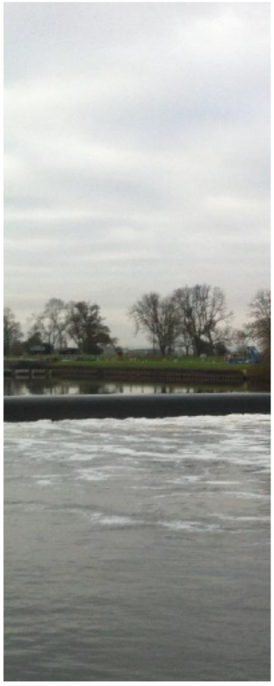
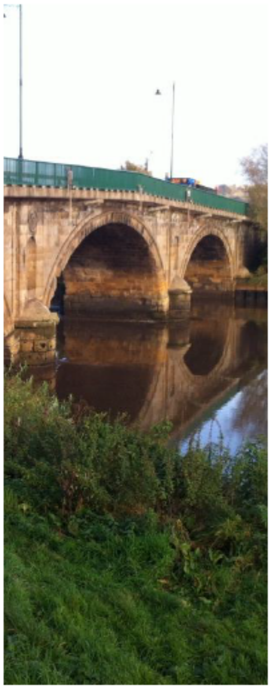


Tidal Trent Modelling & Mapping Study

Modelling & Mapping Report
DRAFT

December 2013

Environment Agency

Mott MacDonald

Tidal Trent Modelling & Mapping Study

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December 2013

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Revision	Date	Originator	Checker	Approver	Description	Standard
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[redacted]

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Mott MacDonald

Executive Summary

In October 2012, the Environment Agency (EA) commissioned Mott MacDonald to undertake a flood risk modelling and mapping study for the Tidal Trent. A fully hydrodynamic 1D/2D ISIS/TUFLOW model was developed to assess flood risk and hazard, and consequently to assess the flood risk and hazard due to overtopping and breach. The calibrated design model was used to:

- Simulate flood paths, depths, velocities and hazard across the floodplain and in-channel for the 1 in 5, 10, 20, 50, 75, 100, 200 and 1000 year fluvial events as well as the 1 in 100 year fluvial event under climate change.
- Simulate flood paths, depths, velocities and hazard across the floodplain and in-channel for the 1 in 200, and 1000 year tidal events as well as the 1 in 200 year event under climate change.
- Simulate undefended scenarios for the 1 in 100 and 1 in 1000 year fluvial events, and the 1 in 200 and 1 in 1000 year tidal events.
- Simulate a scenario with the minor "1 in 10 year" defences removed for the 1 in 10 year fluvial event.
- Undertake breach analysis at 32 locations for the 1 in 100 and 1 in 1000 year fluvial events, and the 1 in 200 and 1 in 1000 year tidal events.
- Derive improved flood zones and flood hazard information.
- Review and update existing 36 Flood Warning Areas along Tidal Trent.

The following conclusions can be drawn from analysis of the results:

- Beckingham Marshes are inundated even during the smallest of modelled events (1 in 5 year fluvial event)
- Flooding occurs near Girton and North Clifton for small events (i.e. 1 in 5 year fluvial event)
- Due to the low-lying nature of the catchment, flooding for large events is widespread, with isolated areas of high ground remaining dry.
- Flooding during large events is extensive enough for flooding from neighbouring catchments to be likely to influence the flood extents and flood depths.
- Significant Areas Benefiting from Defences have been identified for both the 1 in 100 year fluvial event, and the 1 in 200 year tidal event. This highlights the importance of maintaining the existing substantial defences along the banks of the Trent.
- The Minor Defences protect quite a large area of land on the right bank upstream of Torksey, and on the left bank between Torksey and Beckingham Marshes.

The following recommendations were made as part of this study:

- The model should be recalibrated following any major flood event which causes significant property flooding or disruption to local services – In particular following tidal flooding in communities downstream of the M180 on Thursday 5th December 2013, it is recommended that an assessment of asset crest levels, particularly in Keadby and Burringham is undertaken sooner rather than later (As an extension to this study?), as overtopping and some scouring occurred in these locations. Potential changes or planned alterations to these assets should be incorporated into the model to ensure the model is representative of the best available information. This flooding took place during the closing stages of the Tidal Trent Project.
- Review of flood frequency analysis for tidal conditions considering the December 2013 tidal surge event.
- The model should be updated following any future development or change to flood defences within the study area.
- Flow and stage gauging along all the tributaries is recommended. This will allow the hydrology to be re-derived with a reduced level of uncertainty.

- The outputs of this study, particularly the hydrograph shape and travel times can be used to improve flood forecasting services for the Trent.
- Data from the study is used to update the National Flood Risk Assessment data set.

1 Introduction

1.1 Aims and Objectives

Mott MacDonald was appointed by the Environment Agency (EA) in October 2012 to undertake fluvial and tidal modelling of the Tidal Trent. The aims of this study are as follows:

- Develop a thorough understanding of flood risk using updated channel and floodplain survey and updated design tidal and fluvial estimates;
- Use the model to inform sustainable floodplain planning;
- To build on the asset maintenance options initially identified in the Tidal Trent Strategy study;
- Provide detailed information to improve the existing Flood Warning Service.

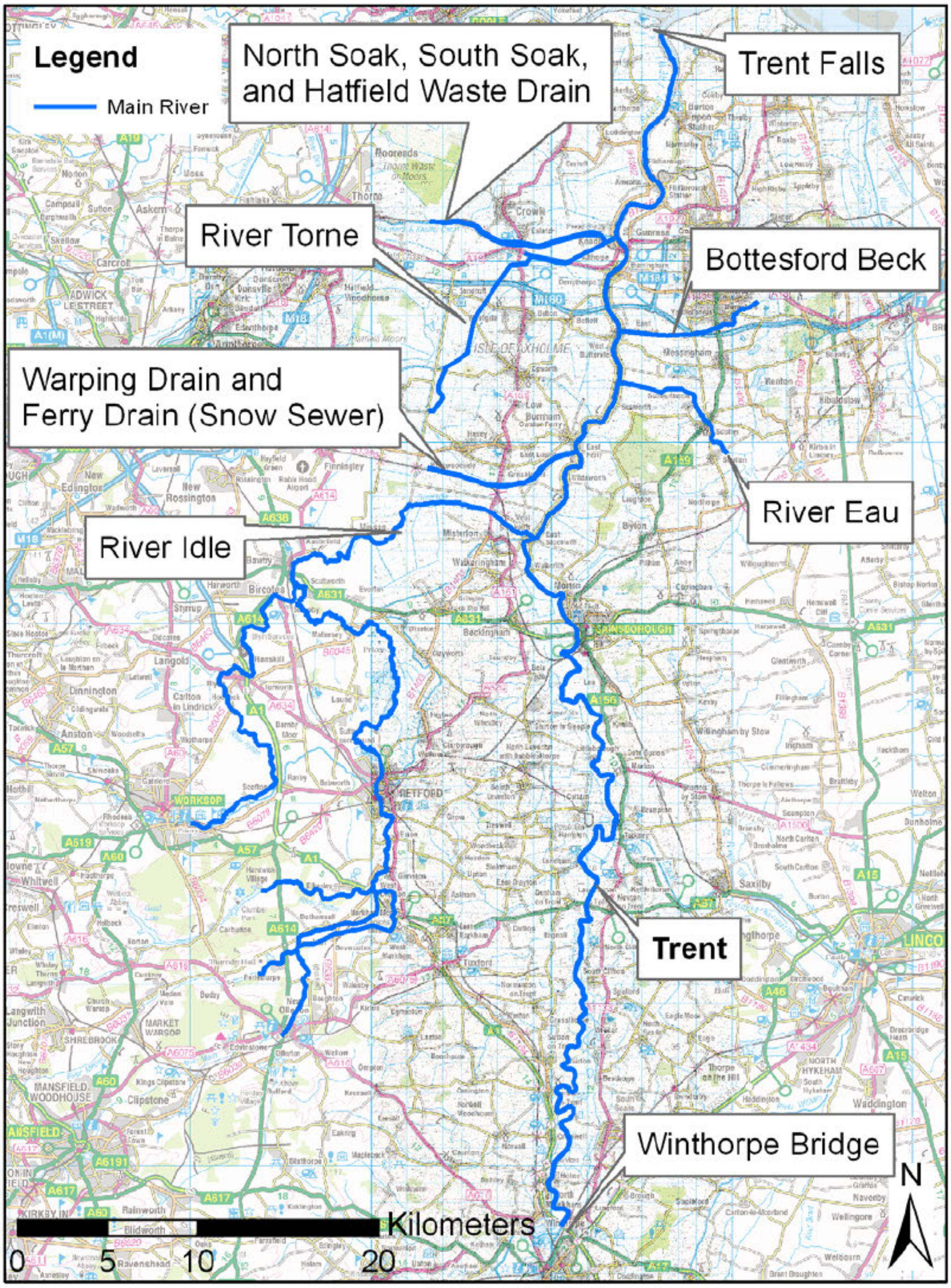
1.2 Study Area

The study area encompasses the whole of the Tidal Trent from its downstream confluence with the Humber Estuary at Trent Falls, to the tidal limit at Cromwell Weir, and extends a further 6 km upstream to Winthorpe Bridge, where the A1 crosses the river. There are eight tributaries which flow into the Tidal Trent within the study area (see Figure 1.1):

- River Idle;
- Snow Sewer;
- River Torne;
- North Soak Drain;
- South Soak Drain;
- Hatfield Waste Drain;
- River Eau;
- Bottesford Beck.

These tributaries all discharge into the Tidal Trent through flapped outfalls and via pumping stations. The backwater effects on those tributaries, caused by raised levels in the Trent, have been considered, although the tributaries themselves have not been explicitly modelled. Figure 1.1 shows the extent of the River Trent modelled in this study, and the tributaries on which backwater effects have been considered.

Figure 1.1: Extent of River Trent and Tributaries Considered in the Study



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1.3 Scope of Work

The scope of work as stated in the brief is:

- Survey
  - Provide channel cross-sections derived from survey from Winthorpe Bridge to Gainsborough.
- Fluvial and Tidal Boundary Conditions
  - Evaluate, and where necessary derive, fluvial inflows for the Trent at Winthorpe Bridge – flows required for the 1 in 5, 10, 20, 50, 75, 100, 200, 1000 year events, and the 100 year event considering potential effects of climate change.
  - Derive flows for intervening catchments which enter the proposed modelled reach.
  - Define design tidal level estimates for the Humber Estuary at the River Trent confluence to be used as a downstream boundary condition. Additionally sea level rise as a result of climate change should be borne in mind.
  - Undertake joint probability analysis identifying appropriate fluvial/tidal design event combinations to use for each respective return period.
- Hydraulic Modelling
  - Produce a calibrated and verified hydraulic model for the Tidal Trent from Winthorpe Bridge to Trent Falls. As a minimum the model should be calibrated to closely replicate suitable tidal and fluvial historic events at the North Muskham, Torksey, Gainsborough and Keadby river gauges.
  - Produce flood extent mapping showing overtopping of defences only for the 1 in 5, 10, 20, 50, 75, 100, 200, 1000 and 100 + Climate Change events.
  - Undertake appropriate breach modelling for the Tidal Trent major defences for the 1 in 100 and 1 in 1000 year fluvial events and the 1 in 200 and 1 in 1000 year tidal events.
  - Produce undefended flood extent mapping for the 1 in 100 fluvial, and 1 in 200 tidal and 1 in 1000 (both) events.
  - Produce peak in-channel modelled levels and flows.
  - Investigate the benefit offered by the minor flood embankments.
- Review the 36 community based warning areas along the Tidal Trent. Revising, where necessary, flood warning area extents and trigger thresholds based on the new modelled outputs from this study.
- Produce Area Benefiting from Defences outline where appropriate
- Undertake sensitivity analysis as specified in the SFRM performance scope
- Provide deliverables in a suitable format for upload into the new MapEdit system – due to replace NFCDD.

2 Description of Flood Response

2.1 Characteristics of Study Area

The River Trent flows from its headwaters in Staffordshire on the southern edge of Biddulph Moor to its confluence with the Humber Estuary at Trent Falls. Cromwell Weir, 6km downstream of North Muskham is the tidal limit of the River Trent. The catchment area of the River Trent is approximately 10,000km^2.

The tidal reach of the Trent is characterised by a large flat floodplain, mainly used for agricultural purposes. The river meanders across the floodplain. The floodplain is protected by a range of minor and major man-made defences, predominantly consisting of large earth embankments.

Gainsborough is the largest settlement on the tidal reach of the Trent, upstream of Gainsborough is mainly fluvially dominated, and downstream of which is tidally dominated. Downstream of Gainsborough on the left bank is an area, known as the Beckingham Marshes, which is used as a flood storage area for both fluvial and tidal events.

A number of tributaries join the Trent downstream of Gainsborough. These include:
- River Idle (whose confluence with the Trent is via Stockwith Pumping Station),
- Warping Drain and Ferry Drain (whose confluence with the Trent is via Warping and Ferry Drain Pumping Stations),
- River Torne, Hatfield Waste Drain, North Soak Drain and South Soak Drain (whose combined confluence with the Trent is via Keadby Pumping Station),
- Bottesford Beck (discharges into Trent via flapped outfalls),
- River Eau (discharges into the Trent via flapped outfalls).

Downstream of Keadby (approximately 15km to it's confluence with the Humber Estuary) the Trent is used for the navigation of large vessels in and out of the Humber Estuary. The channel in this reach is therefore dredged from time to time.

2.2 History of Flooding

The Tidal Trent has been known to flood on a number of occasions, with some records dating back to the 1940s. The Beckingham Cum Saundby Village website provides details of past events when the Beckingham Marshes have been flooded.

Table 2.1 summarises some of the major flood events since the 1940s.

Table 2.1: Chronology of Key Flood Events on the River Trent

Date	Comments
1940	River bank breached, washing away top soil on the fields (Location near Beckingham?). Flood road was flooded
March 1947	Harsh winter with ground freezing and some very heavy snowfall. When the snow melted (14 March) there was nowhere for the excess water to go. Water was pumped out of the fields immediately. River levels rose so that on 18 March, houses along Melrose Road, Gainsborough, were at risk. Dykes and banks burst all the way downstream to Keadby. Crowle Pumping Station (5km east of Keadby) was under water. Force of the water crossing Gainsborough Bridge was extremely strong and up to the axles of a lorry. Beckingham Marshes filled to within 30 feet of the 'Shipyard Houses' in Beckingham (near the railway station) Trent banks burst at Morton (3000 people were evacuated). The breach was 280 feet wide, 50 feet deep and 250m inland.
March 1977	Persistent heavy rain unable to drain away due to exceptionally high spring tides. Large areas of fields were underwater as far as Dunham Bridge.
November 2000	River Trent was 5.8m above normal level Flowed over banks into Beckingham Marshes on Friday 10 November Ramper Road (west of Gainsborough) was flooded. Levels not as high as in 1977 according to anecdotal reports (although annual maximum (AMAX) data suggests a greater flow at North Muskham)
June 2007	Heavy rain, however, tide was very low so no significant fluvial flooding
November 2012	The November 2012event led to flooding of agricultural land upstream of Gainsborough. This was a smaller event than the 1977 and 2000 events.

2.3 Sources, Pathways and Receptors of Flooding

The major source of flooding along the Tidal Trent is from combined fluvial and tidal influence. The most significant flooding has occurred when a fluvial event has coincided with high tides, for example the March 1977 event. During fluvial events which are coincident with high tides, the flow is less able to return under Gainsborough Road Bridge than for lower tides.

In addition a number of breaches have occurred along the Trent during previous flood events:

- 1940 – Breach believed to be near Beckingham;
- 1947 – Breaches near Morton – 3000 people evacuated.

Beckingham Marshes is a designated flood storage area with two spillways, a fluvial spillway located between Gainsborough Road Bridge and Gainsborough Railway Bridge, and a tidal spillway located downstream of Gainsborough Road Bridge.

3 Approach and Justification

3.1 Modelling Approach

A fully integrated 1D/2D hydrodynamically linked model has been developed in ISIS/TUFLOW for the study area using the best available information.

The study area encompasses the Tidal Trent from its confluence with the Humber Estuary, upstream to its tidal limit at Cromwell Weir, and a further 6km upstream to North Muskham. The backwater effects of raised water levels in the Trent on the following tributaries have also been assessed:

- River Idle;
- Warping Drain;
- Ferry Drain;
- River Torne;
- Hatfield Waste Drain;
- North Soak Drain;
- South Soak Drain;
- Bottesford Beck;
- River Eau.

In agreement with the EA, the tributaries have represented as 'gullies' in the 2D domain. This is a simpler representation than using a 1D/2D approach, but is considered suitable for assessing the backwater effects.

The model was built and run using ISIS 3.6.1 and TUFLOW 2012-05-AE-iSP-w64 software.

In addition to overtopping simulations 32 breach scenarios were modelled for four return periods to assess the residual risk of flooding. The models enable a detailed assessment of flood risk within the study area, production of flood hazard maps and identification of Areas Benefiting from Defences (ABDs).

Level of Uncertainty

3.2 Level of Uncertainty

3.2.1 Hydrological Uncertainty

There are uncertainties associated with the estimation of peak flows for the smaller tributaries, as there is little observed data to base the flood growth curve on and the QMED values, particularly for Bottesford Beck, River Eau, Warping Drain and Ferry Drain, North Soak Drain, South Soak Drain and Hatfield Waste Drain, i.e. the ungauged catchemnts.

In the absence of any gauging records near the downstream end of the tributaries, the shape of the hydrographs for the tributaries has been derived using rainfall runoff methods.

Where there is observed information available there are some uncertainties in observed levels and post-flood outlines as the data may not necessarily record the peak water level or extent.

3.2.2 DTM Uncertainty

There are uncertainties in the representation of the Digital Terrain Model including:
- Channel Survey and Structures,
- Bank Levels Survey,
- Floodplain Levels.

The underlying digital terrain model for the 2D domain is based on LiDAR data which has an accuracy of ± 0.15 m. The filtering of the LiDAR data to remove urban features and woodland areas may not accurately represent ground levels. SAR data has also been used in a number of locations where LiDAR data was not available.

3.2.3 Hydraulic Uncertainty

The flood mechanism is a 3D mechanism in reality. There is a large degree of simplification in the numerical representation of the true physical system. There are also uncertainties in the calculation of water levels, flows and the exchange of flows between the 1D ISIS and 2D TUFLOW model domains and the losses through hydraulic structures, hence the flood flood extent. This has been reduced by calibrating the model in the channel and on the floodplain using historical flood evidence where possible.

There is a high level of confidence in the model results for events up to the 1 in 75 fluvial return period because the model has been calibrated using the November 2000 event, which is considered to be a 1 in 77 year event. However, there is greater uncertainty associated with larger events given the limited amount of historical data available and uncertainty in water levels to calibrate the model for these more extreme events.

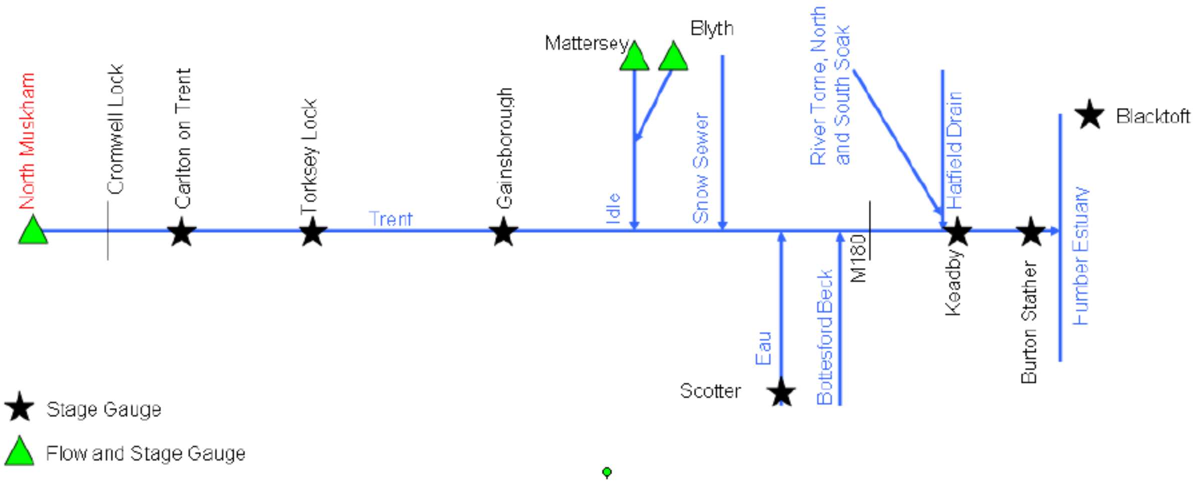
The model has not been calibrated for tidal events upstream of Gainsborough as the fluvial events are considered to be the greatest source of flood risk in this area, and therefore the focus of the model calibration upstream of Gainsborough is on the fluvial events. The flood levels during tidal events upstream of Gainsborough should therefore be treated with caution.

4 Input Data

4.1 Hydrometric Data

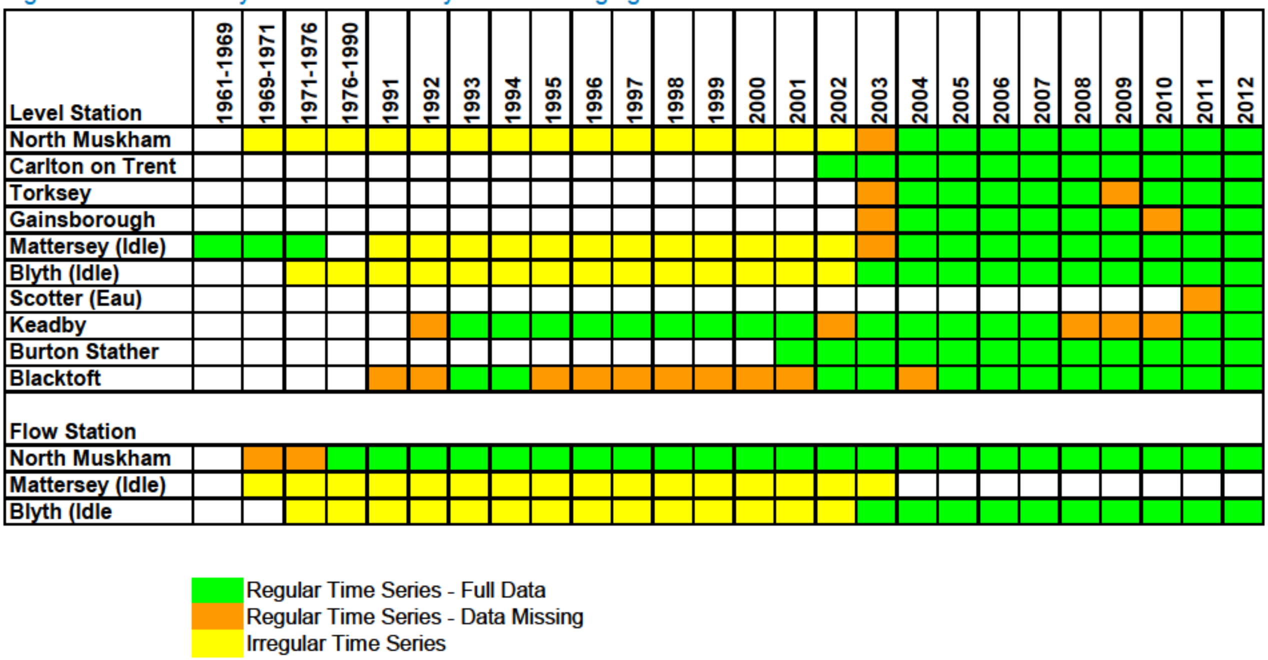
Level and flow data has been made available by the EA and by Associated British Ports (ABP). Figure 4.1 provides a schematic of the Tidal Trent and its tributaries, with the location of the various gauging stations. Figure 4.2 shows the length of data available at each of these stations. This information is also tabulated in Table 4.1.

Figure 4.1: Schematic Diagram Showing Locations of Tributaries and Gauging Stations



Source: Mott MacDonald

Figure 4.2: Summary of Data Availability at Each Gauging Station



Source: Mott MacDonald, EA Data sources and ABP

Table 4.1: Summary of Hydrological Data Availability

Station Name	Data Type	Availability	Source	Comments
Blacktoft (Humber Estuary)	Level Data	1991 - 2012	EA	Some data missing pre 2005
Burton Stather	Level Data	2001 - 2012	ABP	
Keadby	Level Data	1992 – 2012	EA	
Gainsborough	Level Data	2003 – 2012	EA	
Torksey	Level Data	2003 – 2012	EA	
Carlton on Trent	Level Data	2002 – 2012	EA	
North Muskham	Level Data	1969 - 2012	EA	Data pre 2003 available in Irregular Time Series. AMAX data available from 1969
	Flow Data	1969 - 2012	EA	Data missing pre 1976, particularly in 1973
Blyth (Idle)	Level Data	1971 – 2012	EA	Data pre 2003 available in Irregular Time Series
	Flow Data	1971 - 2012	EA	Data pre 2003 available in Irregular Time Series
Mattersey (Idle)	Level Data	1961 – 1976, 1976 - 2012	EA	Data pre 2003 available in Irregular Time Series. All data prior to 1982 thought to be unreliable.
	Flow Data	1969 - 2003	EA	Irregular Time Series data. All data prior to 1982 thought to be unreliable. AMAX data available from 1969 to 2008

Source: Mott MacDonald, EA Data sources and ABP

4.2 Historic Flood Evidence

Historic flood outlines are available for the November 2000 and November 2012 events. These have been digitised from vertical imagery, and aerial photography. In addition, there are a number of spot levels which have been taken by Maltby and Storm Geomatics during the November 2012 event. Gauged water level records are also available for most of the events (except November 2000) at Burton Stather, Keadby, Gainsborough, Torksey and Carlton-on-Trent.

The quality of historical flood evidence was assessed, and subsequently used in the calibration of the model (Chapter 6.2).

4.3 Topographic Data

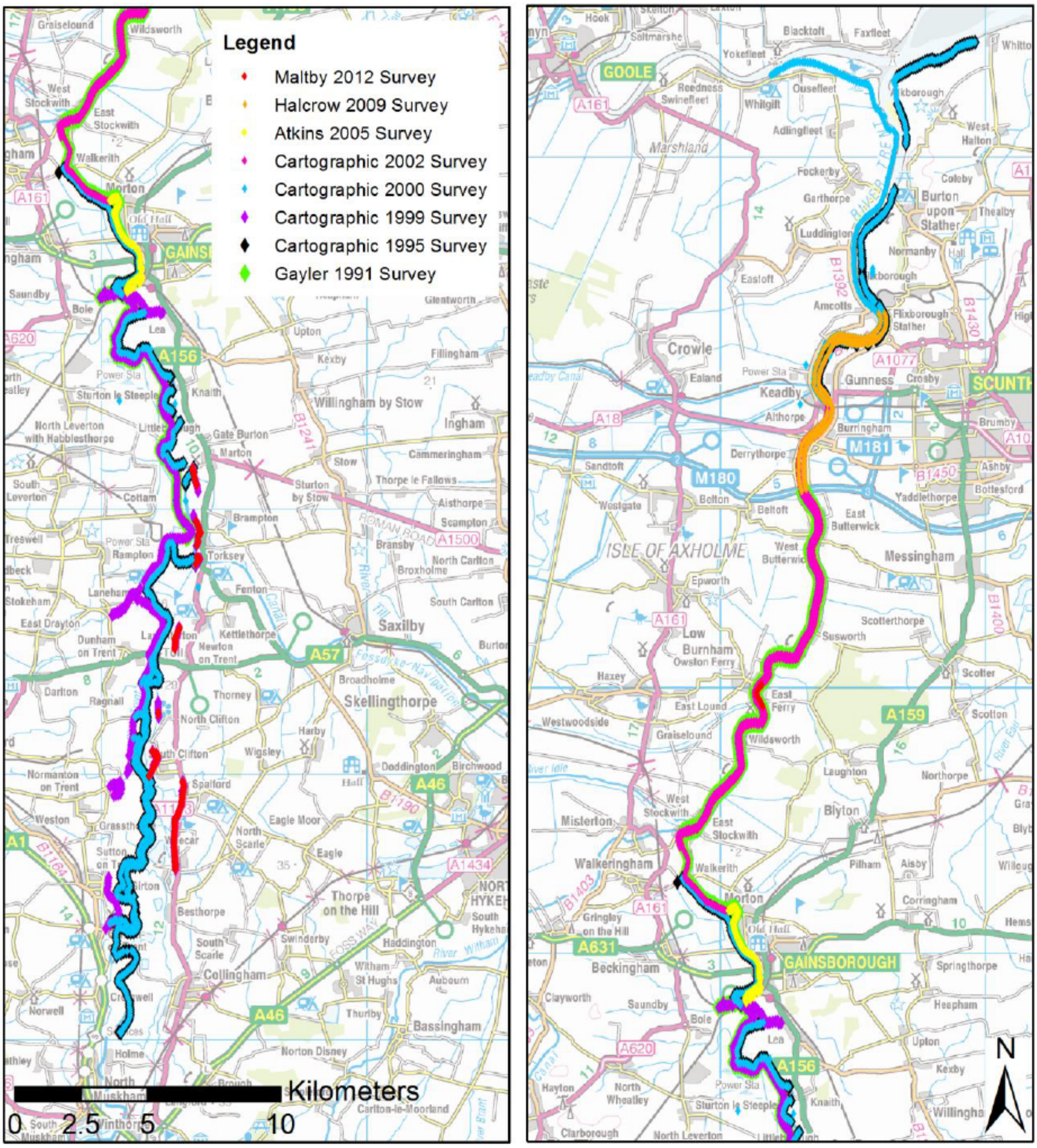
A number of different surveys were available for this study. They are listed in Table 4.2. Where the bank top level survey data was provided by the EA is shown in Figure 4.3. In addition channel survey was commissioned between Winthorpe Bridge and Gainsborough as part of this study, and carried out by Longdin & Browning. The location of this survey is given in Figure 4.4.

Table 4.2: Summary of Available Survey Data

Survey Type	Source	Extent	Date
River Channel Survey	British Waterways Central Engineering	Trent - Winthorpe Bridge to Cromwell	1992
	Gayler Surveying Services	Bottesford Beck	1996
	Cartographical Surveys Ltd	River Idle	2001
	Cartographical Surveys Ltd	River Torne, Hatfield Waste Drain, North Engine Drain, North Soak Drain, South Engine Drain, South Soak Drain, Three Rivers	2006
Embankment Survey	Gayler	Gainsborough to M180 LB	1991
	Gayler	Gainsborough to M180 RB	1991
	Gayler	Torksey to Gainsborough LB	1991
	Cartographical Surveys Ltd	Gainsborough to Morton LB	1995
	Cartographical Surveys Ltd	Cromwell Weir to Gainsborough RB	1995
	Cartographical Surveys Ltd	Keadby to Trent Falls RB	1995
	Cartographical Surveys Ltd	Newark to Gainsborough LB	1999
	Cartographical Surveys Ltd	North Clifton to Gainsborough LB	1999
	Cartographical Surveys Ltd	Torksey Lock to Marton RB	1999
	Cartographical Surveys Ltd	Carlton on Trent to Morton LB	2000
	Cartographical Surveys Ltd	Keadby to Trent Falls LB	2000
	Cartographical Surveys Ltd	Cromwell Weir to Gainsborough RB	2000
	Cartographical Surveys Ltd	Keadby to Trent Falls RB	2000
	Cartographical Surveys Ltd	Gainsborough to Keadby LB	2002
	Cartographical Surveys Ltd	Gainsborough to Keadby RB	2002
	Atkins	Gainsborough Frontage RB	2005
	Halcrow	M180 to Amcotts LB	2009
	Halcrow	M180 to Amcotts RB	2009
	Maltby	Marton Bank RB	2012
	Maltby	Torksey Bank (Including Torksey Lock) RB	2012
	Maltby	East Ferry RB	2012
	Survey 3	Bottesford Beck	2001
	Gayler	River Idle	1999
Threshold Survey	Environment Agency	Carlton-on-Trent	2012

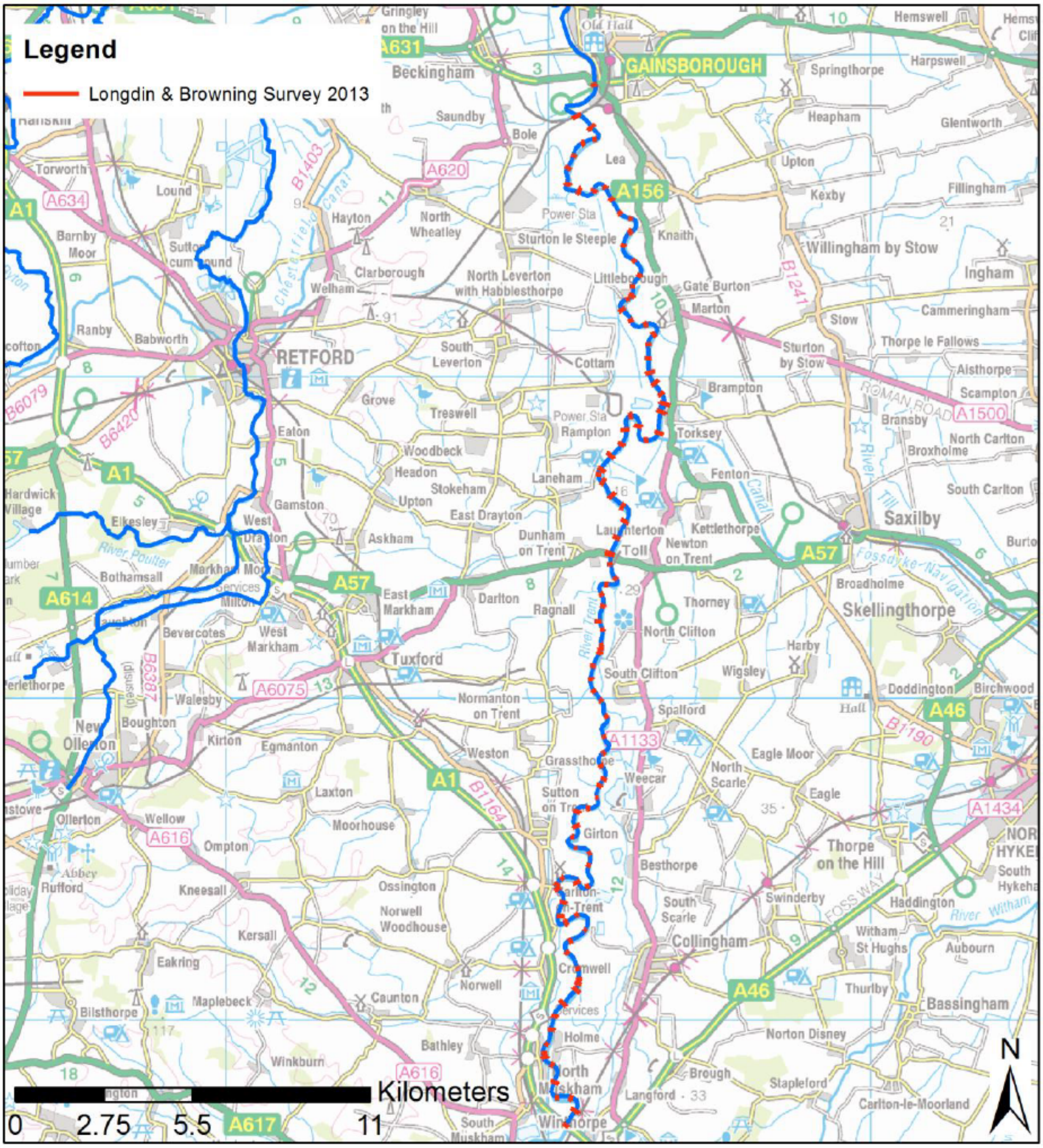
Source: EA data

Figure 4.3: Map Showing where the Bank Top Level Survey data was made Available along the River Trent for this Study



Source: EA. This map is reproduced by permission of Ordnance Survey on behalf of The Controller Of Her Majesty's Stationary Office. © Crown Copyright. All rights reserved. Environment Agency 100026380, 2013.

Figure 4.4: Map Showing the Extent of the Channel Survey Commissioned as Part of this Study



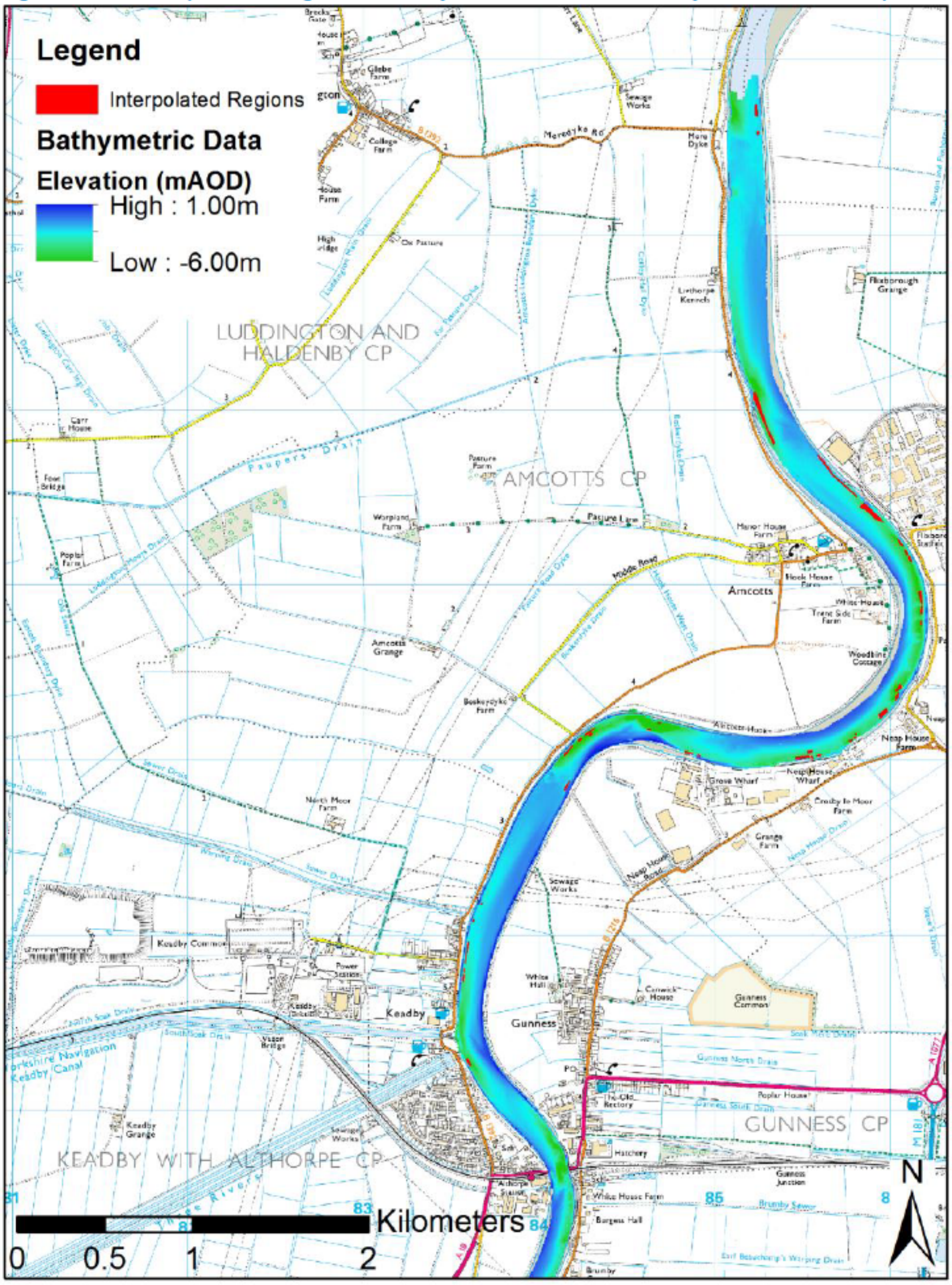
Source: Longdin & Browning. This map is reproduced by permission of Ordnance Survey on behalf of The Controller Of Her Majesty's Stationary Office. © Crown Copyright. All rights reserved. Environment Agency 100026380, 2013.

1m and 2m resolution LiDAR, flown in July 2011, was available for the majority of the study area. The vertical accuracy of the LiDAR data was typically ± 0.15m. In a few locations where LiDAR data was not available, SAR data has been provided by the EA.

Geomatics conducted a bathymetric survey of the Tidal Trent between Gainsborough and Trent Falls, which was provided to Mott MacDonald in July 2013. This was used to extract cross-sections for the lower half of the model. In a number of locations particularly in the lower reaches downstream of Keadby, data was not available due to the high sediment load. These areas are indicated in Figure 4.5 and bed levels have been interpolated from the surrounding data in these areas.

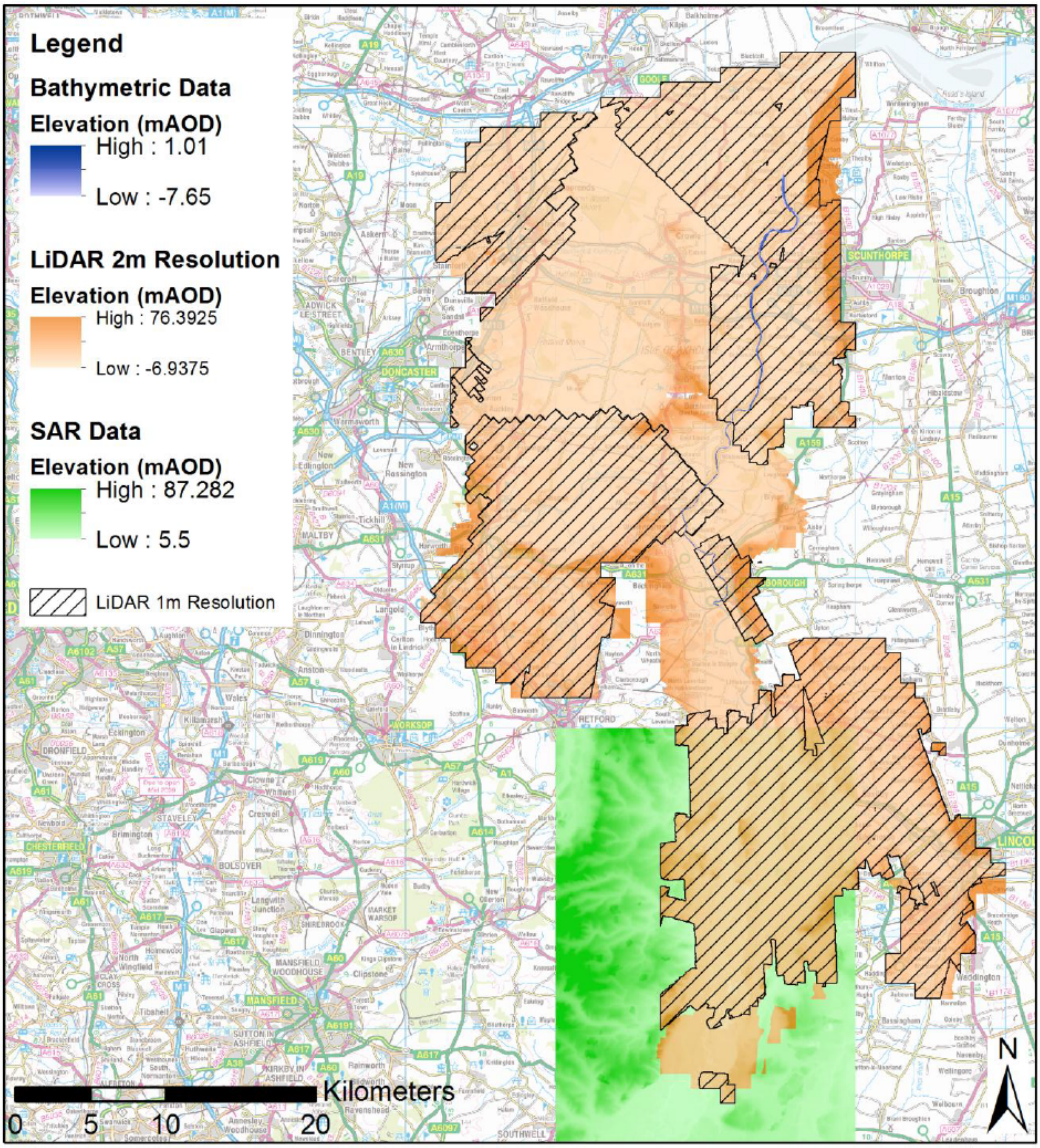
Figure 4.6 maps the coverage of the SAR, LiDAR and bathymetric data.

Figure 4.5: Interpolated Regions of Bathymetric Data Provided by Geomatics Group



Source: Geomatics Group. This map is reproduced by permission of Ordnance Survey on behalf of The Controller Of Her Majesty's Stationary Office. Environment Agency 100026380, 2013.

Figure 4.6: Coverage of SAR, LiDAR and Bathymetric Data.



Source: EA and Geomatics Group Data. This map is reproduced by permission of Ordnance Survey on behalf of The Controller Of Her Majesty's Stationary Office. Environment Agency 100026380, 2013.

The final digital terrain model (DTM) is included in the accompanying digital data.

5 Technical Method and Implementation

5.1 Hydrological Assessment

5.1.1 Fluvial Inflows

A number of hydrological studies have been carried out on the Trent Catchment. They have been used to inform the hydrological assessment for this study. These include:

- Tidal Trent Strategy Report;
- Fluvial Trent Strategy Modelling Report;
- River Idle Flood Risk Mapping Report;
- River Torne Modelling Study Report;
- Scotter Modelling Report (River Eau).

A review of each of these studies is provided in Appendix C.

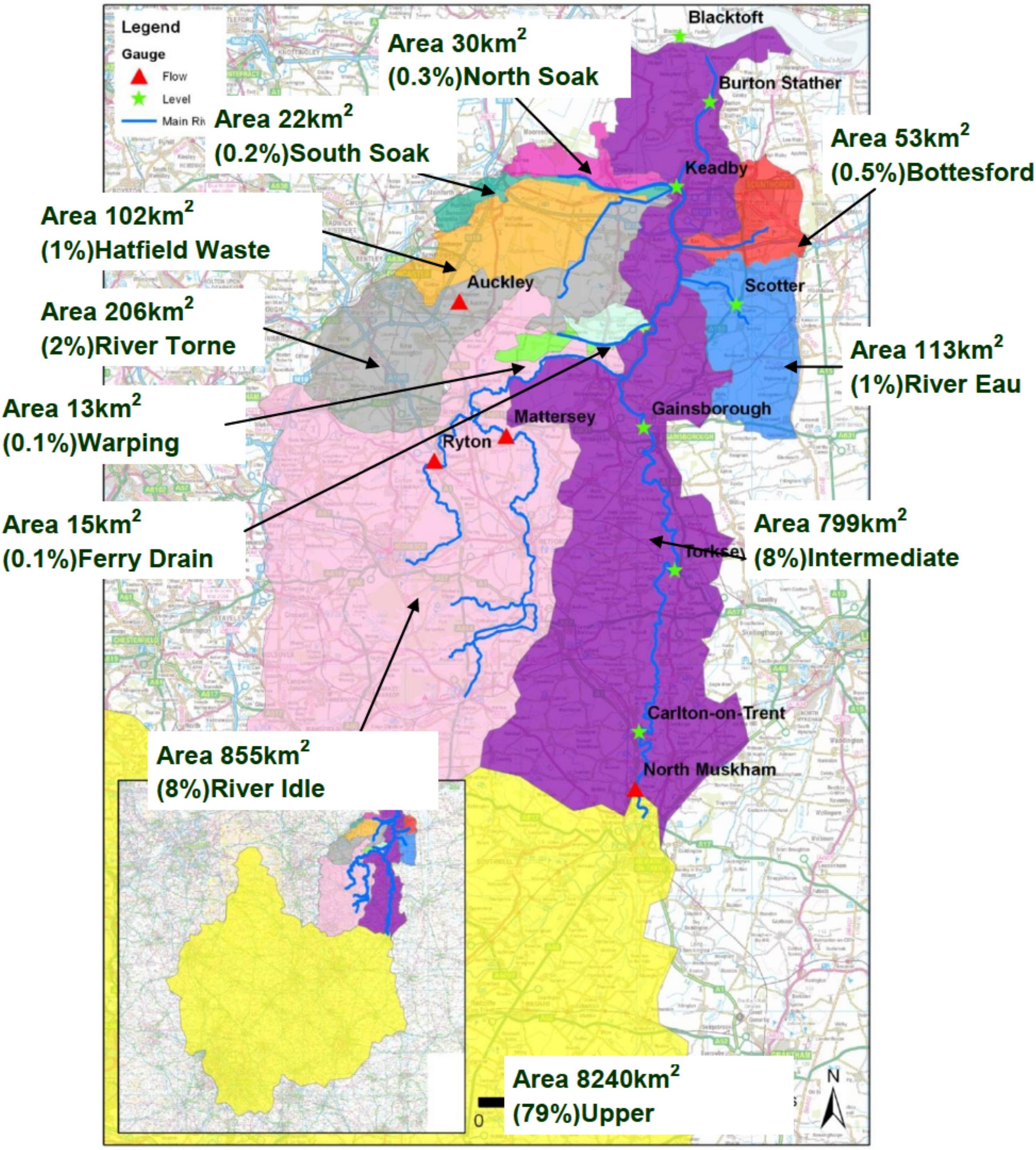
The River Trent catchment covers an area of around 10,450 km^2, the majority of which is upstream of the tidal limit of the Trent. The tidal limit of the Trent is at Cromwell Weir, 1.5km downstream of North Muskham flow and level gauge. The location of the North Muskham gauging station, 4.5 km downstream of the upper limit of the model extent, has been used to separate the catchment into upper and lower catchments.

The upper catchment covers the area upstream of North Muskham. The remaining part of the Trent catchment forms the lower catchment. This was subdivided into a number of sub-catchments (see Figure 5.1), based on the individual sub-catchment characteristics. The corresponding area for each sub-catchment is given in Table 5.1.

Flow gauges along the watercourses are indicated in red, and level gauges in green. Adjacent to the Tidal Trent, there are a large number of small tributaries, draining directly into the Trent. These have been combined into one catchment area named 'Intermediate Catchments'.

The catchment descriptors for each sub-catchment are given in Table 5.2.

Figure 5.1: Map showing Sub-Catchments



Source: Mott MacDonald. This map is reproduced by permission of Ordnance Survey on behalf of The Controller Of Her Majesty's Stationary Office.

Table 5.1: Summary of Areas of Sub-Catchments

Catchment	Area (from DTM) km^2	Proportion of Total Trent Catchment
Upstream of North Muskham	8240	79%
River Idle	855	8%
Warping Drain and Ferry Drain (Combined to make Snow Sewer)	28	0.2%
River Torne	206	2%
Hatfield Waste Drain	102	1%
South Soak Drain	22	0.2%
North Soak Drain	30	0.3%
River Eau	113	1%
Bottesford Beck	53	0.5%
Intermediate Catchments (remaining minor tributaries flowing directly into Tidal Trent)	799	8%

Source: Mott MacDonald: Catchment areas derived from DTM

Table 5.2: Summary of Sub-Catchment Key Parameters

FEH Catchment Descriptor version 3.3	AREA (km^2)	SAAR (mm)	BFIHOST (index)	SPRHOST (% index)	FARL (factor)	URBEXT (index)
Upper Catchment (Fluvial Trent)	8240	747	0.5	34.76	0.95	0.106
River Idle	855	641	0.77	19.12	0.926	0.068
Warping Drain	13	579	0.6	27.74	0.99	0
Ferry Drain	15	579	0.513	33.7	1	0.06
River Torne	206	603	0.72	21.7	0.98	0.08
Hatfield Waste Drain	102	578	0.49	34.56	0.97	0.04
South Soak Drain	22	583	0.53	33.52	1	0.04
North Soak Drain	30	582	0.47	40.06	0.99	0.04
River Eau	113	608	0.54	32.16	0.97	0.016
Bottesford Beck	53	621	0.724	22.58	0.95	0.36

5.1.2 Derivation of Design Flows & Design Flow Hydrographs

5.1.2.1 Upper Catchment

The derivation of design flows at North Muskham has been undertaken based on a number of stages:

- Review of analysis undertaken as part of Fluvial Trent Hydrological Study using data from 1884 – 2000 at Nottingham;
- Analysis of available HiFLOWS data at Nottingham (1958 - 2008);
- Analysis of available data at North Muskham (1969 – 2011);
- Trend analysis and comparison between coincident years' data at Nottingham and North Muskham;
- Estimate QMED at North Muskham;
- Estimate Growth Curve for flow at North Muskham;
- Derive design hydrographs at North Muskham.

There is a long period of data available at Nottingham. Therefore Nottingham has been used as a donor. The derived QMED value is 470 m^3/s at this location. Nottingham has also been used to provide a donor to transfer the growth curve. Table 5.3 provides a summary of the peak flows derived at North Muskham, and Appendix C provides further details on how these values were estimated and agreed with the EA.

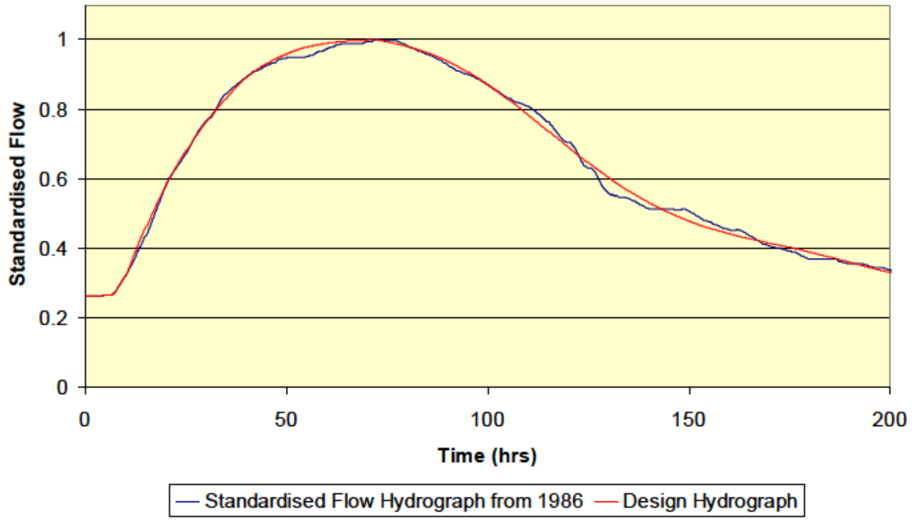
Table 5.3: Summary of Design Peak Flows at North Muskham

Return Period	Design Flows at North Muskham (using composite growth curve from Nottingham)
5	591
10	675
20	804
50	1025
75	1152
100	1250
200	1466
1000	2094

Source: Mott MacDonald.

The design hydrograph shape at North Muskham has been derived using observed hydrograph at all the available AMAX events extracted from WISKI data at North Muskham. One of them was chosen as the representative shape for the design events. In consultation with the EA it has been agreed that the 1986 hydrograph will be used as the design hydrograph shape. The hydrograph has been smoothed to remove any minor flow fluctuations. The resulting normalised, dimensionless, inflow design hydrograph is given in Figure 5.2.

Figure 5.2: Standardised Design Hydrograph for Use at Upstream Limit of the Model of the Trent



Source: Mott MacDonald

5.1.2.2 Lower Catchment

Flow hydrographs are also required for the Trent tributaries. The available observed data for the tributaries was limited. Table 5.4 provides a summary of the adopted methodologies. A detailed analysis of how the flow hydrographs for the design events were derived is provided in Appendix C, along with the alternative approaches that were investigated.

