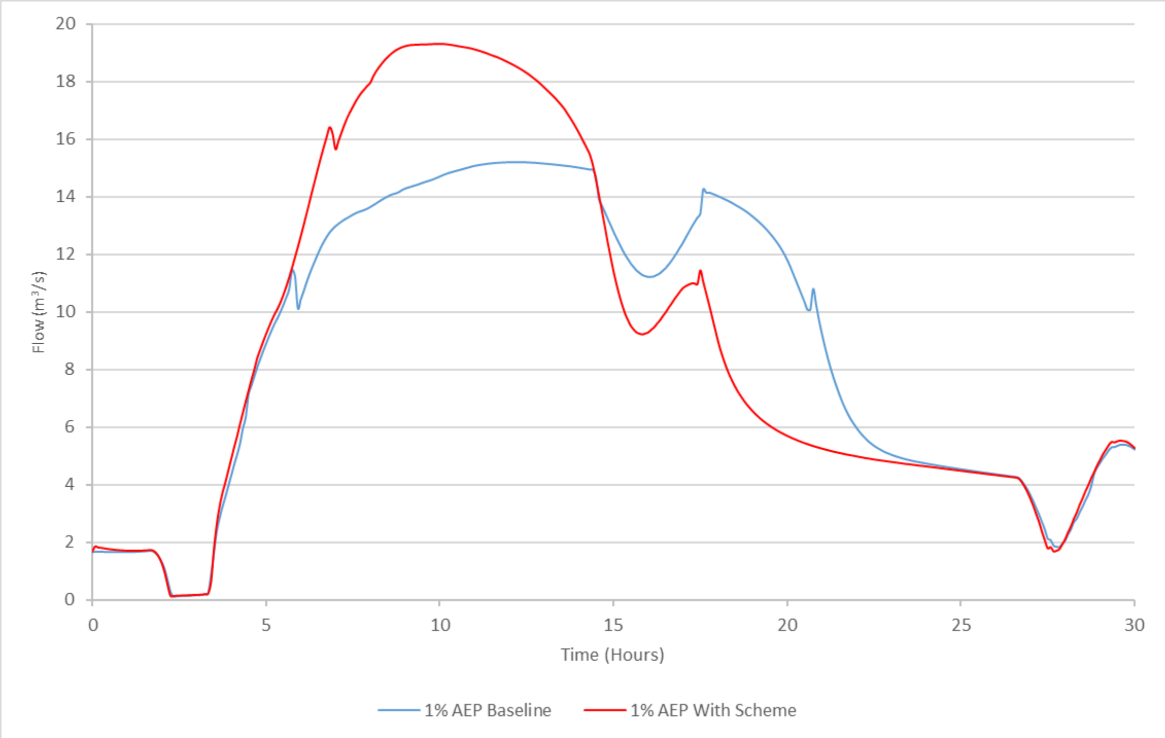
Fluvial Flood Risk

7.4.1 Figures D1 to D11 in Appendix D show that for all modelled fluvial events, flood extents are reduced as a result of implementing the Scheme. This is due to the alteration of the existing Skippool Bridge from 2 1.8m diameter culverts to a single 12.5m wide bridge, increasing conveyance and reducing flood levels upstream of the structure. Table 8 shows the change in peak flow through Skippool Bridge, with the 1% AEP hydrograph shown in Figure 21.

Table 8: Peak Flow through Skippool Bridge

Scenario	Peak Flow 1% AEP	Peak Flow 0.1% AEP
Baseline	15.2 m^3/s	15.9 m^3/s
With Scheme in Place	19.3 m^3/s	20.9 m^3/s

Figure 21: 1% AEP Comparison of Flows Downstream of Skippool Bridge (MAIN02_0147) for the Baseline and Option Model Runs



7.4.2 Modelled peak water levels for all assessed events up to and including the 1% AEP plus a 35% allowance for climate change are below the minimum soffit level (5.02mAOD) of the new A585 Main Dyke crossing. Table 9 summarises these results.

Table 9: Peak Stage at the Proposed A585 Crossing for all Option Model Runs

Event	Peak Stage (mAOD)
50% AEP	3.68
20% AEP	3.73
10% AEP	3.78
5% AEP	4.10
2% AEP	4.28
1.33% AEP	4.34
1% AEP	4.36
1% AEP + 30% CC	4.76
1% AEP + 35% CC	4.79

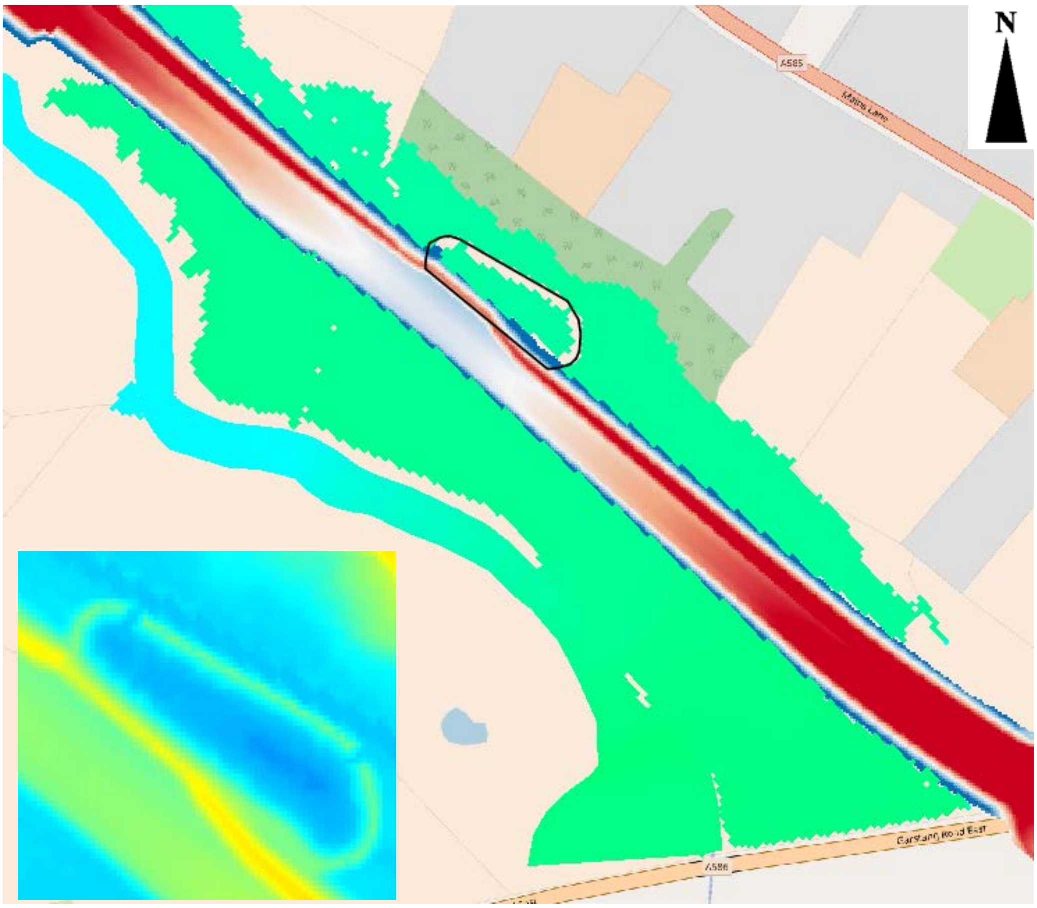
Event	Peak Stage (mAOD)
1% AEP + 70% CC	5.20
0.1% AEP	4.63

7.4.3 Given that the implementation of the Scheme results in a reduction in baseline flood extents, it is not considered that, based on the model results, additional floodplain compensation measures would be required once the Scheme is fully constructed. However, as discussed in Section 7.5, some mitigation would be required for the duration of the construction period.

Surface Water Drainage Ponds

7.4.4 It is a requirement of the highway drainage design that any surface water drainage ponds are not flooded during events up to and including the 1% AEP. Figure 21 shows the only proposed drainage pond located within the fluvial model domain. This pond is set at an elevation of 6.5mAOD compared to a peak 1% AEP water level of 4.74mAOD. The application of the 3D surface TIN onto the model 4m grid has resulted in 2 grid cells at a lower elevation than the remainder of the bund (illustrated by Figure 22). Therefore, some water has entered the pond in the model which would not enter the pond in reality due to the presence of the 6.5mAOD perimeter bund. The impact of this on model results is minimal.

Figure 22: Proposed Drainage Pond



Tidal Flood Risk

7.4.5 Table 10 summarises the modelled tidal levels which are available to inform the assessment of flood risk to the Scheme, in both defended and undefended scenarios, as it crosses the Main Dyke floodplain between Garstang Road and Mains Lane, east of Skippool Junction and west of Windy Harbour Junction (immediately to the south of Pool Foot Creek).

Table 10: Modelled Tidal Flood Levels and Risk to the Scheme

Scenario	Crossing the Main Dyke Floodplain	East of Skippool Junction	West of Windy Harbour Junction
Arcadis Modelled 0.5% AEP (defended)	Not at risk of flooding	At risk of flooding to a depth of approximately 300mm. (Peak stage 6.7mAOD minimum road elevation 6.4mAOD)	Results not available for this area
Arcadis Modelled 0.5% AEP plus climate change (defended)	Not at risk of flooding	At risk of flooding to a depth of approximately 700mm (peak stage 7.1mAOD minimum road elevation 6.4mAOD)	Results not available for this area
JBA Modelled 0.5% AEP plus climate change (defended)	Results superseded by enhanced tidal model	Results superseded by enhanced tidal model	Not at risk of flooding (peak stage of 6.4mAOD minimum road elevation of approximately 7.2mAOD)
JBA Modelled 0.5% AEP (undefended)	Not at risk of flooding (peak stage of 5.6 to 5.7mAOD. Minimum road elevation of approximately 6.7mAOD)	At risk of flooding to a depth of approximately 100mm (peak stage 6.5mAOD minimum road elevation 6.4mAOD)	Not at risk of flooding (peak stage of 6.6mAOD minimum road elevation of 7.2mAOD)

Scenario	Crossing the Main Dyke Floodplain	East of Skippool Junction	West of Windy Harbour Junction
JBA Modelled 0.5% AEP plus climate change (undefended)	Not at risk of flooding (peak stage of 6.1 to 6.2mAOD. Minimum road elevation of approximately 6.7mAOD)	At risk of flooding to a depth of approximately 600mm (peak stage 7.0mAOD minimum road elevation approximately 6.4mAOD)	At risk of flooding to a depth of approximately 100mm (peak stage of 7.3mAOD minimum road elevation of approximately 7.2mAOD)

7.5 Construction Phase Flood Risk

Construction Sequence

Assessment of Impacts on Flood Risk

7.5.1 The proposed widening the existing A585 crossing has been demonstrated to reduce baseline flood extents on the Main Dyke. However, the programme of works for the Scheme construction requires that the embankment is in place before works are carried out to the bridge. Therefore, an assessment of the impact of the Scheme (embankment only, no bridge widening) has been carried out. The resulting changes in baseline in flood levels and extents are illustrated in Figures D23 to D33 in Appendix D.

7.5.2 For the 50% AEP flood, no change is observed as there is negligible out of bank flooding, none of which extends as far as the proposed Scheme embankment.

7.5.3 In the 20% AEP flood, a minor reduction in flood levels to the east of the proposed Scheme embankment is observed. This is due to the proposed culverts under the Scheme embankment providing a slight restriction on flow compared to the baseline, open channel condition.

7.5.4 During the 10% AEP event, small increases in flood levels and extents are observed however these are constrained to areas of open land in close proximity to the Scheme.

7.5.5 During the 5% AEP flood, increases in flood levels across the Main Dyke floodplain are observed. However, only small increases in flood extents occur on areas of open fields between the Main Dyke and the Scheme embankment, approximately 1km upstream of the A585. In addition, there are very small increases in flood extent on open fields between the Main Dyke and The Breck Primary School.

7.5.6 During the 2% AEP event, increases in flood levels across the Main Dyke floodplain are observed. Increases in flood extents occur in open fields on the left bank of the Main Dyke behind Little Poulton Lane. A natural depression in the topography controls the extent of flooding in this location.

7.5.7 A similar pattern of impacts is observed for the 1.33% AEP flood. However, during this event flood extents increase marginally along Fouldrey Avenue outside The Breck Primary School.

7.5.8 During the 1% and 0.1% AEP events, increased flooding in both the baseline and 'with Scheme embankment' models limits the relative increases in flood levels. However, increases in flood extents are observed in line with the 1.33% AEP flood.

7.5.9 During the 1% AEP inclusive of both 30% and 35% for climate change event, widespread flooding in the baseline situation limits the relative increases in both flood level and extent. Notable increases in flood extents occur in the vicinity of Royston Road and Kevin Avenue.

7.5.10 For the 1% AEP plus 70% for climate change, flooding from the Main Dyke reaches the Horsebridge Dyke and hence impacts are observed within the floodplain of the Horsebridge Dyke. Increases in flood extents occur predominantly in open fields opposite Skippool Avenue.

7.5.11 In summary, for the smaller magnitude events that would generally be considered to be more likely to occur during the relatively short duration of the construction phase, the impact of building the Scheme embankment prior to widening the A585 crossing is minimal. Impacts on third parties are, in the main, constrained to open fields rather than property, with the latter only observed in the higher magnitude, less probable, events.

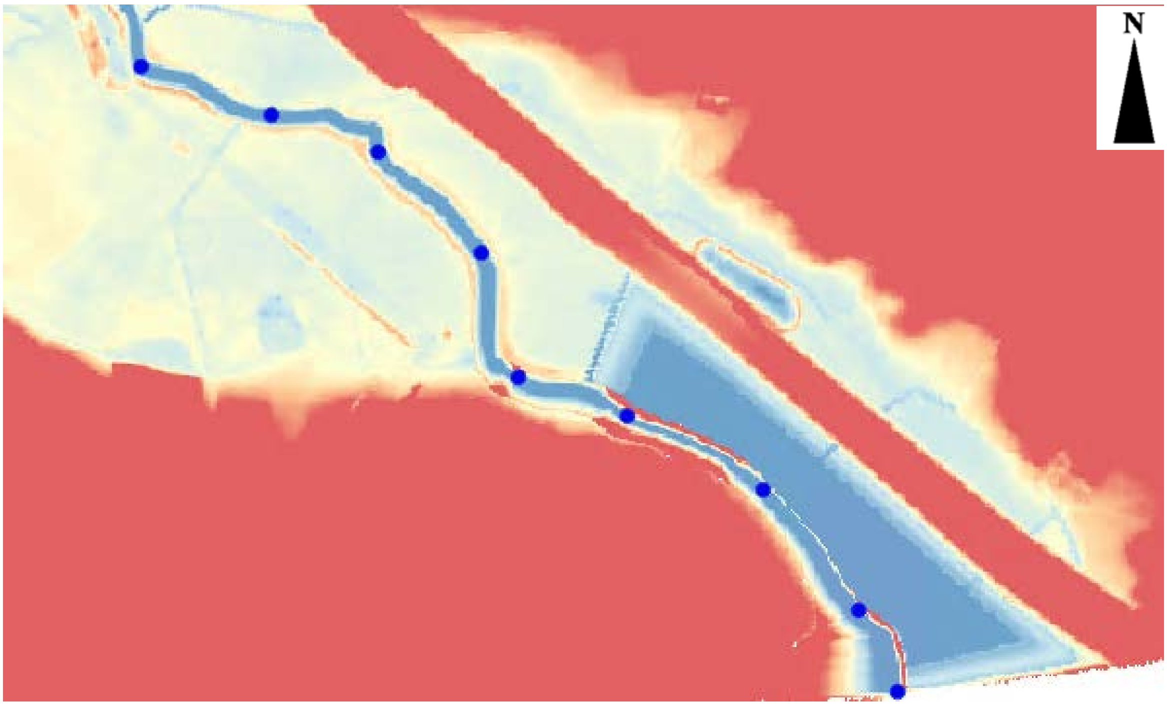
7.5.12 Based on these model results, the EA were consulted on the flood risk associated with the construction phase and confirmed that mitigation would be required to ensure that increases in flood risk to third parties were minimised for all events up to and including the 1% AEP plus 30% for climate change flood event. Paragraphs 6.5.13 to 6.5.15 discuss the work carried out to assess mitigation requirements.

Mitigation

7.5.13 An area of land on the right bank of the Main Dyke immediately downstream of the A586 has been identified as having potential to accommodate floodplain storage to offset that removed by the road embankment during construction. At this stage of the study, an indicative area has been lowered in the fluvial option model to assess whether or not providing compensation storage in this location has the potential to mitigate downstream flood risk.

7.5.14 Figure 23 shows the location and elevations assessed. In conjunction with the changes to the 2D domain, the right bank levels of the adjacent FMP nodes were lowered to allow flows into the compensation area.

Figure 23: Proposed Floodplain Compensation Area for Mitigation during Construction

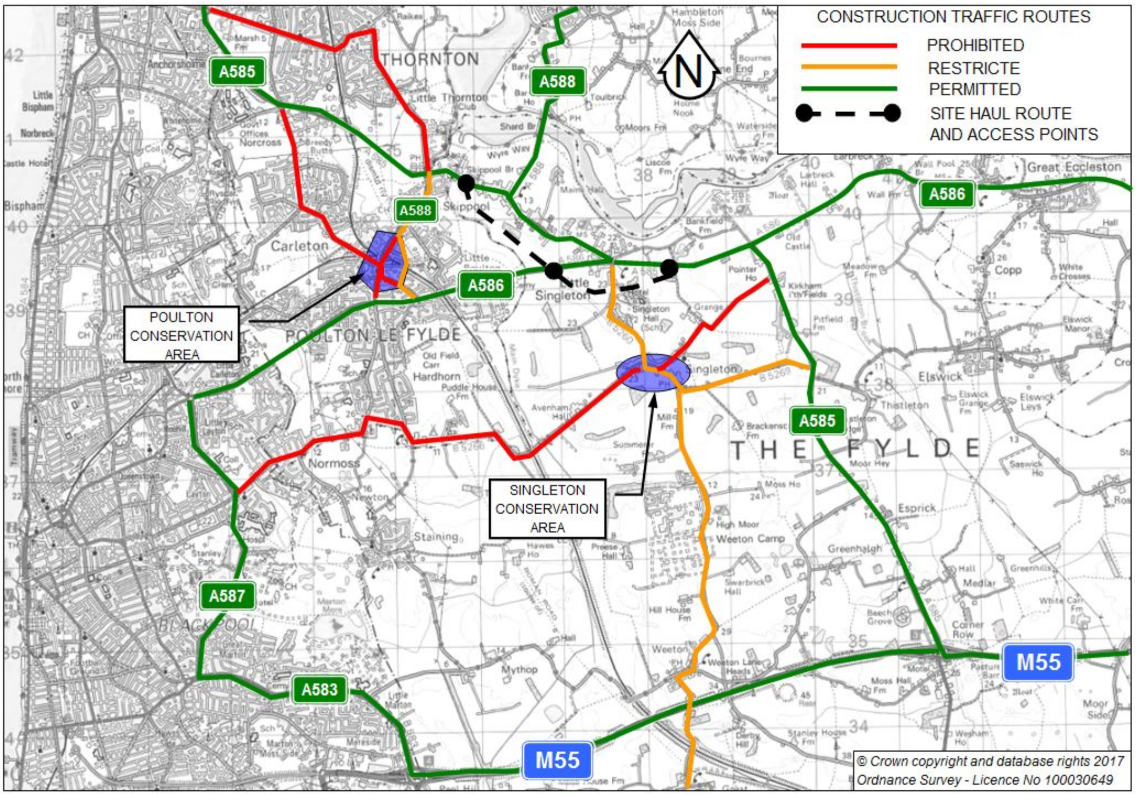


7.5.15 Results from this preliminary run demonstrate that the provision of compensation storage in this location reduces the increases in flood risk to third parties (Figure D49 in Appendix D). The configuration of this compensation area will be refined as part of the detailed design phase and consultation carried out with the EA regarding its suitability. This mitigation measure is included as work items 98, 109, 110 and 111 on the Works Plans (document reference T010035/APP/2.3).

Haul Roads

7.5.16 Figure 24 shows the proposed construction access routes to be used during the Scheme construction. This confirms that there are no additional routes proposed that are in the floodplain, and thus there is no change in flood risk as a result of any haul roads.

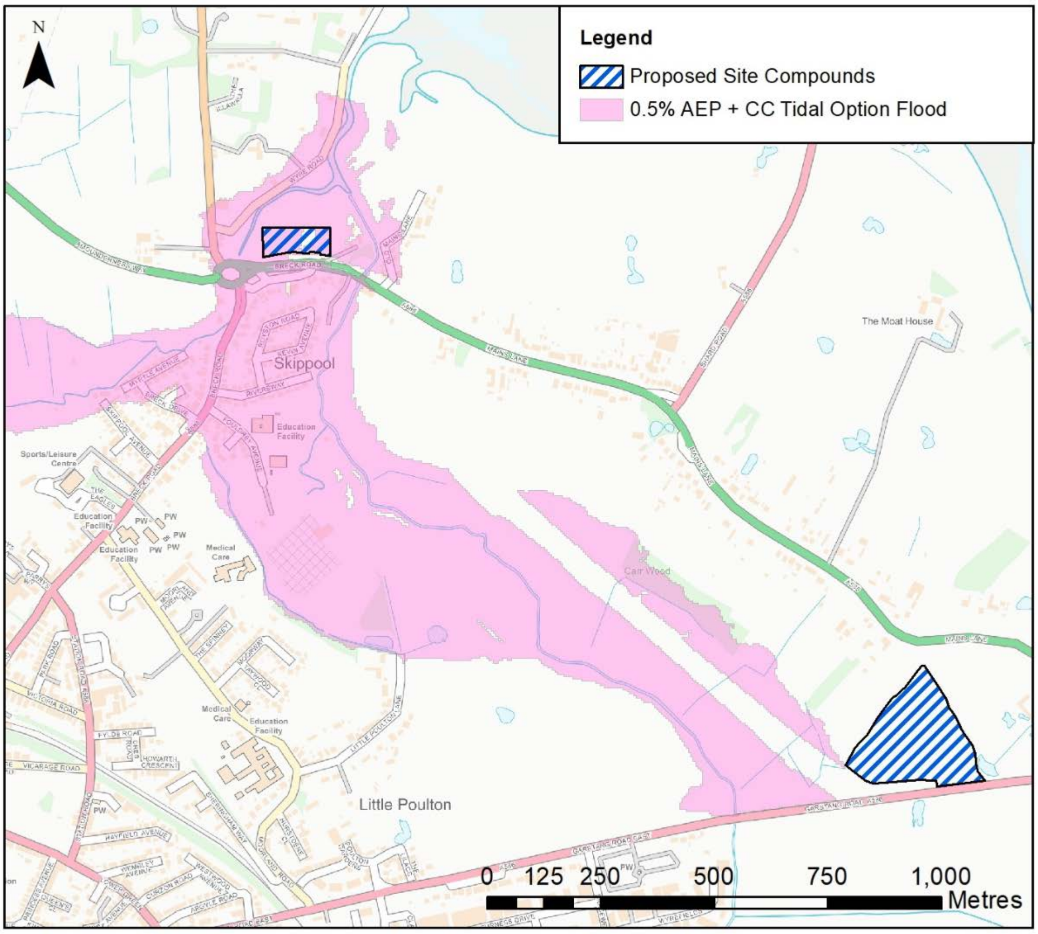
Figure 24: Proposed Construction Access Routes



Site Compounds

7.5.17 A number of site compounds are proposed during the Scheme construction; Figure 25 shows those that are within the fluvial and tidal model extents. The site compound immediately to the north of the A586 is outside all modelled fluvial and tidal flood extents. The site compound immediately to the east of Skippool Junction and north of the A585 is outside all modelled fluvial events although it is within all modelled tidal flood extents as shown in (Figure 25). In this location, the peak 0.5% AEP flood level is 6.78mAOD. There is a further construction compound and laydown area proposed further east on the A585 at the proposed Grange footbridge. Both of these locations are outside the fluvial and tidal model extents but the EA Flood Map shows them to be partially located within defended Flood Zone 3. This zone is indicative of land with a high probability of flooding without the presence of local flood defences. These defences protect the areas against a river flood with a 1% chance of happening each year, or a flood from the sea with a 0.5% chance of happening each year. This actual risk of flooding of these areas during the construction period is therefore low. Residual risks would be managed through implementation of an Emergency Flood Response Plan informed by the EA flood warning service. To ensure no flood risk impacts on third party land in the very unlikely scenario of flooding during the construction period, no ground raising would be undertaken to avoid loss of floodplain storage and the compounds would be secured via open link fencing so as not to impede the flow of floodwater across the sites.

Figure 25: Location of the proposed Site Compounds in relation to the maximum tidal option modelled flood extent (0.5% AEP + CC).



7.6 Pool Foot Creek

7.6.1 The Pool Foot Creek is outside of the area included in the hydraulic model. Defence data from the EA lists the outfall from this watercourse as asset ID 01209WYRE0301L02001 with a condition grade 3 (where 1 is excellent and 5 is very poor). The party responsible for maintaining this asset is listed as unknown.

7.6.2 Given the small catchment area of the Pool Foot Creek and resultant small flows, it is not anticipated that the Scheme would be at risk of fluvial flooding from this watercourse, which crosses the watercourse some 1.8m above the level of the surrounding floodplain. Any changes made to the existing culvert as part of the Scheme design would ensure that conveyance is maintained as existing and therefore no detrimental impacts on third parties would be experienced.

7.6.3 Flood risk linked to overtopping of the tidal defences in this area has been covered in Section 7.3.

7.6.4 Management of any residual risks which might arise as a result of tide locking of the outfall to the Wyre is discussed in Section 9.

7.7 Limitations of the Model

7.7.1 The accuracy of the model is limited by the accuracy of the data used to build it. Specifically, in relation to this study, detailed survey data was not available and hence the channel geometry is based on the EA supplied 1D ISIS models.

8 SURFACE WATER RUNOFF

8.1.1 A surface water drainage strategy has been developed for the Scheme and the proposed strategy is shown in Appendix E and illustrated in the Outline Drainage Works Plans (document reference TR010035/APP/2.9). The strategy uses a combination of pipes, swales and wetland areas to manage surface water runoff in line with the requirements of planning policy and current design standards. Climate change resilience is also included for in the drainage design. It is therefore concluded that there would be no detriment to baseline flood risk from surface water runoff.

9 FLOOD RISK MANAGEMENT MEASURES

9.1 Protection of Third Parties

9.1.1 The removal of the 2 restrictive culverts at the existing A585 crossing of the Main Dyke delivers a reduction in fluvial flood extents upstream. This provides a benefit to existing landowners in this locality.

9.1.2 During construction, the placement of the road embankment on the Main Dyke floodplain has the potential to temporarily increase flood risk to third parties should a large flood event occur. However, initial model runs have shown that there is the potential to mitigate this through the provision of compensation floodplain storage on the right bank of the Main Dyke, immediately to the north of the A586.

9.1.3 The proposed A585 crossing of the Main Dyke allows additional flow to pass downstream; the Skippool Tidal flaps restrict the rate at which this flow can discharge into the Wyre which marginally increases flood levels on the Main Dyke between the A585 and the tidal flaps. However, these increases in flood level do not result in any increase in flood risk to adjacent properties on Old Mains Lane.

9.1.4 Tidal flood risk is increased as a result of the Scheme in some areas and is reduced in other areas. However, maximum increases in flood depth of around 10cm in the 0.5% plus climate change AEP event are in addition to a baseline flood depth of approximately 1m. The change is hence unlikely to significantly alter property damages experienced should a significant tidal flood event occur in the Wyre Estuary over the lifetime of the Scheme. Any increases in flood extents are negligible.

9.1.5 To manage the potential for the Scheme to increase surface water flood risk, as outlined in Section 5.5, a highway drainage strategy has been formulated (Appendix E). The strategy is centred on Sustainable Drainage (SuDS) principles in that attenuation storage and treatment of discharges to improve runoff quality would be provided for, such that there would be no increase in existing rates of discharge to the Main Dyke, Horsebridge Dyke or other receiving waterbodies. This strategy would ensure no increase in surface water flood risk to third party land.

9.2 Protection of the Scheme

9.2.1 Bespoke hydraulic modelling has shown that the Scheme is not at risk of flooding from a purely fluvial flood event inclusive of an allowance of 70% for climate change. However, as discussed in Section 7.3, 2 locations along the proposed Scheme are at risk of tidal flooding. Immediately east of Skippool Junction, the A585 is predicted to flood during the 0.5% AEP event with and without an allowance for climate change in both the defended and undefended scenarios. Modelled flood depths are approximately 300mm and 700mm for the defended scenario and 100mm and 600mm for the undefended scenario. West of Windy Harbour Junction (immediately south of Pool Foot Creek) is at risk of flooding to a depth of around 100mm in the undefended scenario for the 0.5% AEP plus climate change event. It is not possible to fully design out the risk of tidal flooding at these 2eithfdsfds locations as it is necessary for the Scheme to tie into existing road levels. The residual tidal flood risk would be managed through notifying road users via appropriate signage and social media, with warnings, and where necessary road closures, implemented using intelligence provided by the EA flood warning service. The commitment is included in the REAC (document reference TR010035/APP/7.3).

9.3 Management of Residual Risks

Third Parties

9.3.1 Residual risks to third parties include:

- Potential for small and temporary increases in flood depths during construction. As discussed in Section 7.5, a floodplain compensation scheme would be implemented to reduce this risk as far as practicable
- Increase in flood depths during a significant tidal flood event – as discussed in Section 7.2, the increases in flood depths are on top of a significant depth of baseline inundation and any mitigation for such a serious incident would also address this small relative increase in flood depths

The Scheme

9.3.2 Residual risks to the Scheme include:

- Failure of the Skippool Tidal Flaps - this is considered unlikely due to their recent construction and an inspection / maintenance regime overseen by the EA. These structures are a designated critical flood defence asset
- Overtopping of the tidal defences - Section 6.4 discusses the potential for inundation of the Scheme due to tidal defence overtopping. Residual risk has been identified and although these residual risks cannot be designed out, as discussed above, implementation of a suitable flood warning scheme would ensure that danger to life is avoided
- Lack of maintenance of the Main Dyke Channel - the Main Dyke is an EA Main River and hence the responsibility for maintenance lies with this agency. Highways England should work in conjunction with the EA to ensure that maintenance is carried out
- Lack of maintenance of the proposed A585 alignment and associated drainage features - Highways England would adopt maintenance responsibility for all drainage features associated with the development

10 SUMMARY AND CONCLUSIONS

10.1.1 An FRA has been prepared to inform the design and Environmental Impact Assessment (EIA) of a proposed Improvement Scheme along the A585 between Windy Harbour and Skippool, in Lancashire.

10.1.2 The EA Flood Map for Planning (Rivers and Sea) shows that the majority of the Scheme is located in Flood Zone 1. However, a small portion of the Scheme between Windy Harbour Junction and the Grange Junction is located within Flood Zone 3 (land assessed as having a 1 in 100 or greater annual probability of river flooding (>1%) in any year). This source of flood risk has therefore been assessed in detail by bespoke hydraulic and hydrological modelling.

10.1.3 The Scheme is located in an area identified as at risk of tidal flooding. In order to quantitatively assess this risk, the Wyre Tidal model was obtained from the EA and enhanced for use in this FRA.

10.1.4 Additional sources of flood risk have also been reviewed within the FRA. It is considered that there is a limited risk of groundwater flooding and negligible risk of flooding from artificial sources to the Scheme.

10.1.5 The site is mostly at very low risk of surface water flooding and, with the implementation of a suitable surface water drainage strategy, the risk from surface water flooding would not increase across the Scheme. A suitable drainage design (shown in Appendix E and illustrated on the outline drainage works plans provided in document reference TR010035/APP/2.9) will be implemented to ensure that there will be no increase in surface water run-off from the Scheme to the local land drainage system and that there would be no increase in third party flood risk from this source.

10.1.6 A linked 1D2D model of the Horsebridge Dyke and Main Dyke has been developed in order to assess baseline fluvial flood risk and to enable an assessment of the potential impacts of the A585 Scheme on flood risk.

10.1.7 Model results demonstrate that the Scheme is not at risk of fluvial flooding from the Main Dyke or the Horsebridge Dyke during any of the modelled design events. When climate change is taken into account, the 1% AEP plus allowances of up to 70% do not result in flooding of the Scheme.

10.1.8 Incorporating the Scheme into the model demonstrates that replacing the existing Skippool Bridge culverts (2 1.8m diameter) with a 12.5m clear span bridge significantly reduces upstream flood extents in all modelled events.

10.1.9 Outfalls from the Main Dyke and Horsebridge Dyke are at risk of tide locking due to high tide levels in the River Wyre. Model results have demonstrated that the Scheme is not at risk of flooding during a tide locked scenario. Furthermore, the Scheme does not increase flood risk to third parties during a tide locked scenario.

10.1.10 The preferred construction methodology for the Scheme necessitates that the embankment is built before work to increase the capacity of the A585 crossing of the Main Dyke is commenced. Modelling of this scenario indicates that only minor increases in flood levels and extents would occur during smaller, more commonplace events and that these increases were constrained to open fields rather than property.

10.1.11 The EA requested that any increases in flood risk to third parties during construction be mitigated for all events up to and including the 1% AEP plus a 30% allowance for climate change. Initial modelling has shown that provision of some compensatory storage on the right bank of the Main Dyke immediately to the north of the A586 has the potential to reduce this risk and this work is included as items 98, 109, 110 and 111 on the Works Plans (document reference TR10035/APP/2.3). The mitigation strategy will be further refined as part of the next stage of design.

10.1.12 A qualitative assessment of flood risk from the Pool Foot Creek also indicates that the Scheme would not be at risk of fluvial flooding from this source.

10.1.13 The EA 2D only model of the River Wyre was enhanced and used to assess both the risk of tidal flooding to the Scheme and any change in tidal flood risk to third parties resulting from the Scheme, assuming that existing flood defences on the Wyre remain in place.

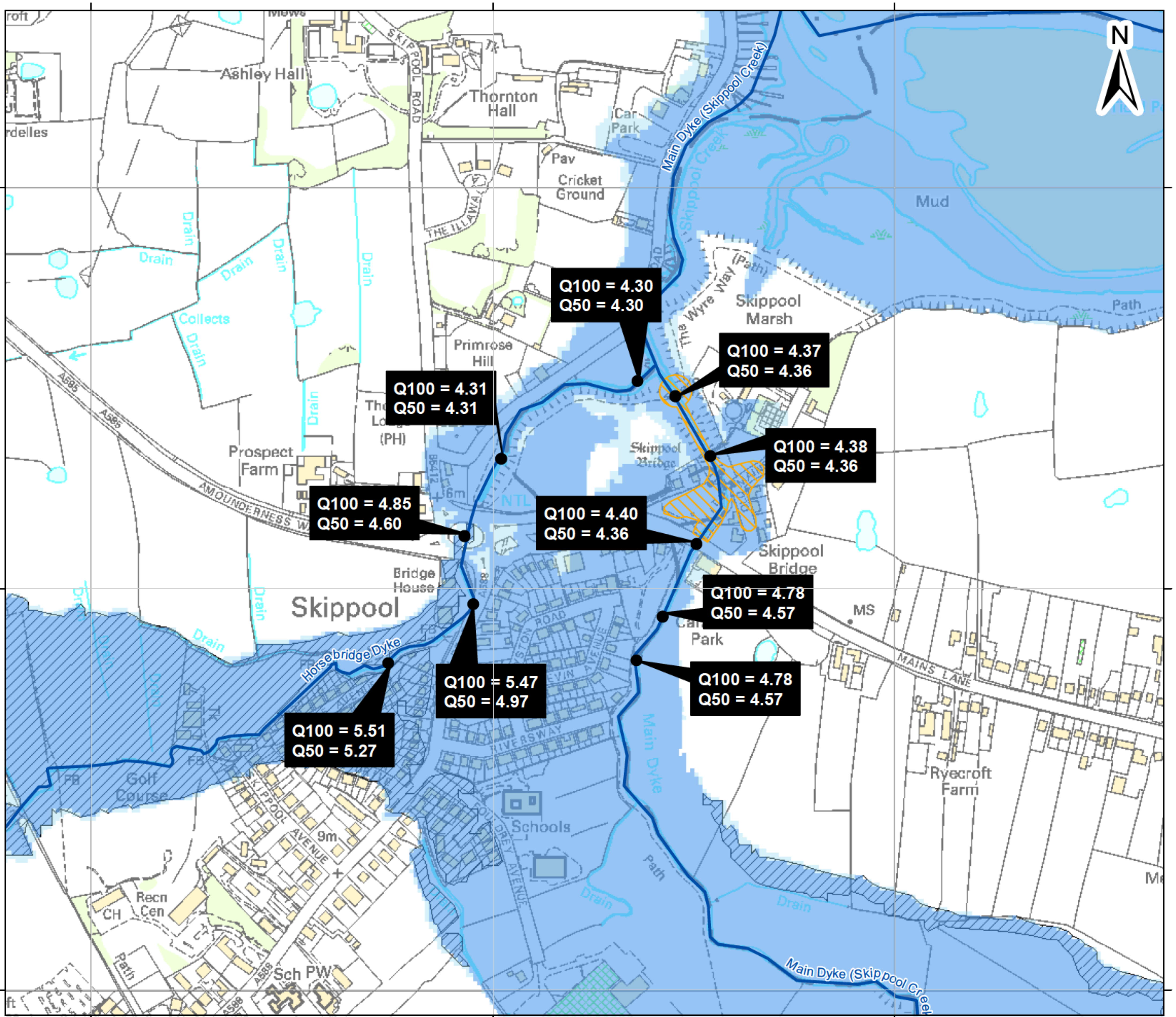
10.1.14 Model results from the enhanced tidal model (defended scenario) show that immediately east of Skippool Junction the Scheme is at risk of tidal flooding during a 0.5% AEP event with and without an allowance for climate change.

