# Lincolnshire Lakes Flood Defence Scheme

## Hydraulic Modelling Report

13 July 2017

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# Issue and Revision Record

| Revision | Date | Originator | Checker | Approver | Description |
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| A | 13/07/2017 | Mary Jeddere-Fisher | John Heald | Peter Charlesworth | Issued to EA with Model for Model Review |
| | | [redacted] | | | |

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# Contents

# 1 Introduction

## 1.1 Scope of work and objectives

Mott MacDonald Ltd (MML) has been instructed by North Lincolnshire Council (NLC) to design improvements to existing flood embankments along a 3.5km length of the River Trent from the M180 motorway bridge, through the village of Burringham to the A18 Keadby Bridge to the north of the village.

This report covers the hydraulic modelling work carried out by MML in order to assess the required flood defence levels, and to demonstrate the impact any improvements might have for the Lincolnshire Lakes Area and surrounding third parties.

## 1.2 Background to the scheme

Numerous reports and studies have been published for the Lincolnshire Lakes Area Action Plan (AAP) development. Of specific relevance to the flood defences is the Lincolnshire Lakes Flood Management and Drainage Strategy report prepared for NLC in October 2014. This report forms a broad appraisal of flood risks to the Lincolnshire Lakes AAP development site, potential measures to mitigate flood risk and recommendations for drainage requirements to inform the delivery of the final option masterplan for Lincolnshire Lakes.

The report identifies and assesses the flood risks posed to the wider AAP area:

- Fluvial flooding from overtopping and breaching of the River Trent Defences and flooding from the local watercourse network.
- Tidal flooding from overtopping and breaching of the River Trent Defences.
- Groundwater flooding.
- Surface water flooding.
- Sewer flooding.
- Reservoir flooding.
- Artificial sources including failure of drainage features within the drainage network.

At the time of the Lincolnshire Lakes Flood Management and Drainage Strategy report, the current defences were considered to provide protection up to the 1% Annual Exceedance Probability (AEP) event from fluvial sources. However, it was noted that there are a number of low spots along the defences that may reduce this Standard of Protection (SoP).

Tidal flooding is considered to pose the greatest of the above risks to the AAP area. For tidal flooding, the SoP is considered to be less than 0.5% AEP due to the presence of low spots. It was also noted that the storm surge event in December 2013 overtopped and breached parts of the defences, however it did not flood the AAP area.

Flooding from groundwater, surface water, sewer and reservoirs is considered a lower risk mitigated by land raising and drainage.

## 1.3 Site Location

The site is located on the right bank of the River Trent in Lincolnshire as shown in Figure 1.

**Figure 1: Site Location**


Source: Contains Ordnance Survey data Crown copyright and database right © 2017

The length of the site runs through Burringham, approximately 5.5km west of Scunthorpe, from the M180 bridge over the river at NGR 483228, 407474, to the A18 bridge at NGR 484198, 410659, and is approximately 3.6km in chainage length. A detailed figure of the site location, including chainage lengths, is provided in Figure 39 contained in Appendix A.

# 2 Data Availability

## 2.1 Hydraulic Model

The Environment Agency (EA) has provided its Interim Tidal Trent Model as part of a Product 7 information request for this project. This model is based on the Mott MacDonald (December 2013) ISIS-TUFLOW model with the following amendments made since by the EA:

- Changes to downstream boundary conditions following severe coastal flooding as the result of a tidal surge which occurred on the 5th December 2013. The revised design water levels were produced in June 2014 through analysis of water levels in the Humber Estuary and Tidal Trent, and have been recommended for use by the Environment Agency in the interim until further detailed analysis of the Humber has been completed. These levels are from here on in referred to as the EA interim tidal boundaries.
- Updated defence crest level survey using bank crest level survey undertaken by the EA following the 5th December 2013 tidal surge event. The survey was undertaken downstream of the M180 road bridge and focused specifically on the left and right bank defences in the vicinity of Burringham and Keadby
- Building representation – Three locations where buildings' footprints were erroneously lowering adjacent defence crest levels
- Defence elevations – A number of minor errors where LiDAR was not picking up wall crest levels
- Inclusion of a flood wall in Sutton on Trent

Further details of the amendments can be found in the EA's "Tidal Trent Modelling and Mapping Addendum 2015" report.

The EA's Interim Tidal Trent model extends from the Tidal limit of the River Trent at North Muskham to its confluence with the River Humber at Trent Falls. A number of tributaries have been included in the model, including the River Eau, Bottesford Beck and the Three Rivers (incorporating the River Torne) which discharges to the Tidal Trent via a pumping station at Keadby.

The EA's Interim Tidal Trent model also includes a number of breach runs, with breach location F (at SE484410), immediately upstream of A18 Bridge (at chainage location 3600 – see Appendix A) falling within the study area. Breach model results for breach location F show that floodplain inundation from the breach extends to the M180 to the south, and to the M181 to the east.

## 2.2 Topographic Data

Topographic data has been taken from a number of sources as detailed below.

### 2.2.1 LiDAR

The EA's Interim Tidal Trent model incorporates 1m and 2m resolution LiDAR flown in July 2011 with a typical vertical accuracy of ± 0.15m. In a few locations, LiDAR data was not available and SAR data (Synthetic-aperture radar) was used; however, in the vicinity of the Lincolnshire Lakes AAP Site, 1m resolution LiDAR data was available and used. It is not thought necessary to update the LiDAR data for this study.

### 2.2.2 Bathymetric Data

Geomatics conducted a bathymetric survey of the Tidal Trent between Gainsborough and Trent Falls in July 2013. This data has been provided by the Environment Agency. In a number of locations, particularly in the lower reaches downstream of Keadby, data was not available due to the high sediment load. Bed levels in these areas were interpolated by Geomatics from the surrounding data.

### 2.2.3 Topographic Survey

A topographic survey by Midland Surveys was undertaken in September 2015 as part of MML's ongoing design works for this project, covering the right bank of the Tidal Trent from the M180 bridge to the A18 bridge (as shown in Figure 39).

Table 1 below gives a summary of the defence type with height of defence and crest level, based upon site observations and the results of the topographic survey.

**Table 1: Summary of flood defence type and level with chainage from the M180 Bridge (NGR 484198, 410659)**

| Chainage (m) | Defence type | Defence crest level (mAOD) | Defence height (m)[1] |
|---|---|---|---|
| 0 – 3100 | Earth embankment | 5.90 – 6.45 | 1.03 – 2.88 |
| 3100 - 3300 | Earth embankment with sheet piles (emergency works) | 6.13 – 6.17 | 1.83 – 3.08 |
| 3300 – 3430 | Earth embankment with sheet pile walls and concrete cap | 6.12 - 6.30 | 2.69 – 2.86 |
| 3430 – 3523 | Earth embankment | 5.83 – 6.04 | 2.39 |
| 3523 - 3588 | Earth embankment with concrete wall (possibly sheet piled) | 6.20– 6.22 | |

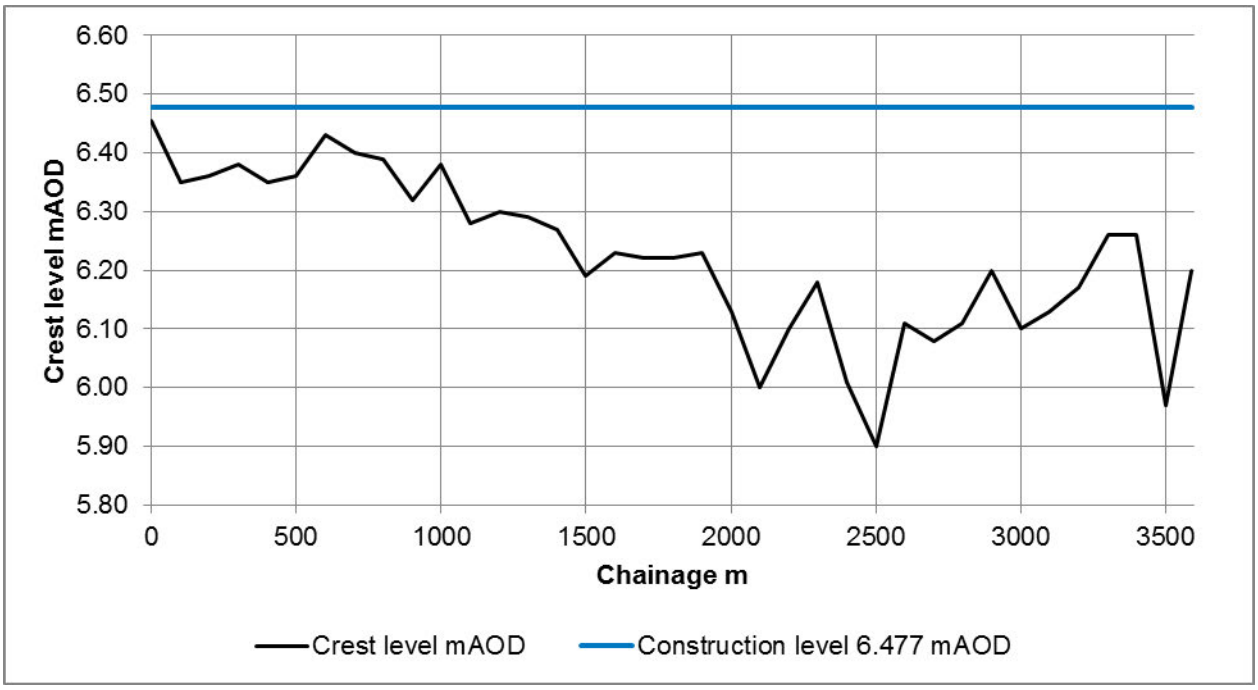
Note 1: Defence height is the vertical difference between the lowest toe and crest of embankments, or the vertical difference between the top of a hard defence and the surrounding ground.

During the course of this flood defence assessment, further topographic survey of the bank levels was undertaken by Survey Operations Ltd for the Environment Agency in August 2016. The survey extends on both banks from Morton (near Gainsborough) to Trent Falls. This data has been incorporated in the final model.

### 2.2.4 Historic Levels

The Trent River Board Report on the Tidal Reach Improvement Scheme (the 'blue book' design levels) records that the flood defences at Burringham were raised during the late 1950s, and built to a level of 21.25 feet AOD (6.477 mAOD). This has enabled an assessment of the embankment settlement since construction, as illustrated in Figure 2.

**Figure 2: Variation in flood defence height with chainage in relation to the 'blue book' level**




## 2.3 Hydrometric Data

### 2.3.1 Fluvial Data

Fluvial peak flow estimates have been taken from the EA's Interim Tidal Trent Model. The Tidal Trent Model Report (2013) includes a detailed review and update of the hydrological analysis of the Trent. Table 2 summarises the peak flows for the Trent and its tributaries within the model domain. North Muskham is located on the Trent, 1.5km upstream of the tidal limit of the Trent at Cromwell Weir, and the upstream extent of the model. No changes have been made to the Trent model's fluvial flows for this study.

**Table 2: Fluvial Design Peak Flows**

| Return Period Event | 2 or QMED | 5 | 10 | 20 | 50 | 75 | 100 | 200 | 1000 |
|---|---|---|---|---|---|---|---|---|---|
| AEP | 50% | 20% | 10% | 5% | 2% | 1.33% | 1% | 0.5% | 0.1% |
| North Muskham | 470 | 591 | 673 | 794 | 1020 | 1136 | 1215 | 1433 | 2124 |
| River Idle | 20.4 | 27.8 | 33.4 | 39.5 | 49.0 | 53.8 | 57.5 | 67.5 | 97.7 |
| Warping Drain | 0.8 | 1 | 1.2 | 1.3 | 1.6 | 1.7 | 1.8 | 2.1 | 3.1 |
| Ferry Drain | 2.1 | 2.6 | 3.1 | 3.5 | 4.2 | 4.6 | 4.9 | 5.7 | 8.3 |
| River Torne | 7.9 | 10.4 | 12.5 | 14.7 | 18.2 | 20.1 | 21.6 | 25.8 | 40.6 |
| Hatfield Waste Drain | 8.1 | 10.1 | 11.6 | 13 | 15.2 | 16.4 | 17.3 | 19.7 | 27.7 |
| South Soak Drain | 2.1 | 2.5 | 2.9 | 3.2 | 3.8 | 4.1 | 4.4 | 5 | 7.1 |
| North Soak Drain | 3.1 | 3.9 | 4.5 | 5.1 | 6.0 | 6.4 | 6.8 | 7.8 | 11.1 |
| River Eau | 10.7 | 17.2 | 20.7 | 23.5 | 27.6 | 29.3 | 30.2 | 36.1 | 53.1 |
| Bottesford Beck | 2.7 | 3.7 | 4.6 | 5.5 | 7.0 | 7.8 | 8.5 | 10.4 | 17.4 |

Source: Tidal Trent Modelling and Mapping Report (Mott MacDonald, 2013)

### 2.3.2 Tidal Levels

Tidal level data for different return periods has been provided by the Environment Agency at Blacktoft. The levels provided are the “Humber Interim Water Levels”, which are interim water levels produced in June 2014 after the December 2013 tidal surge, through analysis of water levels in the Humber Estuary and Tidal Trent. These have been recommended for use by the Environment Agency in the interim until further detailed analysis of the Humber has been completed. Design levels at Blacktoft are provided in Table 3. Both the Best Estimate and 95% Upper Band levels have been provided.

**Table 3: Tidal Design Peak Levels at Blacktoft**

| Return Period Event | 2 | 5 | 10 | 20 | 50 | 70 | 80 | 100 | 200 | 1000 |
|---|---|---|---|---|---|---|---|---|---|---|
| AEP | 50% | 20% | 10% | 5% | 2% | 1.4% | 1.25% | 1% | 0.5% | 0.1% |
| Best Estimate (mAOD) | 5.37 | 5.51 | 5.62 | 5.72 | 5.83 | 5.87 | 5.88 | 5.90 | 5.96 | 6.04 |
| 95% Upper Band (mAOD) | 5.38 | 5.54 | 5.66 | 5.77 | 5.90 | 5.94 | 5.95 | 5.98 | 6.03 | 6.04 |

Source: Environment Agency (Humber Interim Water Levels – 2014)

# 3 Hydrological Inputs

## 3.1 Fluvial Inflows

As detailed in section 2.3.1, no changes have been made to the present day fluvial hydrology as used in the EA's Interim Tidal Trent model.

## 3.2 Tidal Boundaries

The tidal boundaries have been updated using the Humber Interim Water Levels at Blacktoft (as provided in Table 3. The 95% upper band estimate has been used as a conservative estimate. Note that there is no difference between the best estimate and 95% upper band estimate for the 1 in 1000 year event.

The tidal boundary at Trent Falls has been derived in the same way as described in the Tidal Trent Modelling Report (Mott MacDonald 2013, page 150): using a relationship between the water levels at Blacktoft and Burton Stather gauges derived from observed data. The derived relationship is as follows:

Level at Burton Stather = 0.9668*Level at Blacktoft + 0.1605

Table 4 details the peak tidal levels used in the downstream boundary of the model

**Table 4: Summary of peak tidal levels used in model (present day scenario)**

| Tidal Return Period (AEP) | Interim Water Level at Blacktoft (mAOD) (HR Wallingford, 2014) | Target Design Level Burton Stather (mAOD) | Peak Level in TUFLOW boundary file (mAOD) | Level Check at Burton Stather (mAOD) |
|---|---|---|---|---|
| 1.33% | 5.95 | 5.91 | 5.87 | Not run as a present day scenario |
| 0.5% | 6.03 | 5.99 | 5.94 | 6.01 |
| 0.1% | 6.04 | 6.00 | 5.98 | Not run as a present day scenario |

The modelled levels at Burton Stather are within 0.05m of the target design levels.

## 3.3 Climate Change

### 3.3.1 Climate change guidance

The climate change guidance issued by the Environment Agency was updated during the course of this study.

#### 3.3.1.1 Prior to change in guidance on 19th February 2016

Prior to the 19th February 2016 the guidance suggested a uniform 20% increase in flows for climate change to 2115.

#### 3.3.1.2 Post change in guidance on 19th February 2016

On the 19th February 2016, the guidance issued provided regionally specific climate change estimates. The Lincolnshire Lakes Development site falls into the Humber river basin district for river flow guidance, and the East, East Midlands, London and South East region for sea level allowances.

There are four types of climate change allowances for fluvial scenarios:

**Table 5: Fluvial Climate Change Scenarios – Updated guidance**

| Climate change scenario | Guidance origin | % Increase in flows to 2040 | % Increase in flows to 2050 | % Increase in flows to 2115 |
|---|---|---|---|---|
| H++ | Note 1 | 35 | 35 | 65 |
| Upper End | Note 2 | 30 | 30 | 50 |
| Higher Central | Note 2 | 20 | 20 | 30 |
| Central | Note 2 | 15 | 15 | 20 |

Note 1: Table 3: H++ river flood flow scenarios for each river basin district. Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities, first published 1st September 2011, last updated 13th April 2016
Note 2: Table 1: peak river flow allowances by river basin district. Flood risk assessments: Climate change allowance, first published 19th February 2016, last updated 12th April 2016

There are two types of climate change allowances for tidal scenarios:

**Table 6: Tidal Climate Change Scenarios – Updated guidance**

| Climate change scenario | Guidance origin | Sea level rise mm/yr up to 2025 | Sea level rise mm/yr 2026 - 2050 | Sea level rise mm/yr 2051 - 2080 | Sea level rise mm/yr 2081 - 2115 | Total rise to 2115 (m) |
|---|---|---|---|---|---|---|
| H++ | Note 1 | 6 | 12.5 | 24 | 33 | 2.24 |
| Upper End | Note 2 | 4 | 8.5 | 12 | 15 | 1.13 |

Note 1: Table 5: H++ Mean sea level allowances. Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities, first published 1st September 2011, last updated 13th April 2016
Note 2: Table 3: sea level allowance for each epoch per year. Flood risk assessments: Climate change allowance, first published 19th February 2016, last updated 12th April 2016

The guidance published on the 19th February states that:

“The high++ allowances will only apply in assessments for developments that are very sensitive to flood risk and with lifetimes beyond the end of the century. For example, infrastructure projects or developments that significantly change existing settlement patterns. This includes urban extensions and new settlements.”

### 3.3.2 Climate Change Scenarios used in this study

Considerable discussion has taken place between the Environment Agency, North Lincolnshire Council, and Mott MacDonald as to the most appropriate climate change allowance and design epoch to use in this study. A Managed Adaptive Approach (MAA) has been adopted for the design and modelling of defences at LLAP, based on recommendations by the EA in their ‘Lincolnshire Lakes Flood Risk Strategy way forward’ document issued in July 2016. This is a new way of approaching future flood risk and is summarised below.

#### 3.3.2.1 Managed Adaptive Approach – Overview

Initial modelling by Mott MacDonald of the lower probability climate change scenario (H++) shows that the impacts are of such a magnitude that a local flood mitigation scheme is unviable and disproportionate to the scale of the proposed development. A solution based on a catchment management scale would be required. The level of modelling is beyond the remit of North Lincolnshire Council and solutions that may emanate from such a study would likely require the cooperation of numerous Local Authorities across the River Trent catchment area. This modelling is covered in a separately issued Mott MacDonald Ltd report, reference (358811_R02).

The EA have acknowledged this in their 'Lincolnshire Lakes – Flood Risk Strategy way forward' and have developed a Managed Adaptive Approach which effectively permits the provision of flood risk mitigation to revised climate change scenarios with the provision of future cooperation and the implementation of a catchment wide mitigation system.

This approach enables the proposed AAP development to successfully mitigate flood risk locally for a specific future epoch, making the development viable.

The main characteristic of the Managed Adaptive Approach is that it acknowledges that the estimate and scale of climate change effects will change over time. The revised climate change guidance also acknowledges this with estimations of the anticipated magnitude of applicable climate change effects for a variety of epochs up to 2115.

In simplified terms, the estimated level of a particular flood defence required to provide a specific level of protection for 2050 will be different from the level estimated for 2115. The MAA enables the current estimated level of protection for, say, 2050 to be constructed now but in such a way that in, say, 2030, the defence may be increased in level to provide protection up to 2115. It may also take in to account any variation in the calculation of climate change that may arise from increased knowledge about how the climate is actually changing (this could be either an increase or a decrease from the current climate change predictions).

The modelling will provide an estimate of flood risk, based on current climate change prediction models and guidance, of design events for the 2040 (fluvial), 2050 (tidal) and 2115 (both fluvial and tidal) epochs.

The following epochs and climate change scenarios have been considered:

1. Tidal Events
    a. Upper End tidal estimates, and Upper End fluvial estimates for 2050 (0.25m increase to sea levels and 30% increase to fluvial flows)
    b. H++ tidal estimates, and H++ fluvial estimates for 2050 (0.37m increase to sea levels and 35% increase to fluvial flows)
    c. Upper End tidal estimates, and Upper End fluvial estimates for 2115 (1.13m increase to sea levels and 50% increase to fluvial flows)
    d. H++ tidal estimates, and H++ fluvial estimates for 2115 (2.24m increase to sea levels and 65% increase to fluvial flows)
2. Fluvial Events
    a. Upper End tidal estimates, and Higher Central fluvial estimates for 2040 (0.16m increase to sea levels and 20% increase to fluvial flows)
    b. H++ tidal estimates, and H++ fluvial estimates for 2040 (0.24m increase to sea levels and 35% increase to fluvial flows)
    c. Upper End tidal estimates, and Higher Central fluvial estimates for 2115 (1.13m increase to sea levels and 30% increase to fluvial flows)
    d. Upper End tidal estimates and Upper End fluvial estimates for 2115 (1.13m increases to sea levels and 50% increase to fluvial flows)

e. H++ tidal estimates, and H++ fluvial estimates for 2115 (2.24m increase to sea levels and 65% increase to fluvial flows)

# 4 Hydraulic Model Updates

## 4.1 Background

The EA Interim Tidal Trent Model provided by the EA, was reviewed by MML. Particular attention was paid to the level of calibration achieved when simulating the tidal surge event from December 2013. The model was noted to underestimate peak levels at the Keadby gauging station during this event by 0.4m (Modelled peak level of 5.96mAOD compared to observed peak of 6.36mAOD). Burringham, the area of interest, is located very close to Keadby. Therefore, this underestimate of peak flood levels was of concern and a number of alterations were made to the EA Interim model to improve the level of calibration. These model updates, detailed under section 4.2, were submitted to the EA on 20$^{th}$ November 2015, accompanied by a technical note for the EA's approval prior to the updated model being used in this study for design option modelling.

## 4.2 Baseline Model Updates

### 4.2.1 Updates prior to submitting the hydraulic model to the EA for approval

The following alterations have been made to the EA Interim Tidal Trent Model prior to submission to the EA for approval:

1. Model Domain – The 2D model domain was kept the same as the EA model, with the exception of:
    a. The downstream boundary and code region was shaped to gain a better representation of the flow from the Humber into the Trent.
    b. The 1D ISIS model was truncated at Owston Ferry, with the Trent downstream of Owston represented in the 2D domain. The 1D model was linked to the 2D representation of the River Trent through the use of an HX line.
    c. Re-profiling of the 1D channel in 3 of the 4 most downstream nodes (27810, 27360, 27130). This was to smooth the bed levels and ensure a stable transition from the 1D model to the 2D representation of the River Trent.
2. Bed Topography – The bed topography downstream of Owston Ferry was represented using bathymetric data. This is the same data source as was used to derive the 1D ISIS cross-sections in the EA interim model. At the very downstream reach of the Tidal Trent, and within the Humber Estuary, bathymetric data was not available and a conceptualised sloping bed level was incorporated using z-shapes. Gauge data at Burton Stather during the December 2013 event was used to confirm that the conceptualised bed profile reproduced observed levels within this model reach.
3. Bed roughness – A significant change was made to the bed roughness in the lower reaches of the River Trent. The roughness downstream of Keadby was reduced to a value of 0.01 (from a value of 0.02) and a value of 0.018 (from a value of 0.02) was used from Keadby to Owston Ferry. These roughness values are low compared to the widely accepted values suggested by Chow. However, research into the modelling of tidal bores has shown that values as low as 0.004 have been successfully used to replicate the tidal bore on the Qiantang River, China[1].

[1] Modelling the tidal bore on the Qiantang River, China: An application of FVCOM. Environmental Hydraulics. D.F. Xie, C.H. Pan & X.G. Wu

4. The Trent has a bore under non-flood conditions (the Trent Aegir) up to 1.5 metres high, occurring when a high spring tide meets the downstream flow of the river. During the December 2013 event, the water level rose 2.35m in under 15 minutes.
5. Two commands within the .tgc file were re-ordered as the 2d_zsh_TTRENT_BUILDINGS_02 file (updated by the EA on 29/10/14) was being read in after 2d_zsh_TTRENT_TRIBUTARY_OUTFALL. This was lowering the bank in the region of the River Eau outfall causing the Trent to overtop its banks prematurely at a level of around 4mAOD.

#### 4.2.1.1 Baseline model calibration – December 2013

The revised model was run using observed boundary conditions from the December 2013 event and compared against observed data at Burton Stather, Keadby and Gainsborough, and against the modelled results from the EA Interim Model. Figure 3 to Figure 5 show the comparison at each location, and Table 7 shows a comparison of the peak levels.

**Figure 3: Comparison of modelled levels against observed levels at Burton Stather**

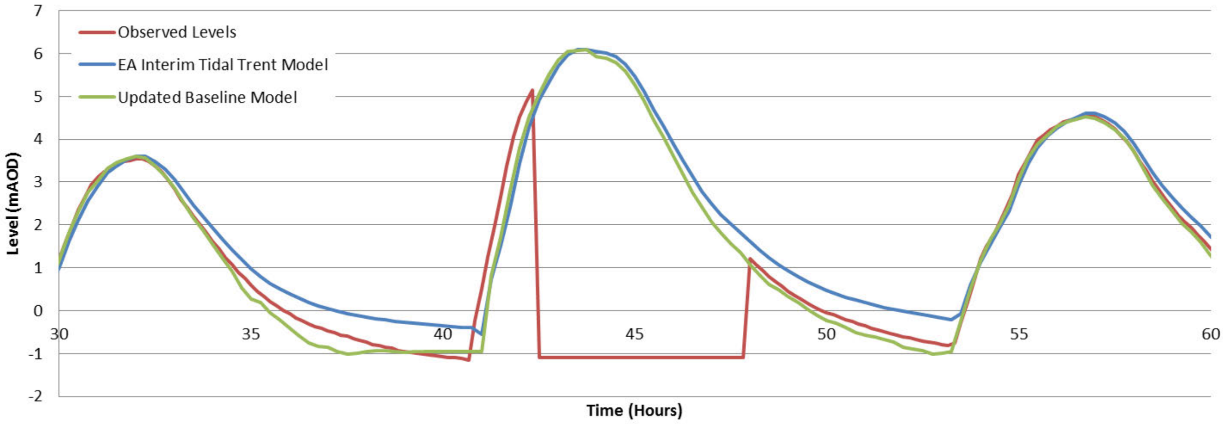



**Figure 4: Comparison of modelled levels against observed levels at Keadby**

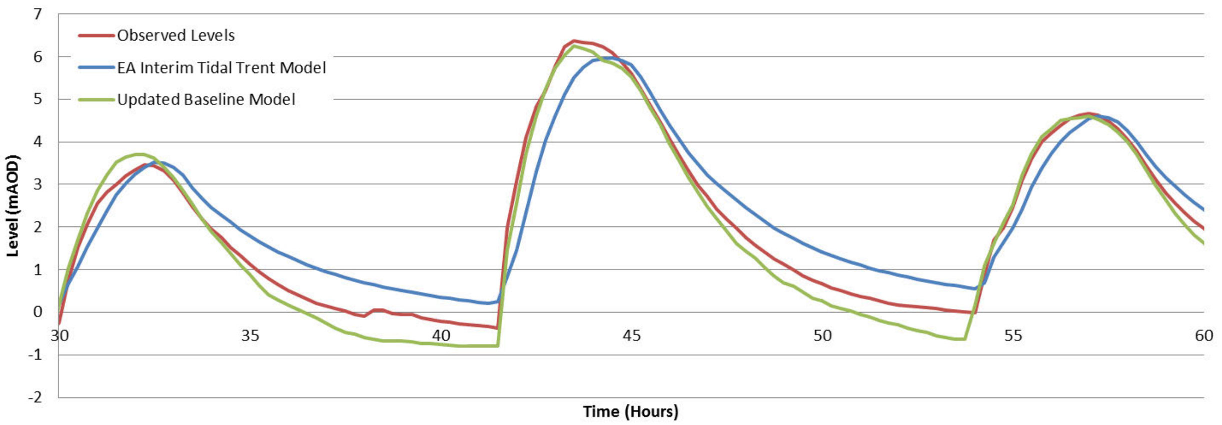
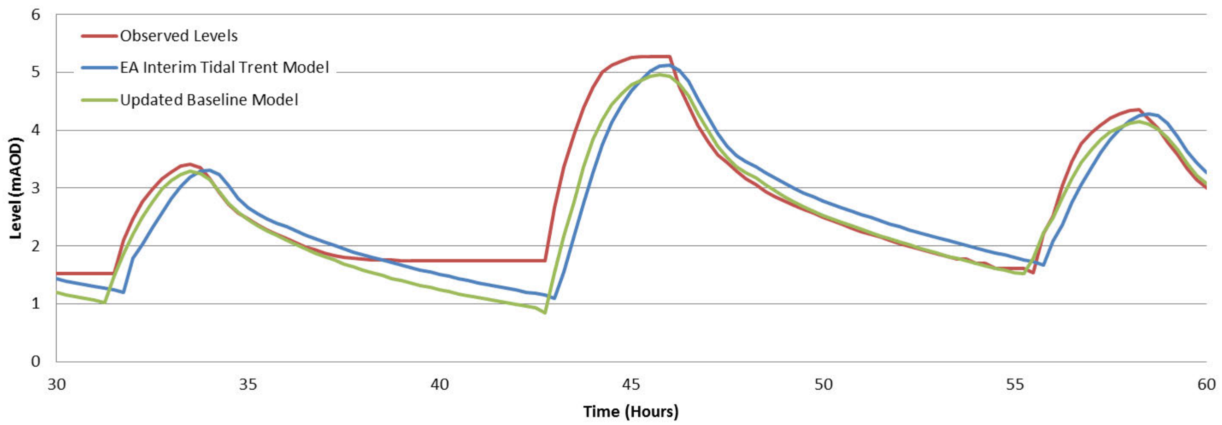



**Figure 5: Comparison of modelled levels against observed levels at Gainsborough**




Source: Mott MacDonald and Environment Agency

**Table 7: Comparison of peak levels at key gauging stations**

| Location | Peak Levels (mAOD) | | | Comments on Updated Baseline Model |
|---|---|---|---|---|
| | Observed | EA Interim Model | Updated Baseline Model | |
| Burton Stather | Peak Missed by recorder | 6.09 | 6.08 | Peak of event missed by recorder, however good match to peak levels during tide cycles either side of main event |
| Keadby | 6.36 | 5.96 | 6.24 | Much improved representation of shape of tidal curve, although still underestimating the peak level at Keadby |
| Gainsborough | 5.27 | 5.12 | 4.96 | Improved representation of receding limb of tide and timing of incoming tide (particularly for the tidal cycles either side of the main event), however peak level is underestimated. |

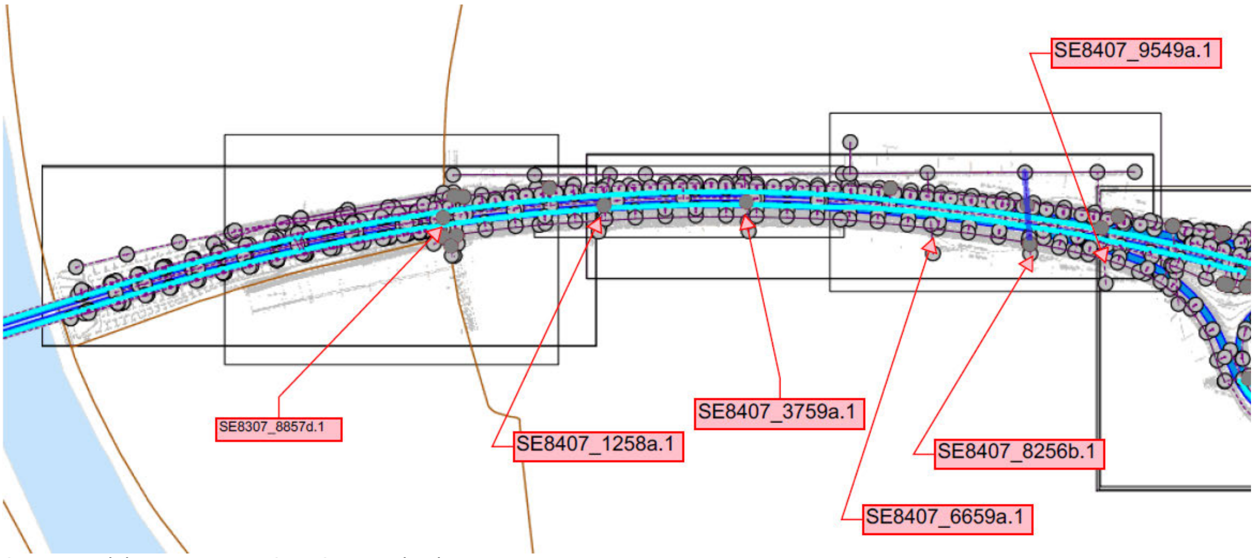
Around Keadby, near the LLAP development site, the updated model provided a much improved level of calibration and was therefore taken forward as the baseline model for this study. The Environment Agency reviewed the model and the December 2013 calibration results at this stage. Their review can be found in Appendix B.