Table 5.4: Summary of Adopted Methodologies for Deriving Key Hydrological Parameters

Location	QMED Approach	Flood Growth Curve Approach	Hydrograph Shape
River Idle	Area Weighted Average of Transferred Mattersey and Blyth Donor Sites (1)	Area Weighted Average of Statistically calculated Growth Curves at Mattersey and Blyth	(3) Observed Time to Peak at Auckley (Calculated in River Torne Modelling Report) has been used to transfer Time to Peak to the Idle Catchment. RefH Hydrograph used with transferred Tp(0) and scaled to target peak flows.
Warping Drain	RefH Method	Growth Curve from ReFH Analysis	ReFH Hydrograph
Ferry Drain	RefH Method	Growth Curve from ReFH Analysis	ReFH Hydrograph
River Torne	Catchment Descriptors	Growth Curve from ReFH Analysis	(3) Observed Time to Peak at Auckley (Calculated in River Torne Modelling Report) has been used to transfer Time to Peak to the River Torne Catchment. RefH Hydrograph used with transferred Tp(0) and scaled to target peak flows.
Hatfield Waste Drain	Catchment Descriptors	Growth Curve from ReFH Analysis	ReFH Hydrograph scaled to target peak flows

Location	QMED Approach	Flood Growth Curve Approach	Hydrograph Shape
South Soak Drain	Catchment Descriptors	Growth Curve from ReFH Analysis	ReFH Hydrograph scaled to target peak flows
North Soak Drain	Catchment Descriptors	Growth Curve from ReFH Analysis	ReFH Hydrograph scaled to target peak flows
River Eau	Value extracted from previous modelling undertaken by the EA	Peak flows extracted from previous modelling undertaken by the EA	ReFH Hydrographs scaled to target peak flows
Bottesford Beck	RefH Method	Growth Curve from ReFH Analysis	ReFH Hydrograph scaled to target peak flows
Intermediate Catchment (2)	See Comment (2)	See Comment (2)	See Comment (2)

(1) There are two gauging stations on the River Idle for which data was provided, covering two separate sub-catchments. Both gauging stations were therefore used as donor sites for the entire Idle sub-catchment with the final QMED being derived using an area weighted average from the two donor sites.
(2) The intermediate catchment contribution to the flow along the Tidal Trent was calculated as a percentage of that derived for North Muskham, using catchment areas to determine the percentage.
(3) Time to Peak for the Rainfall Runoff method was calculated using the observed Time to Peak as documented in “River Torne Modelling Study” by Black & Veatch at Auckley Gauging Station as a donor, and transferring to the River Torne and River Idle Sub-catchments. No suitable observed data was available for the remaining sub-catchments and therefore the Time to Peak calculated using catchment descriptors was used.

Table 5.5 provides a summary of the peak flows derived for the lower catchments. The final design flow hydrographs are provided in Appendix C.

Table 5.5: Summary of Design Peak Flows

Return Period Event	2 or QMED	5	10	20	50	75	100	200	1000
North Muskham	470	591	673	794	1020	1136	1215	1433	2124
River Idle	20.4	27.8	33.4	39.5	49.0	43.8	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	4.4	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

Climate Change Upstream Conditions (2113)

The impacts of climate change up to 2113 were considered by increasing the present day flows by 20% (PPS25 guidelines).

5.1.2.3 Timing and Phasing of Hydrographs

In consultation with the EA the flow hydrographs from the tributaries and the Trent have been phased so that the peak flow on the Trent coincides with the peak flow from the River Idle, at the confluence of the River Idle with the Trent. The remaining tributaries are phased so that the peak flow at the confluence of each tributary with the Trent coincides with the peak flow of the River Idle at its confluence with the Trent thus to achieve a conservative estimate.

5.1.3 Downstream Tidal Boundary

Peak Water Levels

The River Humber, North Bank Tidal modelling study, undertaken by Mott MacDonald (2011), involved detailed analysis of the water levels along the Humber Estuary. Design water levels were derived along the Humber including Blacktoft, which is located 4 km upstream of the Trent confluence with the Humber. Further analysis of the design levels for Blacktoft has not been undertaken as part of this study.

There is a tide level gauge located at Burton Stather on the Trent, near the confluence with the Humber. Data at Burton Stather is available from 2001 till 2012. This is not long enough to derive reliable design levels at the gauging station. A comparison has therefore been made between the monthly maximum water levels at Burton Stather and the corresponding maximum water level at Blacktoft. A linear relation between the levels at Burton Stather and at Blacktoft has been derived and applied to the design levels calculated at Blacktoft as part of the River Humber, North Bank Tidal Modelling study. The resulting target peak levels at Burton Stather are given in Table 5.6.

Table 5.6: Recommended Peak Design Levels for Burton Stather

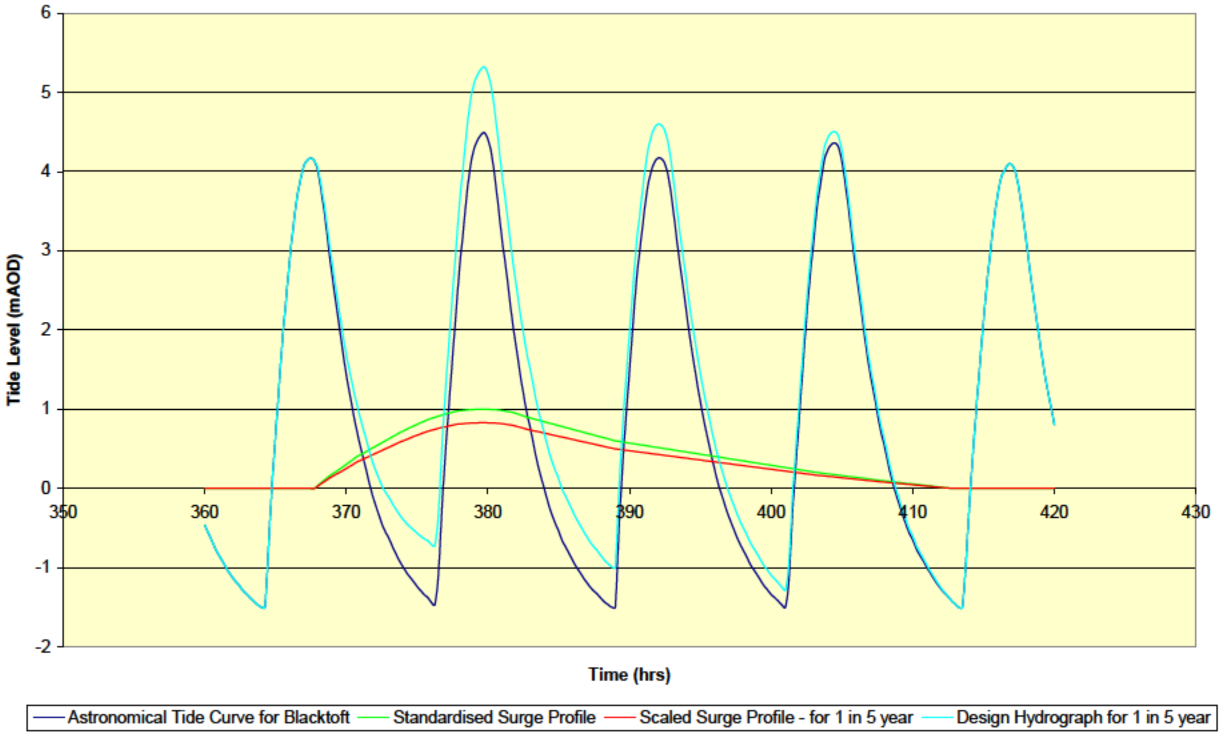
Return Period (1 in x year)	Blacktoft (mAOD)	Burton Stather (mAOD)
1	5.13	5.12
5	5.33	5.31
10	5.43	5.41
20	5.5	5.48
50	5.61	5.58
100	5.65	5.62
200	5.69	5.66
500	5.8	5.77
1000	5.84	5.81

Source: Mott MacDonald

Design Hydrograph

A base tidal curve and surge profile derived as part of the River Humber, North Bank Tidal Modelling study has been used to derive the design water level hydrographs at the downstream boundary of the Trent model. The design hydrographs have been produced by scaling the surge profile, so that when added to the base tidal curve, the peak water level matches the target peak water levels. Figure 5.3 shows an example of how the downstream boundary conditions have been derived.

Figure 5.3: Example of Derivation of Downstream Boundary Conditions at Trent Falls



Source: Mott MacDonald

Climate Change Analysis

The 1 in 200 year event has been simulated with two climate change predictions for the year 2100. In consultation with the EA it was agreed to only use climate change predictions to the year 2100 rather than to the year 2113 as for the fluvial climate change predictions.

(i) The Change factor estimate has been calculated using UKCP09 relative sea level rise (medium emission and 95 percentile) for the area around Trent Falls.
(ii) Upper End Estimate has used the values provided in EA guidance: "Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities, Environment Agency, 2011".

Table 5.7 tabulates the calculations used to determine the relative sea level rise for each scenario. This rise has been added to the entire tidal cycle to ensure that both the low-tide and high-tide levels are increased under climate change conditions.

Table 5.7: Estimation of Water Levels Considering Climate Change Conditions

Scenario	Data used for Calculation	Calculated Sea Level Rise	Final Level at Burton Stather
Change Factor (UKCP09 medium emissions)	Rise from 1990 to 2013: +0.071m Rise from 1990 to 2100: +0.467m	Rise from 2013 to 2100: +0.396m	5.96mAOD
Upper End Estimate (NCBD)	4mm per year from 2013 to 2025 = +0.048mm 7mm per year from 2026 to 2050 = +0.168m 11mm per year from 2051 to 2080 = +0.319m 15mm per year from 2081 to 2100 = +0.285m	Rise from 2013 to 2100: +0.82m	6.38mAOD

Source: Mott MacDonald

The derivation of the downstream tidal conditions are discussed in more detail in Appendix C.

5.1.4 Selection of Model Calibration Events

The model representing the with defences scenarios was calibrated against six historical flood events:
- November 2000;
- January 2005;
- June 2007;
- November 2011;
- July 2012;
- November 2012.

These events were chosen as there is inflow data at North Muskham and Tidal Boundary data at either Blacktoft or Burton Stather for each event. The observed flows at North Muskham have been used as the model inflows for each calibration event. With the exception of the November 2000 event, there is also gauged data at Carlton-on-Trent, Torksey Lock, Gainsborough and Keadby, which has been used to calibrate the model.

Digitised flood outlines are also available for the November 2000 and November 2012 events. The January 2005 and June 2007 events were both tidal events, with the remaining four being fluvial.

Observed flows for the tributaries were not available for the calibration events, although gauged data at Mattersey on the River Idle was available. The gauged data at Mattersey was used to estimate the approximate return period of each event on the Idle. The corresponding design flows for that return period were then used on all the tributaries. Table 5.8 provides the estimated return period of the tributary flow for each calibration event. This method was chosen as the runoff from about 80% of the catchment is gauged at North Muskham and therefore the uncertainty in contribution from the tributaries is unlikely to affect the model calibration.

There is significant uncertainty in the fluvial flows used for the tributaries for the events since the catchment is large enough for the storms to be likely to have had different return periods on each sub-catchment. The flood extents due to the backwater effect of the tributaries should therefore be treated with caution for calibration purposes.

Table 5.8: Return Periods Used on the Tributaries for Each Calibration Event

Event	Return Period	Comment
November 2000	1 in 20 year	Approximately 1 in 12 year flow at Mattersey on the Idle, and 1 in 20 year on Ryton at Blyth (tributary to Idle)
January 2005	No flow	Tidal Event, no significant fluvial flows
June 2007	1 in 50 year	Approximately 1 in 50 year flow at Blyth (River Ryton, tributary of the River Idle) and Mattersey on the River Idle
November 2011	No flow	Tidal Event, no significant fluvial flows
July 2012	1 in 2 year	No data available on tributaries. Flow at North Muskham approximately 1in 2 year
November 2012	1 in 20 Year	No data available on tributaries. Flow at North Muskham approximately 1 in 20 year

Source: Mott MacDonald

5.2 Model Development

5.2.1 Model Extent and Configuration

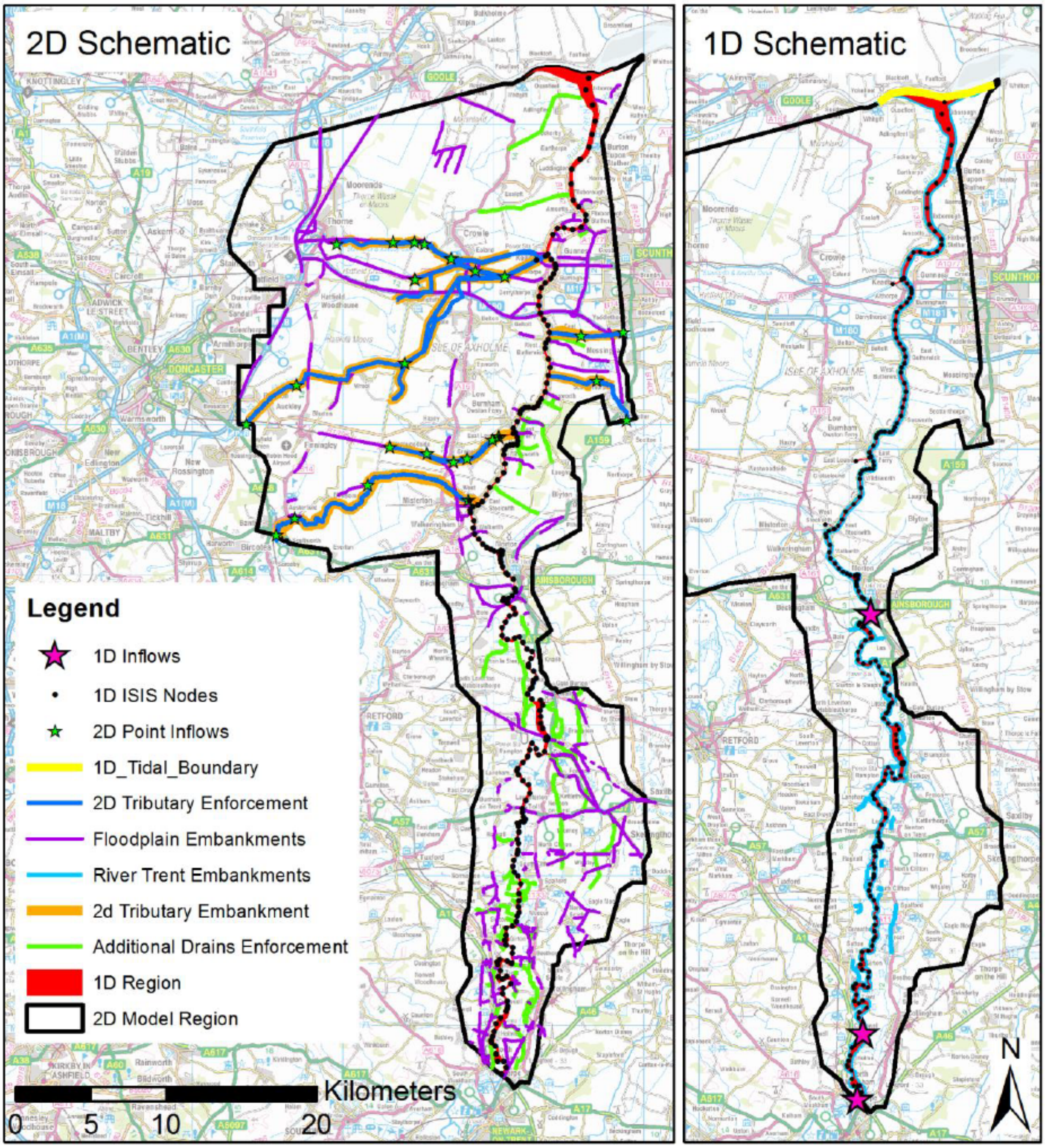
A hydraulic 1D-2D ISIS-TUFLOW model was developed for this study and extends from Winthorpe Bridge, upstream of North Muskham to the confluence of the Tidal Trent with the Humber Estuary at Trent Falls. The backwater effect of the following tributaries has also been assessed as part of the study:

- River Idle;
- Snow Sewer;
- River Torne;
- North Soak Drain;
- South Soak Drain;
- Hatfield Waste Drain;
- River Eau;
- Bottesford Beck.

An existing ISIS model of the Trent has been reviewed and updated with new cross-section survey data. Models of the River Idle, River Torne, North Soak Drain, South Soak Drain, Hatfield Waste Drain and River Eau have been used to inform the representation of the tributaries. The tributaries have been represented within the 2D domain as "Gully Lines". Where possible, the bed levels have been extracted from existing 1D models. Where there are no existing models or survey data available, LiDAR data has been used.

A simplified geo-schematic of the hydraulic model including the location of inflows is shown in Figure 5.4.

Figure 5.4: Model Schematic



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5.2.2 Model Build with Defences

The key elements of the model development and associated approaches for the design defended scenario are outlined in Table 5.9.

Table 5.9: Summary of Model Build for with Defence Conditions

Model Build Scenario	Design Defended
Software Version	▪ ISIS 3.6.1 ▪ TUFLOW 2012-05-AE-iSP-w64
River Channel	
River Sections	▪ ISIS used for Tidal Trent from Winthorpe Bridge to Trent Falls ▪ Gully lines used for representation of Tributaries – bed levels taken from existing 1D models where available ▪ In-channel roughness varied according to channel properties
Bridges	▪ M180 Bridge not included in 1D section of Trent model as unlikely to cause any constriction due to size ▪ The Trent Viaduct has been modelled as a USBPR Bridge since its piers are likely to have the most effect on the flow, and the bridge soffit is unlikely to be reached ▪ Remaining bridges have been modelled as ARCH Bridges in ISIS
2D Floodplain	
Grid	▪ 25m regular grid ▪ Model domain set perpendicular to the dominant flow direction and orientation of the estuary
River Banks	▪ Surveyed bank elevations represented in 2D model ▪ Other bank elevations extracted from LIDAR where there was no cross-section data
Outfalls	▪ Outfall from River Idle modelled in ISIS to represent pumping station at West Stockwith ▪ Outfall from Warping and Ferry Drain at East Ferry modelled in ISIS to represent pumping station ▪ Outfall from River Torne, Hatfield Waste Drain, North Soak Drain and South Soak Drain modelled in ISIS to represent pumping station at Keadby ▪ Flapped outfalls from River Eau and Bottesford Beck represented by unidirectional culverts in ESTRY
Raised Infrastructure	▪ Rail embankment raised above floodplain in the 2D model based on LiDAR ▪ M180 and other key roads represented in the 2D model based on LiDAR
Buildings	▪ A higher roughness value of 0.1 was applied to building footprints, extracted from Mastermap data, to represent the storage and flow diversion of buildings in the town ▪ Buildings were raised to the threshold survey level where available and to 0.3m elsewhere
Land use	▪ 2D model classified into seven different classes based on Mastermap data and assigned roughness values based on Chow 1969

Land Type	Manning's n Value
Natural/Grassland/River Banks/Scrub/Rough Ground	0.06
Roads	0.038
Rail	0.05
Buildings	0.1
Standing water	0.035
Woodland	0.1
Other	0.05

5.2.3 Model Boundaries

Figure 5.4 provides a schematic showing the locations of the inflows and the tidal boundary of the model.

The tributary hydrographs have been distributed along the length of the tributaries and scaled to ensure that the peak flow at their confluence with the Trent is approximately the target peak flow tabulated in Table 5.5.

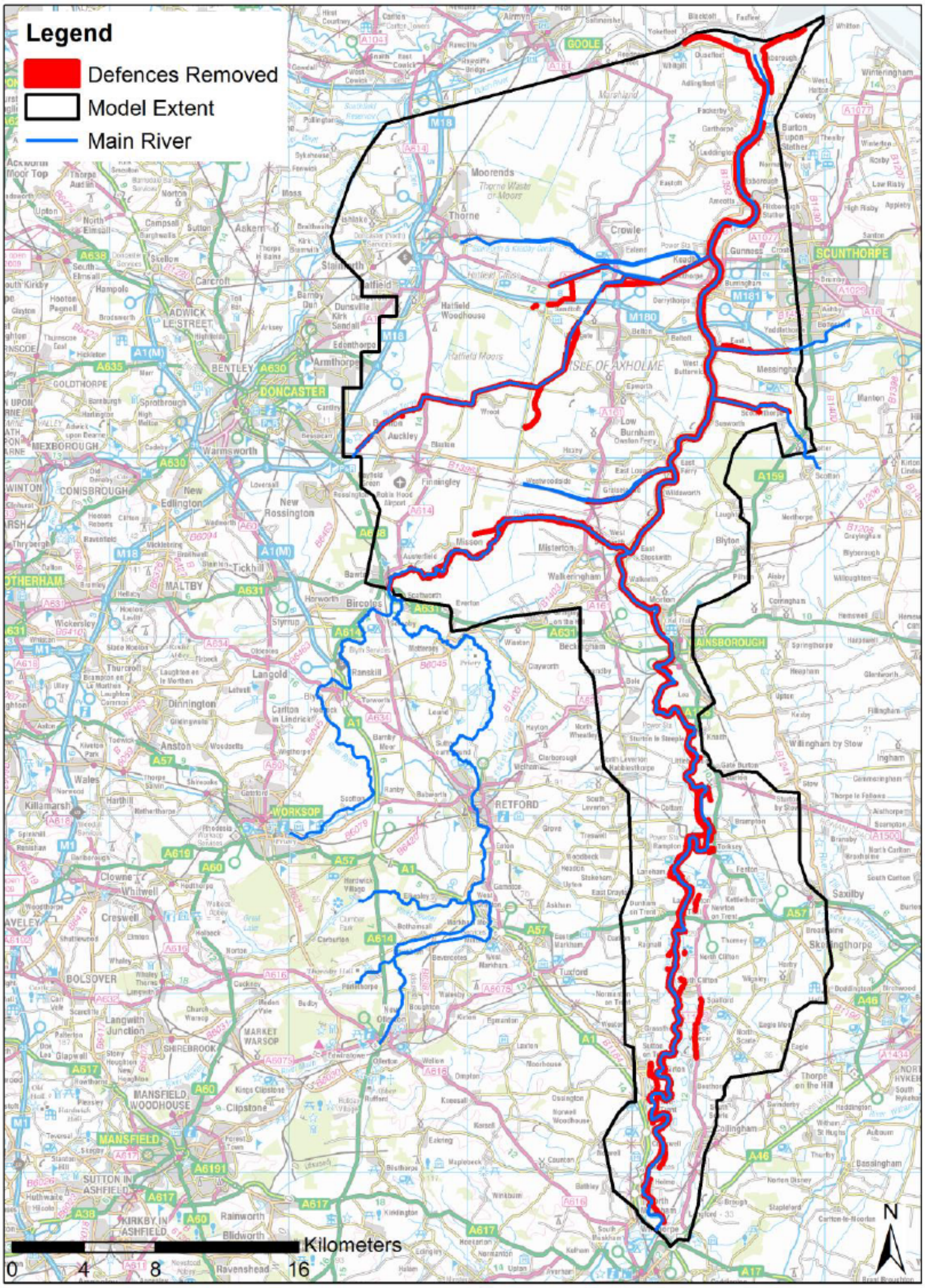
The inflow representing the Intermediate Catchment has been distributed and applied directly to the ISIS model along the course of the Tidal Trent.

5.2.4 Model Build Without Defences

In addition to the defended scenarios, undefended scenarios were required for the 1 in 100 and 1 in 1000 year fluvial return periods (with 1 in 5 year tidal boundary) and the 1 in 200 and 1 in 1000 tidal return periods (with 1 in 2 year fluvial inflows) model runs. All raised flood defences were removed from the defended baseline model build following national guidelines to determine ADBs. This included all the raised banks on either side of the Trent and its tributaries, and the embankments which are set back from the river and whose primary purpose is flood defence. The defences have been reduced to ground level. The main embankments which have not been removed for the undefended model are:

- Railway embankments
- Road embankments
- Areas of naturally occurring high ground.

Figure 5.5: Defences Removed for Undefended Scenario



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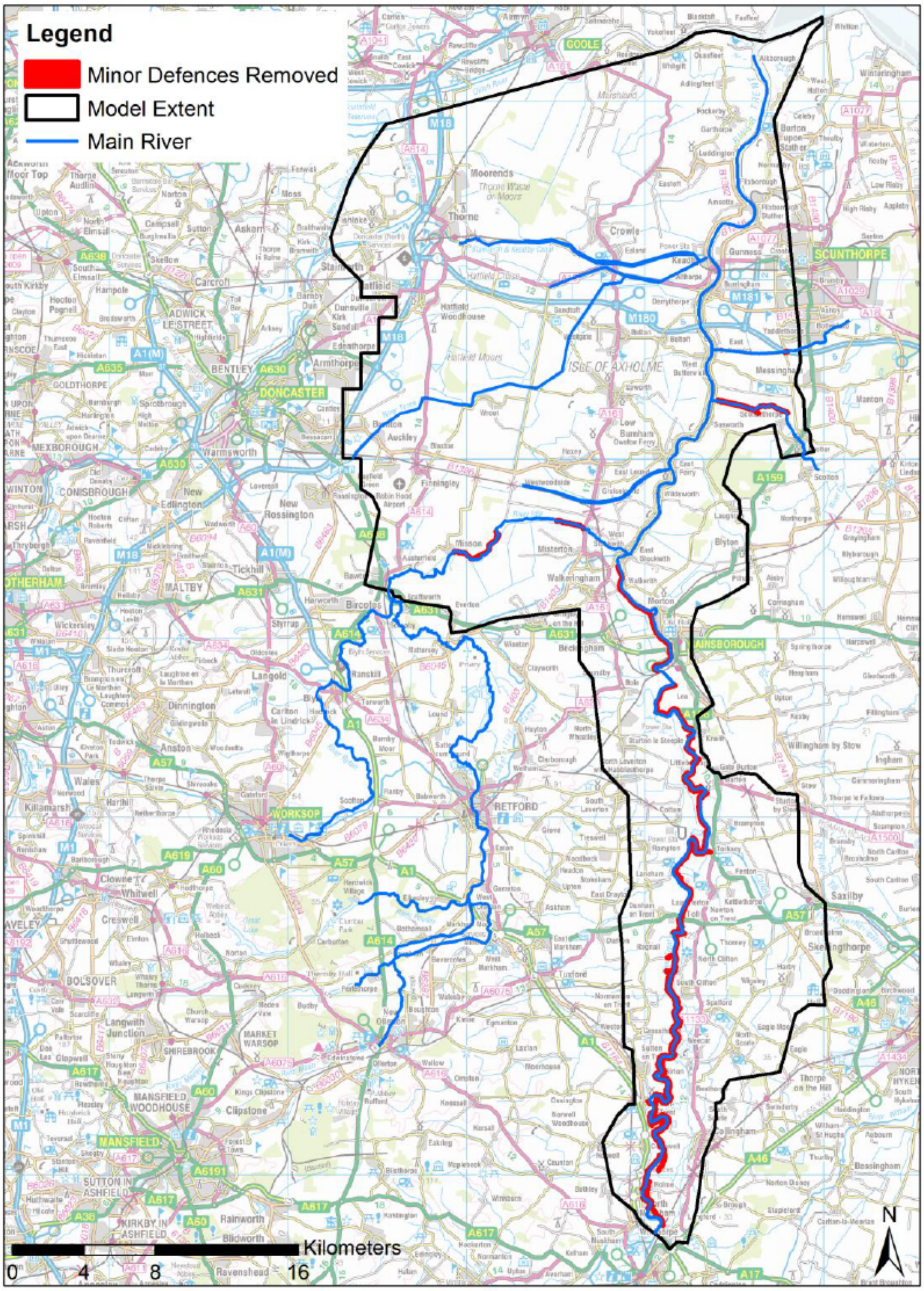
The 'exclusion' of the pumping stations was considered for the undefended scenario. In discussion with the EA it was agreed that the pumping stations should be removed from the model, allowing free flow of water between the tributaries and the Trent. The flapped outfalls at the confluence of the River Eau and Bottesford Beck with the Tidal Trent were modelled as open at all times.

5.2.5 Additional Scenarios – With Minor Defences Removed

A model representing the scenario with the minor (1 in 10 year) defences removed has also been created. This was to assess the benefit that these defences offer to the surrounding farmland and properties. Figure 5.6 shows which defences were removed for this scenario. The pumping stations and flap gates were considered to be in working order. The model was run for the 1 in 10 year event as the defended model results suggested that the majority of the minor defences did contain the 1 in 10 year event. If necessary the model can be run for other return period events such as the 1in 5 and 1 in 20 year events to gain a better understanding of the benefit these defences offer.

Figure 5.6: Minor Defences Removed for Minor Defences Removed Scenario



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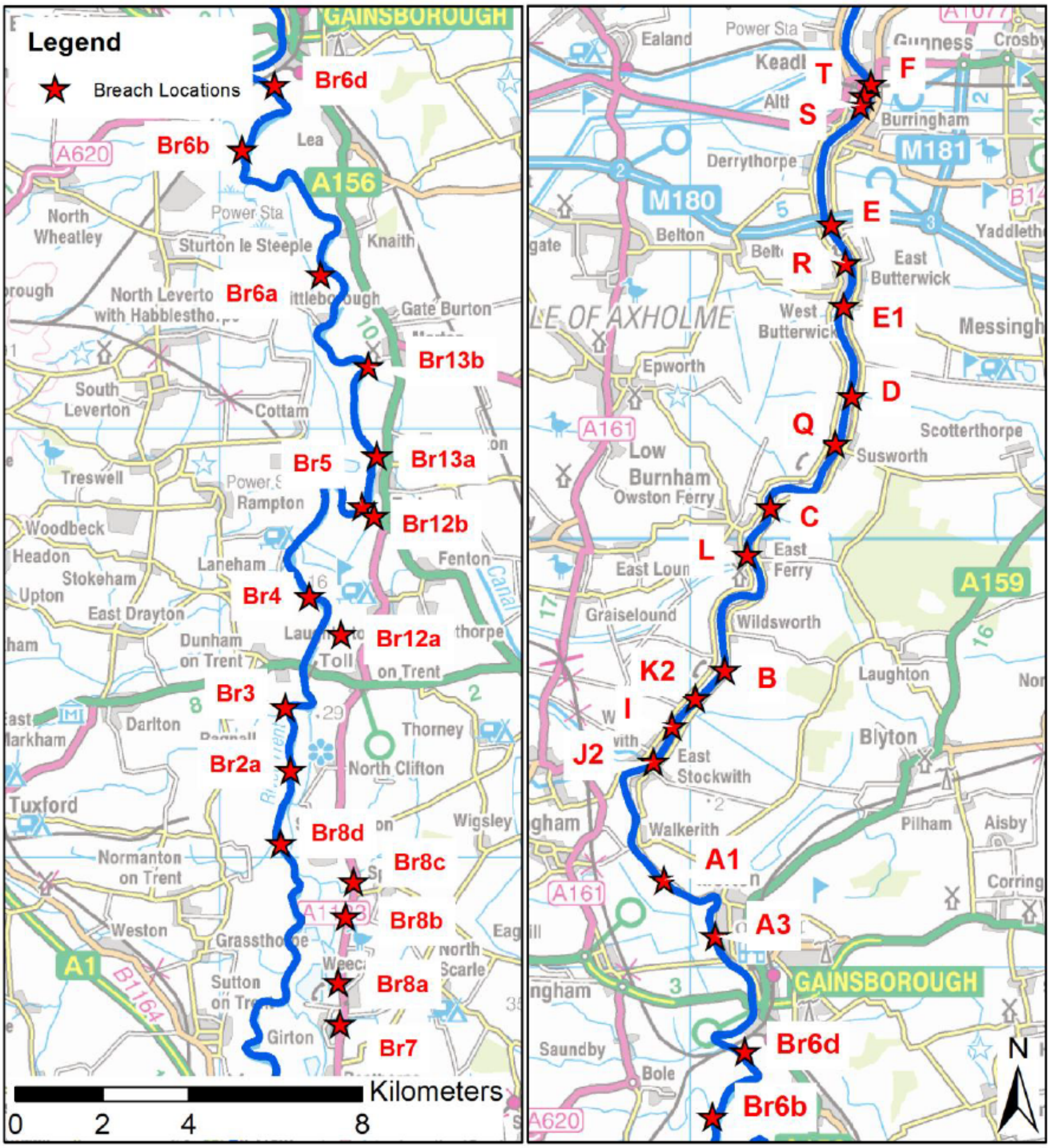
5.3 Breach Analysis

Breach analysis has been undertaken at 32 specified locations between Girton and Keadby . The locations are those previously used as part of the Tidal Trent Strategy Study which were chosen based on historical records of breaching. Figure 5.7 shows the breach locations.

Figure 5.7: Location of Breaches along Tidal Trent



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The breaches were modelled following the guidance provided by the EA and are summarised in Table 5.10.

Table 5.10: Summary of Breach Parameters Used

Breach Parameter	Tidal River / Scenario	Fluvial River Scenario
Breach Level	Floodplain level behind defence	
Breach Width (Hard Defence) (Dependant on location of breach)	20 m	20 m
Breach Width (Soft Defence) (Dependant on location of breach)	50 m	40 m
Breach Duration (Dependant on fluvial or tidal scenario modelled)	72 hours	36 hours
Breach initiation time (Dependant 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

In consultation with the EA it was agreed that breaches upstream of Gainsborough would be considered to be on a fluvial river, and breaches downstream of Gainsborough on a tidal river. The breach models were each run for four return periods:

- 1 in 100 year fluvial with 1 in 5 year tidal;
- 1 in 1000 year fluvial with 1 in 5 year tidal;
- 1 in 2 year fluvial with 1 in 200 year tidal;
- 1 in 2 year fluvial with 1 in1000 year tidal.

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. Further details are provided in Appendix F. Breach summary sheets have been created for each breach location detailing the breach parameters used. These are provided in Appendix G.

5 breach locations which are set back from the main water-course have not been modelled for the two tidal scenarios as the adjacent floodplain is not shown to be flooded during the design runs with defences. Breaching the defences would therefore not lead to any increase in flooding. The breach locations where this occurs are:

- Br7 – Across A1133, East of Girton;
- Br8a – Across A1133, between Home Farm (Trent Lane) and Highfields;
- Br8b – Across A1133, 300m north of Girton Grange;
- Br12a – Behind Caravan Park, between Laughterton and Newton-on-Trent;
- Br 12b – Near Caravan Park, Torksey Lock.

5.4 Post-processing of Model Results

The model results were subsequently used to produce flood depth, velocity and hazard maps for the study areas.

The 1D model results and 2D model results were combined to produce the maximum flood outlines from maximum water level grids. These have been converted to flood outlines for incorporation into the EA's MapEdit Database.

6 Model Proving

6.1 Model Run Performance

A summary of the model run performance for the models is provided in Table 6.1.

Table 6.1: Summary of Model Run Performance

Scenario	Breach	Return Period (Fluvial)	Return Period (Tidal)	1D Model Convergence	2D Peak Mass Balance Error (%)
Calibration	N/A	November 2000		Small periods of non-convergence	0.3
		January 2005		No non-convergence	0.2
		June 2007		Very few points of non-convergence on falling limb of fluvial event	1.9
		November 2011		No non-convergence	0.4
		July 2012		Non-convergence during run (due to oscillations at pumping stations)	2.3
		November 2012		Small periods of non-convergence	0.8
Defended Model	N/A	5	5	Some non-convergence on falling limb of fluvial event	0.7
		10	5	Some non-convergence on falling limb of fluvial event	0.6
		20	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		50	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		75	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		200	5	Very few points of non-convergence on falling limb of fluvial event	0.3
		1000	5	No non-convergence	0.4
		100+CC	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.2
		2	200+CC (Change Factor)	Some non-convergence on falling limb of fluvial event	0.9
		2	200+CC (Upper End)	Some non-convergence on falling limb of fluvial event	0.6
Undefended Model	N/A	100	5	No non-convergence	0.2
		1000	5	No non-convergence	0.2
		2	200	No non-convergence	0.4
		2	1000	No non-convergence	0.4
Minor Defences Removed	N/A	10	5	Very few points of non-convergence	1.3
Breach Model	A1	2	200	Some non-convergence on falling limb of fluvial event	1.3
		2	1000	Some non-convergence on falling limb of fluvial event	1.3
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	A3	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.2

Scenario	Breach	Return Period (Fluvial)	Return Period (Tidal)	1D Model Convergence	2D Peak Mass Balance Error (%)
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	B	2	200	Some non-convergence on falling limb of fluvial event	1.3
		2	1000	Some non-convergence on falling limb of fluvial event	1.3
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	BR12A	100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	BR12B	100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	BR13A	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.2
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	BR13B	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.2
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	BR2A	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.2
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	BR3	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.1
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	BR4	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.2
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	BR5	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.2
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	BR6A	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.2
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	BR6B	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.2

Scenario	Breach	Return Period (Fluvial)	Return Period (Tidal)	1D Model Convergence	2D Peak Mass Balance Error (%)
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	BR6D	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.1
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	BR7	100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	BR8A	100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	BR8B	100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	BR8C	100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	BR8D	2	200	Some non-convergence on falling limb of fluvial event	1.3
		2	1000	Some non-convergence on falling limb of fluvial event	1.2
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	C	2	200	Some non-convergence on falling limb of fluvial event	1.3
		2	1000	Some non-convergence on falling limb of fluvial event	1.2
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	D	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.2
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	E	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.2
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	E1	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.2
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	F	2	200	Some non-convergence on falling limb of fluvial event	1.1
		2	1000	Some non-convergence on falling limb of fluvial event	1
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	I	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.1

Scenario	Breach	Return Period (Fluvial)	Return Period (Tidal)	1D Model Convergence	2D Peak Mass Balance Error (%)
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	J2	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.2
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	K2	2	200	Some non-convergence on falling limb of fluvial event	1.1
		2	1000	Some non-convergence on falling limb of fluvial event	1.1
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	L	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.1
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	Q	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.1
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	R	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.2
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	S	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.1
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4
	T	2	200	Some non-convergence on falling limb of fluvial event	1.2
		2	1000	Some non-convergence on falling limb of fluvial event	1.2
		100	5	Very few points of non-convergence on falling limb of fluvial event	0.4
		1000	5	One instance of non-convergence near peak of fluvial event	0.4

All model runs for the design events are stable with a 2D peak mass balance error of less than 1.4%. The non-convergence that is seen in the 1D model is due to the pumping stations causing oscillations in the model as they switch on and off. This non-convergence is reduced during the larger events when the pumps maintain a constant rate for a prolonged period of time. For the undefended model, where the pumps have been removed, there is no non-convergence in the 1D domain. The simulation of tidal events show an increase in the non-convergence and mass balance error (although still within the recommended limits); this is due to an increase in the flow exchange between the 1D and 2D components of the model.

The model convergence diagnostics and checks for each model run are provided on the accompanying hard drive.

6.2 Calibration and Verification

The defended model was calibrated against six historical flood events which occurred in:

- November 2000;
- January 2005;
- June 2007;
- November 2011;
- July 2012;
- November 2012.

The calibration of the model was focused on matching the model predicted water levels with the observed water levels at Carlton-On-Trent, Torksey Lock, Gainsborough, Keadby and Burton Stather. Flood extents from the November 2000 and November 2012 events were also used to aid the calibration of the 2D model.

The model was initially calibrated using the 1D model only and running the January 2005, November 2011 and July 2012 events as these were either tidal, or predominantly in-bank events. Once a good level of calibration had been achieved for the 1D model, the 1D-2D linked model was then run for all six selected events.

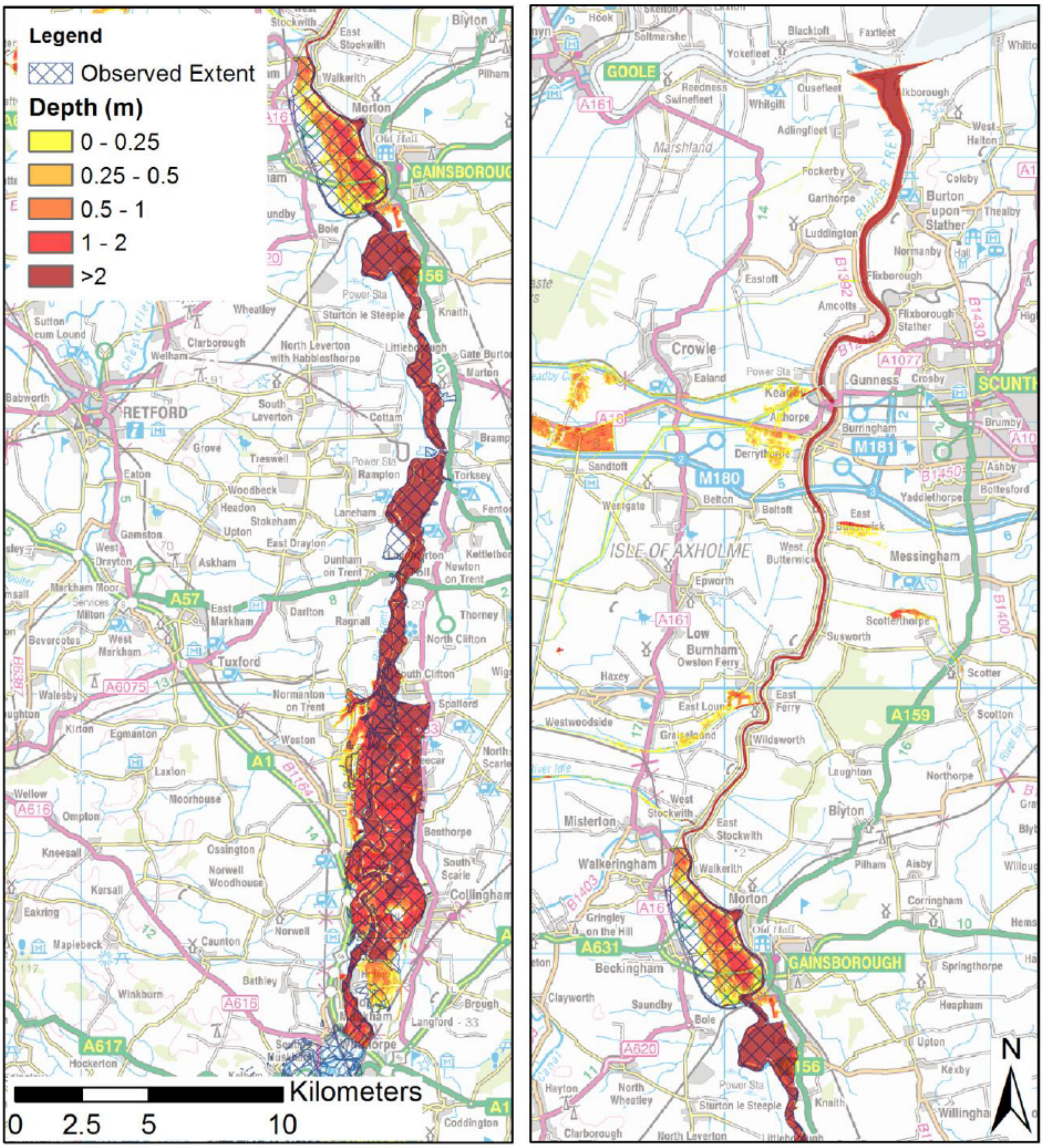
A comparison of the peak water levels modelled and observed at each gauging station for each event has been made and the results are shown in Table 6.2. Figure 6.1 and Figure 6.2 show the comparison of the modelled and recorded flood extents for the November 2000 and November 2012 events. Further details on the level of calibration achieved is given in Appendix D. The November 2012 event was used as a verification event.

Table 6.2: Comparison of Model Predicted and Observed Peak Water Levels for Calibration and Verification Events

Event	Data Source	Level (mAOD) Carlton – on – Trent	Torksey Lock	Gainsborough	Keadby	Burton Stather	Comments
November 2000	Observed	N/A	N/A	N/A	4.99	N/A	Large fluvial event with limited data available at gauging stations.
	Modelled	N/A	N/A	N/A	5.11	N/A	
	Difference	N/A	N/A	N/A	-0.12	N/A	
January 2005	Observed	4.34	4.11	4.82	5.1	5.2	Tidal event, therefore focus of calibration on downstream section of model
	Modelled	4.25	3.98	4.53	5.12	5.16	
	Difference	0.09	0.13	0.28	-0.02	0.04	
June 2007	Observed	7.59	6.01	4.58	4.02	3.9	Predominantly in-bank fluvial event.
	Modelled	7.48	5.95	4.61	4.16	3.98	
	Difference	0.11	0.05	-0.03	-0.13	-0.08	
November 2011	Observed	4	4.05	4.72	4.96	5.3	Tidal event, therefore focus of calibration on downstream section of model. *Low confidence in observed levels recorded at Keadby due to flat observed tidal peak.
	Modelled	3.55	3.64	4.47	5.2*	5.31	
	Difference	0.44	0.41	0.25	-0.24	-0.01	
July 2012	Observed	6.96	5.72	5.17	4.7	4.58	Medium sized fluvial event.
	Modelled	6.94	5.69	5.16	4.67	4.57	
	Difference	0.02	0.04	0.02	0.03	0.01	
November 2012	Observed	7.92	6.43	5.12	4.43	4.09	Large fluvial event
	Modelled	7.79	6.36	5.16	4.39	4.09	
	Difference	0.13	0.07	-0.04	0.05	0.01	

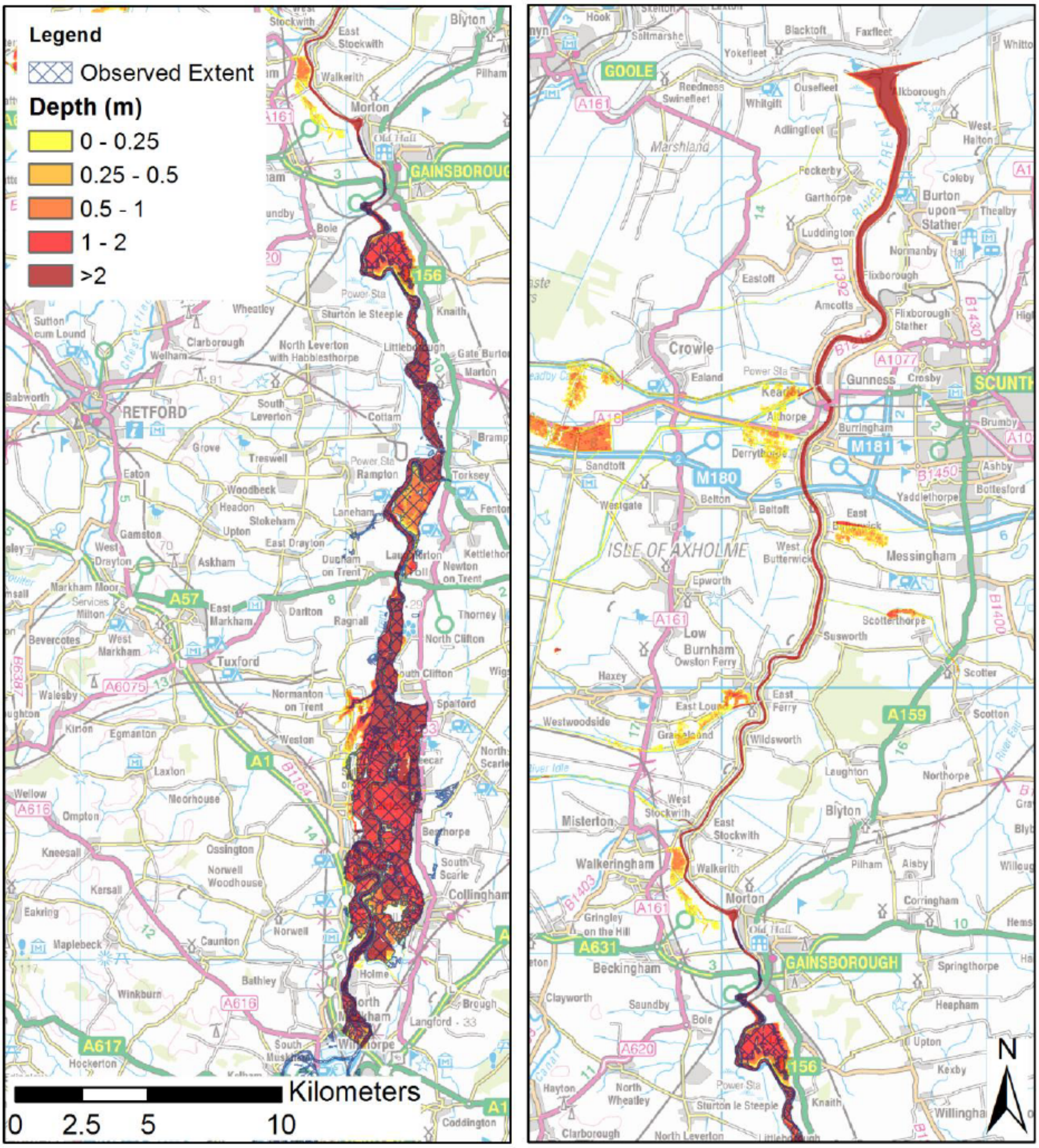
Source: Mott MacDonald

Figure 6.1: Comparison of Observed and Modelled Flood Extents, November 2000



Source: Mott MacDonald. This map is reproduced by permission of Ordnance Survey on behalf of The Controller Of Her Majesty's Stationary Office. Environment Agency 100026380, 2013.

Figure 6.2: Comparison of Observed and Modelled Flood Extents, November 2012,



Source: Mott MacDonald. This map is reproduced by permission of Ordnance Survey on behalf of The Controller Of Her Majesty's Stationary Office.

For fluvial events, particularly the July 2012 event, a very good calibration has been achieved. Modelled levels are within 0.13m at all gauges for each event.

During the November 2012 event, the model is under-predicting the water levels at Carlton-on-Trent by 0.13m, however, the flood extents in this region show a fairly good match with the observed extents.

During the November 2000 event, historic outlines suggest that there was more flooding in Beckingham Marshes. Since the model is over-predicting water levels at Keadby by 0.12m, it was agreed not to attempt to raise water levels further in this area. The additional flooding could be attributed to surface water flooding being picked up by the historic outlines.

The calibration for the tidal events has focused on the lower reaches of the model (downstream of Gainsborough). Calibration upstream of Gainsborough has not been achieved as tidal events are unlikely to cause flooding in this region, and it was considered of greater importance to ensure that the model was well calibrated to fluvial events, the most likely source of flooding upstream of Gainsborough.

Downstream of Gainsborough, the calibration for the January 2005 event is good. For the November 2011 event there is uncertainty in the peak level recorded at Keadby as the level hydrograph appears to flatten off prior to the peak of the tidal cycle. This has led to an observed level 0.24m below that predicted by the model.

The tributaries have not been the focus of the calibration within this study, particularly since there was very limited hydrological data available during the events.

6.3 Sensitivity Analysis

In consultation with the EA, two sensitivity tests were carried out focusing on Manning's roughness for the 1 in 100 year fluvial event:

- Floodplain and in-channel roughness increased by 20%;
- Floodplain and in-channel roughness decreased by 20%.

Figure 6.3 compares the extents with the baseline model for the 1 in 100 year fluvial event. Table 6.3 compares the peak water levels at the gauging stations with the baseline model. Baseline mannings values are given in Table 5.9.

Table 6.3: Comparison of Peak Water Levels at Gauging Stations for Varying Manning's Roughness Coefficients

	Peak Water Level (mAOD)		
Gauging Station	Manning's – 20%	Baseline Values	Manning's + 20%
North Muskham	8.92	8.99	9.07
	-0.07		+0.08
Carlton-on-Trent	8.03	8.26	8.47
	-0.23		+0.21
Torksey Lock	7.23	7.42	7.57
	-0.19		+0.15
Gainsborough	5.92	6.26	6.44
	-0.34		+0.18
Keadby	5.74	5.70	5.70
	+0.04		0
	5.42	5.40	5.40
Burton Stather	+0.02		0

Source: Mott MacDonald

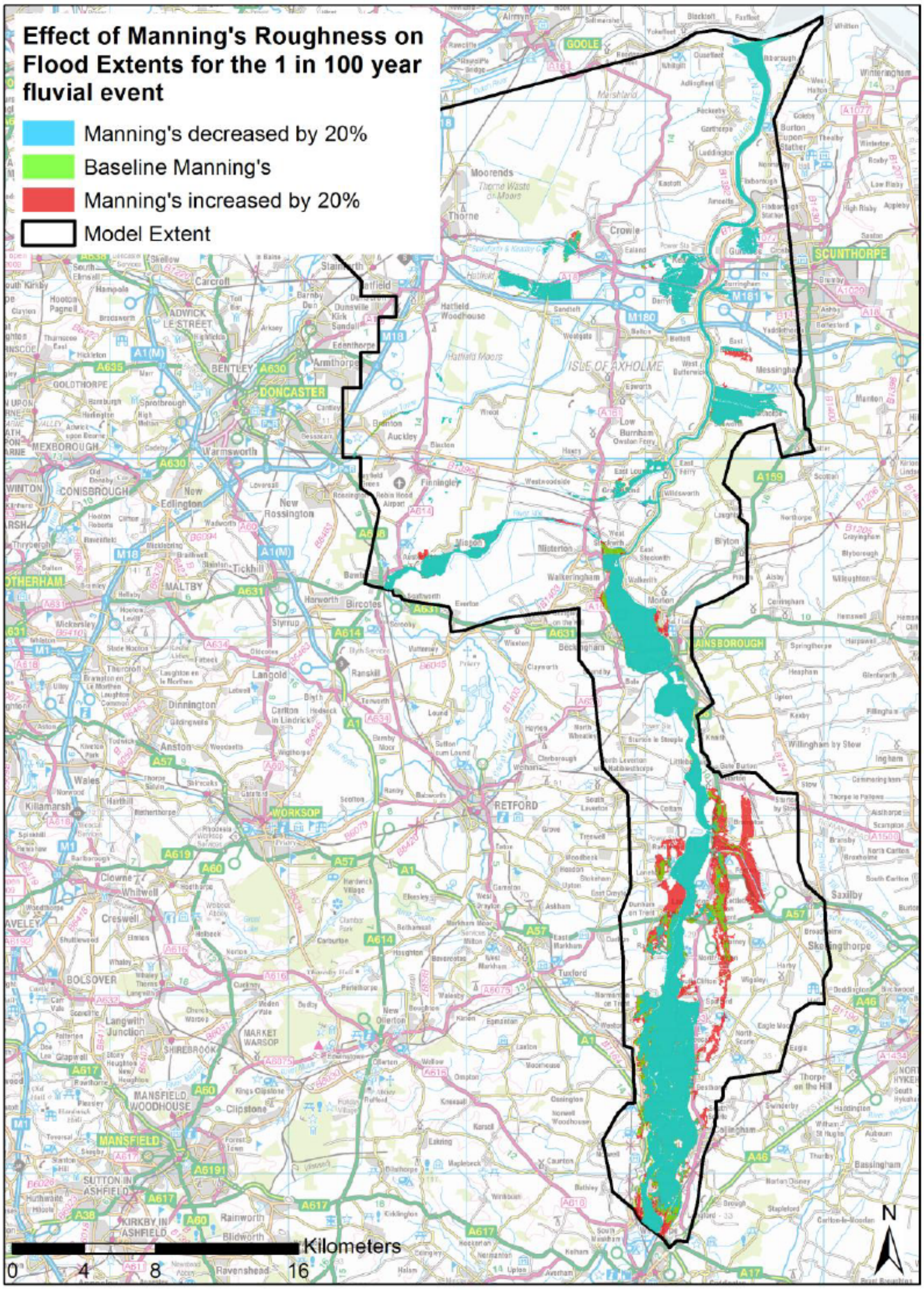
The water levels and flood extents show that in the fluvially dominated areas (upstream of Gainsborough) increasing the Manning's roughness increases the level by around 10 to 20cm. This leads to a large increase in flood extents, particularly around Torksey Lock. Decreasing the Manning's roughness has an opposite effect on the flood levels, reducing them by approximately 10 to 20cm.

In tidally dominated areas (downstream of Gainsborough), reducing the Manning's roughness leads to only very small changes in water levels. This is due to the downstream boundary condition has a dominant effect on the water levels in the lower reaches. Flood extents in the lower reaches of the Tidal Trent are similar for each sensitivity test, i.e. less sensitive to the change of channel and floodplain roughness.

At Keadby and Burton Stather, reducing the Manning's roughness leads to a slight increase (2 to 4cm) in the peak levels. This is due to there being less attenuation in the tidal wave as it flows up the river, resulting in a higher peak. Increasing the Manning's roughness has a negligible effect (<1cm).

The sensitivity of the model to the roughness coefficients used should be taken into account when interpreting the model results.

Figure 6.3: Flood Extents for 1 in 100 Year Fluvial Event with Varying Manning's Roughness Coefficients



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7 Model Results

7.1 Design Scenarios

Table 7.1 summarises the design model runs undertaken in this study.