10.1.15 Results from the supplied (JBA) undefended scenario indicate that the Scheme would be at risk of flooding immediately east of Skippool Junction (0.5% AEP with and without climate change) and west of Windy Harbour Junction (south of Pool Foot Creek) (0.5% AEP plus climate change)

10.1.16 It is considered that the residual flood risks both to third parties as a result of the Scheme construction, and to the Scheme itself can be appropriately managed.

APPENDIX A – EA PRODUCT 4 DATA AND EA CORRESPONDENCE

Page Left Intentionally Blank



Fluvial Flood Level Map: A585, Skippool

Produced: 24 November 2015
Our Ref: CL5227HR
NGR: SD 35465 40565

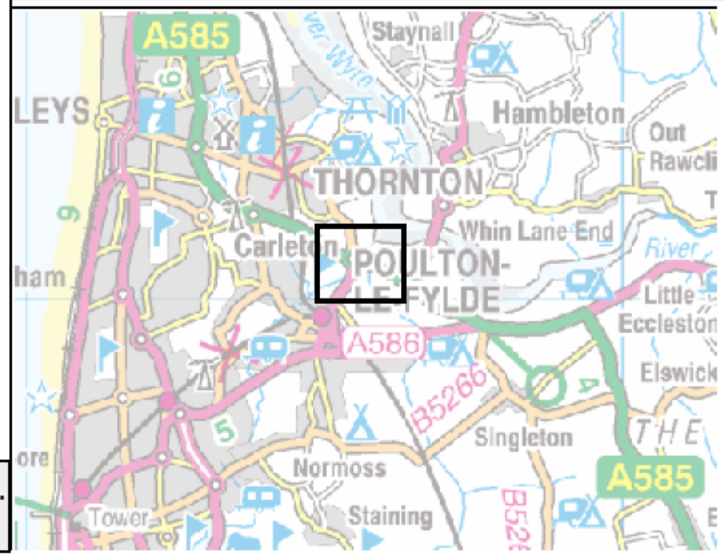
Key

- Main River
- Historic Flooding
- Flood Zone 3
- Flood Zone 2
- Areas Benefitting from Defences

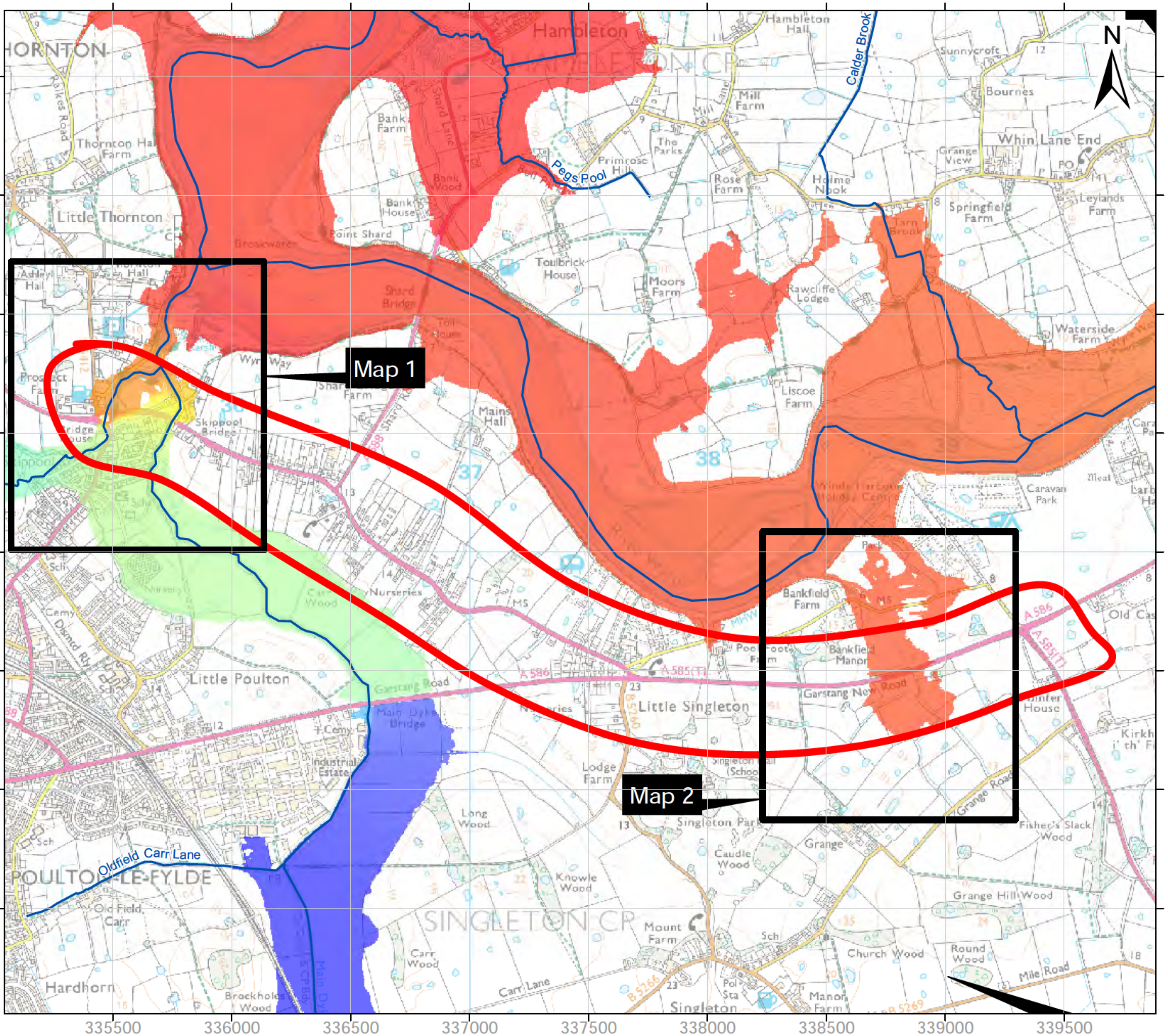
Flood Zone 3 shows the area that could be affected by flooding:
- from the sea with a 1 in 200 or greater chance of happening each year
- or from a river with a 1 in 100 or greater chance of happening each year.

Flood Zone 2 shows the extent of an extreme flood from rivers or the sea with up to a 1 in 1000 chance of occurring each year.

ABDs (Areas Benefiting from Defences) show the area benefiting from defences during a 1 in 200 tidal, or 1 in 100 fluvial flood event.



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



Environment Agency

Tidal Flood Level Map: Skippool - Windy Harbour

Produced: 25 November 2015
Our Ref: CL5227HR

Key

Main River

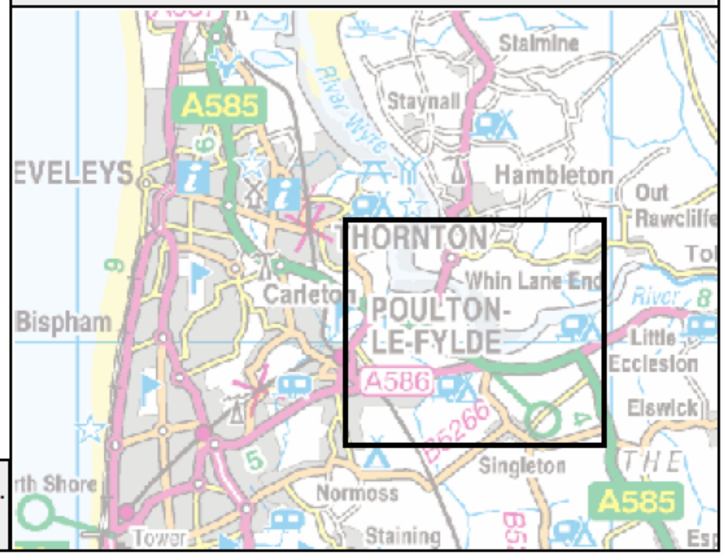
T200 + Climate Change Undefended

mAOD

High : 7.4

Low : 4.99

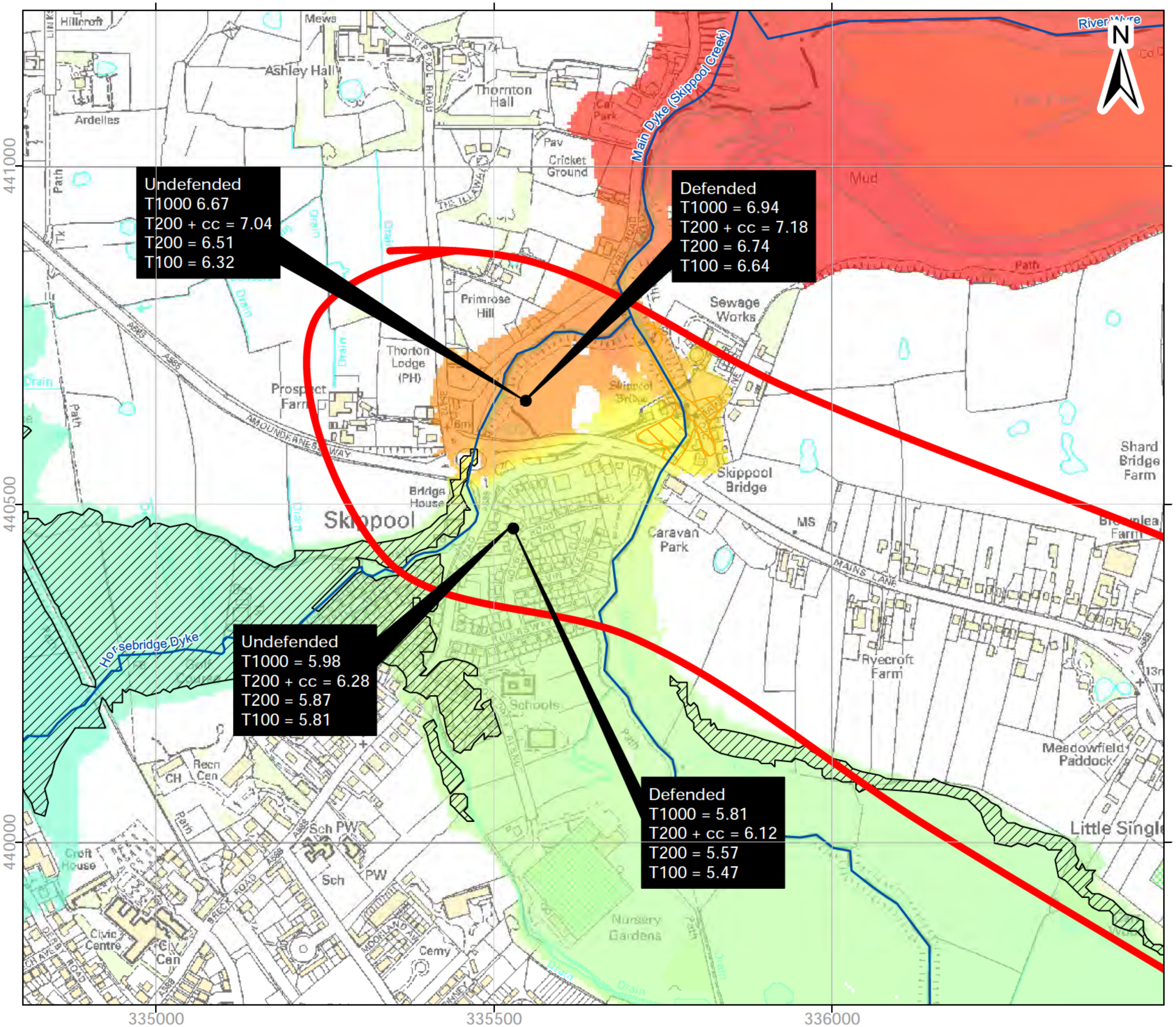
ABDs (Areas Benefiting from Defences) show the area benefiting from defences during a 1 in 200 tidal, or 1 in 100 fluvial flood event.



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

Tidal Flood Level Map: A585, Skippool

Produced: 25 November 2015
Our Ref: CL5227HR
NGR: SD 35536 40571



<u>Key</u>

- Main River
- Historic Flooding
- Areas Benefitting from Defences

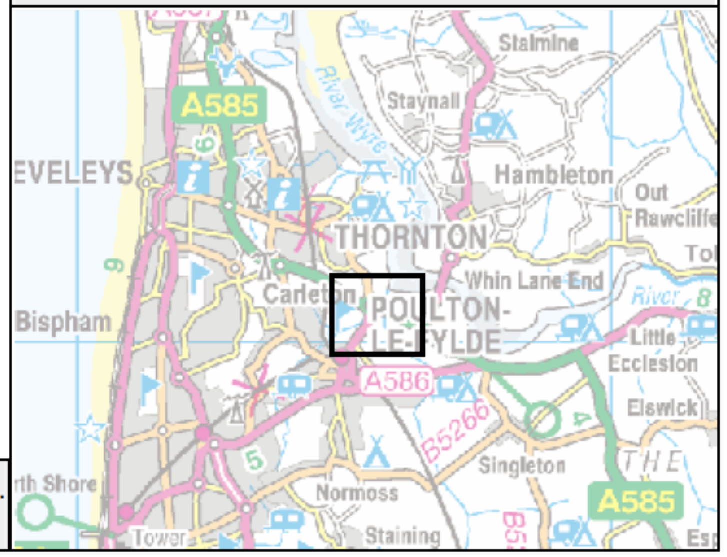
T200 + Climate Change Undefended

mAOD

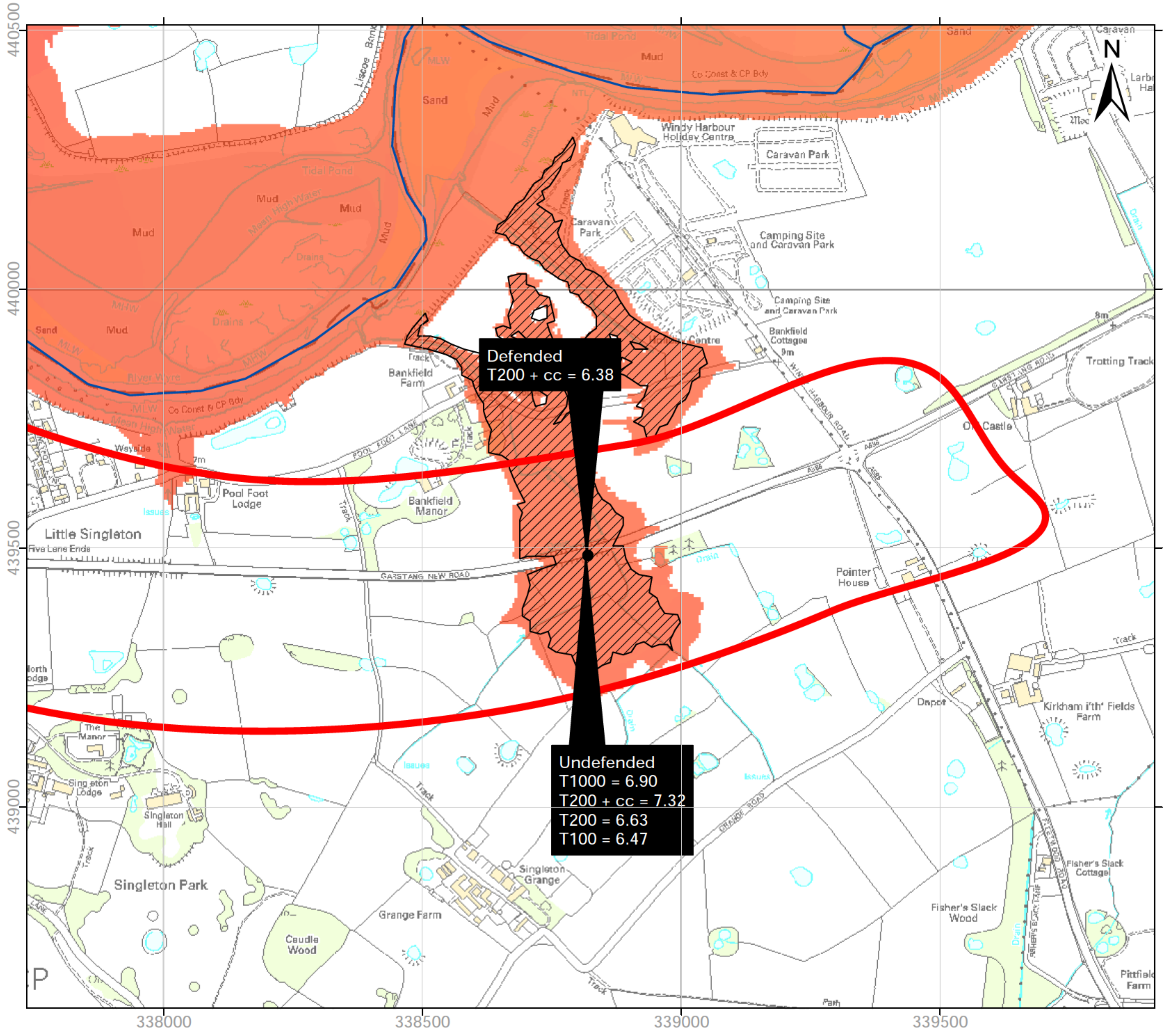
High : 7.4

Low : 4.99

ABDs (Areas Benefiting from Defences) show the area benefiting from defences during a 1 in 200 tidal, or 1 in 100 fluvial flood event.



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



Environment Agency

Tidal Flood Level Map: A585, Windy Harbour

Produced: 25 November 2015
Our Ref: CL5227HR
NGR: SD 38815 39480

Key

Main River

Areas Benefitting from Defences

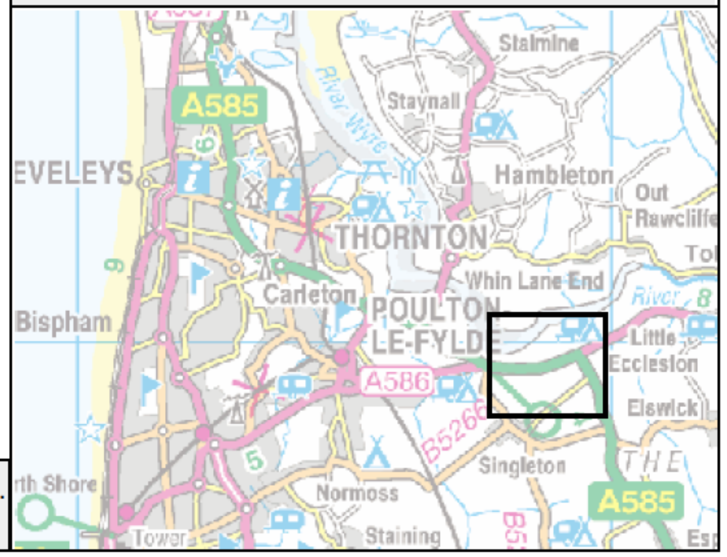
T200 + Climate Change Undefended

mAOD

High : 7.4

Low : 4.99

ABDs (Areas Benefiting from Defences) show the area benefiting from defences during a 1 in 200 tidal, or 1 in 100 fluvial flood event.



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

Lisa Driscoll

From: [redacted]
Sent: 12 January 2017 11:40
To: [redacted]
Subject: RE: A585 mod[redacted]ling study

Hello Lisa

The revised flows will be acceptable for the Flood Risk Assessment without the need for a detailed EA review. As you point out the increased flows for climate change will provide a much more conservative flood estimation.

With regards
Ian

From: [redacted]
Sent: 11 January 2017 14:44
To: [redacted]
Cc: [redacted]
Subject: A585 modelling study

Hello Ian

I am working with [redacted] on the A585 scheme and one of the actions that was agreed during one of your calls was for us to check our new design flow hydrology against the hydrology in the existing EA models of the Main and Horsebridge Dykes. Please see below a summary comparison table.

Flow Estimation Location	2 year flow - Arcadis	2 year flow – EA 2003	100 year flow - Arcadis	100 year flow –EA 2003
Main Dyke at DS limit	11.23	10.09	23.7	24.6
Horsebridge Dyke at DS limit	6.55	3.66	13.95	10.2

In the main our new flows are higher than the EA 2003 model flows, with the exception of a slightly lower flow at the 100yr on the Main Dyke. However, the scenario we are modelling is the 100 year plus climate change event, incorporating a +30% factor for CC (so arriving at a more conservative flow).

I light of these findings I was hoping you could agree that our design hydrology is acceptable without detailed EA review.

Kind Regards

Lisa

[redacted]
Arcadis | Arcadis House Cymru, Fortran Road, St Mellons Business [redacted], Cardiff | CF3 0EY | Wales
T. 02920 926742 | M. + 07947 221117
www.arcadis.com

ARCADIS Design & Consultancy for natural and built assets

Click here to report this email as spam

APPENDIX B – INITIAL MODEL REVIEW REPORT

Page Left Intentionally Blank

MEMO

ARCADIS Design & Consultancy for natural and built assets

SUBJECT
Main Drain and Horsebridge Dyke Hydraulic Model Review

DATE
23 March 2016

DEPARTMENT
Rivers Marine and Coastal

COPIES TO

TO

OUR REF
5000-UA008015-BMR-01

PROJECT NUMBER
UA008849

FROM
[redacted]
T [redacted]

A review of the Environment Agency (EA) hydraulic models of the Main Drain and Horsebridge Dyke has been carried out on behalf of Highways England. The objective of the review was to identify the work required to update and adapt these models to make them suitable for use to inform the design of the Southern Option of the A585 Improvement Scheme, including assessing the flood risk impacts of this Option.

The EA supplied separate ISIS models of the Main Drain and Horsebridge Dyke. These models were constructed in 2002/2003.

The model review findings are summarised under the headings 'Must Do' and 'Should Do'. It is recommended that both the 'Must Do' and 'Should Do' items be actioned in order to develop an appropriately robust baseline model.

Applicable to Both Models

Must Do

1) Panel Markers need to be added to the ISIS channel sections at points where the bank slope changes. At the moment they are predominantly located at the left and right banks which is creating jumps in the conveyance curve.
2) Glass walling and minor levees in the model cross sections need to be removed by creating a 1D-2D linked model which allows flows to spill onto the floodplain.
3) A review of the channel roughness should be carried out; justification for the choice of coefficients (with survey photos) is required.
4) The Main Drain and Horsebridge Dyke ISIS models should be linked in order to assess the interaction between the two watercourses dynamically. This will impact on the backwater effects experienced at the A585 / Breck Road roundabout, the A585 road bridge and on the combined floodplain to the south of the A585.
5) The combined model should be converted to a linked 1D - 2D model in order to improve the modelling of floodplain flows.
6) A detailed hydrological review is required to ensure that the latest flood flow estimation methods are taken into account. This review will also identify whether a single lumped inflow is appropriate or whether additional point / lateral inflows are required.

Should Do

7) A check survey would be useful to ensure that the 2002 data is fit for purpose and that no new structures have been constructed in the intervening period.

8) The supplied model is now 13 years old and therefore the Environment Agency / Lead Local Flood Authority should be consulted to determine if any new data is available for calibration of either the Main Drain or Horsebridge Dyke.

9) IED files have not been used to apply inflows and boundary conditions. This approach is not recommended.

10) Separate initial conditions files have not been used. This is not the recommended approach.

Main Drain

Must Do

11) The spill unit representing overtopping flows need to be added for the Mains Lane culvert and the bridge near the pumping station.

12) The two USPBR bridge units in the model need to be changed to Arch Bridges as this unit is hydraulically more appropriate for the situation being modelled.

13) The same HT (stage time) boundary is used as the downstream boundary condition for all the design events. This represents 24 hours of tidal data which has been extracted from a 'typical' spring tide cycle. Given that this analysis was carried out 13 years ago, it is recommended that further analysis is carried out to re-project the tide levels to the current day. It is also highlighted that the peak fluvial inflow currently coincides with the lowest tidal level. Additional discussion with the EA is recommended to ensure that the most appropriate combinations of inflow and tidal boundaries are being used.

14) The existing A585 crossing of the Main Drain is 373m upstream of the model downstream boundary. Sensitivity testing carried out on the downstream boundary (results supplied by the Environment Agency) indicated that effects of this were significant at the existing A585 bridge. This adds further weight to the requirement to improve the downstream boundary conditions used in the model.

15) The accompanying model report, supplied by the Environment Agency, states that *'the fluvial flow is allowed to flow through the tidal outfall when the water level in the river is higher than the tidal level in the estuary. The tidal outfall is closed when the tidal level is higher than the river water level'*. The model contains a sluice at the downstream boundary which has been modelled with a fixed opening of 2m. Data for the sluice should be located and used to improve the representation of the control mechanisms at the downstream extent of the Main Drain.

Horsebridge Dyke

Must Do

16) Some of the spill coefficients for the spill units representing the structure overtopping flow routes are not appropriate and require review and amendment.

17) The seven USPBR Bridge units in the model need to be changed to Arch Bridge units as this unit is hydraulically more appropriate for the situation being modelled.

18) A fixed stage of 4.3 mAOD has been used at the downstream boundary. This is not consistent with the boundary condition applied to the Main Drain and should be reviewed. Consultation with the Environment Agency will be required to determine the most appropriate set of downstream boundary conditions.

19) Based on the photos supplied in the model report, it is likely that some amendments will be required to the structures in 1D, although the extent of these amendments cannot be finalised as no survey data has been provided for the Horsebridge Dyke.

20) Photographs in the model report suggest that three structures are missing from the model;

HRBD02_3296 (footbridge downstream of A586 Garstang Road), HRBD02_0759 (Poulton Le Fylde golf course footbridge no. 2) and HRBD02_0180 (footbridge crossing no. 7 downstream of Skipool Avenue). It is recommended that these structures are added to the model.

Should Do:

21) Initial water levels are out of bank at the start of the simulation; this does not reflect reality and may result in the over estimation of flooding.

Conclusion

The Environment Agency models of the Main Dyke and Horsebridge Dyke are in excess of ten years old and significant advances in hydraulic and hydrological modelling software and methodologies have been made since these models were built. A number of actions are recommended to update the existing models to create a robust tool to both inform the design and assess the impacts of the Southern Option.

APPENDIX C – FEH CALCULATION RECORD

Page Left Intentionally Blank

Flood estimation calculation record

Introduction

This document is a supporting document to the Environment Agency's flood estimation guidelines. It provides a record of the calculations and decisions made during flood estimation. It will often be complemented by more general hydrological information given in a project report. The information given here should enable the work to be reproduced in the future. This version of the record is for studies where flood estimates are needed at multiple locations.

Contents

Approval

	Signature	Name and qualifications	For Environment Agency staff: Competence level (see below)
Calculations prepared by:	[redacted]	[redacted] Hydrologist MESci	Level 1
Calculations checked by:		[redacted] Senior Hydrologist BSc, MSc, MCIWEM, CWEM	Level 3
Calculations approved by:		[redacted] Senior Hydrologist BSc, MSc, MCIWEM, CWEM	Level 3

Environment Agency competence levels are covered in Section 2.1 of the flood estimation guidelines:

- Level 1 – Hydrologist with minimum approved experience in flood estimation
- Level 2 – Senior Hydrologist
- Level 3 – Senior Hydrologist with extensive experience of flood estimation

ABBREVIATIONS

AM	Annual Maximum
AREA	Catchment area (km^2)
BFI	Base Flow Index
BFIHOST	Base Flow Index derived using the HOST soil classification
CFMP	Catchment Flood Management Plan
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
POT	Peaks Over a Threshold
QMED	Median Annual Flood (with return period 2 years)
ReFH	Revitalised Flood Hydrograph 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

1 Method statement

1.1 Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: • Purpose of study • Approx. no. of flood estimates required • Peak flows or hydrographs? • Range of return periods and locations • Approx. time available	Arcadis Consulting Ltd. (Arcadis) have been commissioned by Highways England to undertake a hydrological assessment of the catchment of the Main Dyke and its main tributary the Horsebridge Dyke, to inform a Flood Risk Assessment for the proposed A585 Windy Harbour to Skippool Road Improvement Scheme, in Lancashire. Design flood hydrographs have been produced for the 2 year, 100 year, 100 year plus 30%, 35% and 70% Climate Change (CC) and 1000 year events. These flows will be routed through a hydraulic model of the watercourses to define baseline flood conditions and to represent the scheme, quantifying any impacts and identifying any mitigation measures required. These watercourses were last modelled by the Environment Agency in 2003 and both the EA hydrology and hydraulic model have been reviewed and updated using current best practice methodologies and available data.

1.2 Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	The study catchment and Flow Estimation Points (FEPs) have been schematised in Figure 1 (Annex 1). A total of 5 FEPs have been defined, to include 1 check point downstream of the confluence of the main channel of the Horsebridge Dyke and a small tributary at National Grid Reference (NGR) 334651, 440077. The FEP *'Add'* a small area of the Horsebridge Dyke catchment that is not represented on the FEH web service. Horsebridge Dyke flows to the Skippool Creek, a 587m length of Environment Agency (EA) Main River which drains into the River Wyre. The dyke itself consists of 5.16km of EA Main River and a non-Main River section of some 2.74km (downstream grid ref SD33703760, upstream SD33163619 at Stanley Park Lake). Approximately 300m of the Main River section is tidally affected, terminating near the Amounderness Way/Breck Road/Mains Lane road traffic roundabout. Main Dyke, also known as the Hillylaid Pool, also drains into the Wyre via the Skippool Creek. It drains an area from Marton Mere in Blackpool to its outfall at Skippool, a channel length of 10.62km which is all defined as Main River (downstream grid ref SD35724074, upstream SD33243536). Further information is provided in the A585 Skippool to Windy Harbour Flood Risk Assessment (Arcadis, 2016).

1.3 Source of flood peak data

Was the HiFlows UK dataset used? If so, which version? If not, why not? Record any changes made	Yes – Version 3.3.4 – August, 2014

1.4 Gauging stations (flow or level)

(at the sites of flood estimates or nearby at potential donor sites)

Water-course	Station name	Gauging authority number	NRFA number (used in FEH)	Grid reference	Catch-ment area (km²)	Type (rated / ultrasonic / level…)	Start and end of flow record
New Mill Brook	New Mill Brook @ Hollowforth Hall	-	72817	SD503364	31.9	Velocity Area	01/1972 to Date

1.5 Data available at each flow gauging station

Station name	Start and end of data in HiFlows-UK	Update for this study?	Suitable for QMED?	Suitable for pooling?	Data quality check needed?	Other comments on station and flow data quality – e.g. information from HiFlows-UK, trends in flood peaks, outliers.
New Brook Mill @ Hollowforth Hall	01/1972 to Date	-	Yes – gauged to around QMED	No – too much uncertainty once flows are out of bank.	-	The weir was primarily constructed as a low flow gauge and drowns out at a relatively low level. Large flows spill onto the right bank floodplain. Rating developed from gaugings, with modelled top-end to allow for bypassing / out of bank flow.
Give link/reference to any further data quality checks carried out	N/A					

1.6 Rating equations

Station name	Type of rating e.g. theoretical, empirical; degree of extrapolation	Rating review needed?	Reasons – e.g. availability of recent flow gaugings, amount of scatter in the rating.
N/A	-	-	-
Give link/reference to any rating reviews carried out	N/A		

1.7 Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available?	Source of data and licence reference if from EA	Date obtained	Details
Check flow gaugings (if planned to review ratings)	N/A	-	-	-	-
Historic flood data – give link to historic review if carried out.	Yes	Yes	Public consultation event	19/09/16	Anecdotal evidence of flooding from local residents gathered during a public consultation event. See Annex 4 for detail.
			EA Ref: CL5227HR	December 2015	Product 4 data pack including historical flood extent maps.

Flow data for events	Yes	No	-	-	-
Rainfall data for events	Yes	No	-	-	-
Potential evaporation data	N/A	-	-	-	-
Results from previous studies	Yes	Yes	Atkins (2003) Hydrologic Report River Wyre Catchment Flood Risk Mapping Investigation		This report informs the River Wyre Catchment Flood Risk Mapping Investigation and reports on the hydrology of the Horsebridge and Main Dykes.
			Persimmon Homes/Jones Homes (2015) Garstang Road East Flood Risk Assessment	November 2015	FRA in support of a residential development scheme located in the lower catchment of the Main Dyke, presenting hydraulic modelling results and flood mapping.
Other data or information (e.g. groundwater, tides)	N/A	-	-	-	-
			-	-	-

1.8 Initial choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	Flood Estimation Handbook (FEH) Statistical and rainfall runoff (ReFH) methods are considered appropriate. However, the catchments draining to FEP2, FEP3, FEP CheckA and FEP Add, are heavily urbanised (URBEXT1990>0.125). Application of the standard ReFH method is therefore not recommended on these catchments and the urban extension to the method has been applied to generate comparative suites of design flow estimates.
Outline the conceptual model, addressing questions such as: • Where are the main sites of interest? • What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides…) • Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir? • Is there a need to consider temporary debris dams that could collapse?	The main site of interest is the lower catchment of the Main/Horsebridge Dyke in the vicinity of the existing A585 road crossing. Situated within the low-lying tidal reaches of the River Wyre catchment, both watercourses drain by gravity, have limited gradients and are subject to tide locking in their lower reaches. Urban land use, which in particular dominates in the Horsebridge Dyke catchment also has an influence on the flood response.
Any unusual catchment features to take into account? e.g. • highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20% • highly urbanised – avoid standard ReFH if URBEXT1990>0.125; consider FEH Statistical	The watercourses are not pumped, are not defined as highly permeable and are not subject to major reservoir influence. However, the catchments are subject to tide locking and the watercourses are constrained by the surrounding urban developments of Flyde and Thornton.

or other alternatives; consider method that can account for differing sewer and topographic catchments • pumped watercourse – consider lowland catchment version of rainfall-runoff method • major reservoir influence (FARL<0.90) – consider flood routing • extensive floodplain storage – consider choice of method carefully	
Initial choice of method(s) and reasons Will the catchment be split into subcatchments? If so, how?	Neither of the subject watercourses are gauged for level or flow therefore flood estimation relies on catchment descriptor based equations and models. The initial choice is the FEH Statistical method, with comparative estimates generated from the ReFH method (urban extension as applicable to FEP2, FEP3, CheckA and FEP Add). The catchments of the subject watercourses have been split to reflect the hydraulic model schematisation and to generate inflows into the model at the required locations. Flow from the lumped catchment to FEP1 has been scaled to account for the proportional area of the catchment draining to the upstream model boundary along the Main Dyke, where an inflow input is required in the hydraulic model. The remainder of the total flow for the catchment will be input into the model as a lateral inflow between the upstream (US) and downstream (DS) model extents. For FEP3 (Horsebridge Dyke), the flow for the lumped catchment will be also apportioned according to the area draining to the US model extent and the DS boundary of the watercourse. Further details of the apportioning methodology is provided in Appendix Annex 3. Check A is a check point flow and does not represent an inflow to the hydraulic model.
Software to be used (with version numbers)	FEH Web Service WINFAP-FEH v3.0.003[1] / ReFH spreadsheet / ReFH Flood Modeller Pro

[1] WINFAP-FEH v3 © Wallingford HydroSolutions Limited and NERC (CEH) 2009.

2 Locations where flood estimates required

The table below lists the locations of subject sites. The site codes listed below are used in all subsequent tables to save space.

2.1 Summary of subject sites

Site code	Watercourse	Site	Easting	Northing	AREA on FEH CD-ROM (km^2)	Revised AREA if altered
FEP1	Main Dyke	Main Dyke between Main Dyke Bridge at Garstang Road and The Wyre Way	335714	440746	28.28	-
FEP2	Unnamed stream	Small tributary of the Horsebridge Dyke	334619	440096	0.94	-
FEP3	Horsebridge Dyke	Horsebridge Dyke between Garstang Road West and Croft House	334646	440063	9.54	-
CheckA	Confluence of the Unnamed stream and Horsebridge Dyke	-	334662	440090	10.48	-
Add		Direct catchment of the Horsebridge Dyke downstream of its confluence with the Main Dyke near Little Thornton.	355690	440780	-	1.66
Reasons for choosing above locations		These subject sites have been defined to represent inflows to the hydraulic model. N.B. Check flow FEPs do not represent inflows to the hydraulic model.				

2.2 Important catchment descriptors at each subject site (incorporating any changes made)

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT*	FPEXT
FEP1	0.97	0.41	0.45	6.24	16.80	924	39.10	0.1460	0.2478
FEP2	1.00	0.52	0.55	1.63	10.50	921	30.57	0.2256	0.3830
FEP3	0.97	0.41	0.35	4.53	16.80	907	40.63	0.3697	0.2166
CheckA	0.968	0.41	0.36	4.31	16.20	908	39.74	0.3449	0.2318
Add	1.00	0.42	0.42	4.97	8.50	910	33.20	0.2628	0.2329
**URBEXT2000 values updated to 2016*									

2.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	Catchment boundaries were checked using OS contour and LiDAR data and no changes to the FEH web service boundaries were required. However, the direct catchment represented by the 'Add' FEP, is not included on the FEH web service and the boundary of this catchment was therefore defined using OS contour and LiDAR data.