### 4.2.2 Updates after submitting model to the EA for approval

#### 4.2.2.1 Culverts within and surrounding the LLAP site

Following the model review by the Environment Agency it was identified that there are a number of culverts under the M180 and M181 that were not included in the EA Interim Model. Details for some of these culverts (particularly under the M180) were obtained from the Highways Agency (now Highways England) GDMS asset database (Figure 6 and Table 8.) Details of further culverts under the M181 have been taken from previous modelling undertaken by URS (Modelling Files, 2014). Figure 7 identifies the full set of culverts included in the model near the site. These culverts have been included in the model using ESTRY culvert units embedded into the 2D domain

**Figure 6: Location of culverts under M180 from the Highways Agency GDMS asset database**




Source: Highways Agency GDMS asset database

**Table 8: Summary of data in Highways Agency GDMS asset database for M180 culverts**

| Asset ID | Diameter (mm) | Invert (mAOD) | Length (m) | Comment |
|---|---|---|---|---|
| SE8407-9549a.1 | | | 181.77 | Insufficient data in GDMS database. Dimensions used in the previous modelling by URS used. |
| SE8407_8256b.1 | | | 106.93 | |
| SE8407_6659a.1 | 150 | US -0.24, DS -0.25 | 53.58 | |
| SE8407_3759a.1 | 300 | Assumed from LiDAR | 64.39 | |
| SE8407_1258a-1 | 300 | Assumed from LiDAR | 67.95 | |
| SE8307_8857d-1 | 1200 | -1.7 | 57.63 | |

Source: Highways Agency GDMS asset database

**Figure 7: Location of additional culverts included in the model near the LLAP site**


Source: Contains Ordnance Survey data Crown copyright and database right © 2017

#### 4.2.2.2 Topographic Defence Data

The model has also been updated with topographical defence survey by Midland Surveys, undertaken in September 2015, covering the right bank of the Tidal Trent from the M180 Bridge to the A18 Bridge (as shown in Figure 39).

The model has also been updated with the August 2016 bank level survey by Survey Operations Ltd which extends from East Ferry in the South to Trent Falls in the north.

## 4.3 Post Scheme Model Updates

### 4.3.1 Findings from initial stage modelling results

During the initial stages of the project a range of post-scheme options were considered in order to provide protection to the LLAP site and minimise third party impact to the surrounding villages. These focussed on the proposed extent and crest-level of defences between the M180 Bridge and the A18 Bridge, including:

- Reinforcing the right bank defence at existing crest level
- Reinforcing the right bank defence and filling low-spots to a minimum crest level of 6.2mAOD
- Reinforcing the right bank defence and filling low-spots/raising the crest level to 6.477mAOD – effectively reinstating the original crest level of the defence.
- Reinforcing the right bank defence and filling low-spots/raising the crest level to 6.477mAOD and filling low-spots/raising the crest level on the left bank to 6.477mAOD.

A review of the initial results identified that:

- Reinforcing the right bank defence and filing low-spots to a minimum crest level of 6.2mAOD did not provide the standard of protection initially expected for LLAP of the 0.5% AEP tidal event, whilst showing significant third party impacts and Althorpe and Keadby.
- Reinforcing the right bank defence to the original crest level of 6.477mAOD provided protection for the 0.5% AEP tidal event however third party impacts were significant.
- Reinforcing the right bank and left bank defences to 6.477mAOD did not reduce the third part impacts, but spread them over a wider region.

These findings have been used to inform the design of the post-scheme defence crest level and mitigation options. In particular, it was decided that:

- The 0.5% AEP Tidal event with Upper End climate change would be the critical flood event to which the defence and any required mitigation options would be designed to.
- The H++ climate scenario would be used for information purposes only, but not to form design criteria.
- Mitigation in the form of a managed overflow would be required to minimise third party impacts to properties. A managed overflow within the LLAP area would be most appropriate in the short term (present day till 2050), and a managed overflow on the left bank between Keadby and Amcotts would be considered for the long term (2050 till 2115)

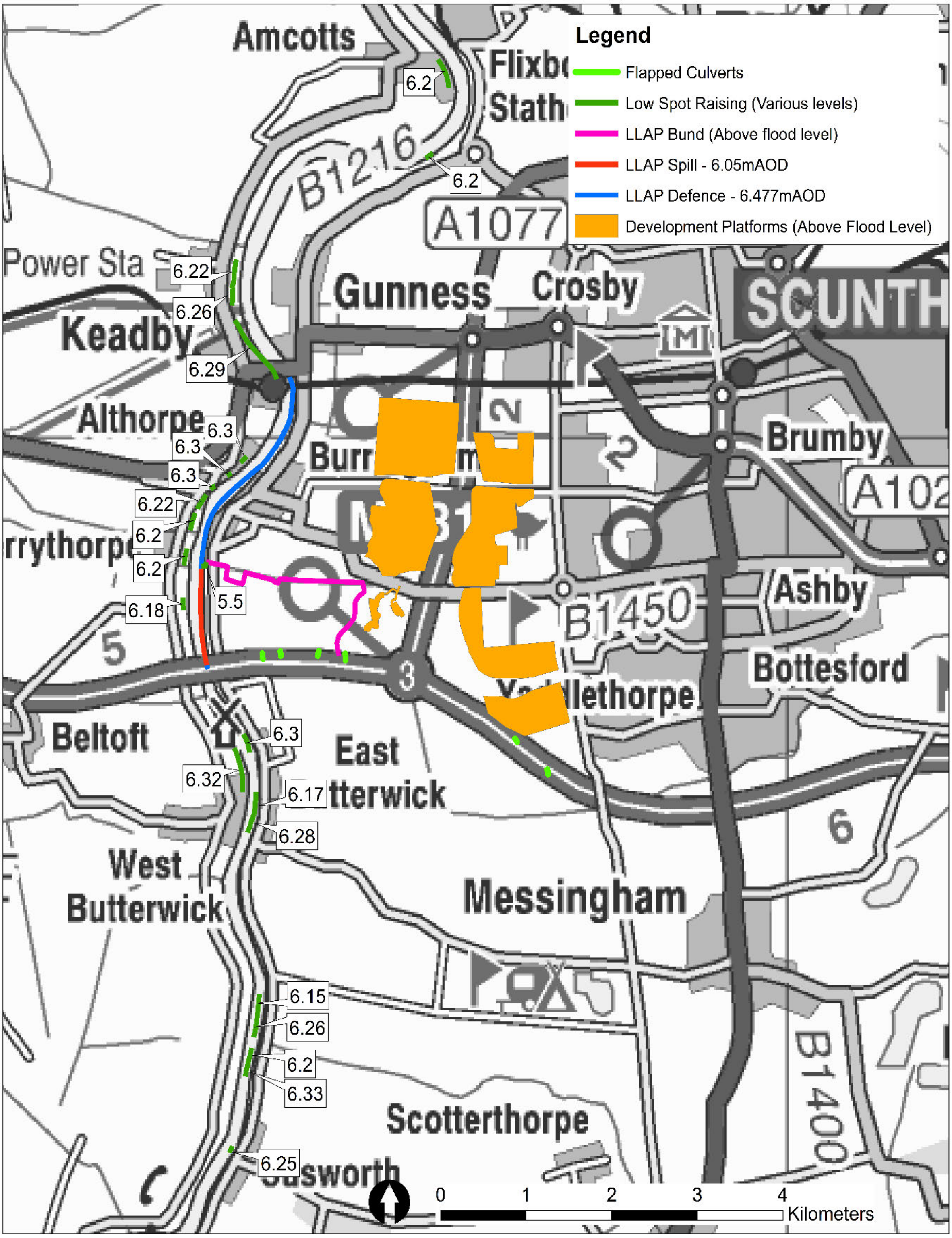
### 4.3.2 Short-Term Defence Crest Level and Mitigation

For the short-term (2040 for fluvial scenarios and 2050 for tidal scenarios) design epoch, the following changes have been made to the baseline model:

- A minimum defence crest level of 6.477mAOD has been applied to the defence on the right bank at Burringham. This has been chosen as it is a reinstatement of the original design crest-level and provides a standard of protection to the LLAP area of the 0.5% AEP tidal event. Any parts of the defence currently higher than the 6.477mAOD level have been retained at their existing level. This has been applied in the 2d_zln_2050_BBook_defence.MIF file, using the THICK MAX command.
- A managed overflow from the M180 to a point 25m south of 'The Poplars' property boundary. The managed overflow has a crest level of 6.05mAOD. This has been applied in the 2d_zln_2050_ST_Mitigation_21_Spill_01.MIF file.
- A bund surrounding the managed overflow area to protect 'The Poplars', 'the Bungalow' and land to the north and east of the managed overflow. This has nominally been given a level of 6mAOD to ensure no overtopping. The precise level for design purposes is to be informed by the modelling results. This has been applied in the 2d_zln_2050_ST_Mitigation_RasiedDefences_LLAP_03.MIF file.
- Raising of low spots in defences on both the right and left banks outwith the AAP right bank area to eliminate third party impacts to other properties. This has been applied in the 2d_zln_2050_ST_Mitigation_23_RaisedDefences_01.MIF file using the THICK MAX command to raise low spots only.
- Raising of development platforms to a nominal level of 100mAOD to remove them from the floodplain. This has been applied in the 2d_zsh_LandRaising_01.MIF file.
- Culverts under the M180 have been flapped to ensure that the managed overflow area does not spread to the south. This has been applied in 1d_nwke_TTRENT_03_flapped.MIF

Figure 8 details the locations of the modifications.

**Figure 8: Modifications made to model for short term defence and mitigation scenario**

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### 4.3.3 Long-Term Defence Crest and Mitigation

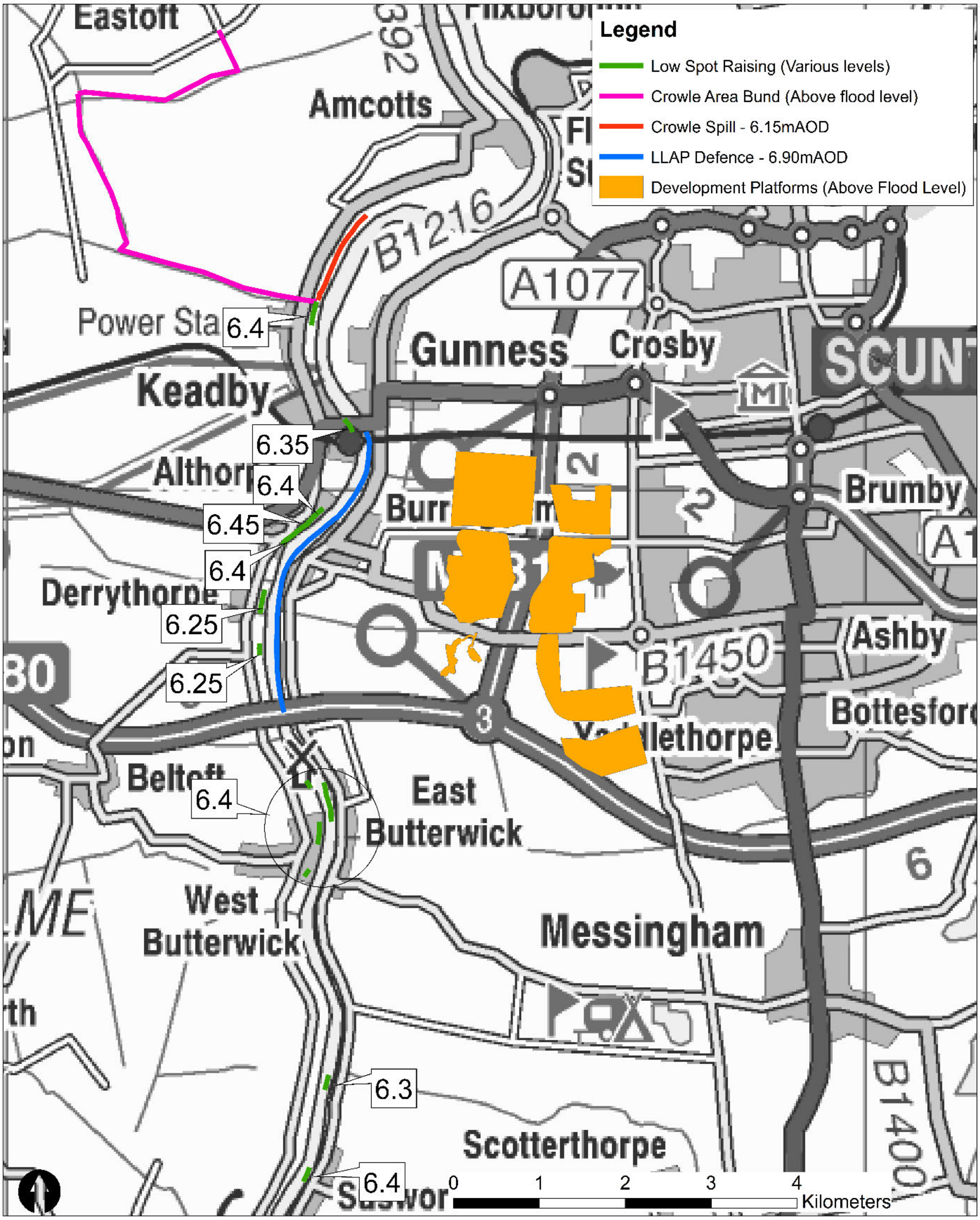
A long-term solution for providing protection of the LLAP area up to the 2115 design epoch has been developed. The presented solution is primarily to demonstrate that a solution is possible, rather than to provide a detailed specification.

The following changes have been made to the baseline model:

- A minimum defence crest level of 6.90mAOD has been applied to the defence to provide a Tidal 0.5% AEP standard of protection with a freeboard of 0.19m. This has been applied in the 2d_zln_690_defence.MIF file, using the THICK MAX command.
- A managed overflow from the M180 to a point 25m short of 'The Poplars' property boundary. The managed overflow has a crest level of 6.05mAOD. This has been applied in the 2d_zln_2050_ST_Mitigation_21_Spill_01.MIF file. (Same as for short term mitigation option)
- A bund surrounding the managed overflow area to protect 'The Poplars', 'the Bungalow' and land to the north and east of the managed overflow. This has nominally been given a level of 6mAOD to ensure no overtopping. Precise level for design purposes to be taken from the modelling results. This has been applied in the 2d_zln_2050_ST_Mitigation_RasiedDefences_LLAP_03.MIF file. (Same as for short term mitigation option)
- Raising of low spots in defences on both the right and left banks to eliminate third party impacts to other properties. This has been applied in the 2d_zln_2050_ST_Mitigation_23_RaisedDefences_01.MIF file using the THICK MAX command to raise low spots only. (Same as for short term mitigation option)
- Raising of development platforms to a nominal level of 100mAOD to remove them from the floodplain. This has been applied in the 2d_zsh_LandRaising_01.MIF file. (Same as for short term mitigation option)
- Culverts under the M180 have been flapped to ensure that the managed overflow area does not spread to the south. This has been applied in 1d_nwke_TTRENT_03_flapped.MIF (Same as for short term mitigation option)
- A managed overflow from North of Keadby to Amcotts. The managed overflow has a crest level of 6.15mAOD. This has been applied in the 2d_zln_2115_Mitigation_Spill_01.MIF file.
- A bund surrounding the additional managed overflow area to protect Keadby, Crowle and Eastoft. This has nominally been given a level of 6mAOD to ensure no overtopping. This has been applied in the 2d_zln_2115_LT_Mitigation_RaisedBanks_Crowle_01.MIF file.
- Raising of low spots in defences on both the right and left banks to eliminate third party impacts to other properties. This has been applied in the 2d_zln_2115_LT_Mitigation_RaisedBanks_03.MIF file using the THICK MAX command to raise low spots only.

Figure 9 details the locations of the modifications. For the raising of low spots, only the additional raising compared to the short-term mitigation has been shown on the figure.

**Figure 9: Modification made to model for long term defence and mitigation scenario**

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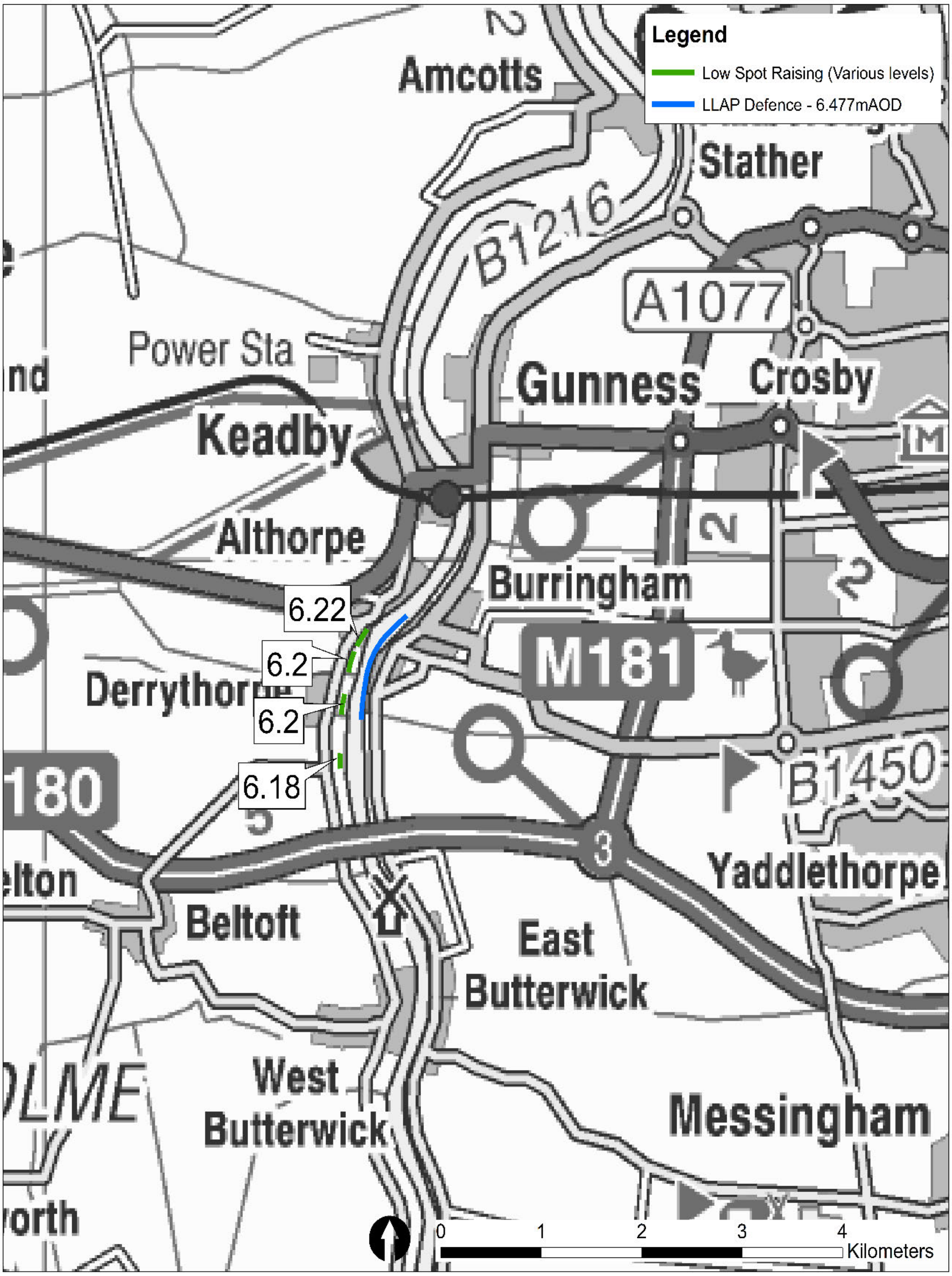
### 4.3.4 Permitted Development Works Modelling

An additional scenario relating to works which come under permitted development rights, has also been modelled. The permitted development works modelling is to identify the maximum length of LLAP defence that can be raised to 6.477mAOD, whilst keeping third party impacts to properties to a minimum, and staying within the NLCC defined 2km limit for permitted development works. The following changes have been made to the baseline model for this scenario:

- A minimum defence crest level of 6.477mAOD has been applied to the defence for a reach of 1.1km starting from the northern end of the proposed managed overflow location. Any parts of the defence currently higher than the 6.477mAOD level have been retained at their existing level. This has been applied in the 2d_zln_2050_BBook_defence_1_1km.MIF file, using the THICK MAX command.
- Raising of low spots in defences around Derrythorpe to eliminate third party impacts to other properties from the raising of the 1.1km reach of the LLAP defence. This has been applied in the 2d_zln_2050_ST_Mitigation_23_Derrythorpe_01.MIF file using the THICK MAX command to raise low spots only.

Figure 10 details the locations of the modifications.

**Figure 10: Modification made to model for permitted development works scenario**

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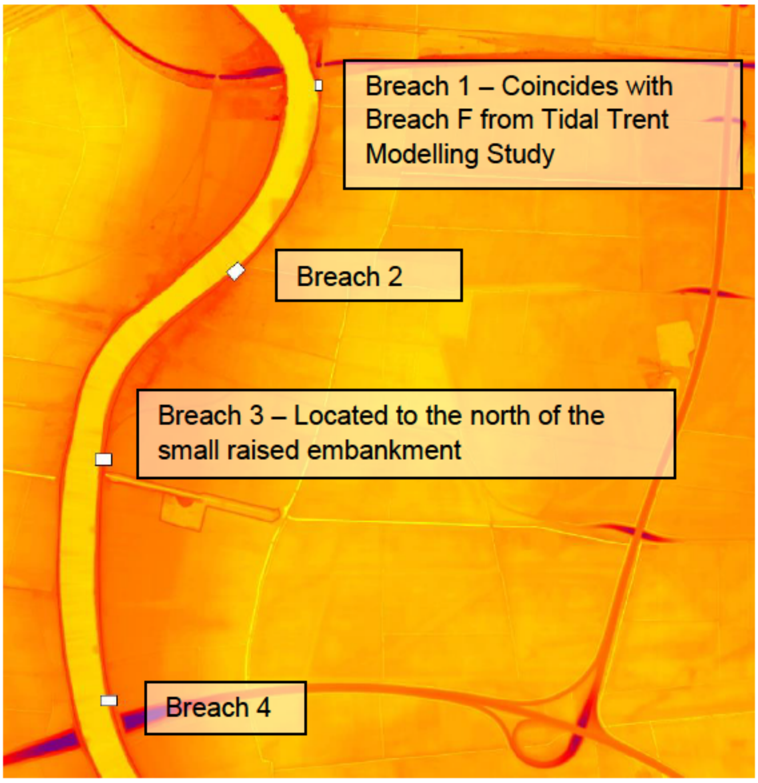
## 4.4 Breach Modelling

Four breach locations have been considered as part of this study. The location of the breaches have been agreed with the EA and are shown in Figure 11.

**Figure 11: Location of breaches**




Source: Mott MacDonald

The same methodology as adopted in the Tidal Trent Modelling Study has been used. This follows the guidance provided by the EA as part of the Tidal Trent Modelling Study and is summarised in Table 9.

**Table 9: Summary of Breach Parameters Used**

| Breach Parameter | Tidal River / Scenario | Fluvial River Scenario |
|---|---|---|
| Breach Level | | Floodplain level behind defence |
| Breach Width (Hard Defence) (Dependent on location of breach) | 20 m | 20 m |
| Breach Width (Soft Defence) (Dependent on location of breach) | 50 m | 40 m |
| Breach Duration (Dependent on fluvial or tidal scenario modelled) | 72 hours | 36 hours |
| Breach initiation time (Dependent on fluvial or tidal scenario modelled) | 1 hour before high water on peak surge | Bank-full or peak level if lower |

Source: EA, Anglian Region

Consistent with the Tidal Trent Modelling study, as the site is downstream of Gainsborough, the Tidal River scenario has been used. The breaches have been incorporated into the 2D domain by the use of variable z-shape files which allow breaching and restoration of embankments at defined user input times. The levels to which each breach has been reduced to are 3.38, 5.15, 4.30 and 4.00 mAOD for breach 1, 2, 3 and 4 respectively. These have been taken from the floodplain levels at the toe of the existing embankments.

The baseline scenario modelling used a breach width of 50m, to represent a breach in the existing soft earth embankment. Post-scheme breach modelling used a breach width of 25m (as the closest to 20m possible with the model grid size, and erring on the conservative side) to represent a breach in the proposed reinforced defence.

All 4 breach locations were run for the key 0.5% AEP tidal scenario with climate change to 2050. From these results, it was identified that breach location 1 provided the largest volume of flow into the LLAP area. This breach location has therefore been used for all subsequent modelling as the critical breach location.

# 5 Model Results

## 5.1 Model Runs

A large number of model runs have been undertaken as part of this study. Table 10 provides a summary of the key model runs presented in this report.

Flood depth maps and comparisons of flood depths between post-scheme model runs and baseline model runs have been produced for all the flood events in Table 10. These are provided as a digital appendix to the report.

In discussion with the Environment Agency, and as part of the Managed Adaptive Approach presented, the key events used to inform the design development of the defences and any third-party mitigation are:

- Permitted development works:
  - Present day 0.5% AEP tidal event
- Short-term mitigation works:
  - Present day 0.5% AEP tidal event
  - 0.5% AEP fluvial event with higher central climate change projection for the 2040s
  - 3.33% AEP tidal event with upper end climate change projection for the 2050s
  - 0.5% AEP tidal event with upper end climate projection for the 2050s
- Long-term mitigation works:
  - 0.5% AEP fluvial event with upper end climate change projection for 2115
  - 0.5% AEP tidal event with upper end climate projection for 2115
- For the breach scenarios:
  - 0.5% AEP fluvial event with higher central climate change projection for the 2040s, with short term mitigation works.
  - 0.5% AEP tidal event with upper end climate projection for the 2050s

The key events have been highlighted in Table 10. These events have been presented in detail in this chapter with summary statistics of the other events provided in Appendix C.