Table 7.1: Design Model Runs

ID	Model Build	Breach	Return Period (Fluvial)	Year	Return Period (Tidal)	Year	File Name
1	Calibration	N/A	November 2000				Mott MacDonald_TTRENT_NOV2000_V17
2			January 2005				Mott MacDonald_TTRENT_JAN2005_V17
3			June 2007				Mott MacDonald_TTRENT_JUN2007_V17
4			November 2011				Mott MacDonald_TTRENT_NOV2011_V17
5			July 2012				Mott MacDonald_TTRENT_JULY2012_V17
6			November 2012				Mott MacDonald_TTRENT_NOV2012_V17
7	Defended Model	N/A	5	2013	5	2013	Mott MacDonald_TTRENT_F0005_T0005_V17
8			10	2013	5	2013	Mott MacDonald_TTRENT_F0010_T0005_V17
9			20	2013	5	2013	Mott MacDonald_TTRENT_F0020_T0005_V17
10			50	2013	5	2013	Mott MacDonald_TTRENT_F0050_T0005_V17
11			75	2013	5	2013	Mott MacDonald_TTRENT_F0075_T0005_V17
12			100	2013	5	2013	Mott MacDonald_TTRENT_F0100_T0005_V17
13			200	2013	5	2013	Mott MacDonald_TTRENT_F0200_T0005_V17
14			1000	2013	5	2013	Mott MacDonald_TTRENT_F1000_T0005_V17
15			100+CC	2113	5	2013	Mott MacDonald_TTRENT_F100CC_T0005_V17
16			2	2013	200	2013	Mott MacDonald_TTRENT_F0002_T0200_V17
17			2	2013	1000	2013	Mott MacDonald_TTRENT_F0002_T1000_V17
18			2	2013	200+CC (Change Factor)	2100	Mott MacDonald_TTRENT_F0002_T0200CC_CF_V17
19			2	2013	200+CC(Upper End)	2100	Mott MacDonald_TTRENT_F0002_T0200CC_UE_V17
20	Undefended Model	N/A	100	2013	5	2013	Mott MacDonald_TTRENT_F0100_T0005_UNDEF_V01
21			1000	2013	5	2013	Mott MacDonald_TTRENT_F1000_T0005_UNDEF_V01
22			2	2013	200	2013	Mott MacDonald_TTRENT_F0002_T0200_UNDEF_V01
23			2	2013	1000	2013	Mott MacDonald_TTRENT_F0002_T1000_UNDEF_V01
24	Minor Defences Removed	N/A	10	2013	5	2013	Mott MacDonald_TTRENT_F0010_T0005_MINOR_V01
25	Breach Model	A1	2	2013	200	2013	Mott MacDonald_TTRENT_A1_F0002_T0200_V01
26			2	2013	1000	2013	Mott MacDonald_TTRENT_A1_F0002_T1000_V01
27			100	2013	5	2013	Mott MacDonald_TTRENT_A1_F0100_T0005_V01

ID	Model Build	Breach	Return Period (Fluvial)	Year	Return Period (Tidal)	Year	File Name
28			1000	2013	5	2013	Mott MacDonald_TTRENT_A1_F1000_T0005_V01
29		A3	2	2013	200	2013	Mott MacDonald_TTRENT_A3_F0002_T0200_V01
30			2	2013	1000	2013	Mott MacDonald_TTRENT_A3_F0002_T1000_V01
31			100	2013	5	2013	Mott MacDonald_TTRENT_A3_F0100_T0005_V01
32			1000	2013	5	2013	Mott MacDonald_TTRENT_A3_F1000_T0005_V01
33		B	2	2013	200	2013	Mott MacDonald_TTRENT_B_F0002_T0200_V01
34			2	2013	1000	2013	Mott MacDonald_TTRENT_B_F0002_T1000_V01
35			100	2013	5	2013	Mott MacDonald_TTRENT_B_F0100_T0005_V01
36			1000	2013	5	2013	Mott MacDonald_TTRENT_B_F1000_T0005_V01
37		BR12A	100	2013	5	2013	Mott MacDonald_TTRENT_BR12A_F0100_T0005_V01
38			1000	2013	5	2013	Mott MacDonald_TTRENT_BR12A_F1000_T0005_V01
39		BR12B	100	2013	5	2013	Mott MacDonald_TTRENT_BR12B_F0100_T0005_V01
40			1000	2013	5	2013	Mott MacDonald_TTRENT_BR12B_F1000_T0005_V01
41		BR13A	2	2013	200	2013	Mott MacDonald_TTRENT_BR13A_F0002_T0200_V01
42			2	2013	1000	2013	Mott MacDonald_TTRENT_BR13A_F0002_T1000_V01
43			100	2013	5	2013	Mott MacDonald_TTRENT_BR13A_F0100_T0005_V01
44			1000	2013	5	2013	Mott MacDonald_TTRENT_BR13A_F1000_T0005_V01
45		BR13B	2	2013	200	2013	Mott MacDonald_TTRENT_BR13B_F0002_T0200_V01
46			2	2013	1000	2013	Mott MacDonald_TTRENT_BR13B_F0002_T1000_V01
47			100	2013	5	2013	Mott MacDonald_TTRENT_BR13B_F0100_T0005_V01
48			1000	2013	5	2013	Mott MacDonald_TTRENT_BR13B_F1000_T0005_V01
49		BR2A	2	2013	200	2013	Mott MacDonald_TTRENT_BR2A_F0002_T0200_V01
50			2	2013	1000	2013	Mott MacDonald_TTRENT_BR2A_F0002_T1000_V01
51			100	2013	5	2013	Mott MacDonald_TTRENT_BR2A_F0100_T0005_V01
52			1000	2013	5	2013	Mott MacDonald_TTRENT_BR2A_F1000_T0005_V01
53		BR3	2	2013	200	2013	Mott MacDonald_TTRENT_BR3_F0002_T0200_V01
54			2	2013	1000	2013	Mott MacDonald_TTRENT_BR3_F0002_T1000_V01
55			100	2013	5	2013	Mott MacDonald_TTRENT_BR3_F0100_T0005_V01

ID	Model Build	Breach	Return Period (Fluvial)	Year	Return Period (Tidal)	Year	File Name
56			1000	2013	5	2013	Mott MacDonald_TTRENT_BR3_F1000_T0005_V01
57		BR4	2	2013	200	2013	Mott MacDonald_TTRENT_BR4_F0002_T0200_V01
58			2	2013	1000	2013	Mott MacDonald_TTRENT_BR4_F0002_T1000_V01
59			100	2013	5	2013	Mott MacDonald_TTRENT_BR4_F0100_T0005_V01
60			1000	2013	5	2013	Mott MacDonald_TTRENT_BR4_F1000_T0005_V01
61		BR5	2	2013	200	2013	Mott MacDonald_TTRENT_BR5_F0002_T0200_V01
62			2	2013	1000	2013	Mott MacDonald_TTRENT_BR5_F0002_T1000_V01
63			100	2013	5	2013	Mott MacDonald_TTRENT_BR5_F0100_T0005_V01
64			1000	2013	5	2013	Mott MacDonald_TTRENT_BR5_F1000_T0005_V01
65		BR6A	2	2013	200	2013	Mott MacDonald_TTRENT_BR6A_F0002_T0200_V01
66			2	2013	1000	2013	Mott MacDonald_TTRENT_BR6A_F0002_T1000_V01
67			100	2013	5	2013	Mott MacDonald_TTRENT_BR6A_F0100_T0005_V01
68			1000	2013	5	2013	Mott MacDonald_TTRENT_BR6A_F1000_T0005_V01
69		BR6B	2	2013	200	2013	Mott MacDonald_TTRENT_BR6B_F0002_T0200_V01
70			2	2013	1000	2013	Mott MacDonald_TTRENT_BR6B_F0002_T1000_V01
71			100	2013	5	2013	Mott MacDonald_TTRENT_BR6B_F0100_T0005_V01
72			1000	2013	5	2013	Mott MacDonald_TTRENT_BR6B_F1000_T0005_V01
73		BR6D	2	2013	200	2013	Mott MacDonald_TTRENT_BR6D_F0002_T0200_V01
74			2	2013	1000	2013	Mott MacDonald_TTRENT_BR6D_F0002_T1000_V01
75			100	2013	5	2013	Mott MacDonald_TTRENT_BR6D_F0100_T0005_V01
76			1000	2013	5	2013	Mott MacDonald_TTRENT_BR6D_F1000_T0005_V01
77		BR7	100	2013	5	2013	Mott MacDonald_TTRENT_BR7_F0100_T0005_V01
78			1000	2013	5	2013	Mott MacDonald_TTRENT_BR7_F1000_T0005_V01
79		BR8A	100	2013	5	2013	Mott MacDonald_TTRENT_BR8A_F0100_T0005_V01

ID	Model Build	Breach	Return Period (Fluvial)	Year	Return Period (Tidal)	Year	File Name
80			1000	2013	5	2013	Mott MacDonald_TTRENT_BR8A_F1000_T0005_V01
81		BR8B	100	2013	5	2013	Mott MacDonald_TTRENT_BR8B_F0100_T0005_V01
82			1000	2013	5	2013	Mott MacDonald_TTRENT_BR8B_F1000_T0005_V01
83		BR8C	100	2013	5	2013	Mott MacDonald_TTRENT_BR8C_F0100_T0005_V01
84			1000	2013	5	2013	Mott MacDonald_TTRENT_BR8C_F1000_T0005_V01
85		BR8D	2	2013	200	2013	Mott MacDonald_TTRENT_BR8D_F0002_T0200_V01
86			2	2013	1000	2013	Mott MacDonald_TTRENT_BR8D_F0002_T1000_V01
87			100	2013	5	2013	Mott MacDonald_TTRENT_BR8D_F0100_T0005_V01
88			1000	2013	5	2013	Mott MacDonald_TTRENT_BR8D_F1000_T0005_V01
89		C	2	2013	200	2013	Mott MacDonald_TTRENT_C_F0002_T0200_V01
90			2	2013	1000	2013	Mott MacDonald_TTRENT_C_F0002_T1000_V01
91			100	2013	5	2013	Mott MacDonald_TTRENT_C_F0100_T0005_V01
92			1000	2013	5	2013	Mott MacDonald_TTRENT_C_F1000_T0005_V01
93		D	2	2013	200	2013	Mott MacDonald_TTRENT_D_F0002_T0200_V01
94			2	2013	1000	2013	Mott MacDonald_TTRENT_D_F0002_T1000_V01
95			100	2013	5	2013	Mott MacDonald_TTRENT_D_F0100_T0005_V01
96			1000	2013	5	2013	Mott MacDonald_TTRENT_D_F1000_T0005_V01
97		E	2	2013	200	2013	Mott MacDonald_TTRENT_E_F0002_T0200_V01
98			2	2013	1000	2013	Mott MacDonald_TTRENT_E_F0002_T1000_V01
99			100	2013	5	2013	Mott MacDonald_TTRENT_E_F0100_T0005_V01
100			1000	2013	5	2013	Mott MacDonald_TTRENT_E_F1000_T0005_V01
101		E1	2	2013	200	2013	Mott MacDonald_TTRENT_E1_F0002_T0200_V01
102			2	2013	1000	2013	Mott MacDonald_TTRENT_E1_F0002_T1000_V01
103			100	2013	5	2013	Mott MacDonald_TTRENT_E1_F0100_T0005_V01
104			1000	2013	5	2013	Mott MacDonald_TTRENT_E1_F1000_T0005_V01
105		F	2	2013	200	2013	Mott MacDonald_TTRENT_F_F0002_T0200_V01
106			2	2013	1000	2013	Mott MacDonald_TTRENT_F_F0002_T1000_V01
107			100	2013	5	2013	Mott MacDonald_TTRENT_F_F0100_T0005_V01
108			1000	2013	5	2013	Mott MacDonald_TTRENT_F_F1000_T0005_V01
109		I	2	2013	200	2013	Mott MacDonald_TTRENT_I_F0002_T0200_V01
110			2	2013	1000	2013	Mott MacDonald_TTRENT_I_F0002_T1000_V01
111			100	2013	5	2013	Mott MacDonald_TTRENT_I_F0100_T0005_V01
112			1000	2013	5	2013	Mott MacDonald_TTRENT_I_F1000_T0005_V01
113		J2	2	2013	200	2013	Mott MacDonald_TTRENT_J2_F0002_T0200_V01
114			2	2013	1000	2013	Mott MacDonald_TTRENT_J2_F0002_T1000_V01

ID	Model Build	Breach	Return Period (Fluvial)	Year	Return Period (Tidal)	Year	File Name
115			100	2013	5	2013	Mott MacDonald_TTRENT_J2_F0100_T0005_V01
116			1000	2013	5	2013	Mott MacDonald_TTRENT_J2_F1000_T0005_V01
117		K2	2	2013	200	2013	Mott MacDonald_TTRENT_K2_F0002_T0200_V01
118			2	2013	1000	2013	Mott MacDonald_TTRENT_K2_F0002_T1000_V01
119			100	2013	5	2013	Mott MacDonald_TTRENT_K2_F0100_T0005_V01
120			1000	2013	5	2013	Mott MacDonald_TTRENT_K2_F1000_T0005_V01
121		L	2	2013	200	2013	Mott MacDonald_TTRENT_L_F0002_T0200_V01
122			2	2013	1000	2013	Mott MacDonald_TTRENT_L_F0002_T1000_V01
123			100	2013	5	2013	Mott MacDonald_TTRENT_L_F0100_T0005_V01
124			1000	2013	5	2013	Mott MacDonald_TTRENT_L_F1000_T0005_V01
125		Q	2	2013	200	2013	Mott MacDonald_TTRENT_Q_F0002_T0200_V01
126			2	2013	1000	2013	Mott MacDonald_TTRENT_Q_F0002_T1000_V01
127			100	2013	5	2013	Mott MacDonald_TTRENT_Q_F0100_T0005_V01
128			1000	2013	5	2013	Mott MacDonald_TTRENT_Q_F1000_T0005_V01
129		R	2	2013	200	2013	Mott MacDonald_TTRENT_R_F0002_T0200_V01
130			2	2013	1000	2013	Mott MacDonald_TTRENT_R_F0002_T1000_V01
131			100	2013	5	2013	Mott MacDonald_TTRENT_R_F0100_T0005_V01
132			1000	2013	5	2013	Mott MacDonald_TTRENT_R_F1000_T0005_V01
133		S	2	2013	200	2013	Mott MacDonald_TTRENT_S_F0002_T0200_V01
134			2	2013	1000	2013	Mott MacDonald_TTRENT_S_F0002_T1000_V01
135			100	2013	5	2013	Mott MacDonald_TTRENT_S_F0100_T0005_V01
136			1000	2013	5	2013	Mott MacDonald_TTRENT_S_F1000_T0005_V01
137		T	2	2013	200	2013	Mott MacDonald_TTRENT_T_F0002_T0200_V01
138			2	2013	1000	2013	Mott MacDonald_TTRENT_T_F0002_T1000_V01
139			100	2013	5	2013	Mott MacDonald_TTRENT_T_F0100_T0005_V01
140			1000	2013	5	2013	Mott MacDonald_TTRENT_T_F1000_T0005_V01
141	Sensitivity Test	N/A	100	2013	5	2013	Mott MacDonald TTRENT F0100 T0005 MANN M20 V17
142			100	2013	5	2013	Mott MacDonald TTRENT F0100 T0005 MANN P20 V17

The design model has been run to simulate a full fluvial event lasting for 120 hours. The outputs from the model have been used to produce flood levels and maps provided in Appendix H.

7.2 Results of Defended Scenarios

Figure 7.1 shows the maximum flood extents for key fluvial return periods specified under the defended scenario.

Figure 7.2 shows the maximum flood for key tidal return periods specified under the defended scenario.

A full set of modelled water levels and flood depth, velocity and hazard maps for the defended scenario is provided in the accompanying digital data on a hard drive.

Figure 7.1: Model Predicted Maximum Flood Extents for Fluvial Return Periods – Present Day

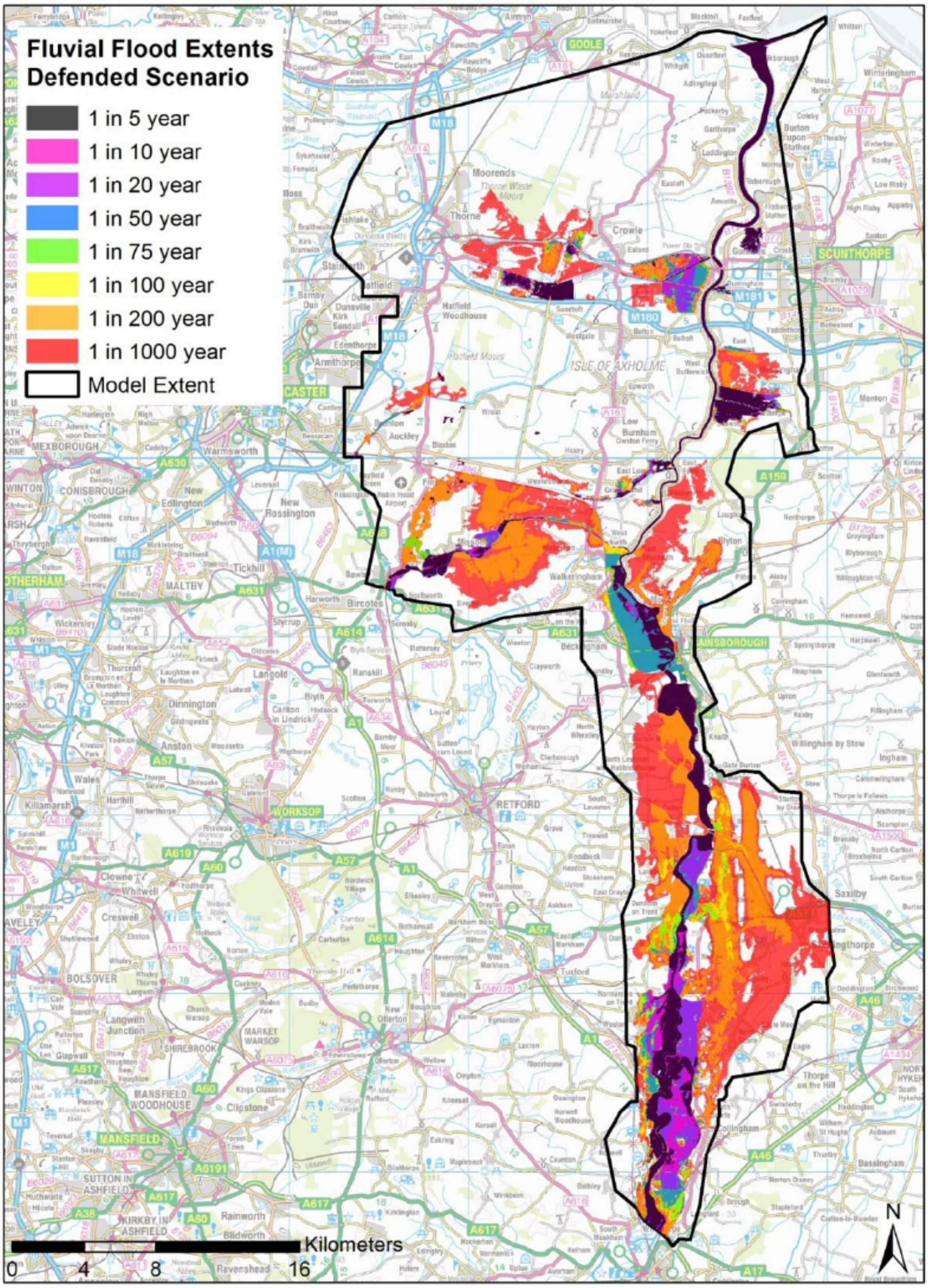

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Figure 7.2: Model PredictedMaximum Flood Extents for Tidal Return Periods – Present Day

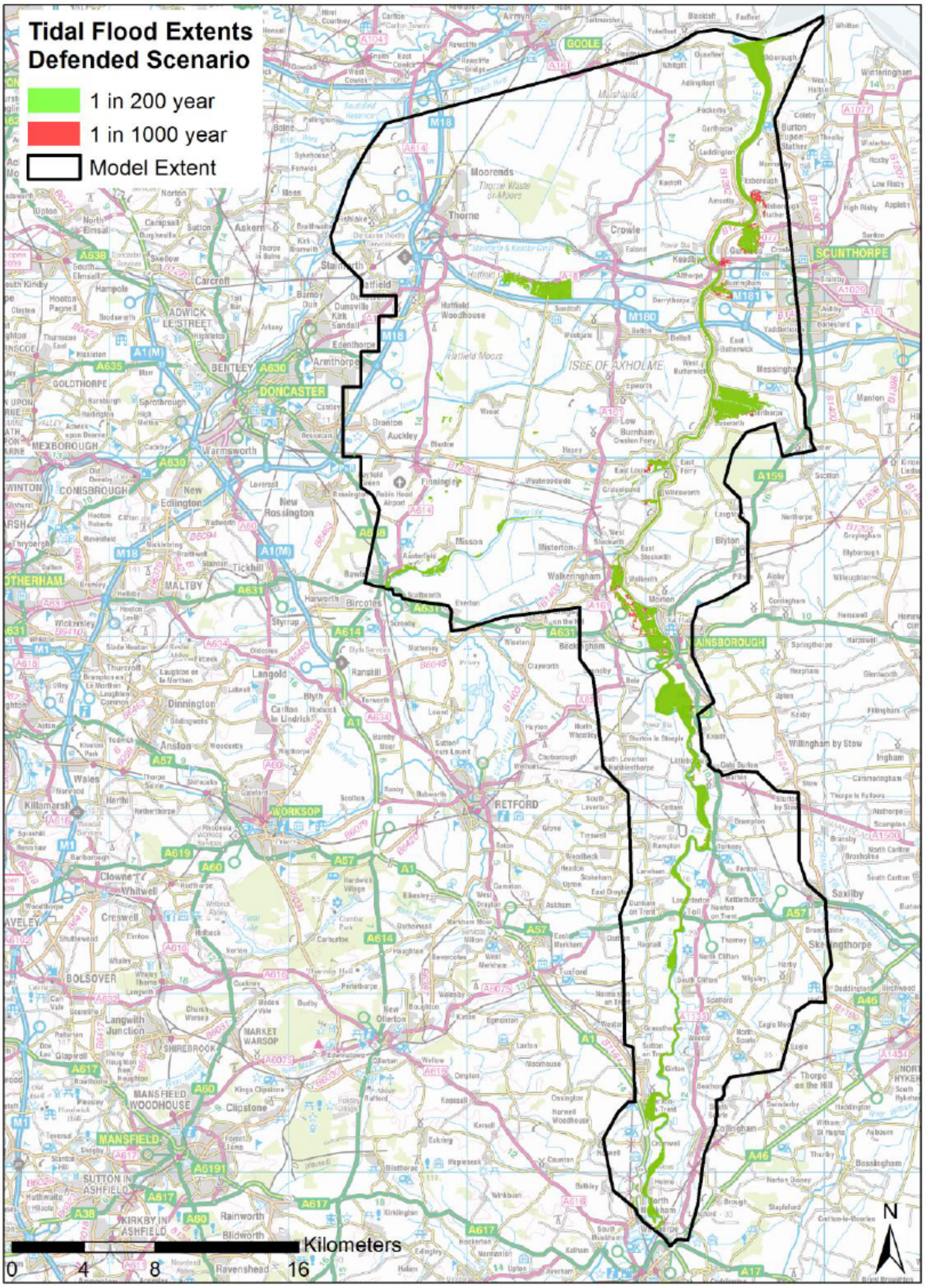

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Table 7.2 summarises the key areas at risk of flooding from fluvial sources for the defended scenario, and the flood depths and velocities associated with each area.

7.2.1 Results for Defended Scenario with Climate Change

The 1 in 100 year fluvial flood event with climate change conditions - 2113 (Figure 7.3) shows an increased flood extent over the present day scenario particularly:

- between South Clifton and Marton, extending east towards Saxilby and Lincoln;
- East of Littleborough;
- Northern edge of Gainsborough, extending north to East Stockwith.

The 1 in 200 year tidal flood event with climate change conditions - 2100 Change Factor (Figure 7.4) show an increased flood extent over the present day scenario particularly:

- Beckingham Marshes;
- Flixborough and Flixborough Stather.

The 1 in 200 year tidal flood event using the Upper End Estimate for sea level rise shows considerably larger flood extents extending from Trent Falls to the M180. In addition, there is increased flooding in Beckingham Marshes.

During the closing stages of this study on Thursday 5th December 2013, tidal flooding was experienced in communities downstream of the M180, with the level at Keadby reaching just over 6.2metres. This level is greater than that predicted by the model for the 1 in 1000 year tidal event, and therefore we would recommend, if budget allows, that the downstream tidal boundary hydrology is reassessed following the tidal surge event.

7.3 Results for Undefended Scenarios

The model results for the fluvial undefended scenarios (Figure 7.5) show extensive flooding throughout the modelled reach. The 100 year and 1000 year extents are fairly similar. A notable dry island is the Isle of Axholme. The railway line linking Doncaster with Goole is a significant barrier to flow in the north-west of the study area, however, during such a significant event, the west side of the railway is likely to be inundated by the River Don.

The flood extent reaches the model boundary near the River Ouse and at Saxilby on the Foss Dyke canal. The water has been allowed glass-wall here under the assumption that flood waters from neighbouring catchments would have similar levels at the boundary of the 2D domain.

The model results for the tidal undefended scenarios (Figure 7.6) show similar flood extents as those for the fluvial undefended scenario downstream of Gainsborough. Upstream of Gainsborough where the tidal influence is less significant, the flood extents are smaller. Once again, the 1 in 200 and 1 in 1000 year flood extents are very similar.

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Table 7.2: Summary of Current Fluvial Flood Risk with Defences in Place

Location	Return Period 1 in 5	1in 10	1in 20	1 in 50	1 in 75	1 in 100	1 in 200	1 in 1000
North Muskham	N/A	N/A	N/A	N/A	Depth:0.27 mAOD Velocity:0.016 m^2/s	Depth: 0.37 mAOD Velocity:0.021 m^2/s	Depth:0.61 mAOD Velocity: 0.11 m^2/s	Depth:1.00 mAOD Velocity:0.27 m^2/s
					Small amount of flooding in village and on right bank, flooding extending over railway line		Flooding up to the A1 on left bank and flooding extending over railway line to Winthorpe on right bank	
Cromwell	Depth:1.08 mAOD Velocity:0.20 m^2/s	Depth:1.16 mAOD Velocity:0.26 m^2/s	Depth:1.23 mAOD Velocity:0.30 m^2/s	Depth:1.41 mAOD Velocity:0.32 m^2/s	Depth:1.54 mAOD Velocity:0.32 m^2/s	Depth:1.63 mAOD Velocity:0.26 m^2/s	Depth:1.87 mAOD Velocity:0.14 m^2/s	Depth:2.31 mAOD Velocity:0.14 m^2/s
	Left bank of Cromwell Weir	Left bank of Cromwell Weir and on Right Bank up to Collingham						
Carlton-on-Trent	Depth:0.37 mAOD Velocity:0.03 m^2/s	Depth:0.43 mAOD Velocity:0.03 m^2/s	Depth:0.49 mAOD Velocity:0.04 m^2/s	Depth:0.68 mAOD Velocity:0.06 m^2/s	Depth:0.82 mAOD Velocity:0.07 m^2/s	Depth:0.93 mAOD Velocity:0.07 m^2/s	Depth:1.18 mAOD Velocity:0.08 m^2/s	Depth:1.59 mAOD Velocity:0.12 m^2/s
	No properties flooded			Possibility of some properties flooding			Village flooded	
Girton	Depth:1.01 mAOD Velocity: 0.07 m^2/s	Depth:1.49 mAOD Velocity:0.12 m^2/s	Depth:2.79 mAOD Velocity:0.15 m^2/s	Depth:3.23 mAOD Velocity:0.22 m^2/s	Depth:3.43 mAOD Velocity:0.23 m^2/s	Depth:3.55 mAOD Velocity:0.22 m^2/s	Depth:3.85 mAOD Velocity:0.25 m^2/s	Depth:4.24 mAOD Velocity: 0.32 m^2/s
	Flooding on both sides of the village		Flooding on both sides of the village and up to A1133 north to South Clifton	Village flooded and flooding extending over the A1133				Village flooded and flooding extending over the A1133 to North Scarle
Sutton on Trent	N/A	Depth:0.67 mAOD Velocity:0.04 m^2/s	Depth:0.86 mAOD Velocity: 0.06 m^2/s	Depth:1.29 mAOD Velocity:0.07 m^2/s	Depth:1.49 mAOD Velocity:0.08 m^2/s	Depth:1.61 mAOD Velocity:0.08 m^2/s	Depth:1.90 mAOD Velocity:0.08 m^2/s	Depth:2.3 mAOD Velocity: 0.11 m^2/s
		Flooding up to eastern edge of village		Flooding of Village and to the south		Flooding of Village and to the north and south		
Low Marnham	N/A	Depth:1.51 mAOD Velocity:0.12 m^2/s	Depth:1.66 mAOD Velocity:0.15 m^2/s	Depth:2.03 mAOD Velocity:0.17 m^2/s	Depth:2.24 mAOD Velocity:0.17 m^2/s	Depth:2.36 mAOD Velocity:0.18 m^2/s	Depth:2.67 mAOD Velocity:0.18 m^2/s	Depth:3.06 mAOD Velocity:0.18 m^2/s
		Flooding on either side of Low Marnham, village on raised ground		Village flooded				
South Clifton	N/A	N/A	N/A	N/A	N/A	N/A	Depth:1.58 mAOD Velocity:0.21 m^2/s	Depth:1.86 mAOD Velocity:0.36 m^2/s
							Village flooded	Village flooded and flooding continuing eastwards to Harby
North Clifton	Depth:0.19 mAOD Velocity: 0.02 m^2/s	Depth:0.27 mAOD Velocity:0.08 m^2/s	Depth:1.71 mAOD Velocity:0.1 m^2/s	Depth:2.13 mAOD Velocity:0.25 m^2/s	Depth:2.31 mAOD Velocity:0.29 m^2/s	Depth:2.45 mAOD Velocity:0.34 m^2/s	Depth:2.66 mAOD Velocity:0.42 m^2/s	Depth:2.88 mAOD Velocity:0.39 m^2/s
	Flooded up to western limit of village					Village flooded		
Dunham on Trent	N/A	N/A	N/A	Depth:1.553 mAOD Velocity:0.62 m^2/s	Depth:1.78 mAOD Velocity:0.72 m^2/s	Depth:1.92 mAOD Velocity:0.77 m^2/s	Depth:2.25 mAOD Velocity:0.92 m^2/s	Depth:2.44 mAOD Velocity: 1.19 m^2/s
				Road to east of Dunham Bridge flooded	Flooding to south of A57 on left bank, and road flooded to east of Dunham Bridge		Village flooded up to Flears Farm on left bank, and road flooded to east of Dunham Bridge	Village flooded up to Flears Farm on left bank, and road flooded to east to Saxilby
Newton on Trent	N/A	N/A	N/A	N/A	N/A	Depth:0.03 mAOD Velocity:0.001 m^2/s	Depth:0.29 mAOD Velocity:0.03 m^2/s	Depth: 1.21 mAOD Velocity: 0.15 m^2/s
						Flooding of A113 north of village	Flooding of A113 north of village and extensive flooding behind village	Flooding of A113 north of village and extensive flooding behind village towards Lincoln
Torksey Lock	N/A	N/A	Depth:0.91 mAOD Velocity:0.04 m^2/s	Depth:3.85 mAOD Velocity: 0.1 m^2/s	Depth:4.06 mAOD Velocity:0.11 m^2/s	Depth:4.17 mAOD Velocity: 0.12 m^2/s	Depth:4.48 mAOD Velocity:0.23 m^2/s	Depth:4.65 mAOD Velocity:0.30 m^2/s
			Flooding of farmland to the south of Torksey Lock				Flooding of Torksey, Torksey Lock, The Elms and on either side of Fossdyke Canal up to Thorney	Flooding of Torksey, Torksey Lock, The Elms and on either side of Fossdyke Canal up to Lincoln
Church Laneham	N/A	N/A	N/A	N/A	N/A	N/A	Depth:0.22 mAOD Velocity:0.12 m^2/s	Depth:1.75 mAOD Velocity:0.26 m^2/s
							Flooding of village and farmland to the north extending to and including Cottam Power Station, Cottam, and Rampton extending to Cottam Power Station	Flooding of village and farmland to the north extending to and including Cottam Power Station, Cottam, and Rampton

Location	Return Period							
	1 in 5	1in 10	1in 20	1 in 50	1 in 75	1 in 100	1 in 200	1 in 1000
Lea Marsh	Depth:0.21 mAOD Velocity:0.01 m^2/s	Depth:0.47 mAOD Velocity:0.06 m^2/s	Depth: 0.73 mAOD Velocity:0.07 m^2/s	Depth:1.23 mAOD Velocity:0.07 m^2/s	Depth: 1.36 mAOD Velocity:0.09 m^2/s	Depth: 1.52 mAOD Velocity:0.09 m^2/s	Depth: 1.84 mAOD Velocity:0.11 m^2/s	Depth: 2.01 mAOD Velocity:0.12 m^2/s
	Flooded up to high-ground to west of Lea Village						Up to high-ground to west of Lea Village and farmland on left bank towards Littleborough	Up to high-ground to west of Lea Village and farmland on left bank towards as far as Cottam Power Station, and extending westwards to North Leverton, Sturton Le Steeple and West Burton Power Station
Gainsborough Rail Station	N/A	N/A	N/A	Depth: 1.62 mAOD Velocity:0.015 m^2/s	Depth:1.87 mAOD Velocity:0.016 m^2/s	Depth:2.07 mAOD Velocity:0.016 m^2/s	Depth:2.40 mAOD Velocity:0.019 m^2/s	Depth:2.5 mAOD Velocity:0.019 m^2/s
				Flooding to the west of rail station		Flooding to the west and south of Rail Station		
Gainsborough	N/A	N/A	N/A	N/A	N/A	Depth: 0.92 mAOD Velocity:0.068 m^2/s	Depth: 1.98 mAOD Velocity:0.076 m^2/s	Depth: 2.27 mAOD Velocity:0.16 m^2/s
						Flooding near allotment gardens	Extensive flooding of properties to the west of A159	
Beckingham Marshes	Depth:0.23 mAOD Velocity:0.25 m^2/s	Depth:0.24 mAOD Velocity:0.26 m^2/s	Depth:0.25 mAOD Velocity:0.28 m^2/s	Depth:2.36 mAOD Velocity:0.23 m^2/s	Depth:3.19 mAOD Velocity:0.1 m^2/s	Depth:3.45 mAOD Velocity:0.23 m^2/s	Depth:3.8 mAOD Velocity:0.14 m^2/s	Depth:3.9 mAOD Velocity:0.17 m^2/s
	Flooding extends 700m westwards from river			Flooding extends 1800m westwards from river	Flooding extends 2000m westwards from river			
Walkeringham	N/A	N/A	N/A	N/A	N/A	Depth:0.38 mAOD Velocity:0.01 m^2/s	Depth:1.03 mAOD Velocity:0.14 m^2/s	Depth:1.14 mAOD Velocity:0.24 m^2/s
						Flooding overtopping railway embankment. Some houses on Marsh Road affected		
West Stockwith	N/A	N/A	N/A	N/A	N/A	Depth: 0.29 mAOD Velocity:0.02 m^2/s	Depth:2.02 mAOD Velocity:0.06 m^2/s	Depth:2.27 mAOD Velocity:0.09 m^2/s
						Flooding from River Idle – no properties affected		
East Stockwith	N/A	N/A	N/A	N/A	N/A	N/A	Depth:0.044 mAOD Velocity:0.01 m^2/s	Depth:0.077 mAOD Velocity:0.02 m^2/s
							Flooding of farmland behind East Stockwith downstream as far as Wildsworth	
Owston Ferry	Depth:0.21 mAOD Velocity:0.39 m^2/s	Depth:0.21 mAOD Velocity:0.39 m^2/s	Depth: 0.22mAOD Velocity:0.41 m^2/s	Depth:0.28 mAOD Velocity:0.55 m^2/s	Depth:0.28 mAOD Velocity:0.54 m^2/s	Depth:0.28 mAOD Velocity:0.53 m^2/s	Depth:0.3 mAOD Velocity:0.61 m^2/s	Depth:0.31 mAOD Velocity:0.62 m^2/s
	Flooding from Ferry Drain							
River Eau	Depth:0.015 mAOD Velocity: .001 m^2/s	Depth:0.096 mAOD Velocity: 0.01 m^2/s	Depth: 0.24 mAOD Velocity:0.04 m^2/s	Depth: 0.48 mAOD Velocity:0.05 m^2/s	Depth:0.6 mAOD Velocity:0.03 m^2/s	Depth:0.67 mAOD Velocity:0.03 m^2/s	Depth:0.86 mAOD Velocity:0.04 m^2/s	Depth:0.98 mAOD Velocity:0.03 m^2/s
	Flooding on either side of River Eau							Flooding on either side of River Eau, and extending downstream to Bottesford Beck
Keadby	N/A	N/A	Depth:0.32 mAOD Velocity:0.24 m^2/s	Depth:0.84 mAOD Velocity:0.33 m^2/s	Depth:1.37 mAOD Velocity:0.36 m^2/s	Depth:1.5 mAOD Velocity:0.33 m^2/s	Depth:1.7 mAOD Velocity:0.39 m^2/s	Depth:2 mAOD Velocity: 0.41 m^2/s
			Flooding of farmland from Three Rivers					
Burringham	Depth:0.1 mAOD Velocity:0.09 m^2/s	Depth:0.11 mAOD Velocity:0.08 m^2/s	Depth:0.11 mAOD Velocity:0.1 m^2/s	Depth:0.17 mAOD Velocity:0.13 m^2/s	Depth:0.17 mAOD Velocity:0.13 m^2/s	Depth:0.17 mAOD Velocity:0.13 m^2/s	Depth:0.17 mAOD Velocity:0.14 m^2/s	Depth:0.17 mAOD Velocity:0.13 m^2/s
	Flooding of part of village							

Source: Mott MacDonald

Hazard Catagories:

- Low
- Medium
- High
- Extreme

Figure 7.3: Maximum Flood Extents for Fluvial Return Periods – 100yr Event With and Without Climate Change

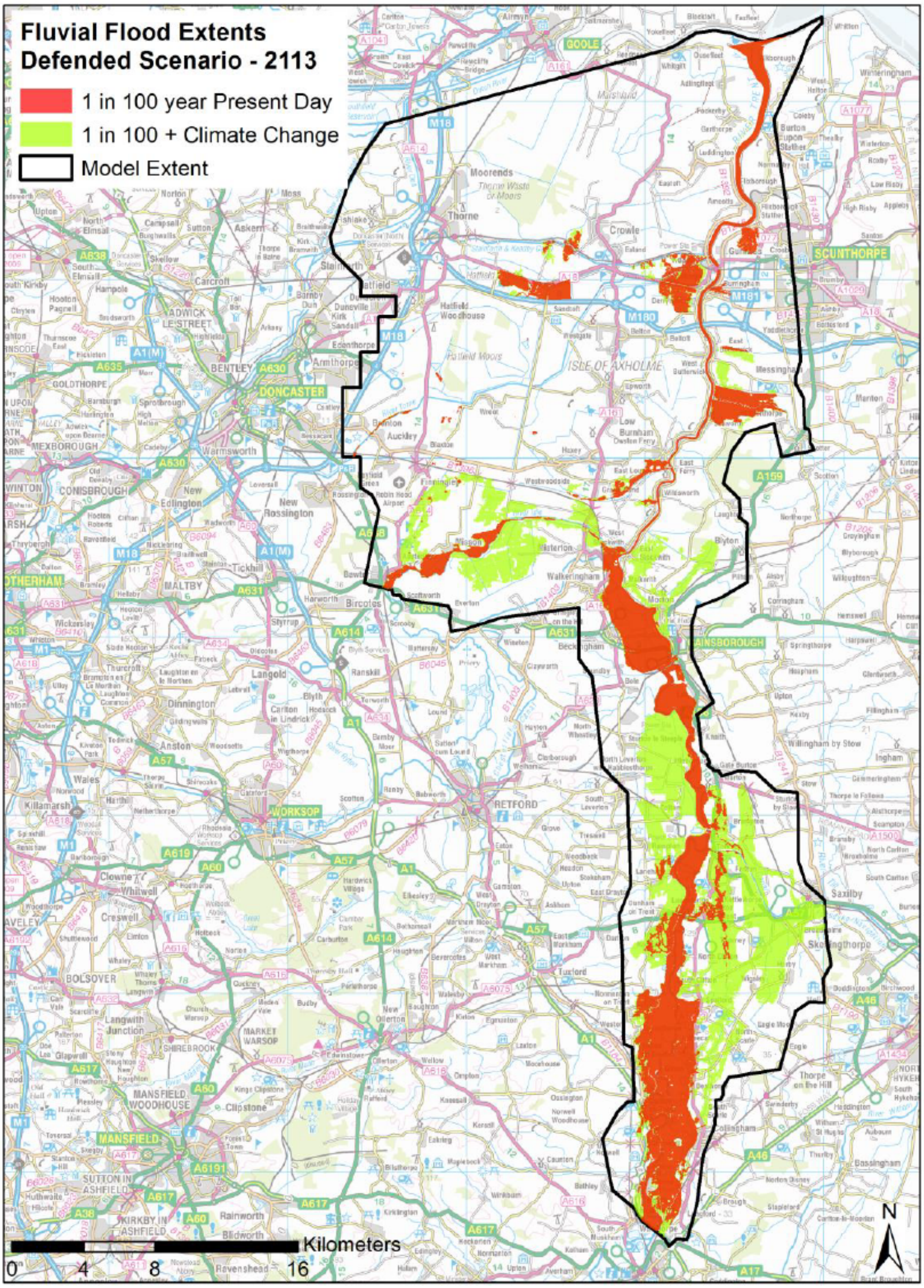

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Figure 7.4: Maximum Flood Extents for Tidal Return Periods – 200yr Event With and Without Climate Change

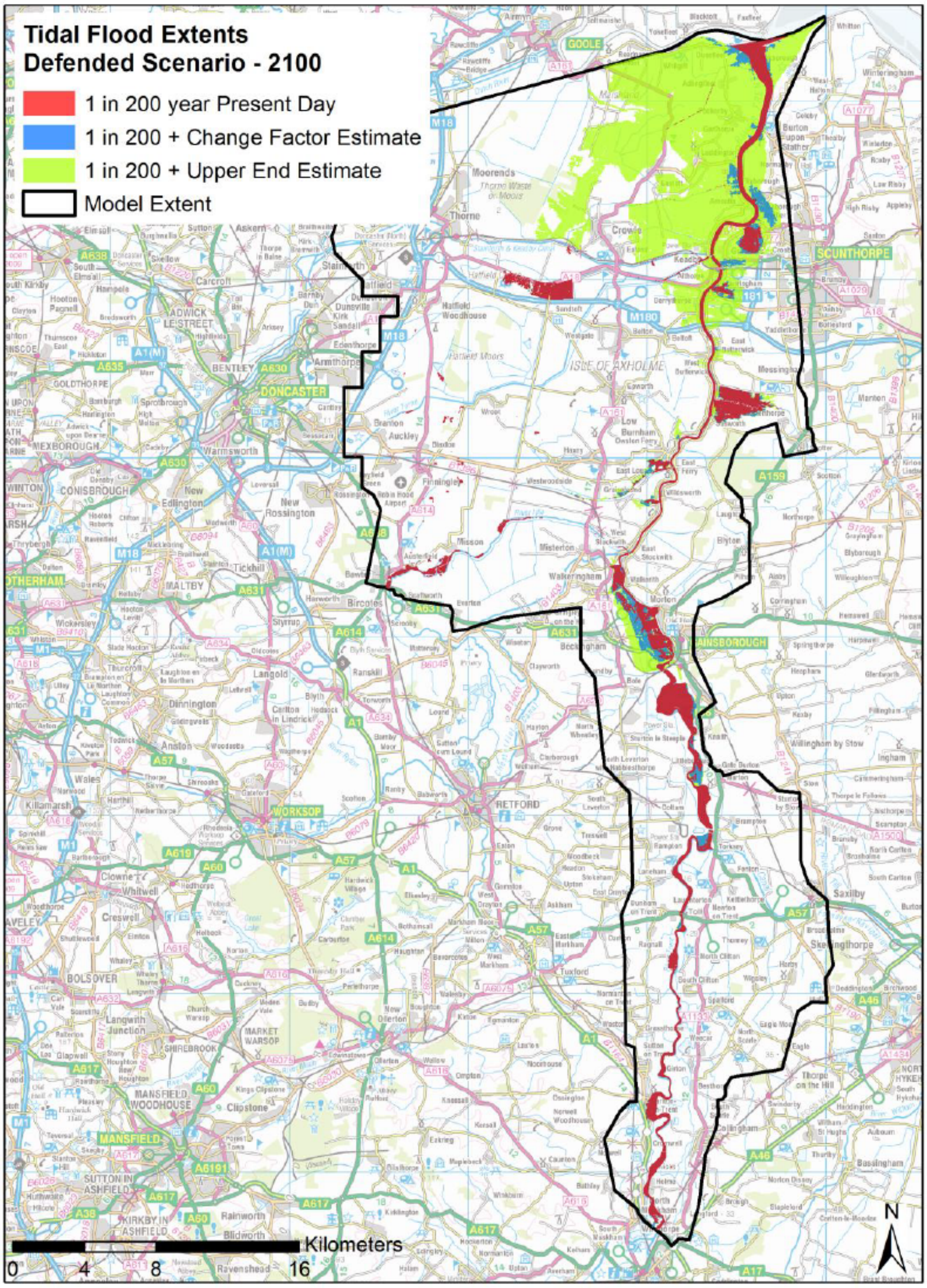

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Figure 7.5: Maximum Flood Extents for Fluvial Undefended Scenario – 100yr Event, Present Day

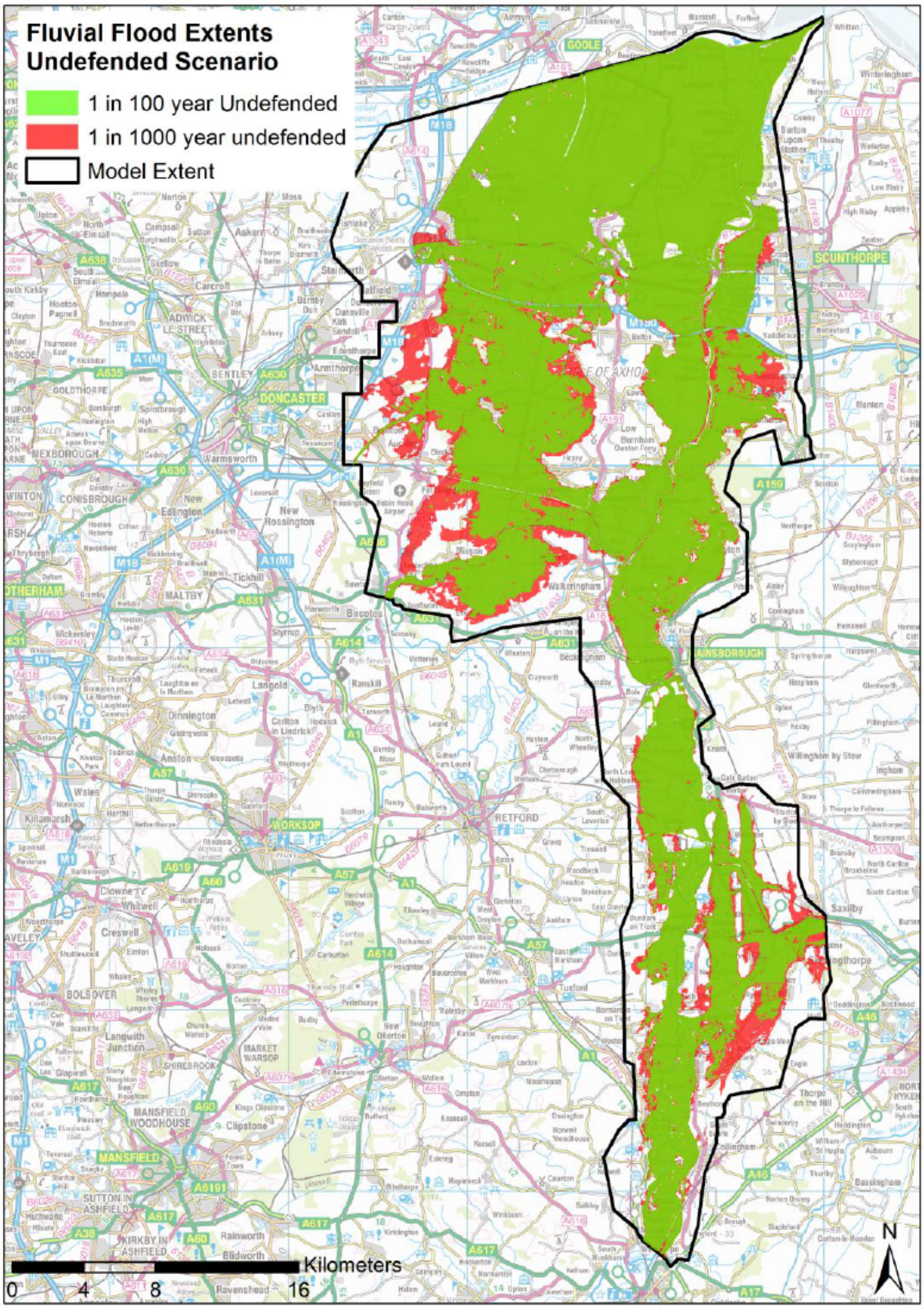

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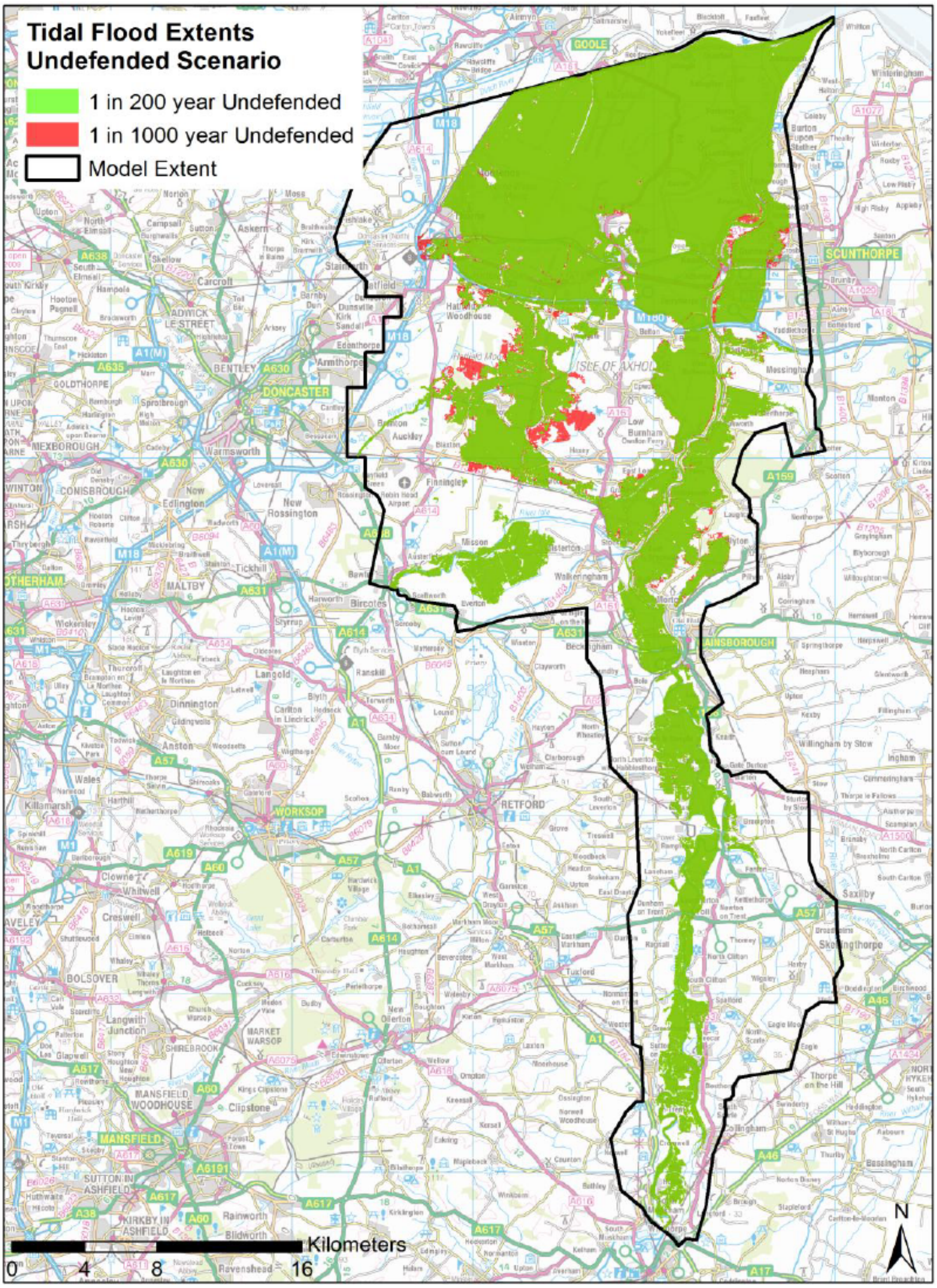
Figure 7.6: Maximum Flood Extents for Tidal Undefended Scenario – 200yr Event, Present Day



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7.4 Results from Breach Analysis

Maximum flood depth, velocity and hazard maps have been provided for each breach run, along with depth progression maps showing the progression of each breach. Breach Origin Maps, showing which breaches have the largest impact on an area, are provided in Figure 7.7 to Figure 7.10. These maps are useful for identifying key locations for prioritising future maintenance of defences and future investment.

For the 1 in 100 year fluvial event, the key breach locations are:

- Breach 12b at Torksey flooding south towards Newton on Trent, Saxilby and North and South Clifton;
- Breach 3 on the left bank of the river flooding Dunham on Trent, Laneham and Rampton;
- Breach 6a on the left bank flooding Littleborough;
- Breach A3 at Gainsborough flooding parts of the river frontage;
- Breach A1 North of Gainsborough flooding Morton, Walkerith, East Stockwith and Wildsworth;
- Breach I at West Stockwith;
- Breach R on left bank at West Butterwick;
- Breach F on the right bank at Burringham;
- Breach S on the left bank at Keadby.

For the 1 in 1000 year fluvial event, the key breach locations are:

- Breach 13a flooding to the east from Torksey Lock to Saxilby;
- Breach 3 flooding the left bank from Dunham on Trent to Gainsborough;
- Breach I flooding the left bank from West Stockwith to Owston Ferry;
- Breach A1 flooding the right bank from Gainsborough to East Butterwick.

For the tidal events, the effect of the breaches is more localised with the exception of Breach B, which floods from Gainsborough to East Ferry (7.5km) for both the 1 in 200 and 1 in 1000 year scenarios.