<table>
<tr><td>Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.</td><td>FEH descriptors describing catchment soils and geology (SPRHOST and BFIHOST) were checked with reference to Sheet 3 of the Soil Survey of England and Wales 1:250k Map.

Catchment descriptors were checked for the catchments draining to FEP1, FEP2, FEP3 and Check A and estimated for the FEP 'Add' using the methods outlined in the table below:

<table>
<tr><td>Descriptor</td><td>Method</td></tr>
<tr><td>SAAR</td><td>Value adopted as average of neighbouring adjacent FEH catchments</td></tr>
<tr><td>FARL</td><td>Visual checks on reservoirs and proportions on OS maps.
Equation 4.1 of FEH Vol 5</td></tr>
<tr><td>SPRHOST</td><td>Calculated following the method set out in the Institute of Hydrology Report No. 126</td></tr>
<tr><td>BFIHOST</td><td>As for SPRHOST</td></tr>
<tr><td>PROPWET</td><td>Value adopted as average of neighbouring adjacent catchments</td></tr>
<tr><td>DPSBAR</td><td>Calculated from LiDAR data</td></tr>
<tr><td>DPLBAR</td><td>Calculated using equation 7.1 FEH Vol 5*</td></tr>
<tr><td>URBEXT1990</td><td>Derived from URBAN50K in accordance with the methodology presented in the R&D Technical Report FD1919 (EA/DEFRA 2006)</td></tr>
<tr><td>URBEXT2000</td><td>As for URBEXT1990</td></tr>
</table>
*with sensibility checks undertaken using GIS</td></tr>
<tr><td>Source of URBEXT</td><td>URBEXT1990 (ReFH)/URBEXT2000 (FEH Statistical)</td></tr>
<tr><td>Method for updating of URBEXT</td><td>CPRE formula from FEH Volume 4</td></tr>
</table>

3 Statistical method

3.1 Search for donor sites for QMED (if applicable)

Comment on potential donor sites Mention: • Number of potential donor sites available • Distances from subject site • Similarity in terms of AREA, BFIHOST, FARL and other catchment descriptors • Quality of flood peak data Include a map if necessary. Note that donor catchments should usually be rural.	Donor sites were investigated for each of the subject catchments. A search radius of 35km was adopted (based on centroid distance) and one potential donor station was found: **72817 New Mill Brook @ Hollowforth Hall** – WINFAP highlights that this station is closest to the subject catchments, with a centroid distance of 18.91km. FEH guidelines stipulate that donor stations should, in most cases, be rural (even if the subject catchment is urbanised). The candidate donor catchment is rural (URBEXT2000 – 0.021) and is similar in terms of area and soil conditions (permeability) to the subject catchments and is within 20km by centroid distance. This station was therefore selected as a donor to inform flow estimation at FEP1, FEP3 and Check A. Owing to the small catchment size of FEP2 (0.94km^2) and FEP Add (1.66km^2), it is considered that the use of this donor station is not appropriate.

3.2 Donor sites chosen and QMED adjustment factors

NRFA no.	Reasons for choosing or rejecting	Method (AM or POT)	Adjustment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjustment ratio (A/B)
72817	See Section 3.1	AM	-	20.91	18.56	1.13
Which version of the urban adjustment was used for QMED at donor sites, and why? Note: The guidelines recommend great caution in urban adjustment of QMED on catchments that are also highly permeable (BFIHOST>0.8).				Kjeldsen (2010)		

3.3 Overview of estimation of QMED at each subject site

Site code	Method	Initial estimate of QMED rural (m^3/s)	Data transfer: NRFA numbers for donor sites used (see 3.3)	Data transfer: Distance between centroids d_{ij} (km)	Data transfer: Power term, a	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 average adjustment factor	Final estimate of QMED* (m^3/s)
FEP1	DT	9.14	72817	18.91	0.32	1.04	-	-	11.23
FEP2	CD	0.41	-	-	-	-	-	-	0.57

Site code	Method	Initial estimate of QMED rural (m^3/s)	Data transfer						Final estimate of QMED* (m^3/s)
			NRFA numbers for donor sites used (see 3.3)	Distance between centroids d_{ij} (km)	Power term, a	Moderated QMED adjustment factor, $(A/B)^a$	If more than one donor: Weight	If more than one donor: Weighted average adjustment factor	
FEP3	DT	4.35	72817	21.73	0.30	1.04	-	-	6.15
CheckA	DT	4.63	72817	21.61	0.30	1.04	-	-	6.55
Add	CD	0.95	-	-	-	-	-	-	1.26

*Urban adjusted to 2016

Are the values of QMED consistent, for example at successive points along the watercourse and at confluences?	Yes, QMED is consistent, increasing at the check flows downstream of confluences.
Which version of the urban adjustment was used for QMED, and why?	Kjeldsen (2010)

Notes

Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer; CD – Catchment descriptors alone.

When QMED is estimated from POT data, it should also be adjusted for climatic variation. Details should be added.

When QMED is estimated from catchment descriptors, the revised 2008 equation from Science Report SC050050Error! Bookmark not defined. should be used. If the original FEH equation has been used, say so and give the reason why.

The guidelines recommend great caution in urban adjustment of QMED on catchments that are also highly permeable (BFIHOST>0.8). The adjustment method used in WINFAP-FEH v3.0.003 is likely to overestimate adjustment factors for such catchments. In this case the only reliable flood estimates are likely to be derived from local flow data.

The data transfer procedure is from Science Report SC050050. The QMED adjustment factor A/B for each donor site is given in Table 3.3. This 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 estimate from catchment descriptors.

If more than one donor has been used, use multiple rows for the site and give the weights used in the averaging. Record the weighted average adjustment factor in the penultimate column.

3.4 Derivation of pooling groups

The composition of the pooling groups is given in the Annex 2. All subject sites have used the same pooling group, based on that formed for FEP3, as it was determined there was no significant difference in the default pooling group compositions. The table below summarises the changes made to the default pooling group composition.

Name of group	**Site code from whose descriptors group was derived**	**Subject site treated as gauged?** (enhanced single site analysis)	**Changes made to default pooling group, with reasons** Note also any sites that were investigated but retained in the group.	**Weighted average L-moments**, L-CV and L-skew, (before urban adjustment)

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (enhanced single site analysis)	Changes made to default pooling group, with reasons Note also any sites that were investigated but retained in the group.	Weighted average L-moments, L-CV and L-skew, (before urban adjustment)
Pool1	FEP3	P	The default pooling group has 17 stations and 520 station years of data. A review of WINFAP-FEH highlights that the default pooling group is heterogenous (H2=3.9776) and a review of the pooling group is desirable. The following stations were removed from the pooling group: **49006 Camel @ Camelford** –short record of data. **47022** [redacted] **@ Newnham Park** –rapid response of catchment to storm events and significant china clay mining in the catchment which has altered the local hydrology. **44008 South Winterbourne @ Winterbourne Steepleton** –significant bypassing at this station. **72014 Condor @ Galgate** – station subject to drowning. **28033 Dove @ Hollinsclough** –difficulty in gauging at higher flows, potential underestimation of high flows at this station. The following stations were added to the pooling group: **48004 Warleggan @Trengoffe** **206006 Annalong @ Recorder** **27010 Hodge Beck @ Bransdale Weir** The modified pooling group has 15 stations and 515 station years of data. WINFAP-FEH suggests that the pooling group remains heterogeneous (H2=2.1694) and a review is still desirable. However, it is considered that no further modifications would be made to the pooling group.	L-SKEW:0.195 L-CV: 0.23
Notes Pooling groups were derived using the revised procedures from Science Report SC050050 (2008). The weighted average L-moments, before urban adjustment, can be found at the bottom of the Pooling-group details window in WINFAP-FEH.				

3.5 Derivation of flood growth curves at subject sites

Site code	Method (SS, P, ESS, J)	If P, ESS or J, name of pooling group (3.4)	Distribution used and reason for choice	Note any urban adjustment or permeable adjustment	Parameters of distribution* (location, scale and shape)	Growth factor for 100-year return period**
FEP3	P	-	GL – WINFAP recommended	Urban Adjustment – Kjedlsen, 2010	Location: 1.00 Scale:0.233 Shape: -0.195	2.13
FEP1	P	-	GL – WINFAP recommended	Urban Adjustment – Kjedlsen, 2010	-	2.10

Site code	Method (SS, P, ESS, J)	If P, ESS or J, name of pooling group (3.4)	Distribution used and reason for choice	Note any urban adjustment or permeable adjustment	Parameters of distribution* (location, scale and shape)	Growth factor for 100-year return period**
FEP2	P	-	GL – WINFAP recommended		-	2.78
Check A	P	-	GL – WINFAP recommended	Urban Adjustment – Kjedlsen, 2010	-	2.13
Add	P	-	GL – WINFAP recommended	Urban Adjustment – Kjedlsen, 2010		2.13

*Rural Parameters of distribution for FEP3 only as urban adjustment not made in WINFAP

**100 year growth factor following urban adjustment

Notes

Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis

A pooling group (or ESS analysis) derived at one gauge can be applied to estimate growth curves at a number of ungauged sites. Each site may have a different urban adjustment, and therefore different growth curve parameters.

Urban adjustments to growth curves should use the version 3 option in WINFAP-FEH: Kjeldsen (2010).

Growth curves were derived using the revised procedures from Science Report SC050050 (2008).

3.6 Flood estimates from the statistical method

Site code	Flood peak (m^3/s) for the following return periods (in years)					
	2yr	100yr	100yr +CC (30%)	100yr +CC (35%)	100yr +CC (70%)	1000yr
FEP1	11.23	23.60	30.68	31.86	40.12	28.20
FEP2	0.57	1.59	2.07	2.15	2.70	2.84
FEP3	6.15	13.09	17.02	17.67	22.25	19.79
Check A	6.55	13.95	18.14	18.83	23.72	21.10
Add	1.26	2.68	3.48	3.62	4.56	4.05

4 Revitalised flood hydrograph (ReFH) method

Note: [1]The Urban Extension to the ReFH method has been applied to the below FEPs in line with best practice guidelines (EA, 2015).

4.1 Parameters for ReFH model

Note: If parameters are estimated from catchment descriptors, they are easily reproducible so it is not essential to enter them in the table.

Site code	Method: OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	Tp (hours) Time to peak	C_{max} (mm) Maximum storage capacity	BL (hours) Baseflow lag	BR Baseflow recharge
FEP1	CD	4.02	346.13	30.45	1.15
FEP2[1]	CD	0.39	395.60	-	1.55
FEP3[1]	CD	0.84	272.62	-	0.88
CheckA[1]	CD	0.94	282.97	-	0.91
Add[1]	CD	2.19	322.30	-	1.08
Brief description of any flood event analysis carried out (further details should be given below or in a project report)		N/A			

4.2 Design events for ReFH method

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)
FEP1	Rural	Winter	7.5	-
FEP2	Urban	Summer	7.5	-
FEP3	Urban	Summer	7.5	-
Check A	Urban	Summer	7.5	-
Add	Urban	Summer	7.5	-
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?			No – a uniform storm duration has been modelled, representative of the recommended duration for the lumped catchments of the Main and Horsebridge dykes.	

4.3 Flood estimates from the ReFH method

Site code	Flood peak (m^3/s) for the following return periods (in years)					
	2	100	100+30% CC	100+35% CC	100+70% CC	1000
FEP1	9.89	23.41	30.43	31.60	39.80	39.55
FEP2	0.95	2.50	3.25	3.38	4.25	4.30
FEP3	6.61	24.79	32.23	33.47	42.14	42.32
Check A	9.18	24.05	31.27	32.47	40.89	41.01
Add	1.03	2.70	3.51	3.65	4.59	4.79

5 Discussion and summary of results

5.1 Comparison of results from different methods

This table compares peak flows from various methods with those from the FEH Statistical method at example sites for two key return periods. Blank cells indicate that results for a site were not calculated using that method.

Site code	Ratio of peak flow to FEH Statistical peak					
	Return period 2 years			Return period 100 years		
	ReFH			ReFH		
FEP1	0.88			0.99		
FEP2	1.67			1.57		
FEP3	1.07			1.89		
Add	0.82			1.01		

5.2 Final choice of method

Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.	Study catchments are not gauged for flow and whilst a donor was identified to inform the FEH Statistical method, this donor was located fairly distantly from the subject catchments, therefore its influence was reduced by the distance weighting factor. Uncertainty in the estimated flows is therefore relatively high. As indicated in Table 5.1 comparative flows from the FEH Statistical and ReFH methods compare closely at FEP1 and Add, which are both more rural catchments, where the 'standard' ReFH model is applicable. The degree of urbanisation in catchments draining to FEPs 2 and 3 triggers application of the urban extension to the ReFH method, which in these catchments has produced higher flow estimates than the FEH Statistical method. Given the uncertainty, it is recommended that flows from the FEH Statistical method are adopted for FEP1 and ReFH flows adopted for the remaining FEPs.

5.3 Checks

What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)	100 year growth factors range from 2.1 (FEH Stat at FEP1) to 2.6 (ReFH urban extension at FEPs 2 and Add) to 3.7 at FEP 3 and are within the typical range.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	Ratios range from 1.2 (FEH Stat at FEP1) to 1.7 (ReFH urban extension at FEPs 2 and 3).
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	Specific runoff rates at the 100 year return period range from 8.3l/s/ha (FEP1) to approximately 26l/s/ha at FEPs 2 and 3, which represent the most urban sub-catchments.
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	Flow estimates have been compared with the flows that were routed through the EA Wyre Catchment Flood Risk Mapping Investigation model (2003). As illustrated in the table below the contemporary flow estimates are higher than the 2003 flows, with the exception of a slightly lower flow at the 100yr on the Main Dyke. This comparison has been presented to the EA and confirmation has been received that the flow estimates from this current study are acceptable for use in informing the A585 Flood Risk Assessment (see Annex 6.5)

Location	2 yr Flow Arcadis	2 yr Flow EA 2003	100 yr Flow Arcadis	100 yr Flow EA 2003
Main Dyke	11.23	10.09	23.7	24.6

	downstream				
	Horsebridge Dyke downstream	6.55	3.66	13.95	10.20

5.4 Final Results

Site code	Flood peak (m^3/s) for the following return periods (in years)							
	2	100	100+30% CC	100+35% CC	100+70% CC	1000		
FEP1	11.23	23.60	30.68	31.86	40.12	28.20		
FEP2	0.95	2.50	3.25	3.38	4.25	4.30		
FEP3	6.61	24.79	32.23	33.47	42.14	42.32		
Add	1.03	2.70	3.51	3.65	4.59	4.79		

If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, name of ISIS model, or reference to table below)	

6 Annex - supporting information

6.1 Catchment Delineation

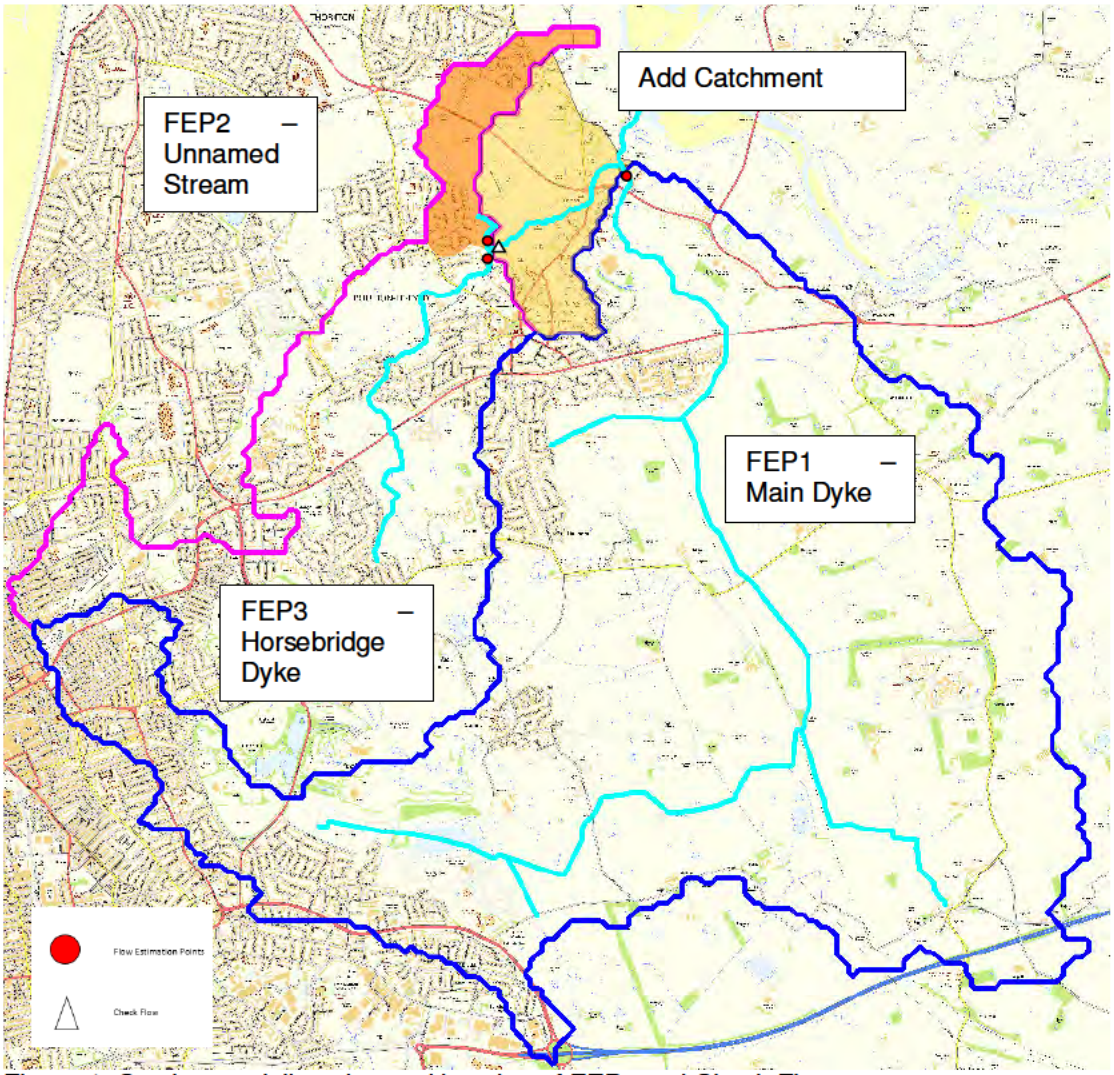


Figure 1: Catchment delineation and location of FEPs and Check Flow

6.2 Pooling Group Composition

DEFAUT POOLING GROUP

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
27073 (Brompton Beck @ Snainton Ings)	0.592	32	0.813	0.197	-0.022	0.386
20002 (West Peffer Burn @ Luffness)	1.892	41	3.299	0.292	0.015	1.774
203046 (Rathmore Burn @ Rathmore Bridge)	2.038	30	10.934	0.136	0.091	1.47
72014 (Conder @ Galgate)	2.221	45	17.703	0.193	0.059	0.274

26802 (Gypsey Race @ Kirby Grindalythe)	2.236	13	0.109	0.261	0.199	0.492
27051 (Crimple @ Burn Bridge)	2.297	40	4.539	0.222	0.149	0.344
73015 (Keer @ High Keer Weir)	2.306	21	12.239	0.156	0.001	0.693
25019 (Leven @ Easby)	2.312	34	5.538	0.347	0.394	0.818
49003 (de Lank @ de Lank)	2.351	46	13.559	0.232	0.241	0.426
47022 (Tory Brook @ Newnham Park)	2.37	19	7.331	0.257	0.071	0.47
45816 (Haddeo @ Upton)	2.416	19	3.456	0.324	0.434	0.708
41020 (Bevern Stream @ Clappers Bridge)	2.424	43	13.49	0.214	0.208	0.906
25003 (Trout Beck @ Moor House)	2.443	39	15.164	0.176	0.291	1.156
28033 (Dove @ Hollinsclough)	2.48	33	4.666	0.266	0.415	0.72
49006 (Camel @ Camelford)	2.485	6	8.832	0.11	-0.293	2.624
25011 (Langdon Beck @ Langdon)	2.502	26	15.878	0.241	0.326	1.929
44008 (South Winterbourne @ Winterbourne Steepleton)	2.505	33	0.42	0.395	0.332	1.81
Total		520				
Weighted means				0.237	0.188	

FINAL POOLING GROUP

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
27073 (Brompton Beck @ Snainton Ings)	0.592	32	0.813	0.197	-0.022	1.239
20002 (West Peffer Burn @ Luffness)	1.892	41	3.299	0.292	0.015	2.252
203046 (Rathmore Burn @ Rathmore Bridge)	2.038	30	10.934	0.136	0.091	1.105
26802 (Gypsey Race @ Kirby Grindalythe)	2.236	13	0.109	0.261	0.199	0.273
27051 (Crimple @ Burn Bridge)	2.297	40	4.539	0.222	0.149	0.83
73015 (Keer @ High Keer Weir)	2.306	21	12.239	0.156	0.001	0.796
25019 (Leven @ Easby)	2.312	34	5.538	0.347	0.394	1.443
49003 (de Lank @ de Lank)	2.351	46	13.559	0.232	0.241	0.524
45816 (Haddeo @ Upton)	2.416	19	3.456	0.324	0.434	1.152
41020 (Bevern Stream @ Clappers Bridge)	2.424	43	13.49	0.214	0.208	0.458
25003 (Trout Beck @ Moor House)	2.443	39	15.164	0.176	0.291	1.142
25011 (Langdon Beck @ Langdon)	2.502	26	15.878	0.241	0.326	1.704
27010 (Hodge Beck @ Bransdale Weir)	2.519	41	9.42	0.224	0.293	0.323
206006 (Annalong @ Recorder)	2.532	48	15.33	0.189	0.052	1.347
48004 (Warleggan @ Trengoffe)	2.603	43	9.799	0.268	0.287	0.412

Total	516		
Weighted means		0.23	0.195

6.3 Additional supporting information – Apportioning of Flows

Flow from the lumped catchment to FEP1 has been scaled to account for the proportional area of the catchment draining to the US model boundary along the Main Dyke, where an inflow input is required in the hydraulic model.
The remainder of the total flow for the catchment will be put into the model as a lateral inflow between the upstream (US) and downstream (DS) model extents for this watercourse.

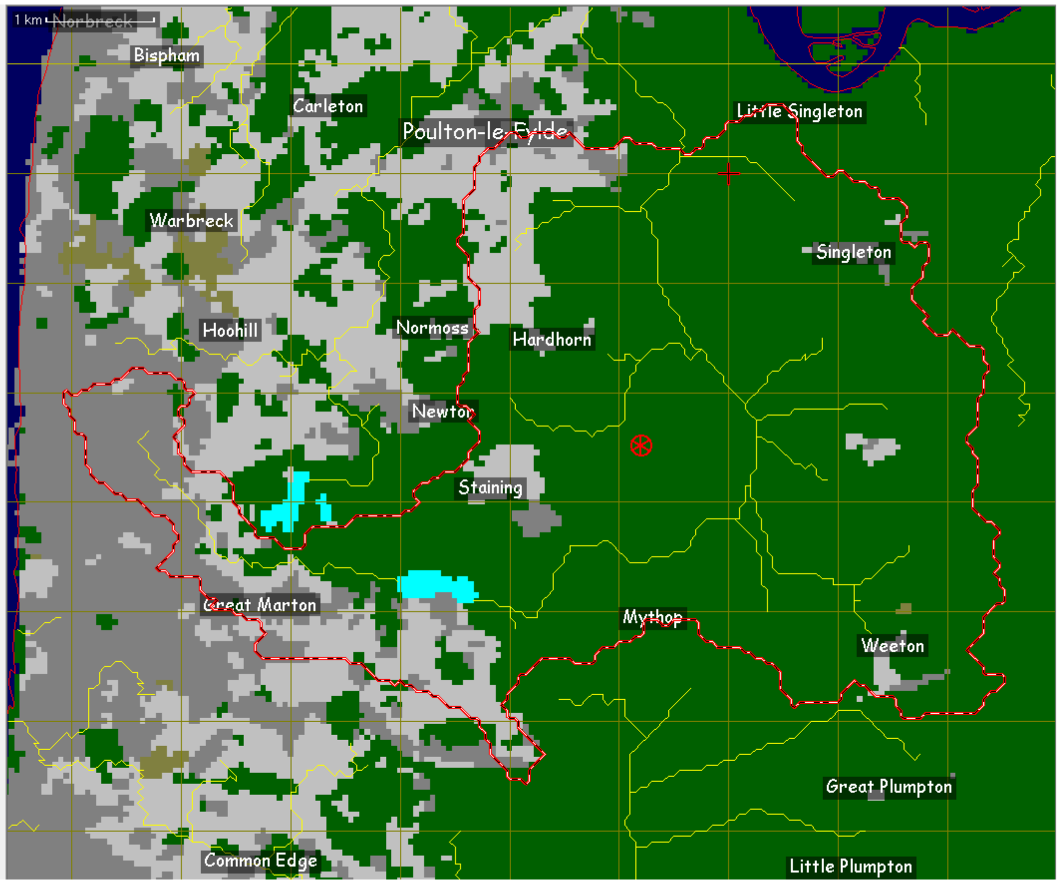


Image 1 – FEH CD-ROM Catchment draining to the US model extent of the Main Dyke. The catchment area totals 26.43km^2. As a proportion of the total catchment to the DS extent of the watercourse, this is equal to 95%.
Therefore, the modelled inflows are as follows for the Main Dyke:

FEP1	**FEH Statistical Flows (m^3/s)**	
Return Period (Years)	***US inflow***	***Lateral***
2	10.67	0.56
100	22.42	1.18
100+30% CC	29.15	1.53

100+35% CC	30.27	1.59
100+70% CC	38.11	2.01
1000	26.79	1.41

For FEP3 (Horsebridge Dyke), the flow for the lumped catchment has also been apportioned according to the area draining to the US model extent and the DS boundary of the watercourse.

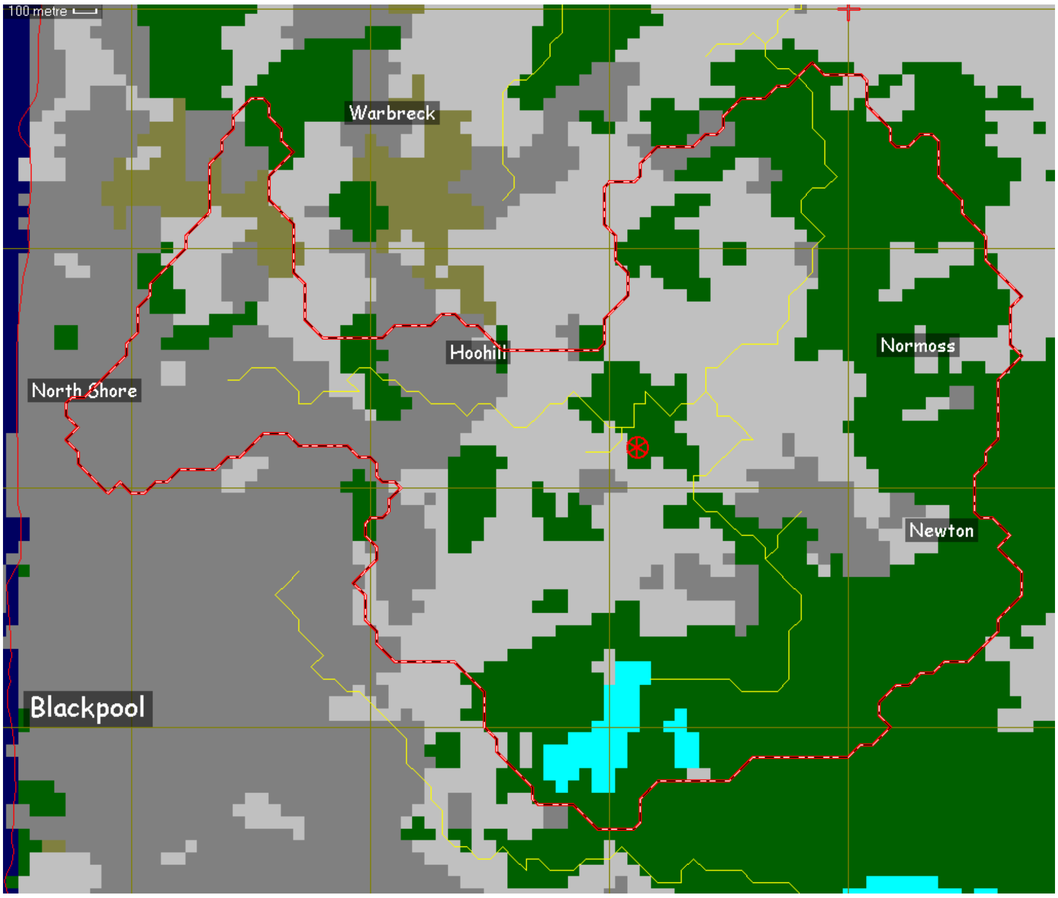


Image 2 - FEH CD-ROM Catchment draining o the US model extent of the Horsebridge Dyke. The catchment area totals 6.79km^2. As a proportion of the total catchment to the DS extent of the watercourse, this is equal to approximately 70%.

6.4 Additional supporting information – Anecdotal Flooding Information

Anecdotal Flooding Information from Public Consultation: A number of people referred to flooding along the Main Dyke being severe and extending quite far south. Apparently this has improved a lot since the tidal gates were installed but they believe that a lack of maintenance of the Dyke in certain stretches is a problem. The Dyke is very narrow and overgrown south of Little Singleton but widens out further south.

6.5 Environment Agency Correspondence

From: [redacted]
Sent: 12 January 2017 11:40

To: [redacted]
Subject: RE: A585 modelling study

Hello Lisa

The revised flows will be acceptable for the Flood Risk Assessment without the need for a detailed EA review. As you point out the increased flows for climate change will provide a much more conservative flood estimation.

With regards
Ian

From: [redacted]
Sent: 11 January 2017 14:44
To: [redacted]
Cc: [redacted]
Subject: A585 modelling study

Hello Ian

I am working with Claire Gibson on the A585 scheme and one of the actions that was agreed during one of your calls was for us to check our new design flow hydrology against the hydrology in the existing EA models of the Main and Horsebridge Dykes. Please see below a summary comparison table.

Flow Estimation Location	2 year flow - Arcadis	2 year flow – EA 2003	100 year flow - Arcadis	100 year flow –EA 2003
Main Dyke at DS limit	11.23	10.09	23.7	24.6
Horsebridge Dyke at DS limit	6.55	3.66	13.95	10.2

In the main our new flows are higher than the EA 2003 model flows, with the exception of a slightly lower flow at the 100yr on the Main Dyke. However, the scenario we are modelling is the 100 year plus climate change event, incorporating a +30% factor for CC (so arriving at a more conservative flow).

I light of these findings I was hoping you could agree that our design hydrology is acceptable without detailed EA review.

Kind Regards

Lisa

[redacted] | Principal Hydrologist | [redacted]
Arcadis | Arcadis House Cymru, Fortran Road, St Mellons Business Park, Cardiff | CF3 0EY | Wales
T. 02920 926742 | M. + 07947 221117
www.arcadis.com

ARCADIS Design & Consultancy for natural and built assets

Be green, leave it on the screen.

APPENDIX D – HYDRAULIC MODEL RESULTS

Page Left Intentionally Blank

Figure D1 – Figure D11: Baseline and Option Flood Extents

Figure D12 – Figure D22: Baseline and Option Difference Grids

Figure D23 – Figure D33: Construction Phasing and Baseline Difference Grids

Figure D34 – Figure D44: Tide Locked Baseline and Option Flood Extents

Figure D45 – Figure D46: Tidal Model Flood Extents

Figure D47 – Figure D48: Tidal Model Difference Grids

Figure D49: Mitigation Scenario and Baseline Difference Grids

Baseline and Option Flood Extents

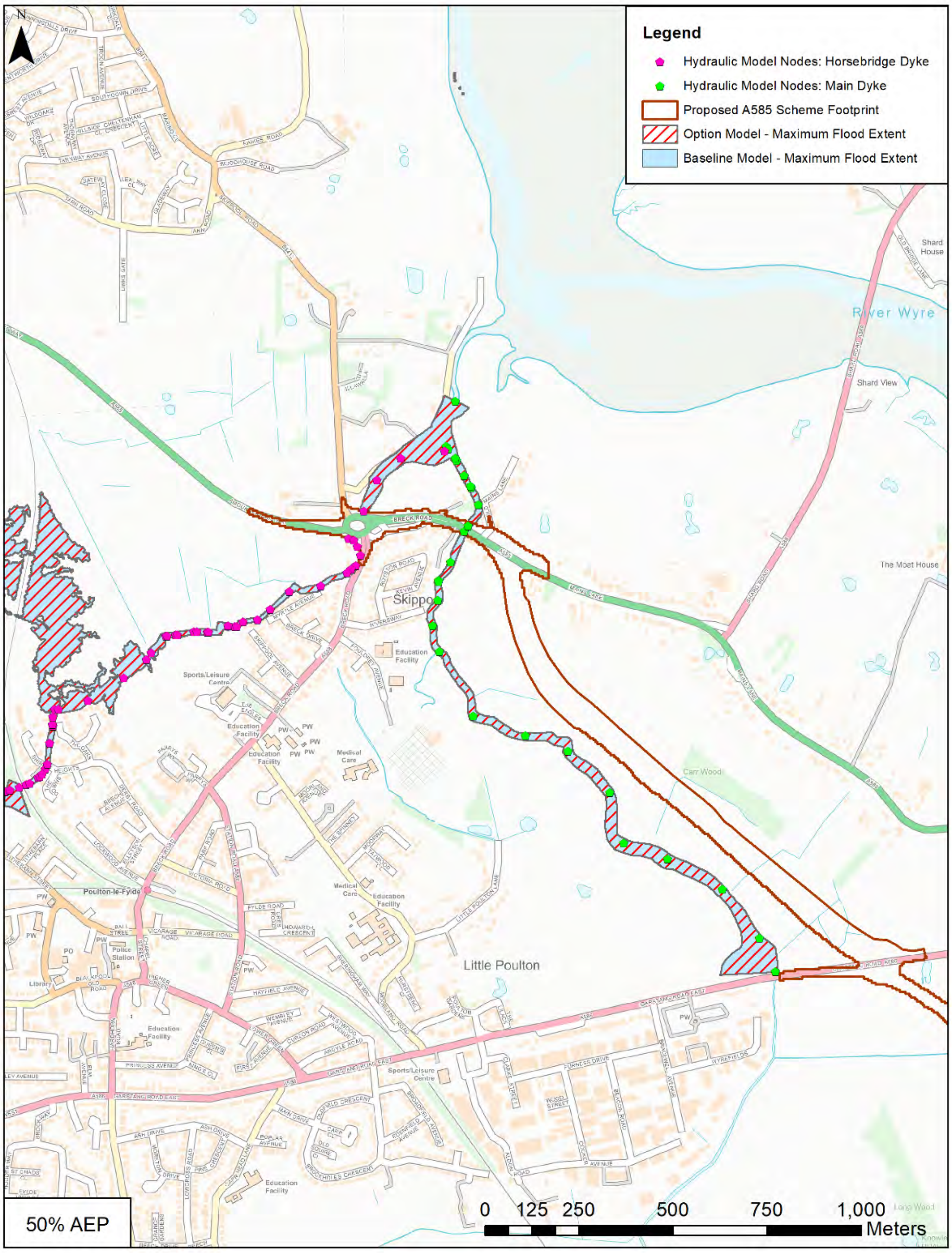


Figure D1 - Maximum flood extents [Baseline and 'With Scheme' (Option)] for the 50% AEP flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