**Table 10: Summary of key model runs**

| Design Epoch | Scenario | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Breach | Run ID |
|---|---|---|---|---|---|---|
| Overtopping Models | | | | | | |
| 2015 | Baseline | Present Day | 50% | 0.50% | | T0200_2015_F0002_2015_OT_BASELINE_V26 |
| | Phase 1 (Permitted Development Works) | | 50% | 0.50% | | T0200_2015_F0002_2015_OT_PD_V26 |
| | Short Term Mitigation | | 50% | 0.50% | | T0200_2015_F0002_2015_OT_ST_MIT_V23_V26 |
| 2040 | Baseline | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | | T0005_2040_UE_F0200_2040_HC_OT_BASELINE_V26 |
| | | | 0.10% | 20% | | T0005_2040_UE_F1000_2040_HC_OT_BASELINE_V26 |
| | | H++ (Fluvial and Tidal) | 0.50% | 20% | | T0005_2040_Hpp_F0200_2040_Hpp_OT_BASELINE_V26 |
| | | | 0.10% | 20% | | T0005_2040_Hpp_F1000_2040_Hpp_OT_BASELINE_V26 |
| | Short Term Mitigation | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | | T0005_2040_UE_F0200_2040_HC_OT_ST_MIT_V23_V26 |
| | | | 0.10% | 20% | | T0005_2040_UE_F1000_2040_HC_OT_ST_MIT_V23_V26 |
| | | H++ (Fluvial and Tidal) | 0.50% | 20% | | T0005_2040_Hpp_F0200_2040_Hpp_OT_ST_MIT_V23_V26 |
| | | | 0.10% | 20% | | T0005_2040_Hpp_F1000_2040_Hpp_OT_ST_MIT_V23_V26 |
| 2050 | Baseline | Upper End (Fluvial and Tidal) | 50% | 3.33% | | T0075_2050_UE_F0002_2050_UE_OT_BASELINE_V26 |
| | | | 50% | 0.50% | | T0200_2050_UE_F0002_2050_UE_OT_BASELINE_V26 |
| | | | 50% | 0.10% | | T1000_2050_UE_F0002_2050_UE_OT_BASELINE_V26 |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | | T0200_2050_Hpp_F0002_2050_Hpp_OT_BASELINE_V26 |
| | | | 50% | 0.10% | | T1000_2050_Hpp_F0002_2050_Hpp_OT_BASELINE_V26 |
| | Phase 1 (Permitted Development Works) | Upper End (Fluvial and Tidal) | 50% | 0.50% | | T0200_2050_UE_F0002_2050_UE_OT_PD_V26 |
| | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 3.33% | | T0075_2050_UE_F0002_2050_UE_OT_ST_MIT_V23_V26 |
| | | | 50% | 0.50% | | T0200_2050_UE_F0002_2050_UE_OT_ST_MIT_V23_V26 |
| | | | 50% | 0.10% | | T1000_2050_UE_F0002_2050_UE_OT_ST_MIT_V23_V26 |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | | T0200_2050_Hpp_F0002_2050_Hpp_OT_ST_MIT_V23_V26 |
| | | | 50% | 0.10% | | T1000_2050_Hpp_F0002_2050_Hpp_OT_ST_MIT_V23_V26 |
| 2115 | Baseline | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | | T0005_2115_UE_F0200_2115_HC_OT_BASELINE_V26 |
| | | | 0.10% | 20% | | T0005_2115_UE_F1000_2115_HC_OT_BASELINE_V26 |
| | | Upper End (Fluvial and Tidal) | 50% | 0.50% | | T0200_2115_UE_F0002_2115_UE_OT_BASELINE_V26 |

| Design Epoch | Scenario | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Breach | Run ID |
|---|---|---|---|---|---|---|
| | | | 50% | 0.10% | | T1000_2115_UE_F0002_2115_UE_OT_BASELINE_V26 |
| | | | 0.50% | 20% | | T0005_2115_UE_F0200_2115_UE_OT_BASELINE_V26 |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | | T0200_2115_Hpp_F0002_2115_Hpp_OT_BASELINE_V26 |
| | | | 50% | 0.10% | | T1000_2115_Hpp_F0002_2115_Hpp_OT_BASELINE_V26 |
| | | | 0.50% | 20% | | T0005_2115_Hpp_F0200_2115_Hpp_OT_BASELINE_V26 |
| | | | 0.10% | 20% | | T0005_2115_Hpp_F1000_2115_Hpp_OT_BASELINE_V26 |
| | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 0.50% | | T0200_2115_UE_F0002_2115_UE_OT_ST_MIT_V23_V26 |
| | | | 0.50% | 20% | | T0005_2115_UE_F0200_2115_UE_OT_ST_MIT_V23_V26 |
| | Long Term Mitigation | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | | T0005_2115_UE_F0200_2115_HC_OT_LT_MIT_V04_V26 |
| | | | 0.10% | 20% | | T0005_2115_UE_F1000_2115_HC_OT_LT_MIT_V04_V26 |
| | | Upper End (Fluvial and Tidal) | 50% | 0.50% | | T0200_2115_UE_F0002_2115_UE_OT_LT_MIT_V04_V26 |
| | | | 50% | 0.10% | | T1000_2115_UE_F0002_2115_UE_OT_LT_MIT_V04_V26 |
| | | | 0.50% | 20% | | T0005_2115_UE_F0200_2115_UE_OT_LT_MIT_V04_V26 |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | | T0200_2115_Hpp_F0002_2115_Hpp_OT_LT_MIT_V04_V26 |
| | | | 50% | 0.10% | | T1000_2115_Hpp_F0002_2115_Hpp_OT_LT_MIT_V04_V26 |
| | | | 0.50% | 20% | | T0005_2115_Hpp_F0200_2115_Hpp_OT_LT_MIT_V04_V26 |
| | | | 0.10% | 20% | | T0005_2115_Hpp_F1000_2115_Hpp_OT_LT_MIT_V04_V26 |
| Breach Models | | | | | | |
| 2040 | Baseline | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | BR1 | T0005_2040_UE_F0200_2040_HC_BR1_BASELINE_V26 |
| | | | 0.10% | 20% | BR1 | T0005_2040_UE_F1000_2040_HC_BR1_BASELINE_V26 |
| | | H++ (Fluvial and Tidal) | 0.50% | 20% | BR1 | T0005_2040_Hpp_F0200_2040_Hpp_BR1_BASELINE_V26 |
| | Short Term Mitigation | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | BR1 | T0005_2040_UE_F0200_2040_HC_BR1_ST_MIT_V23_V26 |
| | | | 0.10% | 20% | BR1 | T0005_2040_UE_F1000_2040_HC_BR1_ST_MIT_V23_V26 |
| | | H++ (Fluvial and Tidal) | 0.50% | 20% | BR1 | T0005_2040_Hpp_F0200_2040_Hpp_BR1_ST_MIT_V23_V26 |
| 2050 | Baseline | Upper End (Fluvial and Tidal) | 50% | 0.50% | BR1 | T0200_2050_UE_F0002_2050_UE_BR1_BASELINE_V26 |
| | | | 50% | 0.50% | BR2 | T0200_2050_UE_F0002_2050_UE_BR2_BASELINE_V26 |
| | | | 50% | 0.50% | BR3 | T0200_2050_UE_F0002_2050_UE_BR3_BASELINE_V26 |
| | | | 50% | 0.50% | BR4 | T0200_2050_UE_F0002_2050_UE_BR4_BASELINE_V26 |

| Design Epoch | Scenario | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Breach | Run ID |
|---|---|---|---|---|---|---|
| | | | 50% | 0.10% | BR1 | T1000_2050_UE_F0002_2050_UE_BR1_BASELINE_V26 |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | BR1 | T0200_2050_Hpp_F0002_2050_Hpp_BR1_BASELINE_V26 |
| | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 0.50% | BR1 | T0200_2050_UE_F0002_2050_UE_BR1_ST_MIT_V23_V26 |
| | | | 50% | 0.50% | BR2 | T0200_2050_UE_F0002_2050_UE_BR2_ST_MIT_V23_V26 |
| | | | 50% | 0.50% | BR3 | T0200_2050_UE_F0002_2050_UE_BR3_ST_MIT_V23_V26 |
| | | | 50% | 0.50% | BR4 | T0200_2050_UE_F0002_2050_UE_BR4_ST_MIT_V23_V26 |
| | | | 50% | 0.10% | BR1 | T1000_2050_UE_F0002_2050_UE_BR1_ST_MIT_V23_V26 |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | BR1 | T0200_2050_Hpp_F0002_2050_Hpp_BR1_ST_MIT_V23_V26 |
| 2115 | Baseline | Upper End (Fluvial and Tidal) | 50% | 0.50% | BR1 | T0200_2115_UE_F0002_2115_UE_BR1_BASELINE_V26 |
| | | | 0.50% | 20% | BR1 | T0005_2115_UE_F0200_2115_UE_BR1_BASELINE_V26 |
| | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 0.50% | BR1 | T0200_2115_UE_F0002_2115_UE_BR1_ST_MIT_V23_V26 |
| | | | 0.50% | 20% | BR1 | T0005_2115_UE_F0200_2115_UE_BR1_ST_MIT_V23_V26 |

Source: Mott MacDonald

## 5.2 Key overtopping scenario results – permitted development and short-term mitigation scenarios

### 5.2.1 Present day 0.5% AEP tidal event with permitted development works and short-term mitigation works

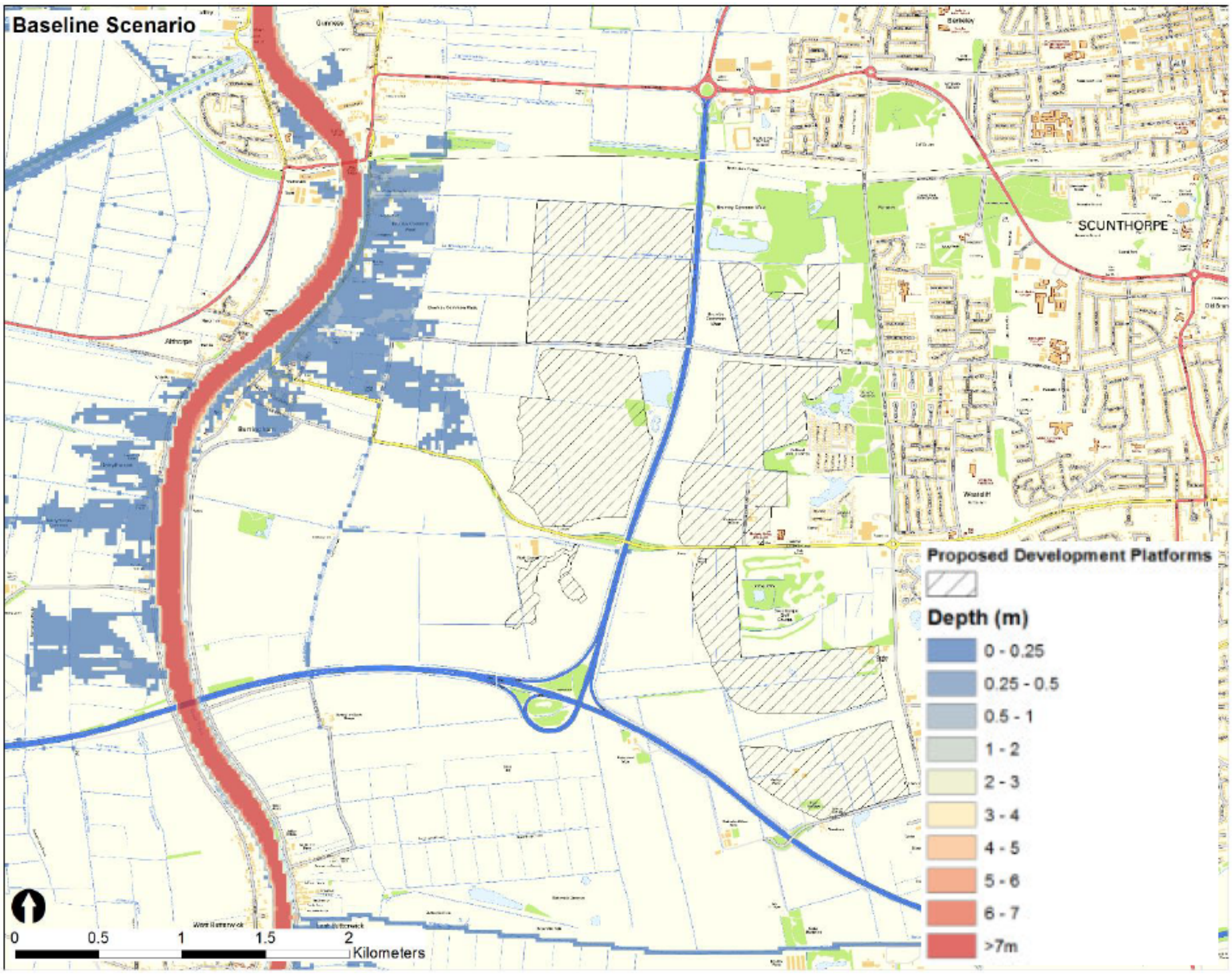
Figure 12, Figure 13 and Figure 14 provides the flood depths in the LLAP area and surrounding villages for the baseline scenario, the permitted development works, and the short-term mitigation works respectively. Figure 15 and Figure 16 show the change in flood depth between the permitted development works scenario and the short-term mitigation works scenario respectively compared to the baseline scenario.

The baseline results show overtopping of the defence adjacent to the LLAP site, with flooding of Burringham village and properties to the north of the village on the right bank, and Derrythorpe on the left bank.

The permitted development works provide some protection to the properties in Derrythorpe and on the southern edge of Burringham. A total of 129 properties are shown to have a reduction in depth of flooding of 0.025m or more in this scenario. No properties are at increased risk or show an increased depth of flooding.

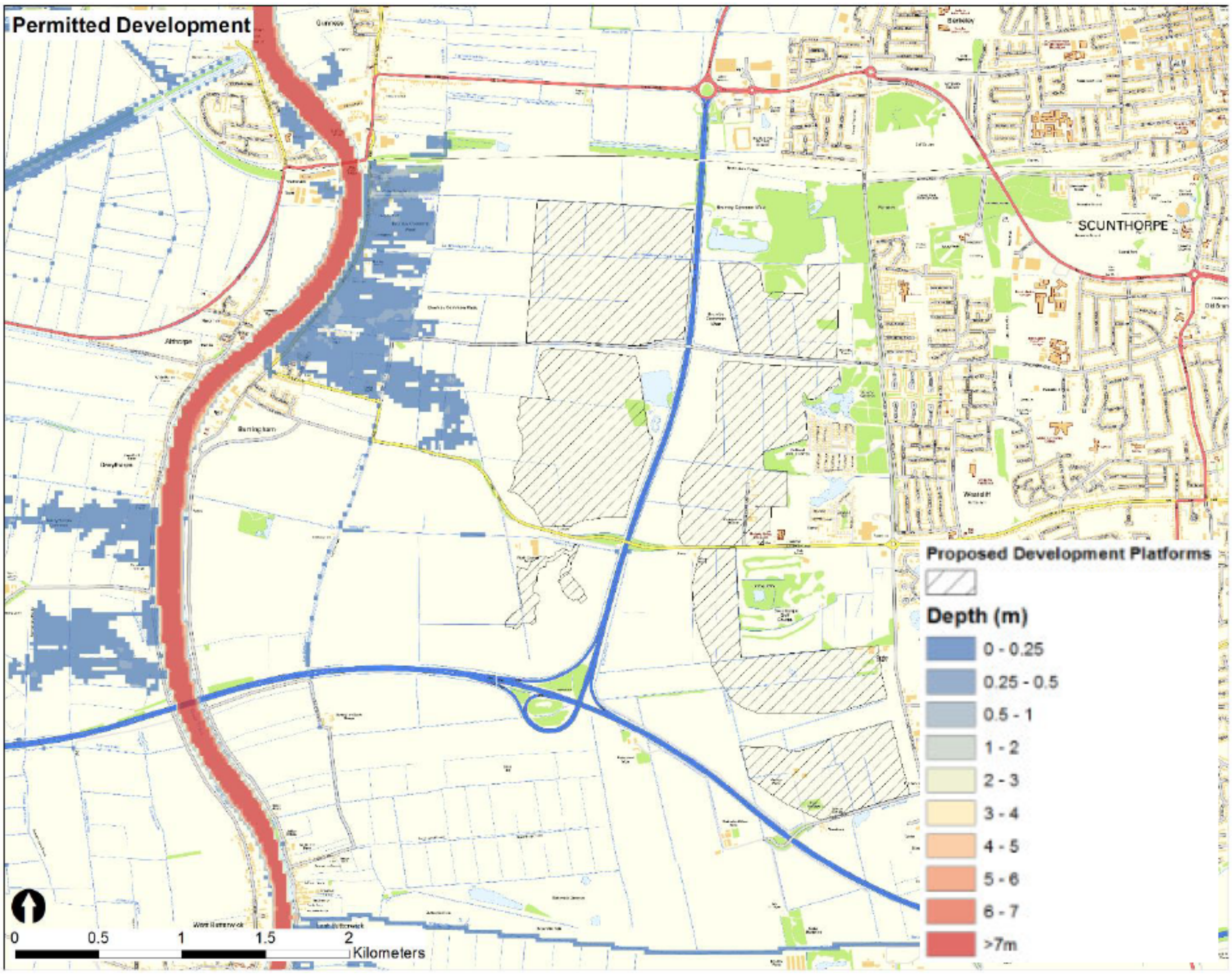
In the short-term mitigation works, all properties in Burringham and to the east of the main defence are removed from the flood extent. The managed overflow into the LLAP area is shown to be active, although the full managed overflow area is not utilised. In Derrythorpe, Keadby and East Butterwick the combined low spot filling of defences and provision of the managed overflow into the LLAP area contribute to an overall reduced level of flooding. A total of 324 properties are shown to have a reduction in depth of flooding of 0.025m or more across the region. No properties are at increased risk or show an increased depth of flooding.

**Figure 12: Baseline flood depths for 0.5% AEP tidal event, present day**




Source: Contains Ordnance Survey data Crown copyright and database right © 2017

**Figure 13: Permitted Development flood depths for 0.5% AEP Tidal event, Present Day**




Source: Contains Ordnance Survey data Crown copyright and database right © 2017

**Figure 14: Short Term Mitigation works flood depths for 0.5% AEP Tidal event, Present Day**

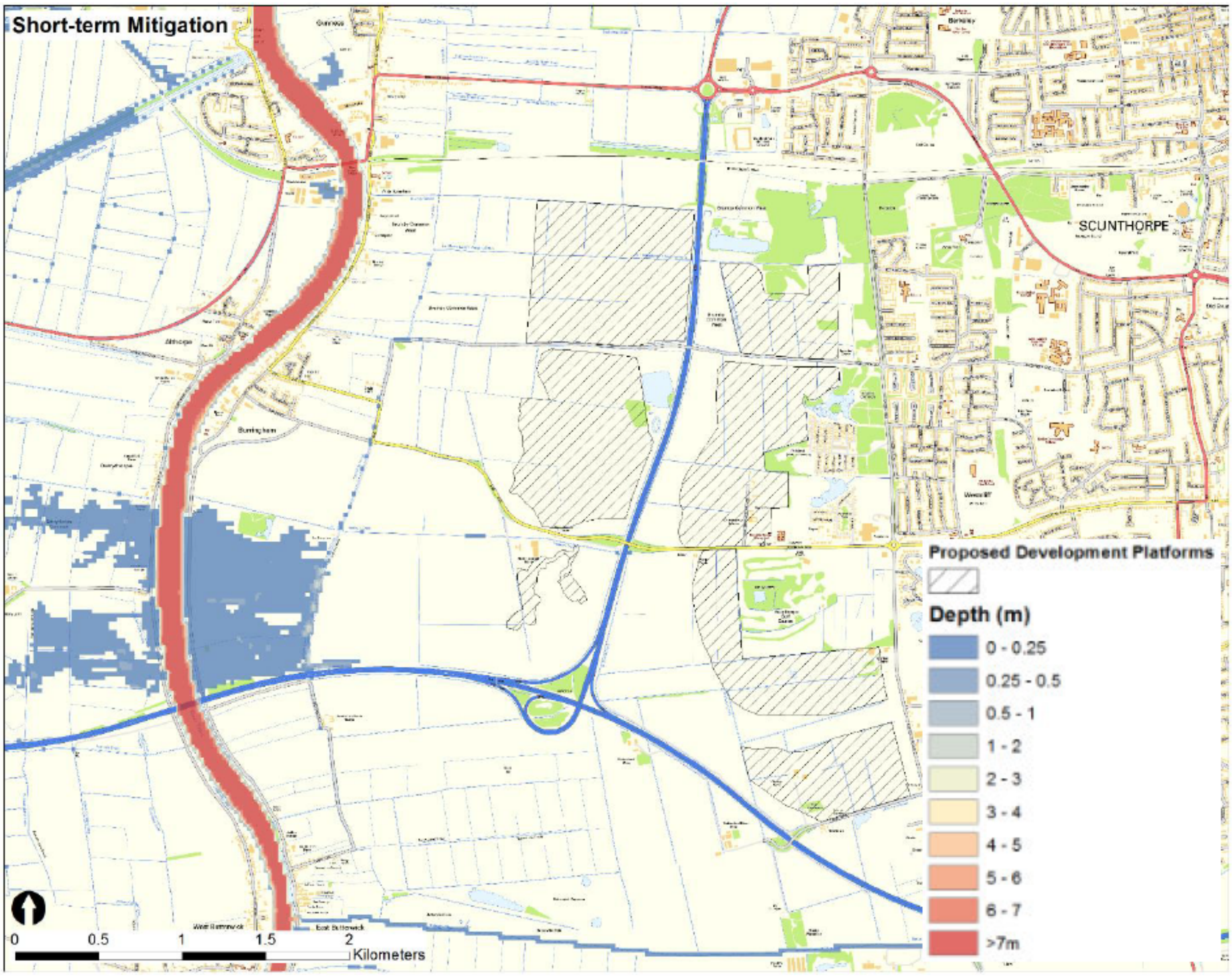



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**Figure 15: Change in flood depth for permitted development works compared to baseline flood depths for 0.5% AEP tidal event, present day**

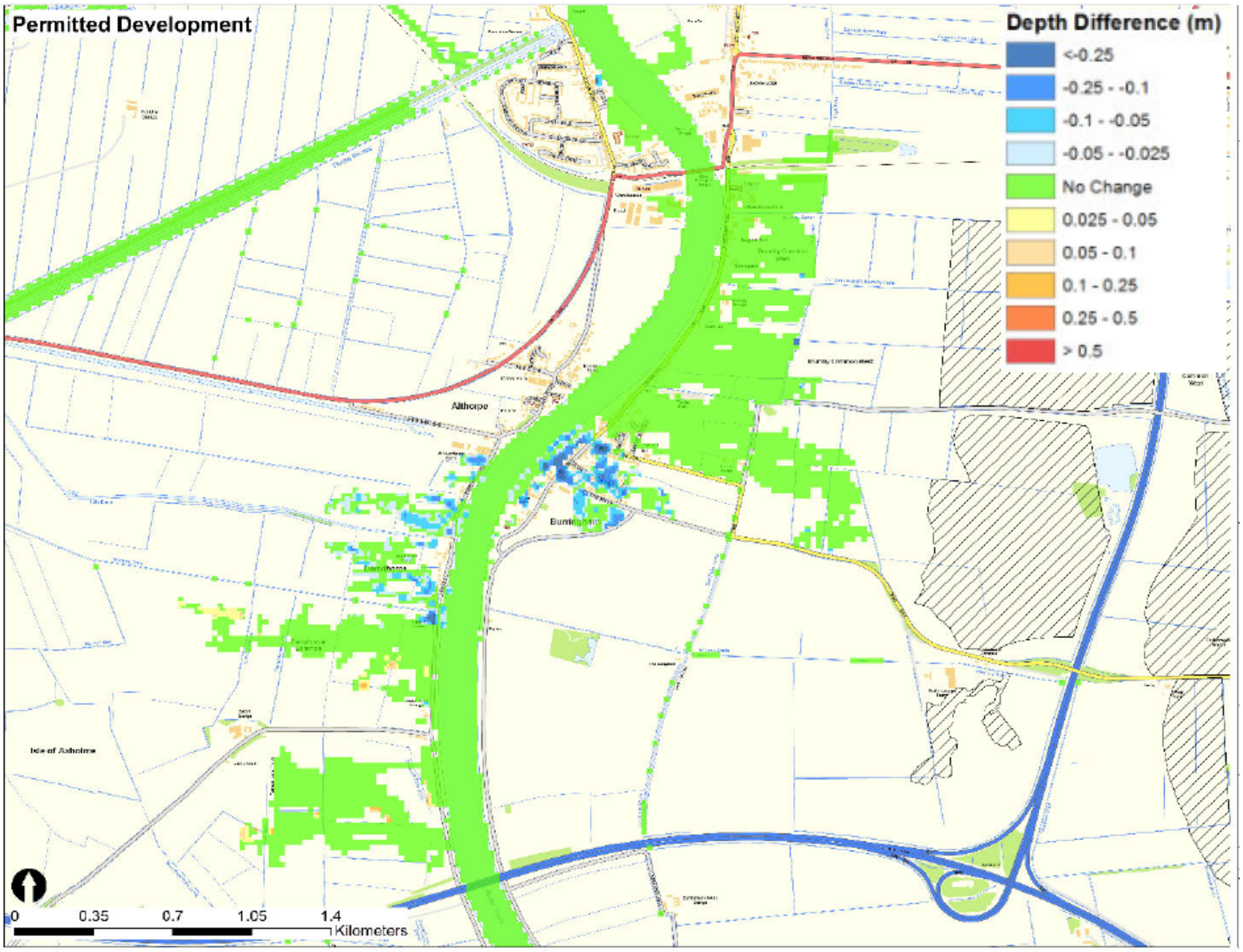


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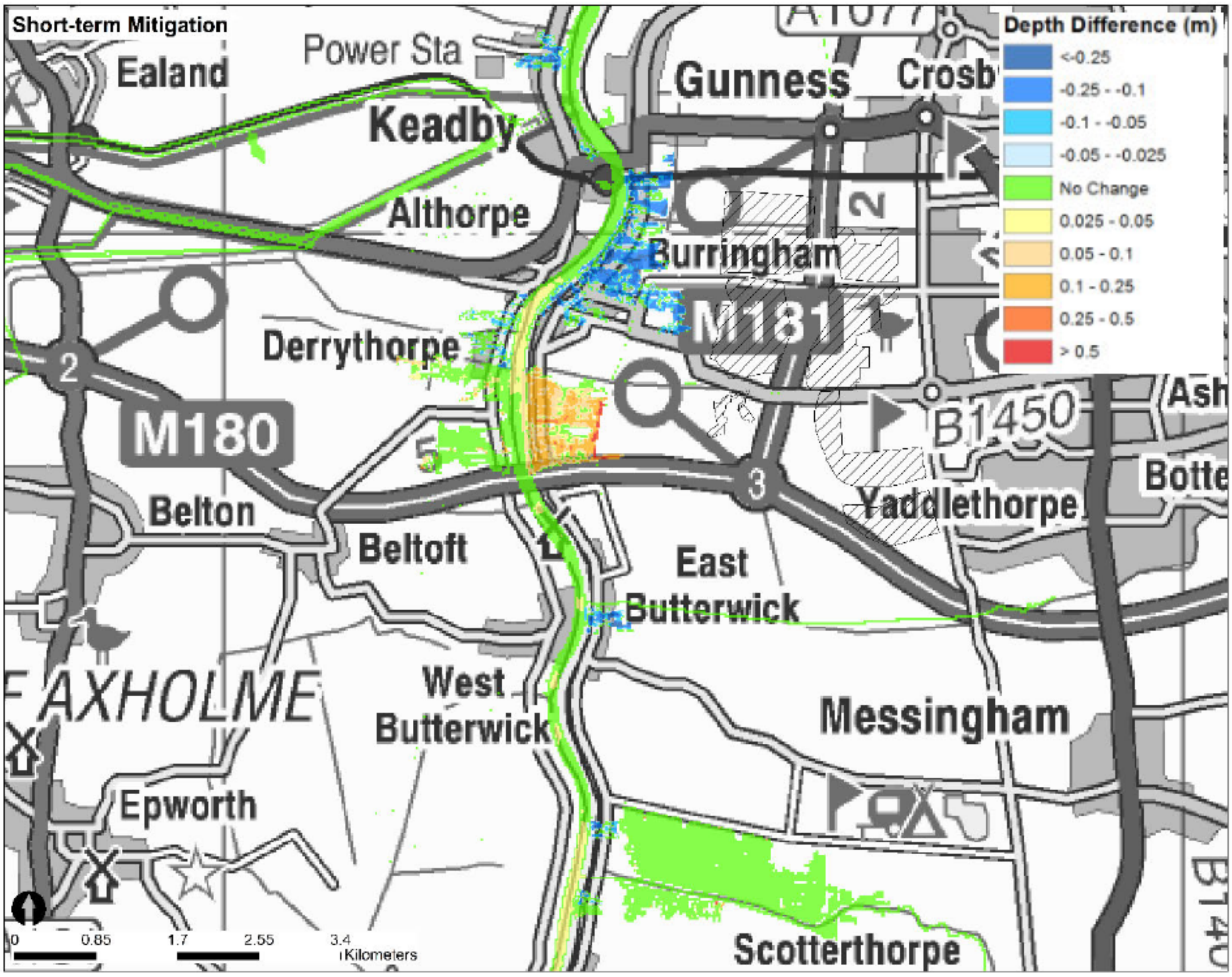
**Figure 16: Change in flood depth for short-term mitigation works compared to baseline flood depths for 0.5% AEP tidal event, present day**

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### 5.2.2 2040 0.5% AEP fluvial event with short-term mitigation works

Figure 17 and Figure 18 provides the flood depths in the LLAP area and surrounding villages for the baseline scenario and the short-term mitigation works respectively. Figure 19 shows the change in flood depth between the short-term mitigation works scenario compared to the baseline scenario.

The baseline results show very little overtopping over the existing defence adjacent to the LLAP site, with minor flooding of Burringham village and land immediately to the south of the railway bridge near Keadby. In the short-term mitigation works, all properties in Burringham and to the east of the main defence are removed from the flood extent. The managed overflow into the LLAP area is shown to be active on the southern edge only. A total of 43 properties are shown to have a reduction in depth of flooding of 0.025m or more across the region. No properties are at increased risk or show an increased depth of flooding.