Figure 7.7: Breach Origin Map for 1 in 100 Year Fluvial Event

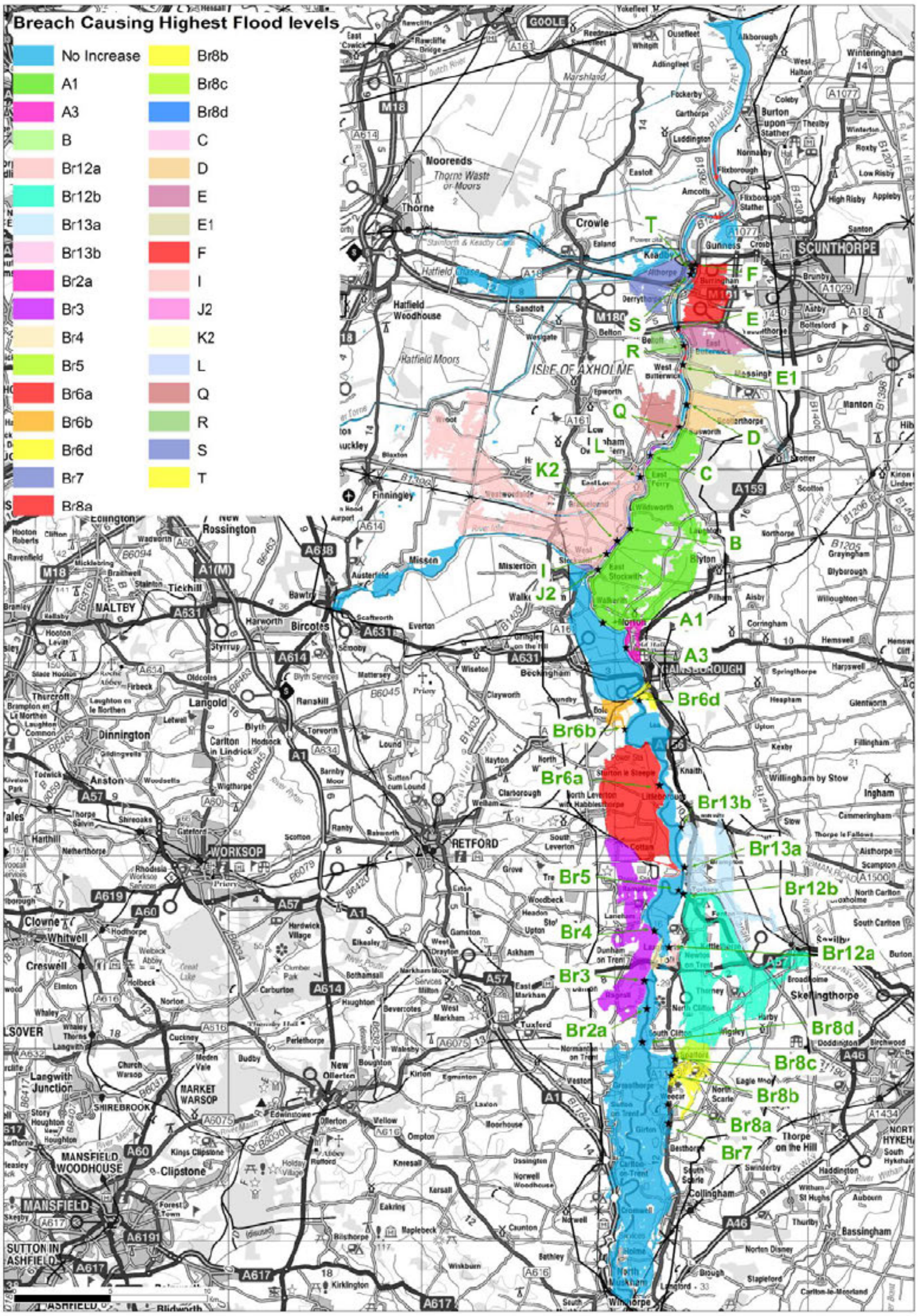

Figure 7.8: Breach Origin Map for 1 in 1000 Year Fluvial Event

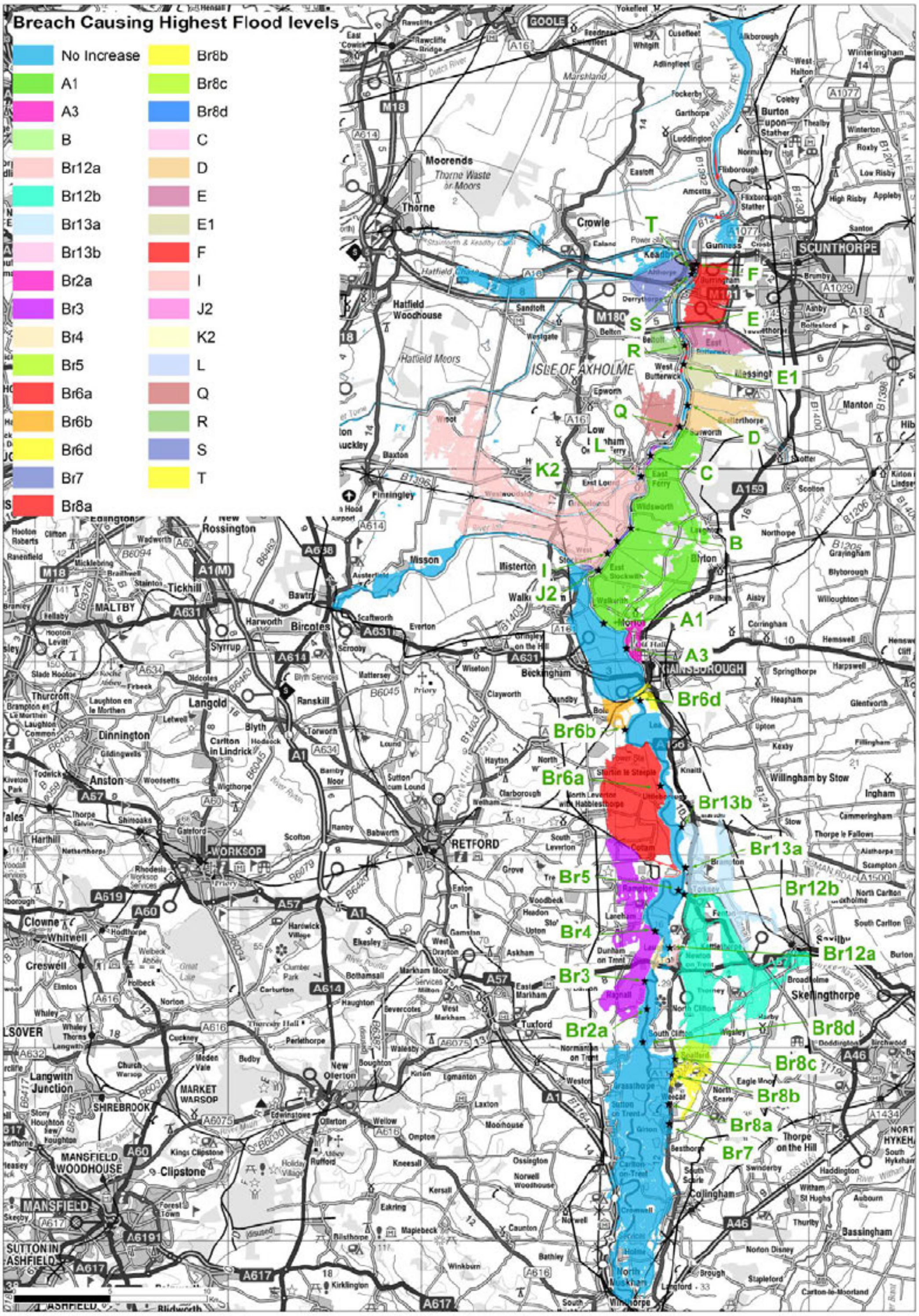

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Figure 7.9: Breach Origin Map for 1 in 200 Year Tidal Event

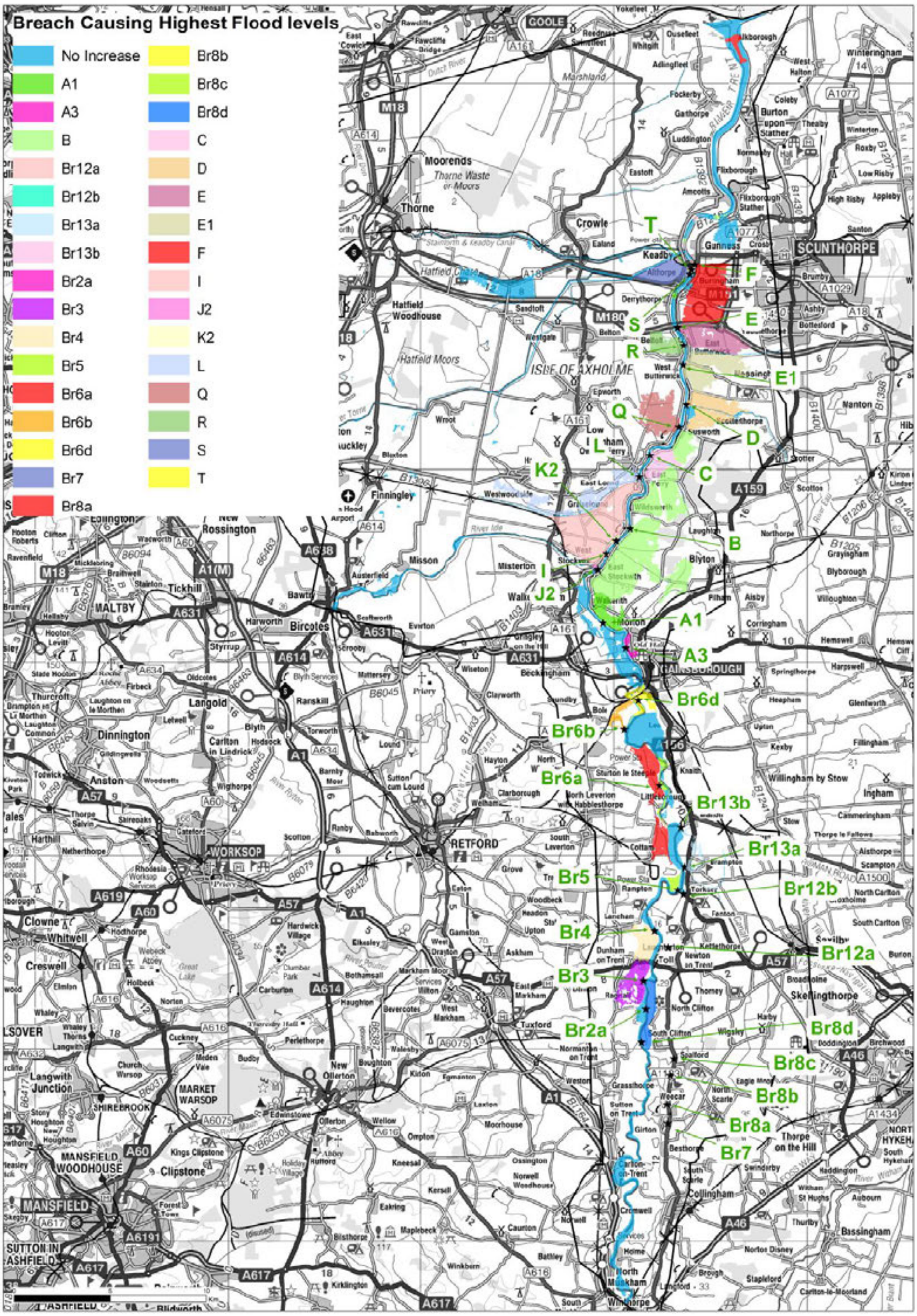
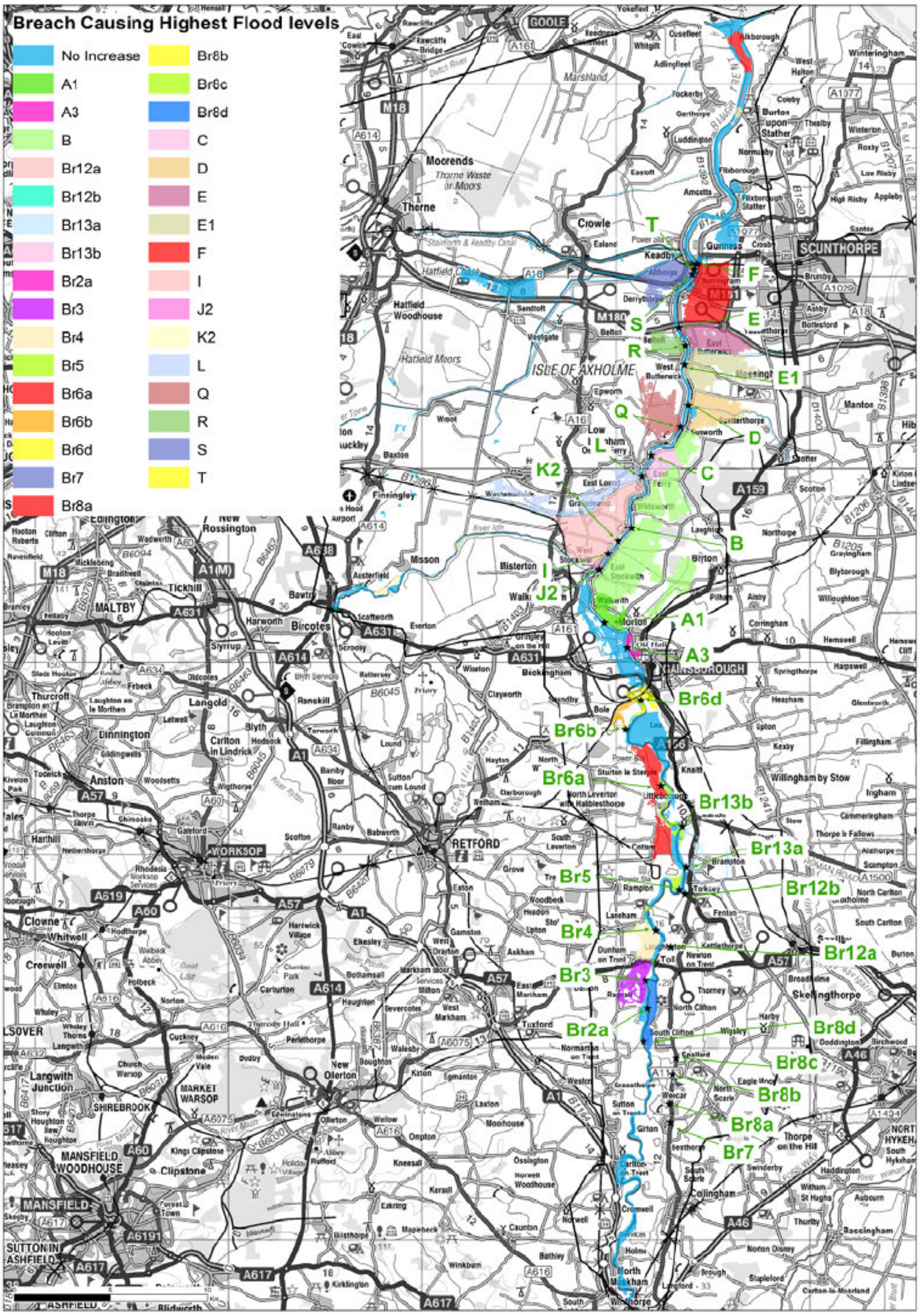


Figure 7.10: Breach Origin Map for 1 in 1000 Year Tidal Event



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7.5 Areas Benefiting from Defences

The modelled flood extents for the defended and undefended scenarios for both tidal and fluvial runs were compared so as to identify Areas Benefiting from Defences (ABDs). ABDs are classified as areas that become inundated during the 'undefended' scenarios, but remain dry during the 'defended' scenarios. For the tidal scenarios the 1 in 200 year event was used to create the ABDs, and for the fluvial scenarios the 1 in 100 year event was used. Figure 7.11 shows the ABD for the 1 in 100 year fluvial event and Figure 7.12 the ABD for the 1 in 200 year tidal event.

The defences protect a vast amount of land along the Tidal Trent (435km^2 for the 1 in 100 year fluvial event and 360km^2 for the 1 in 200 year tidal event). The land in both cases consists of the majority of the low-lying land within the catchment.

The 1 in 10 year fluvial event with the minor defences removed has also been compared with the baseline 1 in 10 year event and the results provided in Figure 7.13.

One key observation can be made from the model test runs that the defences protect a fairly large area on the right bank between North Muskham and Torksey Lock, and on the left bank near Cottam and Littleborough, and reduce flooding of the Beckingham Marshes. It is recommended that, if budget allows the benefit of these minor defences should also be tested for a smaller and larger return period (say 1 in 5 and 1 in 20) to determine the level of benefit they provide over a range of events.

Figure 7.11: Area Benefiting from Defences in Fluvial 1 in 100 Year Event

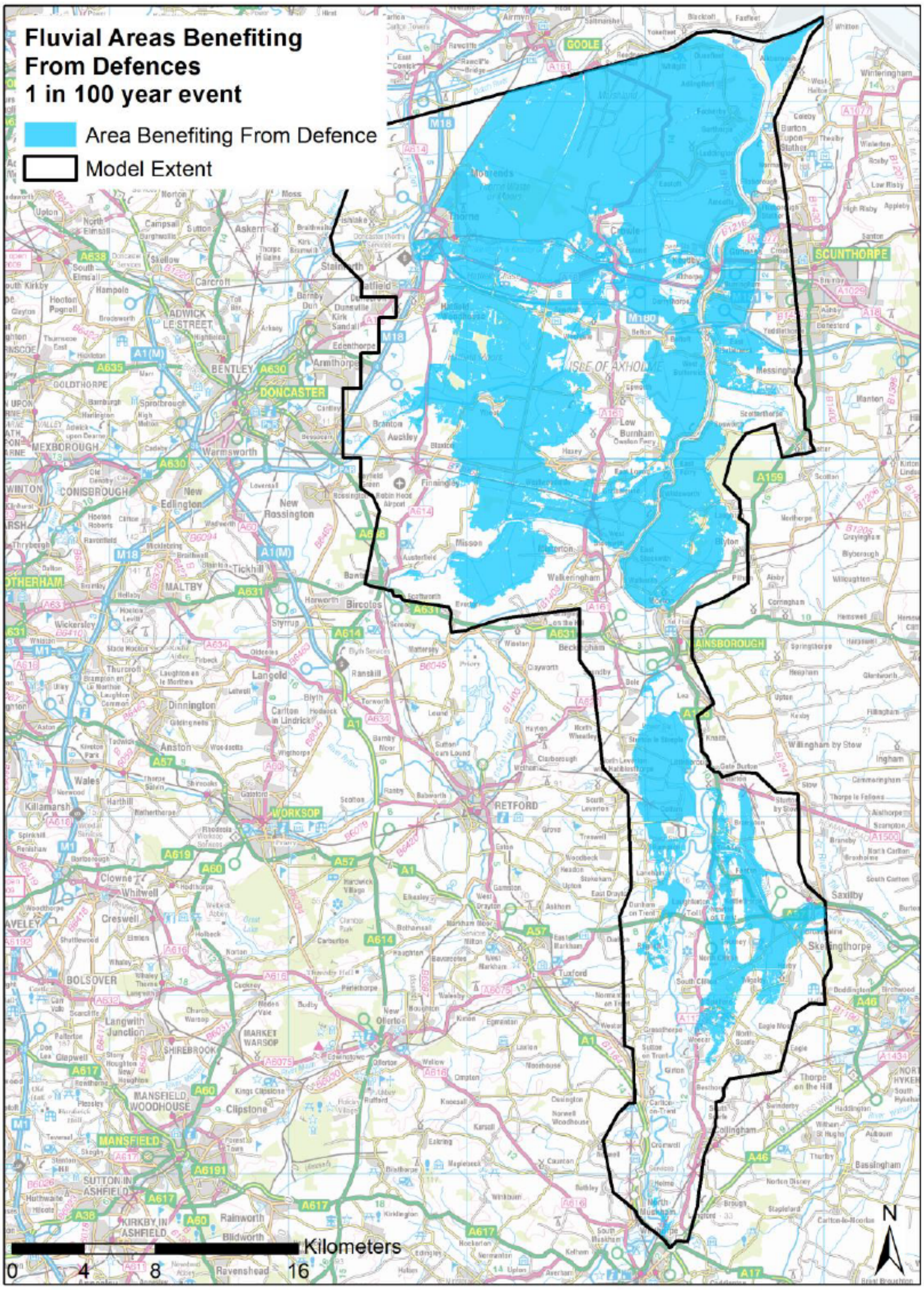

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Figure 7.12: Area Benefiting from Defences in Tidal 1 in 200 Year Event

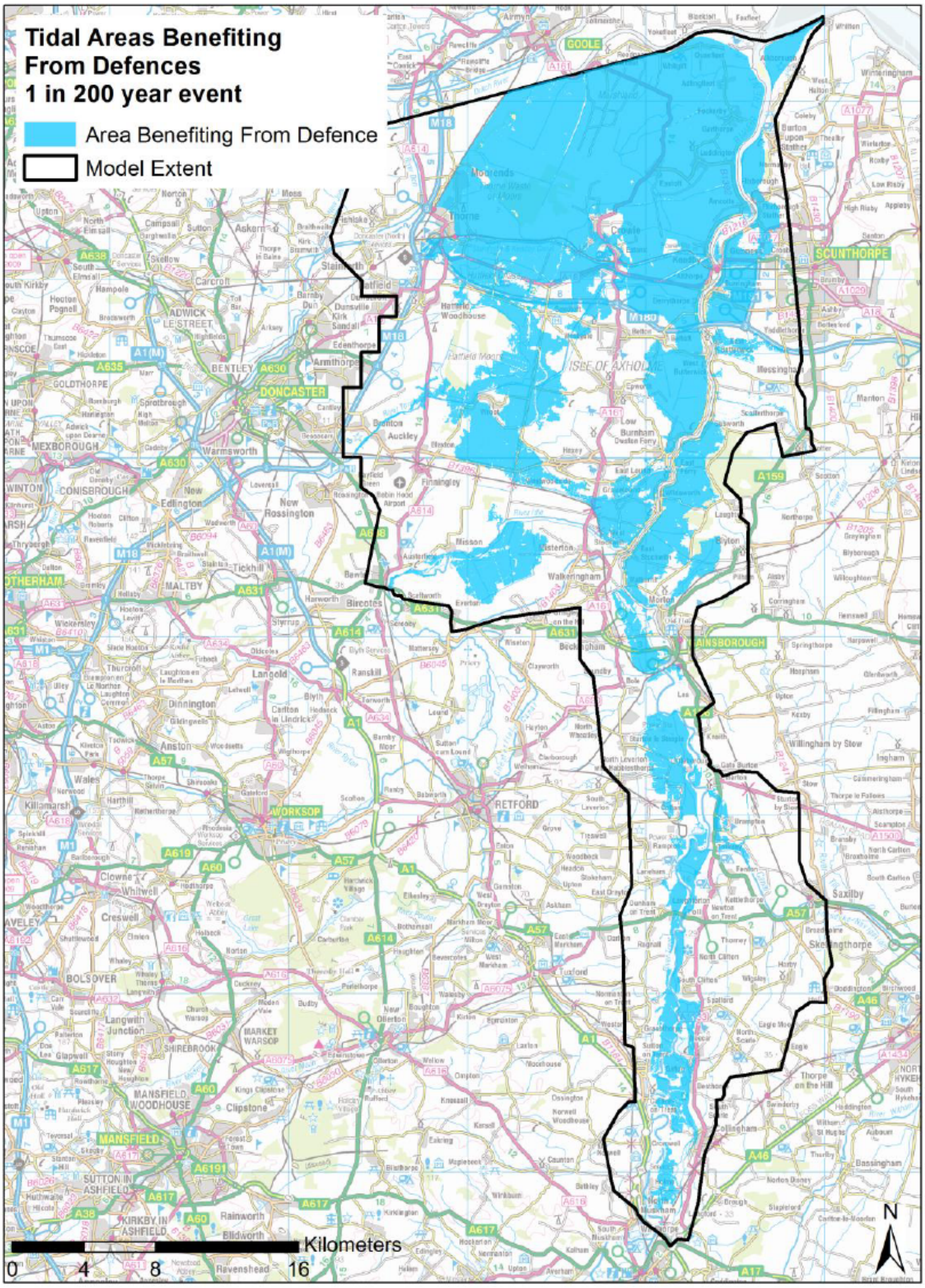

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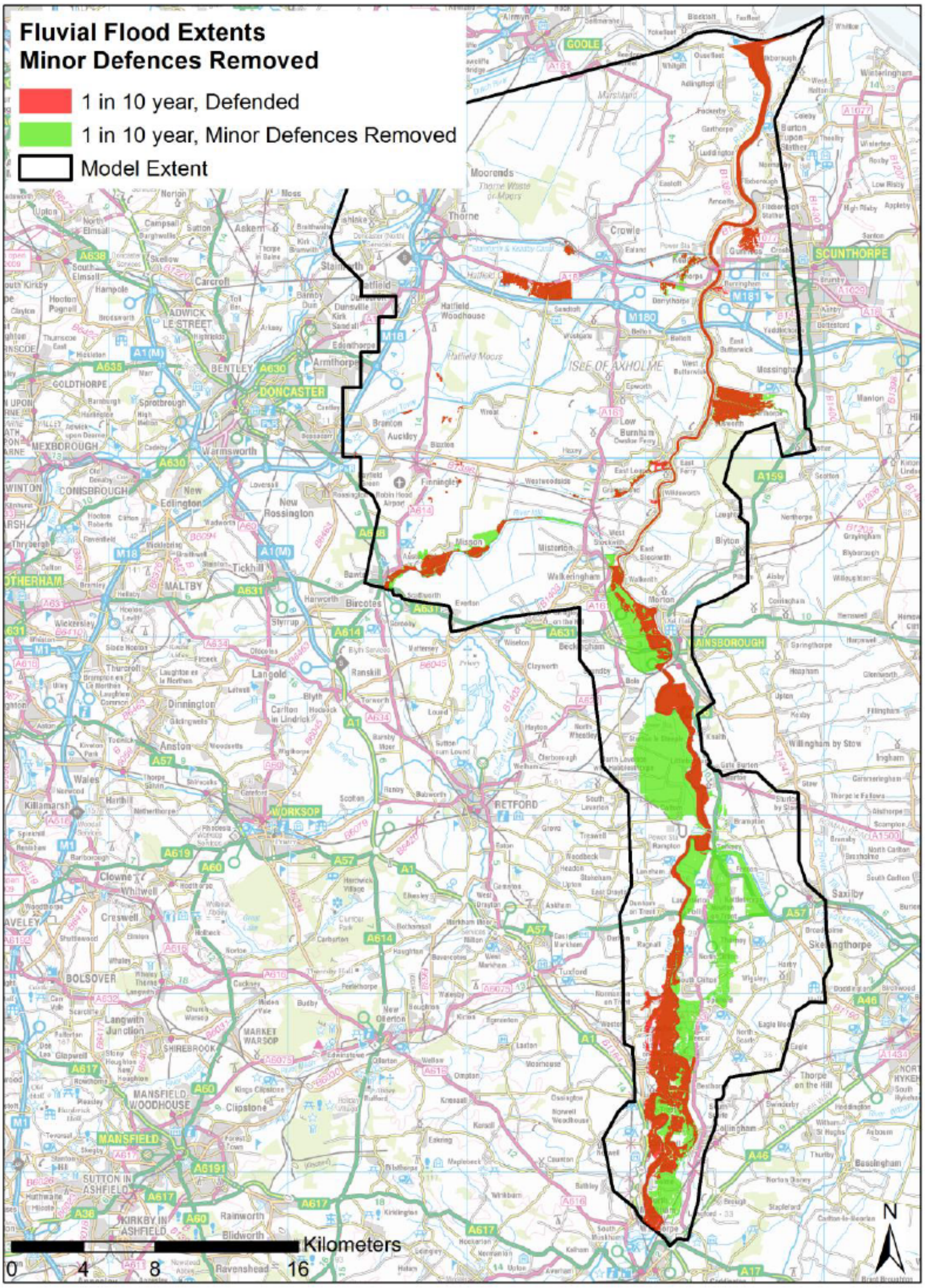
Figure 7.13: Comparison of 1 in 10 Year Fluvial Event with Minor Defences Removed



7.6 Review of Flood Warning Areas and Trigger Levels

As part of the study the Flood Warning Areas and trigger levels have been reviewed. Figure 7.14 provides the original Flood Warning Areas for the Tidal Trent area. The model results have been used to update these areas and provide revised trigger levels. The Flood Warning Areas have been updated using the following principles:

- Properties that flood at similar times to each other in the same locality are grouped together in one Flood Warning Area;
- Flood Warning Areas do not span across both banks of the river;
- No two Flood Warning Areas represent the same stretch of river;
- Properties flooding from the tributaries have not been represented by Flood Warning Areas as it is expected that the more detailed modelling available for the tributaries will be used to define the Flood Warning Areas in these locations.

An attempt has also been made to reduce the number of Flood Warning Areas to simplify the flood warning process.

The updated Flood Warning Areas are shown in Figure 7.15 and have been provided in shapefile format in the accompanying digital data. Trigger levels have been calculated for the flood warning gauges both upstream and downstream of each Flood Warning Area. Table 7.3 indicates the level at which the first property and 10^{th} property within each flood warning area is flooded.

Due to the tidal influence and the time taken for the flood waters to reach properties away from the river, the level reported in the table is the maximum water level recorded at that gauge prior to, or at, the time of the property being flooded.

The updated flood warning areas are primarily located along the upper reaches of the Tidal Trent, using the 1 in 1000 year fluvial flood extent data. It is recommended that flood warning areas are also created along the lower reaches taking into consideration historical flooding, and the predicted flood-extents from breach analysis.

Figure 7.14: EA's Original Flood Warning Areas for the Tidal Trent

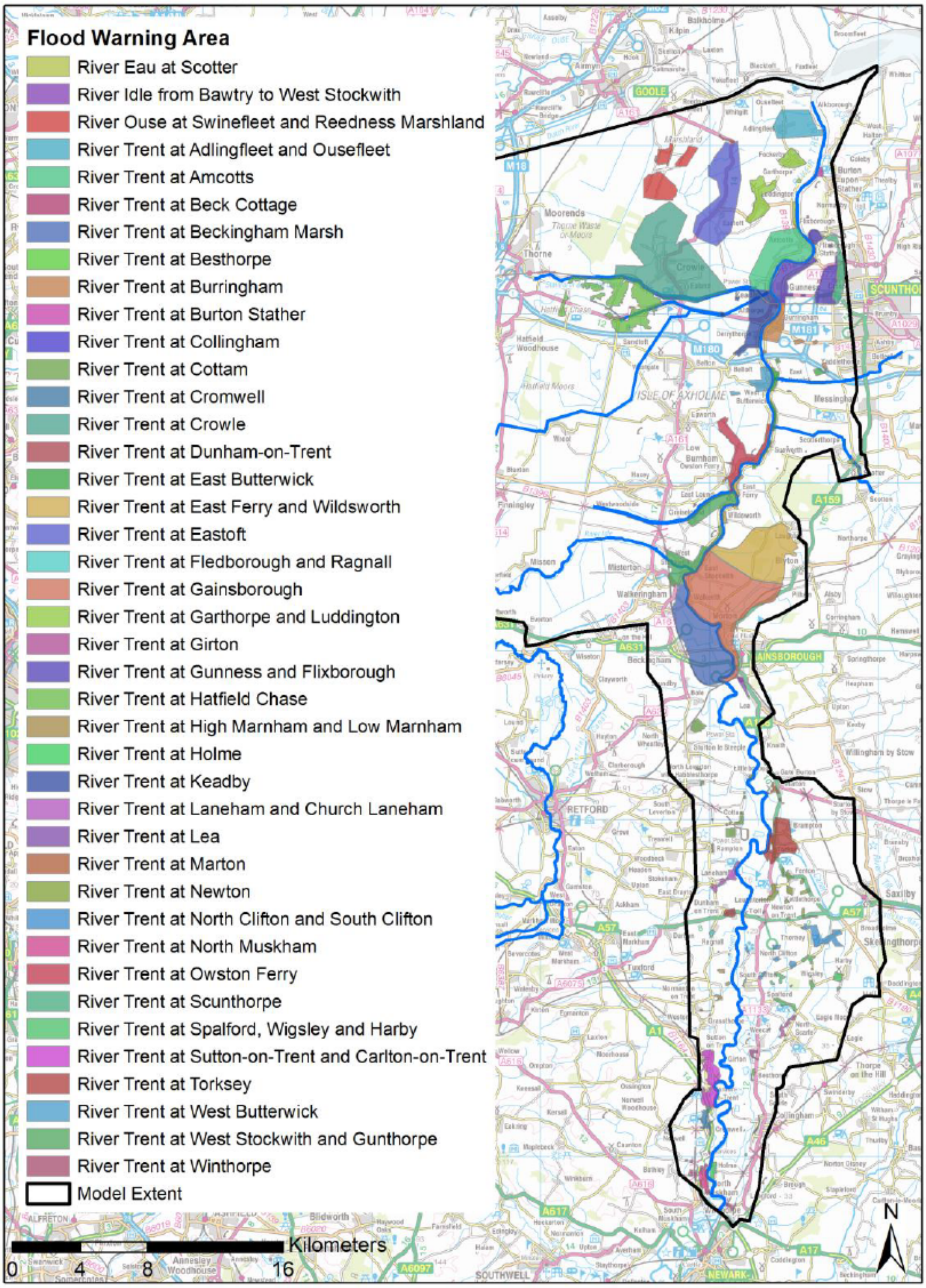


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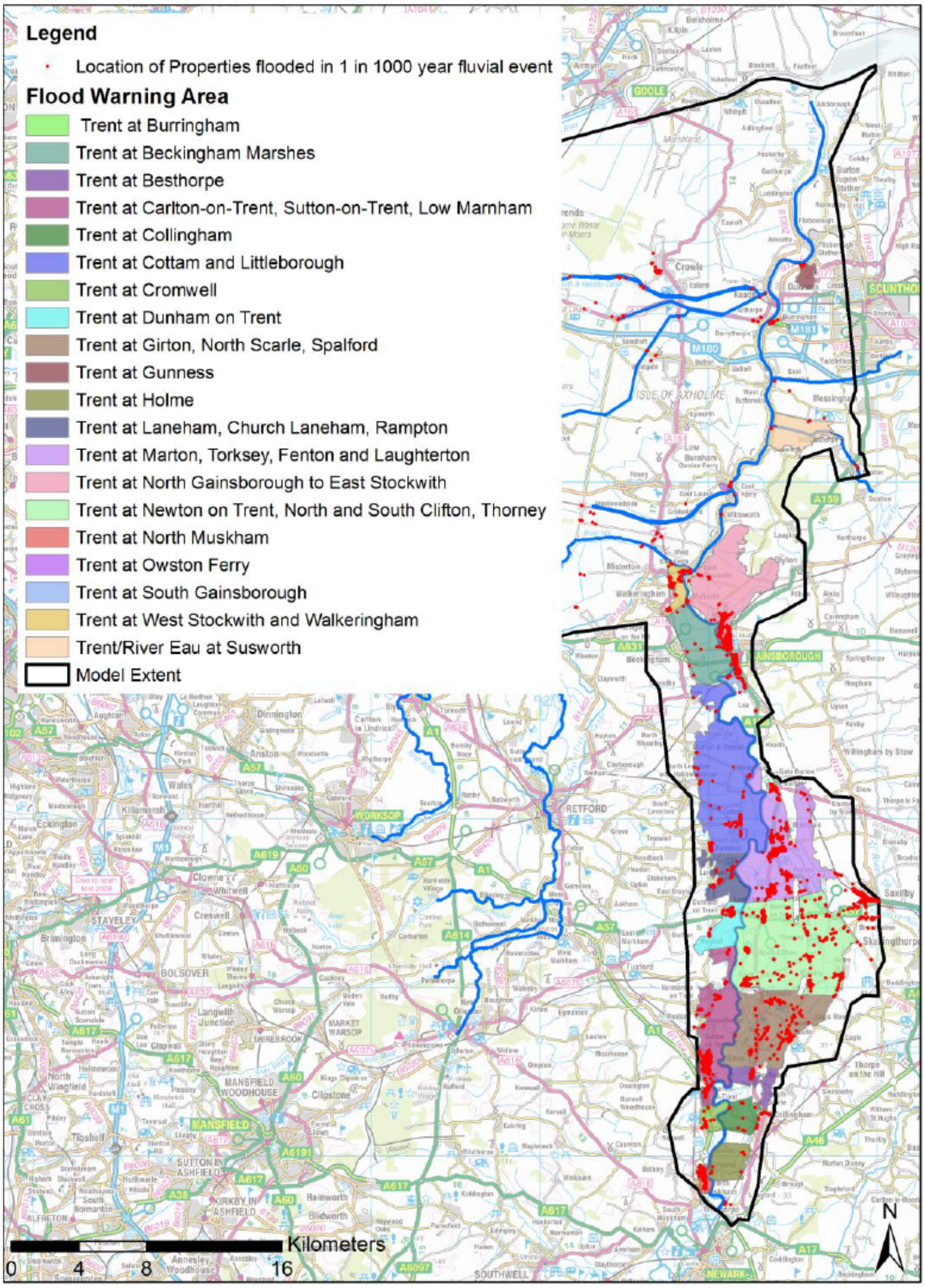
Figure 7.15: Revised Flood Warning Areas



Source: Mott MacDonald. This map is reproduced by permission of Ordnance Survey on behalf of The Controller Of Her Majesty's Stationary Office. Environment Agency 100026380, 2013.

Table 7.3: Trigger Levels for Revised Flood Warning Areas

FWA	Property ID of first property to flood	Gauge Level at North Muskham		Gauge Level at Torksey		Gauge Level at Gainsborough		Gauge Level at Keadby		Comments
		1st Property	10th Property	1st Property	10th Property	1st Property	10th Property	1st Property	10th Property	
Trent at North Muskham	4286257	8.17	9.16	4.29	5.58	N/A	N/A	N/A	N/A	
Trent at Holme	11840605	9.26	N/A	6	N/A	N/A	N/A	N/A	N/A	
Trent at Cromwell	19883420	8.361	9.473	4.441	7.77	N/A	N/A	N/A	N/A	First Property Shown Flooded from 'The Beck' at Carlton on Trent very early in model run due to grid size used in modelling. 10th property flooding levels much more realistic.
Trent at Collingham	19897408	9.24	9.34	5.97	4.76	N/A	N/A	N/A	N/A	
Trent at Carlton-on-T, Sutton-on-T, Low Marnham	19891571	9.14	9.35	5.5	6.07	N/A	N/A	N/A	N/A	
Trent at Besthorpe	19903438	9.39	9.4	6.34	6.41	N/A	N/A	N/A	N/A	
Trent at Girton, North Scarle, Spalford	19903455	9.32	9.355	6.06	6.07	N/A	N/A	N/A	N/A	
Trent at Newton on Trent, N&S Clifton, Thorney	19903881	9.394	9.435	6.41	7.21	N/A	N/A	N/A	N/A	
Trent at Dunham on Trent	19896920	9.473	9.494	7.77	7.87	N/A	N/A	N/A	N/A	
Trent at Laneham, Church Laneham, Rampton	19897559	9.44	9.46	7.21	7.58	N/A	N/A	N/A	N/A	
Trent at Marton, Torksey, Fenton and Laughterton	4290410	N/A	N/A	6.31	7.67	5	5.51	N/A	N/A	
Trent at Cottam and Littleborough	19903936	N/A	N/A	7.75	7.9	5.54	6.3	N/A	N/A	
Trent at S Gainsborough	12253478	N/A	N/A	7.58	7.89	5.41	5.57	N/A	N/A	
Trent at Beckingham Marshes	19899147	N/A	N/A	7.617	7.869	5.47	5.563	N/A	N/A	
Trent at N Gainsborough to E Stockwith	19892365	N/A	N/A	7.9	7.91	6.4	6.47	4.68	4.68	
Trent at W Stockwith and Walkeringham	19874925	N/A	N/A	7.89	7.89	5.68	5.68	4.48	4.48	
Trent at Owston Ferry	19901279	N/A	N/A	N/A	N/A	6.36	N/A	4.68	N/A	
Trent/River Eau at Susworth	23886088	N/A	N/A	N/A	N/A	4.32	N/A	4.02	N/A	First property shown to be flooded fairly early due to model grid size. Recommended alternative triggers are 6.36mAOD at Gainsborough and 4.68mAOD at Keadby
Trent at Burringham	23886728	N/A	N/A	N/A	N/A	6.62	6.62	5.67	5.67	
Trent at Gunness	23891038	N/A	N/A	N/A	N/A	6.32	N/A	4.6	N/A	

Gauge Level taken to be the greatest level achieved at the gauge prior to the property being flooded

8 Assumptions and Limitations

An integrated one-dimensional and two-dimensional modelling approach has been used to simulate tidal and fluvial events on the Tidal Trent and surrounding settlements, and assess flood hazard.

There are uncertainties associated with the flow estimation, particularly for less frequent flood events, and those on ungauged catchments.

A number of minor hydraulic assumptions have been made for this study. They include:

- All culverts and bridge structures would be blockage free for the design defended scenario as per ABD guidance.
- Fences and property walls in the urban areas have not been considered as they are not classified as formal flood defences.
- No attempt has been made to identify areas that are affected by flooding from urban drainage systems.
- Assessment of areas susceptible to drainage system inadequacies or localised ponding or debris blockages are not included.
- Pumping stations are fully operable during the defended and breach scenarios.

There are limitations associated with the input data and the modelling techniques. These limitations should be taken into account when interpreting the model results:

- No flow records are available on the smaller tributaries (particularly Warping Drain, Ferry Drain, River Eau and Bottesford Beck) for calibration, or for determining design inflows.
- Pumping capacity of warping drain and ferry drain pumping stations has been estimated from the available data.
- The survey data used in the model is a static-representation of the watercourse and defences taken at the time the survey was carried out. Any future changes to the topography due to construction of new defences or developments should be incorporated into the model.
- The flood waters have been allowed to 'glass-wall' at the edge of the 2D domain near Saxilby on the Foss Dyke canal and near the boundary with North East region on the right bank of the River Ouse. The results should therefore be treated with caution in these areas, as the flooding dynamics are likely to be affected by flooding from neighbouring catchments, which could not be represented in the current study.
- The 2D model has a grid size of 25m, which does not necessarily pick up all small-scale features that may have an impact on the flow path and/or conveyance.
- Momentum transfer between the 1D and 2D connections, i.e. between ISIS and TUFLOW, is not fully considered. Although in most simulations this is not of concern, it does influence the model results where a large structure (relative to the 2D grid size) is modelled as a 1D element.
- In areas of super-critical flow through the 2D and 1D domains, the results should be treated with caution, particularly if they are in key areas of interest. Hydraulic jumps and surcharging against obstructions may occur in reality. These highly localised 3D effects could not be adequately modelled using TUFLOW as a 2D modelling software.

Based on the assumptions and limitations outlined above, the model predicted water levels and depths results are accurate to 0.15m for fluvial events and accurate to 0.3m for tidal events downstream of Gainsborough. This level of accuracy should be considered when interpreting results.

9 Conclusions and Recommendations

9.1 Summary of Key Outputs and Deliverables

A fully hydrodynamic 1D/2D ISIS/TUFLOW linked model has been developed and used to:

- Simulate flood paths, depths, velocities and hazard on the Tidal Trent as well as over the surrounding land from tidal and fluvial events.
- The calibrated with defences model was used to derive improved flood zones and flood hazard information for the:
  - 1 in 5, 10, 20, 50, 75, 100, 200, and 1000 year fluvial events as well as the 1 in 100 under 2113 climate change conditions.
  - 1 in 200 and 1000 tidal events as well as the 1 in 200 under 2100 climate change conditions.
- Model the without defences scenario for the 1 in 100 and 1 in 1000 year fluvial events, and the 1 in 200 and 1 in 1000 year tidal events.
- Model thirty-two breach locations for both fluvial and tidal events.
- Identify areas benefiting from defences.
- Revise Flood Warning Areas.

9.2 Key Conclusions

With Defences Model

The with defences model was able to replicate past fluvial flood events to a reasonable level, matching historic flood data and flood level information from flood outlines and gauged records, etc. The model was less successful at replicating past tidal events, particularly upstream of Gainsborough. Between Keadby and Trent Falls, a reasonable level of calibration was achieved.

- The Beckingham Flood Marshes are in use during the 1 in 5 year fluvial event and the 1 in 200 year tidal event. The flood storage is fully inundated during the 1 in 50 year flood event.
- Gainsborough is protected from flooding up to and including the 1 in 100 year fluvial flood, however, there is flooding during the 1 in 200 year fluvial flood. There is no flooding here for the tidal events modelled.
- Flood extents for the 1 in 200 year fluvial event are significantly larger than for the 1 in 100 year event, particularly upstream of Gainsborough.
- A number of villages are located on slightly raised land (for example Newton on Trent) and therefore are not indicated as flooded for some return periods, however, it should be noted that they may be cut-off from surrounding dry land due to flooding of access routes.

Undefended Model – and Areas Benefiting from Defences

- The defences along the Tidal Trent are substantial and protect a vast area of land including a large number of villages and extensive farm land.
- 435km^2 of land is protected for the 1 in 100 year fluvial event.
- 360km^2 of land is protected during the 1 in 200 year tidal event.

Sensitivity Testing

Sensitivity tests on the Manning's roughness values have been undertaken and the following key conclusions can be drawn from the sensitivity tests:

- Water levels, especially upstream of Gainsborough, are sensitive to the roughness values used, with levels increasing and decreasing by 10 – 20cm with an increase and decrease of roughness by 20%, respectively.
- Downstream of Gainsborough, levels may be increased with decreased roughness due to the reduction in attenuation of the tidal wave as it progresses up the Trent.

Breach Modelling

- Extents from breach analysis are smaller than those in the completely undefended case. This is due to the assumption that the breach closed within 36 hours for a fluvial breach and 72 hours for a tidal breach. If the breach takes longer to close, then the flood extents may be significantly larger.
- Breach Origin maps have been created which clearly display the breach with the most significant impact in each location.

9.3 Recommendations

The following recommendations have been identified from the analysis of the results:

- Evaluate/Assess gauging station performance, such as at Keadby where there is low confidence in the level for the November 2011 tidal event.
- The model should be recalibrated following any major flood event which caused significant property flooding or disruption to local services.
- The model should be updated following any future development or change to flood defences within the study area.
- Flow and stage gauging along all the tributaries is recommended. This will allow the hydrology to be re-derived with a reduced level of uncertainty.
- Flood warning areas should be reviewed particularly in the lower reaches of the Tidal Trent and the use of the modelled breach flood extents considered as part of the flood warning area assessment.
- The outputs of this study, particularly the assessment of hydrograph shape and travel times which can be extracted from the model, are used to refine/validate the existing flood forecasting model for the Trent.
- Data from the study is used to update the National Flood Risk Assessment (NFRA) data set.
- Following tidal flooding in communities downstream of the M180 on Thursday 5th December 2013 it is recommended that an assessment of asset crest levels, particularly in Keadby and Burringham is undertaken sooner rather than later, as overtopping and some scouring occurred in these locations. Potential changes or planned alterations to these assets should be incorporated into the model to ensure the model is representative of the best available information.
- Review of flood frequency analysis for tidal conditions considering the December 2013 tidal surge event.

10 References

1. Tidal Trent Strategy Report - Appendix F, *Black & Veatch 2005*
2. Fluvial Trent Strategy Modelling Report - Volume 1 Final Hydrological Report, *Black & Veatch 2003*
3. River Idle Flood Risk Mapping Report, *JBA 2005*
4. River Torne Modelling Study Report, *Black & Veatch 2005*
5. Scotter Modelling Report, *Environment Agency*
6. River Humber, North Bank Tidal Modelling, Appendix C Water Level, Tide, Surge and Wave Analysis, *Mott MacDonald 2011*
7. [redacted]
8. Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities, *Environment Agency 2011*

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Appendix A. Model User Report

A.1. Introduction

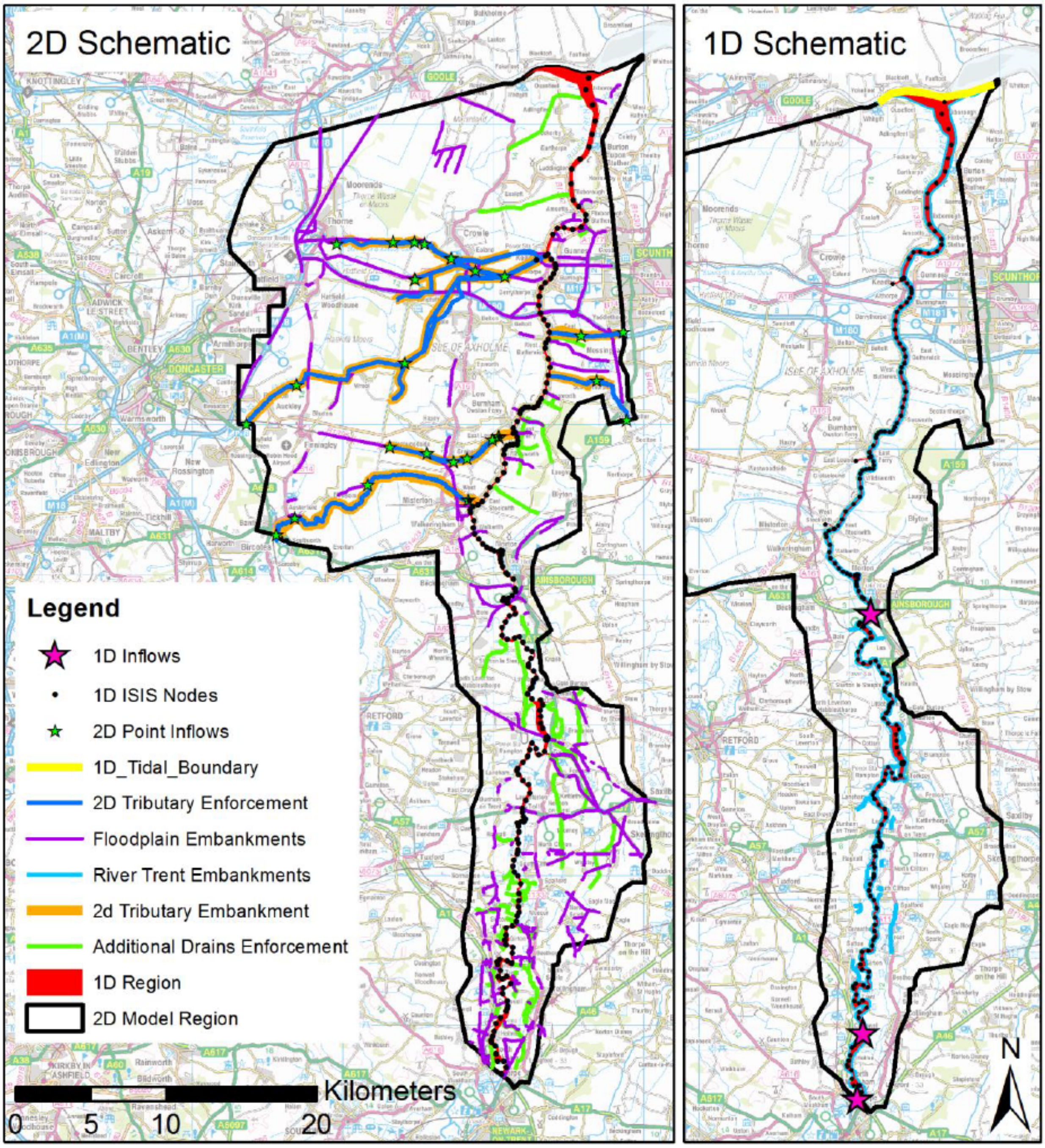
This document provides instructions on how to use the hydraulic models produced for the Tidal Trent SFRM2 study.

The models were developed to provide flood hazard information for the Tidal Trent region, and to undertake breach analysis. The models have been used to assess the design defended, undefended and breach scenarios. A review of the hydraulic model should be undertaken to ensure that it is fit for any purpose other than the aims and objectives of this study.

A.2. Model Extent and Builds

A hydraulic 1D/2D ISIS/TUFLOW model was developed as part of this study and extends from North Muskham at the Tidal Limit of the Trent to the confluence of the Trent with the Humber Estuary. The tributaries, River Idle, River Torne, Hatfield Waste Drain, North Soak Drain, South Soak Drain, River Eau and Bottesford Beck were also included as part of the model extent.

Figure A.1: Design Model Schematic



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A.3. Modelled Scenarios

Four design model scenarios were developed in collaboration with the Environment Agency project team:

- Defended (representing the baseline);
- Undefended (assuming no raised flood defences were in place);
- Minor 1 in 10 year defences removed;
- Breach.

Table A.1 summarises the key assumptions for each design scenario.

Table A.1: Design Modelling and Mapping Scenarios

Scenario	Name prefix	Primary Flood Defences	De-facto Defences	Flapped Outfalls and Pumps
Defended/ (Baseline)	Mott MacDonald_TTRENT_**RP**	Considered at the present day levels	Considered at the present day levels	Considered operational for entire event
Undefended	Mott MacDonald_TTRENT_**RP**_UNDEF	Lowered walls and embankments to surrounding floodplain levels	Considered at the present day levels	Pumps and outfalls removed
Minor Defences Removed	Mott MacDonald_TTRENT_**RP**_MINOR	Lowered minor defences to surrounding floodplain levels	Considered at the present day levels	Considered operational for entire event
Breach	Mott MacDonald_TTRENT_ **BR**_**RP**	Lowered walls and embankments to surrounding floodplain levels at breach location only using time varying shape file	Considered at the present day levels	Considered operational for entire event

In addition to the design scenarios, two sensitivity tests were carried out to assess the impact of key parameters on flows and water levels. Table A.2 summarises the sensitivity tests undertaken.

Table A.2: Sensitivity Test Scenarios

Scenario	Filename Prefix	Floodplain Roughness	In-channel Roughness	Fluvial Trent Inflow	Downstream Tidal Boundary
Defended	Mott MacDonald_TTRENT_**RP**_MANN_P20	+20%	+20%	1 in 100 year	1 in 5 year
Defended	Mott MacDonald_TTRENT_**RP**_MANN_M20	-20%	-20%	1 in 100 year	1 in 5 year

A full list of model runs is provided in the model log (Table A.3).