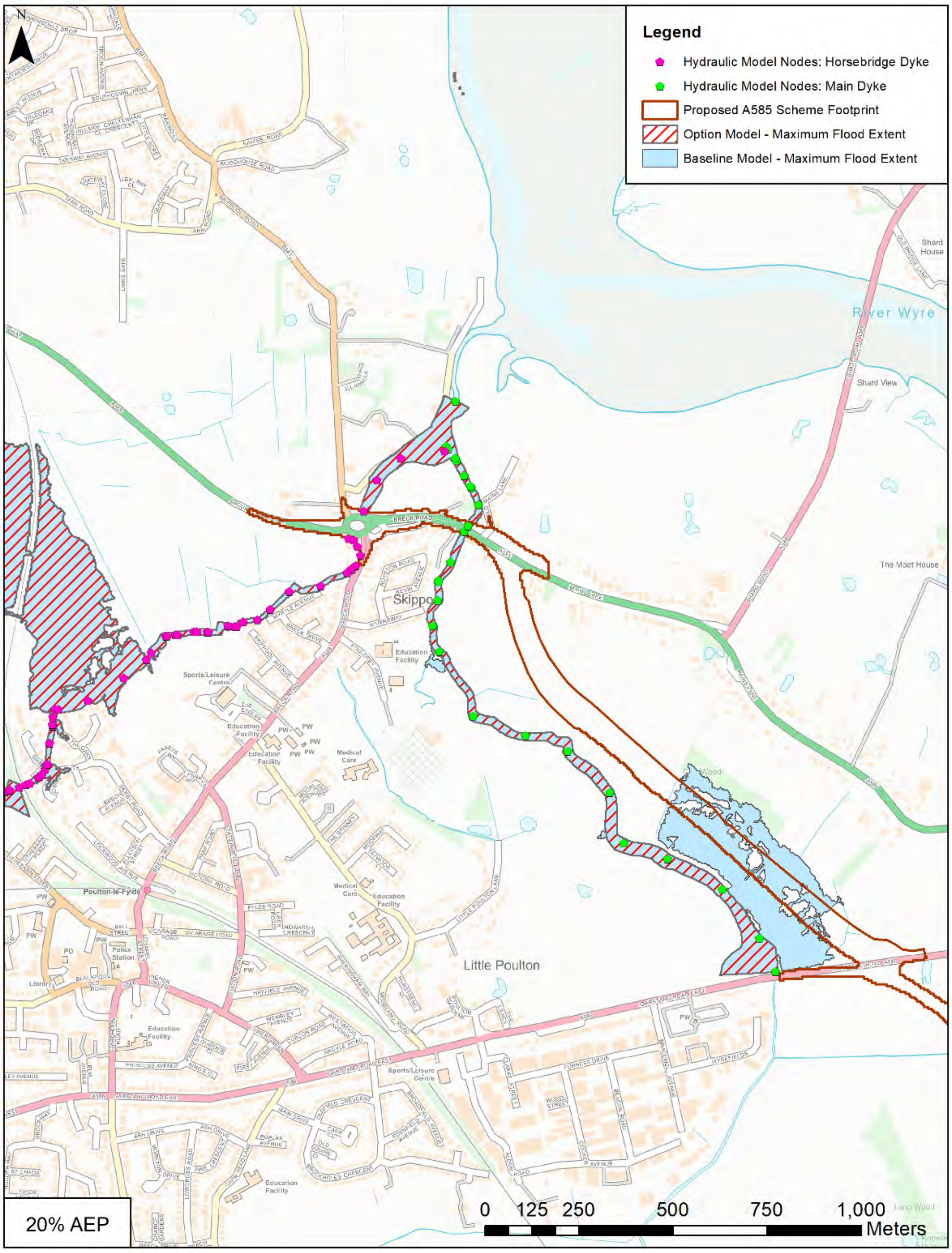


Figure D2 - Maximum flood extents [Baseline and 'With Scheme' (Option)] for the 20% AEP flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

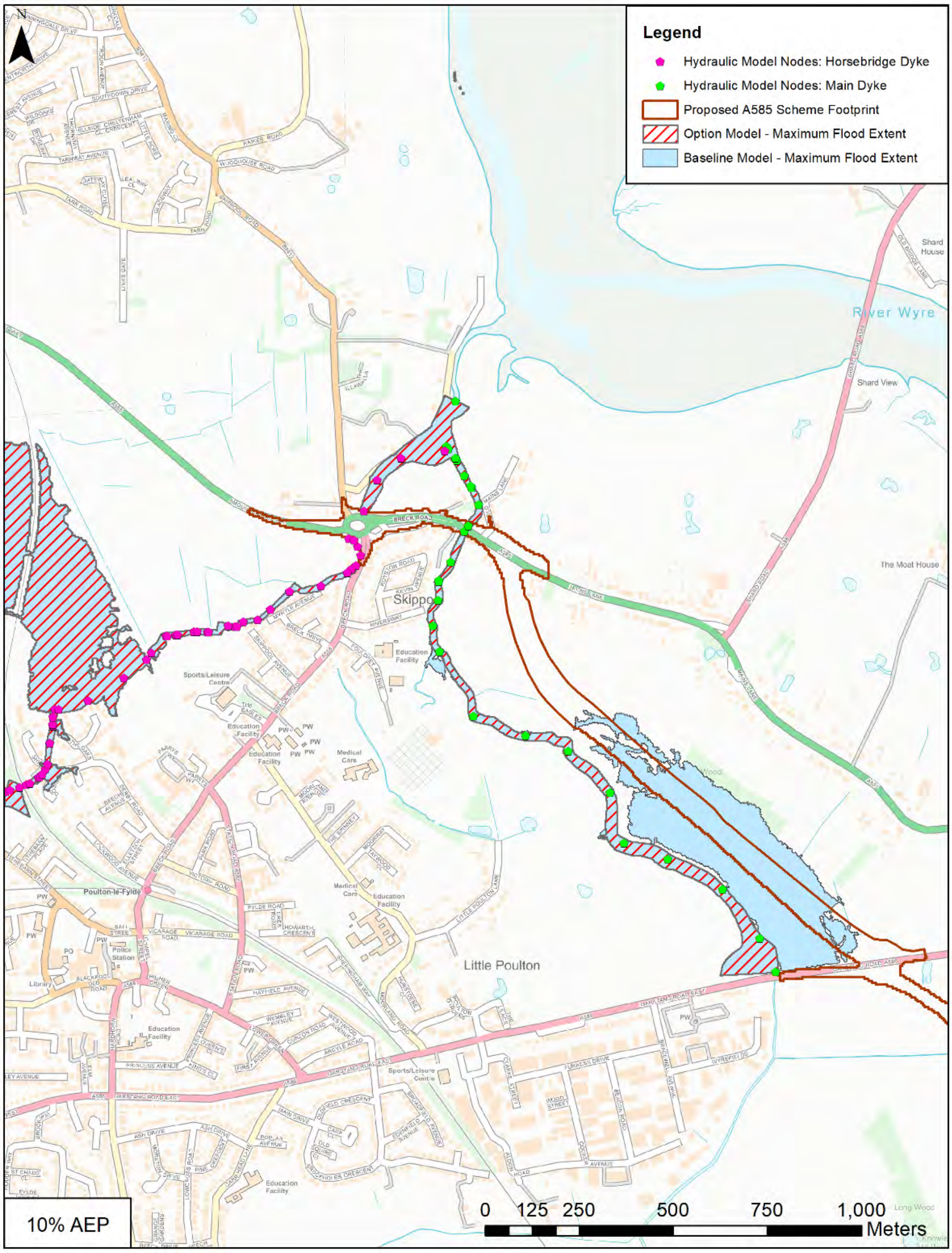


Figure D3 - Maximum flood extents [Baseline and 'With Scheme' (Option)] for the 10% AEP flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

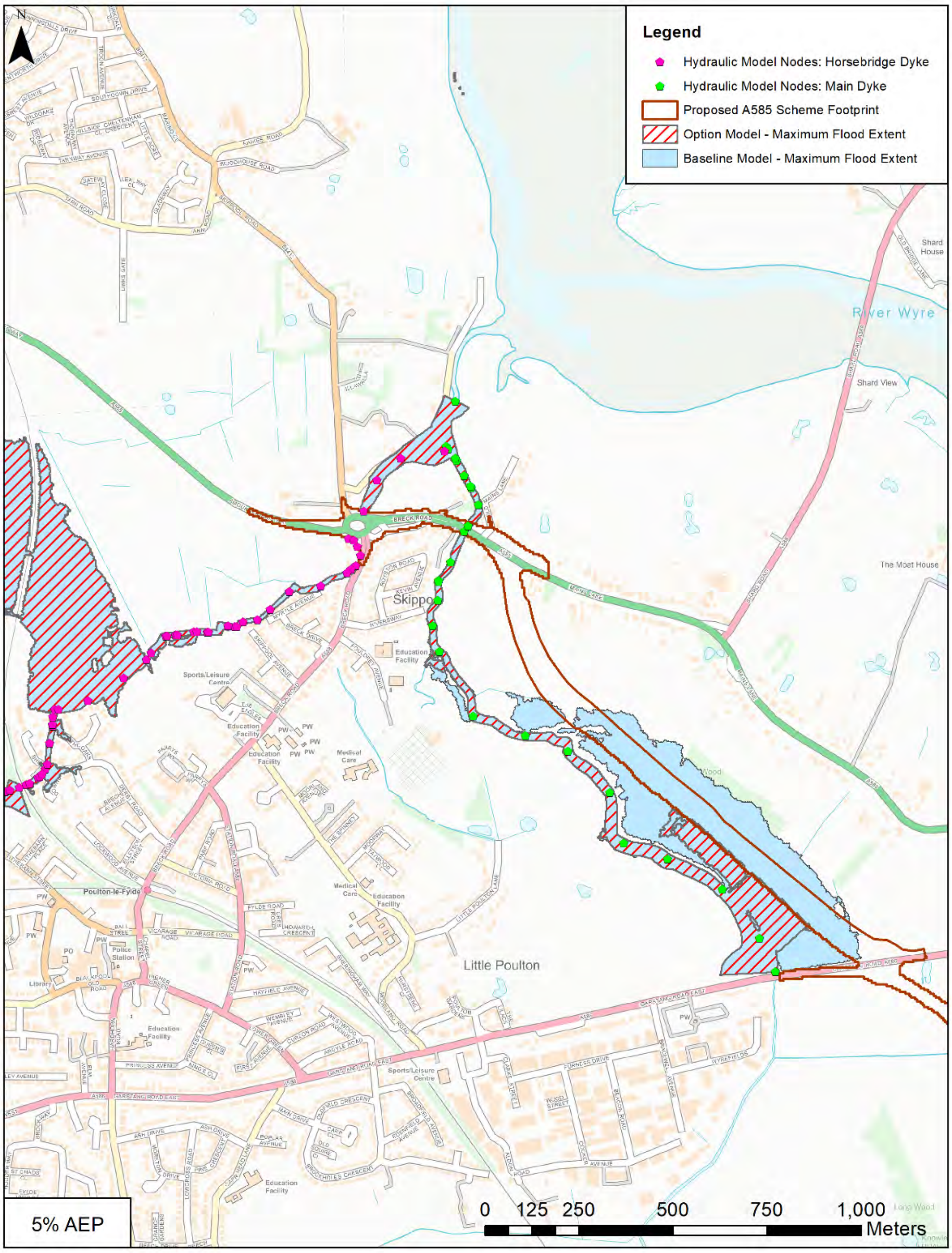


Figure D4 - Maximum flood extents [Baseline and 'With Scheme' (Option)] for the 5% AEP flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

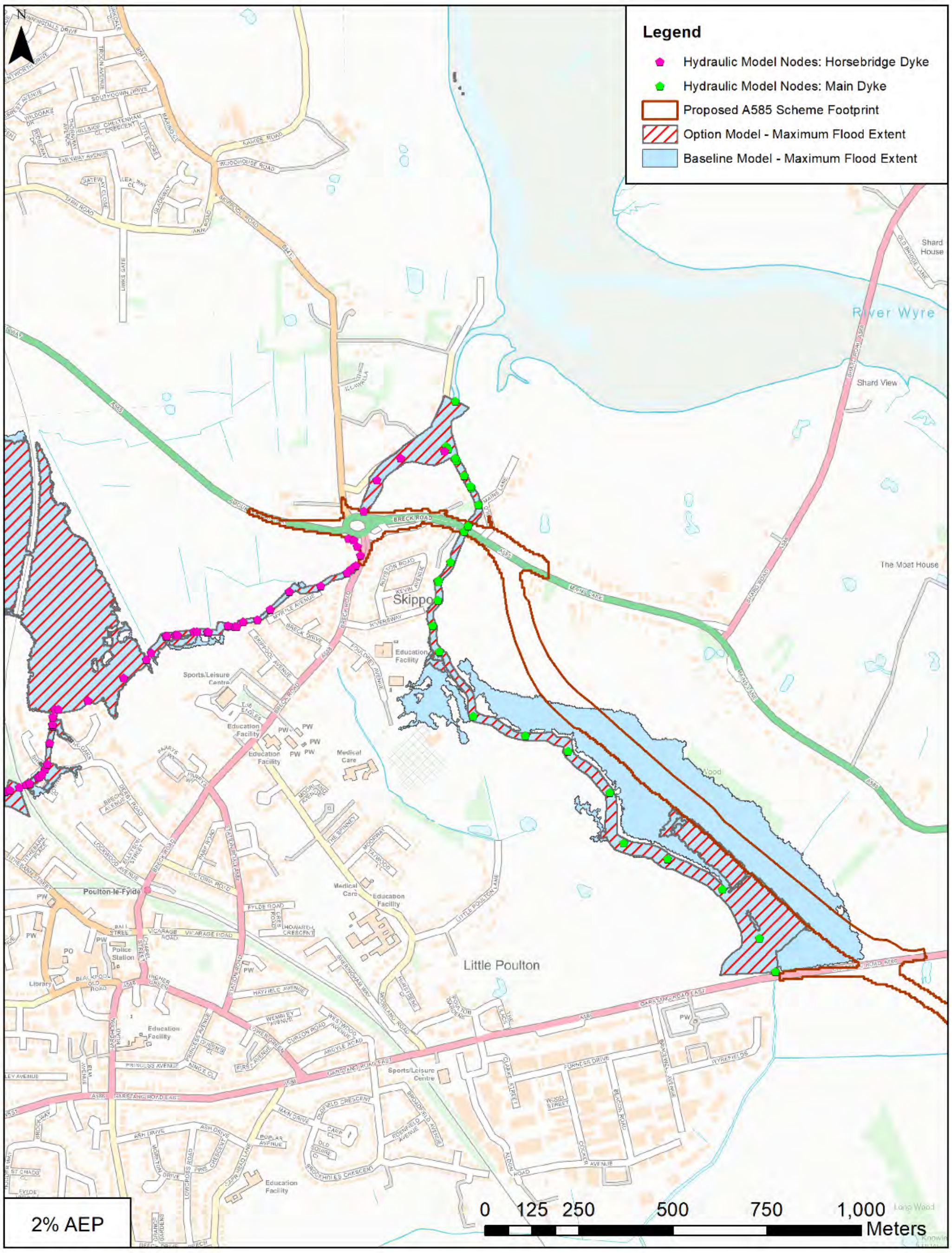


Figure D5 - Maximum flood extents [Baseline and 'With Scheme' (Option)] for the 2% AEP flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

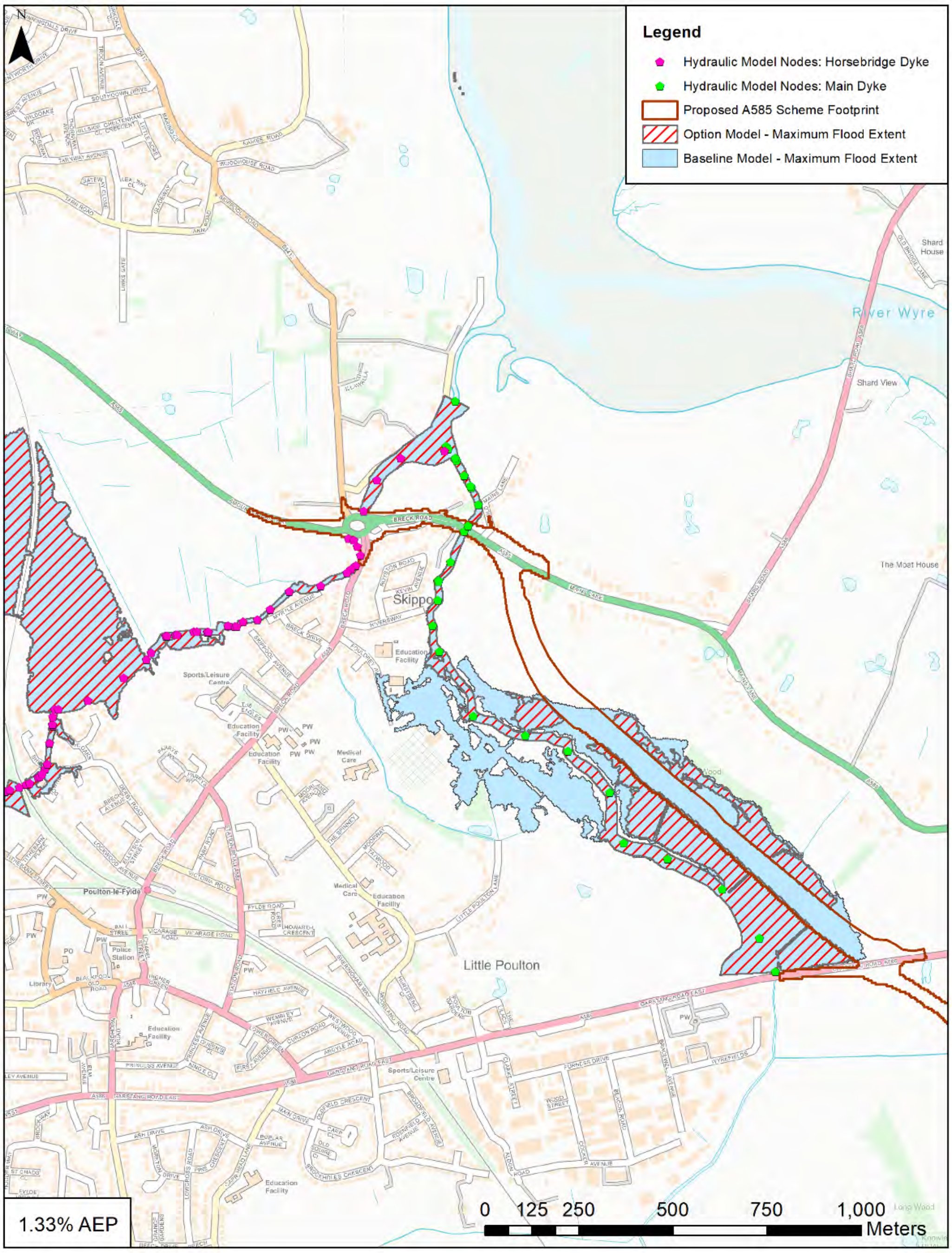


Figure D6 - Maximum flood extents [Baseline and 'With Scheme' (Option)] for the 1.33% AEP flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

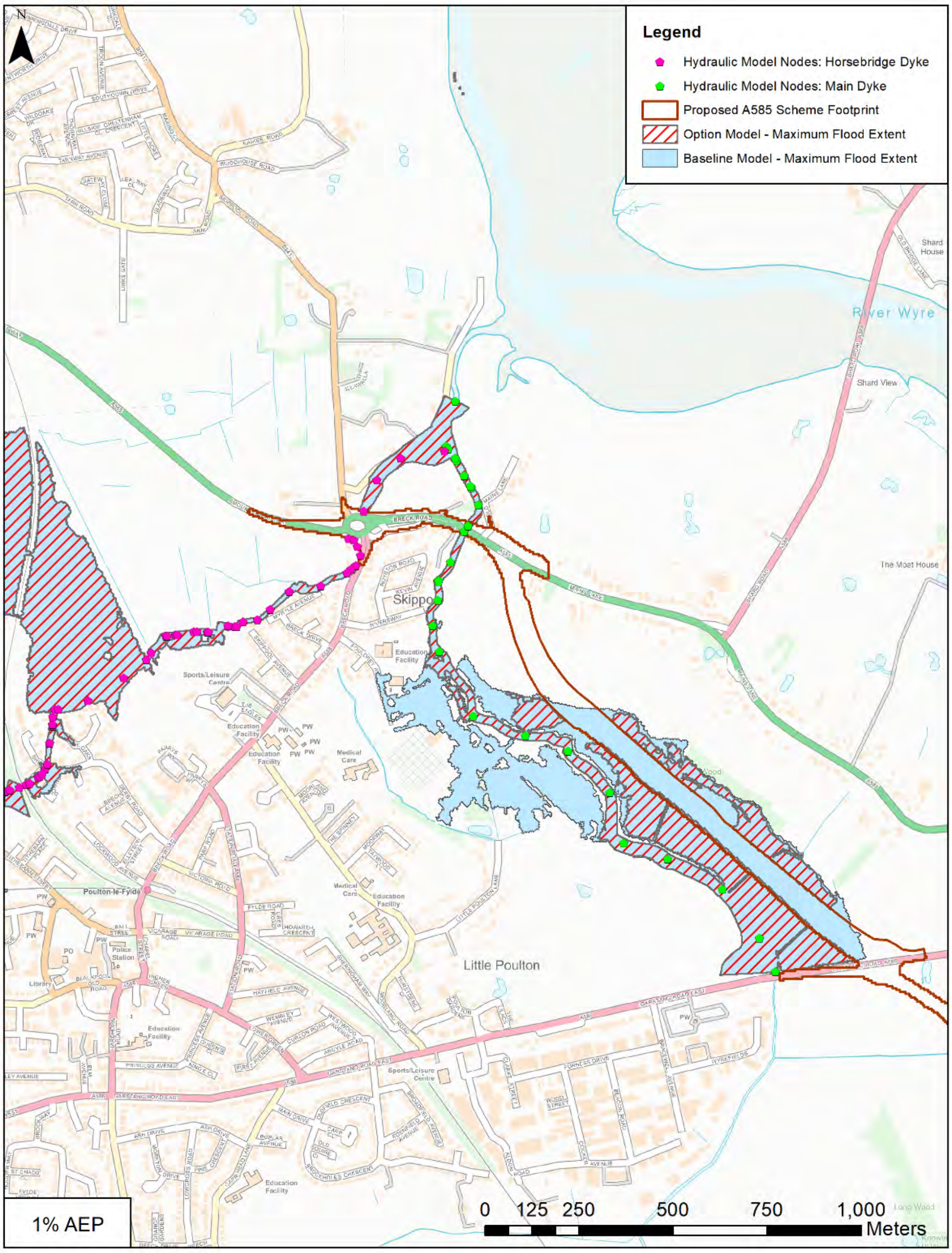


Figure D7 - Maximum flood extents [Baseline and 'With Scheme' (Option)] for the 1% AEP flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

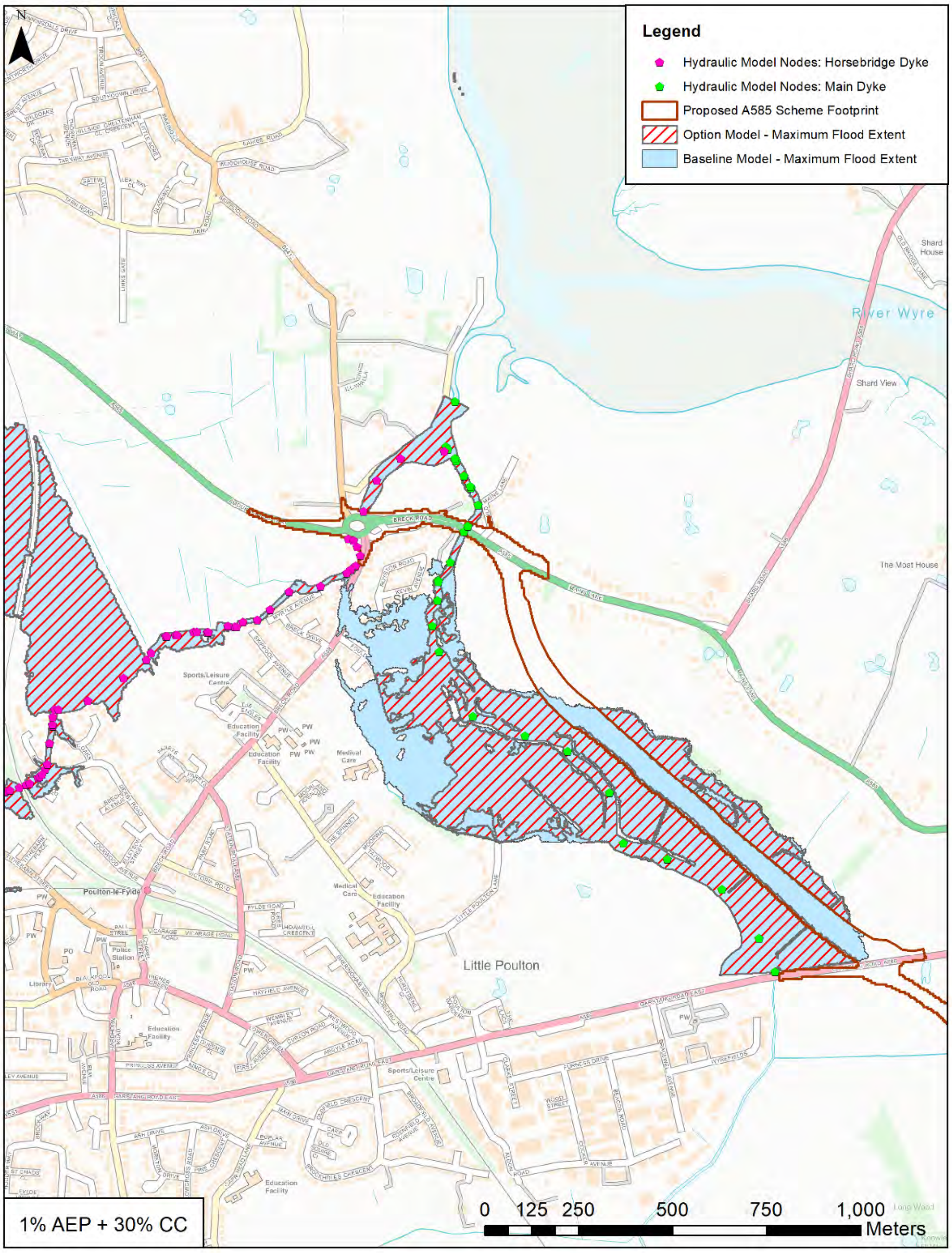


Figure D8 - Maximum flood extents [Baseline and 'With Scheme' (Option)] for the 1% AEP (+30% Climate Change) flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

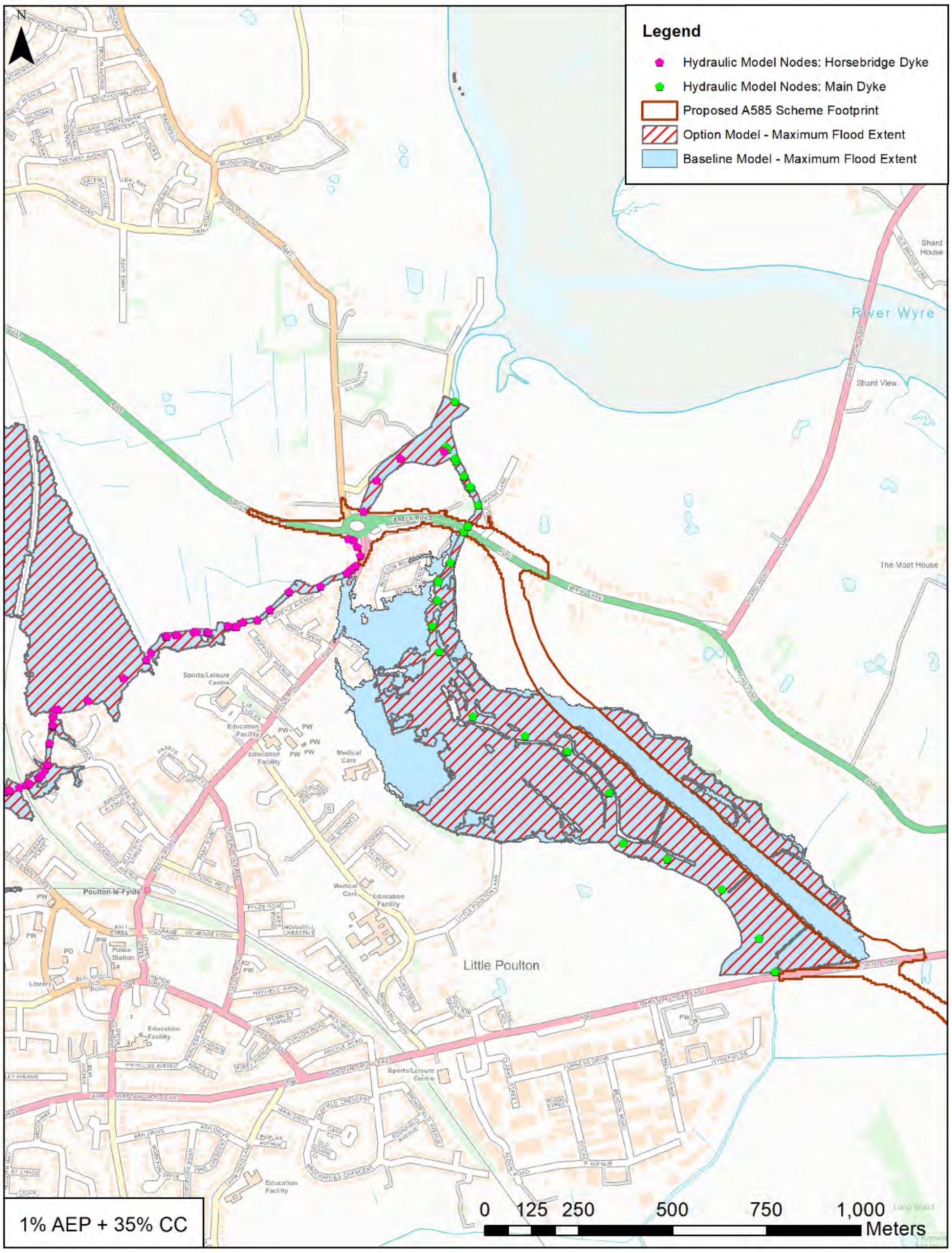


Figure D9 - Maximum flood extents [Baseline and 'With Scheme' (Option)] for the 1% AEP (+35% Climate Change) flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

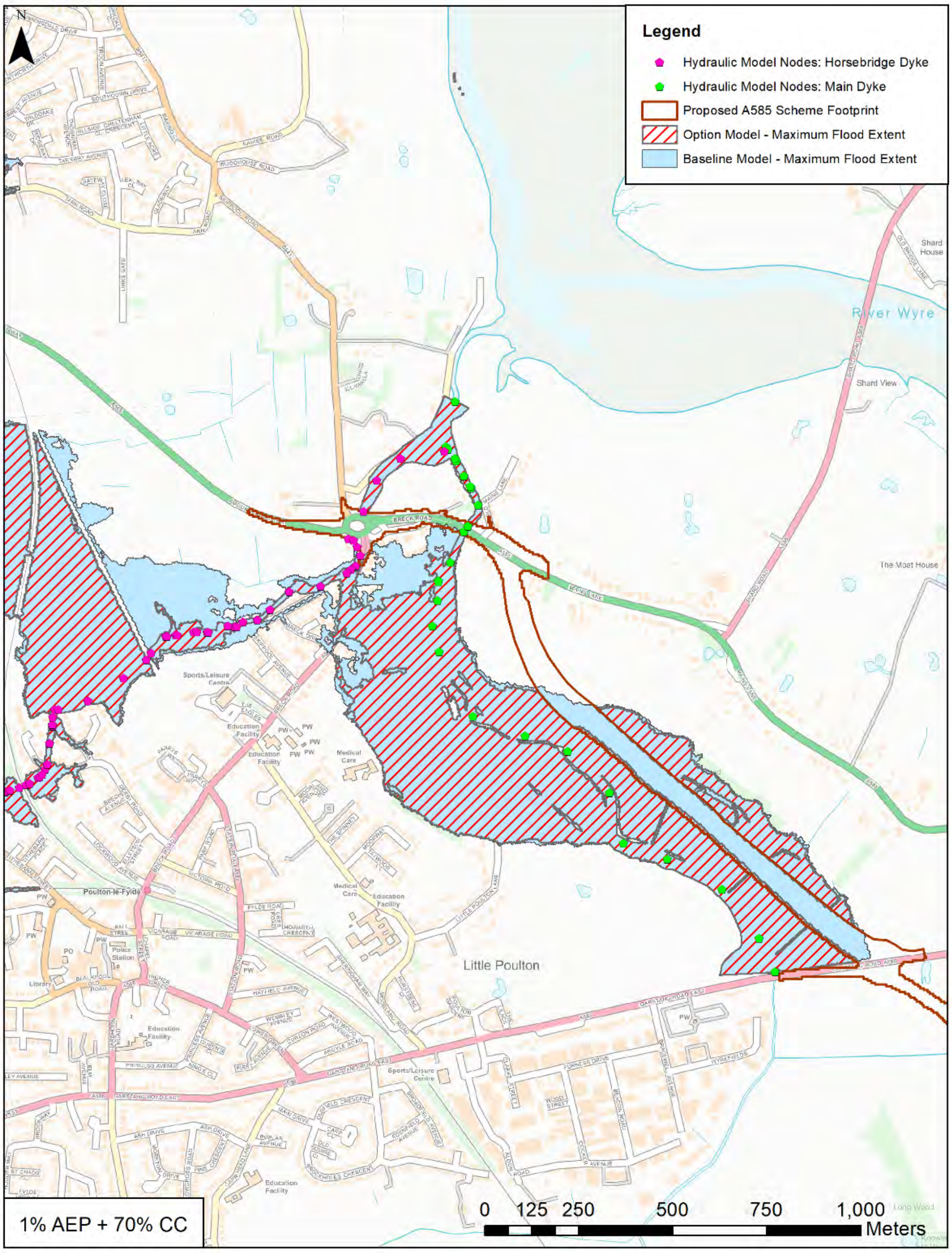


Figure D10 - Maximum flood extents [Baseline and 'With Scheme' (Option)] for the 1% AEP (+70% Climate Change) flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

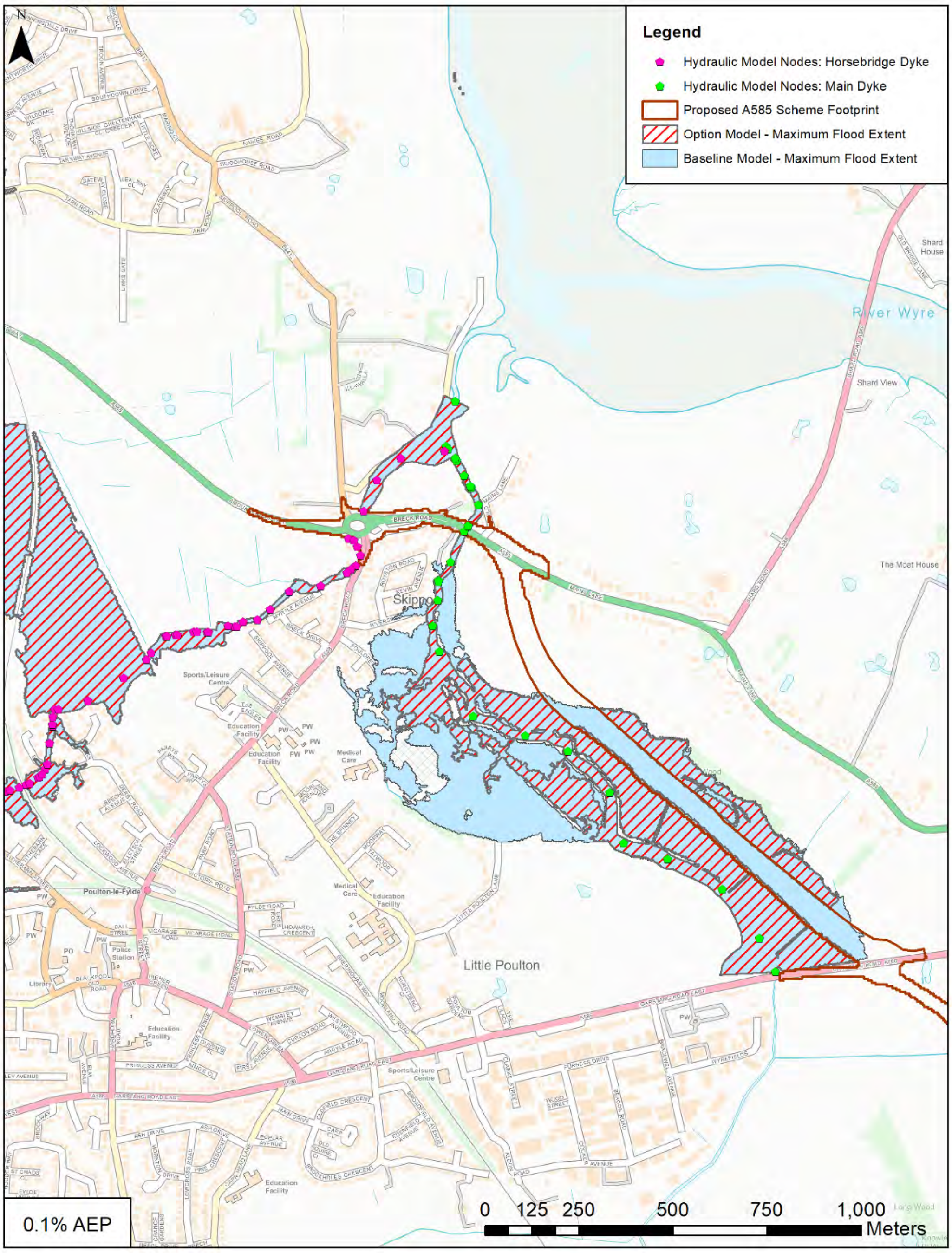


Figure D11 - Maximum flood extents [Baseline and 'With Scheme' (Option)] for the 0.1% AEP flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