**Figure 17: Baseline flood depths for 0.5% AEP fluvial event, 2040s with higher-central fluvial and upper end tidal climate change projection**

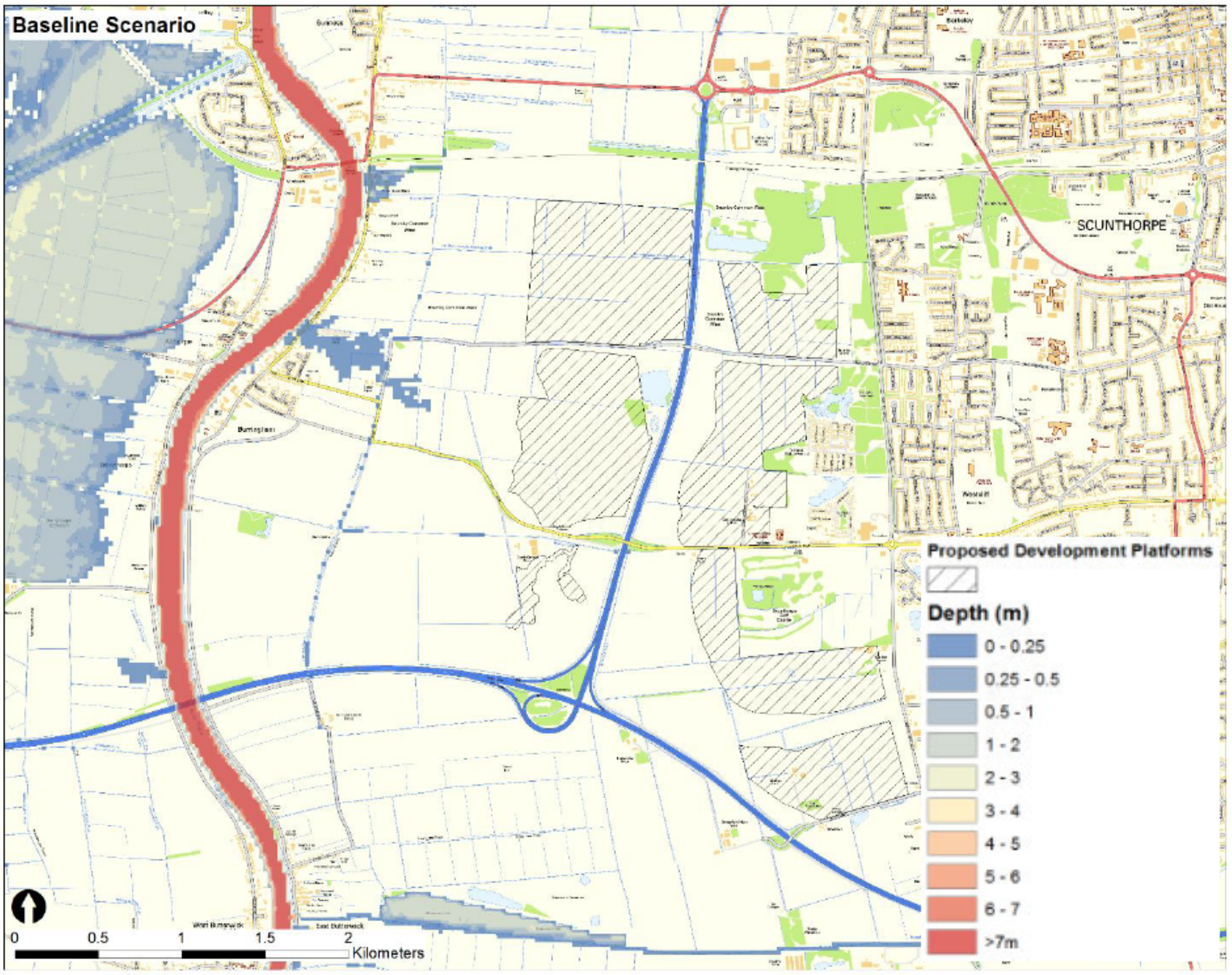


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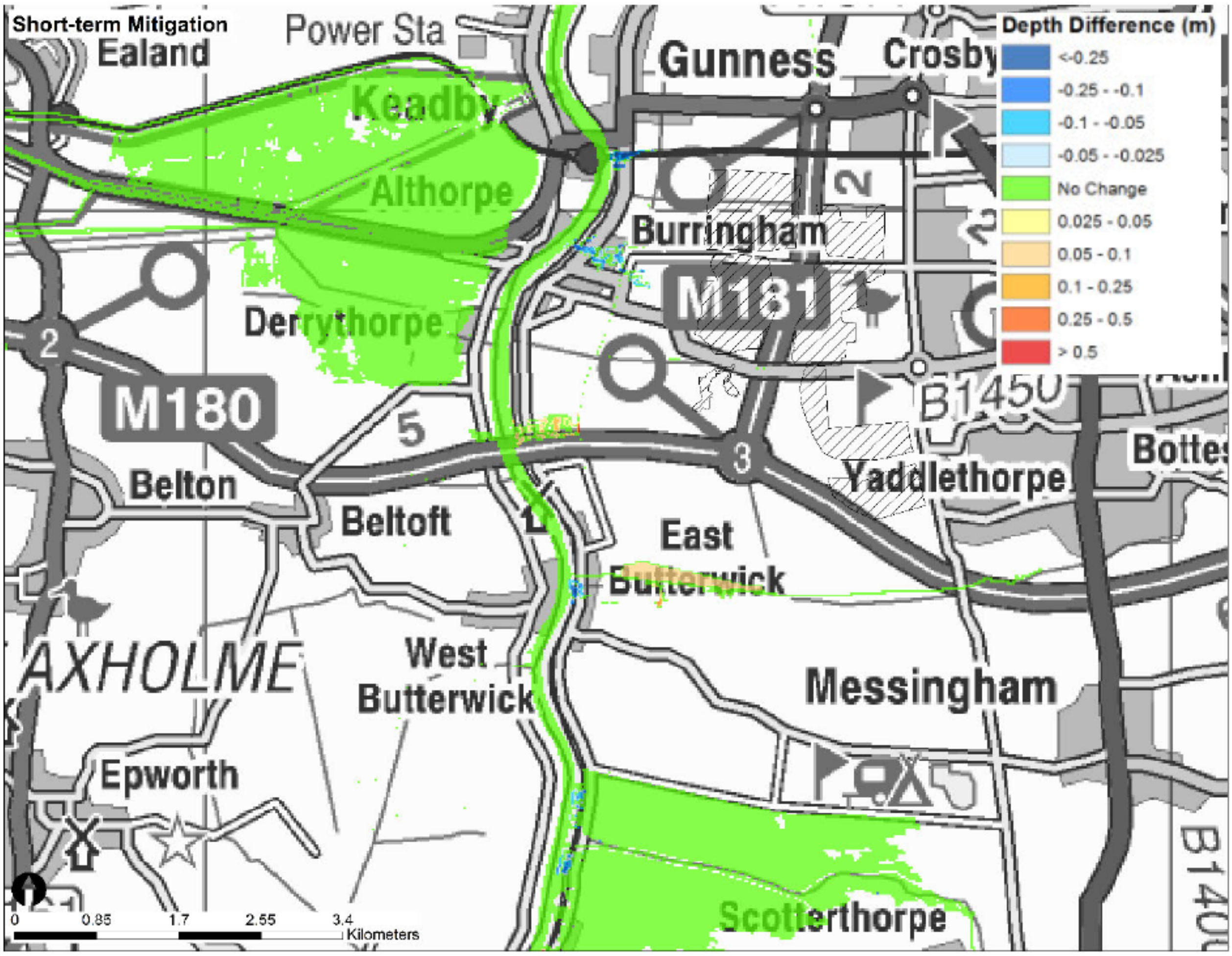
**Figure 18: Short-term mitigation works flood depths for 0.5% AEP fluvial event, 2040s with higher-central fluvial and upper end tidal climate change projection**


Source: Contains Ordnance Survey data Crown copyright and database right © 2017

**Figure 19: Change in flood depth for short-term mitigation works compared to baseline flood depths for 0.5% AEP fluvial event, 2040s with higher-central fluvial and upper end tidal climate change projection**



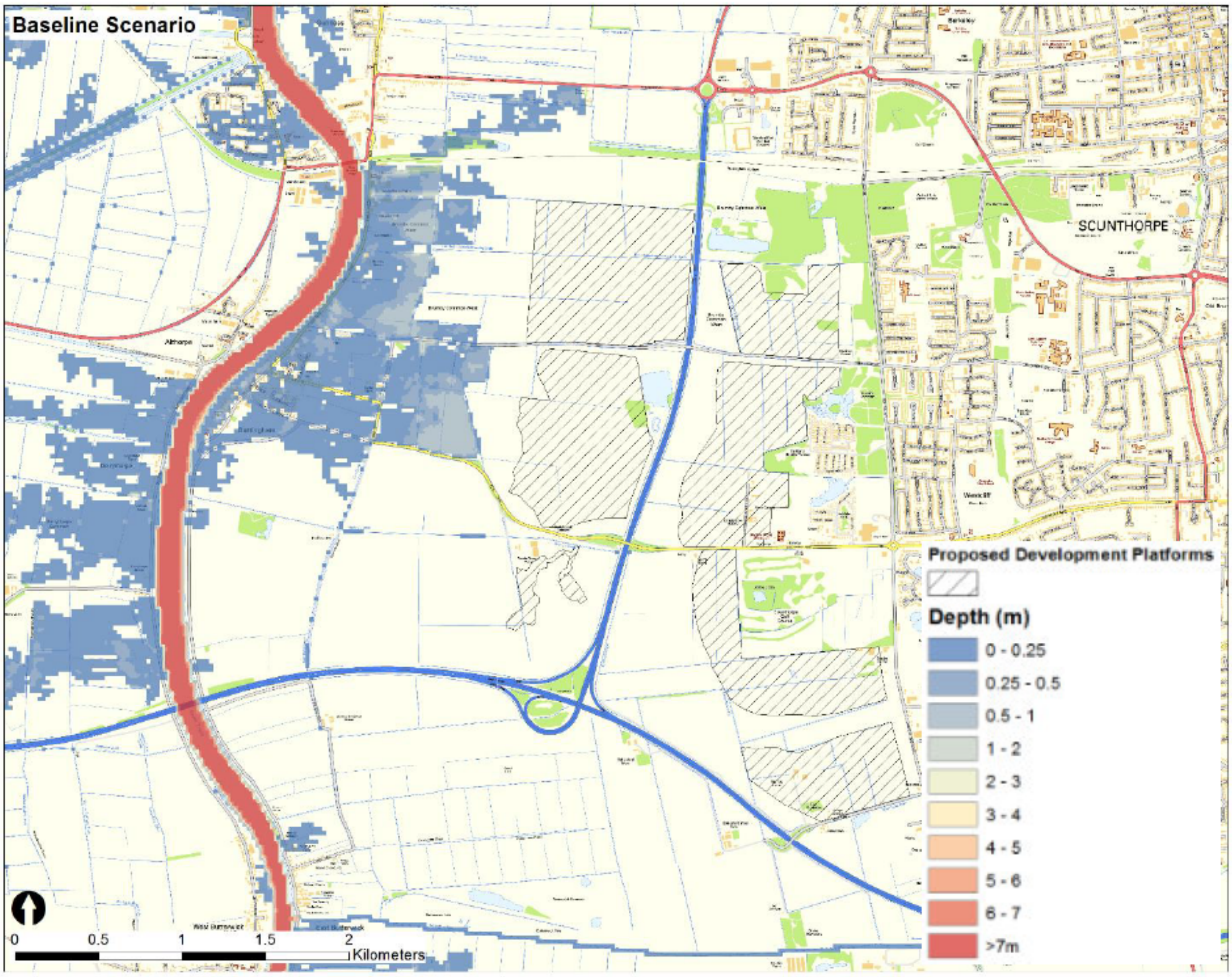

Source: Contains Ordnance Survey data Crown copyright and database right © 2017

### 5.2.3 2050 3.33% AEP tidal event with short-term mitigation works

Figure 20 and Figure 21 provide the flood depths in the LLAP area and surrounding villages for the baseline scenario and the short-term mitigation works respectively. Figure 22 shows the change in flood depth between the short-term mitigation works scenario compared to the baseline scenario.

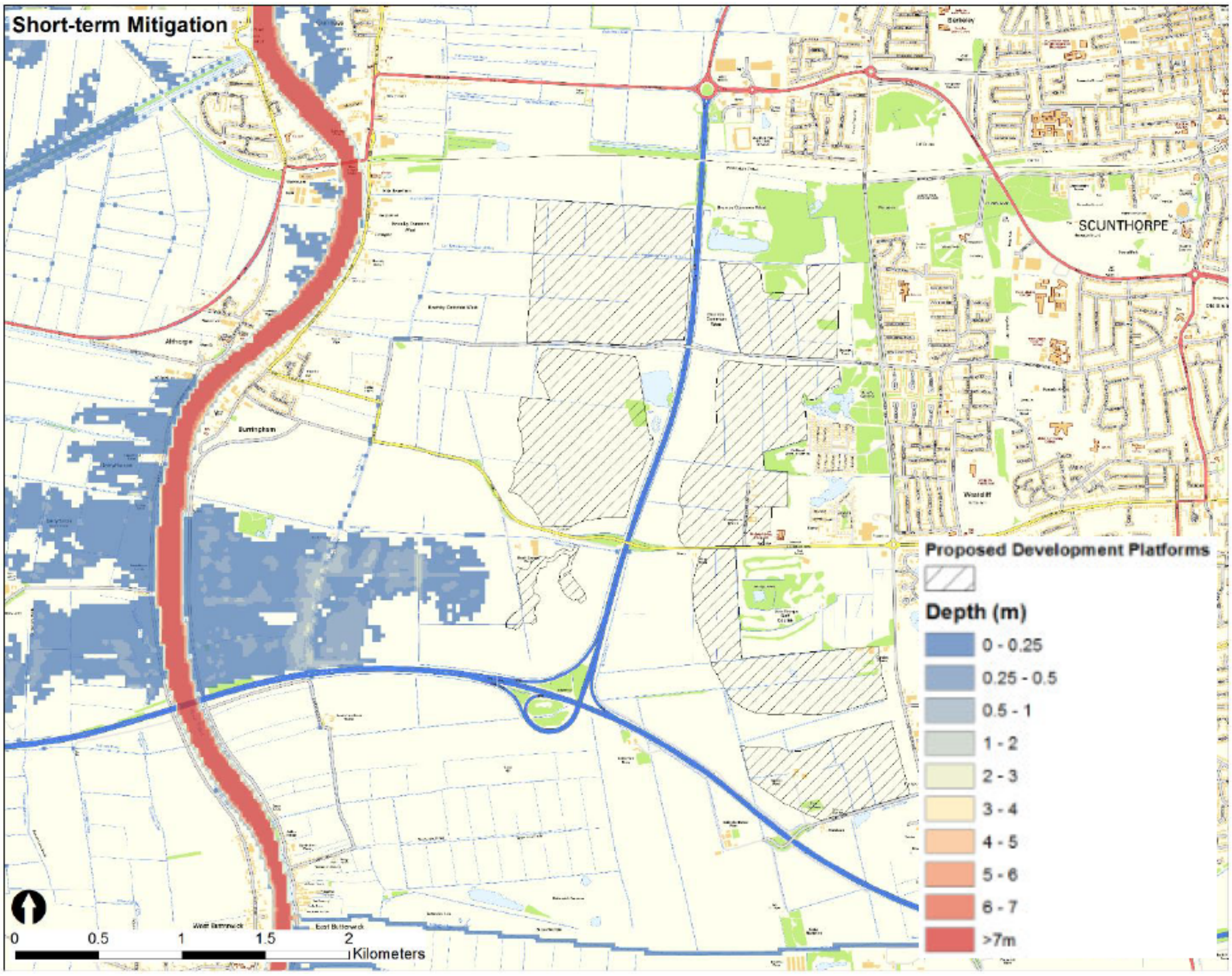
The baseline results show flooding of Burringham, Derrythorpe and Keadby. In the short-term mitigation works, all properties in Burringham and to the east of the main defence are removed from the flood extent. Flooding in Keadby is also removed, and flooding in Derrythorpe reduced. There is also a reduction in flooding to the north of Keadby near the Keadby power station, and to the south around East Butterwick. The managed overflow into the LLAP area is shown to be active across its whole reach, although the full managed overflow area has not been utilised. Opposite the LLAP managed overflow, to the south of Derrythorpe there is an increase in flood depths over an area of open fields. A total of 601 properties are shown to have a reduction in depth of flooding of 0.025m or more across the region. No properties are at increased risk or show an increased depth of flooding.

**Figure 20: Baseline flood depths for 3.33% AEP tidal event, 2050s with upper end climate change projection**



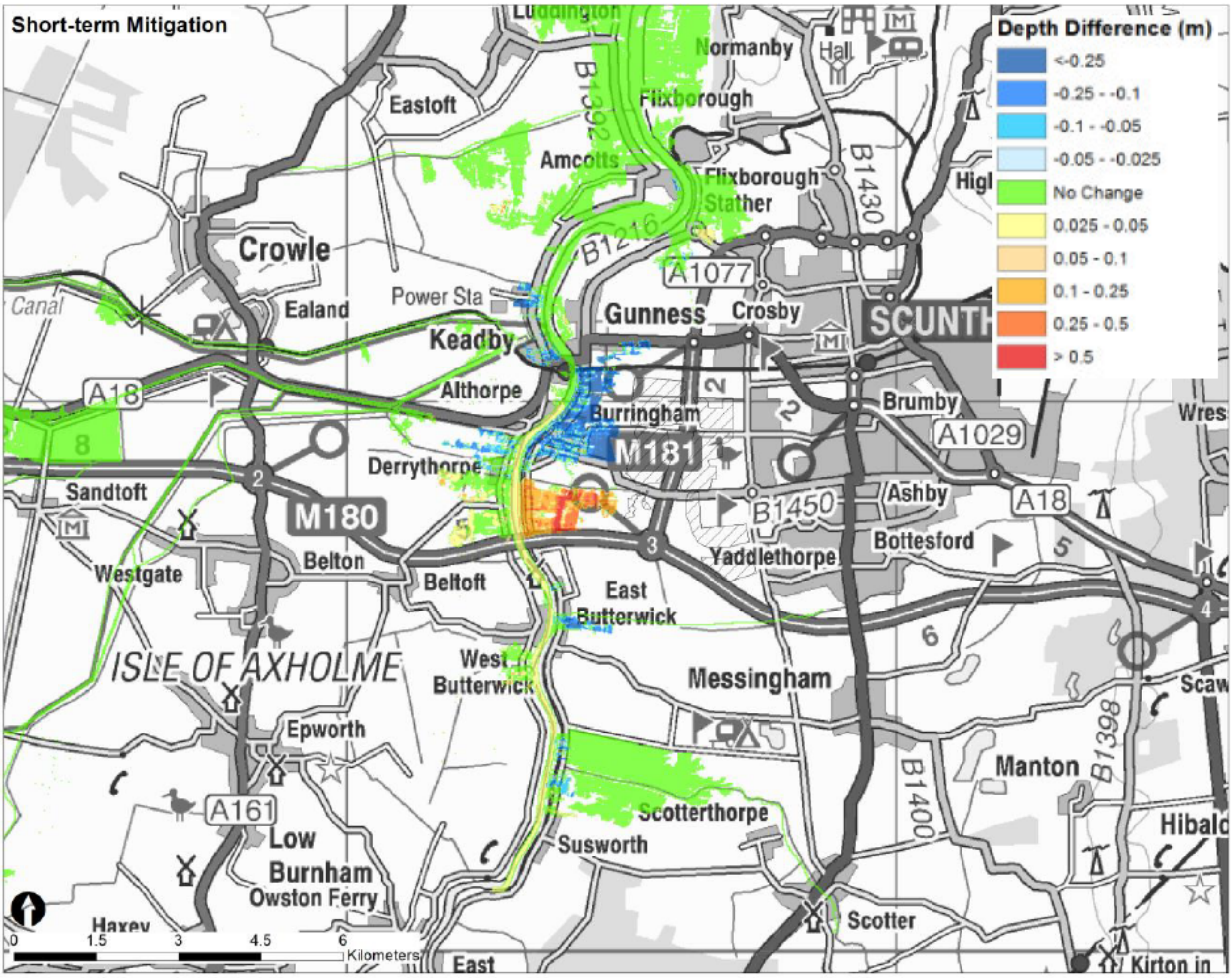

Source: Contains Ordnance Survey data Crown copyright and database right © 2017

**Figure 21: Short-term mitigation works flood depths for 3.33% AEP tidal event, 2050s with upper end climate change projection**




Source: Contains Ordnance Survey data Crown copyright and database right © 2017

**Figure 22: Change in flood depth for short-term mitigation works compared to baseline flood depths for 3.33% AEP tidal event, 2050s with upper end climate change projection**



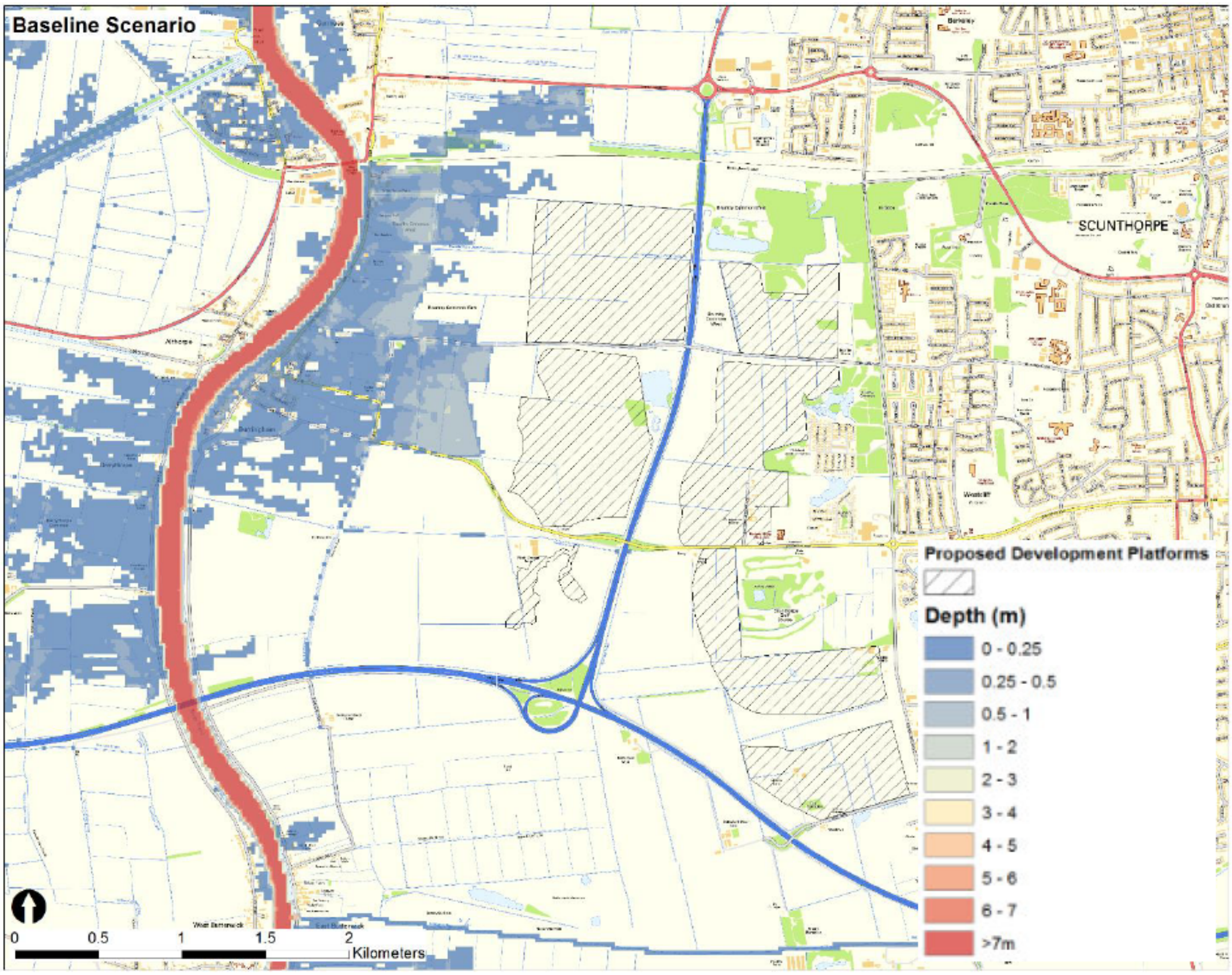

Source: Contains Ordnance Survey data Crown copyright and database right © 2017

### 5.2.4 2050 0.5% AEP tidal event with short-term mitigation works

Figure 23 and Figure 24 provides the flood depths in the LLAP area and surrounding villages for the baseline scenario and the short-term mitigation works respectively. Figure 25 shows the change in flood depth between the short-term mitigation works scenario compared to the baseline scenario.

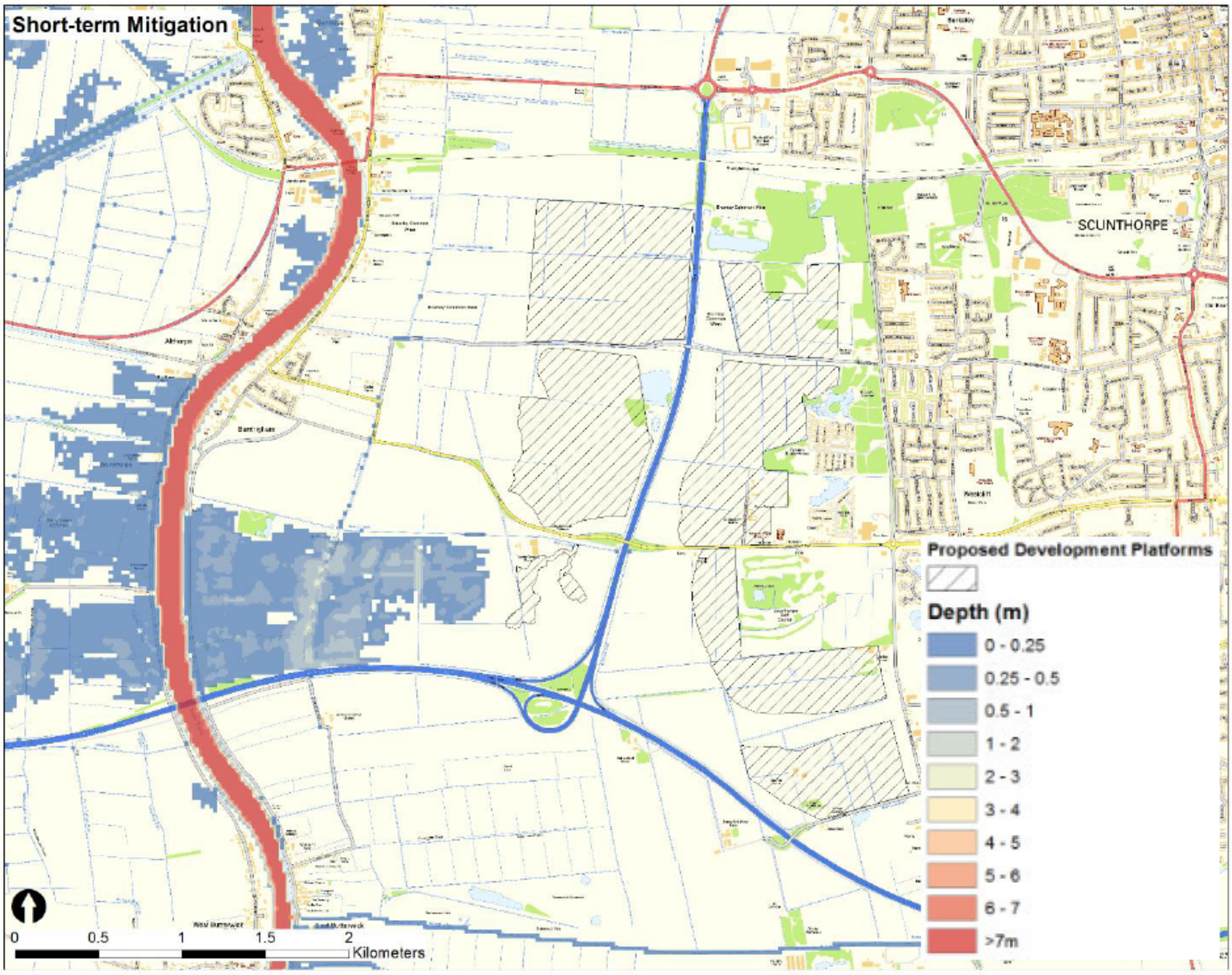
The baseline results show flooding of Burringham, Derrythorpe and Keadby. In the short-term mitigation works, all properties in Burringham and to the east of the main defence are removed from the flood extent. Flooding in Keadby is also removed, and flooding in Derrythorpe reduced. There is also a reduction in flooding to the north of Keadby near the Keadby power station, North near Amcotts, and to the south around East Butterwick. The managed overflow into the LLAP area is shown to be active across its whole reach, although the full managed overflow area has not been utilised. Opposite the LLAP managed overflow, to the south of Derrythorpe there is an increase in flood depths over an area of open fields. There is also an increase in flood depths to the south of Amcotts between the River and the B1392. A total of 601 properties are shown to have a reduction in depth of flooding of 0.025m or more across the region. No properties are at increased risk or show an increased depth of flooding.

**Figure 23: Baseline flood depths for 0.5% AEP tidal event, 2050s with upper end climate change projection**



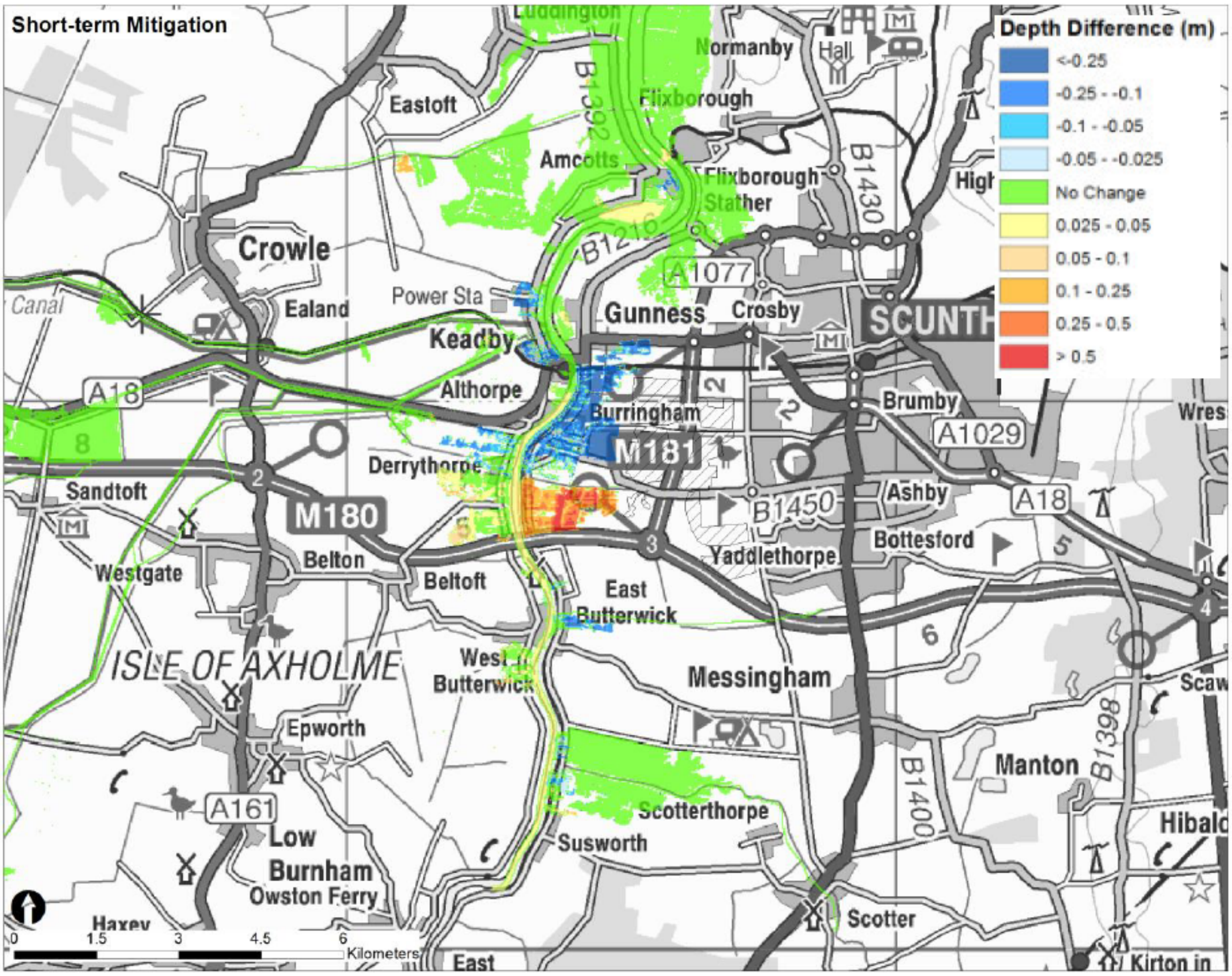

Source: Contains Ordnance Survey data Crown copyright and database right © 2017

**Figure 24: Short-term mitigation works flood depths for 0.5% AEP tidal event, 2050s with upper end climate change projection**




Source: Contains Ordnance Survey data Crown copyright and database right © 2017

**Figure 25: Change in flood depth for short-term mitigation works compared to baseline flood depths for 0.5% AEP tidal event, 2050s with upper end climate change projection**

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### 5.2.5 Flooding statistics for key overtopping events – permitted development and short-term mitigations scenarios

Peak in-channel flood levels along the reach of the LLAP defence and the total volume of flow either overtopping the defence (in the baseline and permitted development cases), or into the LLAP area through the managed oveflow are detailed in Table 11 for the key overtopping events. In all cases the in-channel water levels have increased post development works by a maximum of 0.03m, and in most cases the volumes flowing into the LLAP area have reduced (exception is the fluvial 0.5% AEP event where volumes are very small).

The impact of the proposed works (both permitted development and the short-term mitigation scenarios) on properties in the surrounding area have been calculated using the national receptors database and extracting the change in flood depth at each property. Table 12 details the number of properties which fall into specified depth bands. In all cases there are no properties that are adversely affected by the proposed works by more than 0.025m. A band between -0.025m and 0.025m was chosen as indicating no change to flood risk. This allows for slight differences in flood levels which could be attributed to minor modelling instabilities rather than true changes to flood risk.

None of the key overtopping events result in flooding around the development platforms; therefore, levels adjacent to these platforms to inform their final design heights have not been extracted. Levels have been extracted from the breach runs and runs for more extreme events and are presented in Table 17 and Appendix C respectively.