Table A.3: Model Log

Scenario	Model Run ID	Run File .ief	ISIS model .DAT	ISIS 1D fluvial inflow .IED	ISIS 1D tidal inflow .IED	TUFLOW control file .tcf	TUFLOW Geometry File .tgc	Variable Breach File	TUFLOW Boundary File .tbc	TUFLOW Materials File .tmf
Calibration	Mott MacDonald_TTRENT_JAN2005	Mott MacDonald_TTRENT_JAN2005_V17.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_JAN2005_F	TTRENT_JAN2005_T	Mott MacDonald_TTRENT_JAN2005_V17.tcf	Mott MacDonald_TTRENT_DEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_JULY2012	Mott MacDonald_TTRENT_JULY2012_V17.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_JULY2012_F	TTRENT_JULY2012_T	Mott MacDonald_TTRENT_JULY2012_V17.tcf	Mott MacDonald_TTRENT_DEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_JUN2007	Mott MacDonald_TTRENT_JUN2007_V17.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_JUN2007_F	TTRENT_JUN2007_T	Mott MacDonald_TTRENT_JUN2007_V17.tcf	Mott MacDonald_TTRENT_DEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_NOV2000	Mott MacDonald_TTRENT_NOV2000_V17.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_NOV2000_F	TTRENT_NOV2000_T	Mott MacDonald_TTRENT_NOV2000_V17.tcf	Mott MacDonald_TTRENT_DEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_NOV2011	Mott MacDonald_TTRENT_NOV2011_V17.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_NOV2011_F	TTRENT_NOV2011_T	Mott MacDonald_TTRENT_NOV2011_V17.tcf	Mott MacDonald_TTRENT_DEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_NOV2012	Mott MacDonald_TTRENT_NOV2012_V17.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_NOV2012_F	TTRENT_NOV2012_T	Mott MacDonald_TTRENT_NOV2012_V17.tcf	Mott MacDonald_TTRENT_DEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
Defended Model	Mott MacDonald_TTRENT_F0010_T0005	Mott MacDonald_TTRENT_F0010_T0005_V17.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0010. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_F0010_T0005_V17.tcf	Mott MacDonald_TTRENT_DEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_F0100_T0005	Mott MacDonald_TTRENT_F0100_T0005_V17.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_F0100_T0005_V17.tcf	Mott MacDonald_TTRENT_DEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
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	Mott MacDonald_TTRENT_F0005_T0005	Mott MacDonald_TTRENT_F0005_T0005_V17.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0005. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_F0005_T0005_V17.tcf	Mott MacDonald_TTRENT_DEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
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	Mott MacDonald_TTRENT_F0075_T0005	Mott MacDonald_TTRENT_F0075_T0005_V17.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0075. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_F0075_T0005_V17.tcf	Mott MacDonald_TTRENT_DEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_F0200_T0005	Mott MacDonald_TTRENT_F0200_T0005_V17.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0200. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_F0200_T0005_V17.tcf	Mott MacDonald_TTRENT_DEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_F0002_T0200	Mott MacDonald_TTRENT_F0002_T0200_V17.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_F0002_T0200_V17.tcf	Mott MacDonald_TTRENT_DEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_F0002_T1000	Mott MacDonald_TTRENT_F0002_T1000_V17.ief	Mott MacDonald TTRENT 01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_F0002_T1000_V17.tcf	Mott MacDonald_TTRENT_DEFENDED_01.tgc	N/A	Mott MacDonald TTRENT _01.tbc	Mott MacDonald TTRENT _01 tmf
	Mott MacDonald_TTRENT_F0100CC_T0005	Mott MacDonald_TTRENT_F0100CC_T0005_V17.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100CC.IED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_F0100CC_T0005_V17 tcf	Mott MacDonald_TTRENT_DEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_F0002_T0200CC_CF	Mott MacDonald_TTRENT_F0002_T0200CC_CF_V17.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200CC_CF. ED	Mott MacDonald_TTRENT_F0002_T0200CC_CF_V17.tcf	Mott MacDonald_TTRENT_DEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_F0002_T0200CC_UE	Mott MacDonald_TTRENT_F0002_T0200CC_UE_V17.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200CC_UE.IED	Mott MacDonald_TTRENT_F0002_T0200CC_UE_V17.tcf	Mott MacDonald_TTRENT_DEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
Undefended Model	Mott MacDonald_TTRENT_F0100_T0005	Mott MacDonald_TTRENT_F0100_T0005_UNDEF_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_F0100_T0005_UNDEF_V01.tcf	Mott MacDonald_TTRENT_UNDEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_F1000_T0005	Mott MacDonald TTRENT F1000 T0005 UNDEF V01.ief	Mott MacDonald TTRENT 01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald TTRENT F1000 T0005 UNDEF V01.tcf	Mott MacDonald_TTRENT_UNDEFENDED_01.tgc	N/A	Mott MacDonald TTRENT _01.tbc	Mott MacDonald TTRENT _01 tmf
	Mott MacDonald_TTRENT_F0002_T0200	Mott MacDonald_TTRENT_F0002_T0200_UNDEF_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_F0002_T0200_UNDEF_V01.tcf	Mott MacDonald_TTRENT_UNDEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_F0002_T1000	Mott MacDonald_TTRENT_F0002_T1000_UNDEF_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_F0002_T1000_UNDEF_V01.tcf	Mott MacDonald_TTRENT_UNDEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
Minor Defences Removed	Mott MacDonald_TTRENT_F0010_T0005_M NOR	Mott MacDonald_TTRENT_F0010_T0005_MINOR_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0010. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_F0010_T0005_M NOR_V01.tcf	Mott MacDonald_TTRENT_UNDEFENDED_MINOR_01 tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
Breach	Mott MacDonald_TTRENT_Br2a_F1000_T0005	Mott MacDonald_TTRENT_Br2a_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br2a_F1000_T0005_V01.tcf	Mott MacDonald_TTRENT_Br2a_F1000_T0005_V01 tgc	2d_vzsh_TTRENT_Br2a_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott	Mott	Mott	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott	Mott	2d_vzsh_TTRENT_Br3_F1000_T0005_V01.M F	Mott	Mott

Scenario	Model Run ID	Run File .ief	ISIS model .DAT	ISIS 1D fluvial inflow .IED	ISIS 1D tidal inflow .IED	TUFLOW control file .tcf	TUFLOW Geometry File .tgc	Variable Breach File	TUFLOW Boundary File .tbc	TUFLOW Materials File .tmf
	MacDonald_TTRENT_Br3_F1000_T0005	MacDonald_TTRENT_Br3_F1000_T0005_V01.ief	MacDonald_TTRENT_01.DAT			MacDonald_TTRENT_Br3_F1000_T0005_V01.tcf	MacDonald_TTRENT_Br3_F1000_T0005_V01.tgc		MacDonald_TTRENT_01.tbc	MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br4_F1000_T0005	Mott MacDonald_TTRENT_Br4_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br4_F1000_T0005_V01.tcf	Mott MacDonald_TTRENT_Br4_F1000_T0005_V01.tgc	2d_vzsh_TTRENT_Br4_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br5_F1000_T0005	Mott MacDonald_TTRENT_Br5_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br5_F1000_T0005_V01.tcf	Mott MacDonald_TTRENT_Br5_F1000_T0005_V01.tgc	2d_vzsh_TTRENT_Br5_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br6a_F1000_T0005	Mott MacDonald_TTRENT_Br6a_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br6a_F1000_T0005_V01.tcf	Mott MacDonald_TTRENT_Br6a_F1000_T0005_V01 tgc	2d_vzsh_TTRENT_Br6a_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br6b_F1000_T0005	Mott MacDonald_TTRENT_Br6b_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br6b_F1000_T0005_V01.tcf	Mott MacDonald_TTRENT_Br6b_F1000_T0005_V01 tgc	2d_vzsh_TTRENT_Br6b_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald TTRENT Br6d F1000 T0005	Mott MacDonald TTRENT Br6d F1000 T0005 V01.ief	Mott MacDonald TTRENT 01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald TTRENT Br6d F1000 T0005 V01.tcf	Mott MacDonald TTRENT Br6d F1000 T0005 V01 tgc	2d_vzsh_TTRENT_Br6d_F1000_T0005_V01.M F	Mott MacDonald TTRENT _01.tbc	Mott MacDonald TTRENT _01 tmf
	Mott MacDonald_TTRENT_Br7_F1000_T0005	Mott MacDonald_TTRENT_Br7_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br7_F1000_T0005_V01.tcf	Mott MacDonald_TTRENT_Br7_F1000_T0005_V01.tgc	2d_vzsh_TTRENT_Br7_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br8a_F1000_T0005	Mott MacDonald_TTRENT_Br8a_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br8a_F1000_T0005_V01.tcf	Mott MacDonald_TTRENT_Br8a_F1000_T0005_V01 tgc	2d_vzsh_TTRENT_Br8a_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br8b_F1000_T0005	Mott MacDonald_TTRENT_Br8b_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br8b_F1000_T0005_V01.tcf	Mott MacDonald_TTRENT_Br8b_F1000_T0005_V01 tgc	2d_vzsh_TTRENT_Br8b_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br8c_F1000_T0005	Mott MacDonald_TTRENT_Br8c_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br8c_F1000_T0005_V01.tcf	Mott MacDonald_TTRENT_Br8c_F1000_T0005_V01 tgc	2d_vzsh_TTRENT_Br8c_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br8d_F1000_T0005	Mott MacDonald_TTRENT_Br8d_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br8d_F1000_T0005_V01.tcf	Mott MacDonald_TTRENT_Br8d_F1000_T0005_V01 tgc	2d_vzsh_TTRENT_Br8d_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br12a_F1000_T0005	Mott MacDonald_TTRENT_Br12a_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br12a_F1000_T0005_V01.tcf	Mott MacDonald_TTRENT_Br12a_F1000_T0005_V01 tgc	2d_vzsh_TTRENT_Br12a_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br12b_F1000_T0005	Mott MacDonald_TTRENT_Br12b_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br12b_F1000_T0005_V01.tcf	Mott MacDonald_TTRENT_Br12b_F1000_T0005_V01 tgc	2d_vzsh_TTRENT_Br12b_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br13a_F1000_T0005	Mott MacDonald_TTRENT_Br13a_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br13a_F1000_T0005_V01.tcf	Mott MacDonald_TTRENT_Br13a_F1000_T0005_V01 tgc	2d_vzsh_TTRENT_Br13a_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald TTRENT Br13b F1000 T0005	Mott MacDonald TTRENT Br13b F1000 T0005 V01.ief	Mott MacDonald TTRENT 01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald TTRENT Br13b F1000 T0005 V01.tcf	Mott MacDonald TTRENT Br13b F1000 T0005 V01 tgc	2d_vzsh_TTRENT_Br13b_F1000_T0005_V01.M F	Mott MacDonald TTRENT _01.tbc	Mott MacDonald TTRENT _01 tmf
	Mott MacDonald_TTRENT_A1_F1000_T0005	Mott MacDonald_TTRENT_A1_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_A1_F1000_T0005_V01.tcf	Mott MacDonald_TTRENT_A1_F1000_T0005_V01 tgc	2d_vzsh_TTRENT_A1_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_A3_F1000_T0005	Mott MacDonald_TTRENT_A3_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_A3_F1000_T0005_V01.tcf	Mott MacDonald_TTRENT_A3_F1000_T0005_V01 tgc	2d_vzsh_TTRENT_A3_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_B_F1000_T0005	Mott MacDonald_TTRENT_B_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_B_F1000_T0005_V01 tcf	Mott MacDonald_TTRENT_B_F1000_T0005_V01.tgc	2d_vzsh_TTRENT_B_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_C_F1000_T0005	Mott MacDonald_TTRENT_C_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_C_F1000_T0005_V01 tcf	Mott MacDonald_TTRENT_C_F1000_T0005_V01 tgc	2d_vzsh_TTRENT_C_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald TTRENT D F1000 T0005	Mott MacDonald TTRENT D F1000 T0005 V01.ief	Mott MacDonald TTRENT 01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald TTRENT D F1000 T0005 V01 tcf	Mott MacDonald TTRENT D F1000 T0005 V01 tgc	2d_vzsh_TTRENT_D_F1000_T0005_V01.M F	Mott MacDonald TTRENT _01.tbc	Mott MacDonald TTRENT _01 tmf
	Mott MacDonald_TTRENT_E1_F1000_T0005	Mott MacDonald_TTRENT_E1_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_E1_F1000_T0005_V01.tcf	Mott MacDonald_TTRENT_E1_F1000_T0005_V01 tgc	2d_vzsh_TTRENT_E1_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_E_F1000_T0005	Mott MacDonald_TTRENT_E_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_E_F1000_T0005_V01 tcf	Mott MacDonald_TTRENT_E_F1000_T0005_V01.tgc	2d_vzsh_TTRENT_E_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_F_F1000_T0005	Mott MacDonald_TTRENT_F_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_F_F1000_T0005_V01 tcf	Mott MacDonald_TTRENT_F_F1000_T0005_V01.tgc	2d_vzsh_TTRENT_F_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_I_F1000_T0005	Mott MacDonald_TTRENT_I_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_I_F1000_T0005_V01.tcf	Mott MacDonald_TTRENT_I_F1000_T0005_V01 tgc	2d_vzsh_TTRENT_I_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald TTRENT J2 F1000 T0005	Mott MacDonald TTRENT J2 F1000 T0005 V01.ief	Mott MacDonald TTRENT 01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald TTRENT J2 F1000 T0005 V01.tcf	Mott MacDonald TTRENT J2 F1000 T0005 V01 tgc	2d_vzsh_TTRENT_J2_F1000_T0005_V01.M F	Mott MacDonald TTRENT _01.tbc	Mott MacDonald TTRENT _01 tmf
	Mott MacDonald_TTRENT_K2_F1000_T0005	Mott MacDonald_TTRENT_K2_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_K2_F1000_T0005_V01.tcf	Mott MacDonald_TTRENT_K2_F1000_T0005_V01 tgc	2d_vzsh_TTRENT_K2_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_L_F1000_T000	Mott MacDonald_TTRENT_L_F1000_T0005_V01.ie	Mott MacDonald_TTRENT_	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_L_F1000_T0005_V01 tc	Mott MacDonald_TTRENT_L_F1000_T0005_V01.tg	2d_vzsh_TTRENT_L_F1000_T0005_V01.M F	Mott MacDonald_TTRENT	Mott MacDonald_TTRENT

Scenario	Model Run ID	Run File .ief	ISIS model .DAT	ISIS 1D fluvial inflow .IED	ISIS 1D tidal inflow .IED	TUFLOW control file .tcf	TUFLOW Geometry File .tgc	Variable Breach File	TUFLOW Boundary File .tbc	TUFLOW Materials File .tmf
	5	f	01.DAT			f	c		_01.tbc	_01 tmf
	Mott MacDonald_TTRENT_Q_F1000_T0005	Mott MacDonald_TTRENT_Q_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Q_F1000_T0005_V01 tcf	Mott MacDonald_TTRENT_Q_F1000_T0005_V01 tgc	2d_vzsh_TTRENT_Q_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_R_F1000_T0005	Mott MacDonald_TTRENT_R_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_R_F1000_T0005_V01 tcf	Mott MacDonald_TTRENT_R_F1000_T0005_V01 tgc	2d_vzsh_TTRENT_R_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_S_F1000_T0005	Mott MacDonald_TTRENT_S_F1000_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_S_F1000_T0005_V01 tcf	Mott MacDonald_TTRENT_S_F1000_T0005_V01.tgc	2d_vzsh_TTRENT_S_F1000_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald TTRENT T F1000 T0005	Mott MacDonald TTRENT T F1000 T0005 V01.ief	Mott MacDonald TTRENT 01.DAT	TTRENT_F1000. ED	TTRENT_T0005. ED	Mott MacDonald TTRENT T F1000 T0005 V01 tcf	Mott MacDonald TTRENT T F1000 T0005 V01.tgc	2d_vzsh_TTRENT_T_F1000_T0005_V01.M F	Mott MacDonald TTRENT _01.tbc	Mott MacDonald TTRENT _01 tmf
	Mott MacDonald_TTRENT_Br2a_F0100_T0005	Mott MacDonald_TTRENT_Br2a_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br2a_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_Br2a_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_Br2a_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br3_F0100_T0005	Mott MacDonald_TTRENT_Br3_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br3_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_Br3_F0100_T0005_V01.tgc	2d_vzsh_TTRENT_Br3_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br4_F0100_T0005	Mott MacDonald_TTRENT_Br4_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br4_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_Br4_F0100_T0005_V01.tgc	2d_vzsh_TTRENT_Br4_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br5_F0100_T0005	Mott MacDonald_TTRENT_Br5_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br5_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_Br5_F0100_T0005_V01.tgc	2d_vzsh_TTRENT_Br5_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald TTRENT Br6a F0100 T0005	Mott MacDonald TTRENT Br6a F0100 T0005 V01.ief	Mott MacDonald TTRENT 01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald TTRENT Br6a F0100 T0005 V01.tcf	Mott MacDonald TTRENT Br6a F0100 T0005 V01 tgc	2d_vzsh_TTRENT_Br6a_F0100_T0005_V01.M F	Mott MacDonald TTRENT _01.tbc	Mott MacDonald TTRENT _01 tmf
	Mott MacDonald_TTRENT_Br6b_F0100_T0005	Mott MacDonald_TTRENT_Br6b_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br6b_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_Br6b_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_Br6b_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br6d_F0100_T0005	Mott MacDonald_TTRENT_Br6d_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br6d_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_Br6d_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_Br6d_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br7_F0100_T0005	Mott MacDonald_TTRENT_Br7_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br7_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_Br7_F0100_T0005_V01.tgc	2d_vzsh_TTRENT_Br7_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br8a_F0100_T0005	Mott MacDonald_TTRENT_Br8a_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br8a_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_Br8a_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_Br8a_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald TTRENT Br8b F0100 T0005	Mott MacDonald TTRENT Br8b F0100 T0005 V01.ief	Mott MacDonald TTRENT 01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald TTRENT Br8b F0100 T0005 V01.tcf	Mott MacDonald TTRENT Br8b F0100 T0005 V01 tgc	2d_vzsh_TTRENT_Br8b_F0100_T0005_V01.M F	Mott MacDonald TTRENT _01.tbc	Mott MacDonald TTRENT _01 tmf
	Mott MacDonald_TTRENT_Br8c_F0100_T0005	Mott MacDonald_TTRENT_Br8c_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br8c_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_Br8c_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_Br8c_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br8d_F0100_T0005	Mott MacDonald_TTRENT_Br8d_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br8d_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_Br8d_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_Br8d_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br12a_F0100_T0005	Mott MacDonald_TTRENT_Br12a_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br12a_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_Br12a_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_Br12a_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br12b_F0100_T0005	Mott MacDonald_TTRENT_Br12b_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br12b_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_Br12b_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_Br12b_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald TTRENT Br13a F0100 T0005	Mott MacDonald TTRENT Br13a F0100 T0005 V01.ief	Mott MacDonald TTRENT 01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald TTRENT Br13a F0100 T0005 V01.tcf	Mott MacDonald TTRENT Br13a F0100 T0005 V01 tgc	2d_vzsh_TTRENT_Br13a_F0100_T0005_V01.M F	Mott MacDonald TTRENT _01.tbc	Mott MacDonald TTRENT _01 tmf
	Mott MacDonald_TTRENT_Br13b_F0100_T0005	Mott MacDonald_TTRENT_Br13b_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Br13b_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_Br13b_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_Br13b_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_A1_F0100_T0005	Mott MacDonald_TTRENT_A1_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_A1_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_A1_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_A1_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_A3_F0100_T0005	Mott MacDonald_TTRENT_A3_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_A3_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_A3_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_A3_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_B_F0100_T0005	Mott MacDonald_TTRENT_B_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_B_F0100_T0005_V01 tcf	Mott MacDonald_TTRENT_B_F0100_T0005_V01.tgc	2d_vzsh_TTRENT_B_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_C_F0100_T0005	Mott MacDonald_TTRENT_C_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_C_F0100_T0005_V01 tcf	Mott MacDonald_TTRENT_C_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_C_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_D_F0100_T0005	Mott MacDonald_TTRENT_D_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_D_F0100_T0005_V01 tcf	Mott MacDonald_TTRENT_D_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_D_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_E1_F0100_T0005	Mott MacDonald_TTRENT_E1_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_E1_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_E1_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_E1_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf

Scenario	Model Run ID	Run File .ief	ISIS model .DAT	ISIS 1D fluvial inflow .IED	ISIS 1D tidal inflow .IED	TUFLOW control file .tcf	TUFLOW Geometry File .tgc	Variable Breach File	TUFLOW Boundary File .tbc	TUFLOW Materials File .tmf
	Mott MacDonald TTRENT E F0100 T0005	Mott MacDonald TTRENT E F0100 T0005 V01.ief	Mott MacDonald TTRENT 01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald TTRENT E F0100 T0005 V01 tcf	Mott MacDonald TTRENT E F0100 T0005 V01.tgc	2d_vzsh_TTRENT_E_F0100_T0005_V01.M F	Mott MacDonald TTRENT _01.tbc	Mott MacDonald TTRENT _01 tmf
	Mott MacDonald_TTRENT_F_F0100_T0005	Mott MacDonald_TTRENT_F_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_F_F0100_T0005_V01 tcf	Mott MacDonald_TTRENT_F_F0100_T0005_V01.tgc	2d_vzsh_TTRENT_F_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_I_F0100_T0005	Mott MacDonald_TTRENT_I_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_I_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_I_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_I_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_J2_F0100_T0005	Mott MacDonald_TTRENT_J2_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_J2_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_J2_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_J2_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_K2_F0100_T0005	Mott MacDonald_TTRENT_K2_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_K2_F0100_T0005_V01.tcf	Mott MacDonald_TTRENT_K2_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_K2_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald TTRENT L F0100 T0005	Mott MacDonald TTRENT L F0100 T0005 V01.ief	Mott MacDonald TTRENT 01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald TTRENT L F0100 T0005 V01 tcf	Mott MacDonald TTRENT L F0100 T0005 V01.tgc	2d_vzsh_TTRENT_L_F0100_T0005_V01.M F	Mott MacDonald TTRENT _01.tbc	Mott MacDonald TTRENT _01 tmf
	Mott MacDonald_TTRENT_Q_F0100_T0005	Mott MacDonald_TTRENT_Q_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_Q_F0100_T0005_V01 tcf	Mott MacDonald_TTRENT_Q_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_Q_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_R_F0100_T0005	Mott MacDonald_TTRENT_R_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_R_F0100_T0005_V01 tcf	Mott MacDonald_TTRENT_R_F0100_T0005_V01 tgc	2d_vzsh_TTRENT_R_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_S_F0100_T0005	Mott MacDonald_TTRENT_S_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_S_F0100_T0005_V01 tcf	Mott MacDonald_TTRENT_S_F0100_T0005_V01.tgc	2d_vzsh_TTRENT_S_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_T_F0100_T0005	Mott MacDonald_TTRENT_T_F0100_T0005_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_T_F0100_T0005_V01 tcf	Mott MacDonald_TTRENT_T_F0100_T0005_V01.tgc	2d_vzsh_TTRENT_T_F0100_T0005_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald TTRENT Br2a F0002 T0200	Mott MacDonald TTRENT Br2a F0002 T0200 V01.ief	Mott MacDonald TTRENT 01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald TTRENT Br2a F0002 T0200 V01.tcf	Mott MacDonald TTRENT Br2a F0002 T0200 V01 tgc	2d_vzsh_TTRENT_Br2a_F0002_T0200_V01.M F	Mott MacDonald TTRENT _01.tbc	Mott MacDonald TTRENT _01 tmf
	Mott MacDonald_TTRENT_Br3_F0002_T0200	Mott MacDonald_TTRENT_Br3_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_Br3_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_Br3_F0002_T0200_V01.tgc	2d_vzsh_TTRENT_Br3_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br4_F0002_T0200	Mott MacDonald_TTRENT_Br4_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_Br4_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_Br4_F0002_T0200_V01.tgc	2d_vzsh_TTRENT_Br4_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br5_F0002_T0200	Mott MacDonald_TTRENT_Br5_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_Br5_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_Br5_F0002_T0200_V01.tgc	2d_vzsh_TTRENT_Br5_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br6a_F0002_T0200	Mott MacDonald_TTRENT_Br6a_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_Br6a_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_Br6a_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_Br6a_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald TTRENT Br6b F0002 T0200	Mott MacDonald TTRENT Br6b F0002 T0200 V01.ief	Mott MacDonald TTRENT 01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald TTRENT Br6b F0002 T0200 V01.tcf	Mott MacDonald TTRENT Br6b F0002 T0200 V01 tgc	2d_vzsh_TTRENT_Br6b_F0002_T0200_V01.M F	Mott MacDonald TTRENT _01.tbc	Mott MacDonald TTRENT _01 tmf
	Mott MacDonald_TTRENT_Br6d_F0002_T0200	Mott MacDonald_TTRENT_Br6d_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_Br6d_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_Br6d_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_Br6d_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br7_F0002_T0200	Mott MacDonald_TTRENT_Br7_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_Br7_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_Br7_F0002_T0200_V01.tgc	2d_vzsh_TTRENT_Br7_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br8a_F0002_T0200	Mott MacDonald_TTRENT_Br8a_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_Br8a_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_Br8a_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_Br8a_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br8b_F0002_T0200	Mott MacDonald_TTRENT_Br8b_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_Br8b_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_Br8b_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_Br8b_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br8c_F0002_T0200	Mott MacDonald_TTRENT_Br8c_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_Br8c_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_Br8c_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_Br8c_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br8d_F0002_T0200	Mott MacDonald_TTRENT_Br8d_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_Br8d_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_Br8d_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_Br8d_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br12a_F0002_T0200	Mott MacDonald_TTRENT_Br12a_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_Br12a_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_Br12a_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_Br12a_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br12b_F0002_T0200	Mott MacDonald_TTRENT_Br12b_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_Br12b_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_Br12b_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_Br12b_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br13a_F0002_T0200	Mott MacDonald_TTRENT_Br13a_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_Br13a_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_Br13a_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_Br13a_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br13b_F0002_T0200	Mott MacDonald_TTRENT_Br13b_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_Br13b_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_Br13b_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_Br13b_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott	Mott	Mott	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott	Mott	2d_vzsh_TTRENT_A1_F0002_T0200_V01.M F	Mott	Mott

Scenario	Model Run ID	Run File .ief	ISIS model .DAT	ISIS 1D fluvial inflow .IED	ISIS 1D tidal inflow .IED	TUFLOW control file .tcf	TUFLOW Geometry File .tgc	Variable Breach File	TUFLOW Boundary File .tbc	TUFLOW Materials File .tmf
	MacDonald_TTRENT_A1_F0002_T0200	MacDonald_TTRENT_A1_F0002_T0200_V01.ief	MacDonald_TTRENT_01.DAT			MacDonald_TTRENT_A1_F0002_T0200_V01.tcf	MacDonald_TTRENT_A1_F0002_T0200_V01 tgc		MacDonald_TTRENT_01.tbc	MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_A3_F0002_T0200	Mott MacDonald_TTRENT_A3_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_A3_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_A3_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_A3_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_B_F0002_T0200	Mott MacDonald_TTRENT_B_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_B_F0002_T0200_V01 tcf	Mott MacDonald_TTRENT_B_F0002_T0200_V01.tgc	2d_vzsh_TTRENT_B_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_C_F0002_T0200	Mott MacDonald_TTRENT_C_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_C_F0002_T0200_V01 tcf	Mott MacDonald_TTRENT_C_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_C_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_D_F0002_T0200	Mott MacDonald_TTRENT_D_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_D_F0002_T0200_V01 tcf	Mott MacDonald_TTRENT_D_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_D_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_E1_F0002_T0200	Mott MacDonald_TTRENT_E1_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_E1_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_E1_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_E1_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_E_F0002_T0200	Mott MacDonald_TTRENT_E_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_E_F0002_T0200_V01 tcf	Mott MacDonald_TTRENT_E_F0002_T0200_V01.tgc	2d_vzsh_TTRENT_E_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_F_F0002_T0200	Mott MacDonald_TTRENT_F_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_F_F0002_T0200_V01 tcf	Mott MacDonald_TTRENT_F_F0002_T0200_V01.tgc	2d_vzsh_TTRENT_F_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_I_F0002_T0200	Mott MacDonald_TTRENT_I_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_I_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_I_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_I_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_J2_F0002_T0200	Mott MacDonald_TTRENT_J2_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_J2_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_J2_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_J2_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_K2_F0002_T0200	Mott MacDonald_TTRENT_K2_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_K2_F0002_T0200_V01.tcf	Mott MacDonald_TTRENT_K2_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_K2_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_L_F0002_T0200	Mott MacDonald_TTRENT_L_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_L_F0002_T0200_V01 tcf	Mott MacDonald_TTRENT_L_F0002_T0200_V01.tgc	2d_vzsh_TTRENT_L_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Q_F0002_T0200	Mott MacDonald_TTRENT_Q_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_Q_F0002_T0200_V01 tcf	Mott MacDonald_TTRENT_Q_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_Q_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_R_F0002_T0200	Mott MacDonald_TTRENT_R_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_R_F0002_T0200_V01 tcf	Mott MacDonald_TTRENT_R_F0002_T0200_V01 tgc	2d_vzsh_TTRENT_R_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_S_F0002_T0200	Mott MacDonald_TTRENT_S_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_S_F0002_T0200_V01 tcf	Mott MacDonald_TTRENT_S_F0002_T0200_V01.tgc	2d_vzsh_TTRENT_S_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_T_F0002_T0200	Mott MacDonald_TTRENT_T_F0002_T0200_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T0200. ED	Mott MacDonald_TTRENT_T_F0002_T0200_V01 tcf	Mott MacDonald_TTRENT_T_F0002_T0200_V01.tgc	2d_vzsh_TTRENT_T_F0002_T0200_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br2a_F0002_T1000	Mott MacDonald_TTRENT_Br2a_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_Br2a_F0002_T1000_V01.tcf	Mott MacDonald_TTRENT_Br2a_F0002_T1000_V01 tgc	2d_vzsh_TTRENT_Br2a_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br3_F0002_T1000	Mott MacDonald_TTRENT_Br3_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_Br3_F0002_T1000_V01.tcf	Mott MacDonald_TTRENT_Br3_F0002_T1000_V01.tgc	2d_vzsh_TTRENT_Br3_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br4_F0002_T1000	Mott MacDonald_TTRENT_Br4_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_Br4_F0002_T1000_V01.tcf	Mott MacDonald_TTRENT_Br4_F0002_T1000_V01.tgc	2d_vzsh_TTRENT_Br4_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br5_F0002_T1000	Mott MacDonald_TTRENT_Br5_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_Br5_F0002_T1000_V01.tcf	Mott MacDonald_TTRENT_Br5_F0002_T1000_V01.tgc	2d_vzsh_TTRENT_Br5_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br6a_F0002_T1000	Mott MacDonald_TTRENT_Br6a_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_Br6a_F0002_T1000_V01.tcf	Mott MacDonald_TTRENT_Br6a_F0002_T1000_V01 tgc	2d_vzsh_TTRENT_Br6a_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br6b_F0002_T1000	Mott MacDonald_TTRENT_Br6b_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_Br6b_F0002_T1000_V01.tcf	Mott MacDonald_TTRENT_Br6b_F0002_T1000_V01 tgc	2d_vzsh_TTRENT_Br6b_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br6d_F0002_T1000	Mott MacDonald_TTRENT_Br6d_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_Br6d_F0002_T1000_V01.tcf	Mott MacDonald_TTRENT_Br6d_F0002_T1000_V01 tgc	2d_vzsh_TTRENT_Br6d_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br7_F0002_T1000	Mott MacDonald_TTRENT_Br7_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_Br7_F0002_T1000_V01.tcf	Mott MacDonald_TTRENT_Br7_F0002_T1000_V01.tgc	2d_vzsh_TTRENT_Br7_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br8a_F0002_T1000	Mott MacDonald_TTRENT_Br8a_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_Br8a_F0002_T1000_V01.tcf	Mott MacDonald_TTRENT_Br8a_F0002_T1000_V01 tgc	2d_vzsh_TTRENT_Br8a_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br8b_F0002_T1000	Mott MacDonald_TTRENT_Br8b_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_Br8b_F0002_T1000_V01.tcf	Mott MacDonald_TTRENT_Br8b_F0002_T1000_V01 tgc	2d_vzsh_TTRENT_Br8b_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br8c_F0002_T	Mott MacDonald_TTRENT_Br8c_F0002_T1000_V0	Mott MacDonald_TTRENT_	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_Br8c_F0002_T1000_V0	Mott MacDonald_TTRENT_Br8c_F0002_T1000_V0	2d_vzsh_TTRENT_Br8c_F0002_T1000_V01.M F	Mott MacDonald_TTRENT	Mott MacDonald_TTRENT

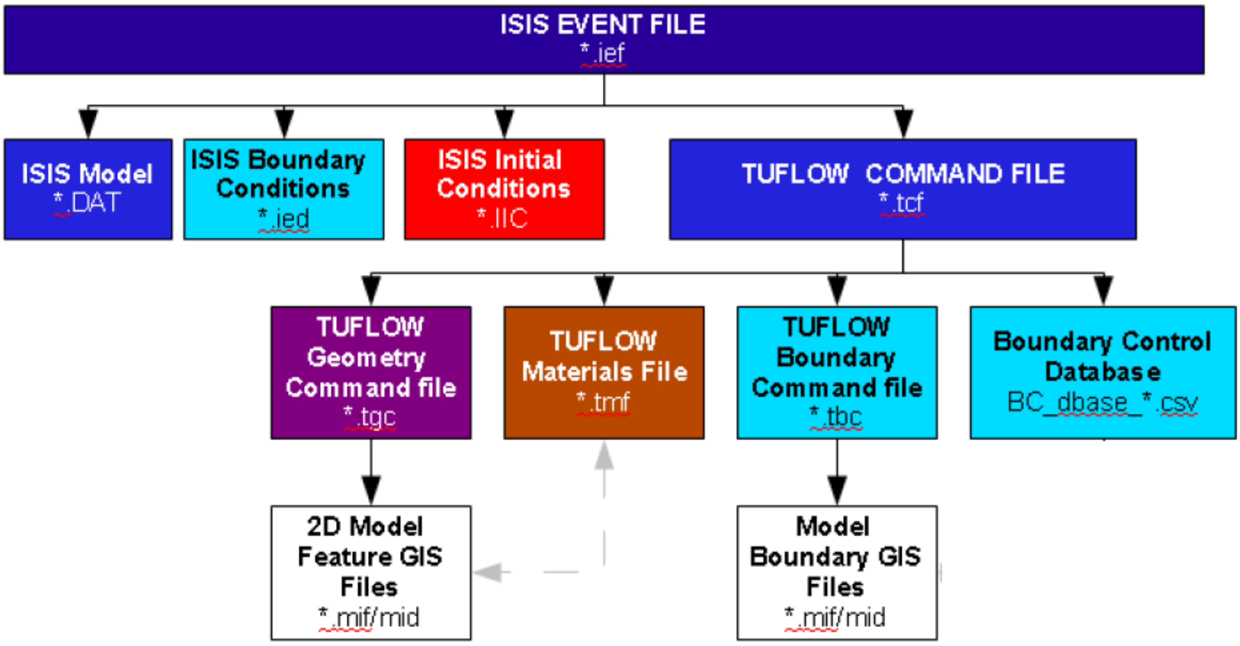
Scenario	Model Run ID	Run File .ief	ISIS model .DAT	ISIS 1D fluvial inflow .IED	ISIS 1D tidal inflow .IED	TUFLOW control file .tcf	TUFLOW Geometry File .tgc	Variable Breach File	TUFLOW Boundary File .tbc	TUFLOW Materials File .tmf
	1000	1.ief	01.DAT			1.tcf	1 tgc		_01.tbc	_01 tmf
	Mott MacDonald_TTRENT_Br8d_F0002_T1000	Mott MacDonald_TTRENT_Br8d_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_Br8d_F0002_T1000_V01.tcf	Mott MacDonald_TTRENT_Br8d_F0002_T1000_V01 tgc	2d_vzsh_TTRENT_Br8d_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br12a_F0002_T1000	Mott MacDonald_TTRENT_Br12a_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_Br12a_F0002_T1000_V01.tcf	Mott MacDonald_TTRENT_Br12a_F0002_T1000_V01 tgc	2d_vzsh_TTRENT_Br12a_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Br12b_F0002_T1000	Mott MacDonald_TTRENT_Br12b_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_Br12b_F0002_T1000_V01.tcf	Mott MacDonald_TTRENT_Br12b_F0002_T1000_V01 tgc	2d_vzsh_TTRENT_Br12b_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald TTRENT Br13a F0002 T1000	Mott MacDonald TTRENT Br13a F0002 T1000 V01.ief	Mott MacDonald TTRENT 01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald TTRENT Br13a F0002 T1000 V01.tcf	Mott MacDonald TTRENT Br13a F0002 T1000 V01 tgc	2d_vzsh_TTRENT_Br13a_F0002_T1000_V01.M F	Mott MacDonald TTRENT _01.tbc	Mott MacDonald TTRENT _01 tmf
	Mott MacDonald_TTRENT_Br13b_F0002_T1000	Mott MacDonald_TTRENT_Br13b_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_Br13b_F0002_T1000_V01.tcf	Mott MacDonald_TTRENT_Br13b_F0002_T1000_V01 tgc	2d_vzsh_TTRENT_Br13b_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_A1_F0002_T1000	Mott MacDonald_TTRENT_A1_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_A1_F0002_T1000_V01.tcf	Mott MacDonald_TTRENT_A1_F0002_T1000_V01 tgc	2d_vzsh_TTRENT_A1_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_A3_F0002_T1000	Mott MacDonald_TTRENT_A3_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_A3_F0002_T1000_V01.tcf	Mott MacDonald_TTRENT_A3_F0002_T1000_V01 tgc	2d_vzsh_TTRENT_A3_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_B_F0002_T1000	Mott MacDonald_TTRENT_B_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_B_F0002_T1000_V01 tcf	Mott MacDonald_TTRENT_B_F0002_T1000_V01.tgc	2d_vzsh_TTRENT_B_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald TTRENT C F0002 T1000	Mott MacDonald TTRENT C F0002 T1000 V01.ief	Mott MacDonald TTRENT 01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald TTRENT C F0002 T1000 V01 tcf	Mott MacDonald TTRENT C F0002 T1000 V01 tgc	2d_vzsh_TTRENT_C_F0002_T1000_V01.M F	Mott MacDonald TTRENT _01.tbc	Mott MacDonald TTRENT _01 tmf
	Mott MacDonald_TTRENT_D_F0002_T1000	Mott MacDonald_TTRENT_D_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_D_F0002_T1000_V01 tcf	Mott MacDonald_TTRENT_D_F0002_T1000_V01 tgc	2d_vzsh_TTRENT_D_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_E1_F0002_T1000	Mott MacDonald_TTRENT_E1_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_E1_F0002_T1000_V01.tcf	Mott MacDonald_TTRENT_E1_F0002_T1000_V01 tgc	2d_vzsh_TTRENT_E1_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_E_F0002_T1000	Mott MacDonald_TTRENT_E_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_E_F0002_T1000_V01 tcf	Mott MacDonald_TTRENT_E_F0002_T1000_V01.tgc	2d_vzsh_TTRENT_E_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_F_F0002_T1000	Mott MacDonald_TTRENT_F_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_F_F0002_T1000_V01 tcf	Mott MacDonald_TTRENT_F_F0002_T1000_V01.tgc	2d_vzsh_TTRENT_F_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald TTRENT I F0002 T1000	Mott MacDonald_TTRENT_I_F0002_T1000_V01.ief	Mott MacDonald TTRENT 01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_I_F0002_T1000_V01.tcf	Mott MacDonald TTRENT I F0002 T1000 V01.tgc	2d_vzsh_TTRENT_I_F0002_T1000_V01.M F	Mott MacDonald TTRENT _01.tbc	Mott MacDonald TTRENT _01 tmf
	Mott MacDonald_TTRENT_J2_F0002_T1000	Mott MacDonald_TTRENT_J2_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_J2_F0002_T1000_V01 tcf	Mott MacDonald_TTRENT_J2_F0002_T1000_V01 tgc	2d_vzsh_TTRENT_J2_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_K2_F0002_T1000	Mott MacDonald_TTRENT_K2_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_K2_F0002_T1000_V01.tcf	Mott MacDonald_TTRENT_K2_F0002_T1000_V01 tgc	2d_vzsh_TTRENT_K2_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_L_F0002_T1000	Mott MacDonald_TTRENT_L_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_L_F0002_T1000_V01 tcf	Mott MacDonald_TTRENT_L_F0002_T1000_V01.tgc	2d_vzsh_TTRENT_L_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_Q_F0002_T1000	Mott MacDonald_TTRENT_Q_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_Q_F0002_T1000_V01 tcf	Mott MacDonald_TTRENT_Q_F0002_T1000_V01 tgc	2d_vzsh_TTRENT_Q_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald TTRENT R F0002 T1000	Mott MacDonald TTRENT R F0002 T1000 V01.ief	Mott MacDonald TTRENT 01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald TTRENT R F0002 T1000 V01 tcf	Mott MacDonald TTRENT R F0002 T1000 V01 tgc	2d_vzsh_TTRENT_R_F0002_T1000_V01.M F	Mott MacDonald TTRENT _01.tbc	Mott MacDonald TTRENT _01 tmf
	Mott MacDonald_TTRENT_S_F0002_T1000	Mott MacDonald_TTRENT_S_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_S_F0002_T1000_V01 tcf	Mott MacDonald_TTRENT_S_F0002_T1000_V01.tgc	2d_vzsh_TTRENT_S_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_T_F0002_T1000	Mott MacDonald_TTRENT_T_F0002_T1000_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0002. ED	TTRENT_T1000. ED	Mott MacDonald_TTRENT_T_F0002_T1000_V01 tcf	Mott MacDonald_TTRENT_T_F0002_T1000_V01.tgc	2d_vzsh_TTRENT_T_F0002_T1000_V01.M F	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
Sensitivity Test	Mott MacDonald_TTRENT_F0100_T0005	Mott MacDonald_TTRENT_F0100_T0005_MANN_p20_V17.ief	Mott MacDonald_TTRENT_01_MAN+20%.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_F0100_T0005_MANN_p20_V17.tcf	Mott MacDonald_TTRENT_DEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01_MANN+20% tmf
	Mott MacDonald_TTRENT_F0100_T0005	Mott MacDonald_TTRENT_F0100_T0005_MANN_m20_V17.ief	Mott MacDonald_TTRENT_01_MAN-20%.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_F0100_T0005_MANN_m20_V17 tcf	Mott MacDonald_TTRENT_DEFENDED_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01_MANN-20% tmf
Newton FAS	Mott MacDonald_TTRENT_F0020_T0005_NFAS	Mott MacDonald_TTRENT_F0020_T0005_NFAS_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0020. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_F0020_T0005_NFAS_V01.tcf	Mott MacDonald_TTRENT_DEFENDED_NFAS_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf
	Mott MacDonald_TTRENT_F0100_T0005_NFAS	Mott MacDonald_TTRENT_F0100_T0005_NFAS_V01.ief	Mott MacDonald_TTRENT_01.DAT	TTRENT_F0100. ED	TTRENT_T0005. ED	Mott MacDonald_TTRENT_F0100_T0005_NFAS_V01.tcf	Mott MacDonald_TTRENT_DEFENDED_NFAS_01.tgc	N/A	Mott MacDonald_TTRENT_01.tbc	Mott MacDonald_TTRENT_01 tmf

A.4. Model Operation

A.4.1. Model Run Files

The hydraulic models have been provided on the accompanying portable hard disk, see Appendix B for a detailed list of files. The model is run through the ISIS event file (*.ief) which in turn references the corresponding TUFLOW command file (*.tcf) which links to the 2D modelling files (see Figure A.2).

Figure A.2: Modelling Structure



The .ief should be used to run the model from the accompanying hard drive to achieve the fastest simulation times. The model can be run across an internal network. However, model run time may increase depending on network speeds, and file paths would need to be updated appropriately.

A.4.2. Hardware and Software Specification

All the hydraulic models developed use the single precision version of TUFLOW 2012-05-AE-isp-w64.

Table A.5 details the hardware system which has been used to run the hydraulic models. Whilst the model may run on computer systems of a lower specification, it is anticipated that this would result in much longer simulation times and could limit the analysis of the model results in SMS and GIS software.

Table A.4: Hardware Specification Used to Run the Tidal Trent Models

Computer System Feature	Specification
Processor	3.4 GHz
Operating System	Windows 7
Memory (RAM)	12GB
Storage	1TB

A.4.3. Model Outputs

Model Result Files

For each individual model run, the following modelling result files have been produced at each timestep as well as the maximum for the entire event simulated:

- 1D water level and flow results (*.zzn)
- 2D Flood depth (*_.xmdf)
- 2D Flow direction and magnitude (velocity) (*_.xmdf)
- 2D Water surface level (*_.xmdf)
- 2D UK Flood Hazard Rating Value (*_.xmdf)

Flood depth, velocity and water surface level are directly calculated in the TUFLOW model. Flood hazard categorises the risk to people based on the combination of flood depth, velocity and the presence of debris in the water for each timestep. The calculation of flood hazard is based on the following formula:

$$FloodHazard = d\left(V + \frac{1}{2}\right) + DF$$

Where:

- *d* is the maximum depth of flooding;
- *V* is the maximum velocity of flood waters; and
- *DF* is the debris factor.

The presence of debris can influence the hazard level. However, the application of debris factors can be subjective. For the purposes of this study, the values used were as per guidance in FD2321/TR1 and FD2320/TR2 (Table A.5).

Table A.5: Debris Factors for Different Depths with Dominant Land Use

Depth (m)	Debris Factor by Dominant Land Use		
	Pasture	Woodland	Urban
0 - 0.25	0	0	0
0.25 – 0.75	0	0.5	1
> 0.75 (or velocity > 2m/s)	0.5	1	1

Source: Table 1. SUPPLEMENTARY NOTE ON FLOOD HAZARD RATINGS AND THRESHOLDS (May 2008)

The raw TUFLOW results can be found in the 'results' folder and viewed directly in SMS software (Surface Water Modelling Software produced by Aquaveo). Alternatively the .xmdf files can be converted to GIS grid files using the TUFLOW_to_GIS.exe utility (produced by TUFLOW WBM-BMT). The grids for the maximums have been provided as ASCII files (Appendix B).

Individual Model Log Files

Model log files (*.zzd and *.tlf) for each model run have been produced, detailing the model files and run diagnostics at each timestep. All log files can be found in the 'Log' folder in the hydraulic modelling files and can be viewed in any text editor.

Model Check Files

A number of check files have been created. Check files for each model scenario can be found in the 'Checks' folder of the hydraulic modelling files and can be imported into MapINFO or Excel depending on the check file type.

A.5. Recommendations for Future Development

The hydraulic models have been developed and used to assess flood risk from the Tidal Trent and its tributaries at a strategic level. The following recommendations can be drawn from the models developed for this study:

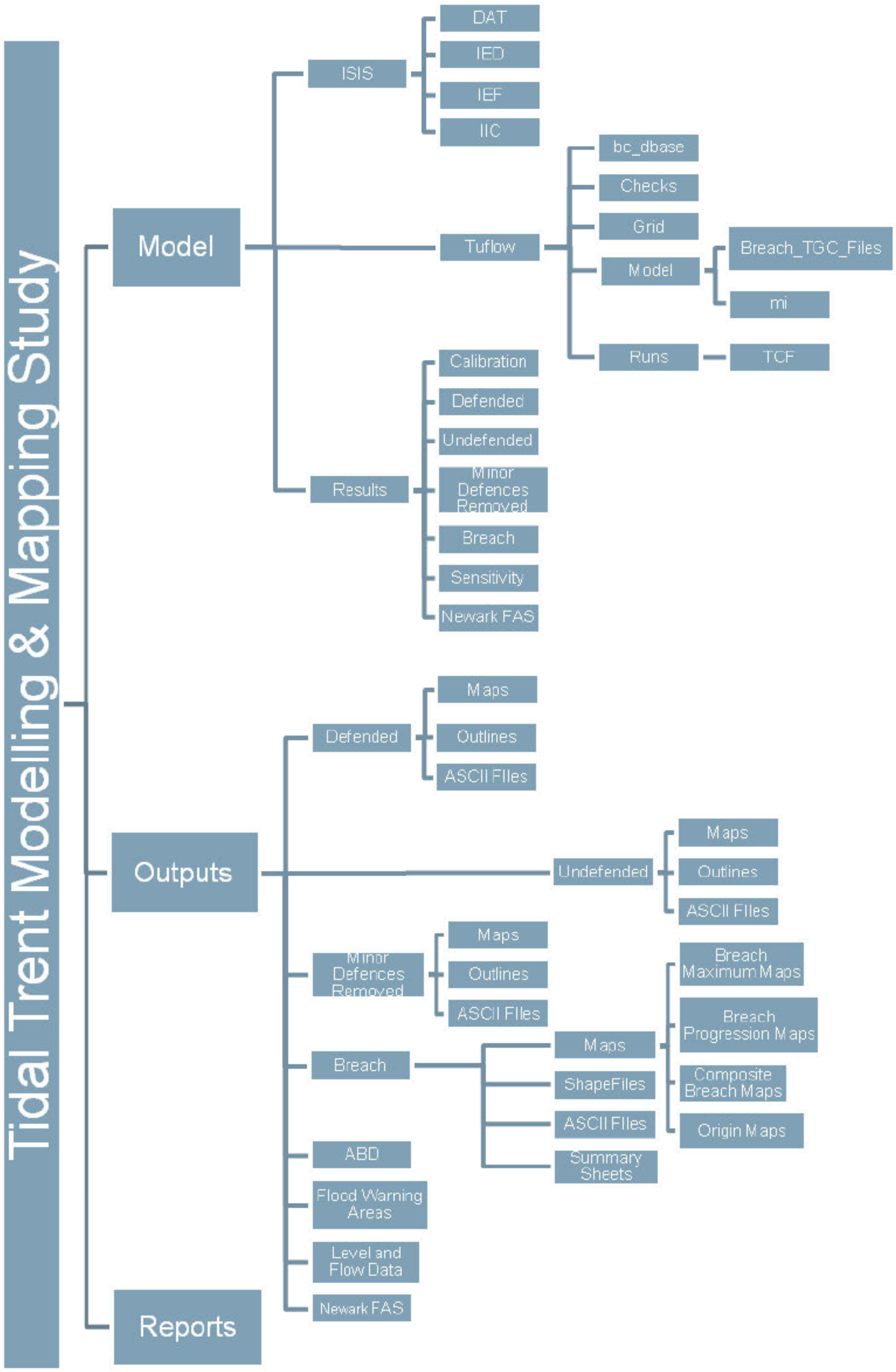
- A review of the hydraulic model should be undertaken to ensure it is fit for any purpose other than the aims and objectives of this study.
- The model has been developed using the best available information. However further calibration of the model following significant flood events in the future would increase confidence in the model outputs.
- The 2D model grid resolution of 25m does not necessarily pick up all small-scale features particularly in the urban environment, including variation in building thresholds. Assessment of localised schemes should review the representation of small-scale local features and representation of buildings to ensure the model is fit for purpose.

Appendix B. Deliverables

A complete set of the digital files, flood maps and animations produced from this study has been supplied to the Environment Agency on the accompanying hard drive along with a complete set of the hydraulic modelling files.

Figure B.1 shows the data file structure on the accompanying hard drive. Table B.1 outlines the deliverables produced.

Figure B.1: Accompanying Hard Drive File Structure



Mott MacDonald

Table B.1: Key Deliverables

Scenario	Model Run ID	Flood Map	Model Outputs	GIS Files			Breach Mapping	
		Maximum Depth, Velocity and Hazard Flood Maps	Level, Depth, Hazard, Flow & Flow Direction	Maximum Extent	Depth, Velocity Level & Hazard Grids	Areas Benefiting from Defences	Flood Progression Mapping	Maximum Depth, Velocity & Hazard Mapping
Calibration	Mott MacDonald_TTRENT_JAN2005	N/A	.xmdf	N/A	.asc	N/A	N/A	N/A
	Mott MacDonald_TTRENT_JULY2012	N/A	.xmdf	N/A	.asc	N/A	N/A	N/A
	Mott MacDonald_TTRENT_JUN2007	N/A	.xmdf	N/A	.asc	N/A	N/A	N/A
	Mott MacDonald_TTRENT_NOV2000	N/A	.xmdf	N/A	.asc	N/A	N/A	N/A
	Mott MacDonald_TTRENT_NOV2011	N/A	.xmdf	N/A	.asc	N/A	N/A	N/A
	Mott MacDonald_TTRENT_NOV2012	N/A	.xmdf	N/A	.asc	N/A	N/A	N/A
Defended Model	Mott MacDonald_TTRENT_F0010_T0005	.pdf	.xmdf	.shp	.asc	N/A	N/A	N/A
	Mott MacDonald_TTRENT_F0100_T0005	.pdf	.xmdf	.shp	.asc	.shp	N/A	N/A
	Mott MacDonald_TTRENT_F1000_T0005	.pdf	.xmdf	.shp	.asc	N/A	N/A	N/A
	Mott MacDonald_TTRENT_F0020_T0005	.pdf	.xmdf	.shp	.asc	N/A	N/A	N/A
	Mott MacDonald_TTRENT_F0005_T0005	.pdf	.xmdf	.shp	.asc	N/A	N/A	N/A
	Mott MacDonald_TTRENT_F0050_T0005	.pdf	.xmdf	.shp	.asc	N/A	N/A	N/A
	Mott MacDonald_TTRENT_F0075_T0005	.pdf	.xmdf	.shp	.asc	N/A	N/A	N/A
	Mott MacDonald_TTRENT_F0200_T0005	.pdf	.xmdf	.shp	.asc	N/A	N/A	N/A
	Mott MacDonald_TTRENT_F0002_T0200	.pdf	.xmdf	.shp	.asc	.shp	N/A	N/A
	Mott MacDonald_TTRENT_F0002_T1000	.pdf	.xmdf	.shp	.asc	N/A	N/A	N/A
	Mott MacDonald_TTRENT_F0100CC_T0005	.pdf	.xmdf	.shp	.asc	N/A	N/A	N/A
	Mott MacDonald_TTRENT_F0002_T0200CC_CF	.pdf	.xmdf	.shp	.asc	N/A	N/A	N/A
	Mott MacDonald_TTRENT_F0002_T0200CC_UE	.pdf	.xmdf	.shp	.asc	N/A	N/A	N/A
Undefended Model	Mott MacDonald_TTRENT_F0100_T0005	.pdf	.xmdf	.shp	.asc	.shp	N/A	N/A
	Mott MacDonald_TTRENT_F1000_T0005	.pdf	.xmdf	.shp	.asc	N/A	N/A	N/A
	Mott MacDonald_TTRENT_F0002_T0200	.pdf	.xmdf	.shp	.asc	.shp	N/A	N/A
	Mott MacDonald_TTRENT_F0002_T1000	.pdf	.xmdf	.shp	.asc	N/A	N/A	N/A
Minor Defences Removed	Mott MacDonald_TTRENT_F0010_T0005_MINOR	.pdf	.xmdf	.shp	.asc	N/A	N/A	N/A
Breach	Mott MacDonald_TTRENT_Br2a_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br3_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br4_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br5_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf

Scenario	Model Run ID	Flood Map	Model Outputs	GIS Files			Breach Mapping	
		Maximum Depth, Velocity and Hazard Flood Maps	Level, Depth, Hazard, Flow & Flow Direction	Maximum Extent	Depth, Velocity Level & Hazard Grids	Areas Benefiting from Defences	Flood Progression Mapping	Maximum Depth, Velocity & Hazard Mapping
	MacDonald_TTRENT_Br6a_F1000_T0005							
	Mott MacDonald_TTRENT_Br6b_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br6d_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br7_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br8a_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br8b_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br8c_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br8d_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br12a_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br12b_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br13a_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br13b_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_A1_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_A3_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_B_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_C_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_D_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_E1_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_E_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_F_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_I_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_J2_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_K2_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_L_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Q_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_R_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_S_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_T_F1000_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf

Scenario	Model Run ID	Flood Map	Model Outputs	GIS Files			Breach Mapping	
		Maximum Depth, Velocity and Hazard Flood Maps	Level, Depth, Hazard, Flow & Flow Direction	Maximum Extent	Depth, Velocity Level & Hazard Grids	Areas Benefiting from Defences	Flood Progression Mapping	Maximum Depth, Velocity & Hazard Mapping
	Mott MacDonald_TTRENT_Br2a_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br3_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br4_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br5_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br6a_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br6b_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br6d_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br7_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br8a_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br8b_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br8c_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br8d_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br12a_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br12b_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br13a_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br13b_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_A1_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_A3_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_B_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_C_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_D_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_E1_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_E_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_F_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_I_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf

Scenario	Model Run ID	Flood Map: Maximum Depth, Velocity and Hazard Flood Maps	Model Outputs: Level, Depth, Hazard, Flow & Flow Direction	GIS Files: Maximum Extent	GIS Files: Depth, Velocity Level & Hazard Grids	GIS Files: Areas Benefiting from Defences	Breach Mapping: Flood Progression Mapping	Breach Mapping: Maximum Depth, Velocity & Hazard Mapping
	Mott MacDonald_TTRENT_J2_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_K2_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_L_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Q_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_R_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_S_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_T_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br2a_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br3_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br4_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br5_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br6a_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br6b_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br6d_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br7_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br8a_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br8b_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br8c_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br8d_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br12a_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br12b_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br13a_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br13b_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_A1_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_A3_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf

Scenario	Model Run ID	Flood Map	Model Outputs	GIS Files			Breach Mapping		
		Maximum Depth, Velocity and Hazard Flood Maps	Level, Depth, Hazard, Flow & Flow Direction	Maximum Extent	Depth, Velocity Level & Hazard Grids	Areas Benefiting from Defences	Flood Progression Mapping	Maximum Depth, Velocity & Hazard Mapping	
	Mott MacDonald_TTRENT_B_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf	
	Mott MacDonald_TTRENT_C_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf	
	Mott MacDonald_TTRENT_D_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf	
	Mott MacDonald_TTRENT_E1_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf	
	Mott MacDonald_TTRENT_E_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf	
	Mott MacDonald_TTRENT_F_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf	
	Mott MacDonald_TTRENT_I_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf	
	Mott MacDonald_TTRENT_J2_F0002_T0200	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf	
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	Mott	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf	

Scenario	Model Run ID	Flood Map	Model Outputs	GIS Files			Breach Mapping	
		Maximum Depth, Velocity and Hazard Flood Maps	Level, Depth, Hazard, Flow & Flow Direction	Maximum Extent	Depth, Velocity Level & Hazard Grids	Areas Benefiting from Defences	Flood Progression Mapping	Maximum Depth, Velocity & Hazard Mapping
	MacDonald_TTRENT_Br12b_F0002_T1000							
	Mott MacDonald_TTRENT_Br13a_F0002_T1000	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
	Mott MacDonald_TTRENT_Br13b_F0002_T1000	N/A	.xmdf	N/A	.asc	N/A	.pdf	.pdf
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Sensitivity Test	Mott MacDonald_TTRENT_F0100_T0005	N/A	.xmdf	N/A	.asc	N/A	N/A	N/A
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Newton Flood Alleviation Scheme	Mott MacDonald_TTRENT_F0020_T0005_NFAS	N/A	.xmdf	N/A	.asc	N/A	N/A	N/A
	Mott MacDonald_TTRENT_F0100_T0005_NFAS	N/A	.xmdf	N/A	.asc	N/A	N/A	N/A

Appendix C. Hydrological Analysis

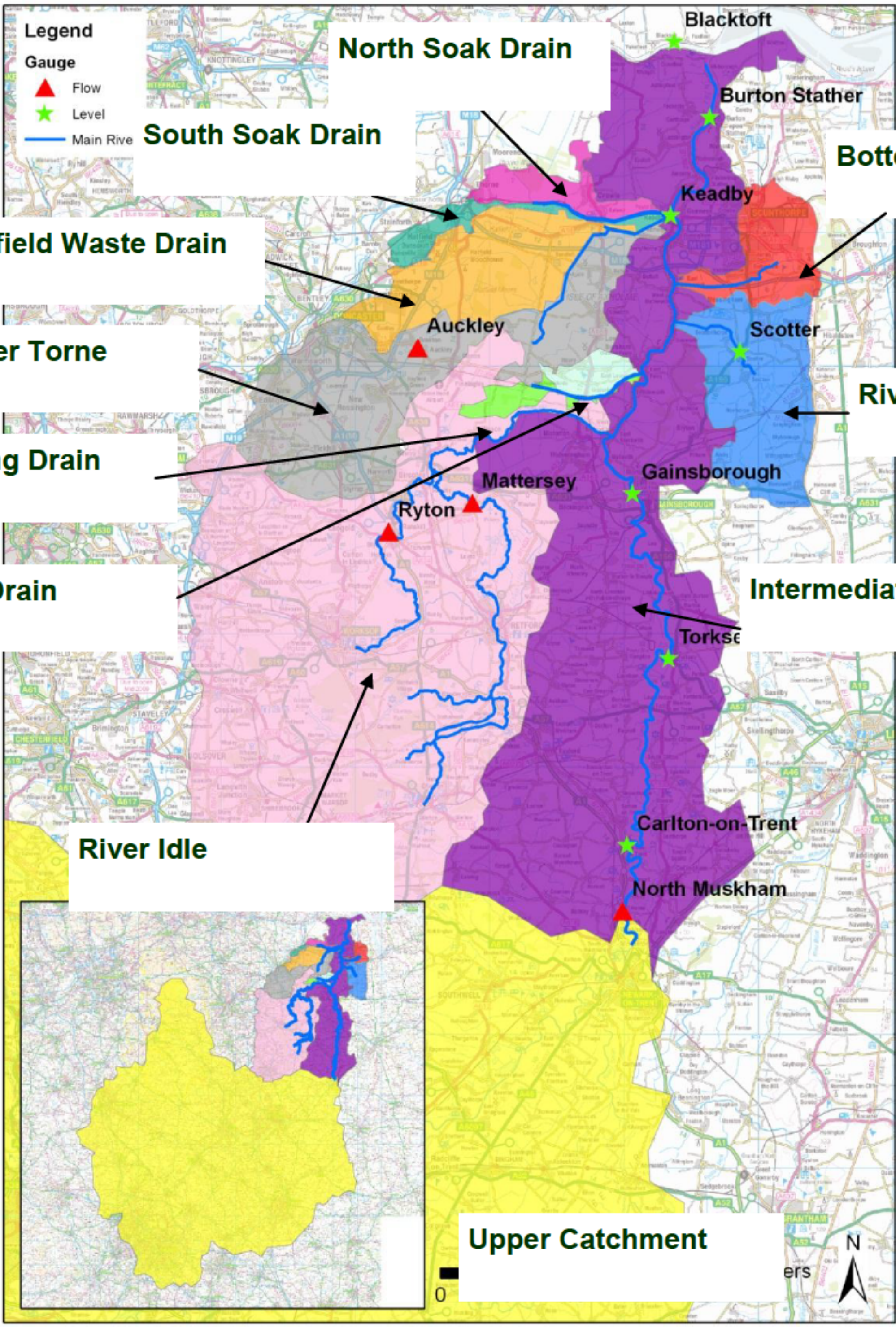
C.1 Catchment Characteristics

The River Trent catchment covers an area of around 10,450 km^2, the majority of which is upstream of the tidal limit of the Trent. The tidal limit of the Trent is 1.5 km upstream of Cromwell Weir at North Muskham flow and level gauge. The location of the North Muskham gauging station, 4.5 km downstream of the upper limit of the model extent, has been used to separate the catchment into upper and lower catchments.