Baseline and Option Difference Grids

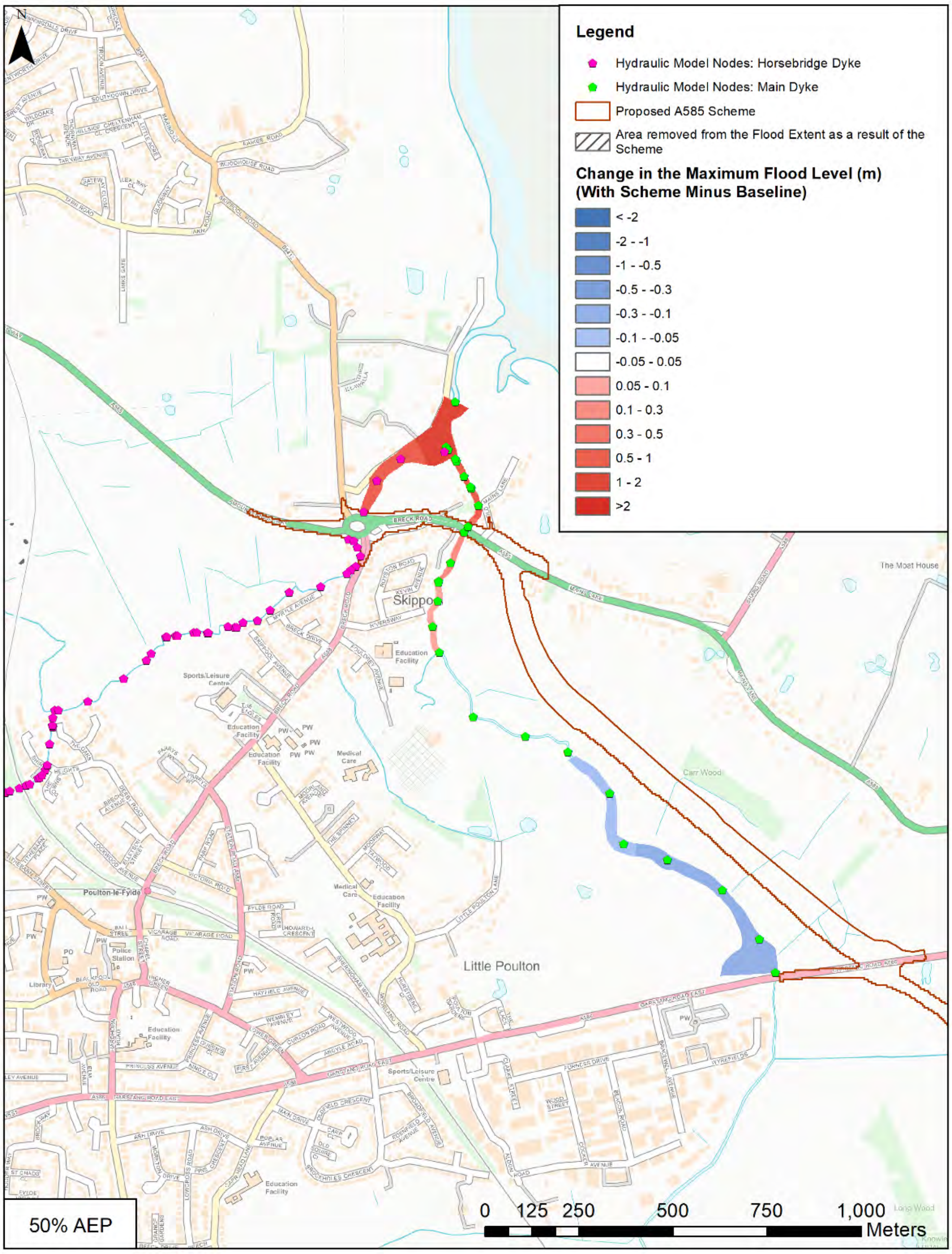


Figure D12 - Maximum flood depth difference [Scheme – Baseline] for the 50% AEP flood event. Includes area removed from the flood extent as a result of the Scheme (Contains Ordnance Survey data © Crown copyright and database right 2017)

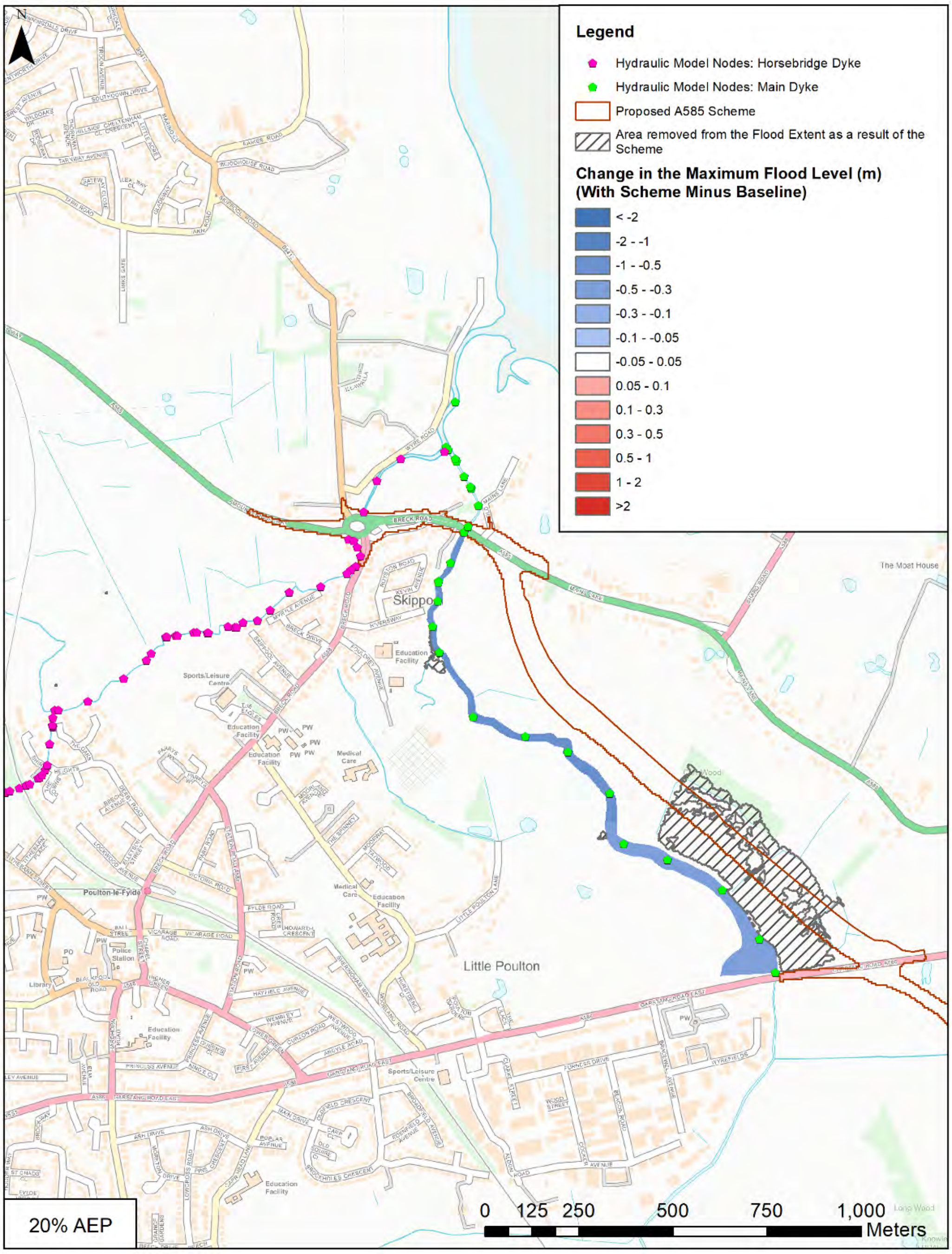


Figure D13 - Maximum flood depth difference [Scheme - Baseline] for the 20% AEP flood event. Includes area removed from the flood extent as a result of the Scheme (Contains Ordnance Survey data © Crown copyright and database right 2017)

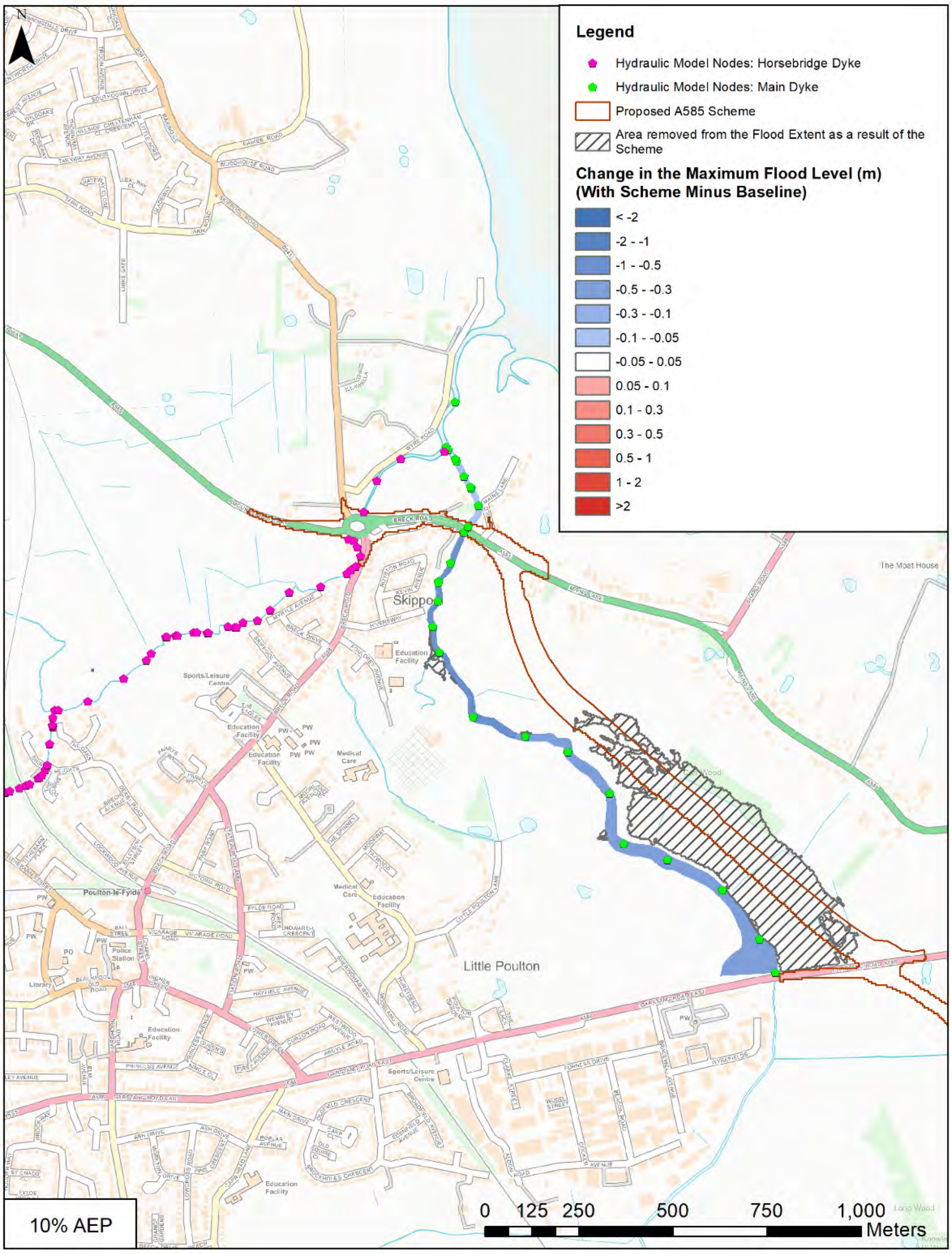


Figure D14 - Maximum flood depth difference [Scheme - Baseline] for the 10% AEP flood event. Includes area removed from the flood extent as a result of the Scheme (Contains Ordnance Survey data © Crown copyright and database right 2017)

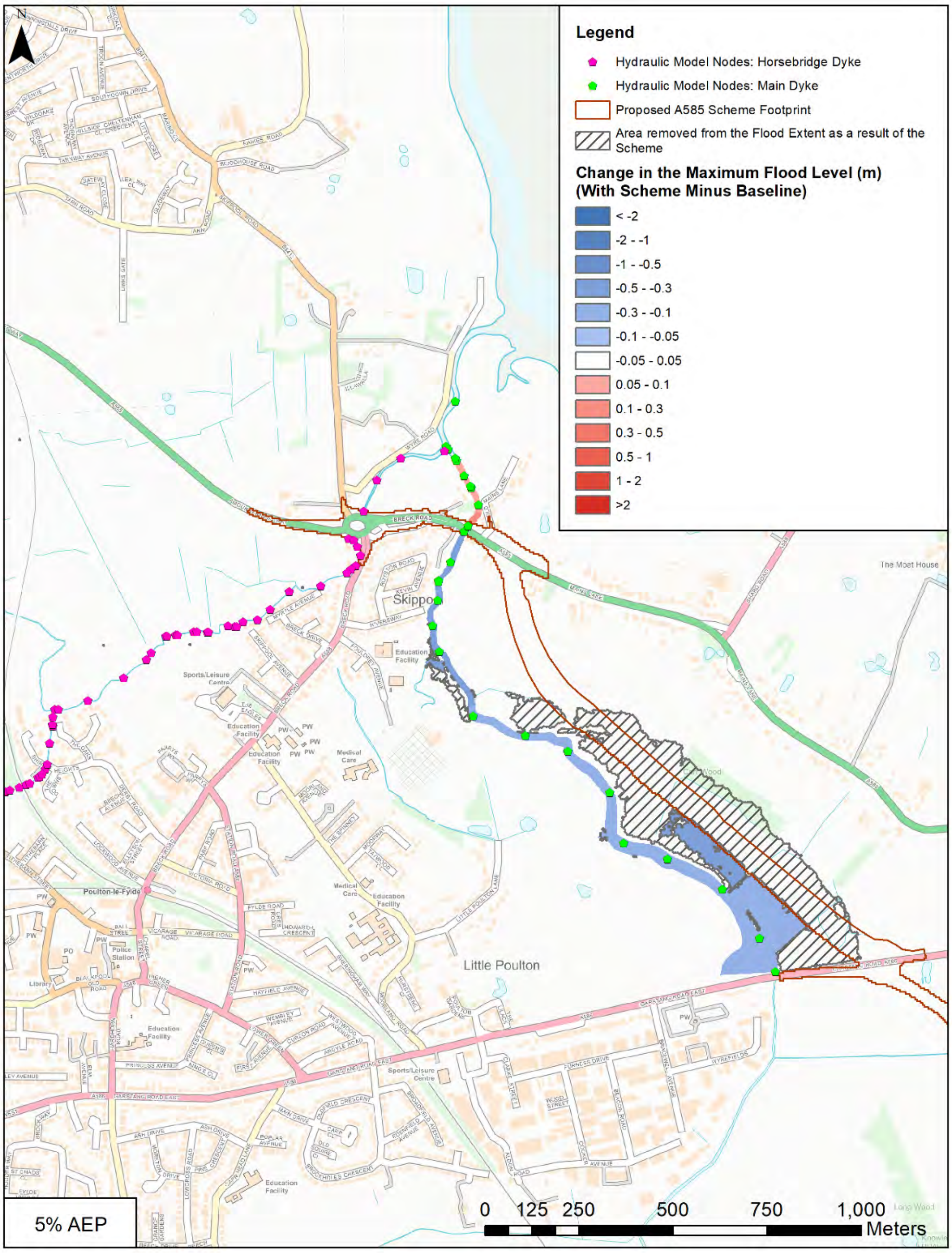


Figure D15 - Maximum flood depth difference [Scheme - Baseline] for the 5% AEP flood event. Includes area removed from the flood extent as a result of the Scheme (Contains Ordnance Survey data © Crown copyright and database right 2017)

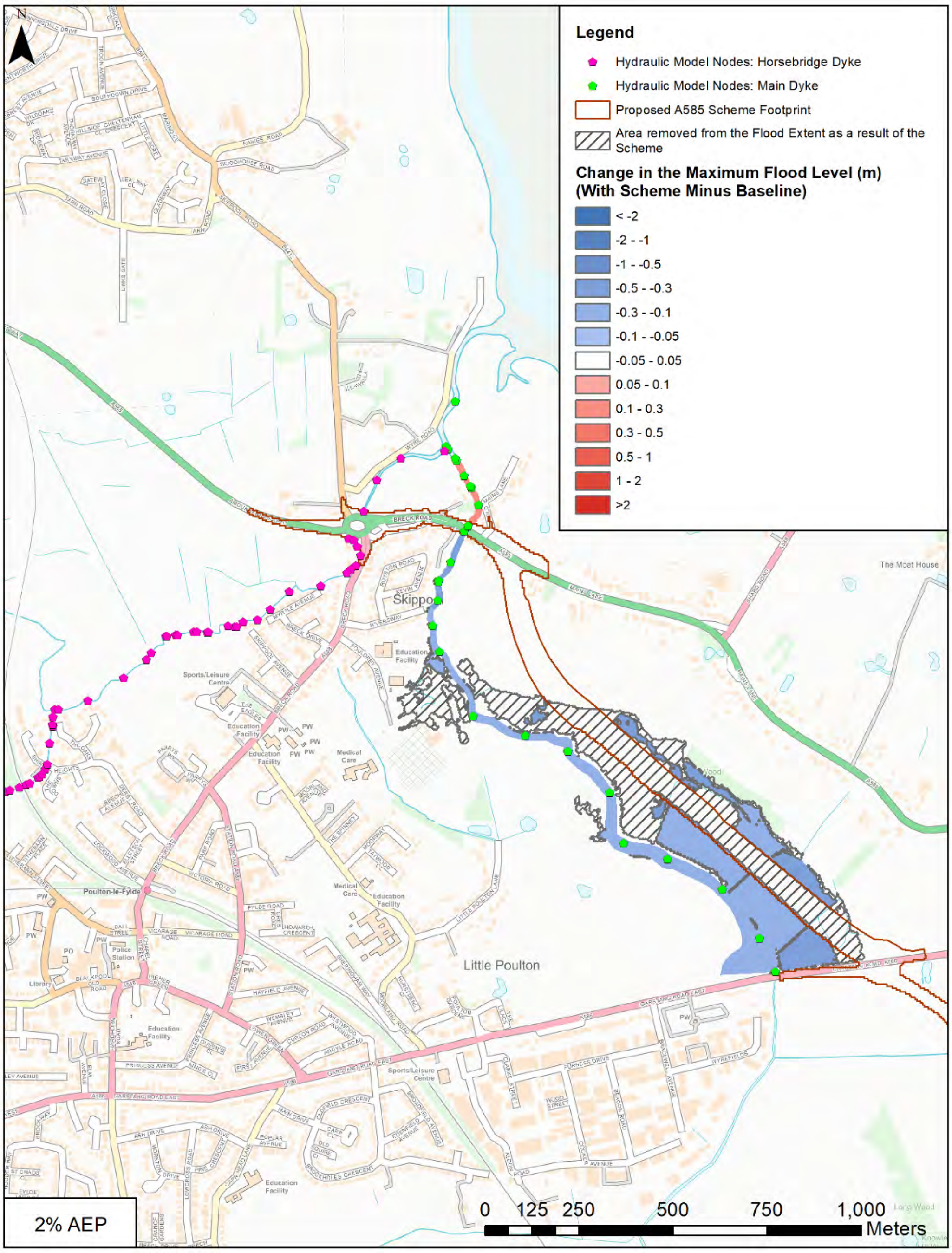


Figure D16 - Maximum flood depth difference [Scheme - Baseline] for the 2% AEP flood event. Includes area removed from the flood extent as a result of the Scheme (Contains Ordnance Survey data © Crown copyright and database right 2017)

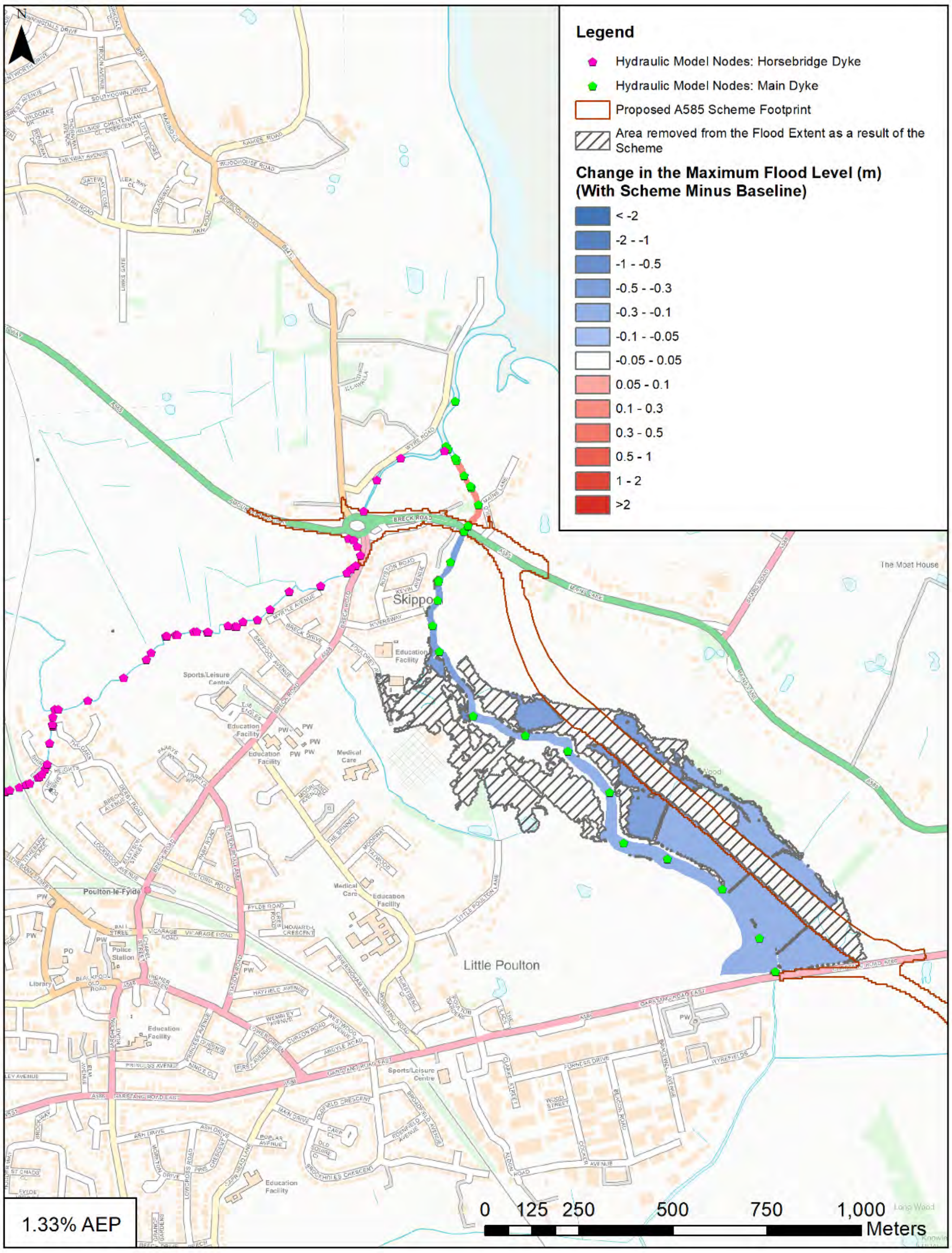


Figure D17 - Maximum flood depth difference [Scheme - Baseline] for the 1.33% AEP flood event. Includes area removed from the flood extent as a result of the Scheme (Contains Ordnance Survey data © Crown copyright and database right 2017)

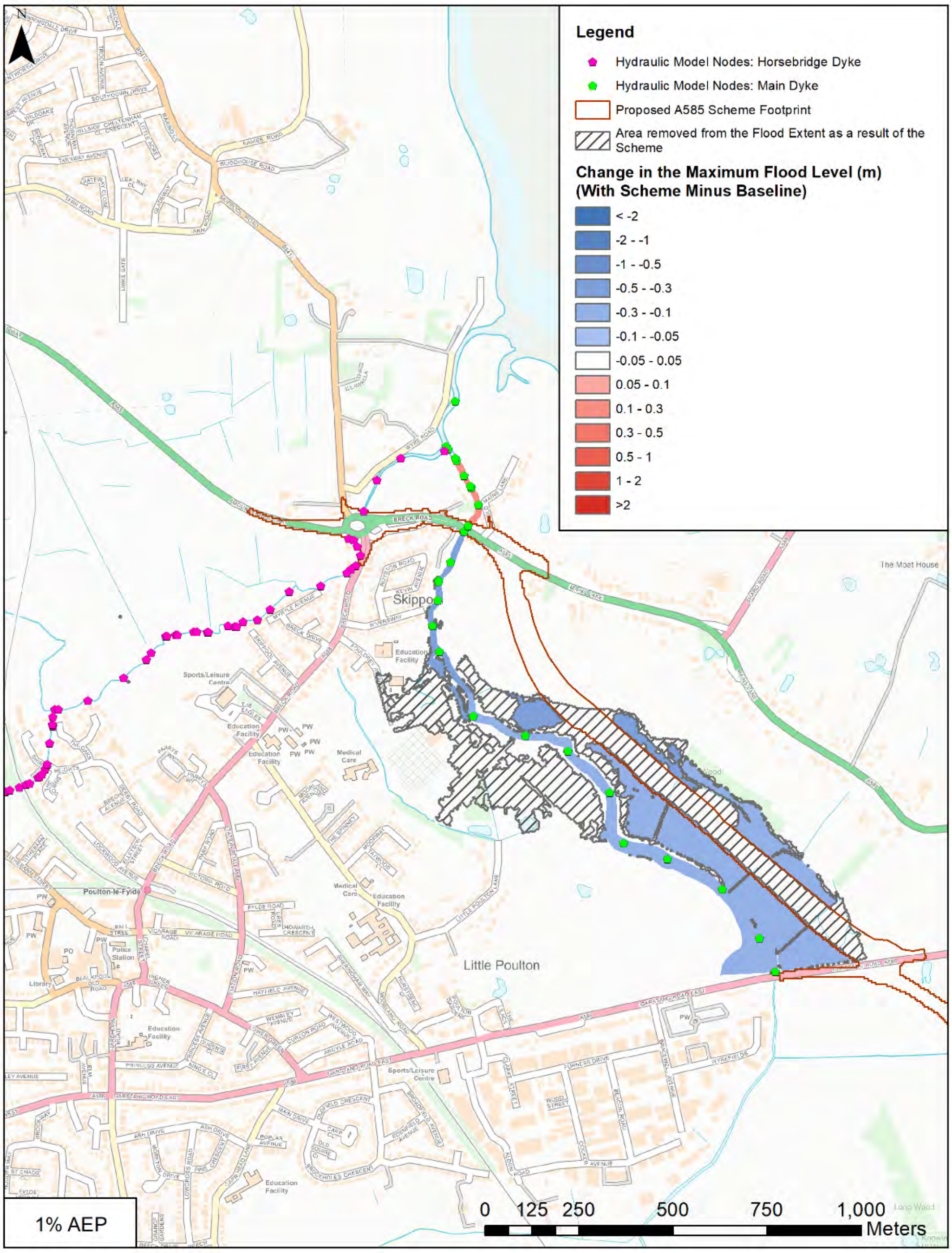


Figure D18 - Maximum flood depth difference [Scheme - Baseline] for the 1% AEP flood event. Includes area removed from the flood extent as a result of the Scheme (Contains Ordnance Survey data © Crown copyright and database right 2017)

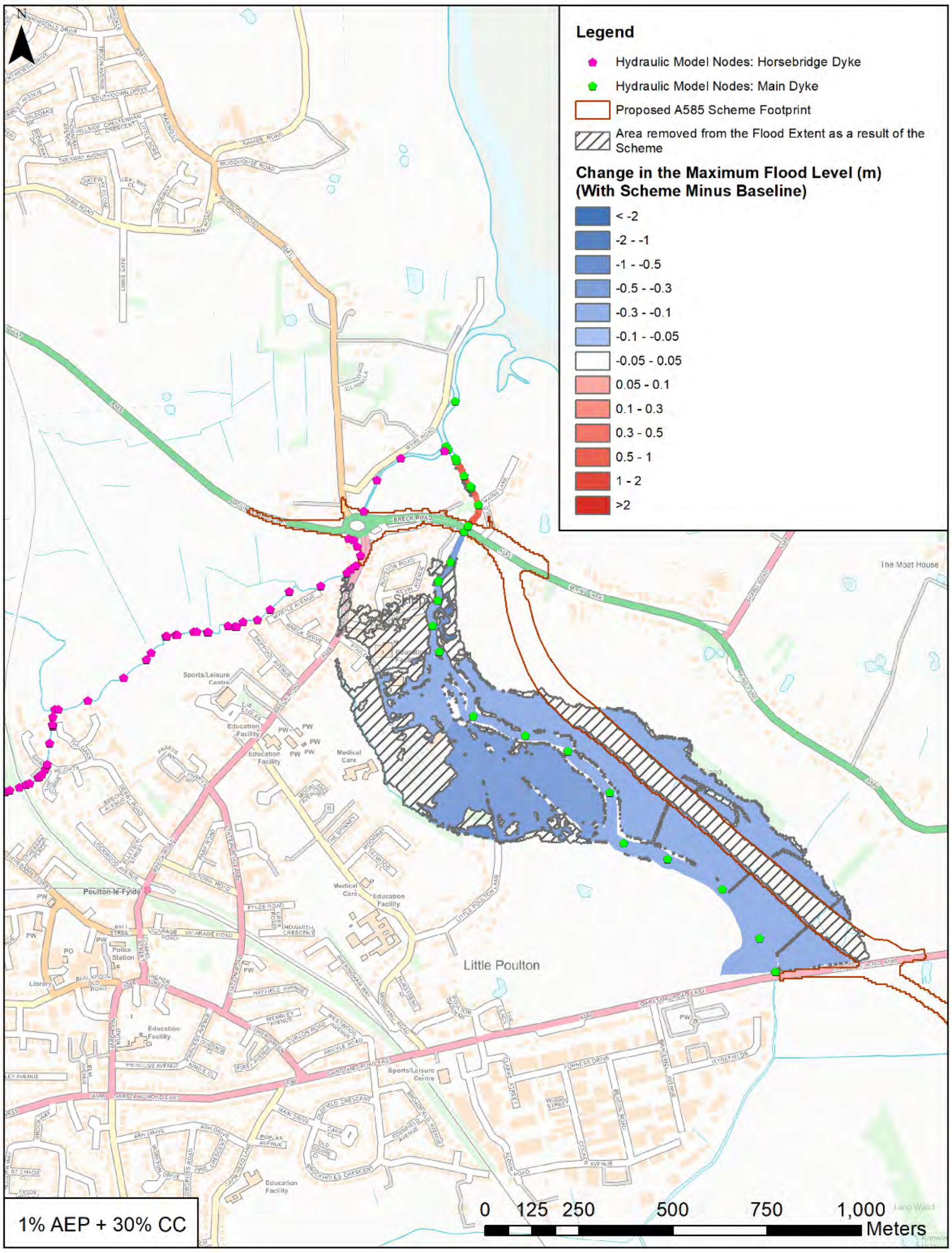


Figure D19 - Maximum flood depth difference [Scheme - Baseline] for the 1% AEP (+30% Climate Change) flood event. Includes area removed from the flood extent as a result of the Scheme (Contains Ordnance Survey data © Crown copyright and database right 2017)

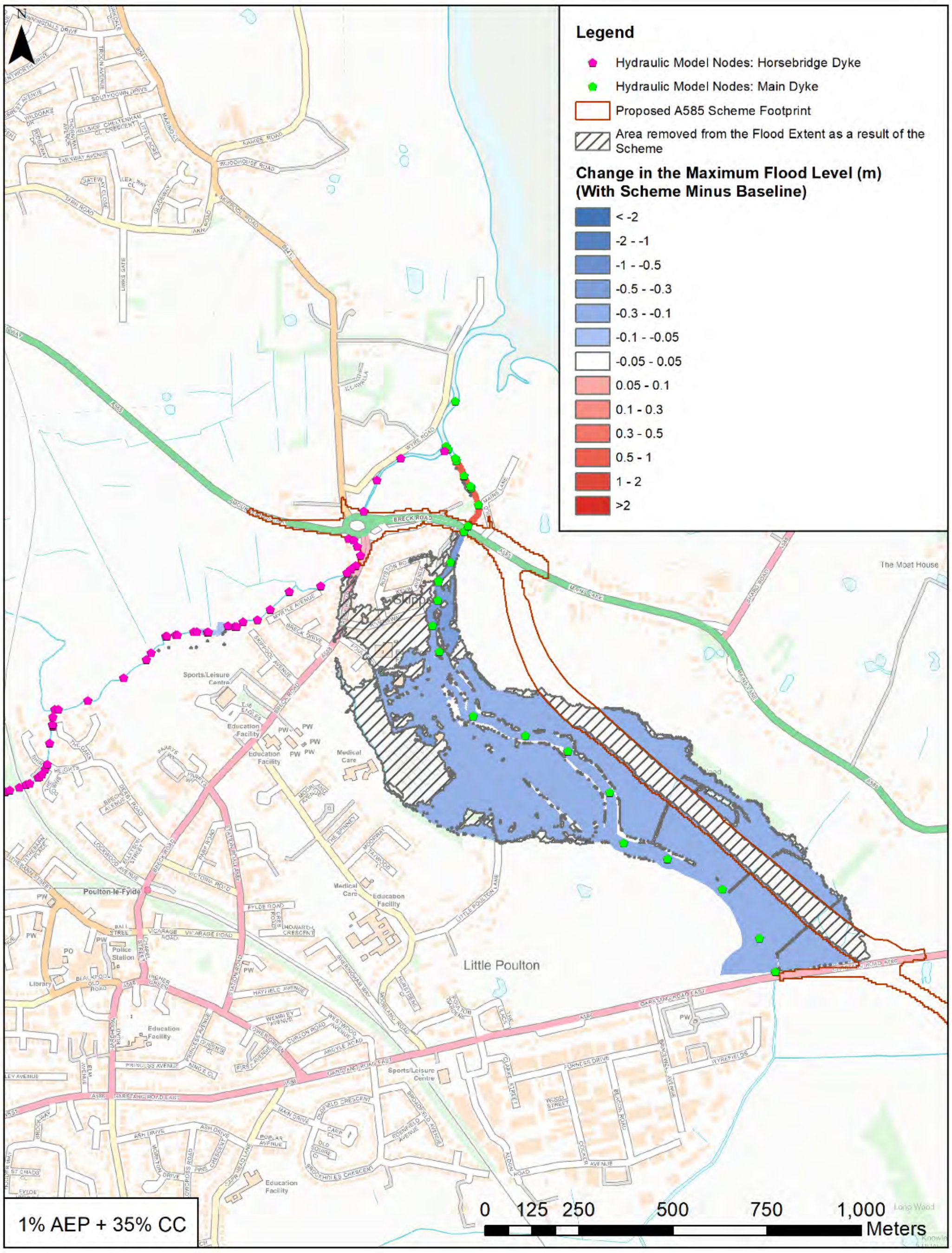


Figure D20 - Maximum flood depth difference [Scheme - Baseline] for the 1% AEP (+35% Climate Change) flood event. Includes area removed from the flood extent as a result of the Scheme (Contains Ordnance Survey data © Crown copyright and database right 2017)

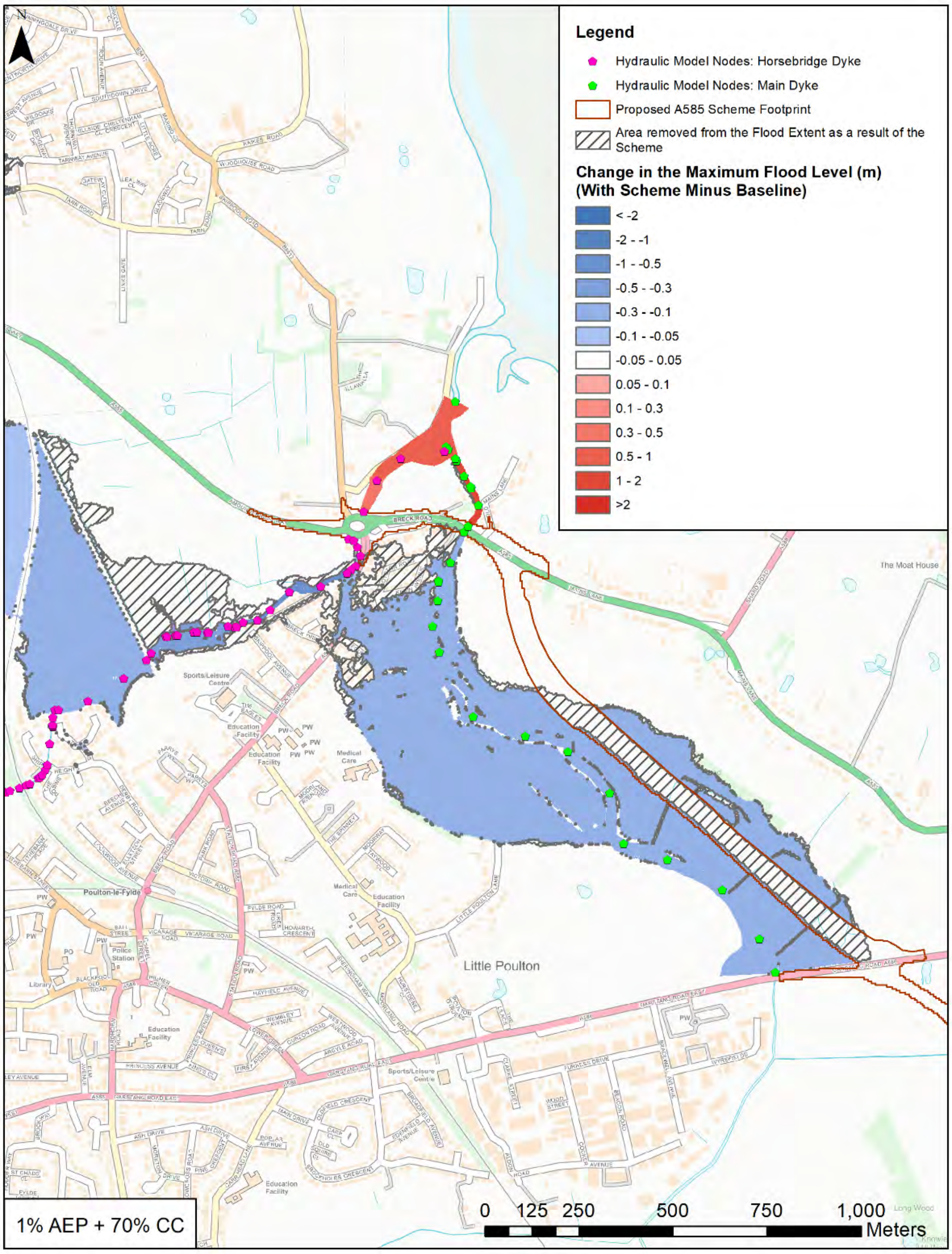


Figure D21 - Maximum flood depth difference [Scheme - Baseline] for the 1% AEP (+70% Climate Change) flood event. Includes area removed from the flood extent as a result of the Scheme (Contains Ordnance Survey data © Crown copyright and database right 2017)