**Table 11: In-channel peak levels and volumes flowing into LLAP area (Key runs only)**

| Design Epoch | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | In-Channel Peak Level adjacent to proposed defence (mAOD) | | | Volume Flowing into LLAP area over defence reach (includes over the managed overflow in the short-term mitigation scenario) $m^3$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Baseline | Permitted Development | Short-term Mitigation | Baseline | Permitted Development | Short-term Mitigation |
| 2015 | Present Day | 50% | 0.5% | 6.17 | 6.17 | 6.20 | 66445 | 59551 | 28524 |
| 2040 | Higher Central (Fluvial), Upper End (Tidal) | 0.5% | 20% | 6.06 | N/A | 6.08 | 4027 | N/A | 6075 |
| 2050 | Upper End (Fluvial and Tidal) | 50% | 3.33% | 6.23 | N/A | 6.25 | 241034 | N/A | 158987 |
| | | 50% | 0.5% | 6.25 | N/A | 6.27 | 334025 | N/A | 215392 |

Source: Mott MacDonald

**Table 12: Impact of Proposed Works on Properties (Key runs only)**

| Design Epoch | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Development Scenario | Number of Properties impacted by development works within each depth range (Depth ranges are for the change in depth of flooding at property locations due to development works. A negative value is a decrease in flood depths) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | <-1m | -1m to -0.5m | -0.5m to -0.25m | -0.25m to -0.1m | -0.1m to -0.05m | -0.05m to -0.025m | Increase in flood depth (>0.025m) |
| 2015 | Present Day | 50% | 0.5% | Permitted Development | 0 | 0 | 8 | 40 | 43 | 38 | 0 |
| | | 50% | 0.5% | Short Term Mitigation | 0 | 1 | 29 | 122 | 98 | 74 | 0 |
| 2040 | Higher Central (Fluvial), Upper End (Tidal) | 0.5% | 20% | Short Term Mitigation | 0 | 1 | 1 | 20 | 10 | 11 | 0 |
| 2050 | Upper End (Fluvial and Tidal) | 50% | 3.33% | Short Term Mitigation | 1 | 3 | 60 | 242 | 156 | 139 | 0 |
| | | 50% | 0.5% | Short Term Mitigation | 1 | 2 | 89 | 278 | 196 | 143 | 0 |

Source: Mott MacDonald

## 5.3 Key overtopping scenario results – long-term mitigation scenarios

### 5.3.1 2115 0.5% AEP fluvial event with long-term mitigation works

Figure 26 and Figure 27 provide the flood depths in the LLAP area and surrounding villages for the baseline scenario and the long-term mitigation works respectively. Figure 28 shows the change in flood depth between the long-term mitigation works scenario compared to the baseline scenario.

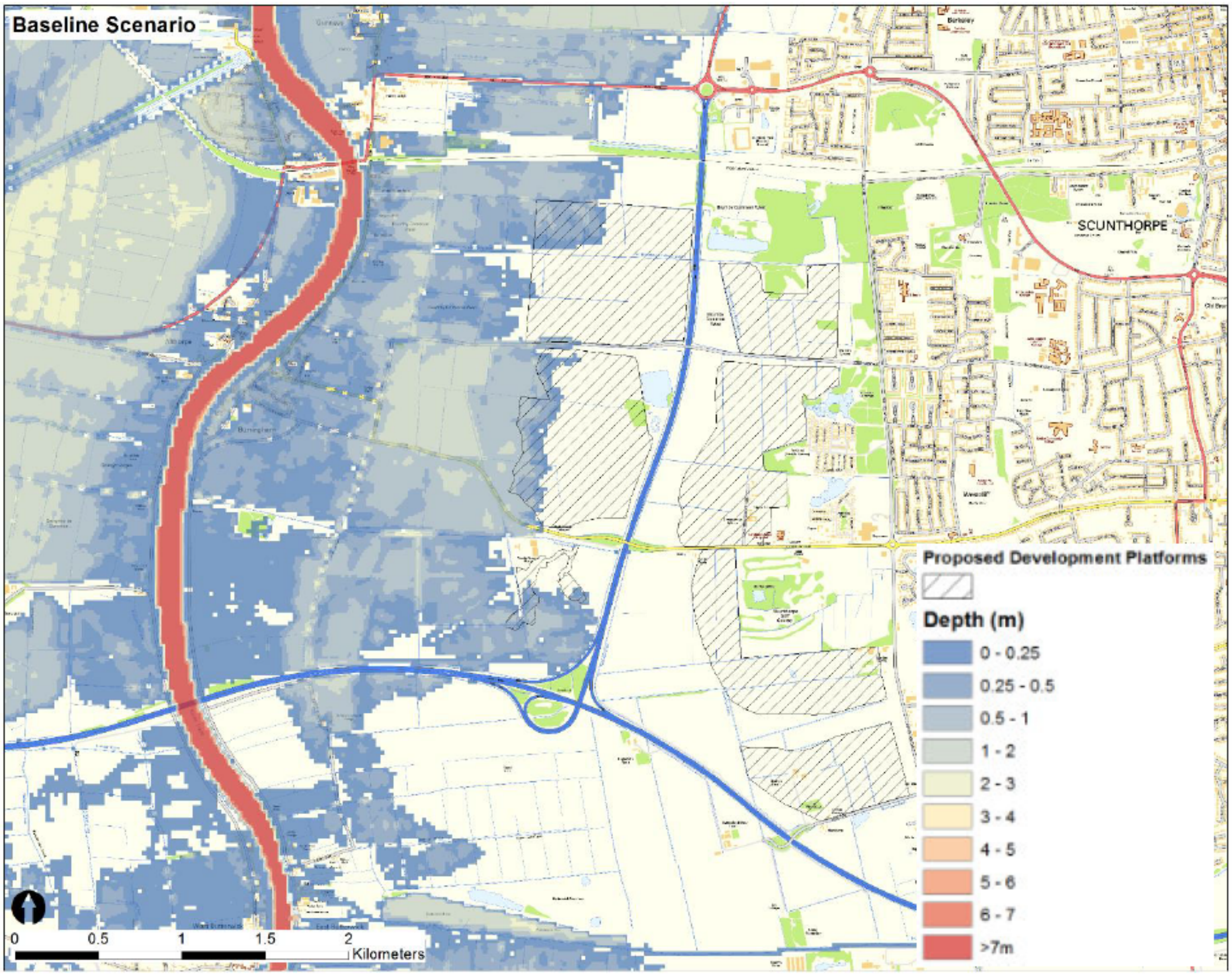
The long-term mitigation works scenarios are intended to show that a general solution to the long-term flooding situation exists, rather than provide the precise design details that would fully mitigate all adverse impacts to third-party properties. It is expected that other works will have been carried out in the catchment, settlement may have occurred, climate projections may have changed, and priorities for protecting regions may have changed before the detailed design of the long-term mitigation options is undertaken. Therefore, fine-tuning a long-term mitigation option would not be appropriate in this study, but rather to show that an overall solution is likely to exist.

The baseline results show extensive flooding on both the right and left banks, although flood extents are contained to the west of the M181.

The long-term mitigation works show the LLAP managed overflow area and the Crowle managed overflow area to be fully utilised. Areas of reduced flood depths are observed in East Butterwick and Keadby, although Keadby is still flooded. The land around Crowle and Eastoft to the west of the Crowle managed overflow area bund is completely removed from the flood extent – providing significant benefit to the area. Isolated properties are shown to be at increased flood risk from Owston Ferry to Flixborough Stather, with increased concentrations of properties in Gunness. Assessment of potential protection measures for Gunness should be considered in the future. Several properties within the Crowle managed overflow area are at significantly increased risk of flooding.

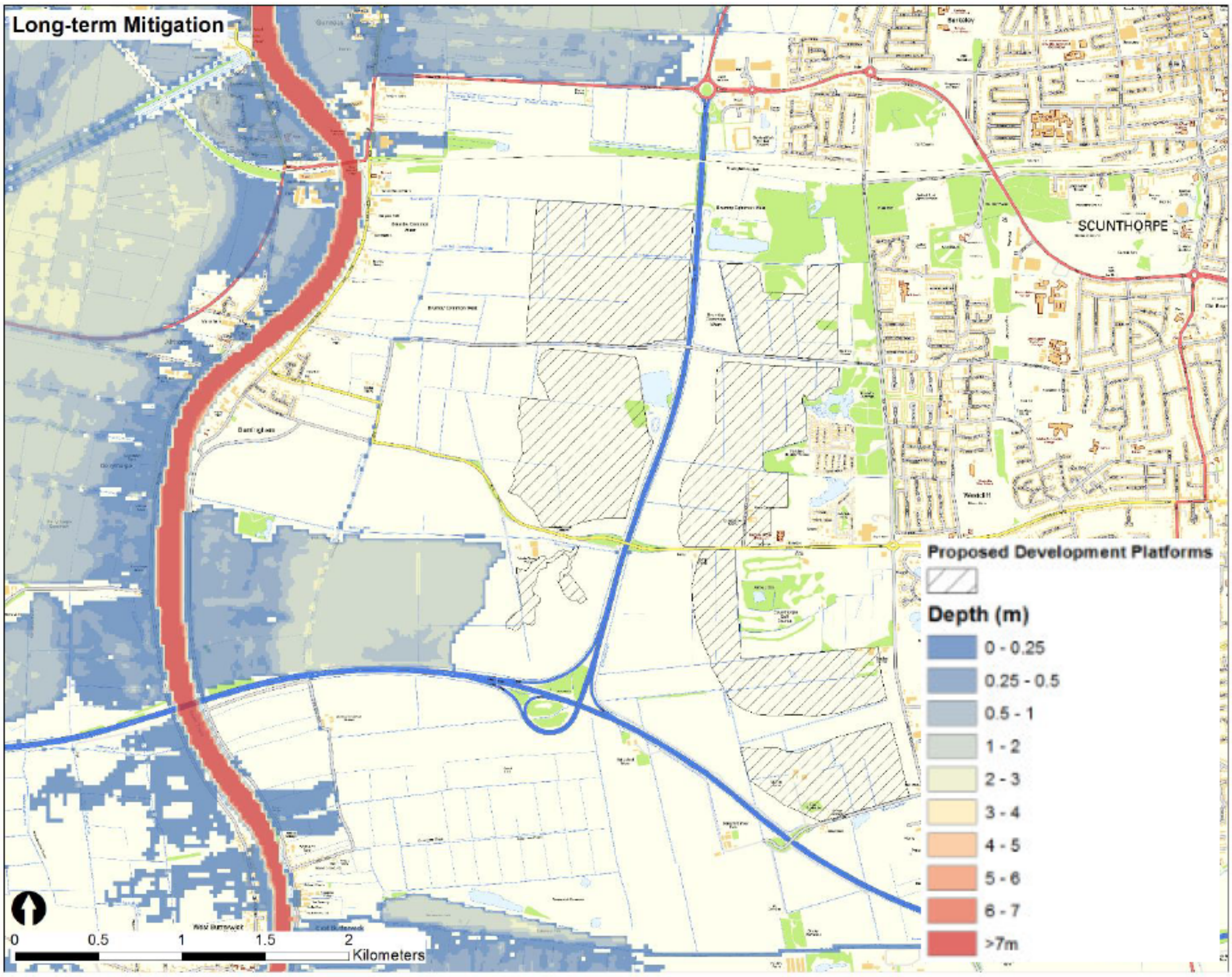
The long-term mitigation works results show no flooding around the proposed development platforms.

**Figure 26: Baseline flood depths for 0.5% AEP fluvial event, 2115 with upper end climate change projection**



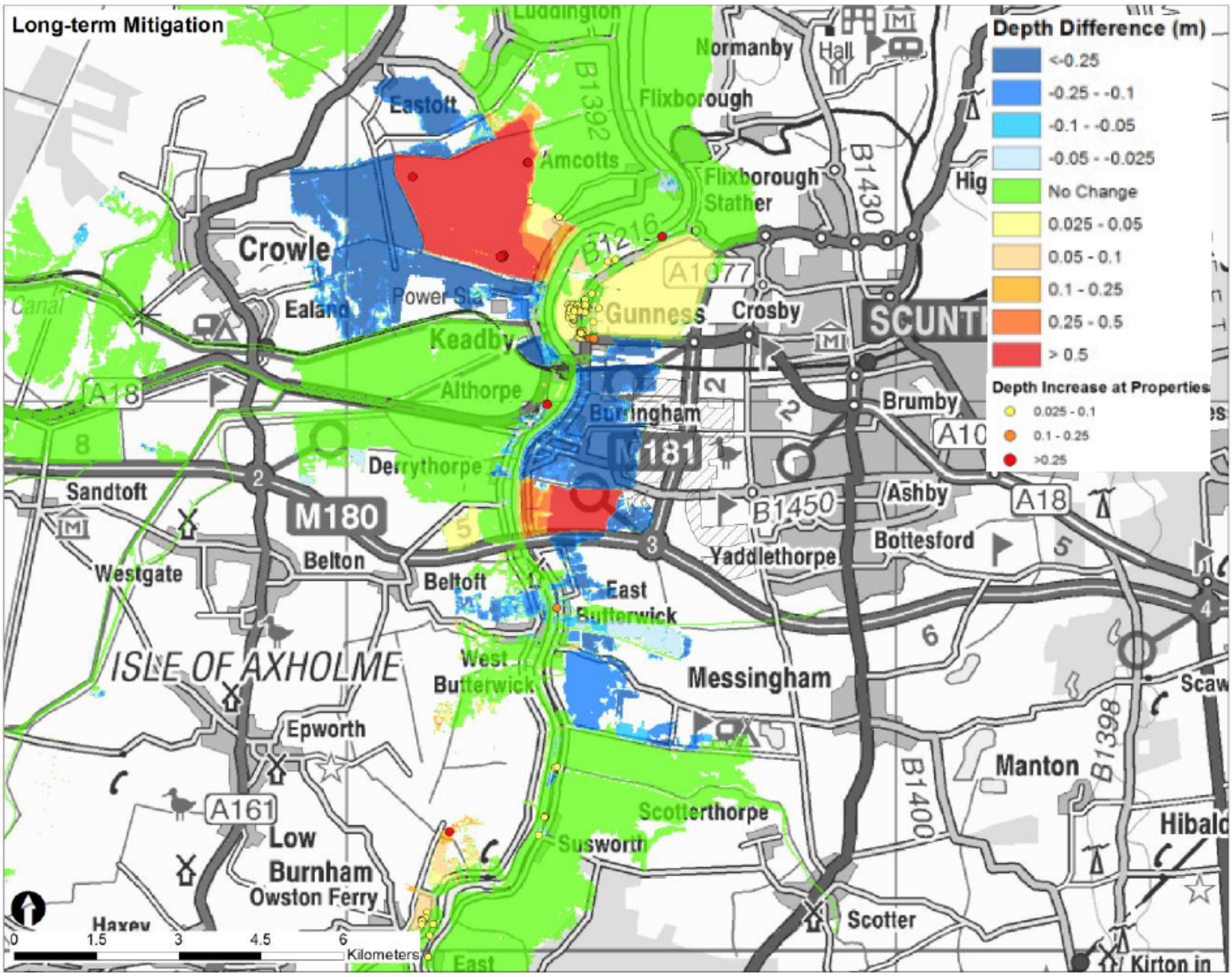

Source: Contains Ordnance Survey data Crown copyright and database right © 2017

**Figure 27: Long-term mitigation works flood depths for 0.5% AEP fluvial event, 2115 with upper end climate change projection**




Source: Contains Ordnance Survey data Crown copyright and database right © 2017

**Figure 28: Change in flood depth for long-term mitigation works compared to baseline flood depths for 0.5% AEP fluvial event, 2115 with upper end climate change projection**

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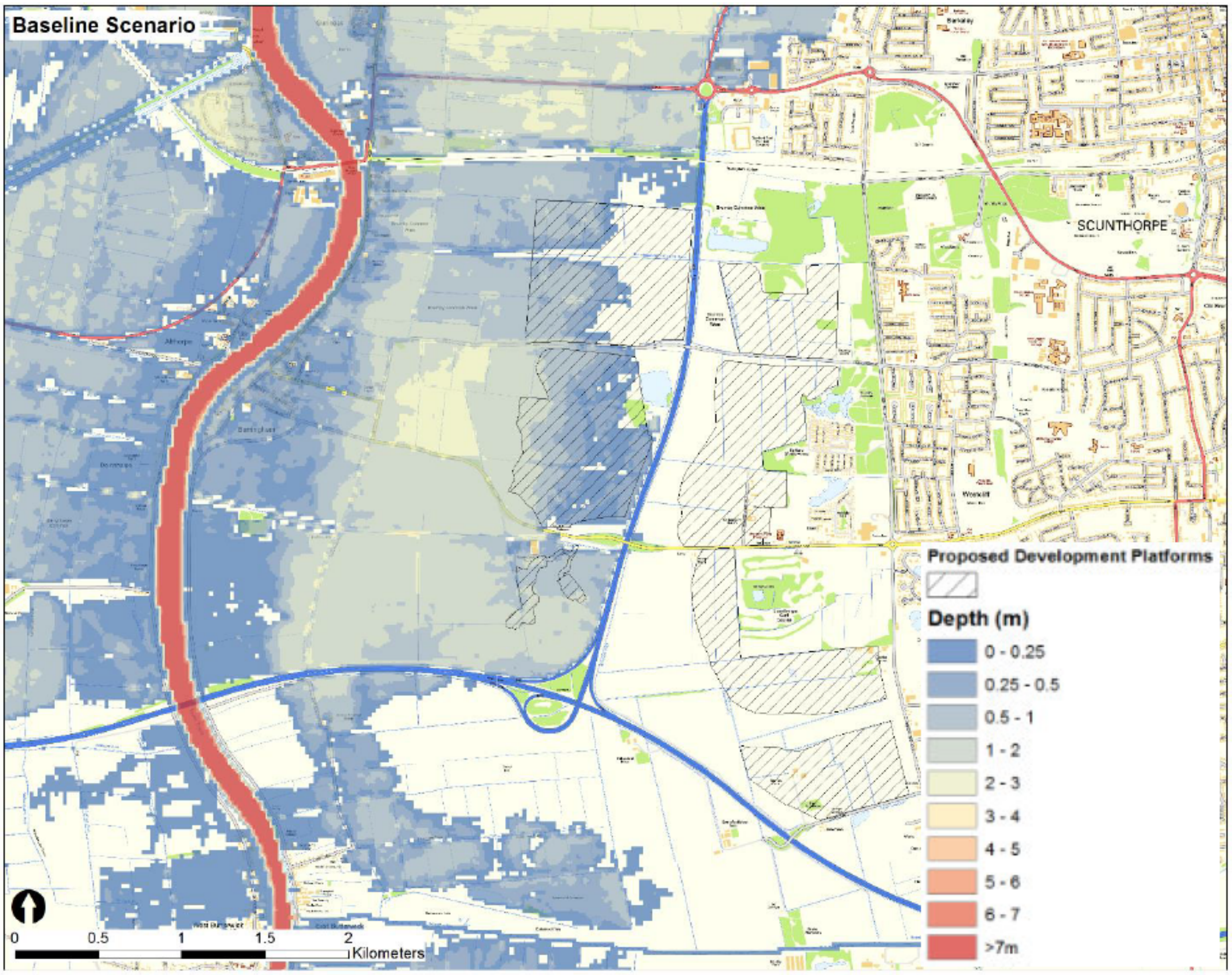
### 5.3.2 2050 0.5% AEP tidal event with long-term mitigation works

Figure 29 and Figure 30 provide the flood depths in the LLAP area and surrounding villages for the baseline scenario and the long-term mitigation works respectively. Figure 31 shows the change in flood depth between the long-term mitigation works scenario compared to the baseline scenario.

The baseline results show extensive flooding on both the right and left banks, although flood extents are contained to the west of the M181 in the LLAP area. The long-term mitigation works show the LLAP managed overflow area and the Crowle managed overflow area to be fully utilised, however, there is still flooding within the LLAP area and around the development platforms. This is due to a flow path under the railway embankment at the M181 into the northern section of the LLAP area. The LLAP defence therefore reduces the amount of flooding in the LLAP area but does not stop it completely. Additional works to contain the flood extent to the north of the railway would be required if all flooding was to be avoided within the LLAP area.

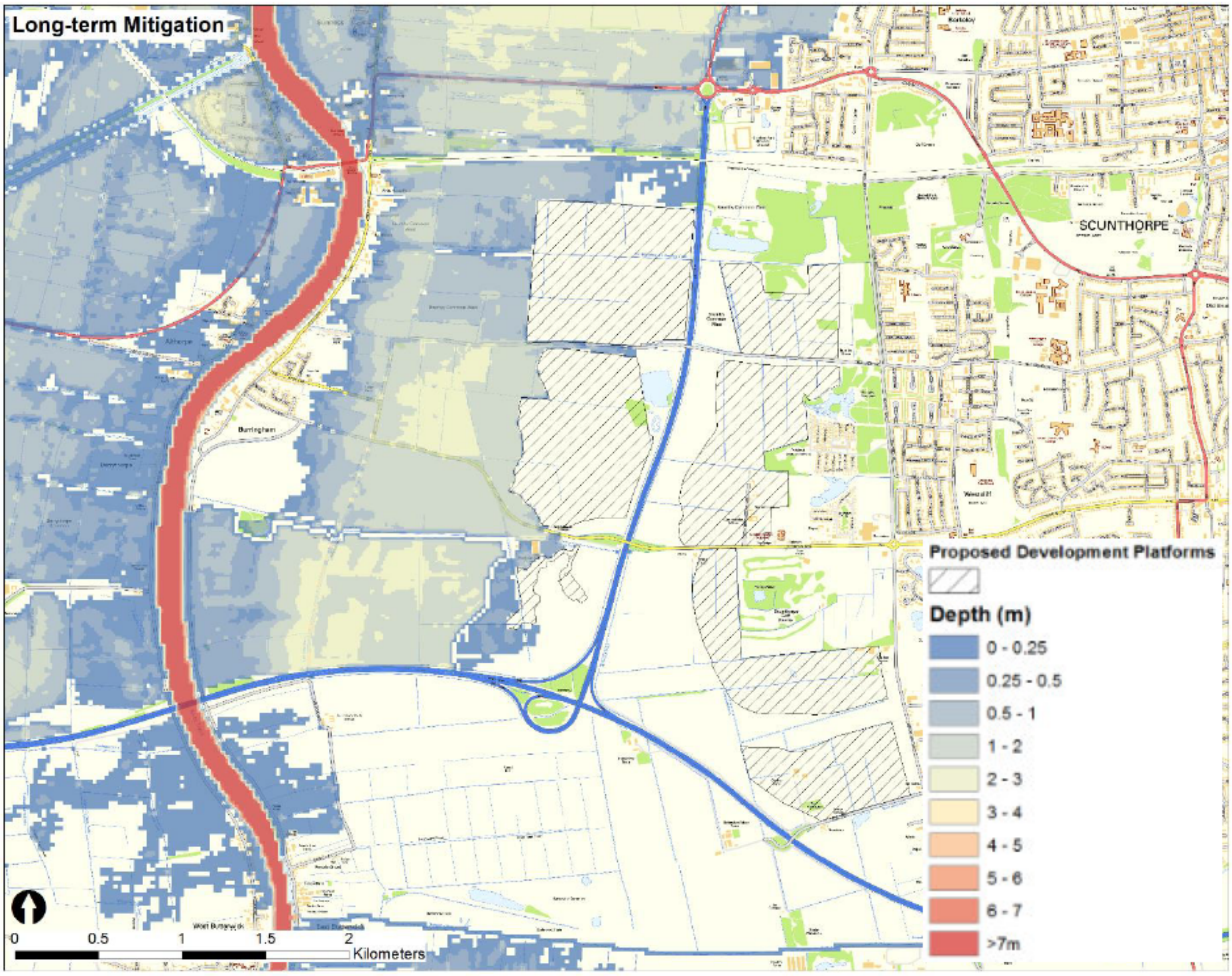
The village of Burringham is predominantly outside of the flood extent. Areas of reduced flood depths are observed in Susworth, East Butterwick and Keadby, although Keadby is still flooded. The land around Crowle and Eastoft to the west of the Crowle Managed overflow area bund is completely removed from the flood extent – providing significant benefit to the area. Isolated properties are shown to be at increased flood risk from Owston Ferry to Amcotts. Several properties within the Crowle managed overflow area are at significantly increased risk of flooding.

**Figure 29: Baseline flood depths for 0.5% AEP tidal event, 2115 with upper end climate change projection**



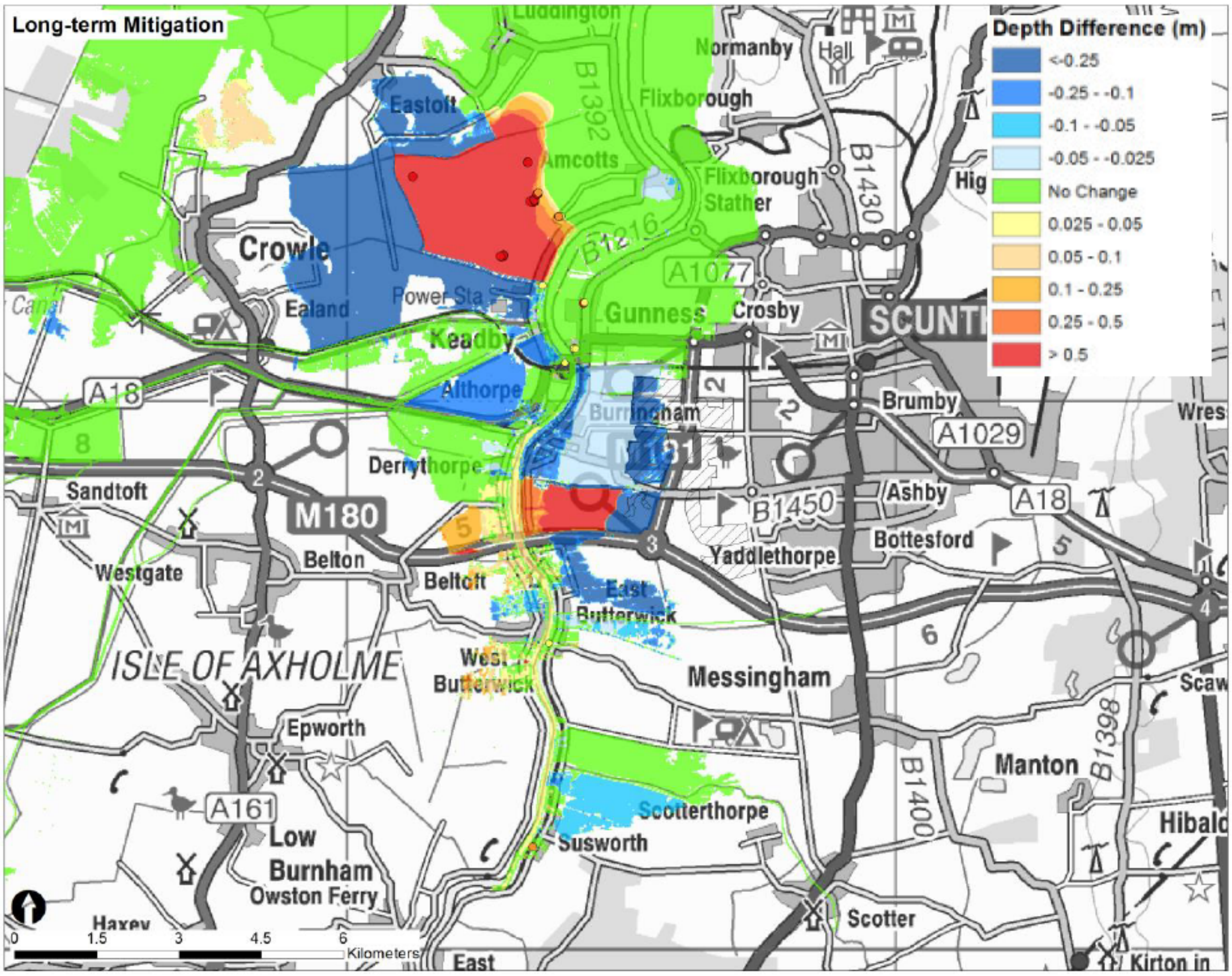

Source: Contains Ordnance Survey data Crown copyright and database right © 2017

**Figure 30: Long-term mitigation works flood depths for 0.5% AEP tidal event, 2115 with upper end climate change projection**




Source: Contains Ordnance Survey data Crown copyright and database right © 2017

**Figure 31: Change in flood depth for long-term mitigation works compared to baseline flood depths for 0.5% AEP tidal event, 2115 with upper end climate change projection**




Source: Contains Ordnance Survey data Crown copyright and database right © 2017

### 5.3.3 Flooding statistics for key overtopping events – long-term mitigation scenarios

Peak in-channel flood levels along the reach of the LLAP defence and the total volume of flow either overtopping the defence (in the baseline cases), or into the LLAP area through the managed overflow are detailed in Table 13 for the key overtopping events. In all cases the in-channel water levels have increased post development works by a maximum of 0.02m, and volumes flowing into the LLAP area have reduced.

The impact of the proposed works (long-term mitigation scenario) on properties in the surrounding area has been calculated using the national receptors database and extracting the change in flood depth at each property. Table 14 details the number of properties which fall into specified depth bands.

In the fluvial 0.5%AEP event with upper end climate change projection a total of 173 properties are adversely affected, whilst 1293 show a reduced depth of flooding. The majority of the adversely affected properties are in Gunness.

In the tidal 0.5% AEP event with upper end climate change projection a total of 38 properties are adversely affected, and 1391 properties show a reduced depth of flooding.

The tidal 0.5%AEP event with upper end climate change shows flooding around the development platforms due to the secondary flow path into the LLAP area from under the railway embankment to the north. The peak levels around these platforms are presented in Table 15.

The fluvial 0.5%AEP event with upper end climate change to 2115 does not show any flooding around the development platforms.

**Table 13: In-channel peak levels and volumes flowing into LLAP area (Key runs only)**

| Design Epoch | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | In-Channel Peak Level adjacent to proposed defence (mAOD) | | Volume Flowing into LLAP area over defence reach (includes over the managed overflow in the short-term mitigation scenario) $m^3$ | |
|---|---|---|---|---|---|---|---|
| | | | | Baseline | Long-term Mitigation | Baseline | Long-term Mitigation |
| 2115 | Upper End (Fluvial and Tidal) | 0.5% | 20% | 6.40 | 6.42 | 1911353 | 1287215 |
| | | 50% | 0.5% | 6.48 | 6.49 | 3006288 | 1878651 |

Source: Mott MacDonald

**Table 14: Impact of Proposed Works on Properties (Key runs only)**

| Design Epoch | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Development Scenario | Number of Properties impacted by development works within each depth range (Depth ranges are for the change in depth of flooding at property locations due to development works. A negative value is a decrease in flood depths) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | <-1m | -1m to -0.5m | -0.5m to -0.25m | -0.25m to -0.1m | -0.1m to -0.05m | -0.05m to -0.025m | 0.025m to 0.05m | 0.05m to 0.1m | 0.1m to 0.25m | 0.25m to 0.5m | 0.5m to 1m | >1m |
| 2115 | Upper End (Fluvial and Tidal) | 0.5% | 20% | Long-term Mitigation | 1 | 350 | 232 | 251 | 271 | 188 | 91 | 36 | 33 | 3 | 10 | 0 |
| | | 50% | 0.5% | | 8 | 98 | 243 | 646 | 212 | 184 | 6 | 5 | 6 | 6 | 14 | 1 |

Source: Mott MacDonald

**Table 15: Peak flood levels adjacent to the development platforms for long-term mitigation scenarios (Key runs only)**

| Design Epoch | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Peak flood level adjacent to development platforms (mAOD) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | North-West | North-East | Central West | Central East (North Burringham Road) | Central East (South Burringham Road) | South-West | South-East |
| 2115 | Upper End (Fluvial and Tidal) | 0.5% | 20% | | | | | | | No Flooding |
| | | 50% | 0.5% | 2.87 | N/A | 2.15 | N/A | N/A | 2.15 | N/A |

Source: Mott MacDonald

## 5.4 Key breach scenario results

### 5.4.1 2050 0.5% AEP tidal event with breach with short-term mitigation works

The 0.5% AEP tidal event for the 2050s with upper end climate change projection has been run for all 4 breach locations, for both the existing scenario (soft defence) and the short-term mitigation scenario (hard defence). Figure 32 and Figure 33 provide the flood depths in the LLAP area and surrounding villages for the baseline scenario and the short-term mitigation works respectively for breach 1. Figure 34 shows the change in flood depth between the short-term mitigation works scenario compared to the baseline scenario for this breach event. The figure also identifies which properties are adversely affected by the proposed development work (larger versions of figures provided in digital appendix).