The upper catchment covers the area upstream of North Muskham. The remaining part of the Trent catchment forms the lower catchment. This was then subdivided into a number of sub-catchments based on the individual sub-catchment characteristics and study requirements, as shown in Figure C.1. The corresponding area for each sub-catchment is given in Table C.1.

Flow gauges along the watercourses are indicated in red, and level gauges in green. Adjacent to the Tidal Trent, there are a large number of small tributaries, draining directly into the Trent. These have been combined into one catchment area named ‘Intermediate Catchments’.

Figure C.1: Division of Sub-catchments



Source: Mott MacDonald. This map is reproduced by permission of Ordnance Survey on behalf of The Controller Of Her Majesty's Stationary Office. © Crown Copyright. All rights reserved. Environment Agency 100026380, 2013.

Table C.1: Areas of Sub-Catchments

Catchment	Area (from DTM) km^2	Proportion of Total Trent Catchment
Upstream of North Muskham	8240	79%
River Idle	855	8%
Warping Drain and Ferry Drain (Combined to make Snow Sewer)	28	0.2%
River Torne	206	2%
Hatfield Waste Drain	102	1%
South Soak Drain	22	0.2%
North Soak Drain	30	0.3%
River Eau	113	1%
Bottesford Beck	53	0.5%
Intermediate catchments (remaining minor tributaries flowing directly into Tidal Trent)	799	8%

Source: Mott MacDonald: catchment areas derived from DTM

C.1.1 Upper Catchments - Upstream of North Muskham

The catchment upstream of North Muskham is the largest gauged catchment on the Trent with a catchment area of 8240 km^2 and contributes to 79% of the overall catchment area for the Trent. There is a large range of land uses and varying geological structure. The catchment is predominantly impervious, due to a bedrock of glacial clay and Mercia Mudstone, although there is some sandstone and limestone around Dove, Derwent and downstream of Nottingham.

The most significant urban area, situated in the head waters of the catchment, is Birmingham. Other large urban areas within the catchment include:

- Leicester;
- Loughborough;
- Derby;
- Nottingham;
- Wolverhampton;
- Stafford;
- Stoke-on-Trent;
- Newark-on-Trent.

The urban areas cover a total of 1244 km^2, 15% of the upper catchment. The north of the catchment incorporates around 70% of the Peak District National Park. The remaining land is mainly used for agricultural purposes.

C.1.2 Lower Catchment – Downstream of North Muskham

The catchment downstream of North Muskham has an area of 2208 km^2, 21% of the overall catchment area for the Trent. The land is mainly low lying with large embankments on either side of the watercourses. The tributaries considered are:

- River Idle;
- Snow Sewer (Comprising Warping Drain and Ferry Drain);
- River Torne;
- Hatfield Waste Drain;
- South Soak Drain;
- North Soak Drain;
- River Eau;
- Bottesford Beck.

The characteristics for the tributaries and intermediate catchment are described in the sections below.

C.1.2.1 River Idle

The River Idle has a predominantly rural catchment, with Mansfield, Worksop and Retford being the only significant urban areas. The catchment is mainly a low relief catchment, although moderate in its headwaters. Its tributaries rise on magnesian limestone, and move onto sandstone, with the lower reaches underlain by alluvium and mudstone. The catchment has a SPRHOST value of 19.12, and is therefore defined as a Permeable Catchment according to the FEH definitions.

In its lower reaches, the river flows behind raised flood embankments, and the surrounding land is drained into the river through a number of sluices and pumping stations. At the confluence of the River Idle with the Tidal Trent, the outflow is controlled by West Stockwith Pumping Station. There is a sluice at the pumping station for discharging flow into the Trent when levels in the Trent are sufficiently low, however, this level is highly unlikely to be attained during a flood event on the Trent.

C.1.2.2 Snow Sewer (Comprising Warping Drain and Ferry Drain)

Snow Sewer is a very small catchment, with Warping Drain draining the southern section, and Ferry Drain the northern section. The Southern Section is entirely rural, and the northern section includes the village of Haxey. The land is very low lying with a number of embanked drainage ditches feeding into the drains.

C.1.2.3 River Torne, Hatfield Waste Drain, South Soak Drain and North Soak Drain

The River Torne, Hatfield Waste Drain, South Soak and North Soak Drains all discharge into the Trent through Keadby Pumping Station. Much of the land is below 2 mAOD and is drained through a network of pumps and sluices into the various drains, leading to Keadby Pumping Station. The pumping station also has a sluice for discharging flow when the levels in the Trent are sufficiently low. The Trent is likely to be above the required level for free discharge during all flood events on the Trent.

The catchment is predominantly underlain by mudstone, siltstone and sandstone. The most significant urban settlement in the catchment is the south eastern edge of Doncaster.

C.1.2.4 River Eau

The River Eau catchment is relatively small with the main settlement being the village of Scotter, which was flooded in June 2007, affecting over 30 properties. The River Eau discharges into the Tidal Trent via flapped outfalls, with a large volume of storage available both upstream of the outfall in the form of washlands, and behind flood banks. The catchment is mainly well drained agricultural land, with sand and gravel overlying layers of mudstone and limestone.

C.1.2.5 Bottesford Beck

Bottesford Beck is a minor tributary of the Tidal Trent and discharges via flapped outfalls into the Trent at West Butterwick. The catchment incorporates the urban area of Scunthorpe, covering around 40% of the catchment.

The headwaters of Bottesford Beck are underlain by limestone, and the lower reaches by mudstone and sandstone.

C.1.2.6 Intermediate Catchments

The remaining catchment area adjacent to the Tidal Trent consists of a large number of small tributaries discharging through numerous flapped outfalls. The land is predominantly used for agricultural purposes, with the most significant settlement being Gainsborough. There are a number of other small settlements located along the banks of the Trent.

The underlying bedrock in this area is mudstone, siltstone and sandstone.

C.2 Existing Studies and Hydrological Data Availability

C.2.1 Existing Hydrological Studies

A number of reports on previous hydrological analyses in the Tidal Trent area have been made available for the purposes of this study. A summary of the relevant sections and methodologies used in each report is provided below. They include:

- Tidal Trent Strategy Report;
- Fluvial Trent Strategy Modelling Report;
- River Idle Flood Risk Mapping Report;
- River Torne Modelling Study Report;
- Scotter Modelling Report;
- River Humber, North Bank Tidal Modelling Report.

C.2.1.1 Tidal Trent Strategy Report

Appendix F - Modelling Report

The Tidal Trent Strategy Report was produced by Black & Veatch in 2005 for the Environment Agency. The study used the recommended peak flows for North Muskham, as provided in the Fluvial Trent Strategy Report, as an inflow at Winthorpe Bridge.

No inflows from the tributaries were considered as the discharge from the largest pumping station (34 m^3/s) was insignificant compared to the flows in the Trent. It was also explained that the response of the tributaries would be much shorter than that of the Tidal Trent due to the relative size of the catchment areas, therefore any flood waves from the tributaries will have dissipated before the main fluvial flood wave from the Trent catchment arrives.

A design hydrograph for the model inflow at Winthorpe Bridge, covering the fluvial Trent catchment, was generated using the Archer Method. The same hydrograph shape was used for all design inflows, with the flow being scaled to ensure that the peak flow corresponded to that recommended in the Fluvial Trent Strategy Report.

C.2.1.2 Fluvial Trent Strategy Modelling Report

Volume 1 - Final Hydrological Report

The Fluvial Trent Strategy Report was issued in 2003 by Black & Veatch for the Environment Agency, and details the methodologies adopted and results obtained in producing design flow estimates for key gauging stations on the River Trent. These were used as inflows for the final hydraulic models produced during the Fluvial Trent Strategy.

"To ensure consistency of design flows in the downstream sections of the River Trent the recommended design values for North Muskham have been adjusted with reference to the corresponding estimates for the Trent at Nottingham.

The recommended 2-year flood peak of 484 m^3/s for North Muskham was obtained by multiplying the recommended 2-year flood peak at Nottingham by the ratio of the 2-year flood estimates for the two locations as obtained from the GEV analysis for the common period of records 1968 – 2000.

The recommended design flood estimates at North Muskham for larger events were obtained by multiplying the 2-year flood peak of 484 m^3/s by flood growth factors implicit in the recommended design values for the Trent at Nottingham."

Fluvial Trent Strategy Report – Black & Veatch, 2003, Page 11

Table C.2: provides the recommended peak flow estimates at North Muskham in the Fluvial Trent Strategy Hydrological Report.

Table C.2: Peak Flow Estimates at North Muskham from Fluvial Trent Strategy Hydrological Report

Return Period (1 in x year)	Flow (m^3/s)
2	484
5	680
10	815
25	990
50	1110
75	1175
100	1220
150	1270
200	1320

Source: Fluvial Trent Strategy Hydrological Report – Black & Veatch, 2003

C.2.1.3 River Idle Flood Risk Mapping Report

The River Idle Flood Risk Mapping Report was produced by JBA Consulting in March 2005 for the Environment Agency. The study included an assessment of the flood hydrology and the development of a hydraulic model to provide flood outline extents.

The hydrological assessment focused on five gauging stations located on the important tributaries of the River Idle –River Maun, River Meden, River Poulter, and River Ryton. These gauging stations were then used as donor sites for design-flood estimation at other sub-catchments. Both the statistical and rainfall-runoff methods were used at each of the five gauging stations, with the exception of the statistical method on the River Poulter (as the EA advised caution on using the data from the River Poulter gauging station).

Pooled analysis was undertaken at gauging stations on the River Maun and River Meden due to short record length, and single site analysis at stations on the River Idle and River Ryton as the pooled analysis yielded growth curves that were considered to be too shallow. The rainfall-runoff method was found to yield higher estimates than the statistical method, however, due to the permeable nature of many areas of the catchment, the statistical method was chosen to estimate design floods.

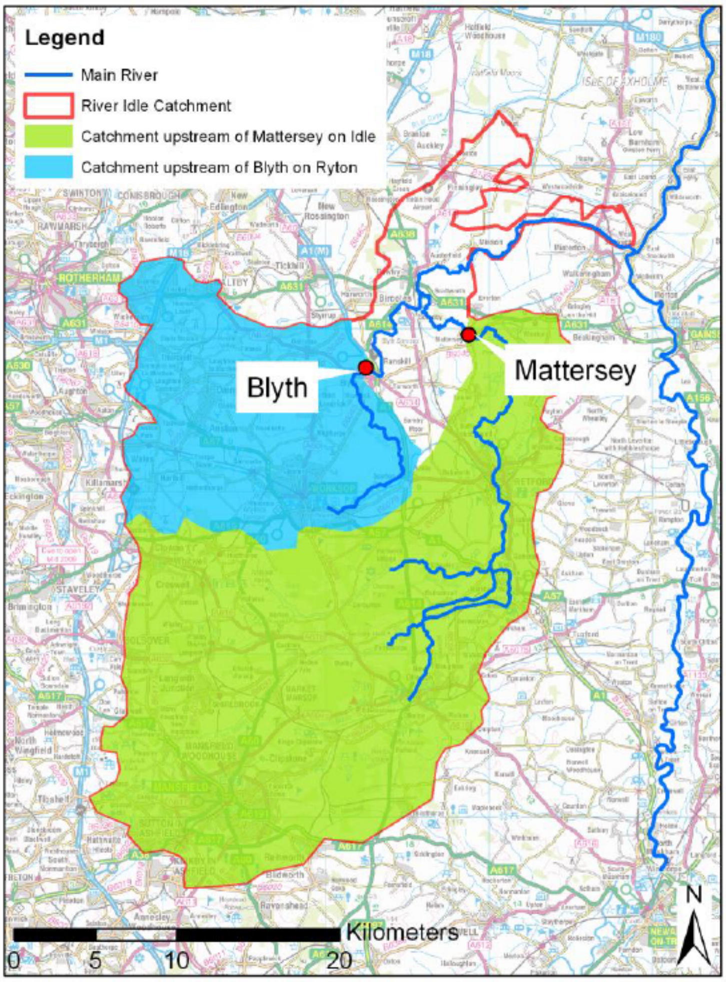
The catchment areas upstream of Mattersey on the River Idle and Blyth on the River Ryton cover 61% and 26% respectively of the total Idle catchment area, and therefore the design flood estimates calculated at these gauging stations have been provided in Table C.3 as together they cover the majority of the Idle catchment. The locations of these gauging stations and their respective catchments are shown in Figure C.2.

Table C.3: Design Peak Flow Estimates at Mattersey and Blyth from River Idle Flood Risk Mapping Report

Return Period (1 in x year)	Design Flow at Mattersey (m^3/s) Single Site GL-LMOM analysis	Design Flow at Blyth (m^3/s) Single Site GL-LMOM analysis
2	8.7	8.9
5	12	12.1
10	14.6	14.7
25	18.8	19.1
50	22.9	23.3
75	25.6	26.2
100	27.8	28.6
150	31.2	32.3
200	33.9	35.2

Source: River Idle Flood Risk Mapping Report – JBA, 2005

Figure C.2: Location of Gauging Stations and Catchment Extents on River Idle



Source: Mott MacDonald. This map is reproduced by permission of Ordnance Survey on behalf of The Controller Of Her Majesty's Stationary Office. © Crown Copyright. All rights reserved. Environment Agency 100026380, 2013.

C.2.1.4 River Torne Modelling Study Report

The River Torne Modelling Study Report, issued in 2005 by Black & Veatch for the Environment Agency, covers the River Torne, Hatfield Waste Drain, North Soak Drain, South Soak Drain, South Level Engine Drain and North Level Engine Drain, all of which feed Keadby Pumping Station. The study area included one flow measuring station on the Torne at Auckley, and seven level gauges, predominantly used for calibration purposes.

The catchment area upstream of Auckley is 118 km^2, 33% of the overall catchment area considered in this study. Data was available at this station from 1971 till when the study was undertaken. The analysis undertaken showed that seasonal weed growth at the station had a significant effect on the stage-discharge relationship at the station. Single site, pooled analysis and rainfall runoff analysis were all undertaken and the pooled analysis results used, as the total record length was deemed too short for single site analysis, and the dryness of the catchment (SAAR<800mm) appears to have overestimated flows derived from rainfall runoff analysis. Table C.4 shows the adopted design flows at Auckley.

Table C.4: Design Flows at Auckley Used as Part of the Torne Modelling Study

Return Period (1 in x year)	Design Flow at Auckley Mattersey (m^3/s) Pooled Analysis - GL Distribution
2	7.2
5	10.1
10	11.9
25	14.3
50	16.1
75	17.2
100	18.1
150	19.2
200	20.1
1000	25.6

Source: River Torne Modelling Study Report – Black & Veatch, 2005

The study area includes an additional ungauged 'natural' inflow and 18 ungauged 'pumped' inflows. The 'natural' inflow was derived using catchment descriptors from the FEH CD ROM. The 'pumped' inflows were derived by calculating the flow arriving at each pumping station using FEH calculations, converting this to a volume of water, and assuming that the pumps would begin pumping at maximum capacity when the flow arriving at the pumping station equalled the amount that could be pumped. The pumps were then switched off when the total volume pumped equalled the total volume that would arrive at the station over the entire event.

The maximum pumping rate of Keadby Pumping Station allowed in the model is 29.1 m^3/s, and this flow rate is attained for all return periods modelled (1 in 5 year to 1 in 1000 year).

C.2.1.5 Scotter Modelling Report

The Scotter Modelling Report, produced by the Environment Agency, was undertaken to assess the potential benefit of a flood relief culvert through the A159 road bridge following flooding in June 2007 where over 30 properties in Scotter were affected.

Design flows were estimated using FEH catchment descriptors for the River Eau at Scottor, slightly upstream of Scotter. These were then adjusted to include the slightly larger catchment for the village of Scotter. Table C.5 provides these estimated flows.

Table C.5: Estimated Design Flows for Hydraulic Modelling at Scotter Village

Return Period (1 in x year)	Design Flow upstream of Scotter Village (m^3/s) FEH Characteristics
5	18.42
10	22.57
20	26.3
50	31.62
100	35.35

Source: Scotter Modelling Report, Environment Agency

The flows extracted from the downstream end of the model at its confluence with the Tidal Trent are given in Table C.6.

Table C.6: Modelled Design Flows at Confluence of River Eau and Tidal Trent from EA's Scotter Model

Return Period (1 in x year)	Design Flow at Confluence of River Eau and Tidal Trent
5	17.15
10	20.56
20	23.53
50	27.64
100	30.23

Source: Environment Agency

C.2.1.6 River Humber, North Bank Tidal Modelling

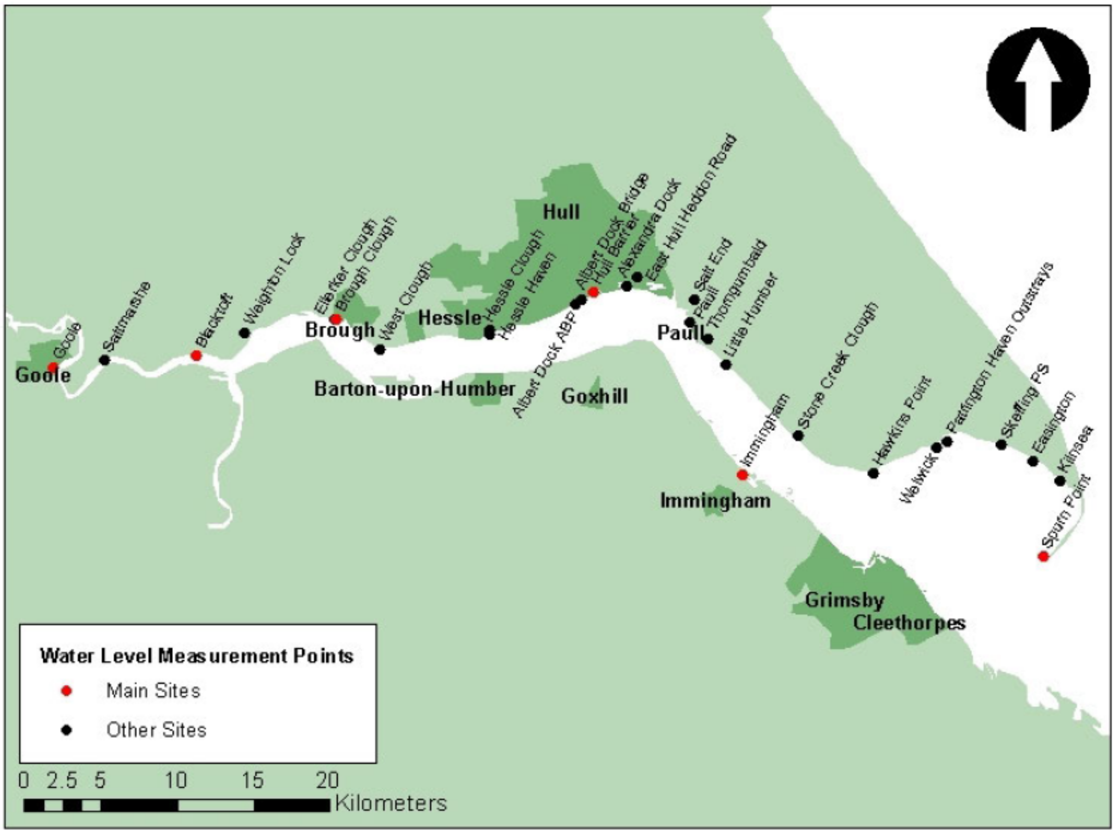
Appendix C - Water Level, Tide, Surge and Wave Analysis

The Water Level, Tide, Surge and Wave Analysis report produced by Mott MacDonald in 2011 for the Environment Agency created design hydrological parameters such as the tide, surge and wave conditions for a range of design events for use in the tidal modelling and mapping study of the Humber.

Water level data from the Environment Agency and Associated British Ports (ABP) at over 16 locations, including Blacktoft and Weighton Lock, was used to derive the design water levels. These locations are shown in Figure C.3.

Table C.7 provides the recommended design peak water levels at Blacktoft and Weighton Lock. The confluence of the Trent with the Humber is located 4km downstream of Blacktoft and 3km upstream of Weighton Lock.

Figure C.3: Location of Level Gauges Used as Part of River Humber, North Bank Tidal Modelling Study



Source: River Humber, North Bank Tidal Modelling Report - Mott MacDonald, 2011

Table C.7: Recommended Peak Design Levels from River Humber, North Bank Tidal Modelling Study Report

Return Period (1 in x year)	Blacktoft (mAOD)	Weighton Lock (mAOD)
1	5.13	5.06
5	5.33	5.28
10	5.43	5.37
20	5.5	5.44
50	5.61	5.56
100	5.65	5.6
200	5.69	5.64
500	5.8	5.71
1000	5.84	5.76
200 (2115)	6.82	6.77
1000 (2115)	6.97	6.89

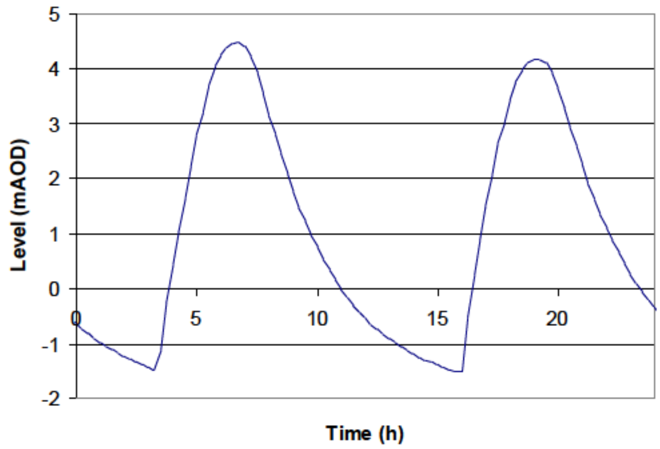
Source: River Humber, North Bank Tidal Modelling Report - Mott MacDonald, 2011

As part of the study representative astronomical tide hydrographs were defined for three stretches of the Humber Estuary:

- Spurn Head to Salt End – Data from Immingham used;
- Salt End to Brough – Data from Albert Dock used;
- Brough to Goole – Data from Blacktoft used.

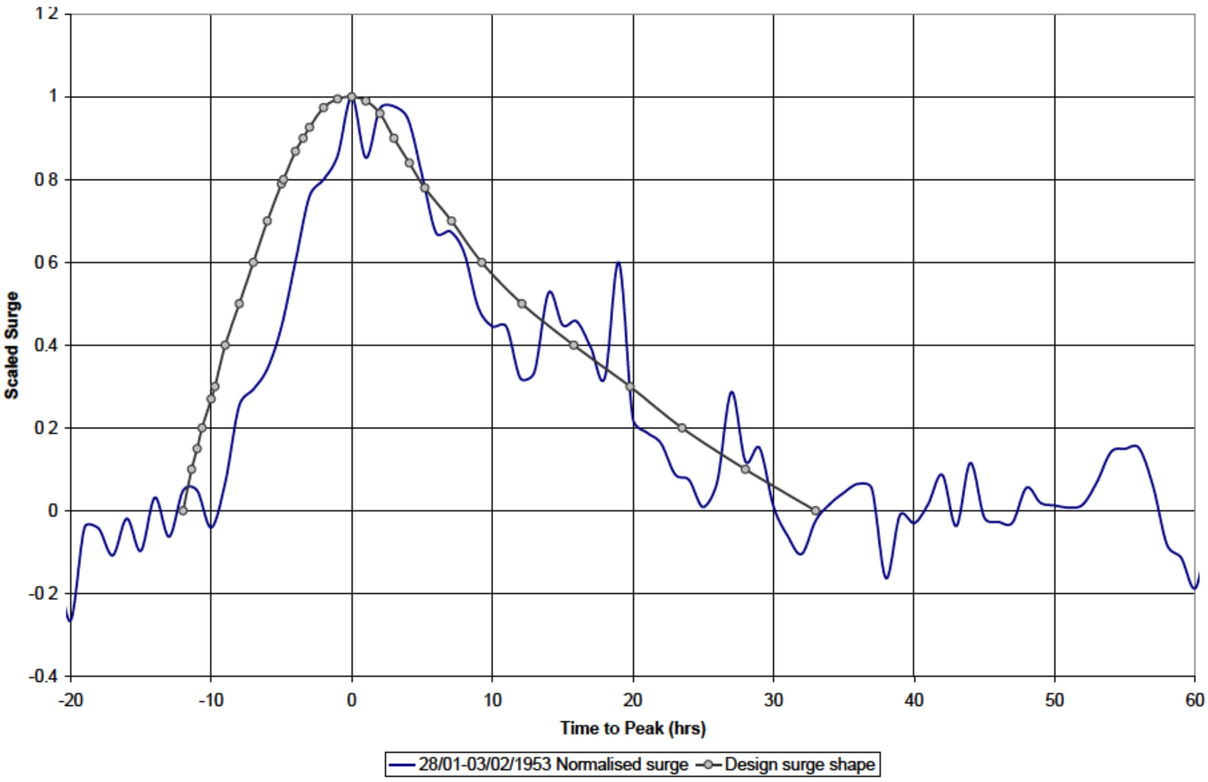
A surge profile at Immingham for use throughout the estuary was also defined. The derived astronomical tide hydrograph and surge profile for the reach between Brough and Goole is provided in Figure C.4 and Figure C.5.

Figure C.4: Astronomical Tidal Curve Derived for Reach between Brough and Goole



Source: River Humber, North Bank Tidal Modelling Report - Mott MacDonald, 2011

Figure C.5: Surge Profile Derived for the Humber Estuary

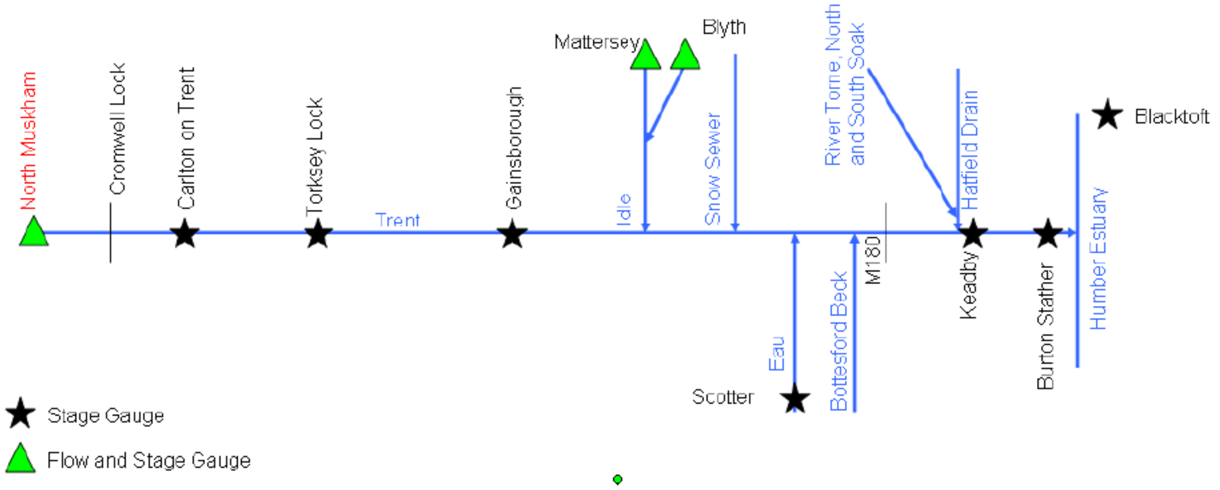


Source: River Humber, North Bank Tidal Modelling Report - Mott MacDonald, 2011

C.2.2 Level and Flow data

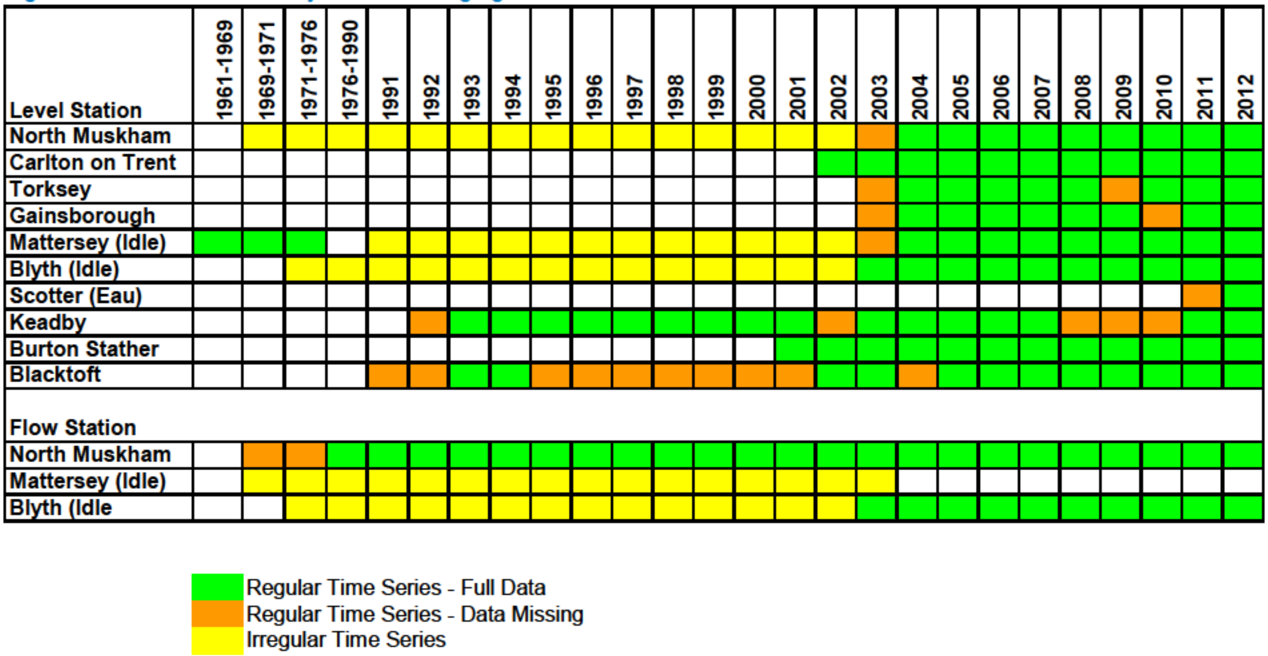
Level and flow data has been made available by the Environment Agency and by Associated British Ports (ABP). Figure C.6 provides a schematic of the Tidal Trent and its tributaries, with the location of the various gauging stations. Figure C.7 shows the length of data available at each of these stations. This information is also tabulated in Table C.8.

Figure C.6: Schematic Location of Gauging Stations and Tributaries



Source: Mott MacDonald

Figure C.7: Data Availability at Each Gauging Station



Source: Mott MacDonald, EA Data sources and ABP

Table C.8: Hydrological Data Availability

Station Name	Data Type	Availability	Source	Comments
Blacktoft (Humber Estuary)	Level Data	1991 - 2012	EA	Some Data missing pre 2005
Burton Stather	Level Data	2001 - 2012	ABP	
Keadby	Level Data	1992 – 2012	EA	
Gainsborough	Level Data	2003 – 2012	EA	
Torksey	Level Data	2003 – 2012	EA	

Station Name	Data Type	Availability	Source	Comments
Carlton on Trent	Level Data	2002 – 2012	EA	
North Muskham	Level Data	1969 - 2012	EA	Data pre 2003 available in Irregular Time Series. Amax data available from 1969
	Flow Data	1969 - 2012	EA	Data missing pre 1976, particularly in 1973
Blyth (Idle)	Level Data	1971 – 2012	EA	Data pre 2003 available in Irregular Time Series
	Flow Data	1971 - 2012	EA	Data pre 2003 available in Irregular Time Series
Mattersey (Idle)	Level Data	1961 – 1976, 1976 - 2012	EA	Data pre 2003 available in Irregular Time Series. All data prior to 1982 thought to be unreliable.
	Flow Data	1969 - 2003	EA	Irregular Time Series data. All data prior to 1982 thought to be unreliable. Amax data available from 1969 to 2008

Source: Mott MacDonald, EA Data sources and ABP

C.3 Fluvial Hydrology

The purpose of the hydrological analysis was primarily two-fold for this study:

- To derive flow hydrographs for model calibration and verification events;
- To derive flow hydrographs for specified design events.

Design flows for the tributaries downstream of Cromwell Weir are required in order to state the potential backwater effects of raised water levels in the Trent. This chapter describes the methodology employed for hydrological analysis. The results are presented and discussed.

C.3.1 Upper Catchment – Upstream of North Muskham

Flow data for the fluvial Trent is available at North Muskham between 1969 and 2011 and at Nottingham between 1884 and 2008. The fluvial Trent hydrological study has used the data from Nottingham between 1884 and 2008 to derive design flows at North Muskham due to the greater period of gauge data available. The source of the data prior to 1958 has been taken from Volume IV of the Flood Studies Report, however, it is unclear whether this is from directly recorded flows, or flow values derived from other observed data. Due to the age of the data it is not expected that the flows are directly recorded.

The derivation of design flows at North Muskham has been undertaken in the following stages:

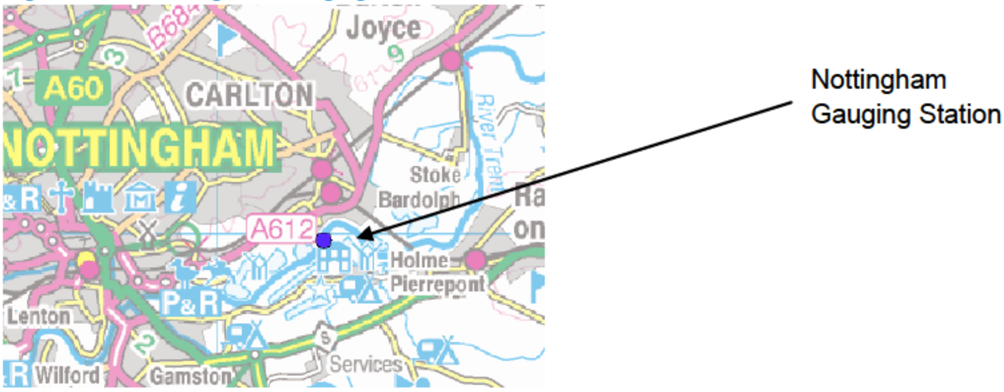
- Review of analysis undertaken as part of fluvial Trent hydrological study using data from 1884 to 2000 at Nottingham;
- Analysis of available HiFLOWS data at Nottingham (1958 to 2008);
- Analysis of available data at North Muskham (1969 to 2011);
- Trend analysis and comparison between coincident years' data at Nottingham and North Muskham;
- QMED estimation for North Muskham Inflow;
- Estimation of growth curve for North Muskham Inflow;
- Derivation of design hydrographs for North Muskham Inflow.

C.3.1.1 Hydrological Analysis – Nottingham Gauging Station

Nottingham Gauging Station – Review of gauging station

Nottingham Gauging Station is located on the eastern edge of Nottingham as shown in Figure C.8.

Figure C.8: Nottingham Gauging Station



The station is a HiFLOWS gauging station and has been a velocity-area station since 1958. There are sluices 750 m upstream of the station which affect the water levels up to medium flows. The station is bypassed at high flows on the right bank, however, recent bank modifications have made this less likely. According to the HiFLOWS database, the current meter and rated flows correlate well throughout the flow range up to 5.5 mAOD, the level of the maximum recorded flow (8/11/2000).

The Fluvial Trent Hydrology Study carried out by Black & Veatch in 2003 incorporated data from 1884 to 2000 in its analysis of the Trent at Nottingham. The sources of data used are as follows:

- 1884 – 1954: Values from Trent Bridge as published in Volume IV of the Flood Studies Report;
- 1955 – 1957: Estimated peak flows at Nottingham based on records for upstream stations;
- 1958 – 2000: AMAX series from Colwick Gauging Station.

The data from Trent Bridge and Colwick were combined as part of that study as there are no significant flood inflows to the River Trent between the two measurement sites. The recommended QMED derived at Nottingham using a GEV L-moments calculation was 476 m^3/s.

Nottingham Gauging Station – Analysis of HiFLOWS data from 1958 – 2008

i) QMED Estimation - Nottingham

The AMAX data extracted from the HiFLOWS database for the Trent at Nottingham is given in Table C.9.

Table C.9: AMAX Series for Nottingham

Water Year	Date	Peak Flow	Water Year	Date	Peak Flow
1958	23/01/1959	539.03	1984	24/11/1984	331.51
1959	31/01/1960	806.13	1985	12/01/1986	450.44
1960	05/12/1960	971.86	1986	02/01/1987	469.97
1961	12/01/1962	285.38	1987	26/01/1988	519.84
1962	31/03/1963	301.2	1988	07/04/1989	369.28
1963	15/03/1964	366.6	1989	09/02/1990	447.61
1964	24/03/1965	349.94	1990	11/01/1991	401.18
1965	11/12/1965	800.8	1991	23/12/1991	351.27
1966	12/12/1966	391.95	1992	04/12/1992	455.74
1967	15/01/1968	461.6	1993	14/12/1993	440.4
1968	08/05/1969	452.73	1994	30/01/1995	586.95
1969	22/02/1970	449.2	1995	23/12/1995	267.92
1970	25/04/1971	402.34	1996	21/12/1996	295.8
1971	04/02/1972	352.76	1997	08/03/1998	484.29
1972	07/12/1972	354.59	1998	29/10/1998	483.85
1973	12/02/1974	421.54	1999	25/12/1999	351.27
1974	11/03/1975	369.28	2000	08/11/2000	1018.35
1975	03/12/1975	242.43	2001	27/02/2002	459.11
1976	26/02/1977	956.1	2002	31/12/2002	610.22
1977	30/01/1978	485.81	2003	01/02/2004	396.73
1978	30/12/1978	702.73	2004	24/10/2004	315.3
1979	09/02/1980	499.61	2005	25/10/2005	277.08
1980	12/03/1981	571.64	2006	27/06/2007	489.3
1981	01/01/1982	710.02	2007	17/01/2008	508.24
1982	03/05/1983	381.58	2008	14/12/2008	305.51
1983	08/02/1984	496.09			

Source: EA HiFLOWS Database

The QMED value derived from the flow records at Nottingham for this period of data (from 1958 to 2008) is 449 m^3/s.

Table C.10 provides the catchment descriptors for the catchment upstream of Nottingham and the QMED derived from the FEH CDROM descriptors.

Table C.10: Catchment Descriptors for Nottingham Catchment

Station	Area (km^2)	SAAR	BFI	SPR	FARL	QMED Catchment Descriptors (m^3/s)	QMED Adjusted for Urbanisation (m^3/s)
Trent @ Nottingham	7466	760	0.51	34.2	0.94	522	611

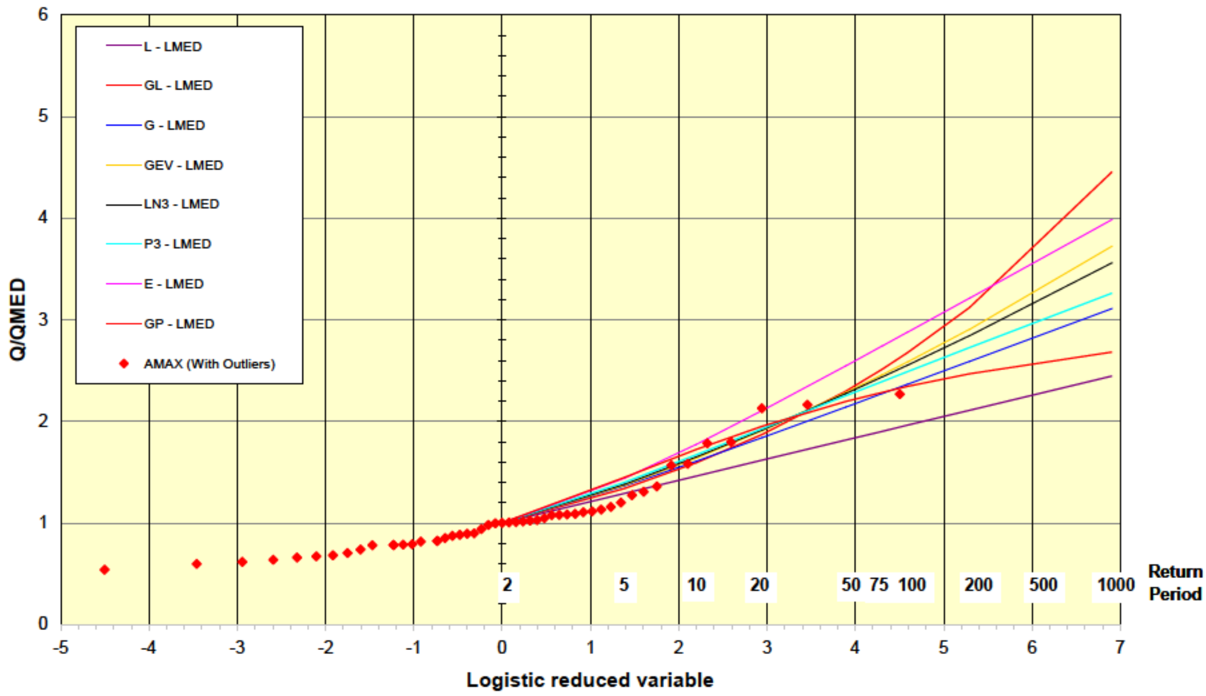
ii) Flood Frequency Analysis - Nottingham

a) Single Site Analysis

Single site analysis has been undertaken using the data from 1958 to 2008.

Figure C.9 shows the resulting growth curves.

Figure C.9: Single Site Analysis - Nottingham



Source: Mott MacDonald

b) Pooled Analysis

A pooling group was created using the WINFAP-FEH Software. The initial pooling group is provided in Table C.11. Two sites were removed from the pooling group due to their unsuitability for pooling and one added. The final pooling group is provided in Table C.12.

Table C.11: Initial Pooling Group Created by WINFAP-FEH Software for Nottingham

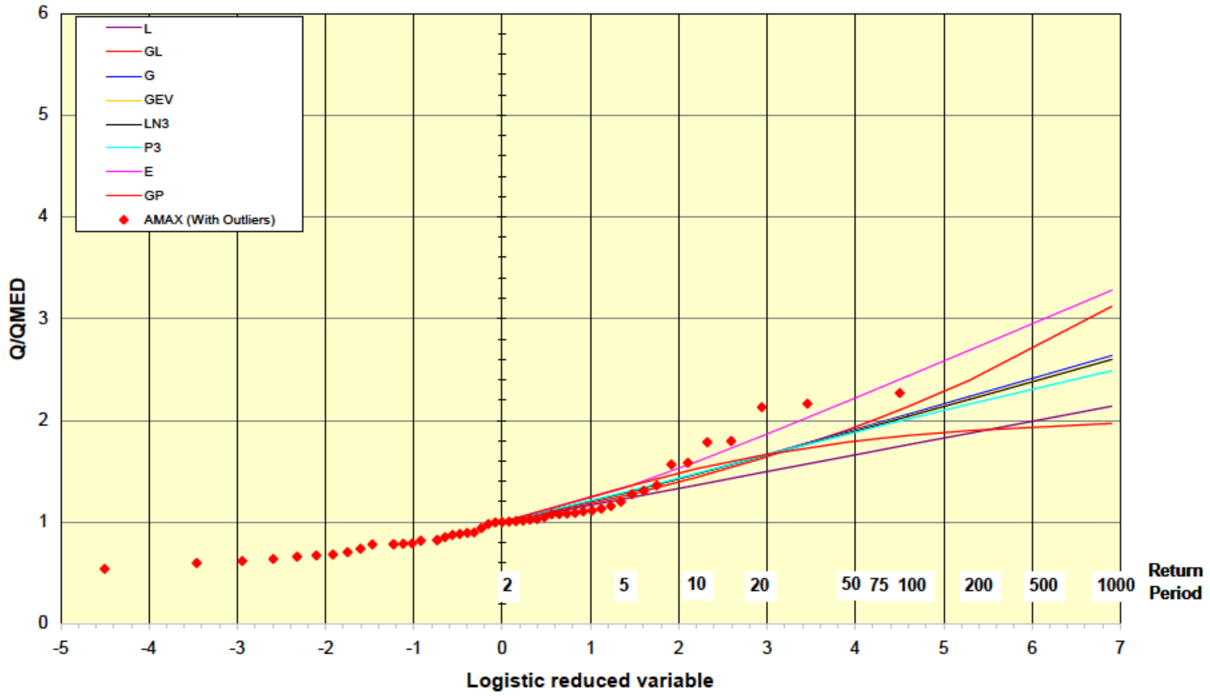
Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	Eliminated / Added	Comment
54001 (Severn @ Bewdley)	1.027	85	337	0.135	0.131	0.578		
55001 (Wye @ Cadora)	1.285	33	558	0.128	0.179	0.762	Eliminated	No Pooling, No QMED
55023 (Wye @ Redbrook)	1.292	38	536	0.14	0.191	1.292	Eliminated	No Pooling
21009 (Tweed @ Norham)	1.328	46	792	0.204	0.202	2.116		
27009 (Ouse @ Skelton)	1.343	123	315	0.136	0.117	0.686		
39002 (Thames @ Days Weir)	1.309	70	148	0.196	0.094	1.337		
21021 (Tweed @ Sprouston)	1.691	36	817	0.188	0.127	0.512		
15006 (Tay @ Ballathie)	1.824	54	993	0.158	0.156	0.391		
8006 (Spey @ Boat o Brig)	1.886	54	479	0.191	0.155	1.326		
Total		**539**						
Weighted means				**0.163**	**0.149**			

Table C.12: Amended pooling group for Nottingham

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	Eliminated/ Added
54001 (Severn @ Bewdley)	1.027	85	337	0.135	0.131	0.801	
21009 (Tweed @ Norham)	1.328	46	792	0.204	0.202	1.016	
27009 (Ouse @ Skelton)	1.343	123	315	0.136	0.117	0.797	
39002 (Thames @ Days Weir)	1.309	70	148	0.196	0.094	1.879	
21021 (Tweed @ Sprouston)	1.691	36	817	0.188	0.127	0.456	
15006 (Tay @ Ballathie)	1.824	54	993	0.158	0.156	0.352	
8006 (Spey @ Boat o Brig)	1.886	54	479	0.191	0.155	1.727	
8001 (Spey & Aberlour)	1.786	65	415.619	0.21	0.201	1.037	Added
Total		**533**					
Weighted means				**0.175**	**0.147**		

Figure C.10 provides the growth curves generated from the pooling group.

Figure C.10: Growth Factors from Pooled analysis - Nottingham



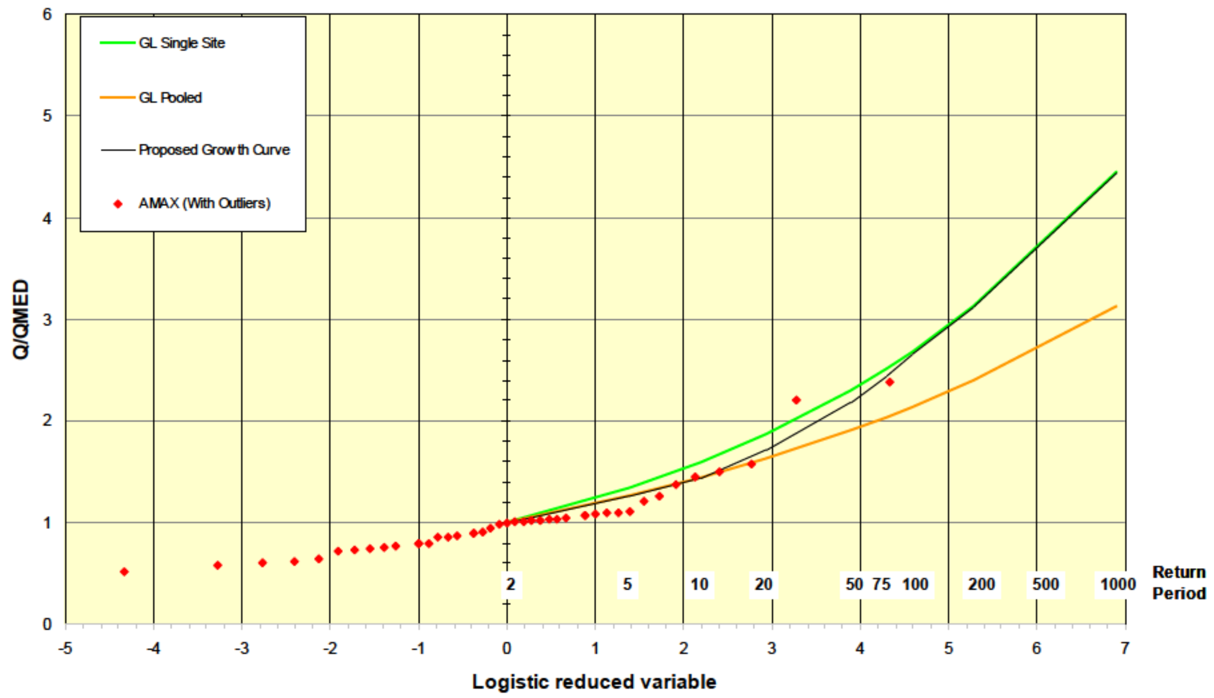
Source: Mott MacDonald

The growth factors derived from single site analysis are greater than those derived from the pooled analysis.

c) Composite Growth Curve

At low return periods (up to 1 in 5 year) the growth curve derived from the pooled analysis provides a better fit to the observed data. At high return periods (above 1 in 10 year), the growth curve derived from the single site analysis provides a better fit to the observed data. Therefore in consultation with the EA we agreed to derive a composite design flood frequency curve, i.e. the lower return periods will be based on the pooled analysis growth curves, and the higher return periods on the single site analysis.

Figure C.11: Composite Growth Curve – Nottingham



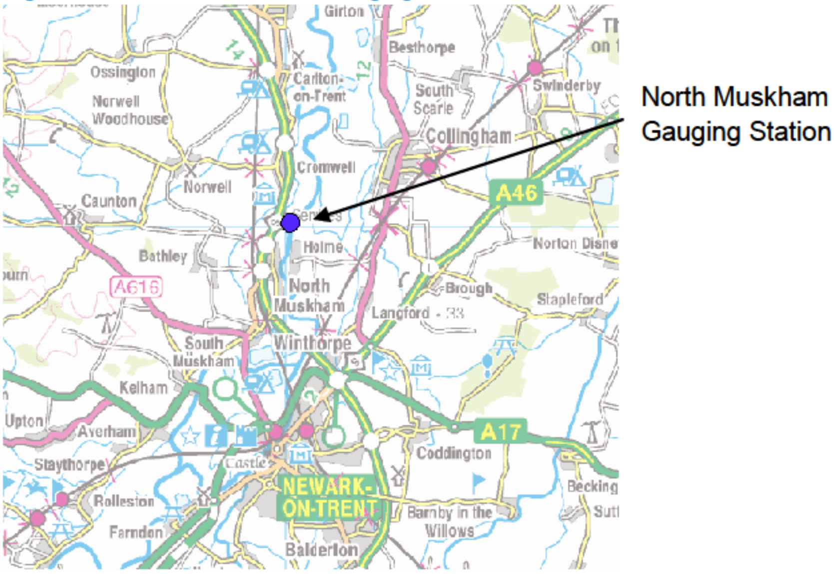
Source: Mott MacDonald

C.3.1.2 Hydrological Analysis – North Muskham Gauging Station

North Muskham Gauging Station – Analysis of AMAX data from 1969 - 2011

North Muskham Gauging Station is located 1.5 km upstream of the Cromwell Weir, the tidal limit of the Trent. Its location is shown in Figure C.12.

Figure C.12: North Muskham Gauging Station



Source: Mott MacDonald. This map is reproduced by permission of Ordnance Survey on behalf of The Controller Of Her Majesty's Stationary Office. © Crown Copyright. All rights reserved. Environment Agency 100026380, 2013.

The station is an EA HiFLOWS gauging station and was a velocity-area station from 1968 to 1996. In 1996 an ultrasonic gauge was installed. The station is bypassed on the right bank if water levels are greater than 7.8 mAOD due to low lying land on this bank, although volumes are not thought to be large. At high flows backwater from Cromwell Weir can affect the rating.