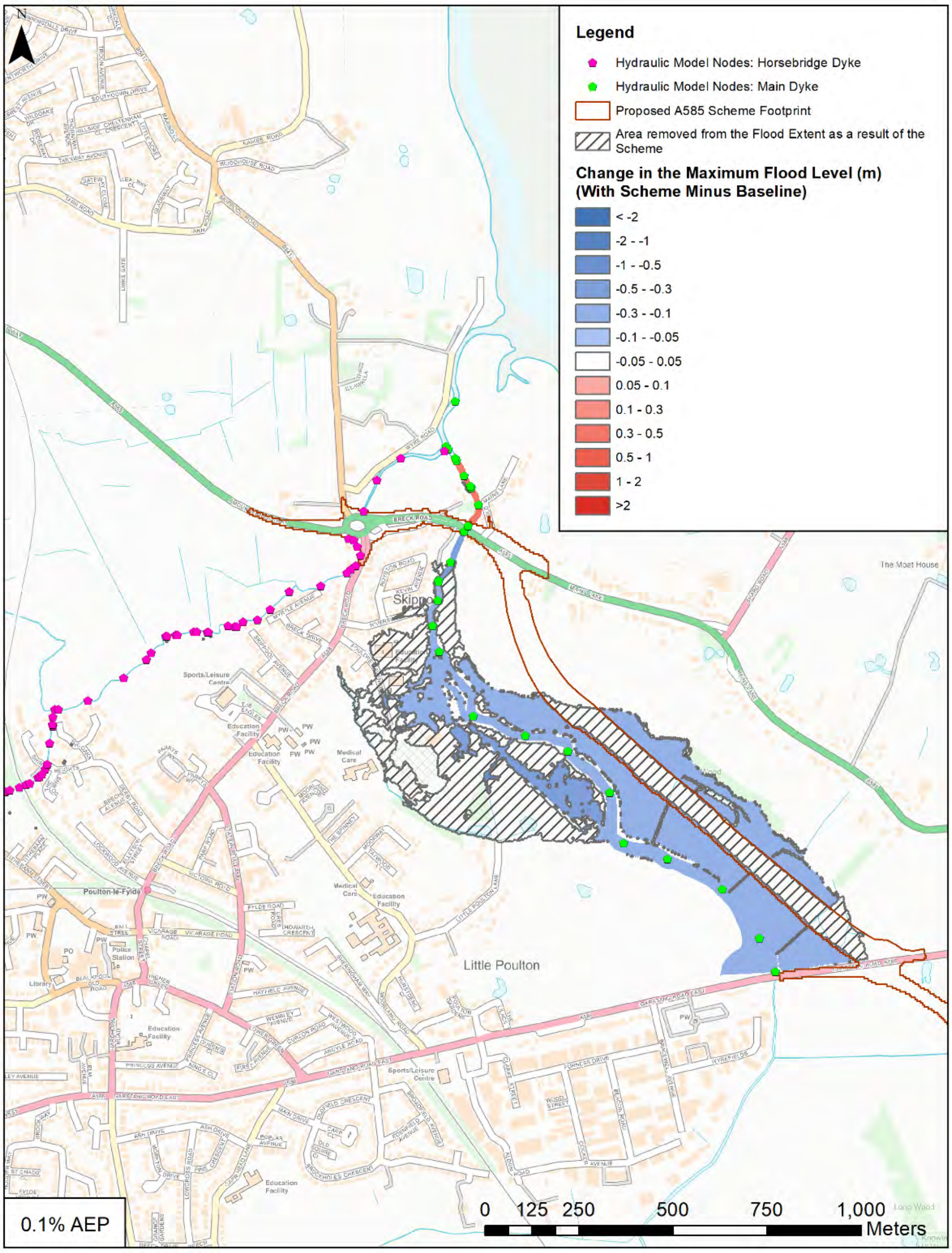


Figure D22 - Maximum flood depth difference [Scheme - Baseline] for the 0.1% AEP flood event. Includes area removed from the flood extent as a result of the Scheme (Contains Ordnance Survey data © Crown copyright and database right 2017)

Construction Phasing and Baseline Difference Grids

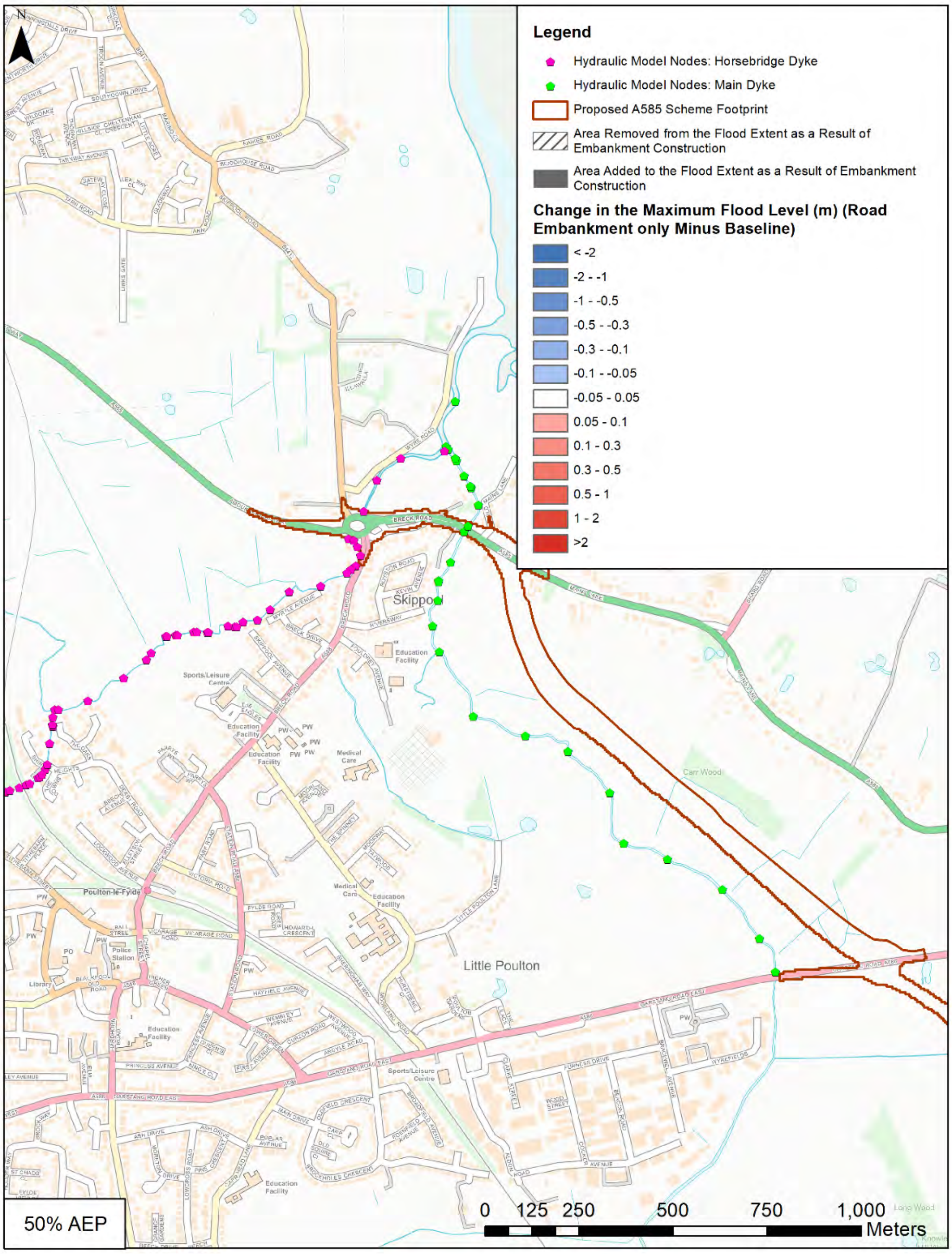


Figure D23 - Maximum flood depth difference [Scheme with embankment only and no widening of the A585 Main Dyke crossing - Baseline] for the 50% AEP flood event. Includes areas removed from and added to the flood extent as a result of embankment construction. (Contains Ordnance Survey data © Crown copyright and database right 2017)

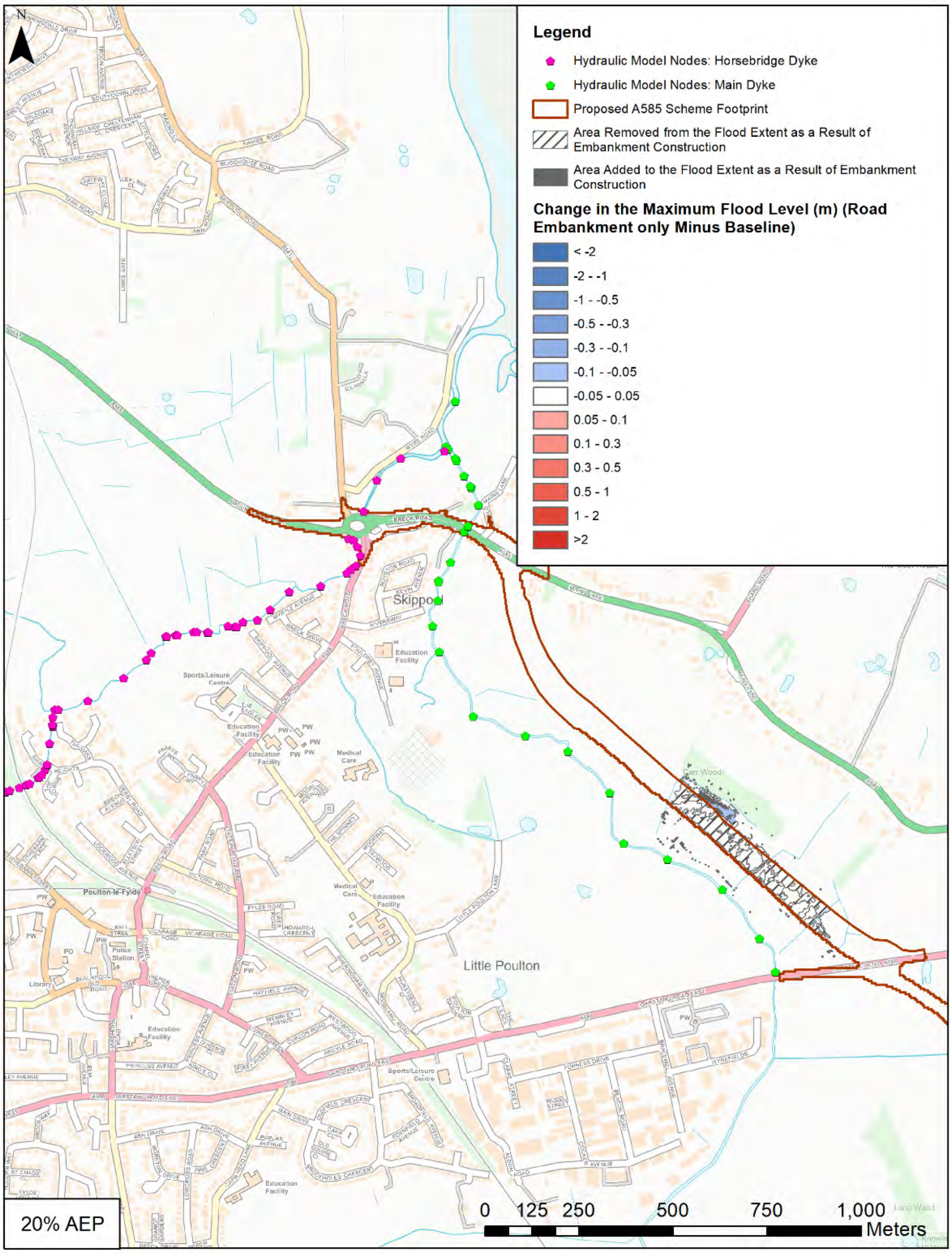


Figure D24 - Maximum flood depth difference [Scheme with embankment only and no widening of the A585 Main Dyke crossing - Baseline] for the 20% AEP flood event. Includes areas removed from and added to the flood extent as a result of embankment construction. (Contains Ordnance Survey data © Crown copyright and database right 2017)

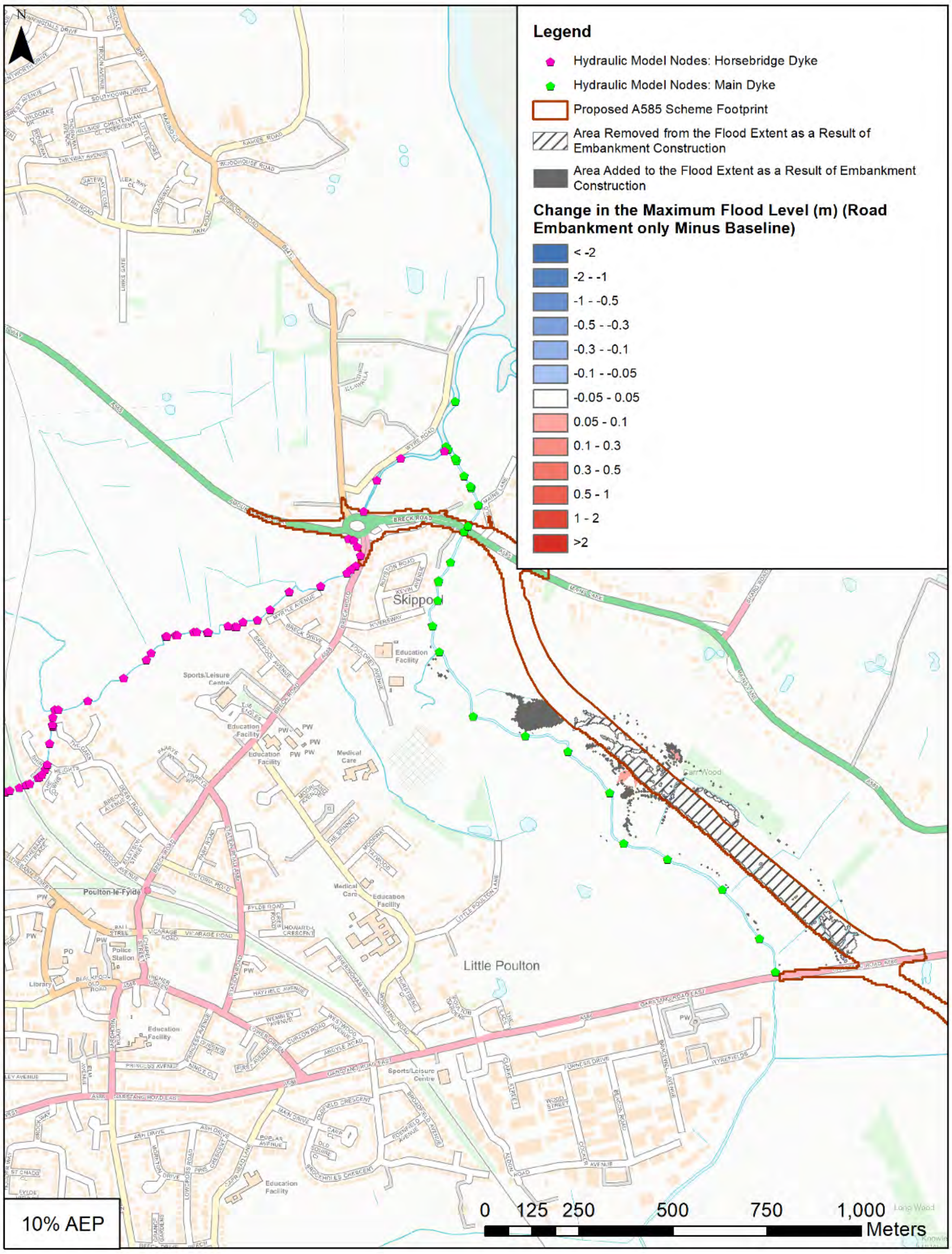


Figure D25 - Maximum flood depth difference [Scheme with embankment only and no widening of the A585 Main Dyke crossing - Baseline] for the 10% AEP flood event. Includes areas removed from and added to the flood extent as a result of embankment construction. (Contains Ordnance Survey data © Crown copyright and database right 2017)

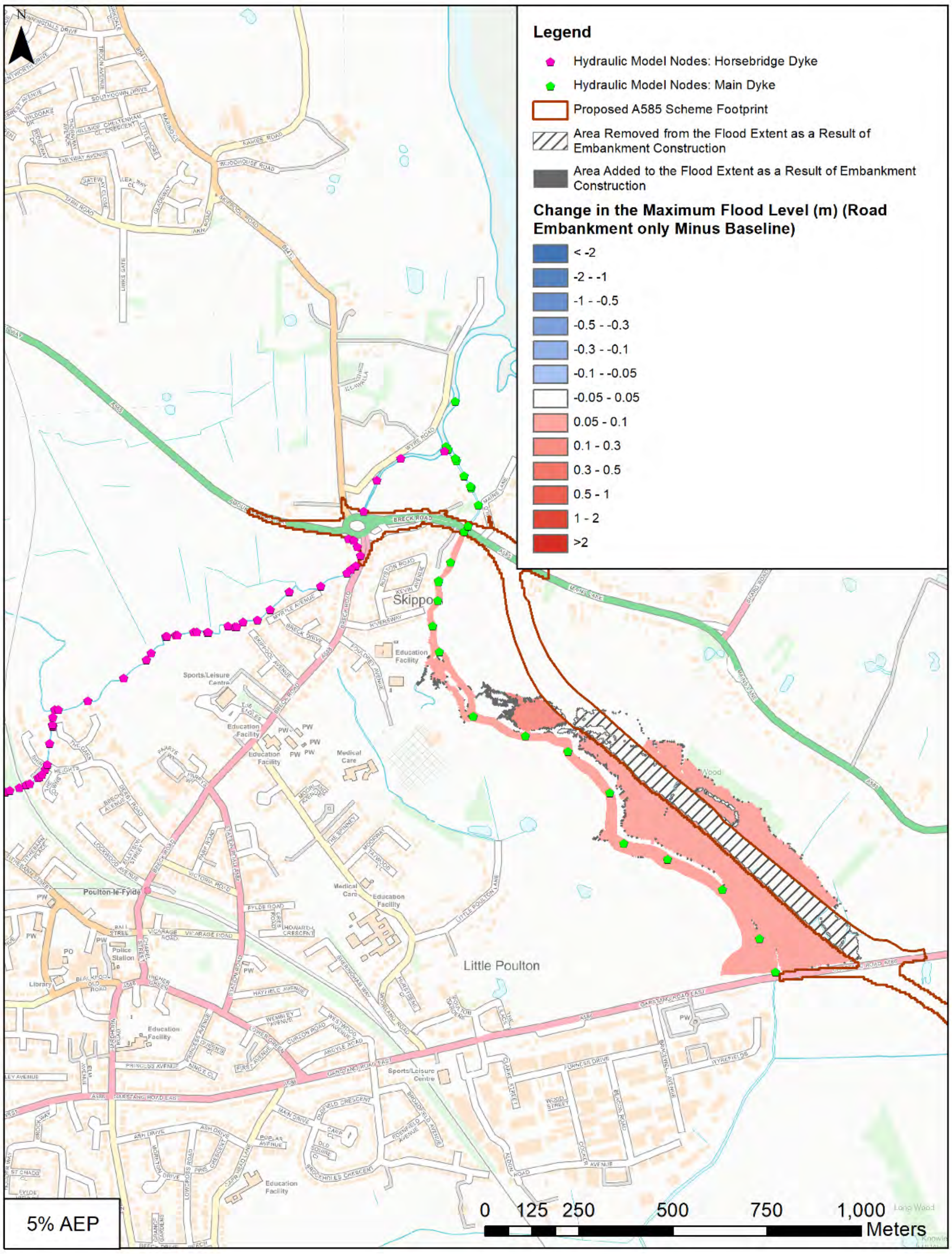


Figure D26 - Maximum flood depth difference [Scheme with embankment only and no widening of the A585 Main Dyke crossing - Baseline] for the 5% AEP flood event. Includes areas removed from and added to the flood extent as a result of embankment construction. (Contains Ordnance Survey data © Crown copyright and database right 2017)

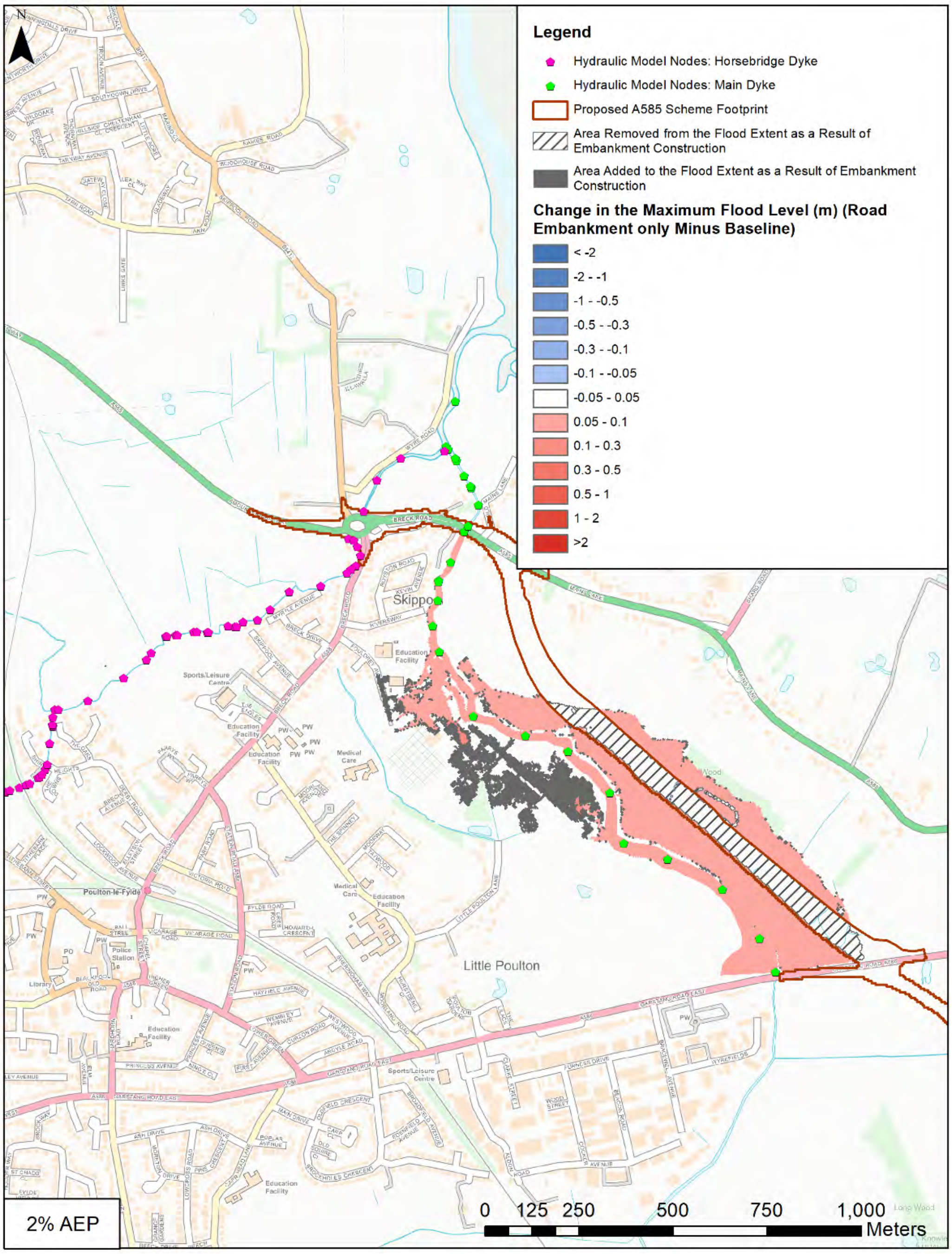


Figure D27 - Maximum flood depth difference [Scheme with embankment only and no widening of the A585 Main Dyke crossing - Baseline] for the 2% AEP flood event. Includes areas removed from and added to the flood extent as a result of embankment construction. (Contains Ordnance Survey data © Crown copyright and database right 2017)

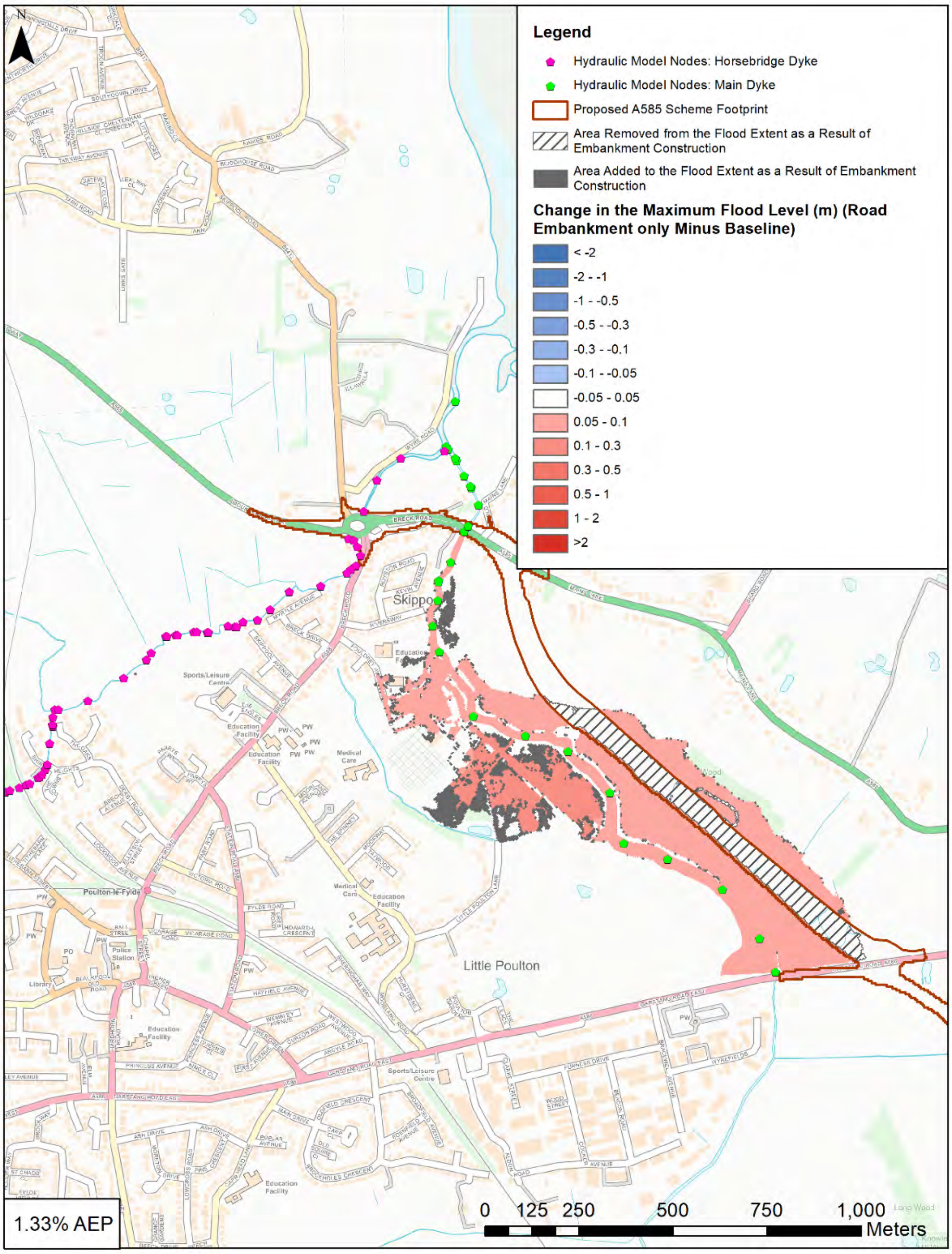


Figure D28 - Maximum flood depth difference [Scheme with embankment only and no widening of the A585 Main Dyke crossing - Baseline] for the 1.33% AEP flood event. Includes areas removed from and added to the flood extent as a result of embankment construction. (Contains Ordnance Survey data © Crown copyright and database right 2017)[1]

[1] Note that impacts for the 1% AEP and the 1.33% AEP are very similar; in channel peak water levels increase upstream of Skippool Bridge increase by 0.05 and 0.06m respectively. Therefore the mapped grid differences are sensitive to the 0.05m cut of depth used for mapping.

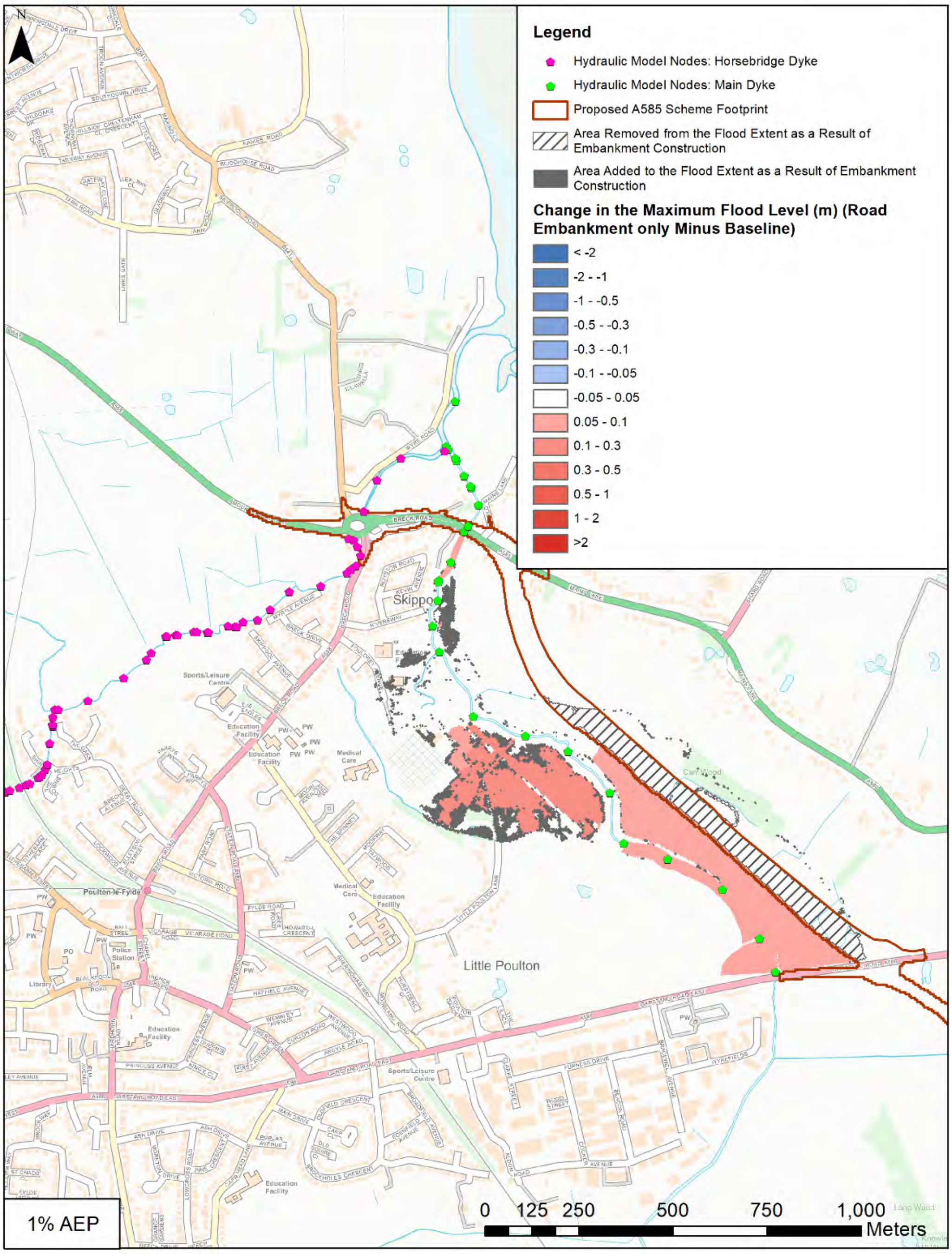


Figure D29 - Maximum flood depth difference [Scheme with embankment only and no widening of the A585 Main Dyke crossing - Baseline] for the 1% AEP flood event. Includes areas removed from and added to the flood extent as a result of embankment construction. (Contains Ordnance Survey data © Crown copyright and database right 2017)[1]

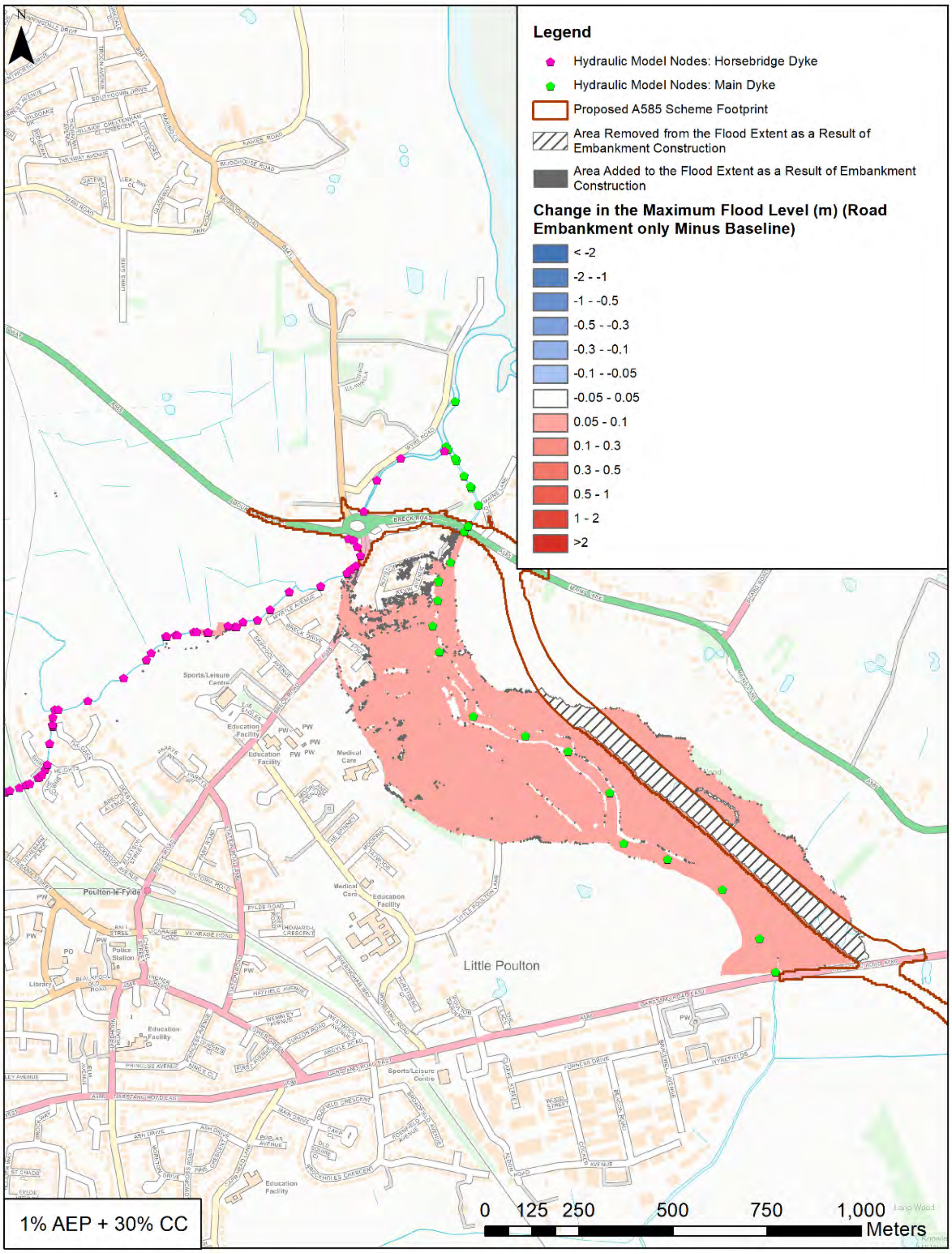


Figure D30 - Maximum flood depth difference [Scheme with embankment only and no widening of the A585 Main Dyke crossing - Baseline] for the 1% AEP (+30% Climate Change) flood event. Includes areas removed from and added to the flood extent as a result of embankment construction. (Contains Ordnance Survey data © Crown copyright and database right 2017)