For the breach scenarios, it should be expected that flood depths away from the immediate breach impact region will be adversely affected by the development works, as a narrow breach (due to the defence changing from soft to hard) will reduce the volume entering the immediate breach impact region causing in-channel water levels to remain at a higher level – leading to increased overtopping elsewhere. The increased overtopping elsewhere is still less than the overtopping that would occur if there was no breach. Table 16 details the volumes flowing into the LLAP area for all four breach locations.

For the breach scenarios, it should be expected that flood depths away from the immediate breach impact region will be adversely affected by the development works. A narrow breach in a hard defence, compared to a wider breach in a soft defence, will result in less water entering the immediate breach impact region. The in-channel water levels therefore remain at a higher level leading to increased overtopping elsewhere. However, the increased overtopping elsewhere is still less than the overtopping that would occur if there was no breach at all.

Of importance in the breach scenarios is whether the decrease in available flood storage (due to the introduction of the raised development platforms and the bunded managed overflow area) is more than the decrease in flood volume entering through the breach. If the decrease in flood storage is larger than the decrease in flood volume then it will lead to increased flood depths in the LLAP.

Table 16 details the volumes flowing into the LLAP area for all four breach locations. Table 17 details the peak flood levels adjacent to the development platforms for short-term mitigation works for each breach scenario.

The short-term mitigation works result in a decrease in flood volumes entering the LLAP area for all breach scenarios compared to the baseline. As breach 1 is the most severe, this breach scenario has been used for determining the impact of the proposed development works for other flood events.

For the breach 1 scenario, the short-term mitigation works cause flood depths to be reduced across the whole LLAP area with the exception of the bunded managed overflow area where there is some increase in flood depths. No properties directly affected by the breach show an increased depth of flooding. The flood extent does surround the development platforms to the east of the M181.

**Figure 32: Baseline flood depths for 0.5% AEP tidal event, 2050s with upper end climate change projection**

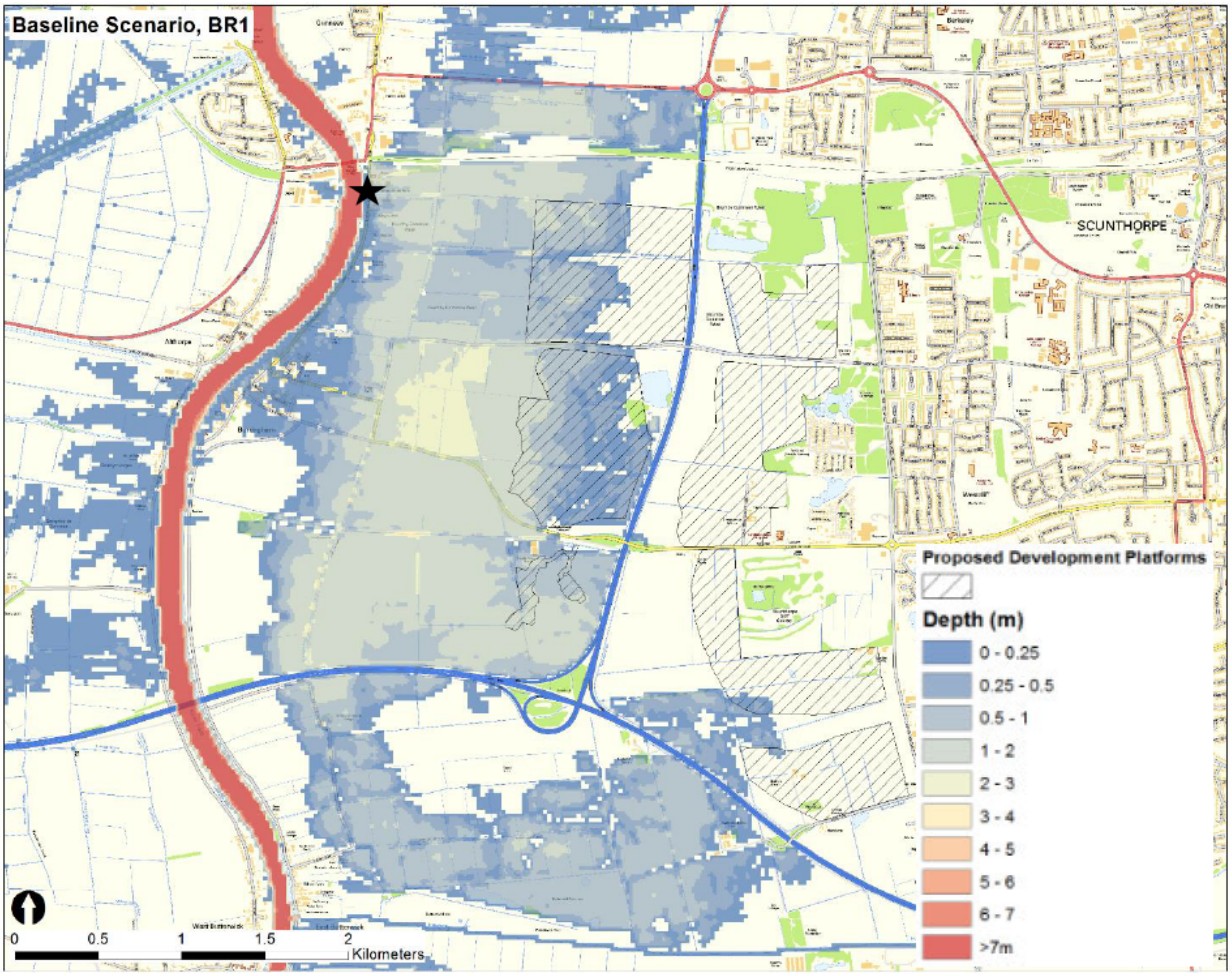



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**Figure 33: Short-term mitigation works flood depths for 0.5% AEP tidal event, 2050s with upper end climate change projection**

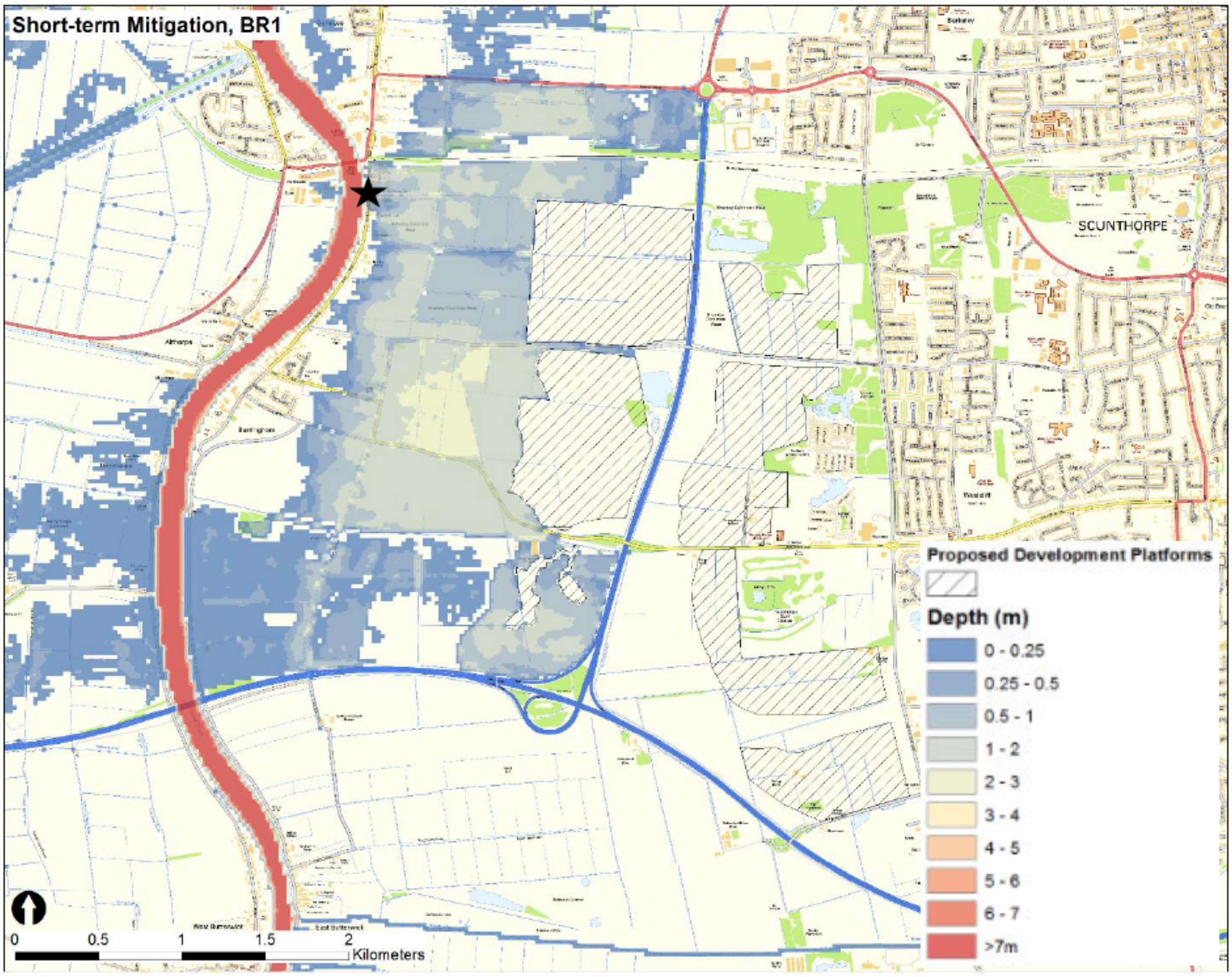


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**Figure 34: Change in flood depth for short-term mitigation works compared to baseline flood depths for 0.5% AEP tidal event, 2050s with upper end climate change projection**

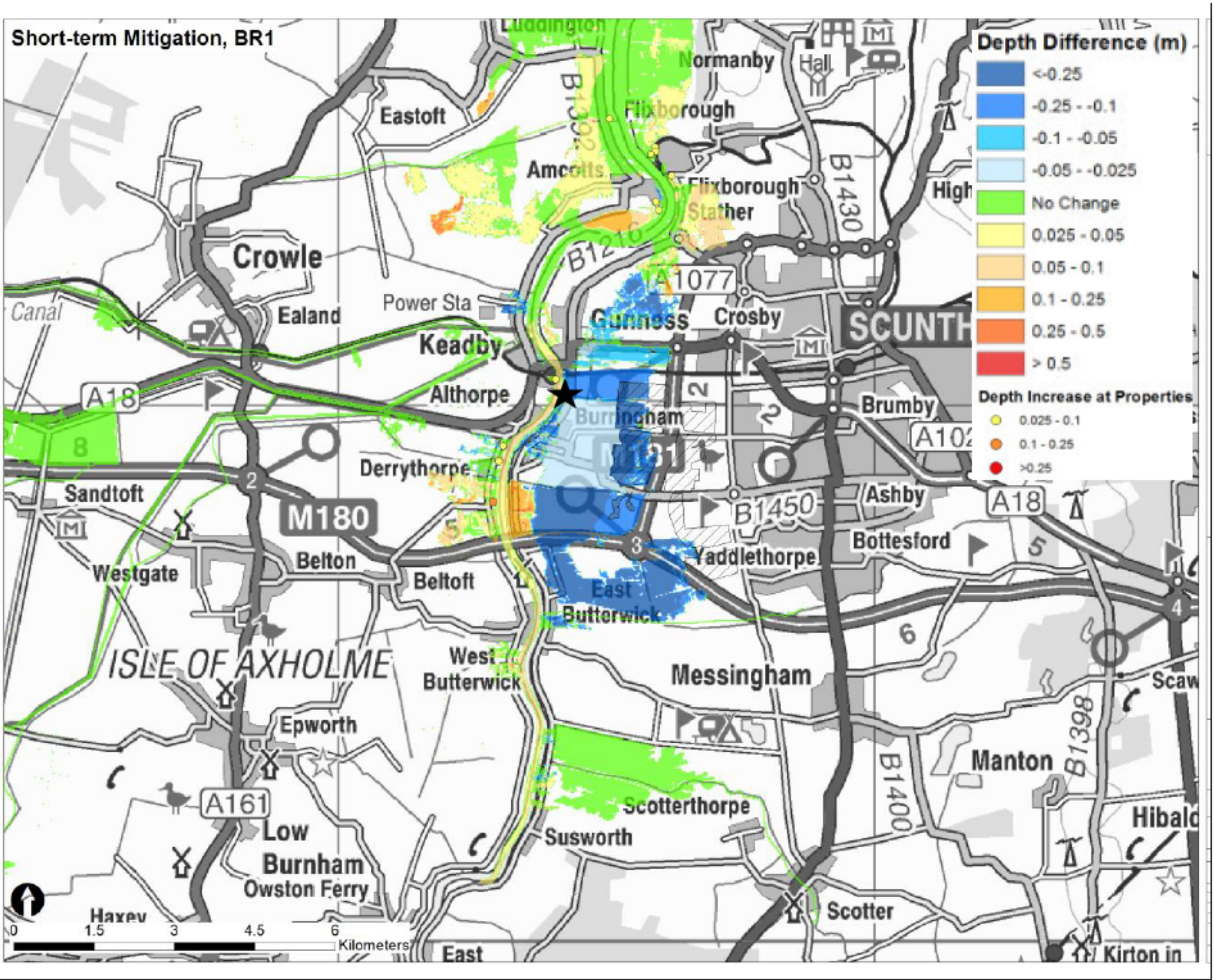


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**Table 16: Volumes flowing into LLAP area for breach scenarios for 0.5% AEP tidal event, 2050s with upper end climate change projection**

| Design Epoch | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Breach | Volume flowing into LLAP area (through managed overflow, over defence and through breach) $m^3$ | |
|---|---|---|---|---|---|---|
| | | | | | Baseline | Short-term Mitigation |
| 2050 | Upper End (Fluvial and Tidal) | 50% | 0.5% | BR1 | 6640423 | 3593245 |
| | | | | BR2 | 542116 | 326008 |
| | | | | BR3 | | 1049286 |
| | | | | BR4 | 3262996 | 1731116 |

**Table 17: Peak flood levels adjacent to the development platforms for breach scenarios for 0.5% AEP tidal event, 2050s with upper end climate change projection**

| Design Epoch | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Breach | Peak flood level adjacent to development platforms (mAOD) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | North-West | North-East | Central West | Central East (North Burringham Road | Central East (South Burringham Road) | South-West | South-East |
| 2050 | Upper End (Fluvial and Tidal) | 50% | 0.5% | BR1 | 2.43 | - | 2.12 | - | - | 2.12 | - |
| | | | | BR2 | No flooding adjacent to platforms | | | | | | |
| | | | | BR3 | 1.22 | - | 1.22 | - | - | - | - |
| | | | | BR4 | No flooding adjacent to platforms | | | | | | |

### 5.4.2 2040 0.5% AEP fluvial event with breach with short-term mitigation works

The 0.5% AEP fluvial event for the 2040s with higher central climate change projection has been run for breach 1, for both the existing scenario (soft defence) and the short-term mitigation scenario (hard defence). Figure 35 and Figure 36 provide the flood depths in the LLAP area and surrounding villages for the baseline scenario and the short-term mitigation works respectively for breach 1. Figure 37 shows the change in flood depth between the short-term mitigation works scenario compared to the baseline scenario for this breach event. The figure also identifies which properties are adversely affected by the proposed development work.

There is a single property within the LLAP area that is adversely affected by the proposed development works. The property is on the High Street at the northern end of Burringham. The property is not within the flood extent during the baseline scenario, however it is modelled to have a peak flood level of 1.90mAOD during a breach event for the short-term mitigation development works scenario. LiDAR data suggests ground levels of between 1.64 and 2.48mAOD across the property. It is therefore recommended that a threshold survey is carried out for this property.

**Figure 35: Baseline flood depths for 0.5% AEP fluvial event, 2040s with higher-central fluvial and upper end tidal climate change projection**

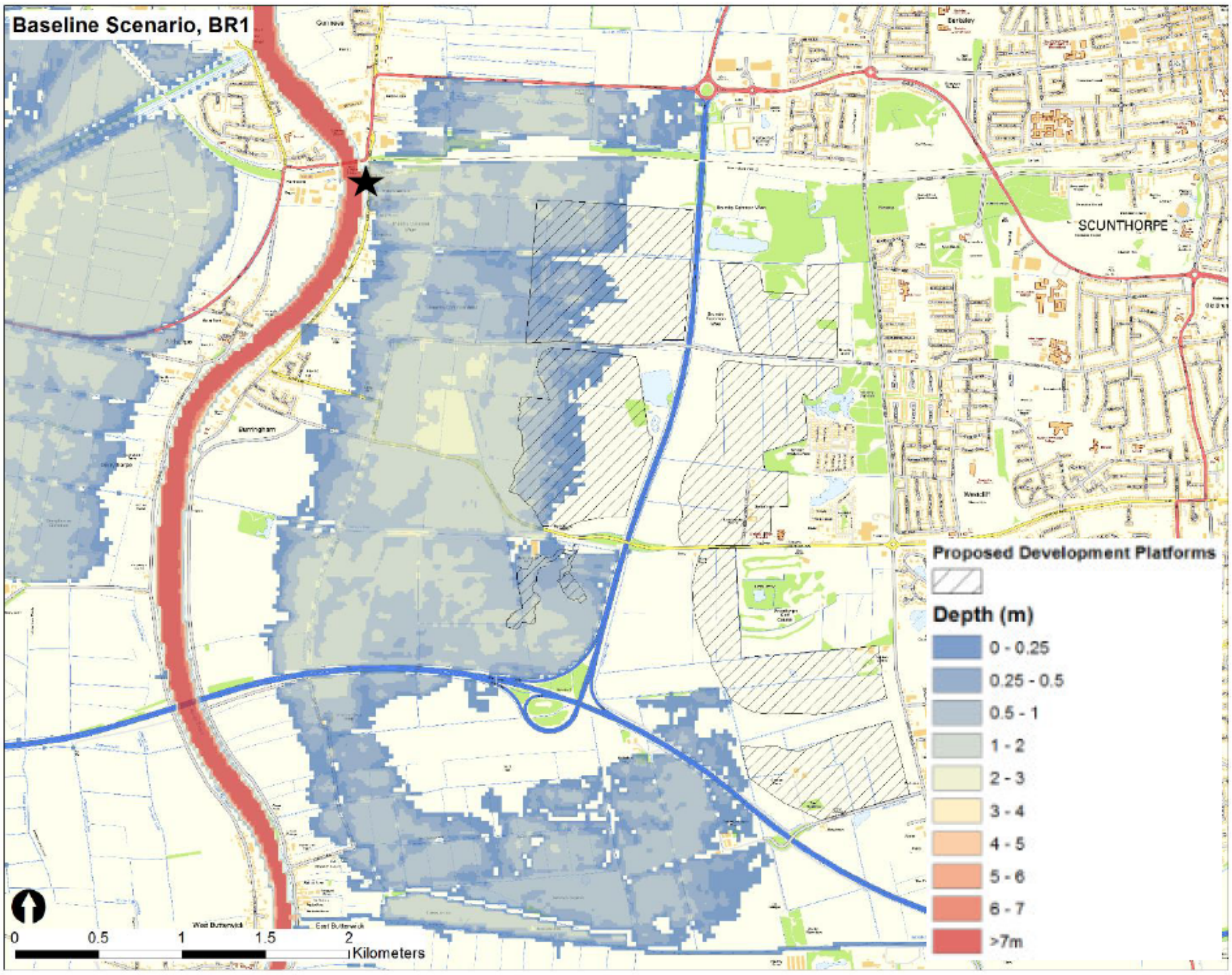


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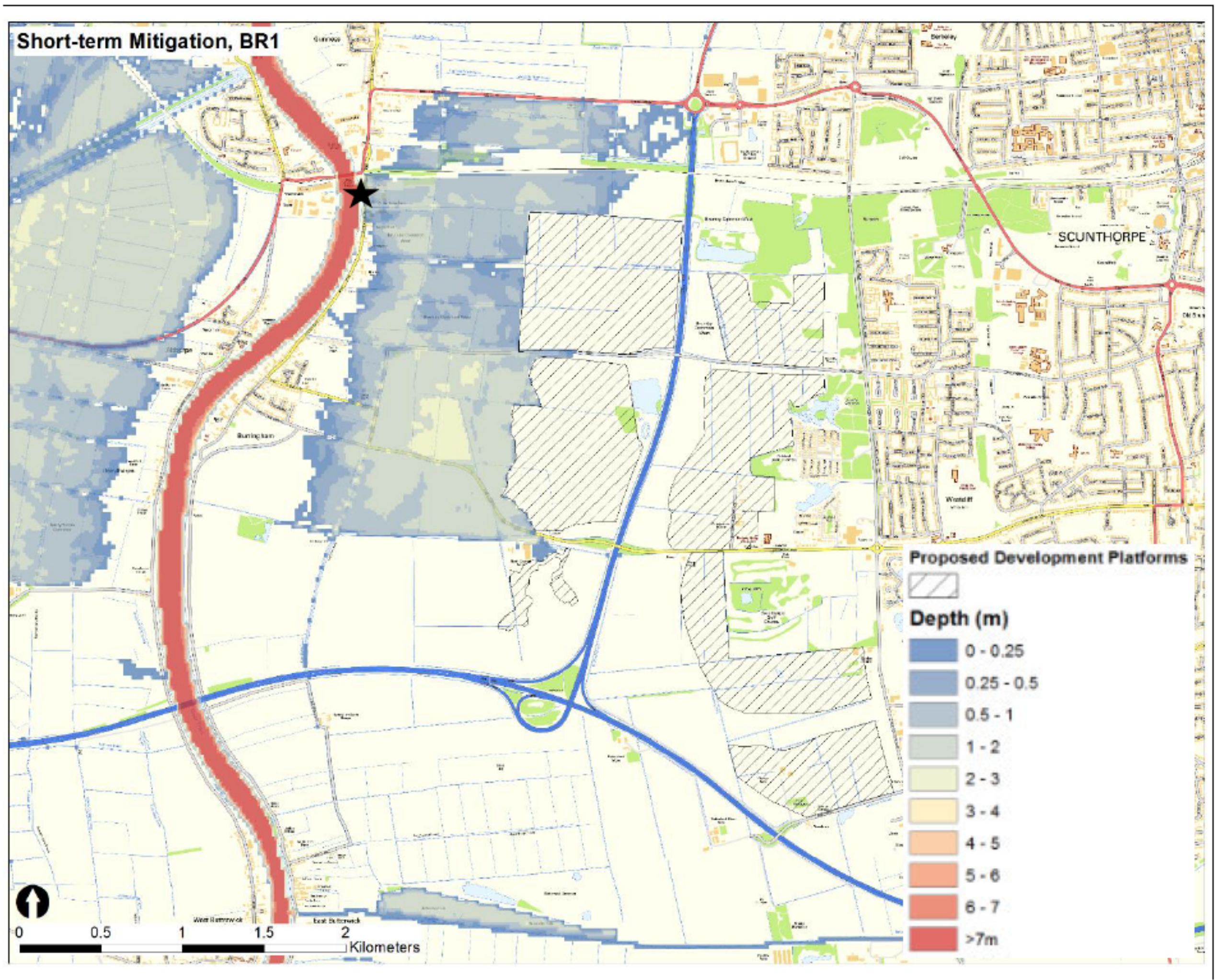
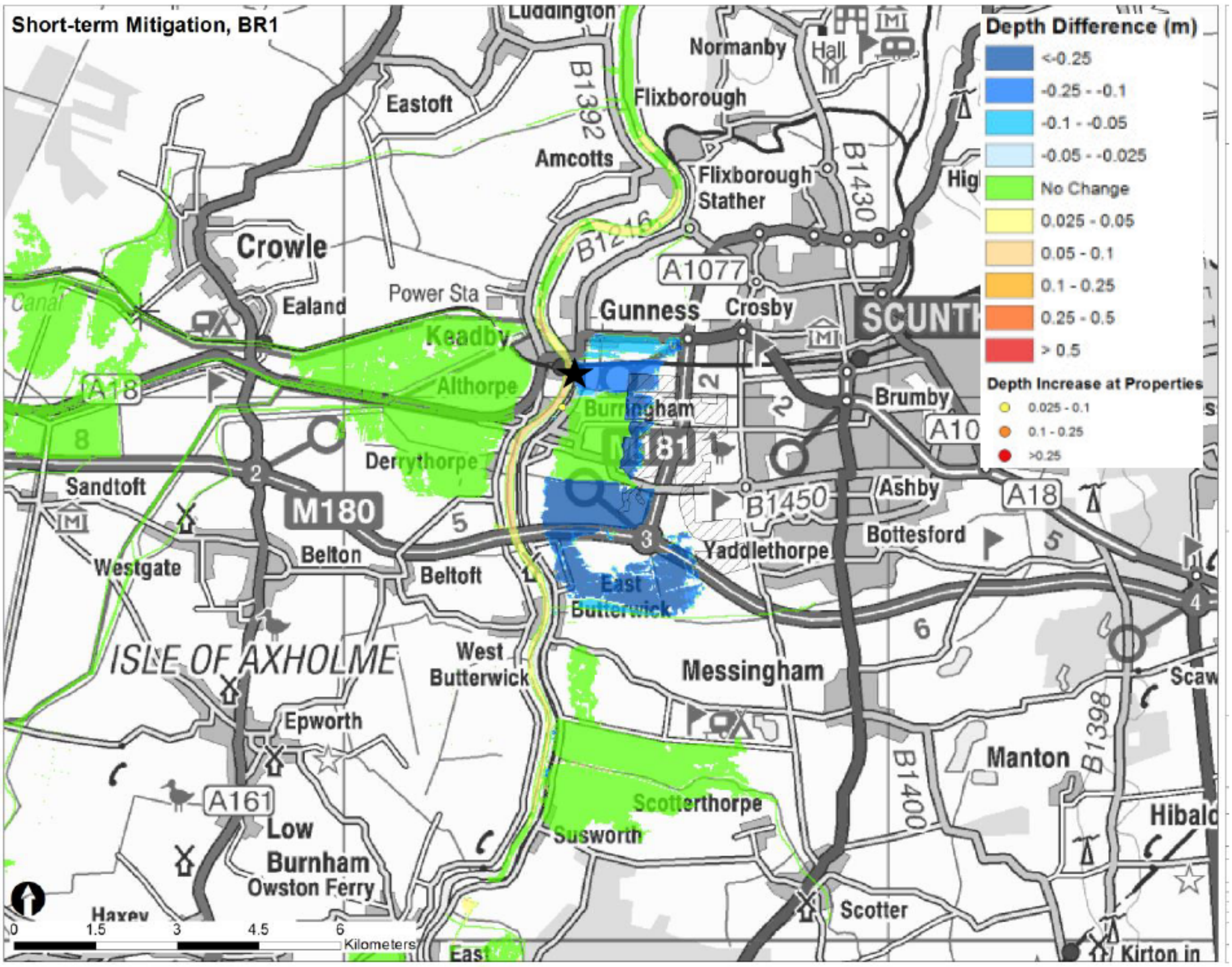
**Figure 36: Short-term mitigation works flood depths for 0.5% AEP fluvial event, 2040s with higher-central fluvial and upper end tidal climate change projection**




Source: Contains Ordnance Survey data Crown copyright and database right © 2017

**Figure 37: Change in flood depth for short-term mitigation works compared to baseline flood depths for 0.5% AEP fluvial event, 2040s with higher-central fluvial and upper end tidal climate change projection**




Source: Contains Ordnance Survey data Crown copyright and database right © 2017

## 5.5 Level, velocity and depth data at key locations within the LLAP managed overflow area

In order to inform the design of the LLAP managed overflow area, level, velocity and depth data at key locations within the LLAP managed overflow area have been extracted and plotted in Figure 38. The key locations identified (shown in Figure 38) are:

- The Poplars
- The Bungalow
- Sewage Treatment Works
- Wind turbines

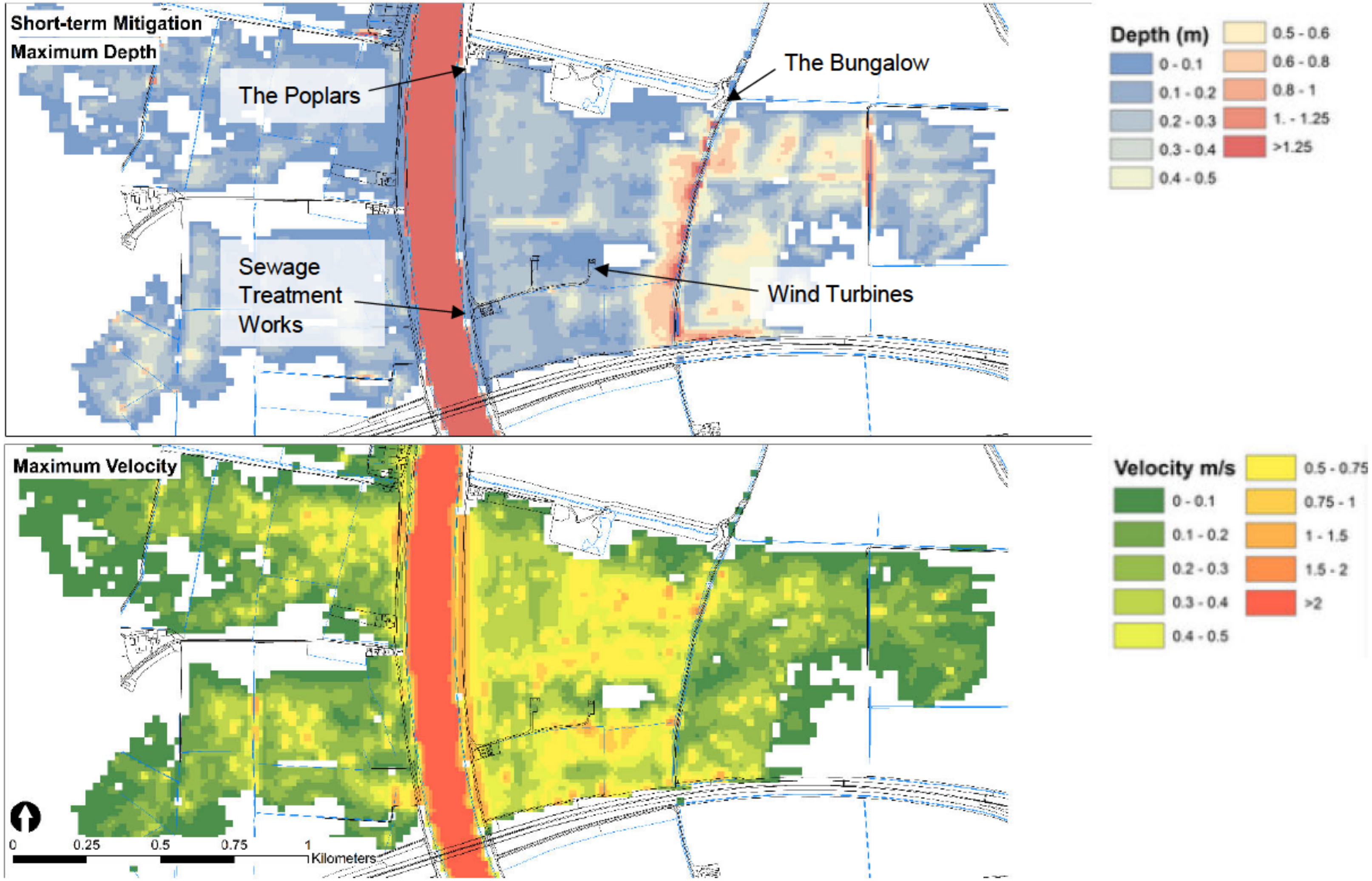
For The Poplars, flood levels have been extracted on the road adjacent to the property to determine if protection works are required to stop the flow from using the road as a flow route and thereby flooding the property and behind the property where water would pond as part of the flood storage area. Typical velocities around the property, not including the high velocity area where flow is on the managed overflow crest, have also been extracted.