According to the HiFLOWS database, the ultrasonic gauge is thought to underestimate flows, and the rating curve to overestimate flows.

i) QMED Estimation – North Muskham

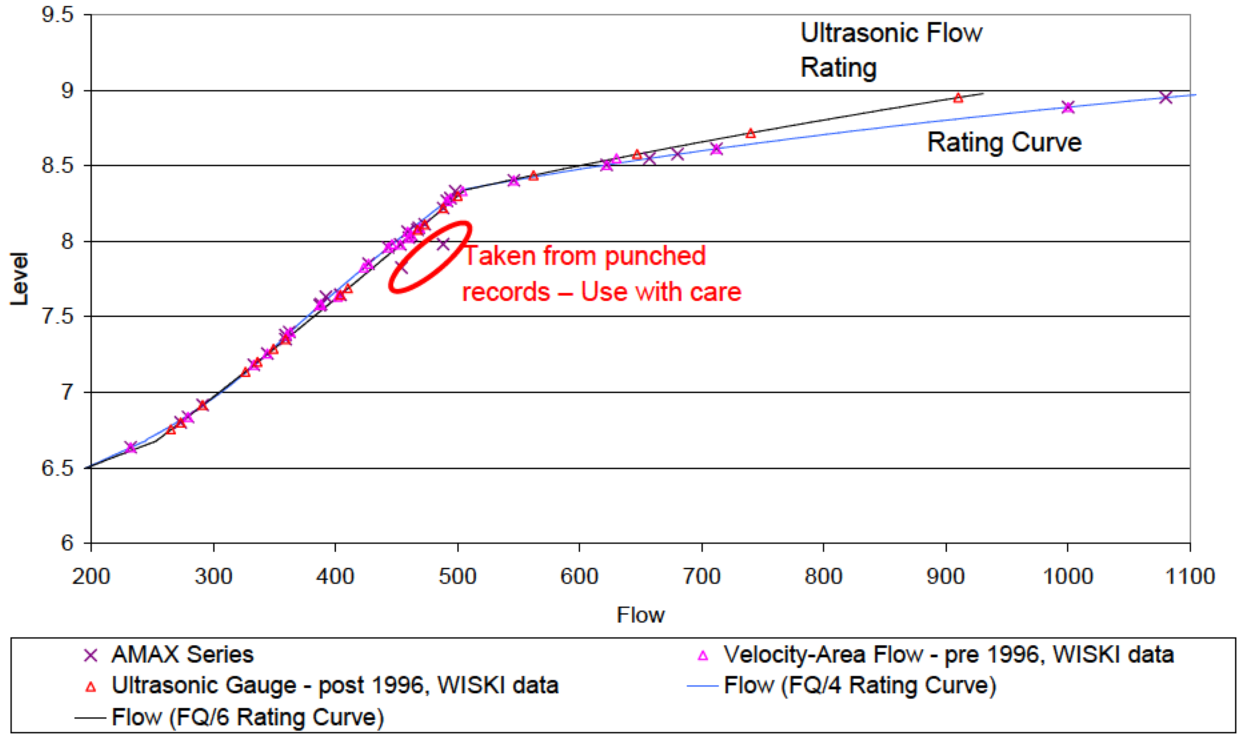
The AMAX data series provided by the Environment Agency uses the Rating Curve to derive the peak flows. There is a total of 42 years of AMAX data available at this station. Table C.13 shows the AMAX series from 1969 to 2011. compares:

- Ultrasonic flow data;
- AMAX data;
- Rating derived from ultrasonic data provided by the EA;
- Rating provided by the EA for calculating AMAX data.

Table C.13: AMAX Series for North Muskham

Water Year	Date	Peak Flow (m^3/s)	Peak Water Level (mAOD)	Equivalent return period	Comments
1969	23/02/1970	488	7.98	3.4	Data taken from Punched Records – use with care
1970	26/04/1971	454	7.83	2.1	Data taken from Punched Records – use with care
1971	05/02/1972	359	7.38	1.4	
1972	18/07/1973	362	7.4	1.4	
1973	13/02/1974	427	7.85	1.8	
1974	11/03/1975	388	7.59	1.5	
1975	03/12/1975	232	6.64	1.0	
1976	27/02/1977	1000	8.89	27.6	
1977	30/01/1978	459	8.06	2.2	
1978	31/12/1978	712	8.61	16.8	
1979	10/02/1980	494	8.29	4.1	
1980	13/03/1981	546	8.41	5.7	
1981	02/01/1982	622	8.51	7.8	
1982	04/05/1983	387	7.58	1.5	
1983	09/02/1984	491	8.27	3.7	
1984	25/11/1984	344	7.26	1.2	
1985	13/01/1986	443	7.96	1.9	
1986	02/01/1987	468	8.09	2.8	
1987	26/01/1988	498	8.33	4.5	
1988	08/04/1989	392	7.63	1.6	
1989	10/02/1990	460	8.03	2.3	
1990	11/01/1991	404	7.65	1.7	
1991	23/12/1991	333	7.18	1.2	
1992	05/12/1992	462	8.04	2.5	
1993	15/12/1993	453	7.98	2.0	
1994	30/01/1995	657	8.55	9.5	
1995	24/12/1995	279	6.84	1.1	
1996	21/12/1996	291	6.92	1.1	
1997	07/01/1998	488	8.22	3.4	
1998	30/10/1998	473	8.11	3.0	
1999	26/12/1999	359	7.35	1.4	
2000	09/11/2000	1080	8.95	77.0	Largest event on record using Rating Curve to derive Flow – WISKI data gives a flow of 910 m^3/s
2001	28/02/2002	467	8.08	2.6	
2002	01/01/2003	680	8.58	12.1	
2003	02/02/2004	404	7.65	1.7	
2004	24/10/2004	336	7.20	1.2	
2005	26/10/2005	273	6.80	1.1	
2006	27/06/2007	500	8.30	5.0	
2007	23/01/2008	569	8.44	6.6	
2008	15/12/2008	326	7.14	1.1	
2009	18/01/2010	349	7.29	1.3	
2010	10/11/2010	265	6.75	1.0	
2011	08/07/2012	410	7.69	1.8	

Figure C.13: Comparison of AMAX and WISKI Data against Rating Curves at North Muskham



Source: EA

The graph shows a large difference between the flows obtained using the ultrasonic gauge and those derived from the rating curve at high flows, with the ultrasonic flow readings being less than those obtained from the rating curve.

In subsequent analysis the AMAX series provided by the EA has been used in preference to the values obtained from the ultrasonic gauge.

The QMED flow has been estimated from the AMAX data series extending from 1969 to 2011. It should be noted that the flows from 1969 and 1970 have been transferred from punched records, and were not checked when they were transferred, therefore they should be used with care.

The QMED has been calculated to be 453 m^3/s based on the full set of flow records including 1969 and 1970, and 443 m^3/s excluding 1969 and 1970. The Fluvial Trent Strategy Report derived a value of 484 m^3/s at North Muskham by considering the data record on the Trent at Nottingham which extended from 1884 to 2000 at that gauging station.

Table C.14 provides the catchment descriptors for the Upper Catchment and the QMED derived from these descriptors.

Table C.14: Catchment Descriptors for the North Muskham Catchment

Station	Area (km²)	SAAR	BFI	SPR	FARL	QMED Catchment Descriptors (m³/s)	QMED Adjusted for Urbanisation (m³/s)
Trent @ North Muskham	8208	747	0.5	34.76	0.95	551	639

ii) Flood Frequency Analysis – North Muskham

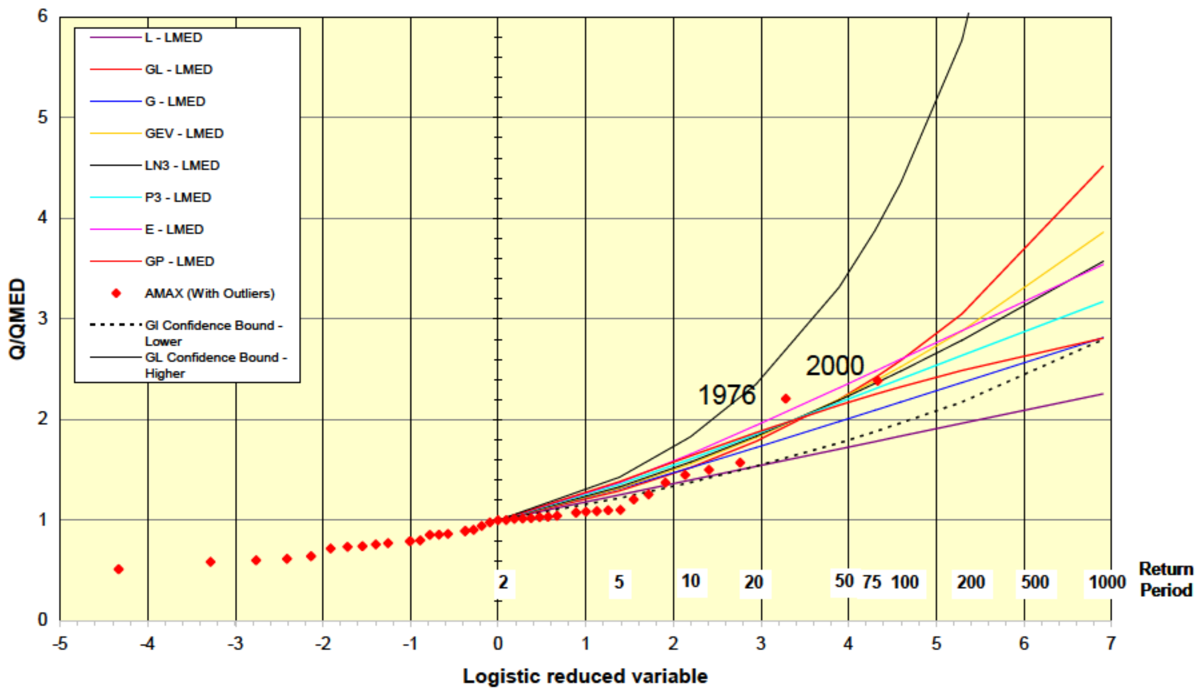
a) Single Site Analysis – North Muskham

Single site analysis has been undertaken both including AMAX data from 1969 and 1970 and excluding it.

Figure C.14 and Figure C.15 show the resulting growth curves. For the data including 1969 and 1970, the General Logistic Confidence bounds have also been plotted.

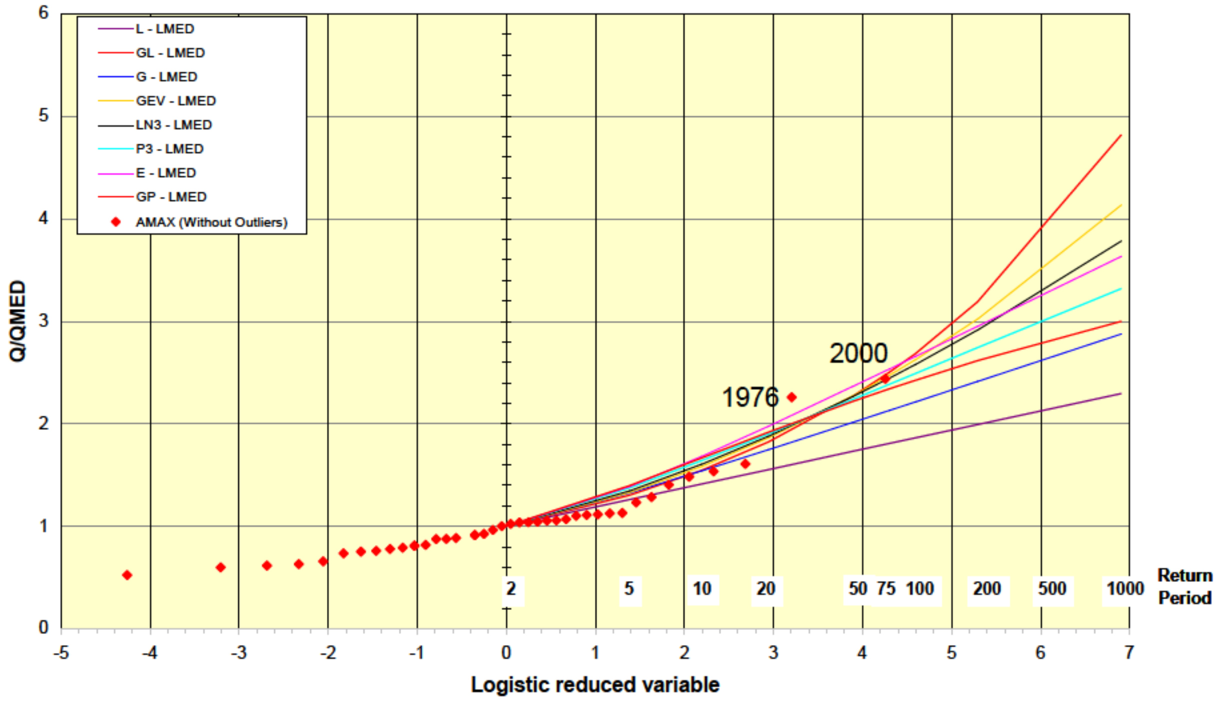
Table C.15 tabulates the resulting design peak flow estimates, using the General Logistic distribution. This shows that there is at most a 4% difference in the flows for the 1000 year return period, with the data excluding the two years providing the steeper growth curve.

Figure C.14: Single Site Flood Frequency Analysis Including Data from 1969 and 1970 – North Muskham



Source: Mott MacDonald

Figure C.15: Single Site Flood Frequency Analysis Excluding Data from 1969 and 1970 – North Muskham



Source: Mott MacDonald

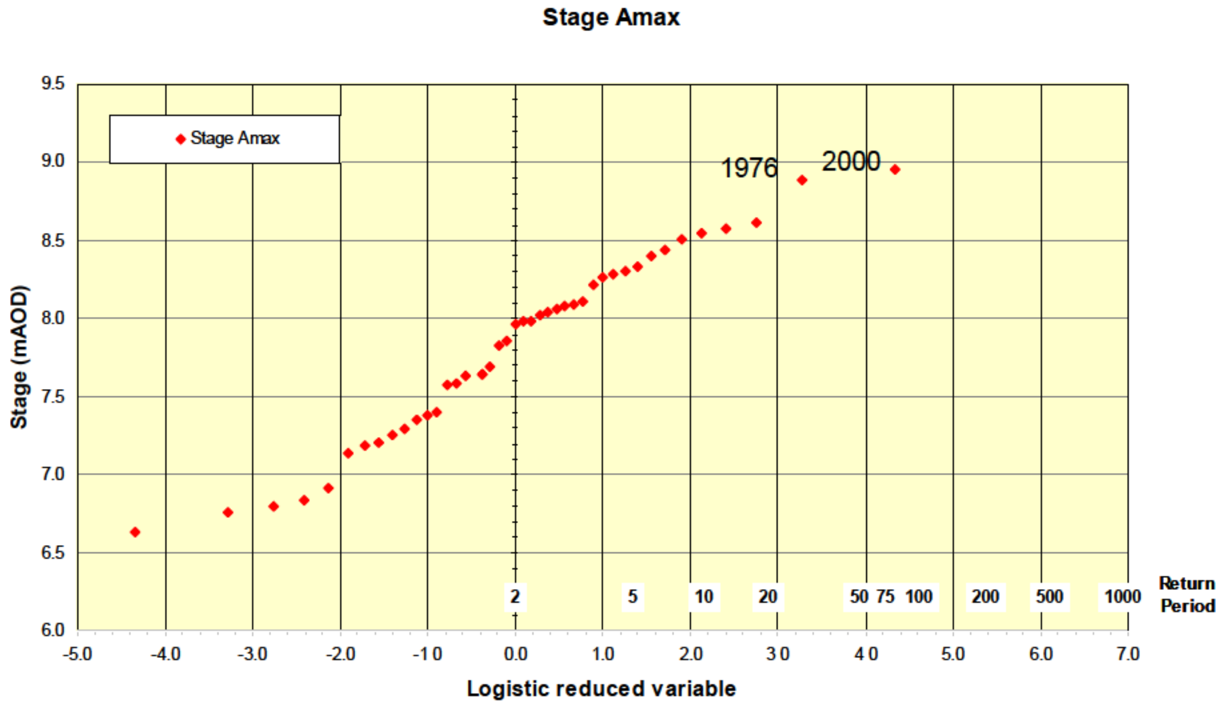
Table C.15: Comparison of Design Flow Estimates from Single Site Analysis

Return Period (1 in x year)	Flow from GL Distribution Including 1970 and 1971 (m^3/s)	Flow from GL Distribution Excluding 1969 and 1970 (m^3/s)
50	999	1004
100	1174	1189
200	1384	1413
1000	2052	2135

Source: Mott MacDonald

The peak flow from the 1976 event does not appear to follow the general trend of the other AMAX events. A Flood Frequency analysis has been undertaken using the AMAX stage data to assess if the flow data can be relied upon. The flow records do not suggest any problem with the gauge during the event. Figure C.16 shows the results. This analysis shows that the stage data follows a similar pattern, and therefore it implies that the recorded AMAX flow is accurate and should not be discarded.

Figure C.16: Flood Frequency Analysis of Stage AMAX – North Muskham



Source: Mott MacDonald

b) Pooled Analysis – North Muskham

A pooling group was created using the WINFAP-FEH Software. The initial pooling group is provided in Table C.16 Two sites were removed from the pooling group due to their unsuitability for pooling and a further two added. The final pooling group is provided in Table C.17.

Table C.16: Initial Pooling Group Created by WINFAP-FEH Software for North Muskham

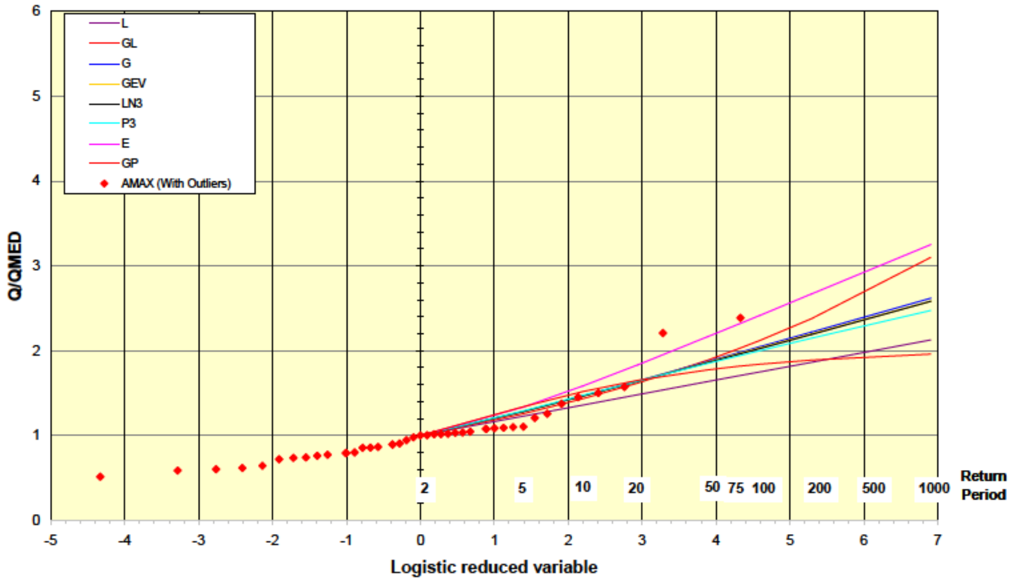
Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	Eliminated / Added	Comment
54001 (Severn @ Bewdley)	1.027	85	337	0.135	0.131	0.578		
55001 (Wye @ Cadora)	1.285	33	558	0.128	0.179	0.762	Eliminated	No Pooling, No QMED
55023 (Wye @ Redbrook)	1.292	38	536	0.14	0.191	1.292	Eliminated	No Pooling
39002 (Thames @ Days Weir)	1.309	70	148	0.196	0.094	1.337		
21009 (Tweed @ Norham)	1.328	46	792	0.204	0.202	2.116		
27009 (Ouse @ Skelton)	1.343	123	315	0.136	0.117	0.686		
21021 (Tweed @ Sprouston)	1.691	36	817	0.188	0.127	0.512		
15006 (Tay @ Ballathie)	1.824	54	993	0.158	0.156	0.391		
8006 (Spey @ Boat o Brig)	1.886	54	479	0.191	0.155	1.326		
Total		**539**						
Weighted means				**0.163**	**0.149**			

Table C.17: Amended Pooling Group for North Muskham

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	Eliminated/ Added
54001 (Severn @ Bewdley)	1.027	85	337	0.135	0.131	0.801	
39002 (Thames @ Days Weir)	1.309	70	148	0.196	0.094	1.879	
21009 (Tweed @ Norham)	1.328	46	792	0.204	0.202	1.016	
27009 (Ouse @ Skelton)	1.343	123	315	0.136	0.117	0.797	
21021 (Tweed @ Sprouston)	1.691	36	817	0.188	0.127	0.456	
15006 (Tay @ Ballathie)	1.824	54	993	0.158	0.156	0.352	
8006 (Spey @ Boat o Brig)	1.886	54	479	0.191	0.155	1.727	Added
76007 (Eden @ Sheepmount)	2.101	42	612	0.187	0.216	0.972	Added
Total		**510**					
Weighted means		**510**		**0.173**	**0.148**		

Figure C.17 provides the growth curves generated from the pooling group.

Figure C.17: Growth Factors from Pooled Analysis at North Muskham

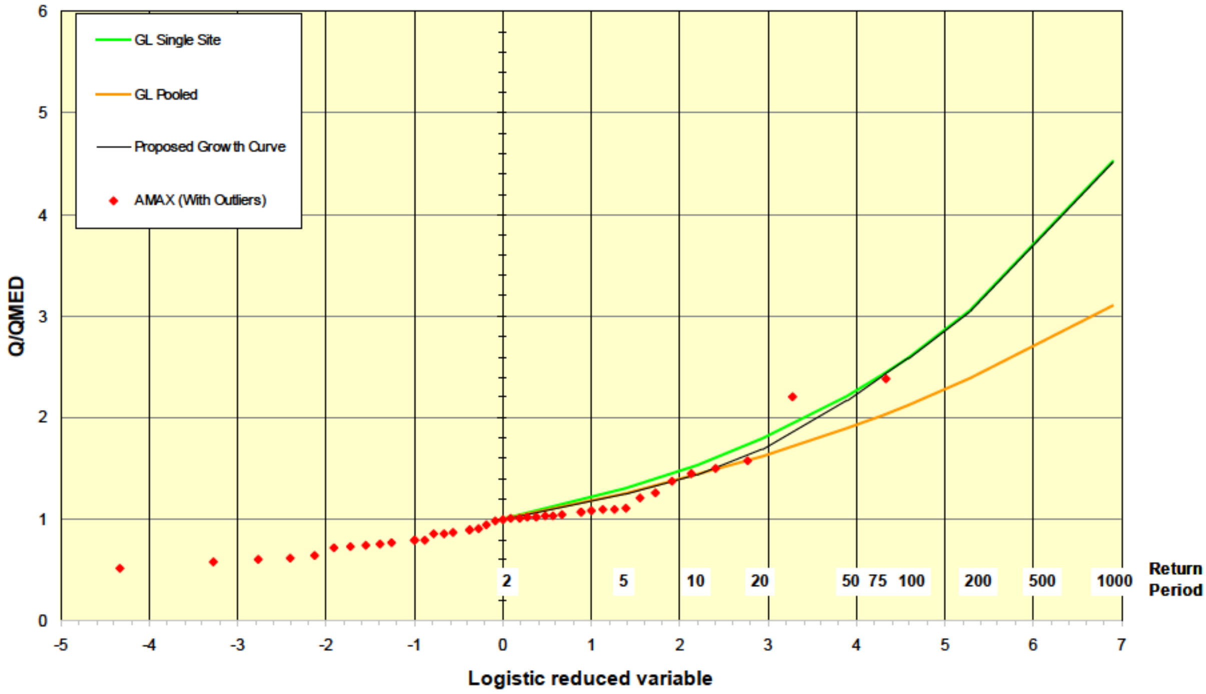


Source: Mott MacDonald

c) Composite Growth Curve

At low return periods (up to 1 in 5 year) the growth curve derived from the pooled analysis provides a better fit to the observed data. At high return periods (above 1 in 10 year), the growth curve derived from the single site analysis provides a better fit to the observed data. Therefore, in consultation with the EA we agreed to derive a composite design flood frequency curve, i.e. the lower return periods will be based on the pooled analysis growth curves, and the higher return periods on the single site analysis.

Figure C.18: Composite Growth Curve – North Muskham



Source: Mott MacDonald

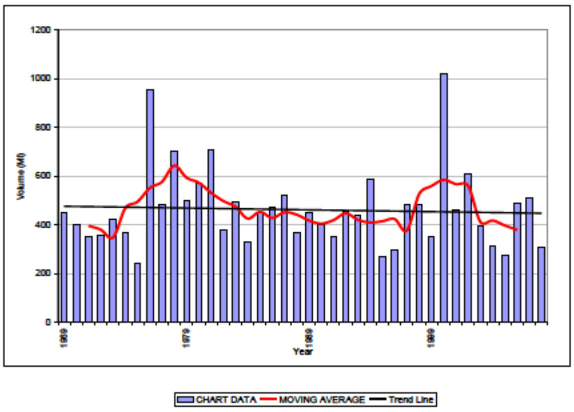
C.3.1.3 Reconcile Flow Data at Nottingham and North Muskham

Trend Analysis

Trend analysis of the data at Nottingham and North Muskham has been undertaken to determine if the longer record of data available at Nottingham could be used to assist the estimation of the QMED value and growth factors at North Muskham.

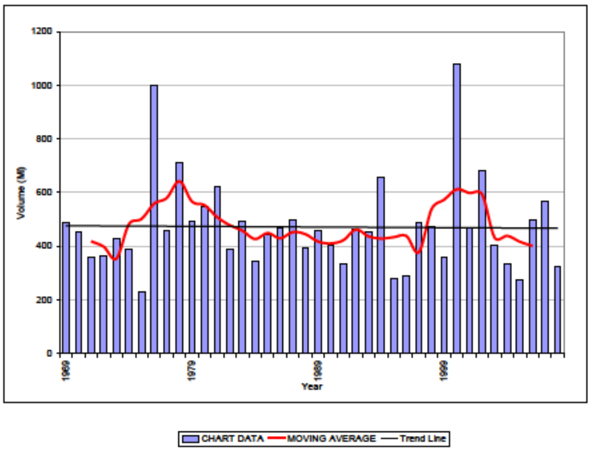
Trend analysis has initially been undertaken for the years with coincident data (1969 – 2008), using a five year moving average. This is shown in Figure C.19 and Figure C.20.

Figure C.19: Trend Analysis at Nottingham



Source: Mott MacDonald

Figure C.20: Trend Analysis at North Muskham



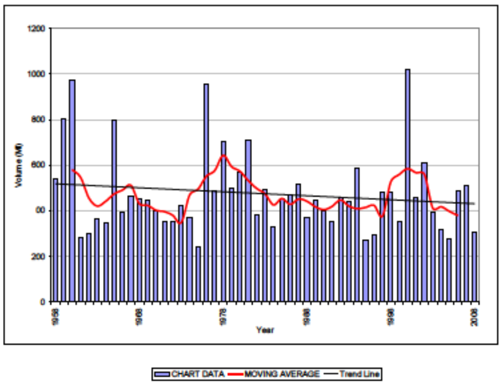
Source: Mott MacDonald

There is a slight downward trend in both the Nottingham and North Muskham data, however, having undertaken a number of statistical tests, as listed below, this trend is not thought to be significant, as only the Mann-Whitney U Test lies outside the 95% confidence interval.

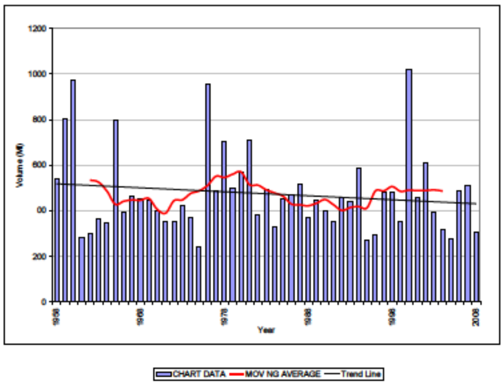
- Number of Median Crosses;
- Number of Turning Points;
- First-Order Serial Correlation;
- Spearman Rank Test;
- Rank Order Test;
- Mann-Whitney U Test;
- Wald-Wolfowitz Runs Test.

To ensure that no trends have been missed by only looking at the five year moving average, the 5, 9, 15, and 19 year moving average trends have been calculated on the available data at Nottingham (1958 – 2008). This is shown in Figure C.21.

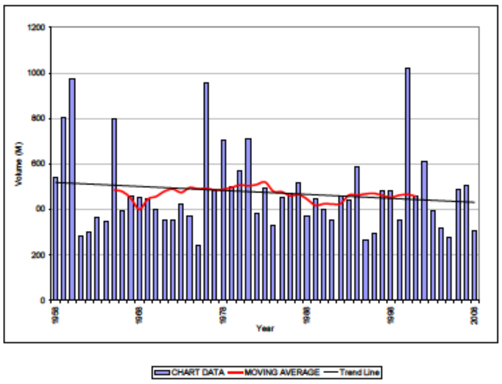
Figure C.21: Trend Analysis at Nottingham Using 5-Year Moving Average



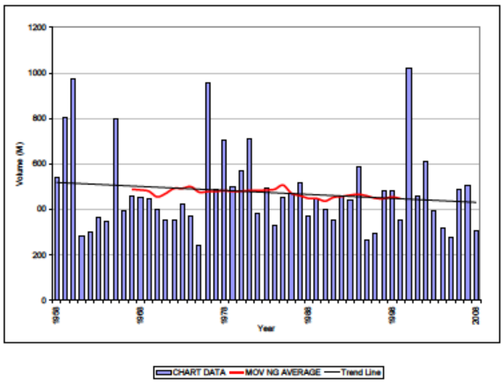
9-Year Moving Average



15-Year Moving Average



19-Year Moving Average



Source: Mott MacDonald

From this analysis it can be seen that although there is a slight downward trend in the AMAX events this is neither significant nor dependant on the number of years taken for calculating the moving average. Most importantly, the flow data at North Muskham follows a similar trend to that at Nottingham.

Nottingham Gauging Station is 40 km upstream of North Muskham Gauging Station. The key catchment parameters derived from the FEH CDROM descriptors for the catchment upstream of Nottingham and North Muskham Gauging Stations are tabulated on Table C.18. They are very similar to each other.

Table C.18: Catchment Descriptors for Nottingham and North Muskham Catchments

Station	Area (km^2)	SAAR	BFI	SPR	FARL	Centroid X	Centroid Y
Trent @ Nottingham	7466	760	0.51	34.2	0.94	425256	326248
Trent @ North Muskham	8208	747	0.5	34.76	0.95	429403	327743

Source: FEH Catchment Descriptors

Based on the above analysis it is considered appropriate to determine the QMED at North Muskham using that at Nottingham as a donor site.

QMED Estimation at North Muskham – Extended Analysis

In order to make the best use of the available flow records at Nottingham and North Muskham Gauging Stations, the QMED at North Muskham has been estimated using a combination of approaches outlined below:

- Based on observed AMAX data at North Muskham (including 1969 and 1970)
- Based on observed AMAX data at North Muskham (excluding 1969 and 1970)
- Using Nottingham as a donor site and transferring the observed QMED at Nottingham to North Muskham.

The QMED values derived using these three methods are given in Table C.19.

Table C.19: QMED Estimates at North Muskham

Estimation Method	Transfer Method	Length of Recorded Data Used	QMED Flow (m^3/s)
Observed AMAX data at North Muskham (including 1969 and 1970)	N/A	1969 - 2011	453
Observed AMAX data at North Muskham (including 1969 and 1970)	N/A	1971 - 2011	443
Using Nottingham as donor site (using coincident years of data only – not including distance)	Distance between catchment centroids not considered	1969 - 2008	469
Using Nottingham as donor site (using entire data set)	Distance between catchment centroids not considered	1958 - 2008	470
Using Nottingham as donor site (using coincident years of data only – not including distance)	2008 Transfer methodology (including distance)	1969 - 2008	547
Using Nottingham as donor site (using entire data set)	2008 Transfer methodology (including distance)	1958 - 2008	547

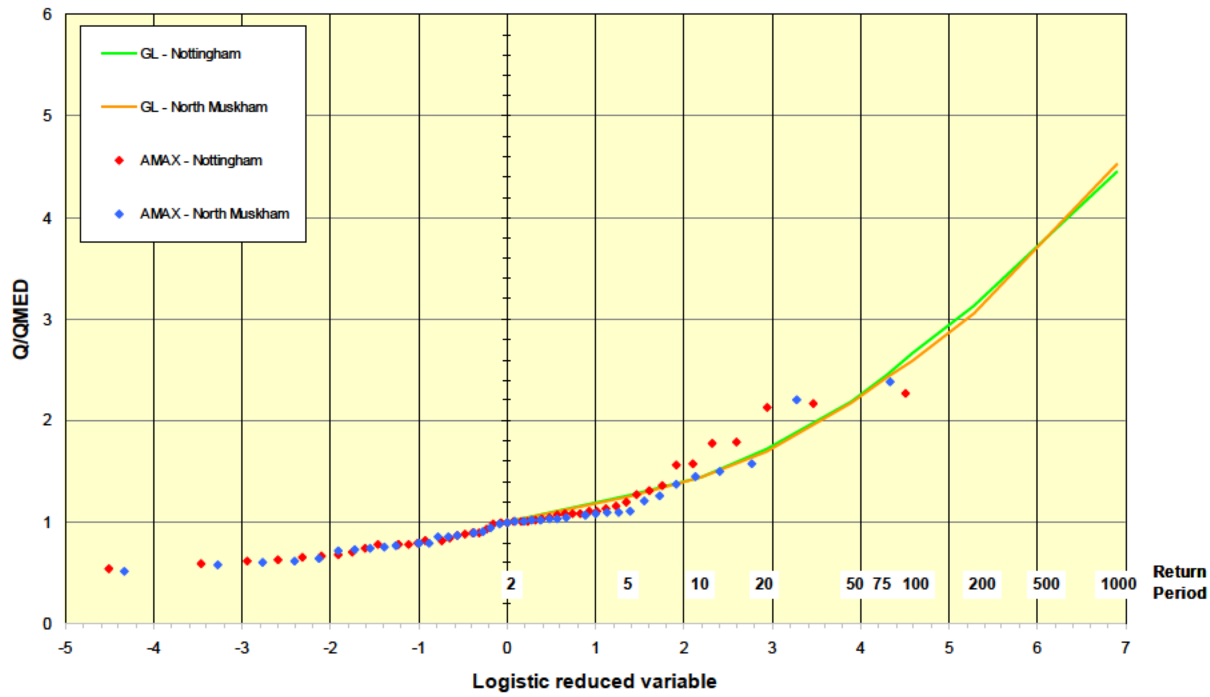
Source: Mott MacDonald

In consultation with the EA, a QMED value of 470 m^3/s has been used for the design flow at North Muskham, as this makes full use of the longer period of data available at Nottingham.

Estimation of Growth Curve at North Muskham – Extended Analysis

The two composite growth curves calculated for Nottingham and North Muskham gauging stations have been compared in Figure C.22.

Figure C.22: Comparison of Composite Growth Curves at Nottingham and North Muskham



Source: Mott MacDonald

Table C.20 tabulates the derived growth factors.

Table C.20: Growth Factors from Composite Growth Curves

Return Period	Growth Factor using Composite Growth Curve from Nottingham	Growth Factor using Composite Growth Curve from North Muskham
5	1.23	1.26
10	1.44	1.43
20	1.71	1.69
50	2.18	2.17
75	2.45	2.42
100	2.66	2.59
200	3.12	3.05
1000	4.46	4.52

Source: Mott MacDonald

In consultation with the EA, the composite growth curve derived at Nottingham has been used to determine the design peak flows.

C.3.1.4 Derivation of Design Peak Flows

A number of methods for deriving peak flows at North Muskham have been discussed. Table C.21 summarises the flows derived using some of the key methods, and compares these to the flows derived in the Fluvial Trent Strategy Modelling Study, and the flows derived at Nottingham.

Table C.21: Summary of Design Flows

Return Period	Design Flows at North Muskham (using composite growth curve from North Muskham)	Design Flows at North Muskham (using composite growth curve from Nottingham)	Design Flows at North Muskham from previous Fluvial Trent Strategy Modelling Study	Design Flows at Nottingham (using composite growth curve from Nottingham)
5	589	591	680	565
10	673	675	815	646
20	794	804		768
50	1020	1025	1110	979
75	1136	1152		1101
100	1215	1250	1220	1195
200	1433	1466	1320	1402
1000	2124	2094		2001

Source: Mott MacDonald and Fluvial Trent Strategy Modelling Study.

The design flows which have been used at North Muskham have been circled in green. The QMED (470m^3/s) has been derived by using the full data set at Trent @ Nottingham as a donor site. The growth factors used are derived from a composite of single site and pooled growth curves, derived at Nottingham.

C.3.1.5 Design Hydrograph Shape

There is a reasonable length of flow data available at North Muskham gauge and therefore it is appropriate to use the recorded hydrograph shapes to aid in creating a design hydrograph shape for this study.

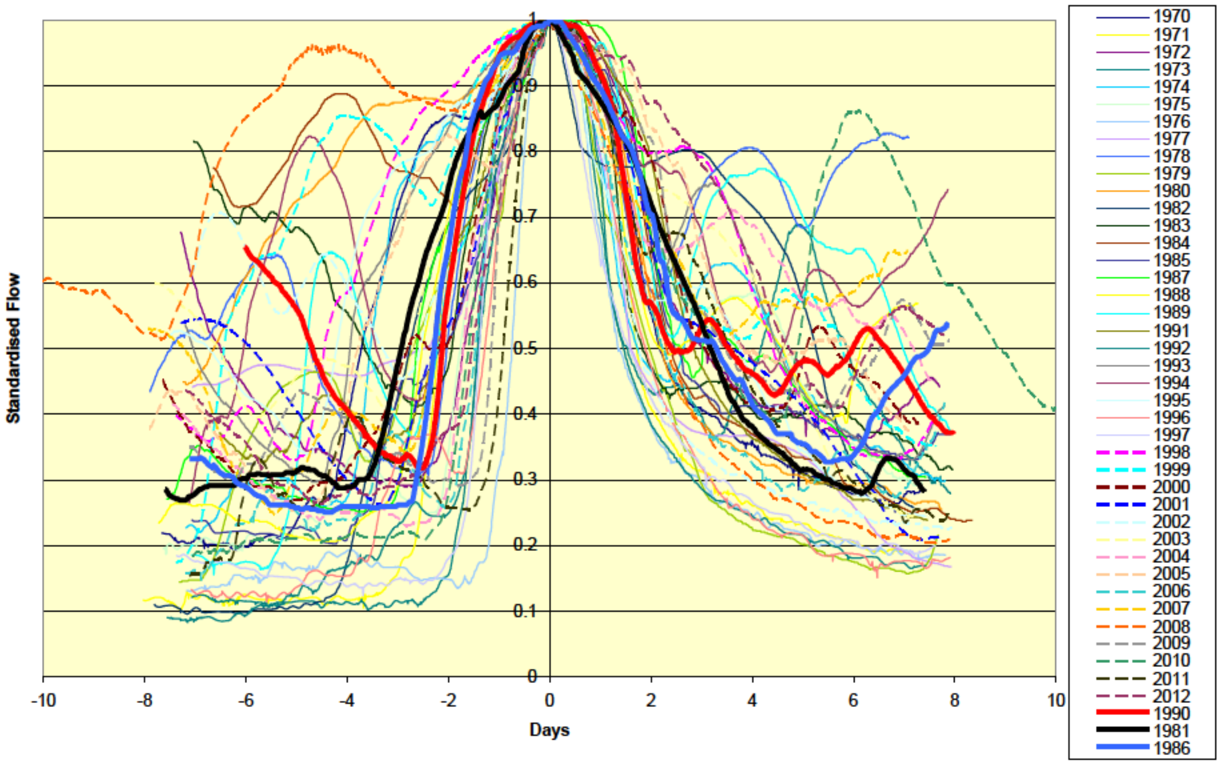
The flow hydrographs for all the AMAX events from 1970 till 2012 have been extracted from the WISKI flow data. These have all been standardised to have a dimensionless peak flow of 1, and aligned so that the flow peaks coincide at the same time. This allows a number of typical hydrograph shapes for the catchment to be identified and a suitable event to be chosen as a design hydrograph.

Figure C.23 shows the standardised hydrographs with three potential events highlighted. The shape of the hydrograph above a standardised flow of around 0.6 is most important as this determines the volume of flooding when the river is likely to be out-of-bank. The key characteristics of each of the highlighted events is described below:

- 1981 (Black Line)
  - The rising limb begins earlier than for most events, with an above average time to peak, and has a shallower gradient;
  - The peak is narrower than the average and therefore if used as a design hydrograph may underestimate out-of-bank volumes;
  - The falling limb is more prolonged than most events, giving a very wide hydrograph base.
- 1986 (Blue Line)

- Steep rising limb with an about average time to peak;
  - Fairly average shape at peak;
  - Prolonged falling limb compared to average.
- 1990 (Red Line)
  - Steep rising limb with an average time to peak;
  - Broad shape at peak, which would provide a conservative estimate of out-of-bank volumes;
  - Average falling limb shape.

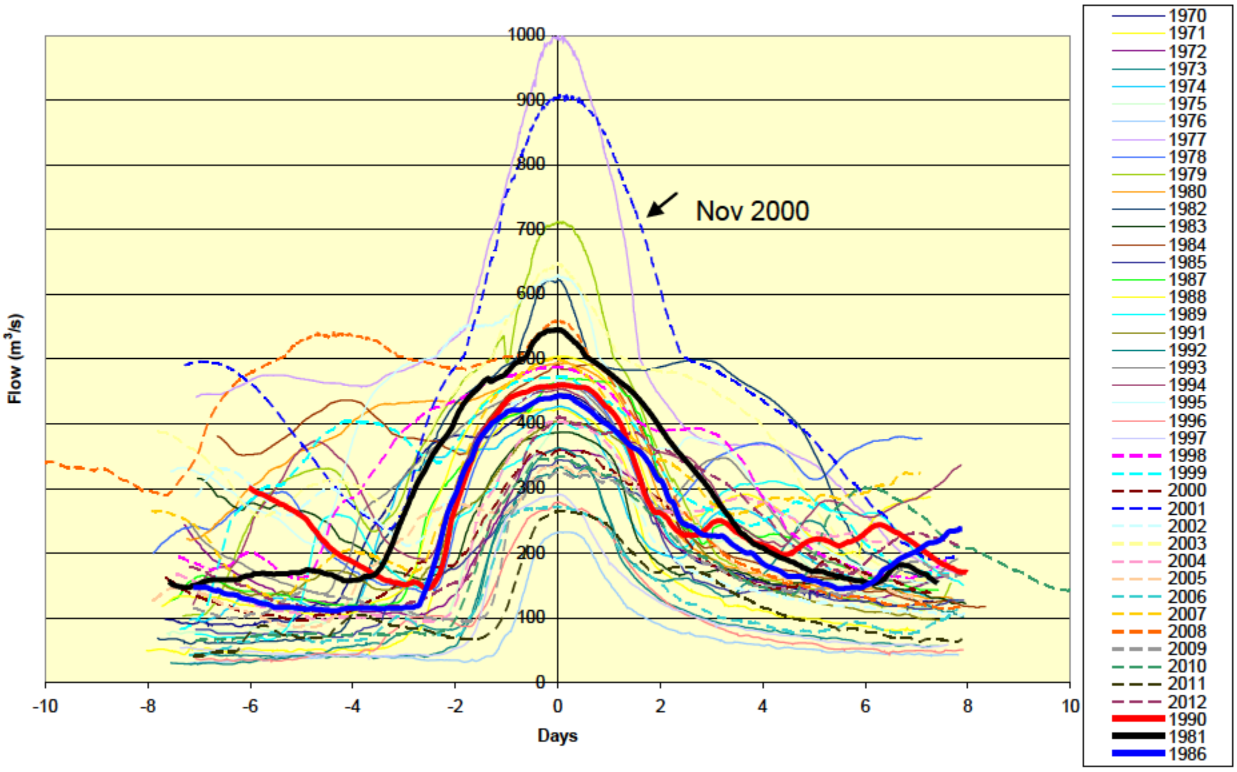
Figure C.23: Standardised Hydrographs for AMAX Events 1970 – 2012, North Muskham



Source: Mott MacDonald

Figure C.24 shows the actual hydrographs before being scaled to a peak of 1, to ensure that the three selected event hydrographs look representative of the rest.

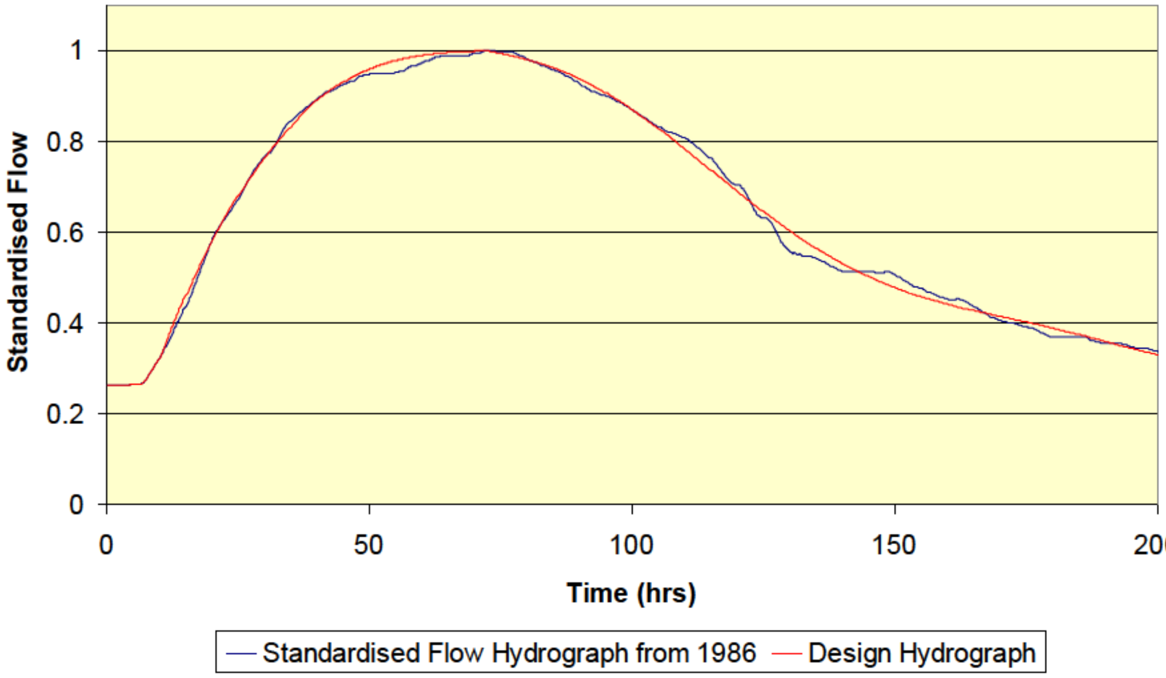
Figure C.24: AMAX Event Hydrographs from 1970 – 2012, North Muskham



Source: Mott MacDonald

In consultation with the EA, it was agreed that the 1986 hydrograph would be used as the design hydrograph shape. The hydrograph has been smoothed to remove any minor flow spikes or undulations. The resulting normalised dimensionless inflow design hydrograph is given in Figure C.25.

Figure C.25: Standardised Design Hydrograph for Use at Upstream Inflow to Model.



Source: Mott MacDonald

C.3.2 River Idle

The River Idle joins the Trent at West Stockwith as shown in Figure C.2. The total catchment area for the River Idle is 855 km^2. There is one flow gauging station located at Mattersey on the River Idle.

The River Ryton is the main tributary of the River Idle. It joins the River Idle upstream of Bawtry. There is one flow gauging station situated at Blyth on the River Ryton.

The catchment area upstream of Mattersey is 528 km^2, equivalent to 61% of the River Idle catchment, and the catchment area upstream of Blyth is 228 km^2, equivalent to 27% of the overall Idle catchment. The runoff from 89% of the Idle catchment passes through these two gauging stations before entering the Tidal Trent at West Stockwith.

C.3.2.1 Mattersey and Blyth Gauging Station Data Reviews

AMAX data is available at Mattersey Gauging Station from 1983 through to 2012. The HiFLOWS database suggests that there is very high scatter at high flows at this station. The QMED derived from the observed flows is 9.5 m^3/s, compared to 8.7 m^3/s from the River Idle Flood Risk Mapping Report.

At Blyth gauging station there is an electromagnetic station installed in March 1984. This is providing good quality data except at low flows. The QMED derived from the observed flows is 12 m^3/s compared to 9.1 m^3/s from the River Idle Flood Risk Mapping Report.

C.3.2.2 QMED Estimation – River Idle

The estimated QMED value at the downstream end of the River Idle has been calculated in a number of ways:

- Using Idle @ Mattersey as a donor site;
- Using Ryton @ Blyth as a donor site;
- Using an area weighted average of the above two options;
- Deriving QMED value from catchment descriptors;
- Deriving QMED using rainfall runoff methods.

Catchment descriptors have been extracted from FEH for the entire Idle catchment, and the Mattersey and Blyth catchments. They are provided in Table C.22 along with the measured QMED at each gauging station.

Table C.22: Catchment Descriptors for Idle Catchment

Station	Area (km^2)	SAAR	BFI	SPR	FARL	Centroid X	Centroid Y	QMED measured
IDLE – Downstream End	870	641	0.77	19.12	0.926	460336	376827	N/A
Idle @ Mattersey	528	650	0.79	18.92	0.90	460697	370350	9.50
Ryton @ Blyth	228	646	0.76	17.71	0.96	455873	383900	12.00

Source: FEH Catchment Descriptors

The Idle upstream of Mattersey is characterised by a number of washlands and reservoirs (low FARL number of 0.9). This attenuates the flow and therefore, despite other similar catchment descriptors as for Ryton @ Blyth with the exception of FARL, a lower QMED is observed. Downstream of Mattersey and downstream of the Idle's confluence with the Ryton, there are no significant reservoirs or washlands to further attenuate the flow.

The URBEXT2013 values for the catchments above Mattersey and Blyth are 0.075 and 0.073 respectively and therefore are considered to be urban. They are also both very representative of the entire catchment characteristics, and the remaining part of the IDLE catchment does not contain significant urban areas. Based on the catchment descriptors for Mattersey and Blyth, it would be appropriate to consider them both as donor sites for deriving the QMED for the entire catchment. In order to accurately transfer the QMED from an urban donor site, the urban adjustment factors for each donor site have been calculated, and the observed QMED for each site adjusted to represent a rural catchment. The QMED has then been transferred, and the urban adjustment factor for the entire catchment applied, to obtain the final transferred QMED. Table C.23 shows the data used and calculation for transferring QMED from the two donor sites.

Table C.23: Transferred QMED Values from Donor Sites

Donor Site	Area (km^2)	SAAR	BFI	SPR	FARL	UAF	QMED observed	Observed QMED adjusted to become Rural	QMED from Catchment Descriptors	QMED Transferred to represent entire Idle Catchment	QMED Transferred to represent entire Idle Catchment with Urban adjustment
Idle @ Mattersey	528	650	0.79	18.92	0.90	1.26	9.50	7.95	10.13	13.75	16.15
Ryton @ Blyth	228	646	0.76	17.71	0.96	1.26	12.00	9.99	6.80	25.74	30.24

A QMED estimation has also been derived based on an area weighted average of the two donor sites, Mattersey and Blyth. The Mattersey Catchment covers 70% of the gauged catchment area, and therefore the transferred QMED derived using Mattersey as a donor site has been given a weighting of 0.7, and the transferred QMED derived using Blyth as a donor site has been given a weighting of 0.3.

QMED at the downstream end of the Idle Catchment has in addition been derived solely using the FEH CD-ROM descriptors and using rainfall runoff methods. It should be noted that as the catchment is considered permeable (SPR host <20) the ReFH method is not recommended. Table C.24 summarises the derived QMED values.

Table C.24: Summary of Estimated QMED Values

Method for Deriving QMED at Downstream End of Catchment	Estimated QMED (m^3/s)
Transferred using Mattersey as donor site	16.15
Transferred using Blyth as donor site	30.24
Transferred using area weighted average of Mattersey and Blyth as donor sites	20.38
FEH catchment characteristics	20.59
Rainfall runoff	16

Design QMED – Idle

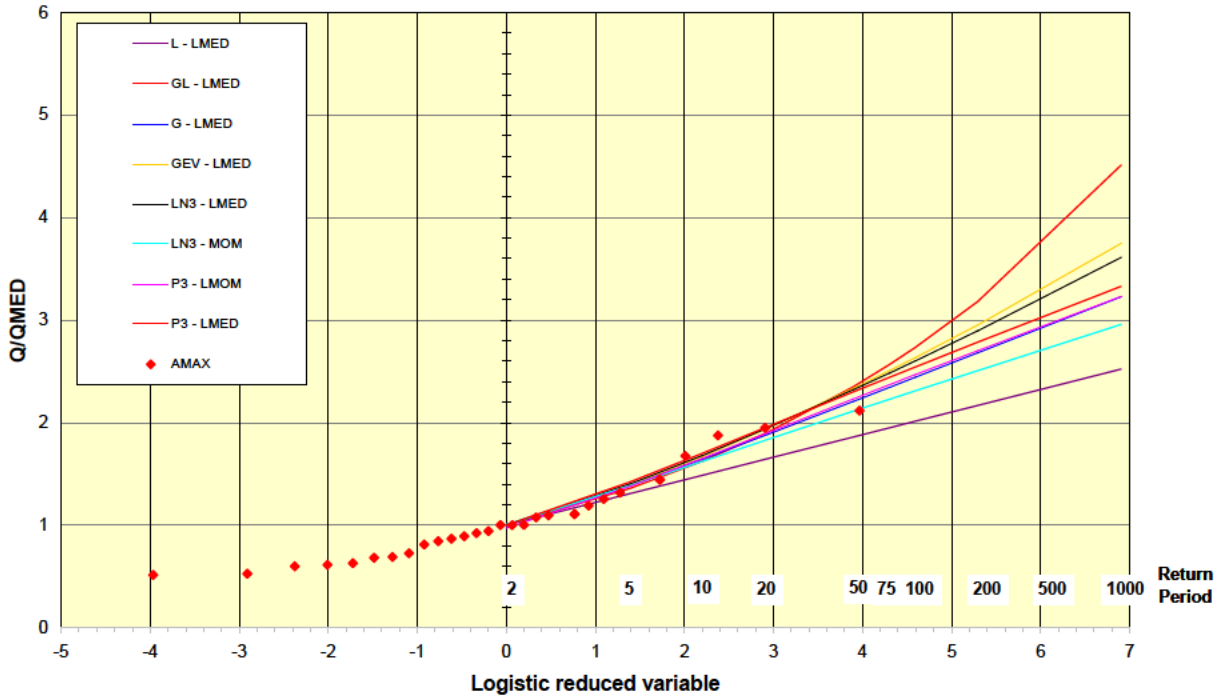
The area weighted average of the transferred Mattersey and Blyth donor sites has been used to derive the QMED at the downstream end of the River Idle catchment. This ensures that data from both donor sites is used. The final QMED is therefore 20.38 m^3/s.

C.3.2.3 Flood Frequency Analysis – River Idle

Flood frequency analysis has been undertaken at both Mattersey and Blyth. These are both permeable catchments, with an SPRHOST value < 20%, however, at Mattersey there are no years with an AMAX less than QMED/2 and therefore no permeable adjustment is needed to the growth curve.

Due to the long period of data available at Mattersey, and the findings of the River Idle Flood Risk Mapping Report which showed that the pooled analysis underestimated the growth factors, single site analysis has been carried out at this gauging station. The growth curves for Mattersey are provided in Figure C.26.

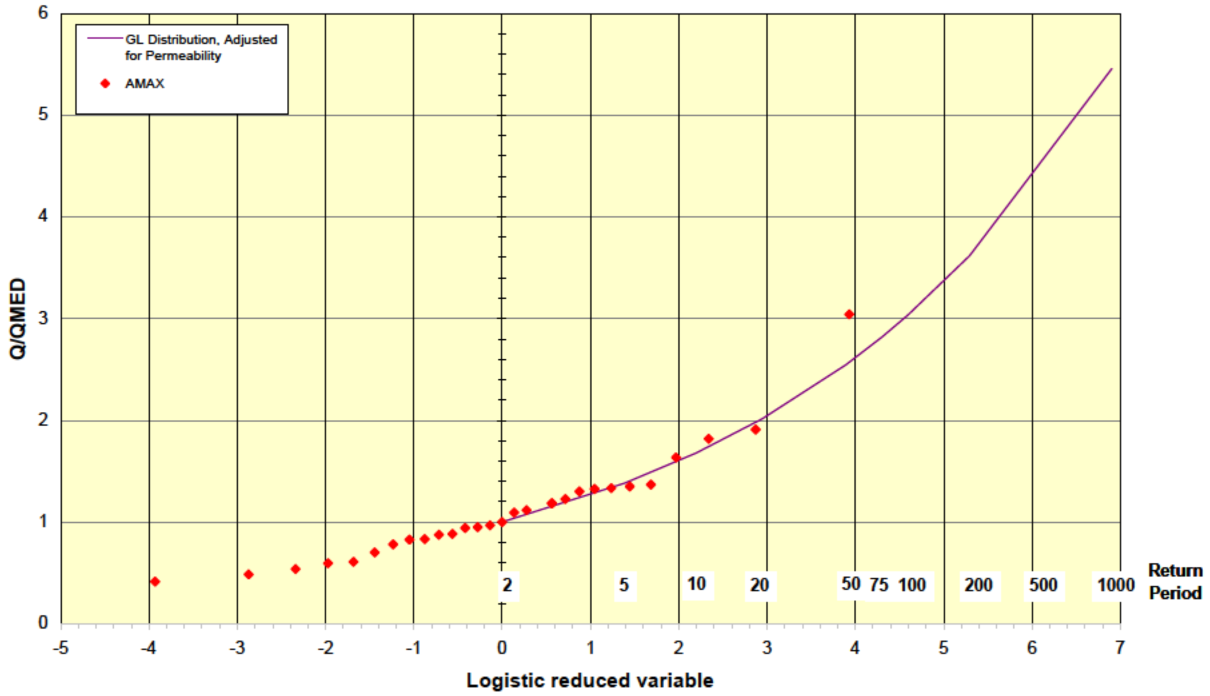
Figure C.26: Single Site Growth Curves for Mattersey Gauging Station



Source: Mott MacDonald

At Blyth there are two years where the annual maximum flood is less than half of the observed QMED, these are 1984 and 1996. Therefore the flood years General Logistic growth curve has been calculated and then adjusted to take into account the non-flood years. This is provided in Figure C.27.