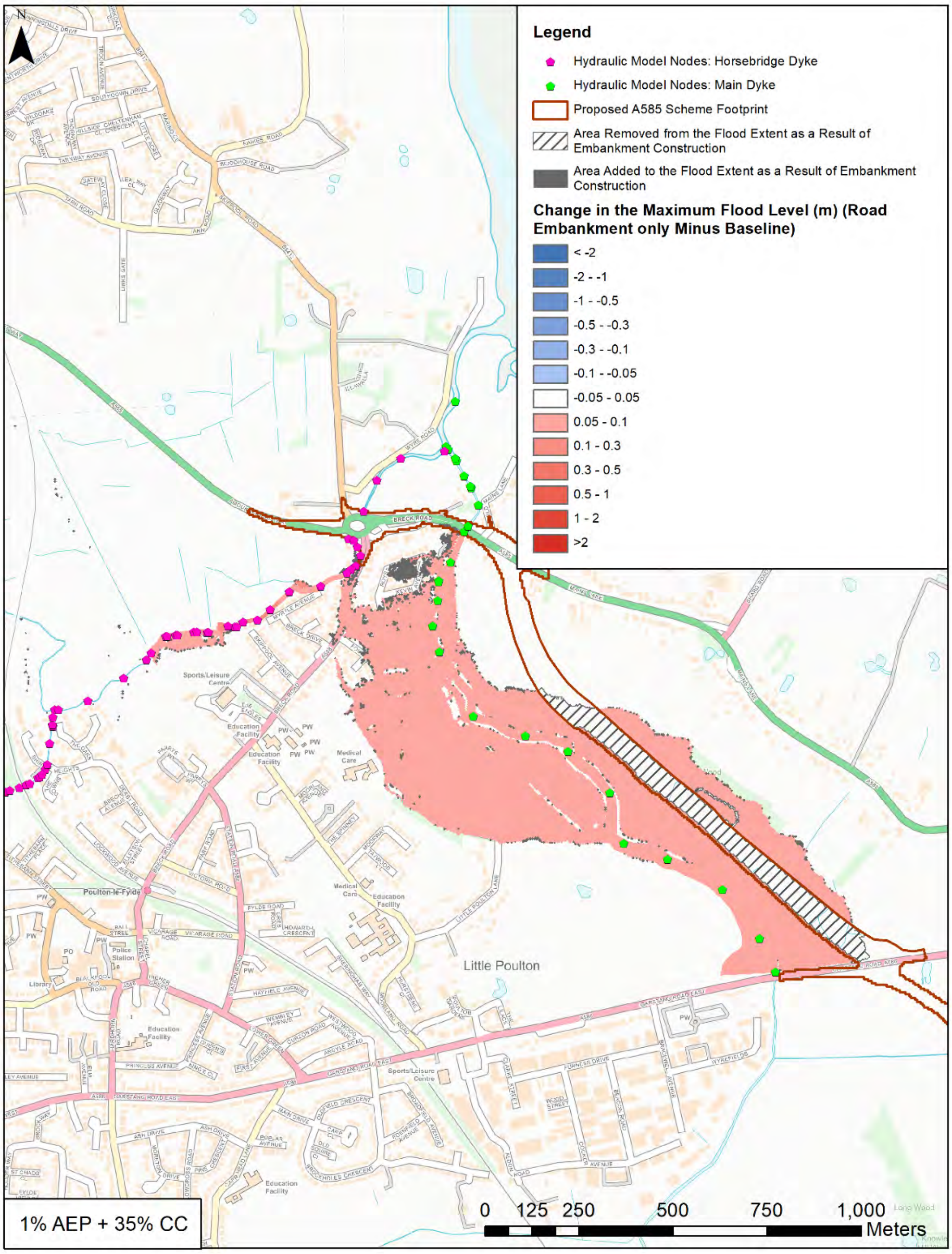


Figure D31 - Maximum flood depth difference [Scheme with embankment only and no widening of the A585 Main Dyke crossing - Baseline] for the 1% AEP (+35% Climate Change) flood event. Includes areas removed from and added to the flood extent as a result of embankment construction. (Contains Ordnance Survey data © Crown copyright and database right 2017)

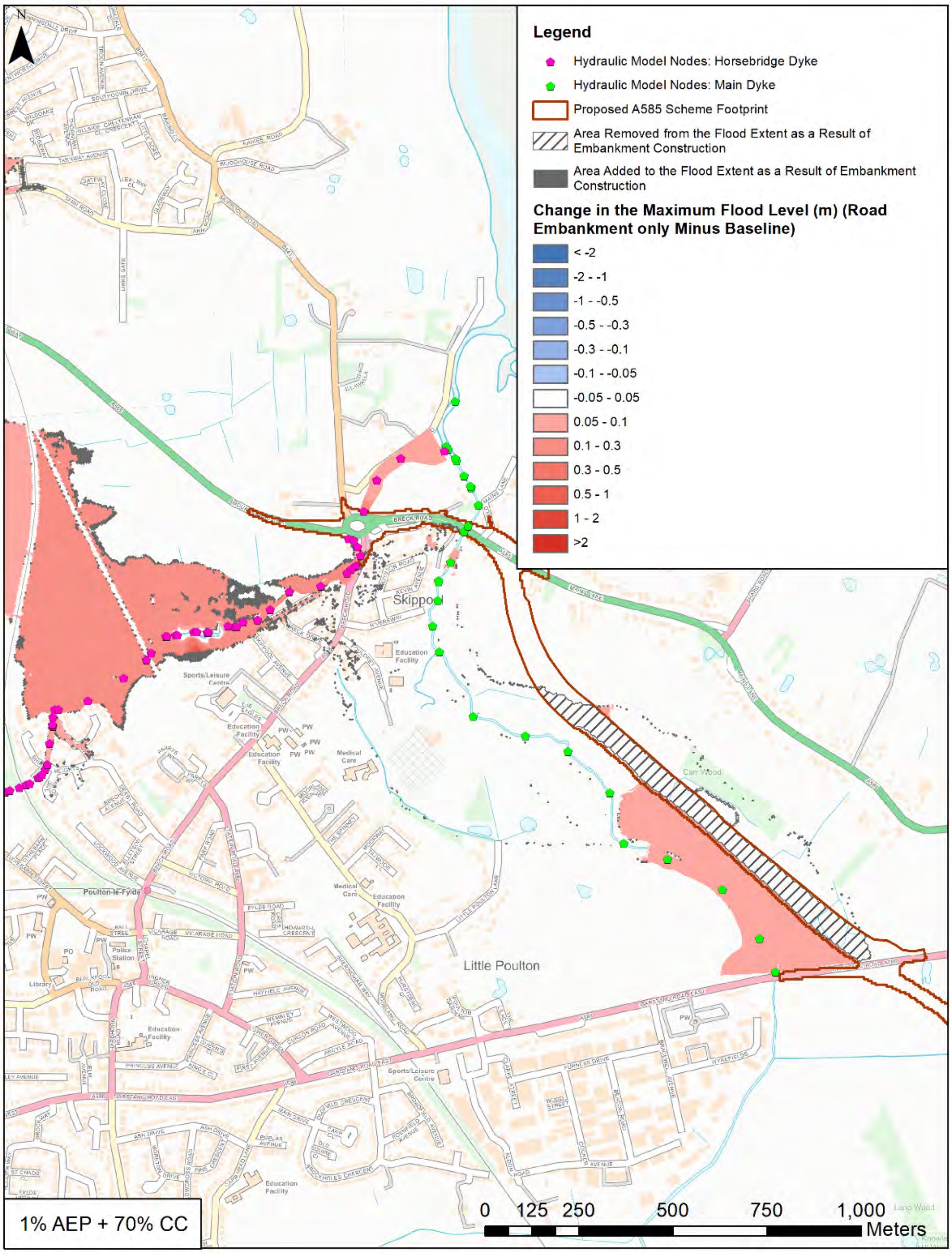


Figure D32 - Maximum flood depth difference [Scheme with embankment only and no widening of the A585 Main Dyke crossing - Baseline] for the 1% AEP (+70% Climate Change) flood event. Includes areas removed from and added to the flood extent as a result of embankment construction. (Contains Ordnance Survey data © Crown copyright and database right
2017)

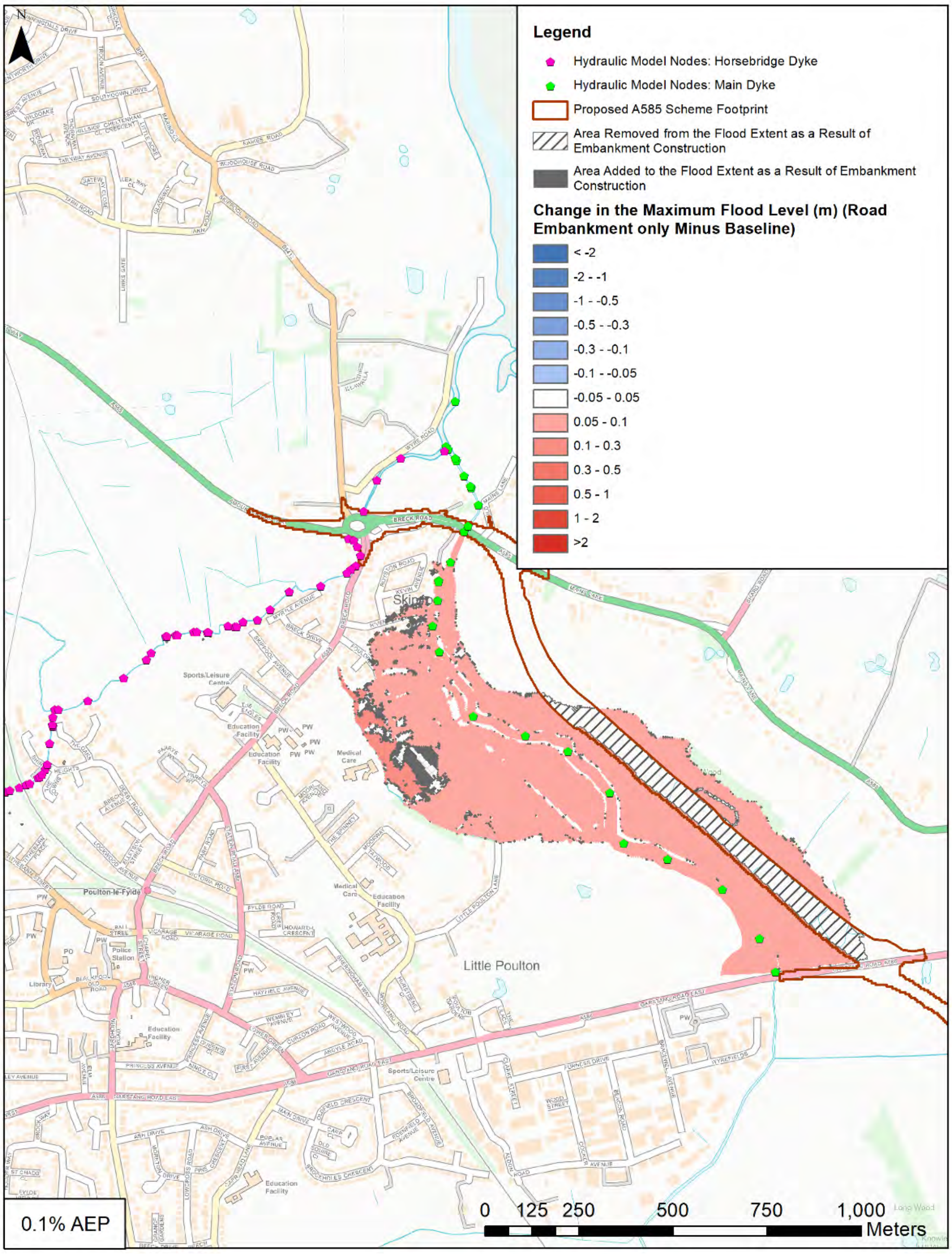


Figure D33 - Maximum flood depth difference [Scheme with embankment only and no widening of the A585 Main Dyke crossing - Baseline] for the 0.1% AEP flood event. Includes areas removed from and added to the flood extent as a result of embankment construction. (Contains Ordnance Survey data © Crown copyright and database right 2017)

Tide Locked Baseline and Option Flood Extents

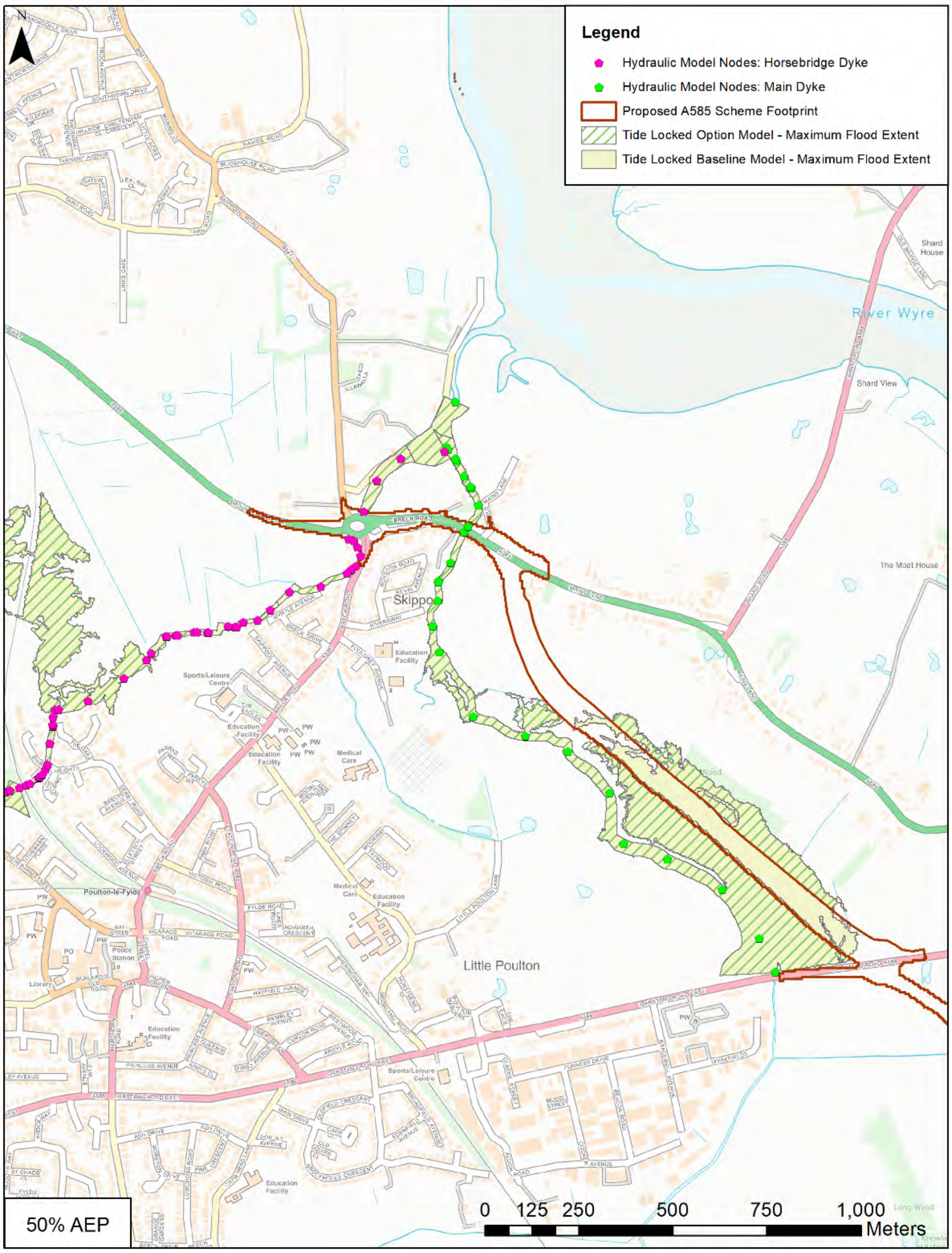


Figure D34 - Maximum flood extents [Tide Locked Baseline and 'With Scheme' (Option)] for the 50% AEP flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

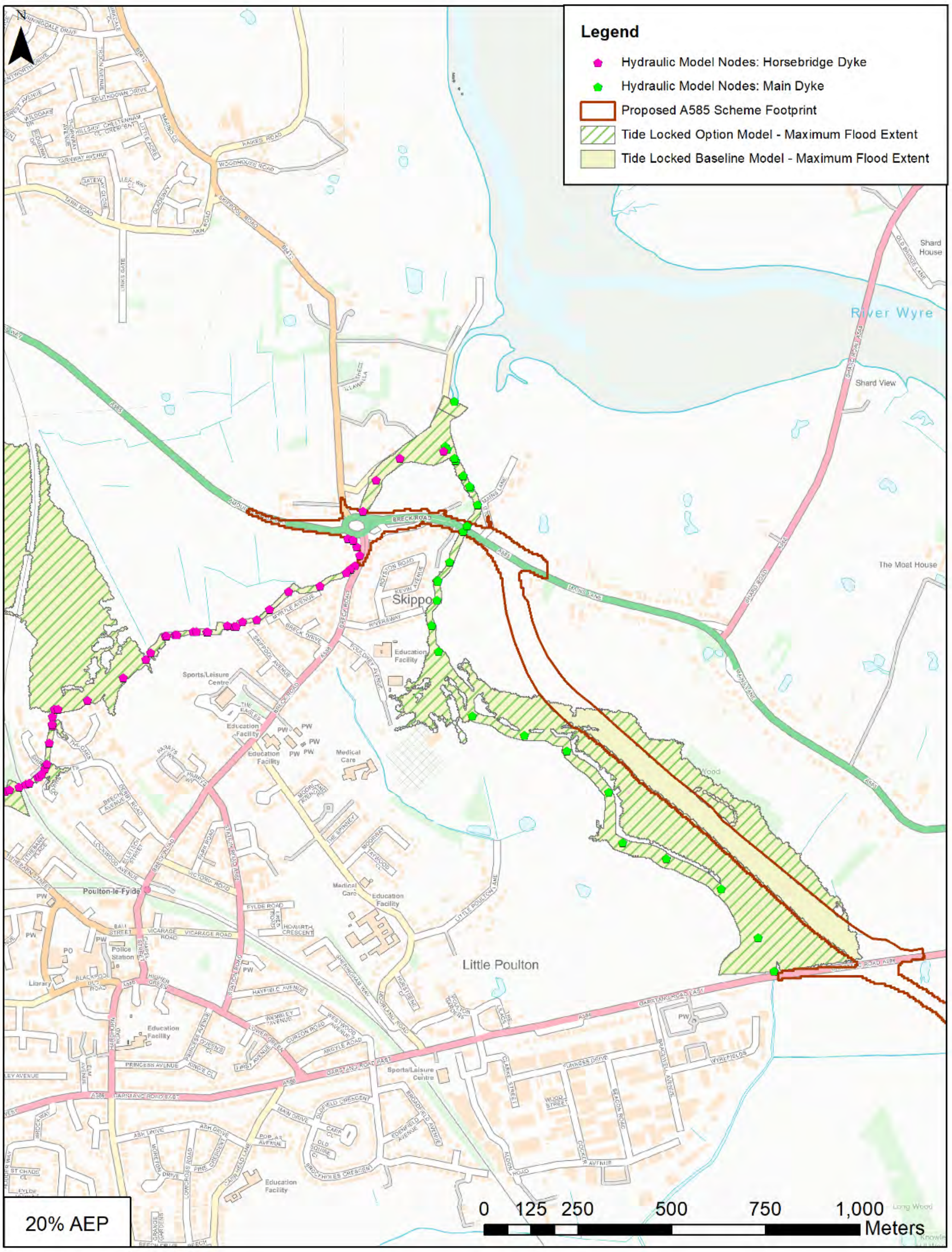


Figure D35 - Maximum flood extents [Tide Locked Baseline and 'With Scheme' (Option)] for the 20% AEP flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

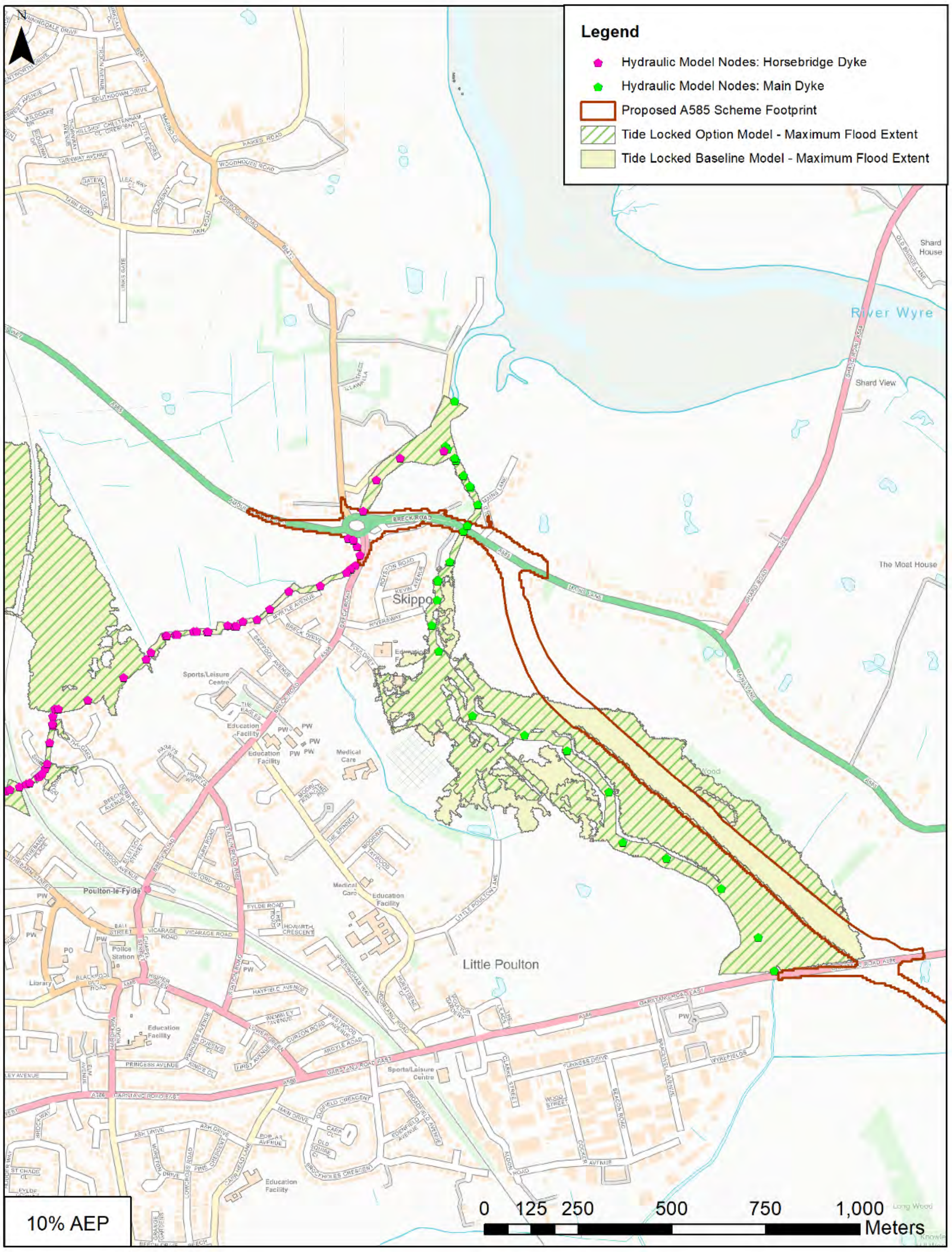


Figure D36 - Maximum flood extents [Tide Locked Baseline and 'With Scheme' (Option)] for the 10% AEP flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

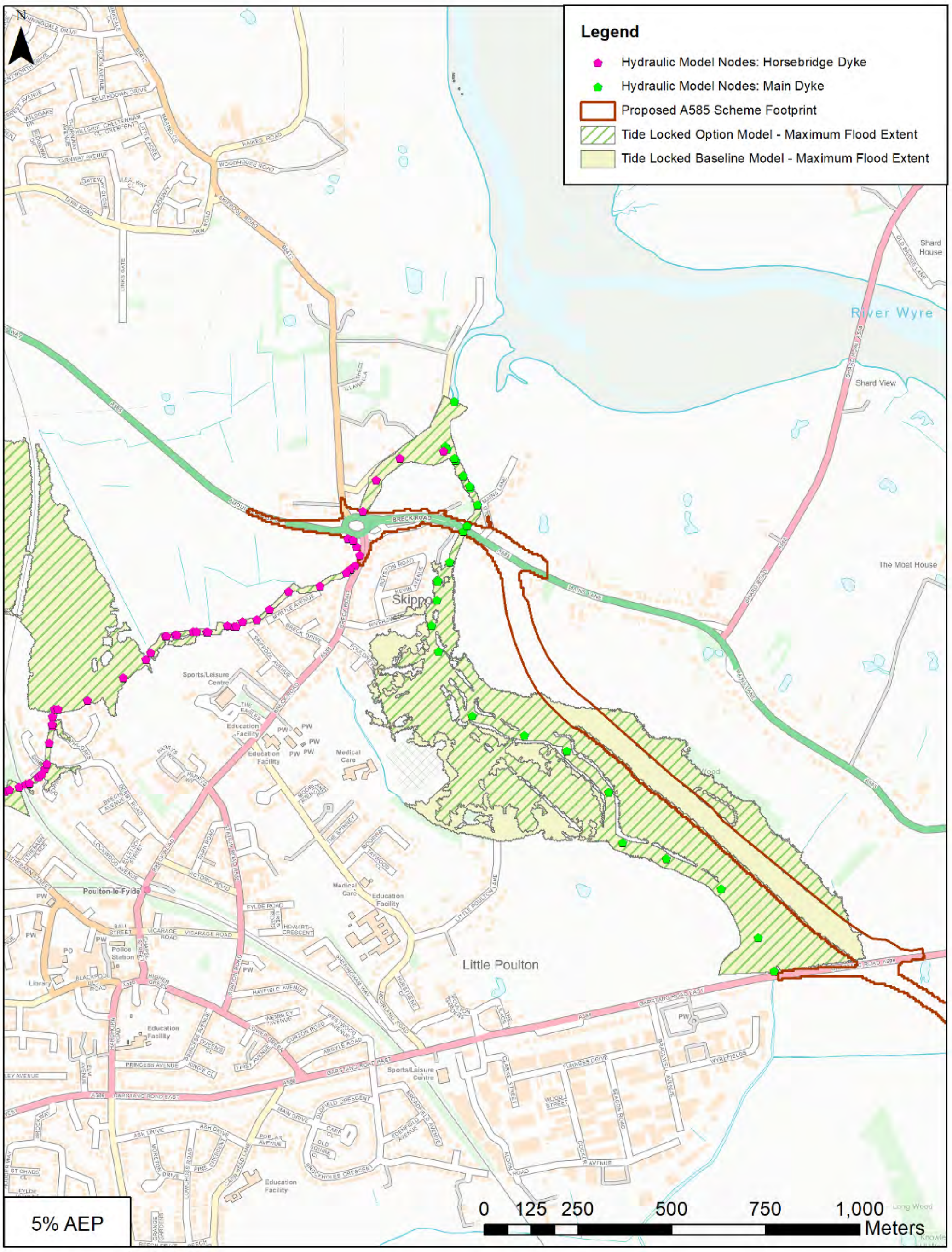


Figure D37 - Maximum flood extents [Tide Locked Baseline and 'With Scheme' (Option)] for the 5% AEP flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

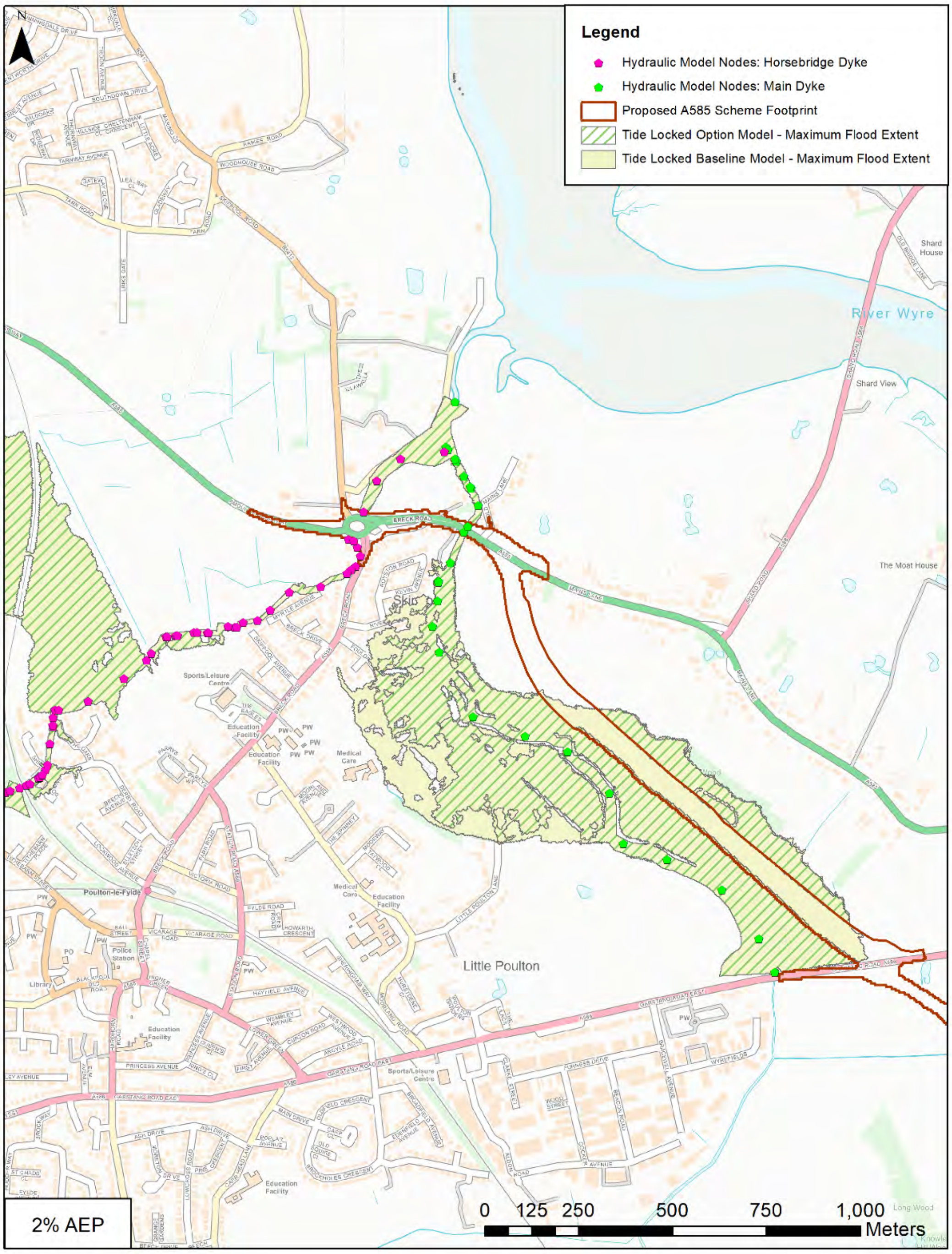


Figure D38 - Maximum flood extents [Tide Locked Baseline and 'With Scheme' (Option)] for the 2% AEP flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

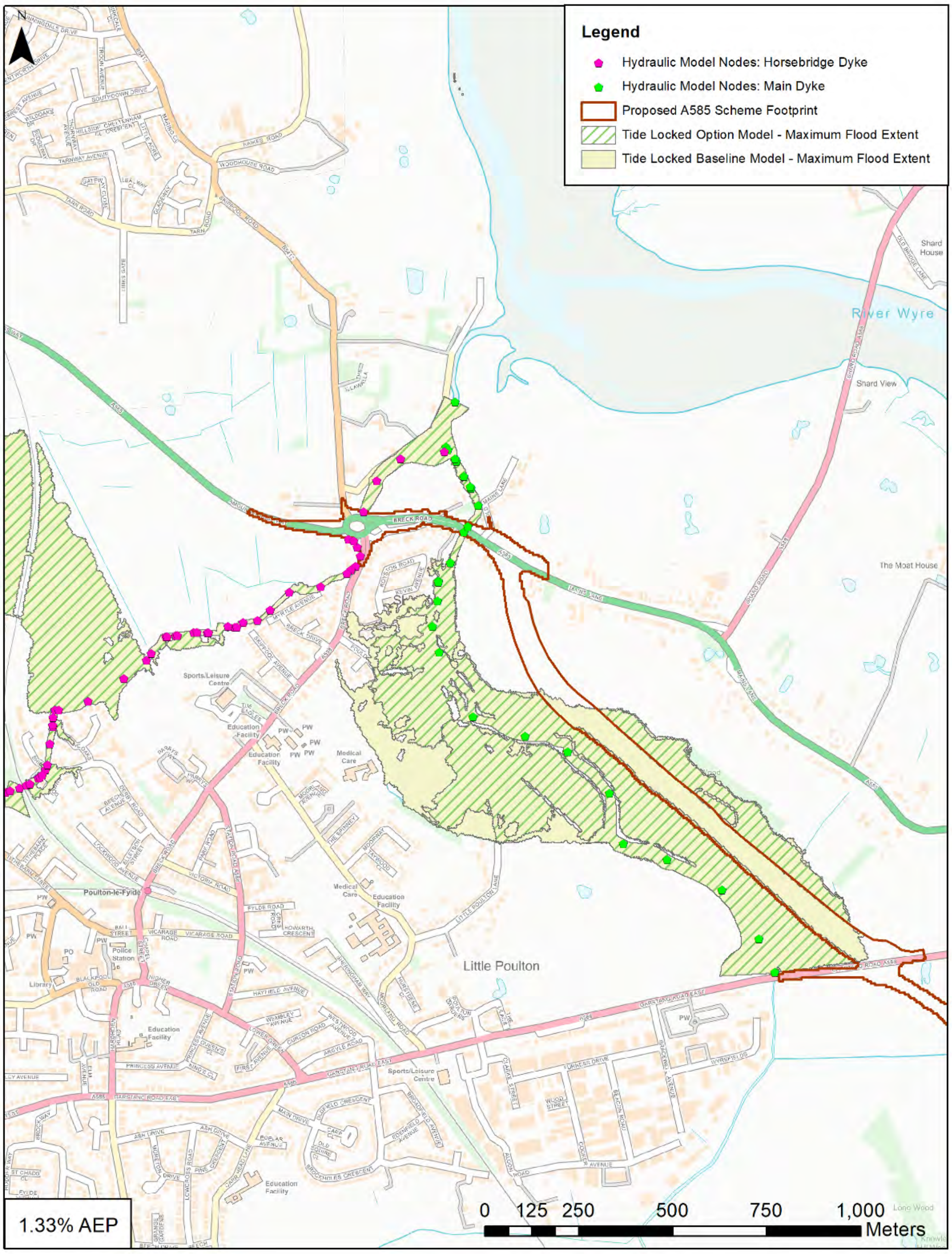


Figure D39 - Maximum flood extents [Tide Locked Baseline and 'With Scheme' (Option)] for the 1.33% AEP flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