For The Bungalow, flood levels in the managed overflow area where water would pond as part of the storage area have been extracted, and typical velocities adjacent to the property within the managed overflow. The velocities reported in Table 18 do not include the isolated high velocities within the ditches surrounding the property.

At the sewage treatment works, a typical flood level has been taken, and the maximum depth and velocity across the works extracted. For the wind turbines, levels at each of the individual generators have been extracted and the maximum depth and velocity across both sites extracted.

Figure 38 shows where these four locations are and a detailed flood depth and velocity map of the LLAP managed overflow area for the 0.5% AEP tidal event with upper end climate change projection to 2050. Figures for all events are provided in the digital data. Table 18 details the levels, depths and velocities for the key runs described in this chapter. Events where The Bungalow is flooded from behind (i.e. due to breach or severe event) are highlighted in blue. All level, flow and velocity data however relate to locations within the managed overflow area, rather than at the property location itself. A full table of data is provided in Appendix C.4.

**Figure 38: Short-term mitigation works peak flood depths and velocities for 0.5% AEP tidal event, 2050s with upper end tidal climate change projection**




Source: Contains Ordnance Survey data Crown copyright and database right © 2017

**Table 18: Peak flood levels, velocities, and depths at key locations within the LLAP managed overflow for short-term and long-term mitigation scenarios**

| Design Epoch | Scenario | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Breach | The Poplars | | | The Bungalow | | Sewage Treatment Works | | | Wind Farm | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Level on the road (mAOD) | Level at back of poplars (mAOD) | Typical Velocity in Managed overflow area | Level in Managed overflow area | Typical Velocity in Managed overflow area | Typical Level (mAOD) | Maximum Depths (m) | Maximum Velocity (m/s) | Level (Western wind generator) (mAOD) | Level (Eastern wind generator) (mAOD) | Maximum Depth (m) | Maximum Velocity (m/s) |
| Overtopping Runs | | | | | | | | | | | | | | | | | |
| 2015 | Short Term Mitigation | Present Day | 50% | 0.50% | | 5.06 | 3.58 | 0.10 | N/A | N/A | 3.87 | 0.20 | 0.40 | 3.33 | 2.33 | 0.10 | 0.20 |
| 2040 | Short Term Mitigation | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2050 | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 3.33% | | 5.11 | 3.76 | 0.20 | 1.11 | 0.30 | 3.90 | 0.30 | 0.50 | 3.41 | 2.35 | 0.20 | 0.30 |
| | | | 50% | 0.50% | | 5.12 | 3.78 | 0.30 | 1.19 | 0.50 | 3.91 | 0.30 | 0.50 | 3.43 | 2.36 | 0.20 | 0.40 |
| 2115 | Long Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 0.50% | | 5.22 | 4.06 | 0.50 | 2.81 | 0.75 | 4.05 | 0.40 | 1.00 | 3.62 | 2.81 | 0.80 | 0.75 |
| | | | 0.50% | 20% | | 5.21 | 4.02 | 0.30 | 2.24 | 0.40 | 4.01 | 0.40 | 1.00 | 3.58 | 2.50 | 0.40 | 0.75 |
| Breach Runs | | | | | | | | | | | | | | | | | |
| 2040 | Short Term Mitigation | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | BR1 | N/A | N/A | N/A | Floods from behind due to breach (no flooding from managed overflow area) | | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2050 | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 0.50% | BR1 | 5.09 | 3.73 | 0.30 | 1.08 | 0.30 | 3.89 | 0.30 | 0.50 | 3.38 | 2.35 | 0.20 | 0.30 |
| | | | 50% | 0.50% | BR2 | 5.11 | 3.77 | 0.30 | 1.17 | 0.40 | 3.91 | 0.30 | 0.75 | 3.42 | 2.36 | 0.20 | 0.40 |
| | | | 50% | 0.50% | BR3 | 5.10 | 3.75 | 0.30 | 1.12 | 0.40 | 3.90 | 0.30 | 0.75 | 3.40 | 2.35 | 0.20 | 0.30 |
| | | | 50% | 0.50% | BR4 | 5.09 | 3.73 | 0.30 | 2.73 | 1.50 | 4.05 | 0.40 | 0.75 | 3.50 | 2.73 | 0.60 | 0.75 |

## 5.6 Summary of results for all model runs

Table 19 provides a high-level overview of the impact of the proposed development works across the full range of events and scenarios modelled. Specific details of the number of properties affected, in-channel peak flood levels and flood levels adjacent to the development platforms are provided in Appendix C.

For the 0.1% AEP fluvial events the volume of flow passing through the model is significant, and in particular the 2115 model with H++ climate change projection was unstable. No results have been presented for this event. For the 0.1% AEP fluvial events that did run successfully, the adverse impact to surrounding land and properties is significant. This is primarily due to the main flow path into the LLAP area changing from being over the proposed LLAP defence (which is the case in more frequent events and the tidal events) to a flow path coming down the floodplain and overtopping the M180 into the LLAP area. The overtopping into the floodplain originates from the south near Gainsborough. The proposed LLAP defence therefore has limited positive impact in reducing flood volumes in the area in the 2115 epoch scenario, whilst the raised development platforms reduce the available flood storage area significantly.

**Table 19: Summary of impact of proposed development works for all events**

| Design Epoch | Scenario | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Breach No. | Summary of Impact |
|---|---|---|---|---|---|---|
| Overtopping Models | | | | | | |
| 2015 | Phase 1 (Permitted Development Works) | Present Day | 50% | 0.50% | | No properties adversely affected. Overall reduction of flood levels in Derrythorpe (See Section 5.2.1) |
| | Short Term Mitigation | | 50% | 0.50% | | No properties adversely affected. Overall reduction of flood levels in East Butterwick and Derrythorpe (See Section 5.2.1) |
| 2040 | Short Term Mitigation | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | | No properties adversely affected. LLAP managed overflow just active (See Section 5.2.2) |
| | | | 0.10% | 20% | | Widespread impact on the right bank from Susworth to the A18. Key flow path is through the floodplain from the south near Gainsborough. Proposed defence does not therefore provide protection to the LLAP area, and the raising of the development platforms reduces the available flood storage area. Large numbers of properties affected in East Butterwick, Messingham, Yaddlethorpe and Crosby |
| | | H++ (Fluvial and Tidal) | 0.50% | 20% | | Some impact to the south in Susworth, and Owston Ferry. LLAP managed overflow just active |
| | | | 0.10% | 20% | | Isolated properties affected from Owston Ferry to Flixborough Stather |
| 2050 | Phase 1 (Permitted Development Works) | Upper End (Fluvial and Tidal) | 50% | 0.50% | | Isolated properties affected from Susworth to Keadby. Overall reduction in flood levels in Derrythorpe. |
| | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 3.33% | | No properties adversely affected. Overall reduction of flood levels in East Butterwick, Derrythorpe and Keadby (See Section 5.2.3) |
| | | | 50% | 0.50% | | No properties adversely affected. Overall reduction of flood levels in East Butterwick, Derrythorpe and Keadby (See Section 5.2.4) |
| | | | 50% | 0.10% | | No properties adversely affected. Overall reduction of flood levels in East Butterwick, Derrythorpe, Keadby and Amcotts. |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | | Isolated groups of properties affected from East Butterwick to Flixborough. Overall reduction in flood levels in East Butterwick, Derrythorpe, Keadby and Amcotts. |
| | | | 50% | 0.10% | | Isolated groups of properties affected from East Butterwick to Flixborough. Overall reduction in flood levels in East Butterwick, Derrythorpe and Keadby |
| 2115 | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 0.50% | | Isolated groups of properties affected from Susworth to Flixborough Stather. Higher number of properties effected in Gunness. |
| | | | 0.50% | 20% | | Isolated groups of properties affected from Owston Ferry to Keadby. Higher number of properties effected in Gunness and Flixborough. |

| Design Epoch | Scenario | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Breach No. | Summary of Impact |
|---|---|---|---|---|---|---|
| | Long Term Mitigation | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | | Isolated groups of properties affected from Owston Ferry to Flixborough Stather. Higher number of properties effected in Gunness and Owston Ferry. |
| | | | 0.10% | 20% | | Isolated groups of properties affected from Owston Ferry to Flixborough Stather. Higher number of properties effected in Gunness. Properties within the proposed Crowle managed overflow area affected. |
| | | Upper End (Fluvial and Tidal) | 50% | 0.50% | | Isolated properties affected from Susworth to Gunness. Properties within the proposed Crowle managed overflow area affected. Overall widespread reduction in flood levels in Susworth, East Butterwick, Althorpe, Keadby and land surrounding Crowle and Eastoft outside of the managed overflow area (See Section 5.3.2) |
| | | | 50% | 0.10% | | Isolated properties affected from Susworth to Gunness. Properties within the proposed Crowle sill area affected. Overall widespread reduction in flood levels in Susworth, East Butterwick, Althorpe, Keadby and land surrounding Crowle and Eastoft outside of the managed overflow area |
| | | | 0.50% | 20% | | Isolated properties affected from Susworth to Gunness. Higher number of properties affected in Gunness. Properties within the proposed Crowle managed overflow area affected. Overall widespread reduction in flood levels in East Butterwick, Keadby and land surrounding Crowle and Eastoft outside of the managed overflow area |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | | Widespread increases in flood depths within the LLAP area, around Amcotts, to the north of Eastoft and to the west of Crowle. High numbers of properties affected in Burringham, West Butterwick Amcotts, Yaddlethorpe and in Scunthorpe west of Scotter Road. |
| | | | 50% | 0.10% | | Widespread increases in flood depths within the LLAP area, around Amcotts, to the north of Eastoft and to the west of Crowle. High numbers of properties affected in Burringham, West Butterwick Amcotts, Yaddlethorpe and in Scunthorpe west of Scotter Road. |
| | | | 0.50% | 20% | | Widespread increases in flood depths within the LLAP area, around Amcotts, to the north of Eastoft and to the west of Crowle. High numbers of properties affected in Burringham, East Butterwick, Amcotts, Messingham, Yaddlethorpe and in Scunthorpe west of Scotter Road. |
| | | | 0.10% | 20% | | Baseline model not stable – so unable to assess impacts |
| Breach Models | | | | | | |
| 2040 | Short Term Mitigation | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | BR1 | Single property affected within the LLAP area. No flooding around the developments to the east of the M181 (See Section 5.4.2) |
| | | | 0.10% | 20% | BR1 | Increased flood depths within the LLAP area around Burringham, Yaddlethorpe and Scunthorpe west of Scotter Road. All development platforms surrounded. |
| | | H++ (Fluvial and Tidal) | 0.50% | 20% | BR1 | No properties adversely affected within the LLAP area. No flooding around the development platforms to the east of the M181 |

| Design Epoch | Scenario | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Breach No. | Summary of Impact |
|---|---|---|---|---|---|---|
| 2050 | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 0.50% | BR1 | No properties adversely affected within the LLAP area. No flooding around the development platforms to the east of the M181 (See Section 5.4.1) |
| | | | 50% | 0.50% | BR2 | No properties adversely affected within the LLAP area. No flooding around the development platforms to the east of the M181 |
| | | | 50% | 0.50% | BR3 | No properties adversely affected within the LLAP area. No flooding around the development platforms to the east of the M181 |
| | | | 50% | 0.50% | BR4 | No properties adversely affected within the LLAP area. No flooding around the development platforms to the east of the M181 |
| | | | 50% | 0.10% | BR1 | No properties adversely affected within the LLAP area. No flooding around the development platforms to the east of the M181 |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | BR1 | No properties adversely affected within the LLAP area. No flooding around the development platforms to the east of the M181 |
| 2115 | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 0.50% | BR1 | No properties adversely affected within the LLAP area. Some locally increased depths of flooding surrounding the north-eastern development platform |
| | | | 0.50% | 20% | BR1 | No properties adversely affected within the LLAP area |

Source: Mott MacDonald

# 6 Conclusions and Recommendations

## 6.1 Overview

Mott MacDonald Ltd (MML) was instructed by North Lincolnshire Council (NLC) to design improvements to existing flood embankments along a 3.5km length of the River Trent from the M180 motorway bridge, through the village of Burringham to the A18 Keadby Bridge to the north of the settlement. Hydraulic modelling was carried out to assess the required flood defence levels, mitigation works required and to demonstrate the impact any improvements might have for the Lincolnshire Lakes Area and surrounding third parties.

The hydraulic model is based on the EA's Interim Tidal Trent Model developed by Mott MacDonald in 2013. The model has been updated to include:

- Improved calibration to the December 2013 tidal surge event
- New topographic bank level survey data from the EA undertaken in 2016
- New topographic survey of the existing flood embankment where improvements are proposed
- Additional detail in the area of interest, such as culverts under embankments

In consultation with the Environment Agency, a Managed Adaptive Approach has been developed which effectively permits the provision of flood risk mitigation to revised climate change scenarios with the provision of future cooperation and the implementation of a catchment wide mitigation system in the future. The main characteristic of the Managed Adaptive Approach is that it acknowledges that the estimate and scale of climate change will change over time. The MAA enables the current estimated level of protection for, say, 2050 to be constructed now but in such a way that in, say, 2030, the defence may be increased in level to provide protection up to 2115.

This approach enables the proposed AAP development to successfully mitigate flood risk locally for a specific future epoch, showing benefits from a viable development.

The modelling provided an estimate, based on current climate change prediction models and guidance, of design events for the 2040 (fluvial), 2050 (tidal) and 2115 (both fluvial and tidal) epochs.

The following epochs and climate change scenarios have been considered:

1. Tidal Events
   a. Upper End tidal estimates, and Upper End fluvial estimates for 2050 (0.25m increase to sea levels and 30% increase to fluvial flows)
   b. H++ tidal estimates, and H++ fluvial estimates for 2050 (0.37m increase to sea levels and 35% increase to fluvial flows)
   c. Upper End tidal estimates, and Upper End fluvial estimates for 2115 (1.13m increase to sea levels and 50% increase to fluvial flows)
   d. H++ tidal estimates, and H++ fluvial estimates for 2115 (2.24m increase to sea levels and 65% increase to fluvial flows)
2. Fluvial Events

a. Upper End tidal estimates, and Higher Central fluvial estimates for 2040 (0.16m increase to sea levels and 20% increase to fluvial flows)
b. H++ tidal estimates, and H++ fluvial estimates for 2040 (0.24m increase to sea levels and 35% increase to fluvial flows)
c. Upper End tidal estimates, and Higher Central fluvial estimates for 2115 (1.13m increase to sea levels and 30% increase to fluvial flows)
d. Upper End tidal estimates and Upper End fluvial estimates for 2115 (1.13m increases to sea levels and 50% increase to fluvial flows)
e. H++ tidal estimates, and H++ fluvial estimates for 2115 (2.24m increase to sea levels and 65% increase to fluvial flows)

Four development scenarios have been modelled:

- Baseline scenario representing the existing state of defences
- Permitted development scenario, looking at improvement works that are restricted to 2km or less of defences
- Short-term mitigation scenario, looking at the required defence level and mitigation works required to provide protection to the 2040s (fluvial) and 2050s (tidal) without adversely affecting third party properties up to the 0.5% AEP event (with upper end climate change projection for the tidal scenario, and higher central climate change projection for the fluvial events)
- Long-term mitigation scenario, looking at the feasibility for a catchment scale solution providing protection to 2115

## 6.2 Conclusions

The following conclusions have been drawn from the modelling for each scenario:

- Permitted Development Scenario
  - A length of 1.1km of defence can be reinstated on the right bank starting from 'The Poplars' and heading northward towards Keadby. The remaining 0.9km of permitted works would be required to provide mitigation works of 'low spot filling' on the left bank at Derrythorpe.
  - This scenario provides no adverse impact to third parties for the present day 0.5% AEP tidal event
- Short-term mitigation scenario
  - The full length of proposed defence can be reinstated to the historic blue-book level of 6.477mAOD. Mitigation works required a managed overflow on the right bank extending from the M180 to the south of 'The Poplars' with a crest level of 6.05mAOD. Additional low-spot raising of defence was required on the left and right banks from Susworth to Amcotts.
  - In the overtopping scenarios modelled there are no third-part impacts for events up to the 0.5% AEP tidal event with upper end climate change projection to 2050, and the 0.5% AEP fluvial event with higher central climate change projection to 2040.
  - In the breach scenarios modelled up to the 0.5% AEP events for both tidal and fluvial scenarios (same climate change projections as in the above point), only a single property in Burringham is affected in the fluvial 0.5% AEP event (2040s)
  - Wide spread reduction in flood depths is modelled, in particular for Keadby which would be removed from the flood extent up to the 0.5% AEP tidal event with upper end climate change to 2050.

  - For increasingly lower probability events (i.e. more sever events), adverse third-party impacts are shown to increase.
- Long-term mitigations scenario
  - A viable solution to the long-term flood risk to 2115 has been identified comprising of a new managed overflow between Keadby and Amcotts, flowing into a flood storage area towards Crowle and Eastoft. The managed overflow area has existing flood connectivity to the River Trent, and therefore this solution is optimising the existing flooding mechanism. Additional raising of low spots in defences would be required
  - This mitigation provides minimal third party impacts for events up to the 0.5% AEP tidal event with upper end climate change to 2115, and the 0.5% AEP fluvial event with upper end climate change to 2115.
  - Full details of the long-term mitigation scenario have not been analysed as additional changes to the catchment are likely to have taken place between now and when the long-term solution would be implemented, and climate change projections may also have been revised.

## 6.3 Recommendations

The following recommendations are made:

The threshold of the single property in Burringham adversely affected by the 0.5% AEP fluvial breach event (with higher central climate change projection to 2050) is surveyed to compare against the peak flood level, and therefore confirm whether this property is at increased flood risk and what local solutions could be implemented.

The modelling is reviewed and updated following changes to the catchment and revisions to climate change projections

Additional modelling is carried out closer to the implementation of the long-term mitigation scenario to account for any changes to the catchment, revised hydrological data, and to determine the finer details of the works.

# Appendices

# A. Site Location Plan

**Figure 39: Site location plan**

# B. Environment Agency Model Audit

# Lincolnshire Lakes Model review

**Background.**

Mott MacDonald Consultants have been commissioned by North Lincolnshire County Council to produce a flood risk assessment to determine the affect of raising defences upstream of Burringham, as part of the Lincolnshire Lakes Development.

In 2012 Mott MacDonald were commissioned by the Environment Agency to develop a model for tidal reaches of the River Trent. Subsequently this model was developed further by the Environment Agency and retitled the EA Interim Tidal Trent model. This model was returned to Mott MacDonald for them to use in this flood risk assessment.

In December 2013 the highest recorded tidal surge event was experienced on in the Trent Estuary. As part of this FRA Mott Macdonald have attempted to calibrate the model so that it better reproduces the levels recorded during 2013 surge event.

Mott MacDonald have provided a report detailing the changes that they have made to the model in calibration. It is the task of this review to compare the EA interim Tidal Trent model against the model supplied as part of the Lincolnshire Lakes FRA to ensure all changes are reasonable and as per the report.

**Model comparison.**

The comparison tool in ISIS 3.7 was used to directly compare the EA interim Tidal Trent model against Lincolnshire Lakes FRA model. Highlighted differences were checked against the report.

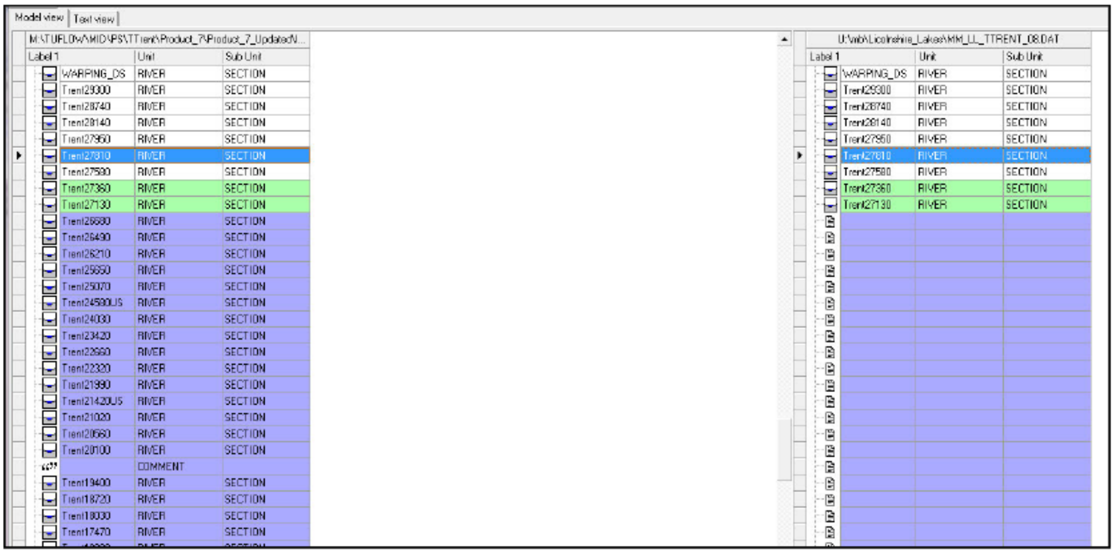
Extracts from Mott MacDonald report in *italics*.

1. *Model Domain – The 2D model domain has been kept the same as the EA model, with the exception of:*
*a. The downstream boundary and code region was shaped to gain a better representation of the flow from the Humber into the Trent.*

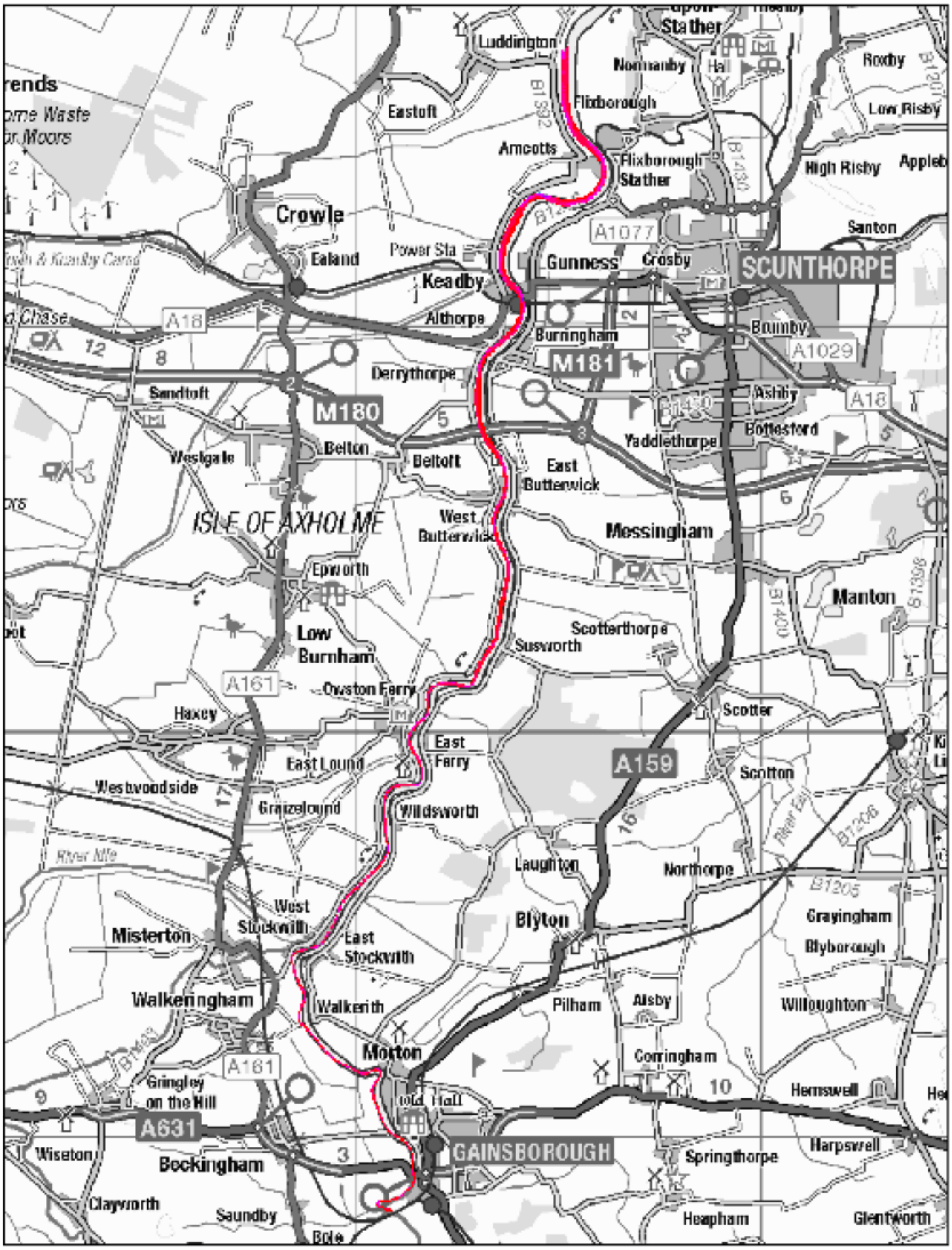
This has been verified.

*b. The 1D ISIS model was truncated at Owston Ferry, with the Trent downstream of Owston represented in the 2D domain. The 1D model has been linked to the 2D representation of the River Trent through the use of an HX line.*

This has been verified.



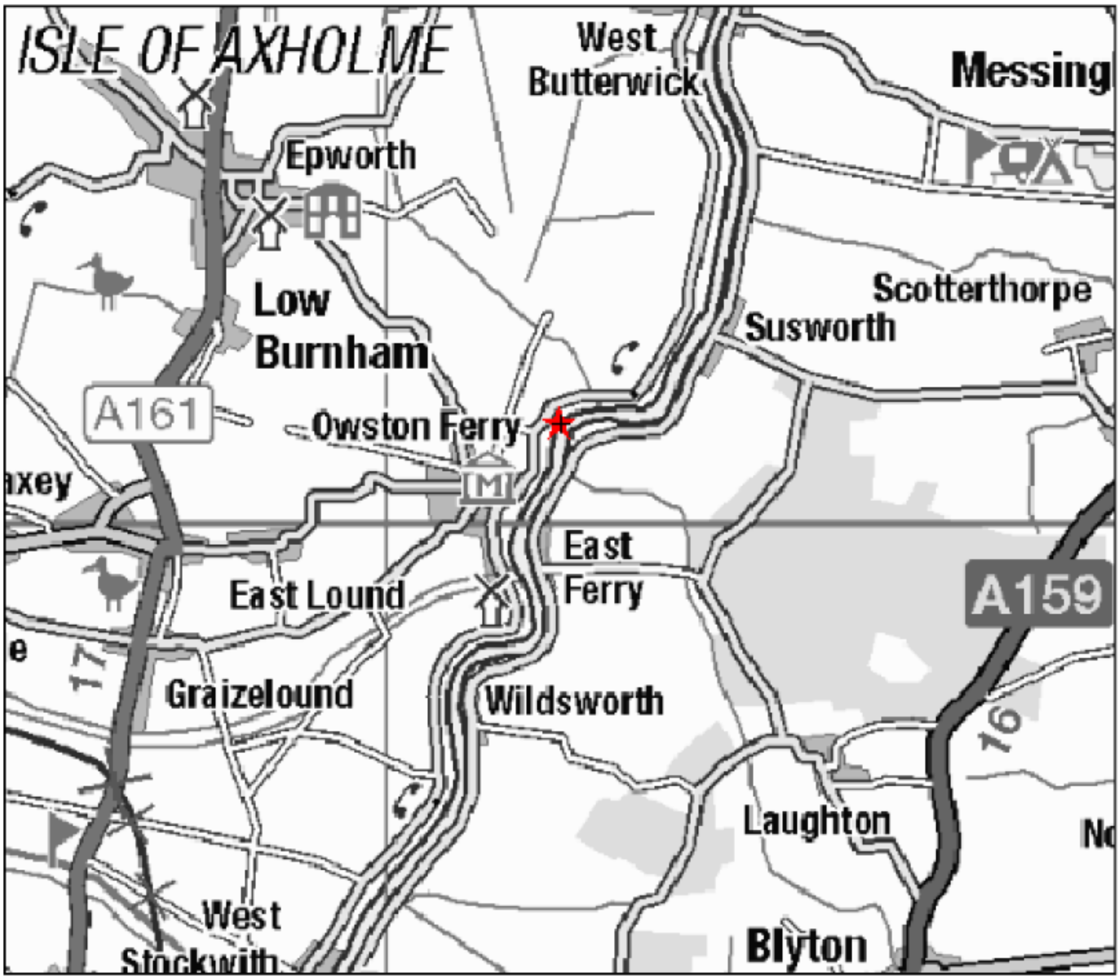
*Comparison of ISIS DAT files showing truncated files in the Lincolnshire Lakes model (right)*



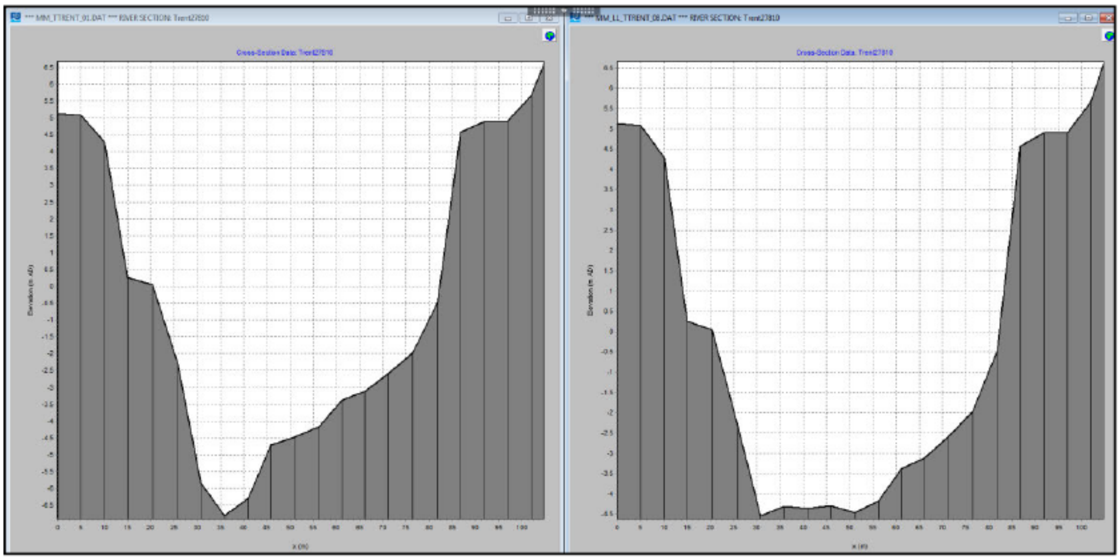

*2D channel over basemapping.*

*2. Bed Topography – The bed topography downstream of Owston Ferry has been represented using bathymetric data. This is the same data source as was used to derive the 1D ISIS cross-sections in the EA interim model.*

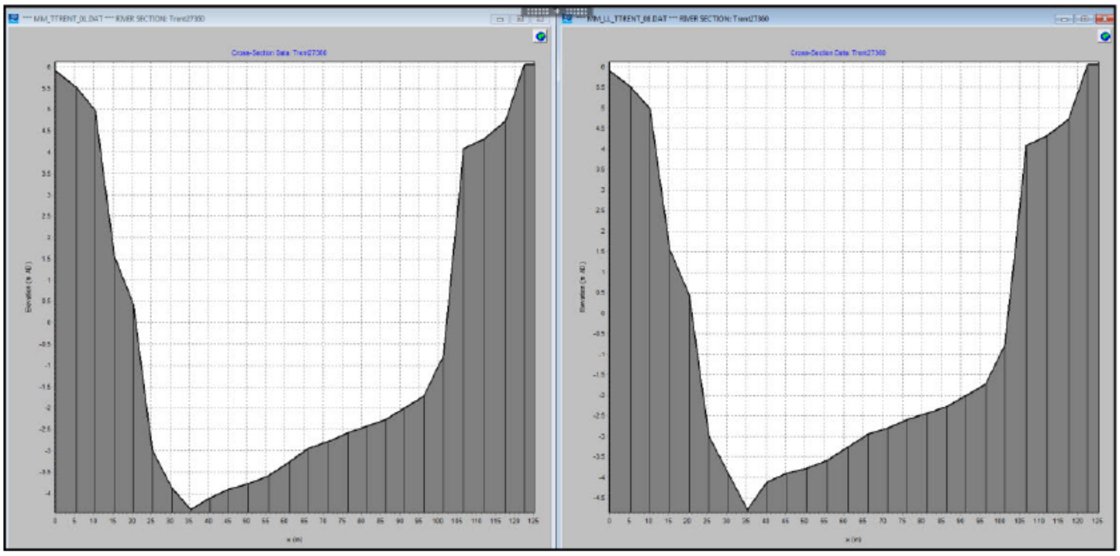
Changes to the bed profile have been made in the vicinity of Owston Ferry;


ISLE OF AXHOLME
West
Butterwick
Messing
Epworth
Low
Burnham
Scotterthorpe
Susworth
A161
Owston Ferry
East
Ferry
A159
East Lound
Graizelound
Wildsworth
Laughton
West
Stockwith
Blyton

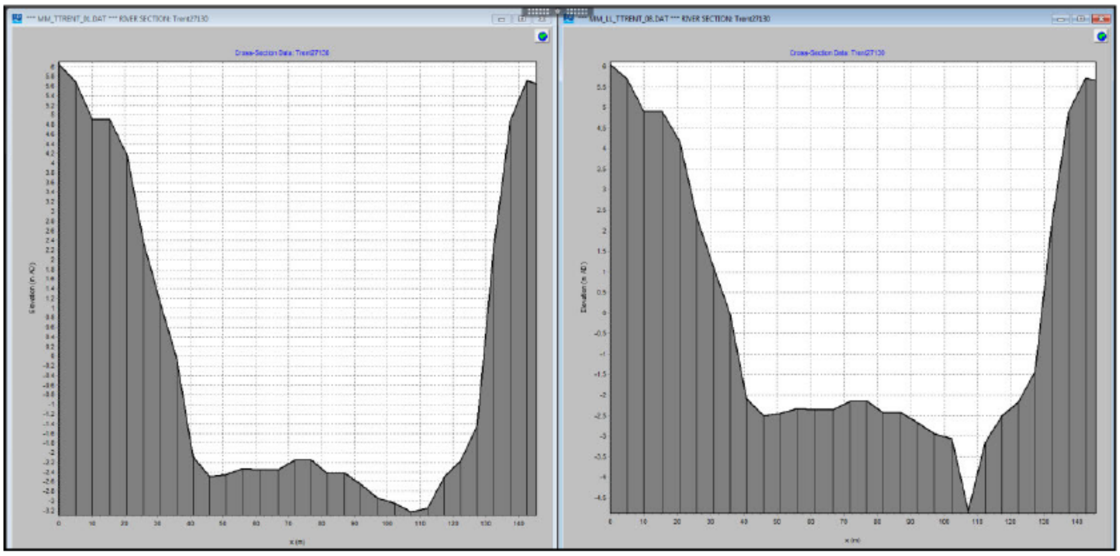
Node 27810



Node 27360



Node 27130



This is not explicitly mentioned in the report. Changes to node 27810 appears to represent a significant increase in channel capacity.

*At the very downstream reach of the Tidal Trent, and within the Humber Estuary, bathymetric data was not available, and a conceptualised sloping bed level has been incorporated using z-shapes. Gauge data at Burton Stather during the December 2013 event has been used to confirm that the conceptualised bed profile is reproducing observed levels within this model reach.*

This has been verified.

*3. Bed roughness – A significant change has been made to the bed roughness in the lower reaches of the River Trent. The roughness downstream of Keadby has been reduced to a value of 0.01 (from a value of 0.02), and from Keadby to Owston Ferry, a value of 0.018 has been used (from a value of 0.02). These roughness values are very low compared to the widely accepted values suggested by Chow, however research into the modelling of tidal bores has shown that values as low as 0.004 have been successfully used to replicate the tidal bore on the Qiantang River, China1.*
*The Trent has a bore (the Trent Aegir) up to 1.5 metres high, occurring when a high spring tide meets the downstream flow of the river. During the December 2013 event, the water level rose 2.35m in under 15 minutes.*

A random check was made on the MM_LL_TTRENT_F0002_T0200CC_V16_grd_check file to ensure that grid that over lapped the 2d channel had the material value of 11. Cross referencing to the look up table below to achieve the stated roughness value of 0.018.

```
##########################################################################################
! ****************************** TIDAL TRENT 1D-2D Model ******************************
! ******************************** MOTT MACDONALD 2015 ********************************
! ******************************* MATERIAL CONTROL FILE *******************************
##########################################################################################

! Comments and blank lines are allowed in this file
! First value refers to class assigned in 2d_mat
! Second values refers to manning's n value

  1, 0.050 !Default global
  2, 0.10 !Trees
  3, 0.060 !Scrub,Orchard,Marsh,RoughGround
  4, 0.05 !Rail
  5, 0.038 !Roads
  6, 0.05 !Manmade
  7, 0.05 !Multi surface
  8, 0.035 !Water
  9, 0.500 !Buildings
  10, 0.010 ! downstream of Keadby
  11, 0.018  ! upstream of Keadby
  12, 0.02   ! transaction area

!END
!-----------------------------------------------------------------------------
```

This is a very smooth surface but the reasons have been justified in the report.

| | |
|---|---|
| Polyethylene PE - Corrugated with corrugated inner walls | 0.018 - 0.025 |

*4. Two commands within the .tgc file were re-ordered as the 2d_zsh_TTRENT_BUILDINGS_02 file (updated by the EA on 29/10/14) was being read in after 2d_zsh_TTRENT_TRIBUTARY_OUTFALL and lowering the bank in* *the region of the River Eau outfall to allow the Trent to overtop it's banks at a level of around 4m*

This has been verified in the TGC files;

```
!Other adjustments

Read MI Z pts == mi\2d_zsh_TTRENT_BUILDINGS_02.MIF
Read MI Z pts ADD == mi\2d_zsh_TTRENT_BUILDINGS_ADD_01.MIF
Read GIS FC Shape == mi\2d_fcsh_TTRENT_VIADUCT_01.MIF
Read MI Z Shape == mi\2d_zsh_TTRENT_TRIBUTARY_OUTFALL.MIF
```

*Lincolnshire Lakes model*

```
!Other adjustments
Read MI Z Shape == mi\2d_zsh_TTRENT_TRIBUTARY_OUTFALL.MIF
Read MI Z pts == mi\2d_zsh_TTRENT_BUILDINGS_02.MIF
Read MI Z pts ADD == mi\2d_zsh_TTRENT_BUILDINGS_ADD_01.MIF
Read GIS FC Shape == mi\2d_fcsh_TTRENT_VIADUCT_01.MIF
```

*EA Interim Tidal Trent Model*

These changes should be carried forward with any improvement the EA make to the EA Interim Tidal Trent Model.

**Conclusions.**

All changes outlined in the report have been found in the model and all changes found in the model have been mentioned in the report. The only exception is the reprofiling of the channel in 3 of the 4 most downstream nodes. Although this has not been mentioned explicitly in the report there is description of changes in this area as the ISIS 1D channel is replaced with 2D bathymetry.

All other changes have been justified in terms of moving the model towards the stated aim of better representing the levels observed during the December 2013 surge event.

**Recommendations.**

Mott MacDonald have reordered command lines in the TGC file so that bank levels are not artificially lowered in the vicinity of the River Eau outfall. It is recommended that this edit is carried forward into any future EA work on the EA Interim Tidal Trent model.

# C. Summary results tables for all runs

## C.1 In-channel peak levels

**Table 20: Summary of in-channel peak levels adjacent to proposed LLAP flood defence**

| Design Epoch | Scenario | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Breach | In-Channel Peak Level adjacent to proposed defence (mAOD) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Baseline scenario | Permitted development | Short-term mitigation | Long-term mitigation |
| Overtopping Models | | | | | | | | | |
| 2015 | Baseline | Present Day | 50% | 0.50% | | 6.17 | 6.17 | 6.20 | |
| 2040 | Baseline | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | | 6.06 | | 6.08 | |
| | | | 0.10% | 20% | | 6.00 | | 6.02 | |
| | | H++ (Fluvial and Tidal) | 0.50% | 20% | | 6.11 | | 6.12 | |
| | | | 0.10% | 20% | | 6.09 | | 6.13 | |
| 2050 | Baseline | Upper End (Fluvial and Tidal) | 50% | 3.33% | | 6.23 | | 6.25 | |
| | | | 50% | 0.50% | | 6.25 | 6.26 | 6.27 | |
| | | | 50% | 0.10% | | 6.27 | | 6.28 | |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | | 6.27 | | 6.32 | |
| | | | 50% | 0.10% | | 6.27 | | 6.32 | |
| 2115 | Baseline | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | | 6.40 | | | 6.42 |
| | | | 0.10% | 20% | | 6.40 | | | 6.42 |
| | | Upper End (Fluvial and Tidal) | 50% | 0.50% | | 6.48 | | 6.50 | 6.49 |
| | | | 50% | 0.10% | | 6.49 | | | 6.50 |
| | | | 0.50% | 20% | | 6.40 | | 6.42 | 6.42 |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | | 6.64 | | | 6.64 |
| | | | 50% | 0.10% | | 6.64 | | | 6.64 |
| | | | 0.50% | 20% | | | | | 6.64 |
| | | | 0.10% | 20% | | Model Unstable | | | 6.64 |
| Breach Models | | | | | | | | | |
| 2040 | Baseline | | 0.50% | 20% | BR1 | 5.94 | | 6.00 | |

| Design Epoch | Scenario | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Breach | In-Channel Peak Level adjacent to proposed defence (mAOD) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Baseline scenario | Permitted development | Short-term mitigation | Long-term mitigation |
| | | Higher Central (Fluvial), Upper End (Tidal) | 0.10% | 20% | BR1 | 5.89 | | 5.95 | |
| | | H++ (Fluvial and Tidal) | 0.50% | 20% | BR1 | 5.99 | | 6.05 | |
| 2050 | Baseline | Upper End (Fluvial and Tidal) | 50% | 0.50% | BR1 | 6.17 | | 6.23 | |
| | | | 50% | 0.50% | BR2 | 6.24 | | 6.26 | |
| | | | 50% | 0.50% | BR3 | 6.21 | | 6.25 | |
| | | | 50% | 0.50% | BR4 | 6.19 | | 6.24 | |
| | | | 50% | 0.10% | BR1 | 6.19 | | 6.24 | |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | BR1 | 6.22 | | 6.27 | |
| 2115 | Baseline | Upper End (Fluvial and Tidal) | 50% | 0.50% | BR1 | 6.44 | | 6.48 | |
| | | | 0.50% | 20% | BR1 | 6.38 | | 6.41 | |

## C.2 Properties affected

**Table 21: Summary of properties affected by proposed development works for all overtopping events**

| Design Epoch | Scenario | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Number of Properties impacted by development works within each depth range (Depth ranges are for the change in depth of flooding at property locations due to development works. A negative value is a decrease in flood depths) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | <-1m | -1m to -0.5m | -0.5m to -0.25m | -0.25m to -0.1m | -0.1m to -0.05m | -0.05m to -0.025m | 0.025m to 0.05m | 0.05m to 0.1m | 0.1m to 0.25m | 0.25m to 0.5m | 0.5m to 1m | >1m |
| Overtopping Models | | | | | | | | | | | | | | | | |
| 2015 | Phase 1 (Permitted Development Works) | Present Day | 50% | 0.50% | 0 | 0 | 8 | 40 | 43 | 38 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Short Term Mitigation | | 50% | 0.50% | 0 | 1 | 29 | 122 | 98 | 74 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2040 | Short Term Mitigation | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | 0 | 1 | 1 | 20 | 10 | 11 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | 0.10% | 20% | 30 | 115 | 65 | 31 | 16 | 9 | 39 | 107 | 314 | 626 | 320 | 24 |
| | | H++ (Fluvial and Tidal) | 0.50% | 20% | 0 | 1 | 2 | 30 | 15 | 17 | 5 | 2 | 7 | 0 | 0 | 0 |
| | | | 0.10% | 20% | 28 | 2 | 22 | 12 | 57 | 253 | 34 | 9 | 7 | 2 | 1 | 0 |
| 2050 | Phase 1 (Permitted Development Works) | Upper End (Fluvial and Tidal) | 50% | 0.50% | 0 | 0 | 32 | 85 | 46 | 25 | 4 | 3 | 6 | 1 | 0 | 0 |
| | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 3.33% | 1 | 3 | 60 | 242 | 156 | 139 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | 50% | 0.50% | 1 | 2 | 89 | 278 | 196 | 143 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | 50% | 0.10% | 1 | 7 | 108 | 301 | 206 | 144 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | 1 | 30 | 154 | 302 | 230 | 133 | 13 | 3 | 5 | 0 | 0 | 0 |
| | | | 50% | 0.10% | 1 | 54 | 172 | 311 | 186 | 119 | 19 | 3 | 4 | 0 | 0 | 0 |
| 2115 | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 0.50% | 1 | 42 | 205 | 507 | 153 | 135 | 552 | 51 | 41 | 4 | 3 | 0 |
| | | | 0.50% | 20% | 1 | 333 | 224 | 174 | 177 | 140 | 265 | 67 | 46 | 5 | 0 | 0 |

| Design Epoch | Scenario | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Number of Properties impacted by development works within each depth range (Depth ranges are for the change in depth of flooding at property locations due to development works. A negative value is a decrease in flood depths) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Long Term Mitigation | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | 2 | 351 | 232 | 252 | 271 | 187 | 1342 | 103 | 27 | 47 | 9 | 12 |
| | | | 0.10% | 20% | 27 | 307 | 64 | 117 | 409 | 751 | 88 | 21 | 11 | 2 | 10 | 0 |
| | | Upper End (Fluvial and Tidal) | 50% | 0.50% | 8 | 98 | 243 | 646 | 212 | 184 | 6 | 5 | 6 | 6 | 14 | 1 |
| | | | 50% | 0.10% | 9 | 103 | 245 | 644 | 218 | 170 | 1497 | 36 | 8 | 6 | 8 | 14 |
| | | | 0.50% | 20% | 1 | 350 | 232 | 251 | 271 | 188 | 91 | 36 | 33 | 3 | 10 | 0 |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | 9 | 103 | 245 | 644 | 218 | 170 | 1497 | 36 | 8 | 6 | 8 | 14 |
| | | | 50% | 0.10% | 14 | 280 | 166 | 197 | 751 | 531 | 4290 | 168 | 294 | 173 | 27 | 175 |
| | | | 0.50% | 20% | 26 | 12 | 330 | 219 | 549 | 128 | 350 | 1682 | 105 | 85 | 83 | 34 |
| | | | 0.10% | 20% | Baseline Model Unstable, so comparison not possible | | | | | | | | | | | |

Source: Mott MacDonald

## C.3 Levels adjacent to development platforms (Short-term and long-term mitigation runs only)

**Table 22: Peak flood levels adjacent to the development platforms for short and long-term mitigation scenarios (Event with greatest levels highlighted)**

| Design Epoch | Scenario | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Breach | Peak flood level adjacent to development platforms (mAOD) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | North-West | North-East | Central West | Central East (North Burringham Road) | Central East (South Burringham Road) | South-West | South-East |
| Overtopping Models | | | | | | | | | | | | |
| 2015 | Short Term Mitigation | Present Day | 50% | 0.50% | | | | | | | | No Flooding |
| 2040 | Short Term Mitigation | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | | | | | | | | No Flooding |
| | | | 0.10% | 20% | | 2.97 | 4.46 | 3.7 | 4.5 | 4.513 | 3.23 | 4.523 |
| | | H++ (Fluvial and Tidal) | 0.50% | 20% | | | | | | | | No Flooding |
| | | | 0.10% | 20% | | 5.64 | 5.63 | 5.64 | 5.65 | 5.68 | 5.65 | 5.67 |
| 2050 | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 3.33% | | | | | | | | No Flooding |
| | | | 50% | 0.50% | | | | | | | | No Flooding |
| | | | 50% | 0.10% | | | | | | | | No Flooding |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | | | | | | | | No Flooding |
| | | | 50% | 0.10% | | | | | | | | No Flooding |
| 2115 | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 0.50% | | 2.88 | N/A | 2.21 | N/A | N/A | 2.21 | N/A |
| | | | 0.50% | 20% | | | | | | | | No Flooding |
| | Long Term Mitigation | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | | | | | | | | No Flooding |
| | | | 0.10% | 20% | | 5.28 | 5.28 | 5.29 | 5.31 | 5.30 | 5.30 | 5.30 |
| | | Upper End (Fluvial and Tidal) | 50% | 0.50% | | 2.87 | N/A | 2.15 | N/A | N/A | 2.15 | N/A |
| | | | 50% | 0.10% | | 2.89 | N/A | 2.23 | N/A | N/A | 2.23 | N/A |
| | | | 0.50% | 20% | | | | | | | | No Flooding |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | | 4.48 | 4.44 | 4.46 | 4.43 | 4.26 | 4.45 | 4.26 |
| | | | 50% | 0.10% | | 4.50 | 4.46 | 4.48 | 4.45 | 4.28 | 4.47 | 4.27 |
| | | | 0.50% | 20% | | 5.10 | 5.10 | 5.10 | 5.10 | 5.10 | 5.10 | 5.10 |
| | | | 0.10% | 20% | | 6.28 | 6.26 | 6.31 | 6.30 | 6.35 | 6.34 | 6.38 |

| Design Epoch | Scenario | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Breach | Peak flood level adjacent to development platforms (mAOD) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | North-West | North-East | Central West | Central East (North Burringham Road) | Central East (South Burringham Road) | South-West | South-East |
| Breach Models | | | | | | | | | | | | |
| 2040 | Short Term Mitigation | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | BR1 | 2.29 | N/A | 1.90 | N/A | N/A | 1.90 | N/A |
| | | | 0.10% | 20% | BR1 | 4.41 | 4.45 | 4.41 | 4.48 | 4.50 | 4.41 | 4.51 |
| | | H++ (Fluvial and Tidal) | 0.50% | 20% | BR1 | 2.31 | N/A | 1.99 | N/A | N/A | 1.99 | N/A |
| 2050 | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 0.50% | BR1 | 2.43 | N/A | 2.12 | N/A | N/A | 2.12 | N/A |
| | | | 50% | 0.50% | BR2 | | | | | | | No Flooding |
| | | | 50% | 0.50% | BR3 | 1.22 | N/A | 1.22 | N/A | N/A | N/A | N/A |
| | | | 50% | 0.50% | BR4 | | | | | | | No Flooding |
| | | | 50% | 0.10% | BR1 | 2.43 | N/A | 2.13 | N/A | N/A | 2.13 | N/A |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | BR1 | 2.44 | N/A | 2.19 | N/A | N/A | 2.12 | N/A |
| 2115 | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 0.50% | BR1 | 3.27 | 3.15 | 3.27 | 3.03 | 1.93 | 3.27 | 1.90 |
| | | | 0.50% | 20% | BR1 | 2.57 | N/A | 2.57 | 2.52 | N/A | 2.57 | N/A |

## C.4 Level, Velocity and Depth data within the LLAP managed overflow area (Short-term and long-term mitigation runs only)

Levels, velocities and depths have been extracted at key locations within the LLAP managed overflow area. For the Poplars, this is the level on the road adjacent to the property to determine if protection works are required to stop the flow from using the road as a flow route and thereby flooding the property, the level behind the property where water is ponding as part of the flood storage area, and typical velocities around the property, not including the high velocity area where flow is on the managed overflow crest. For the Bungalow, this includes a level in the managed overflow area where water is ponding as part of the storage area, and typical velocities adjacent to the property within the managed overflow, this does not include the velocities within the ditches surrounding the property. Where The Poplars or The Bungalow are flooded due to flow pathways from the north (ie breach or during large fluvial flood events) the rows have been highlighted to indicate this. At the sewage treatment works a typical flood level has been taken, and the maximum depth and velocity across the works extracted. For the wind farm, levels at each of the individual generators have been extracted and the maximum depth and velocity across both sites extracted.

**Table 23: Peak flood levels, velocities, and depths at key locations within the LLAP managed overflow for short-term and long-term mitigation scenarios**

| Design Epoch | Scenario | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Breach | The Poplars | | | The Bungalow | | Sewage Treatment Works | | | Wind Farm | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Level on the road (mAOD) | Level at back of poplars (mAOD) | Typical Velocity in Managed overflow area | Level in Managed overflow | Typical Velocity in Managed overflow area | Typical Level (mAOD) | Maximum Depths (m) | Maximum Velocity (m/s) | Level (Western wind generator) (mAOD) | Level (Eastern wind generator) (mAOD) | Maximum Depth (m) | Maximum Velocity (m/s) |
| Overtopping Runs | | | | | | | | | | | | | | | | | |
| 2015 | Short Term Mitigation | Present Day | 50% | 0.50% | | 5.06 | 3.58 | 0.10 | N/A | N/A | 3.87 | 0.20 | 0.40 | 3.33 | 2.33 | 0.10 | 0.20 |
| 2040 | Short Term Mitigation | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| | | | 0.10% | 20% | | 4.53 | 4.53 | 0.30 | 4.52 | 0.40 | 4.52 | 2.20 | 0.20 | 4.52 | 4.52 | 3.40 | 0.30 |
| | | H++ (Fluvial and Tidal) | 0.50% | 20% | | 5.01 | N/A | 0.10 | N/A | N/A | 3.83 | 0.10 | 0.10 | N/A | N/A | N/A | N/A |
| | | | 0.10% | 20% | | 5.68 | 5.67 | 0.20 | 5.67 | 0.50 | 5.65 | 2.20 | 0.20 | 5.66 | 5.66 | 3.40 | 0.40 |
| 2050 | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 3.33% | | 5.11 | 3.76 | 0.20 | 1.11 | 0.30 | 3.90 | 0.30 | 0.50 | 3.41 | 2.35 | 0.20 | 0.30 |
| | | | 50% | 0.50% | | 5.12 | 3.78 | 0.30 | 1.19 | 0.50 | 3.91 | 0.30 | 0.50 | 3.43 | 2.36 | 0.20 | 0.40 |
| | | | 50% | 0.10% | | 5.12 | 3.79 | 0.40 | 1.22 | 0.40 | 3.92 | 0.30 | 0.50 | 3.44 | 2.36 | 0.20 | 0.40 |

| Design Epoch | Scenario | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Breach | The Poplars | | | The Bungalow | | Sewage Treatment Works | | | Wind Farm | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Level on the road (mAOD) | Level at back of poplars (mAOD) | Typical Velocity in Managed overflow area | Level in Managed overflow | Typical Velocity in Managed overflow area | Typical Level (mAOD) | Maximum Depths (m) | Maximum Velocity (m/s) | Level (Western wind generator) (mAOD) | Level (Eastern wind generator) (mAOD) | Maximum Depth (m) | Maximum Velocity (m/s) |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | | 5.13 | 3.81 | 0.30 | 1.28 | 0.40 | 3.93 | 0.30 | 0.75 | 3.46 | 2.36 | 0.20 | 0.40 |
| | | | 50% | 0.10% | | 5.13 | 3.82 | 0.40 | 1.32 | 0.40 | 3.94 | 0.30 | 0.75 | 3.46 | 2.37 | 0.30 | 0.40 |
| 2115 | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 0.50% | | 5.21 | 4.05 | 0.50 | 2.80 | 0.75 | 4.04 | 0.40 | 1.00 | 3.61 | 2.80 | 0.40 | 0.75 |
| | | | 0.50% | 20% | | 5.22 | 4.03 | 0.30 | 2.26 | 0.40 | 4.01 | 0.40 | 1.00 | 3.58 | 2.50 | 0.40 | 0.75 |
| | Long Term Mitigation | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | | 5.21 | 4.02 | 0.30 | 2.27 | 0.30 | 4.01 | 0.40 | 1.00 | 3.58 | 2.50 | 0.40 | 0.75 |
| | | | 0.10% | 20% | | 5.44 | 5.31 | 0.40 | 5.31 | 0.50 | 5.31 | 1.90 | 0.50 | 5.30 | 5.32 | 3.10 | 0.75 |
| | | Upper End (Fluvial and Tidal) | 50% | 0.50% | | 5.22 | 4.06 | 0.50 | 2.81 | 0.75 | 4.05 | 0.40 | 1.00 | 3.62 | 2.81 | 0.80 | 0.75 |
| | | | 50% | 0.10% | | 5.22 | 4.07 | 0.40 | 2.90 | 0.75 | 4.05 | 0.50 | 1.00 | 3.63 | 2.90 | 0.80 | 0.75 |
| | | | 0.50% | 20% | | 5.21 | 4.02 | 0.30 | 2.24 | 0.40 | 4.01 | 0.40 | 1.00 | 3.58 | 2.50 | 0.40 | 0.75 |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | | 5.33 | 4.61 | 0.40 | 4.56 | 0.40 | 4.59 | 1.10 | 1.50 | 4.56 | 4.55 | 2.30 | 1.00 |
| | | | 50% | 0.10% | | 5.33 | 4.61 | 0.75 | 4.56 | 0.40 | 4.60 | 1.20 | 1.50 | 4.57 | 4.56 | 2.30 | 1.00 |
| | | | 0.50% | 20% | | 5.46 | 5.12 | 0.30 | 5.11 | 0.40 | 5.11 | 1.70 | 1.50 | 5.11 | 5.11 | 2.90 | 0.75 |
| | | | 0.10% | 20% | | 6.35 | 6.30 | 0.40 | 6.32 | 0.40 | 6.31 | 2.90 | 1.50 | 6.31 | 6.33 | 4.10 | 1.00 |
| Breach Runs | | | | | | | | | | | | | | | | | |
| 2040 | Short Term Mitigation | Higher Central (Fluvial), Upper End (Tidal) | 0.50% | 20% | BR1 | N/A | N/A | N/A | Floods from behind due to breach (no flooding from managed overflow area) | | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| | | | 0.10% | 20% | BR1 | 4.52 | 4.52 | 0.20 | 4.51 | 0.30 | 4.52 | 1.00 | 0.20 | 4.51 | 4.51 | 2.30 | 0.40 |
| | | H++ (Fluvial and Tidal) | 0.50% | 20% | BR1 | N/A | N/A | N/A | Floods from behind due to breach (no flooding from | | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

| Design Epoch | Scenario | Climate Change Projection | Fluvial Annual Exceedance Probability (%) | Tidal Annual Exceedance Probability (%) | Breach | The Poplars | | | The Bungalow | | Sewage Treatment Works | | | Wind Farm | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Level on the road (mAOD) | Level at back of poplars (mAOD) | Typical Velocity in Managed overflow area | Level in Managed overflow | Typical Velocity in Managed overflow area | Typical Level (mAOD) | Maximum Depths (m) | Maximum Velocity (m/s) | Level (Western wind generator) (mAOD) | Level (Eastern wind generator) (mAOD) | Maximum Depth (m) | Maximum Velocity (m/s) |
| | | | | | | | | | managed overflow area) | | | | | | | | |
| 2050 | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 0.50% | BR1 | 5.09 | 3.73 | 0.30 | 1.08 | 0.30 | 3.89 | 0.30 | 0.50 | 3.38 | 2.35 | 0.20 | 0.30 |
| | | | 50% | 0.50% | BR2 | 5.11 | 3.77 | 0.30 | 1.17 | 0.40 | 3.91 | 0.30 | 0.75 | 3.42 | 2.36 | 0.20 | 0.40 |
| | | | 50% | 0.50% | BR3 | 5.10 | 3.75 | 0.30 | 1.12 | 0.40 | 3.90 | 0.30 | 0.75 | 3.40 | 2.35 | 0.20 | 0.30 |
| | | | 50% | 0.50% | BR4 | 5.09 | 3.73 | 0.30 | 2.73 | 1.50 | 4.05 | 0.40 | 0.75 | 3.50 | 2.73 | 0.60 | 0.75 |
| | | | 50% | 0.10% | BR1 | 5.10 | 3.73 | 0.30 | 1.12 | 0.40 | 3.89 | 0.30 | 0.50 | 3.38 | 2.35 | 0.20 | 0.30 |
| | | H++ (Fluvial and Tidal) | 50% | 0.50% | BR1 | 5.11 | 3.76 | 0.30 | 1.19 | 0.40 | 3.91 | 0.30 | 0.50 | 3.41 | 2.35 | 0.20 | 0.30 |
| 2115 | Short Term Mitigation | Upper End (Fluvial and Tidal) | 50% | 0.50% | BR1 | 5.21 | 4.04 | 0.30 | 2.65 | 0.40 | 4.03 | 0.30 | 1.00 | 3.61 | 2.65 | 0.50 | 0.75 |
| | | | 0.50% | 20% | BR1 | 5.21 | 4.01 | 0.30 | 2.14 | 0.40 | 4.00 | 0.40 | 1.00 | 3.57 | 2.49 | 0.40 | 0.75 |

[redacted]