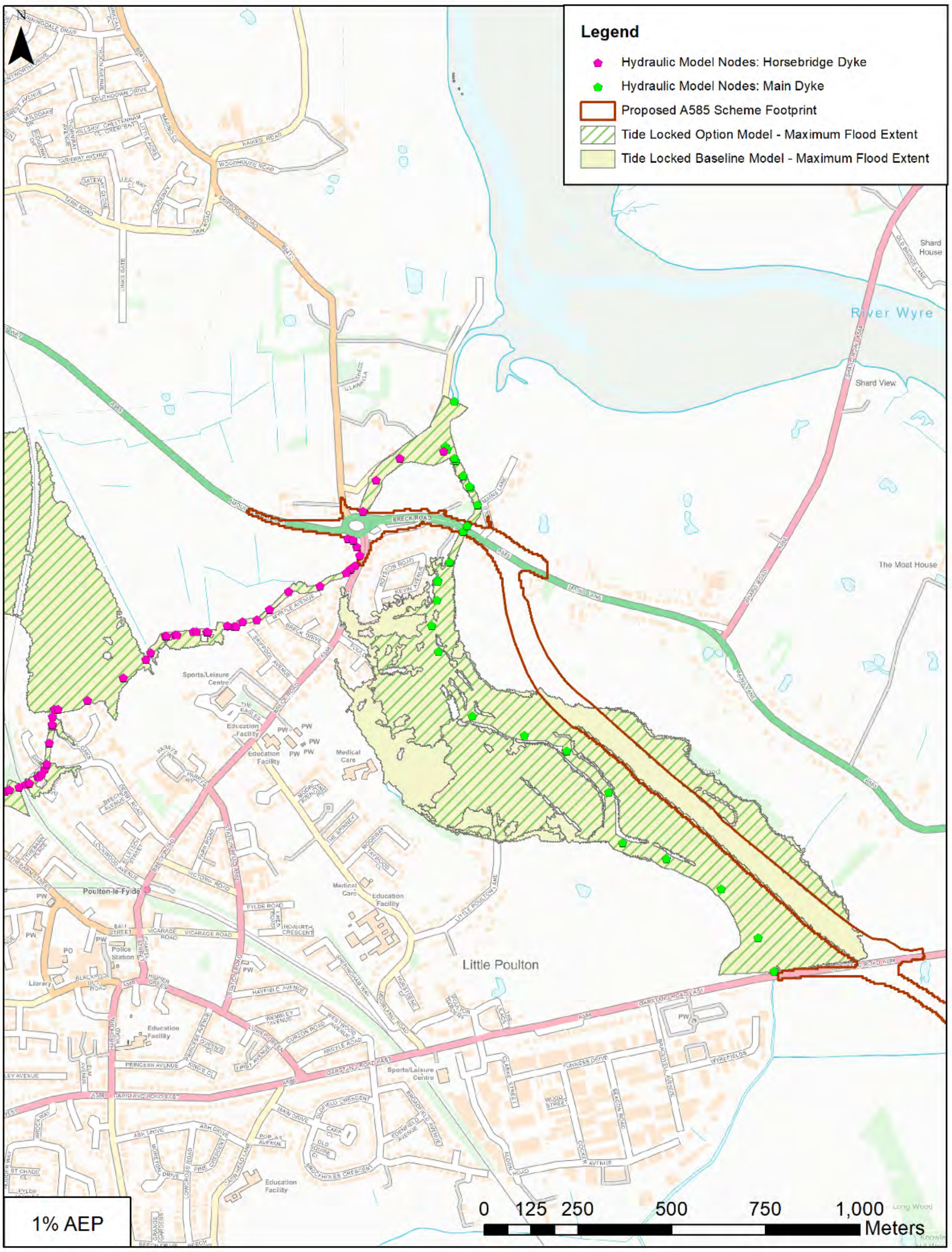


Figure D40 - Maximum flood extents [Tide Locked Baseline and 'With Scheme' (Option)] for the 1% AEP flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

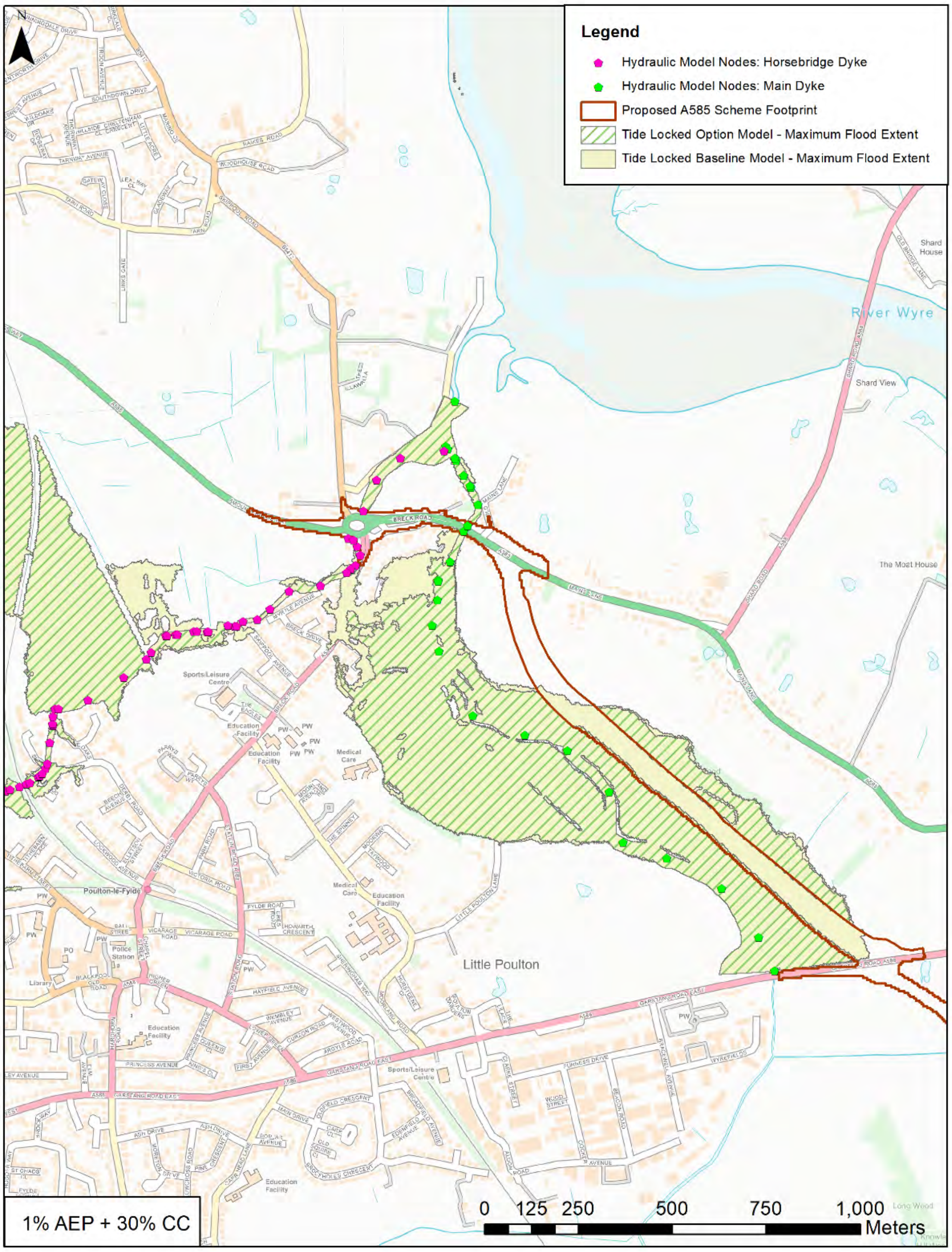


Figure D41 - Maximum flood extents [Tide Locked Baseline and 'With Scheme' (Option)] for the 1% AEP (+30% Climate Change) flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

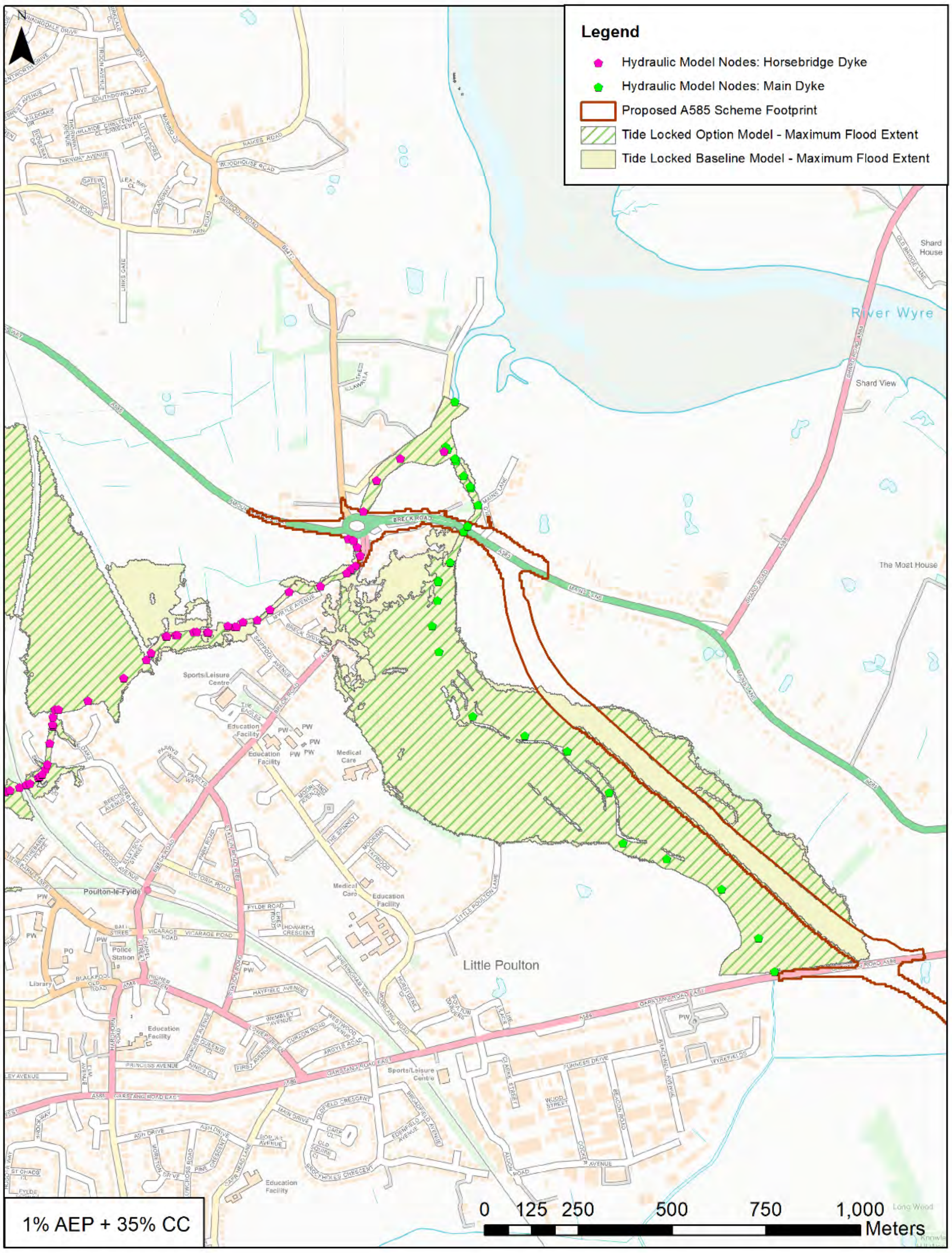


Figure D42 - Maximum flood extents [Tide Locked Baseline and 'With Scheme' (Option)] for the 1% AEP (+35% Climate Change) flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

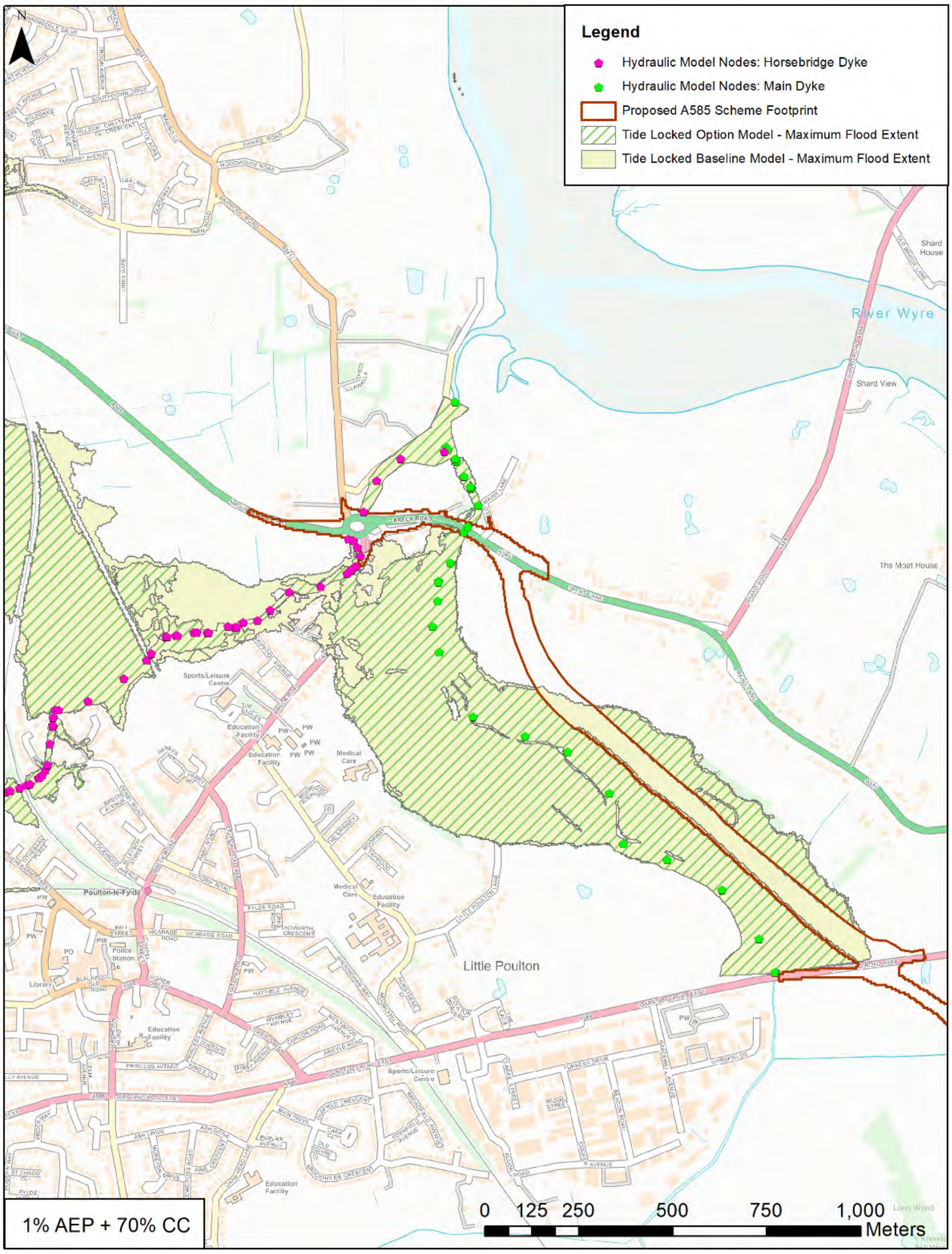


Figure D43 - Maximum flood extents [Tide Locked Baseline and 'With Scheme' (Option)] for the 1% AEP (+70% Climate Change) flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

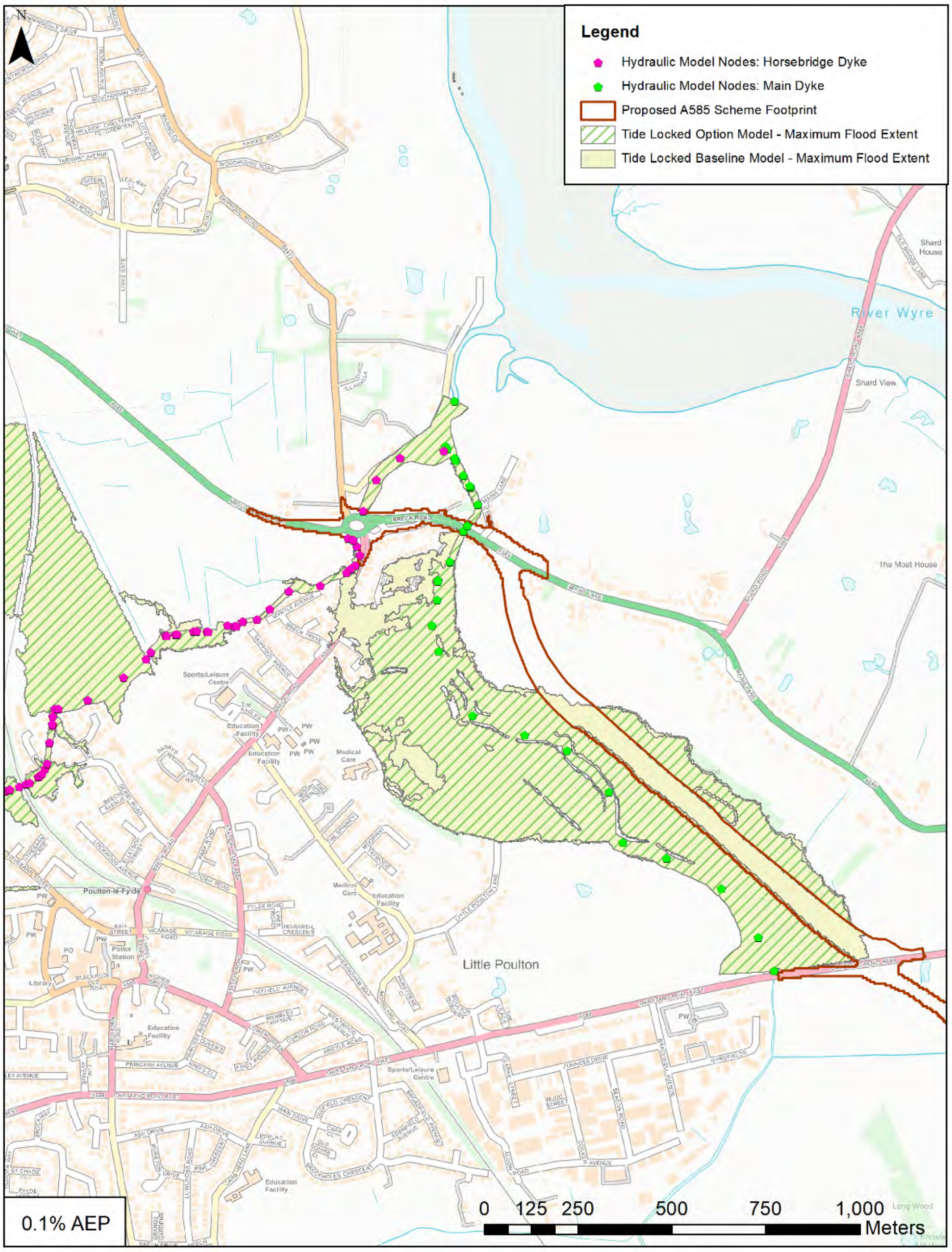


Figure D44 - Maximum flood extents [Tide Locked Baseline and 'With Scheme' (Option)] for the 0.1% AEP flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

Tidal Model Flood Extents

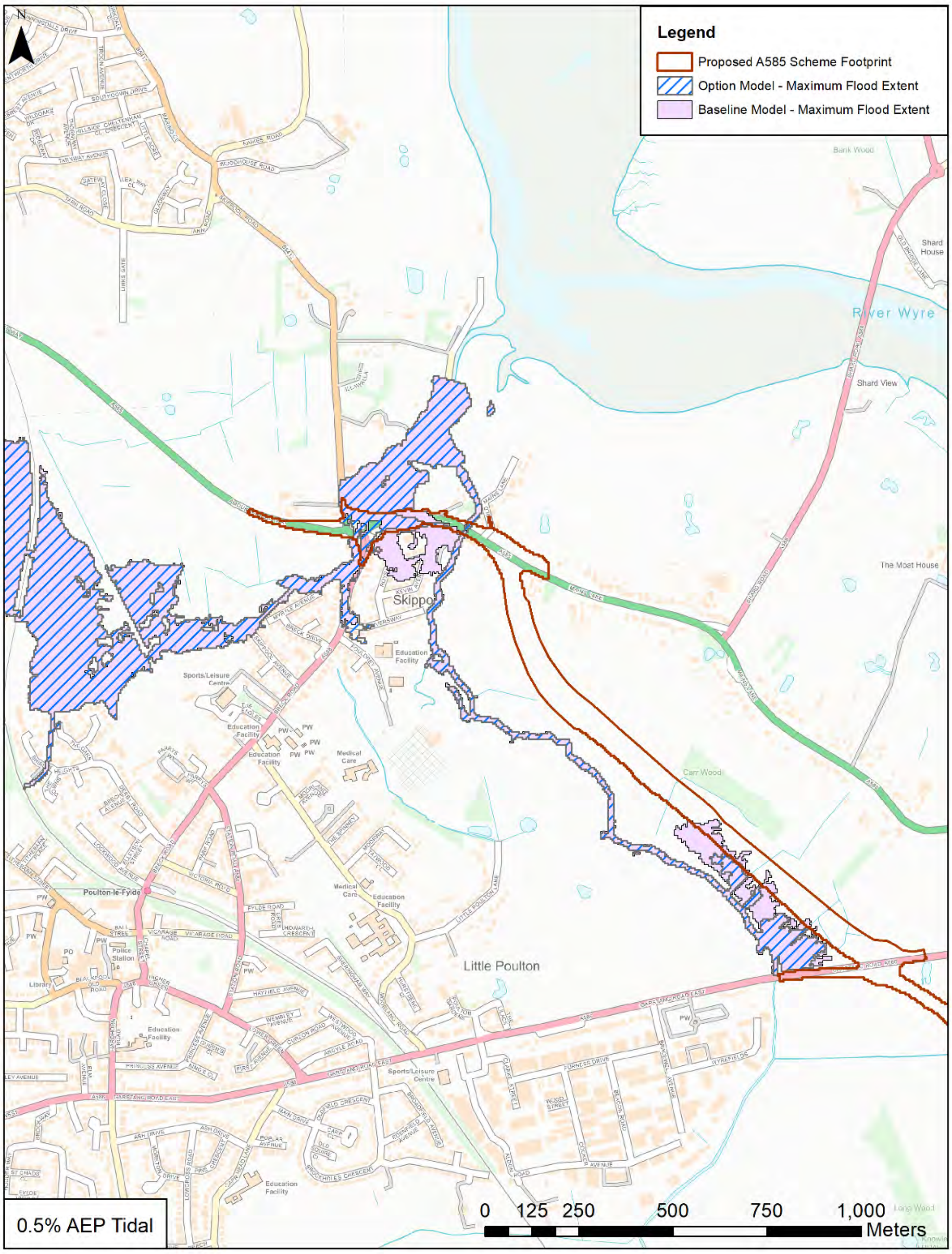


Figure D45 - Maximum flood extents [Tidal Baseline and ‘With Scheme’ (Option)] for the 0.5% AEP Tidal flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

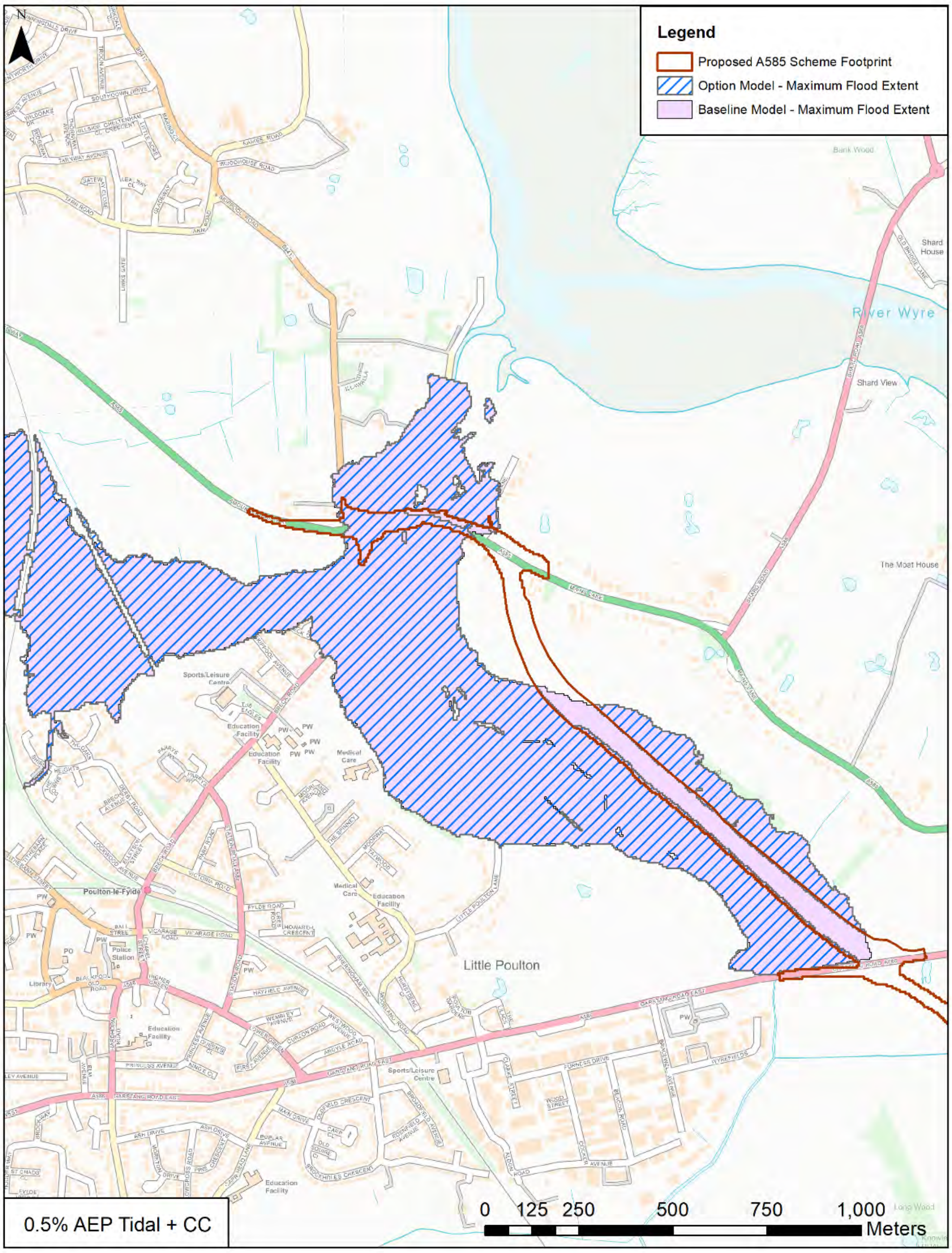


Figure D46 - Maximum flood extents [Tidal Baseline and 'With Scheme' (Option)] for the 0.5% AEP Tidal + Climate Change flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

Tidal Model Difference Grids

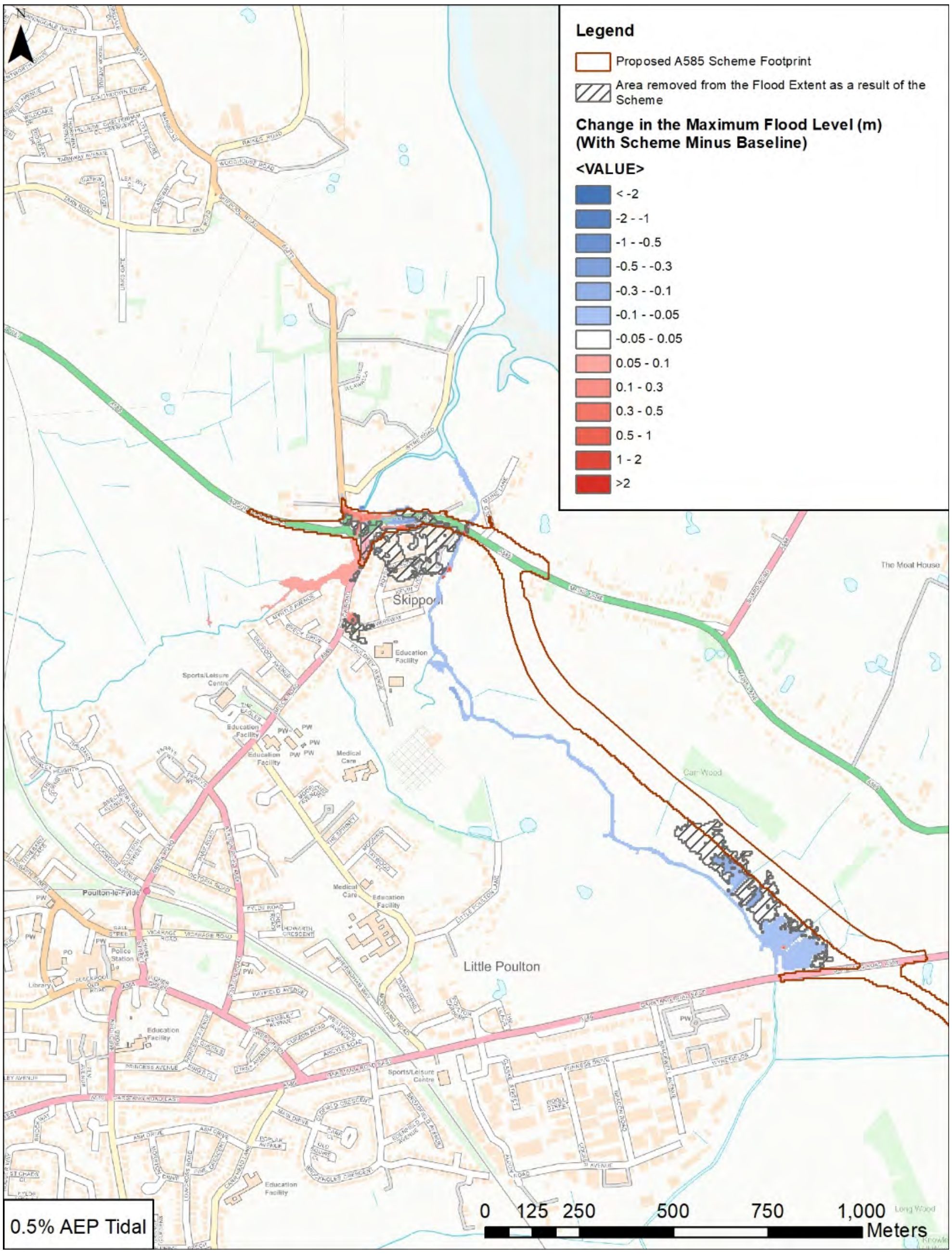


Figure D47 - Maximum flood depth difference [Tidal Baseline and 'With Scheme' (Option)] for the 0.5% AEP Tidal flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)

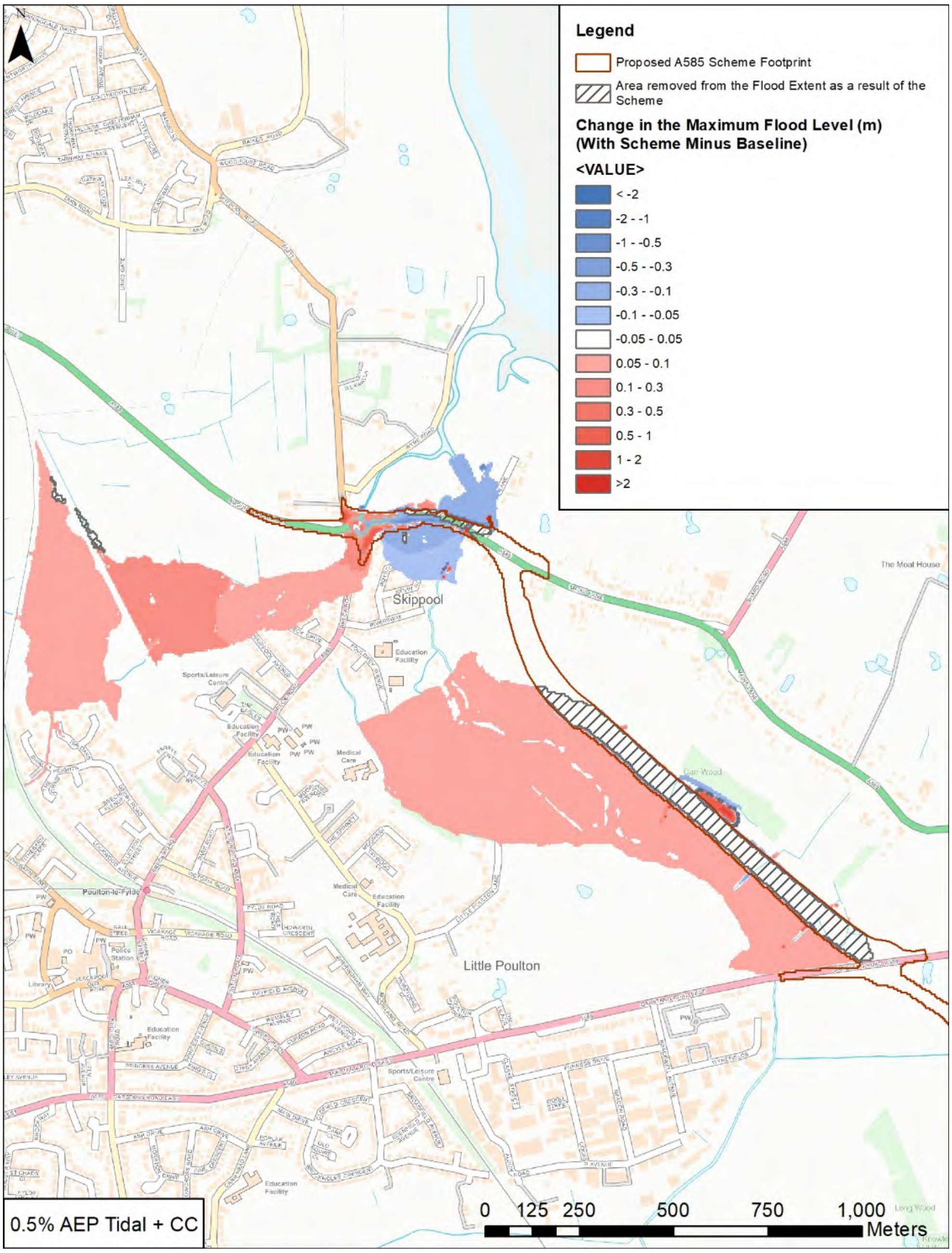


Figure D48 - Maximum flood depth difference [Tidal Baseline and 'With Scheme' (Option)] for the 0.5% AEP Tidal + Climate Change flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)[2]

[2] Dark red area to the north east of the Scheme is a proposed drainage pond. See section 6.4.1 of 5_2_HE548643-ARC-HGN-A585-RP-ZM-3094

Mitigation Scenario and Baseline Difference Grids

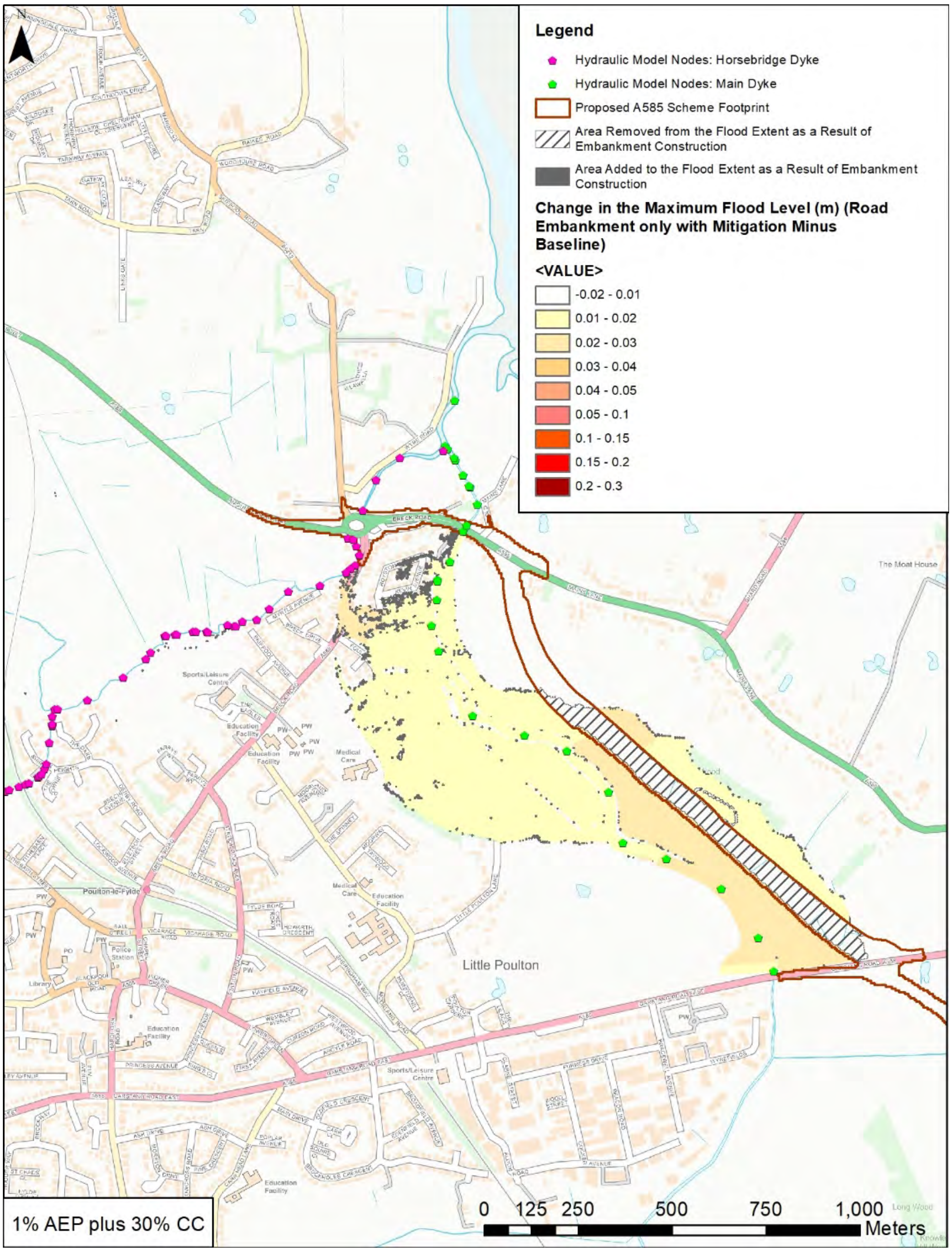


Figure D49 - Maximum flood depth difference [Baseline and 'with Mitigation'] for the 1% AEP + 30% Climate Change flood event (Contains Ordnance Survey data © Crown copyright and database right 2017)[3]

[3] In this case, a change of +/- 1cm has been used to colour the difference grid to aid clarity of understanding