Figure C.27: General Logistic Growth Curve for Ryton @ Blyth – Adjusted for Permeability



Source: Mott MacDonald

Table C.25 tabulates the flows for each return period if the General Logistic growth curve at Mattersey or at Ryton is used to derive design flows from the Idle catchment. The flow using an area weighted average of the two is also provided.

Table C.25: Design Flows for Idle Catchment

Return Period (1 in x year)	Flow using GL growth curve from Mattersey (m^3/s)	Flow using GL growth curve from Ryton (m^3/s)	Flow using an area weighted average between Mattersey and Ryton growth curves (m^3/s)
5	27.65	28.14	27.8
10	33.03	34.18	33.38
20	38.88	41.01	39.52
50	47.8	51.84	49.01
75	52.29	57.46	53.84
100	55.71	61.81	57.54
200	64.82	73.72	67.49
1000	91.96	111.22	97.74

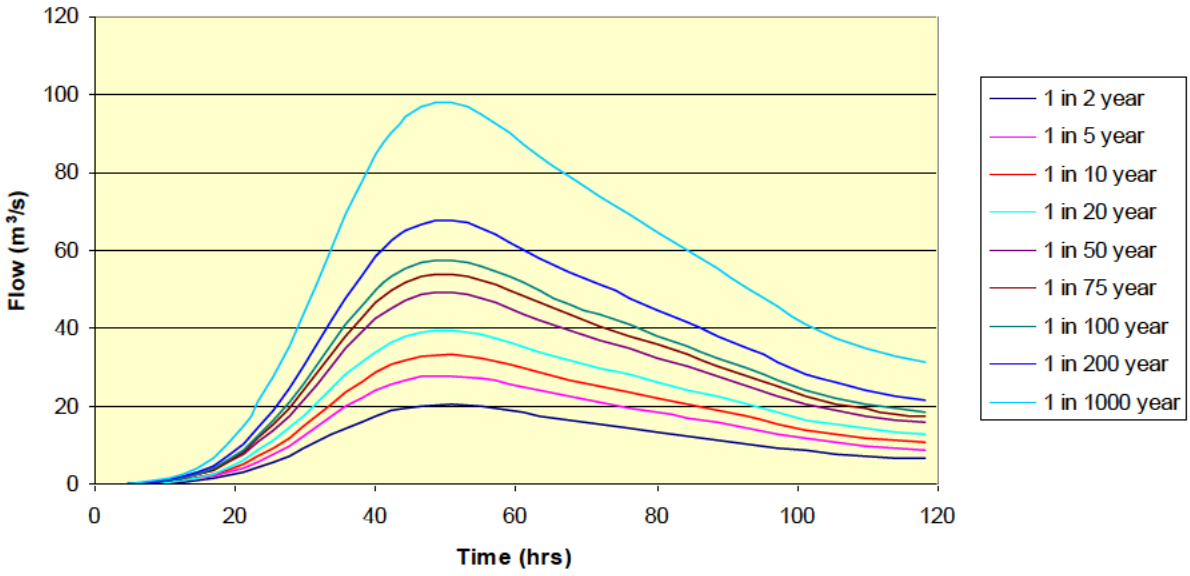
Source: Mott MacDonald

The area weighted average between Mattersey and Ryton growth curves has been used for calculating the design flows (circled in green).

C.3.2.4 Design Hydrograph Shape

The design hydrographs have been derived using ReFH, with the peaks of the hydrographs matching the design flows. Figure C.28 shows the resulting hydrographs.

Figure C.28: Design Flow Hydrographs - Idle



Source: Mott MacDonald

C.3.3 River Torne, North Soak Drain, South Soak Drain, Hatfield Waste Drain

The River Torne, North Soak Drain, South Soak Drain and Hatfield Waste Drain all discharge into the Trent via Keadby Pumping Station. One gauging station exists on the River Torne at Auckley, however, this is situated at the upstream end of the River Torne and therefore is of limited use for this study.

C.3.3.1 QMED Estimation

Catchment descriptors have been extracted from FEH for each of the sub-catchments. The QMED values have been derived using the catchment descriptors, and through ReFH analysis.

Table C.26: Catchment Descriptors for Keadby Catchments

Station	Area (km^2)	SAAR	BFI	SPR	FARL	QMED Catchment Descriptors (m^3/s)	QMED Adjusted for Urbanisation (m^3/s)	QMED Calculated using ReFH Analysis (m^3/s)
River Torne @ Keadby Pumping Station	208	603	0.72	21.7	0.98	6.63	7.87	6.4
Hatfield Waste Drain @ Keadby Pumping Station	108	578	0.49	34.56	0.97	7.91	8.14	8.4
South Soak Drain @ Keadby Pumping Station	21.1	583	0.53	33.52	1	1.92	2.05	1.6
North Soak Drain @ Keadby Pumping Station	29.86	582	0.47	40.06	0.99	2.93	3.1	2.8

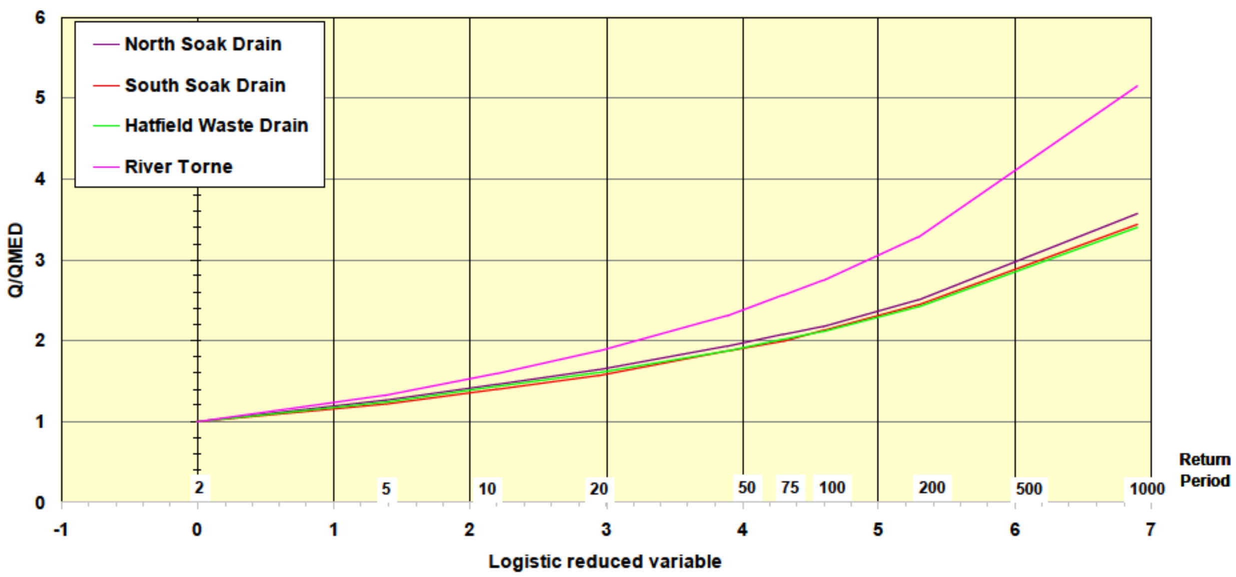
Source: FEH Catchment Descriptors

The QMED values have been derived using the catchment descriptors (circled in green).

C.3.3.2 Flood Frequency Analysis

The growth factors for each catchment have been extracted from the ReFH analysis and are shown in Figure C.29. This shows that the ReFH suggests a similar growth curve for the drains and a steeper growth curve for the River Torne.

Figure C.29: Growth Factors Extracted from ReFH Analysis for the Tributaries Discharging via Keadby Pumping Station



Source: Mott MacDonald – ReFH Analysis

Table C.27 provides the estimated design flows which have been used for these sub-catchments, using the growth factors derived from ReFH analysis and the QMED derived from catchment descriptors.

Table C.27: Estimates of Design Flows for the Tributaries Discharging via Keadby Pumping Station

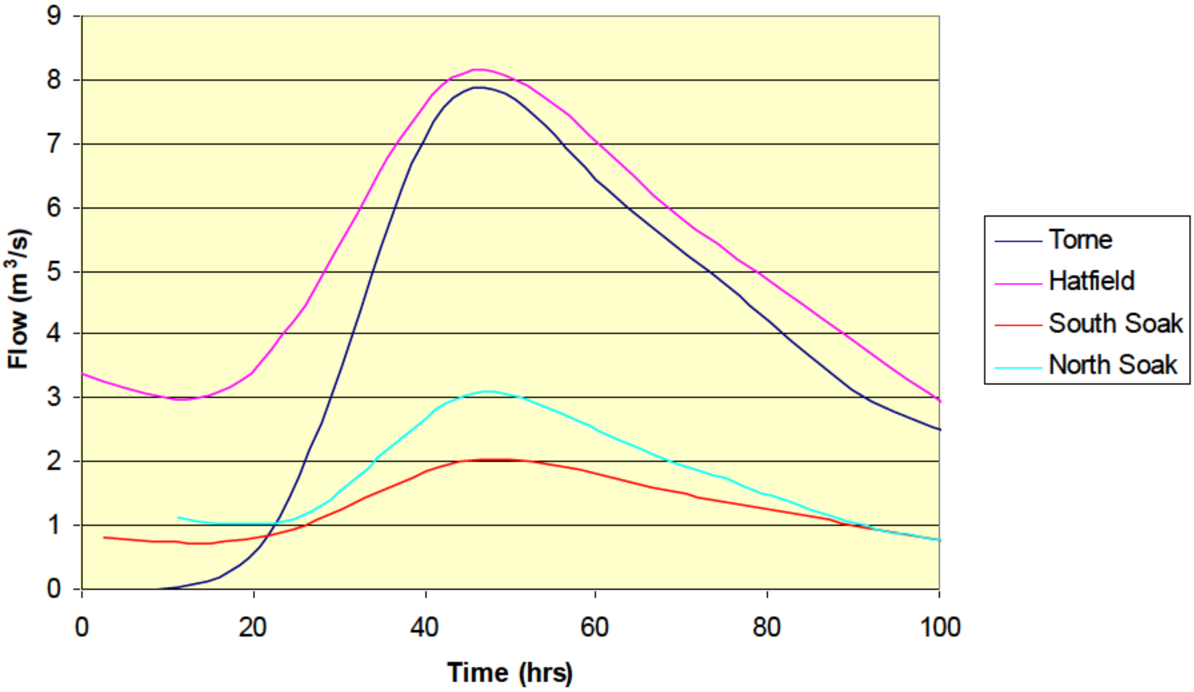
Return Period	River Torne	Hatfield Waste Drain	South Soak Drain	North Soak Drain
2	7.9	8.1	2.1	3.1
5	10.4	10.1	2.5	3.9
10	12.5	11.6	2.9	4.5
20	14.7	13	3.2	5.1
50	18.2	15.2	3.8	6.0
75	20.1	16.4	4.4	6.4
100	21.6	17.3	4.4	6.8
200	25.8	19.7	5	7.8
1000	40.6	27.7	7.1	11.1

Source: Mott MacDonald

C.3.3.3 Design Hydrograph Shape

Due to the lack of information about the expected flow hydrograph at Keadby Pumping Station and the minimal contribution from these catchments to the Tidal Trent in comparison to the flow in the Trent, the ReFH hydrographs have been used, with the peaks of the hydrographs matching the design flows. Figure C.30 shows the resulting hydrographs for the 1 in 2 year flood.

Figure C.30: 1 in 2 Year Hydrographs at Keadby Pumping Station – Calculated Using ReFH Analysis



Source: Mott MacDonald

C.3.4 River Eau

There is very limited data available on the River Eau, with the level gauge at Scotter being installed only in March 2011.

Table C.28 provides the catchment descriptors and the QMED value derived using these descriptors and using ReFH analysis. The catchment is considered to be rural (URBEXT2013 = 0.016) and therefore urban adjustment is not needed.

Table C.28: Catchment Descriptors for the Eau Catchment

Station	Area (km^2)	SAAR	BFI	SPR	FARL	QMED Catchment Descriptors (m^3/s)	QMED Calculated using ReFH Analysis (m^3/s)
River Eau @ Confluence with Trent	117	608	0.54	32.16	0.97	8.20	11

The flows at the confluence of the River Eau and the Tidal Trent, extracted from the EA's existing model for the River Eau, have been compared to those obtained using RefH analysis. Table C.29 tabulates the peak flows.

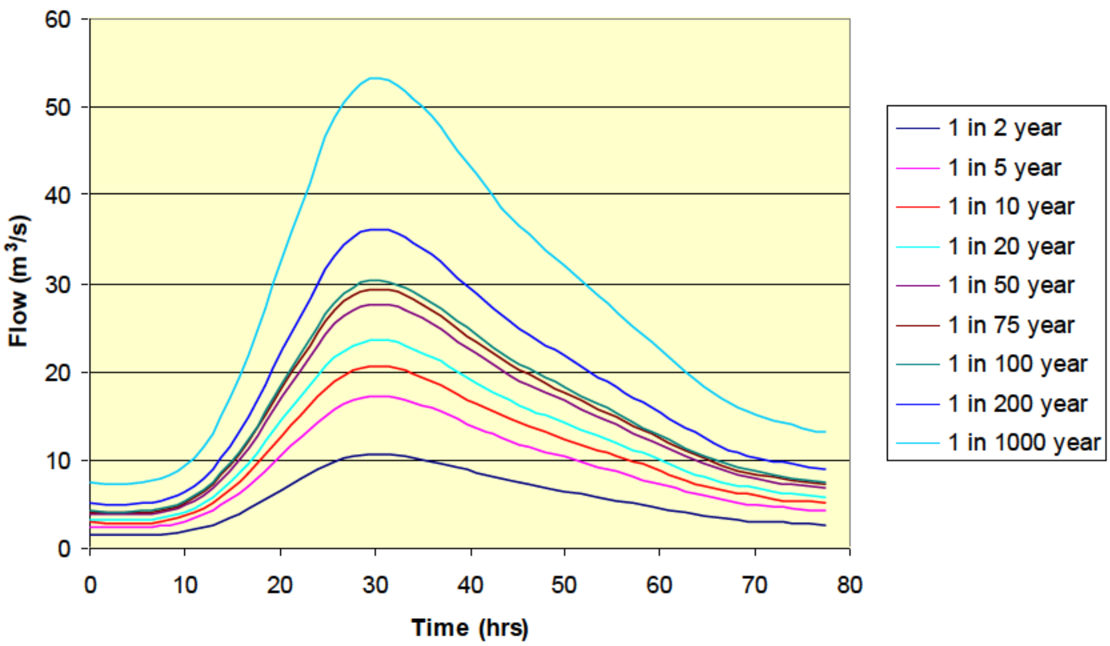
To provide consistency with the previous work undertaken by the EA, the peak flows extracted from the existing River Eau model have been used. ReFH methods have been used to determine the hydrograph shapes, provided in Figure C.31.

Table C.29: Design Peak Flows at Downstream End of River Eau – Calculated Using ReFH Analysis

Return Period	Peak Flow (m^3/s) (extracted from downstream end of EA model for River Eau	Peak Flow (m^3/s) (RefH Analysis)
5	17.15	13.4
10	20.56	15.6
20	23.53	17.7
50	27.64	21.1
75	29.3	22.9
100	30.23	24.3
200	36.1	28.2
1000	53.1	41.5

Source: Mott MacDonald – ReFH Analysis

Figure C.31: Design Flow Hydrographs – River Eau



Source: Mott MacDonald

C.3.5 Snow Sewer

Hydrological analysis for Snow Sewer has been based on the combined catchments of Warping Drain and Ferry Drain, as these run parallel to each other and discharge into the Trent at the same location.

Table C.30 provides the catchment descriptors and the QMED values derived using these descriptors and using ReFH analysis.

Table C.30: Catchment Descriptors for Warping Drain and Ferry Drain Catchments

Station	Area (km^2)	SAAR	BFI	SPR	FARL	QMED Catchment Descriptors (m^3/s)	QMED Calculated using ReFH Analysis (m^3/s)
Warping Drain @ Downstream End	13.6	579	0.6	27.74	0.99	0.96	2.05
Ferry Drain @ Downstream End	15.64	579	0.513	33.7	1	1.51	0.8

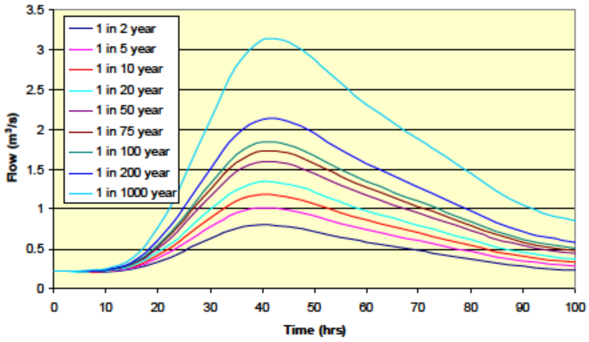
Due to the lack of information on this catchment and the small amount of flow it will contribute to the Tidal Trent, ReFH methods have been used to determine peak flows and hydrograph shapes. Table C.31 tabulates the peak flows and Figure C.32 the flow hydrographs.

Table C.31: Design Peak Flows at Downstream End of Warping Drain and Ferry Drain – Calculated Using ReFH Analysis

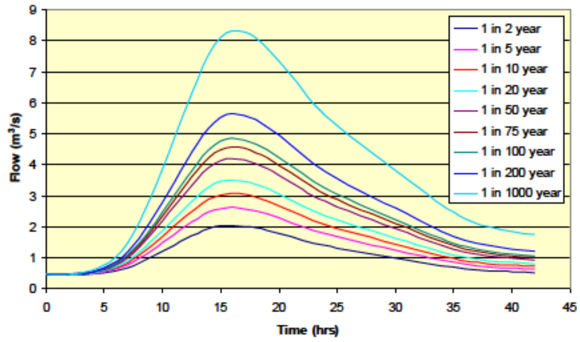
Return Period	Peak Flow – Warping Drain (m^3/s)	Peak Flow – Ferry Drain (m^3/s)	Peak Flow – Combined (m^3/s)
5	1.0	2.6	3.6
10	1.2	3.1	4.3
20	1.3	3.5	4.8
50	1.6	4.2	5.8
75	1.7	4.6	6.3
100	1.8	4.9	6.7
200	2.1	5.7	7.8
1000	3.1	8.3	11.4

Source: Mott MacDonald – ReFH Analysis

Figure C.32: Design Flow Hydrographs - Warping Drain



Design Flow Hydrographs - Ferry Drain



Source: Mott MacDonald

C.3.6 Bottesford Beck

No data other than catchment descriptors from the FEH CD are available for Bottesford Beck. The catchment is heavily urbanised with an URBEXT(2013) value of 0.36. Table C.32 provides the catchment descriptors and the QMED calculated using these descriptors and using ReFH analysis.

Table C.32: Catchment Descriptors for Bottesford Beck Catchment

Station	Area (km^2)	SAAR	BFI	SPR	FARL	QMED Catchment Descriptors (m^3/s)	QMED Adjusted for Urbanisation (m^3/s)	QMED Calculated using ReFH Analysis (m^3/s)
Bottesford Beck @ Downstream End	52.77	621	0.724	22.58	0.95	1.98	3.75	2.7

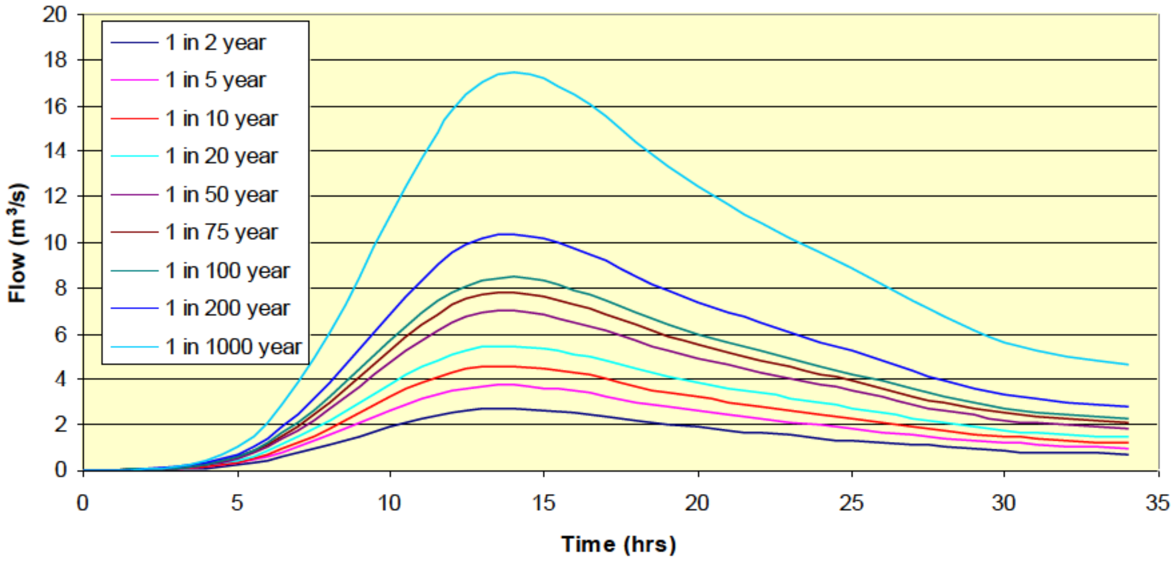
Due to the lack of information on this catchment and the small amount of flow it will contribute to the Tidal Trent, ReFH methods have been used to determine peak flows and hydrograph shapes. Table C.33 tabulates the peak flows and Figure C.33 the flow hydrographs.

Table C.33: Design Peak Flows at Downstream End of Bottesford Beck - Calculated Using ReFH Analysis

Return Period	Peak Flow – Bottesford Beck (m^3/s)
5	3.7
10	4.6
20	5.5
50	7.0
75	7.8
100	8.5
200	10.4
1000	17.4

Source: Mott MacDonald – ReFH Analysis

Figure C.33: Design Flow Hydrographs - Bottesford Beck



Source: Mott MacDonald

C.3.7 Intermediate Catchment

The intermediate catchment, which makes up 8% of the total catchment area, is made up of multiple small tributaries draining the land immediately adjacent to the Tidal Trent. It is not necessary to undertake analysis of each individual tributary. A simplified approach has been adopted by adding a proportion of the flow derived at North Muskham to represent the flow from the intermediate catchments. The additional flow has been distributed along the Trent between Cromwell Weir and the Trent Humber Confluence.

C.3.8 Time to Peak Analysis

Time to peak analysis from the River Torne Modelling Study Report has been transferred to this study. The River Torne Modelling Study carried out event analysis using the gauge at Auckley on the River Torne. The analysis suggested an observed time to peak of 15.27h. The time to peak calculated using the catchment characteristic for the catchment upstream of Auckley is 9.47h. The ratio between the observed and derived time to peaks has been used to calculate the time to peak for the River Torne and the River Idle as the catchment descriptors for these catchments are comparable to those at Auckley. Table C.34 provides the transferred times to peak.

Table C.34: Time to Peak Analysis

Catchment	Observed Time to Peak (h)	Time to Peak from Catchment Characteristics (h)	Transferred Time to Peak (h)
River Torne (Upstream of Auckley)	15.27	9.47	N/A
River Torne (At confluence with Trent)		19.1	30.75
River Idle (At confluence with Trent)		22.9	36.9

Source: River Torne Modelling Study Report and Mott MacDonald

Due to a lack of data on the other tributaries and to lack of similarity with the River Torne at Auckley catchment, catchment characteristics have been used to derive the time to peak on the remaining tributaries.

C.4 Tidal Hydrology

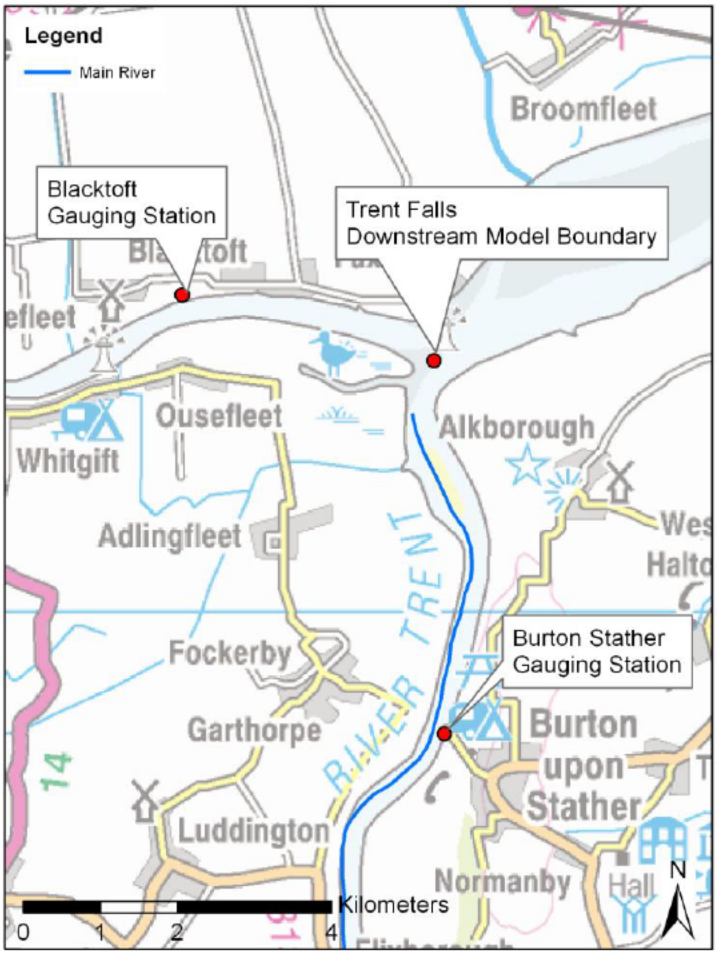
C.4.1 Design Extreme Water Levels

The River Humber North Bank Tidal modelling study, undertaken by Mott MacDonald (2011), involved detailed analysis of the water levels along the Humber Estuary. Design water levels were derived along the Humber including Blacktoft, which is located 4 km upstream of the Trent confluence with the Humber. Further analysis of the design levels for Blacktoft will not be undertaken as part of this study. However, these levels will be used to help inform the design levels for the downstream boundary of the model.

There is a tide level gauge located at Burton Stather on the Trent, near the confluence with the Humber. Data at Burton Stather (Figure C.34) is available from 2001 till 2012. This is not long enough to undertake reliable frequency analysis at the gauging station. A comparison has therefore been made between the monthly maximum water levels at Burton Stather and the corresponding maximum water level at Blacktoft.

The levels at Burton Stather relate to chart datum, which is 1.1m below O.D. Newlyn. The data has been adjusted to O.D. Newlyn.

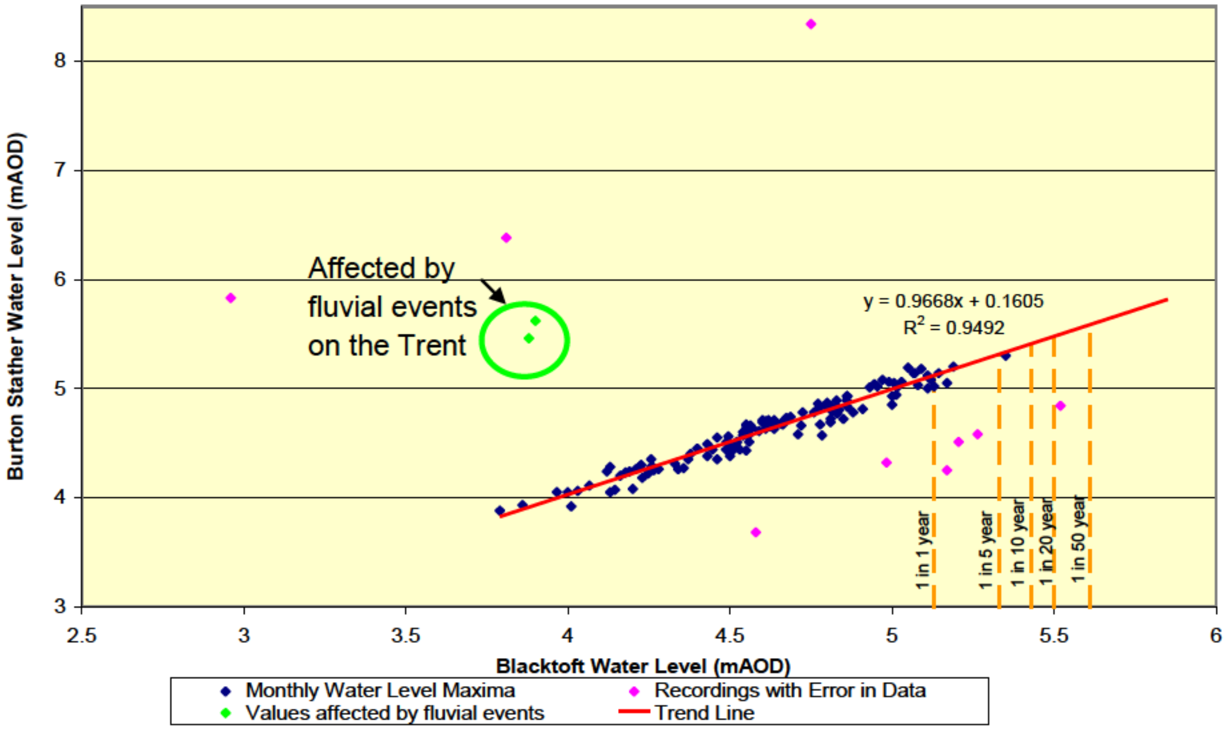
Figure C.34: Location of Blacktoft and Burton Stather Gauging Stations



Source: Mott MacDonald. This map is reproduced by permission of Ordnance Survey on behalf of The Controller Of Her Majesty's Stationary Office. © Crown Copyright. All rights reserved. Environment Agency 100026380, 2013.

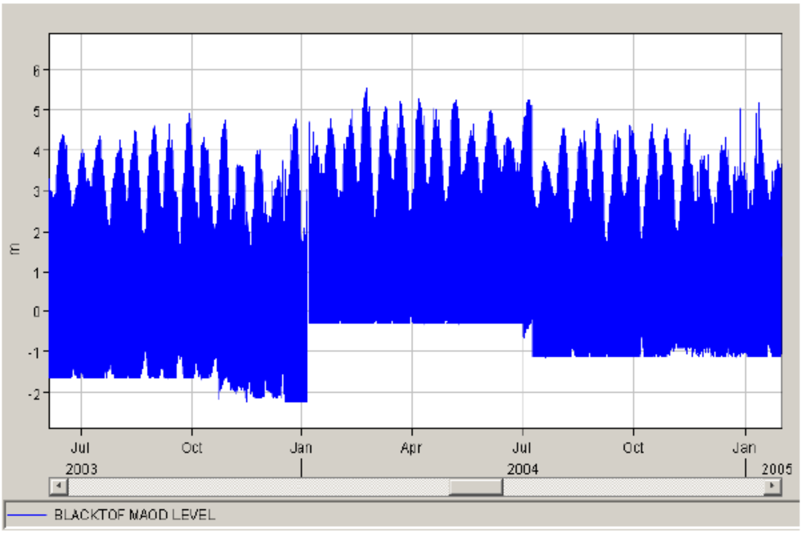
The comparison between the water levels is provided in Figure C.35. A number of the recordings had clear errors; these have been plotted separately. These were either due to an unnaturally high spike (Burton Stather levels above 5.5 mAOD), or between January 2004 and July 2004 when the datum at Blacktoft appears to have been shifted, Figure C.36. Omitting the erroneous data, a linear trend line has been fitted to the data and is also represented on the graph along with the recommended design levels at Blacktoft.

Figure C.35: Comparison of Water Levels at Burton Stather and Blacktoft



Source: Mott MacDonald

Figure C.36: Shift of Datum at Blacktoft Gauging Station



Source: Mott MacDonald

The correlation between the levels at Burton Stather and Blacktoft is very high, and therefore the linear trend has been used to transfer the design levels calculated at Blacktoft to create design levels at Burton Stather. The downstream boundary of the model at Trent Falls has been calibrated to allow the modelled levels at Burton Stather to match the calculated design levels. Table C.35 provides design levels at Burton Stather, calculated from those at Blacktoft.

Table C.35: Peak Design Levels for Burton Stather

Return Period (1 in x year)	Blacktoft (mAOD)	Burton Stather (mAOD)
1	5.13	5.12
5	5.33	5.31
10	5.43	5.41
20	5.5	5.48
50	5.61	5.58
100	5.65	5.62
200	5.69	5.66
500	5.8	5.77
1000	5.84	5.81

Source: Mott MacDonald

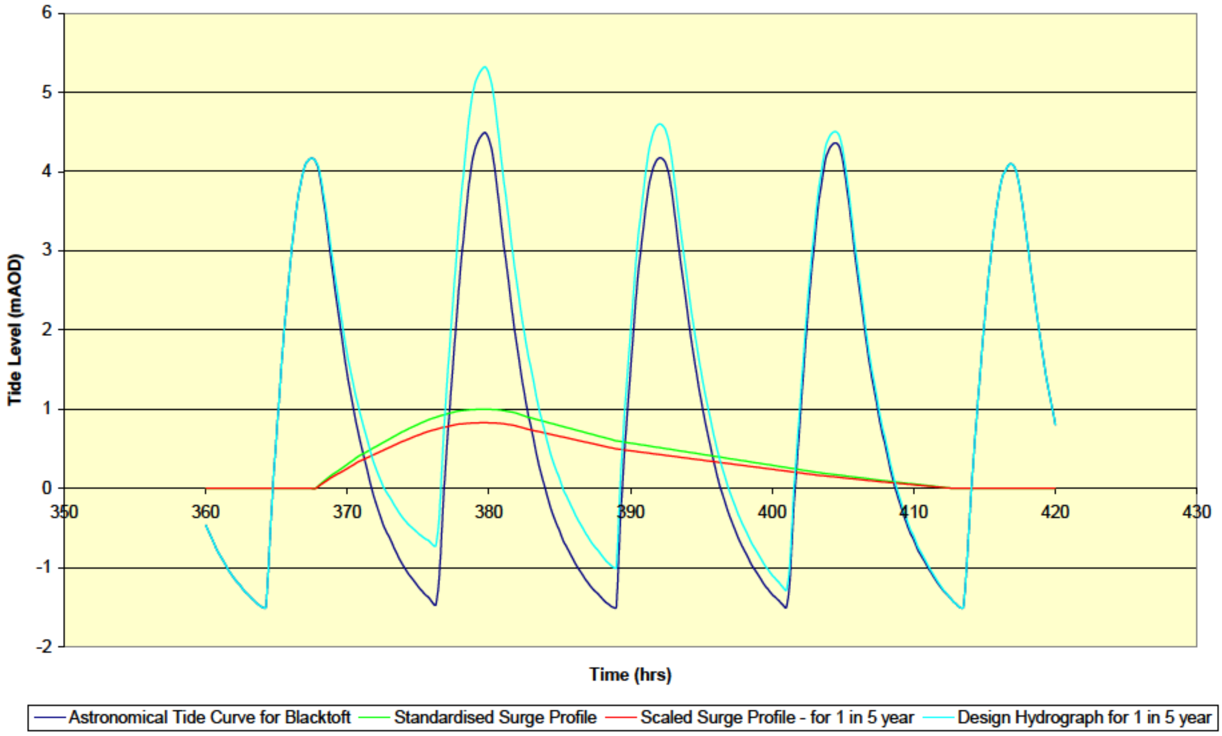
C.4.2 Design Astronomical Tide and Surge Profile

The design astronomical tide and surge profiles derived for the Trent Falls region as part of the River Humber, North Bank Tidal Modelling study are shown in Figure C.4 and Figure C.5. They have been used to derive the design water level hydrographs at the downstream boundary of the Trent model.

C.4.3 Design Water Level Hydrographs at Trent Falls

The design water level hydrographs have been derived by scaling the surge profile, so that when added to the design astronomical tide curve, the resulting peak water levels match the target peak design levels derived at Burton Stather. The surge peak and astronomical tide peak have been aligned to ensure that the most conservative approach is used. Figure C.37 shows an example of how the downstream boundary conditions have been derived.

Figure C.37: Example of Derivation of Downstream Boundary Conditions at Trent Falls



Source: Mott MacDonald

Note: Surge scaled to create peak of 5.32 mAOD (mid level between Blacktoft and Burton Stather Design levels)

C.4.4 1 in 200 Year Climate Change Tide Levels

The 1 in 200 year event has been simulated with two climate change predictions for the year 2100. The change factor estimate has been calculated using UKCP09 relative sea level rise (medium emission and 95 percentile) for the area around Trent Falls, and the Upper End Estimate has used the values provided in EA guidance: "Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities, Environment Agency, 2011".

Table C.36 tabulates the calculations used to determine the relative sea level rise for each scenario. This rise has been added to the entire tidal cycle to ensure that both the low-tide and high-tide levels are increased.

Table C.36: Climate Change Calculations

Scenario	Data used for Calculation	Calculated Sea Level Rise	Final Level at Burton Stather
Change Factor	Rise from 1990 to 2013: +0.071m Rise from 1990 to 2100: +0.467m	Rise from 2013 to 2100: +0.396m	5.96mAOD
Upper End Estimate	4mm per year from 2013 to 2025 = +0.048mm 7mm per year from 2026 to 2050 = +0.168m 11mm per year from 2051 to 2080 = +0.319m 15mm per year from 2081 to 2100 = +0.285m	Rise from 2013 to 2100: +0.82m	6.38mAOD

Source: Mott MacDonald

C.5 Calibration Hydrology

The design defended model was calibrated against six historical flood events:

- November 2000;
- January 2005;
- June 2007;
- November 2011;
- July 2012;
- November 2012.

These events were chosen as there is inflow data at North Muskham and tidal boundary data at either Blacktoft or Burton Stather for each event. The observed flows at North Muskham have been used as the model inflows for each calibration event. With the exception of the November 2000 event, there is also gauged data at Carlton-on-Trent, Torksey Lock, Gainsborough and Keadby which has been used to calibrate the model.

Digitised flood outlines are also available for the November 2000 and November 2012 events. The January 2005 and June 2007 events were both tidal events, with the remaining four being fluvial.

Observed inflows for the tributaries were not available for the calibration events, although gauged data at Mattersey on the River Idle was available. The gauged data at Mattersey was used to estimate the approximate return period of each event on the Idle. The corresponding design flows for that return period were then used on all the tributaries. Table C.37 provides the estimated return period of the tributary flow for each calibration event.

There is significant uncertainty in the fluvial inflows for the tributaries during all the events since the catchment is large enough for the storms to be likely to have had different return periods on each sub-catchment. The flood extents due to the backwater effect of the tributaries should therefore be treated with caution for calibration purposes.

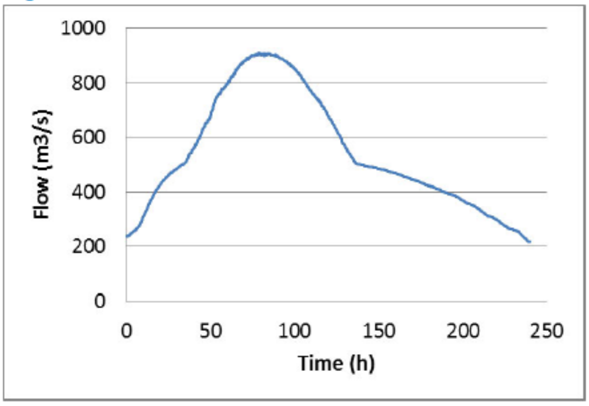
Table C.37: Return Periods Used on the Tributaries for Each Calibration Event

Event	Return Period	Comment
November 2000	1 in 20 year	Approximately 1 in 12 year flow at Mattersey on the Idle, and 1 in 20 year on Ryton at Blyth (tributary to Idle)
January 2005	No flow	Tidal Event, no significant fluvial flows
June 2007	1 in 50 year	Approximately 1 in 50 year flow at Blyth (River Ryton, tributary of the River Idle) and Mattersey on the River Idle
November 2011	No flow	Tidal Event, no significant fluvial flows
July 2012	1 in 2 year	No data available on tributaries. Flow at North Muskham approximately 1in 2 year
November 2012	1 in 20 Year	No data available on tributaries. Flow at North Muskham approximately 1 in 20 year

Source: Mott MacDonald

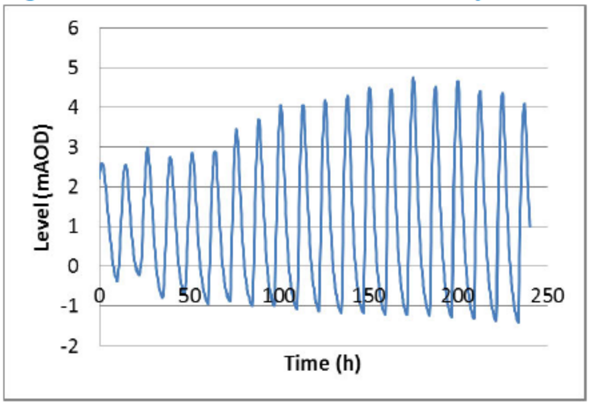
The hydrographs used for the upstream model inflow and the downstream tidal boundary for each event are given in Figure C.38 to Figure C.49.

Figure C.38: November 2000 Inflow



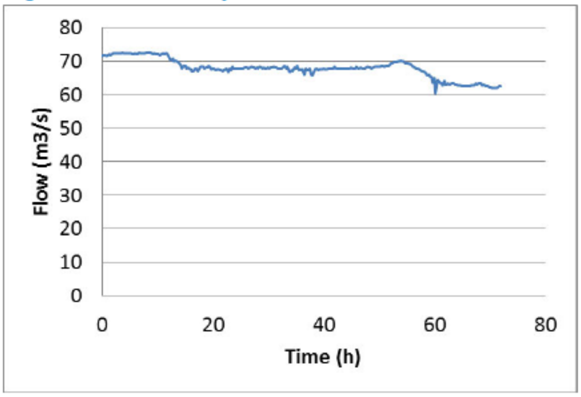
Source: Mott MacDonald

Figure C.39: November 2000 Tidal Boundary



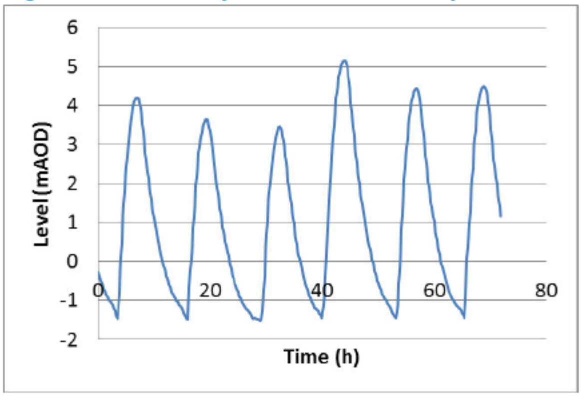
Source: Mott MacDonald

Figure C.40: January 2005 Inflow



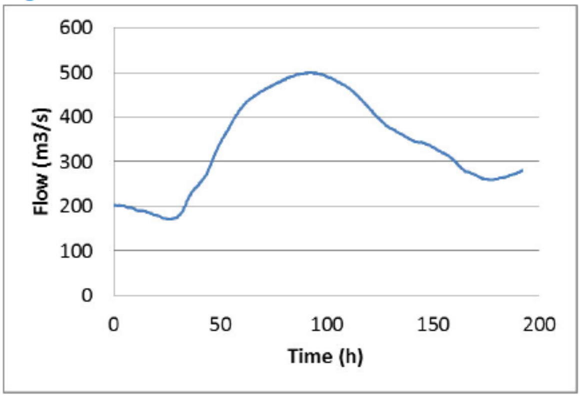
Source: Mott MacDonald

Figure C.41: January 2005 Tidal Boundary



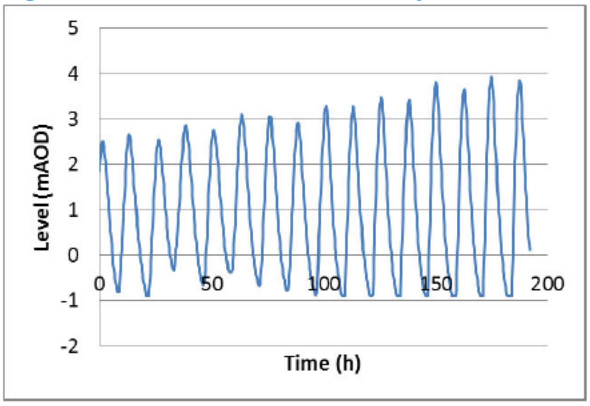
Source: Mott MacDonald

Figure C.42: June 2007 Inflow



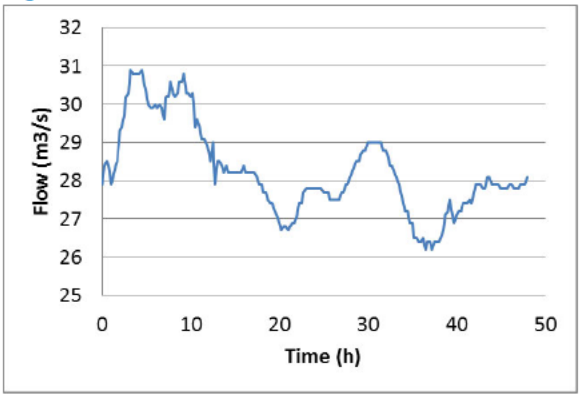
Source: Mott MacDonald

Figure C.43: June 2007 Tidal Boundary



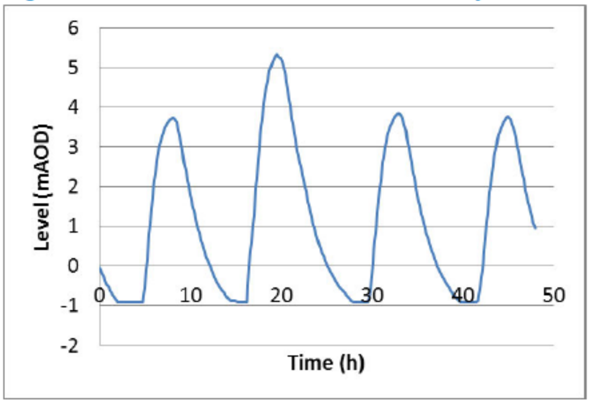
Source: Mott MacDonald

Figure C.44: November 2011 Inflow



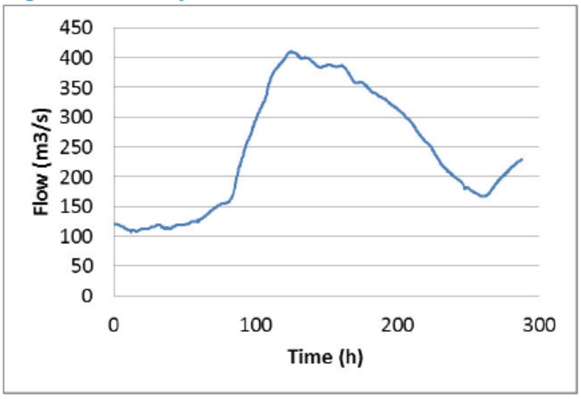
Source: Mott MacDonald

Figure C.45: November 2011 Tidal Boundary



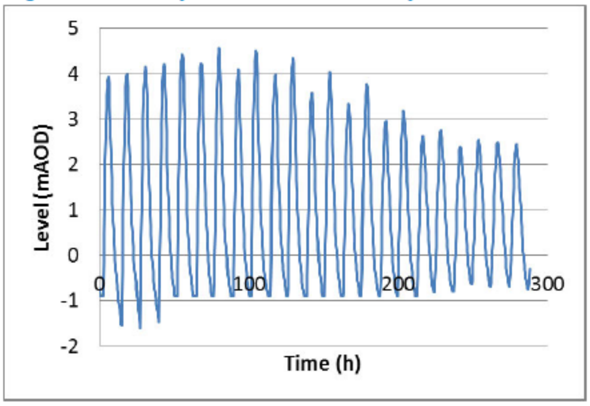
Source: Mott MacDonald

Figure C.46: July 2012 Inflow



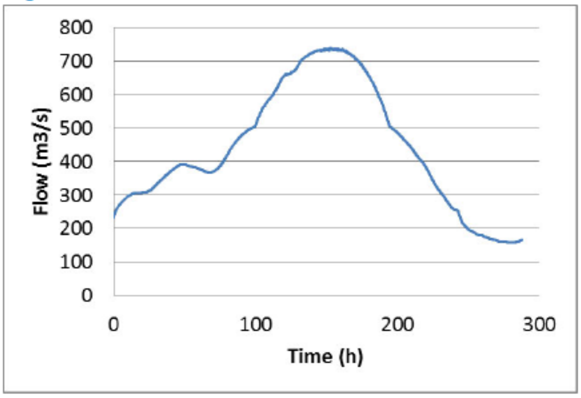
Source: Mott MacDonald

Figure C.47: July 2012 Tidal Boundary



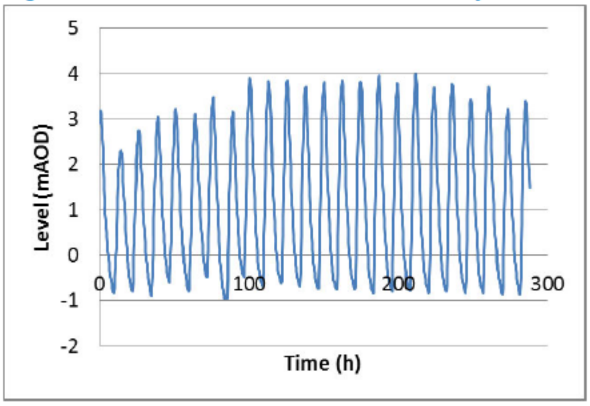
Source: Mott MacDonald

Figure C.48: November 2012 Inflow



Source: Mott MacDonald

Figure C.49: November 2012 Tidal Boundary



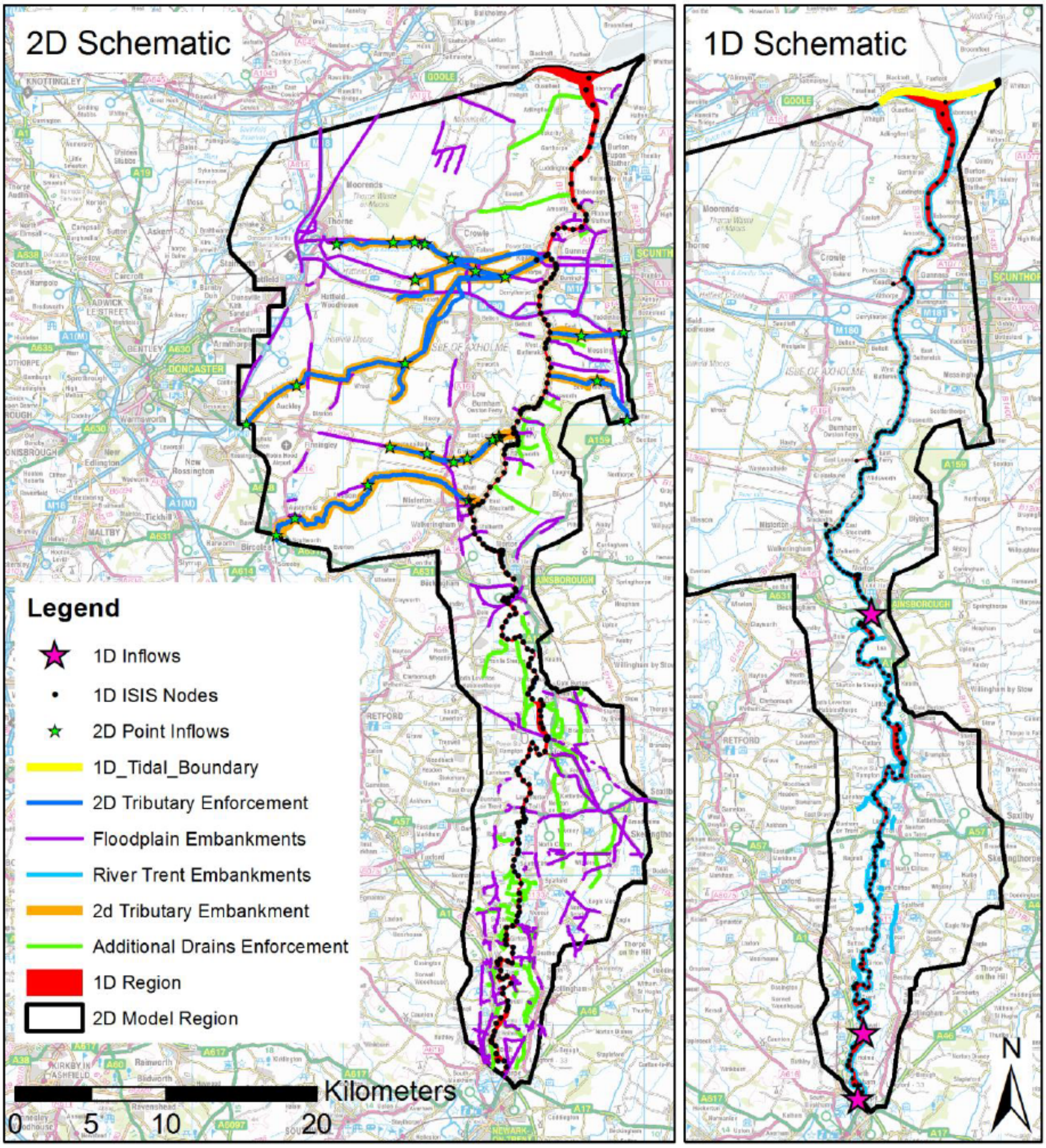
Source: Mott MacDonald

Appendix D. Hydraulic Model Development

D.1 Model Extent and Configuration

A hydraulic 1D-2D ISIS-TUFLOW model was developed for this study and extends from the tidal limit of the Trent at North Muskham to the confluence of the Tidal Trent with the Humber Estuary, and includes consideration of the River Idle, River Torne, Warping Drain, Ferry Drain, Hatfield Waste Drain, North Soak Drain, South Soak Drain, River Eau and Bottesford Beck. The schematic of the design hydraulic model can be found in Figure D.1. An existing ISIS model for the Trent was used as a basis, and models for the River Idle and River Torne used to help inform the representation of these tributaries.

Figure D.1: Design Model Schematic



Source: Mott MacDonald. This map is reproduced by permission of Ordnance Survey on behalf of The Controller Of Her Majesty's Stationary Office. Environment Agency 100026380, 2013.

The existing 1D ISIS model of the Tidal Trent from Winthorpe Bridge to Trent Falls has been updated using new survey data, and forms the basis of the model. This has been represented in 1D, and hydrodynamically linked to a 2D representation of the floodplain.

The key tributaries have been represented in the model using "gully lines" in the 2D domain to carve a flow channel through the floodplain. Detailed representation of these tributaries has not been a focus of the study as it is the backwater effects of the Tidal Trent that are of interest, and on most of these tributaries, separate studies have already been undertaken to assess the flood risk from the tributaries themselves.

D.2 Representation of the Tidal Trent

D.2.1 Review of Existing ISIS Model

The existing 1D ISIS model of the Tidal Trent was created as part of the Tidal Trent Flood Management Strategy project in July 2005 by Black & Veatch on behalf of the Environment Agency. The upstream limit of the model is Winthorpe Bridge and the downstream limit Trent Falls. The floodplain is represented using reservoir units connected to the river section units by the use of spills.

The model contains a single time-varying flow boundary at Winthorpe Bridge and a time-varying stage boundary at Trent Falls. The tributaries to the Tidal Trent have not been incorporated into the existing study.

D.2.2 Updates to ISIS Model

The ISIS model has been updated to satisfy two purposes:

- Incorporate new survey data commissioned in 2012 / 2013;
- Prepare the model for linking to a 2D representation of the floodplain.

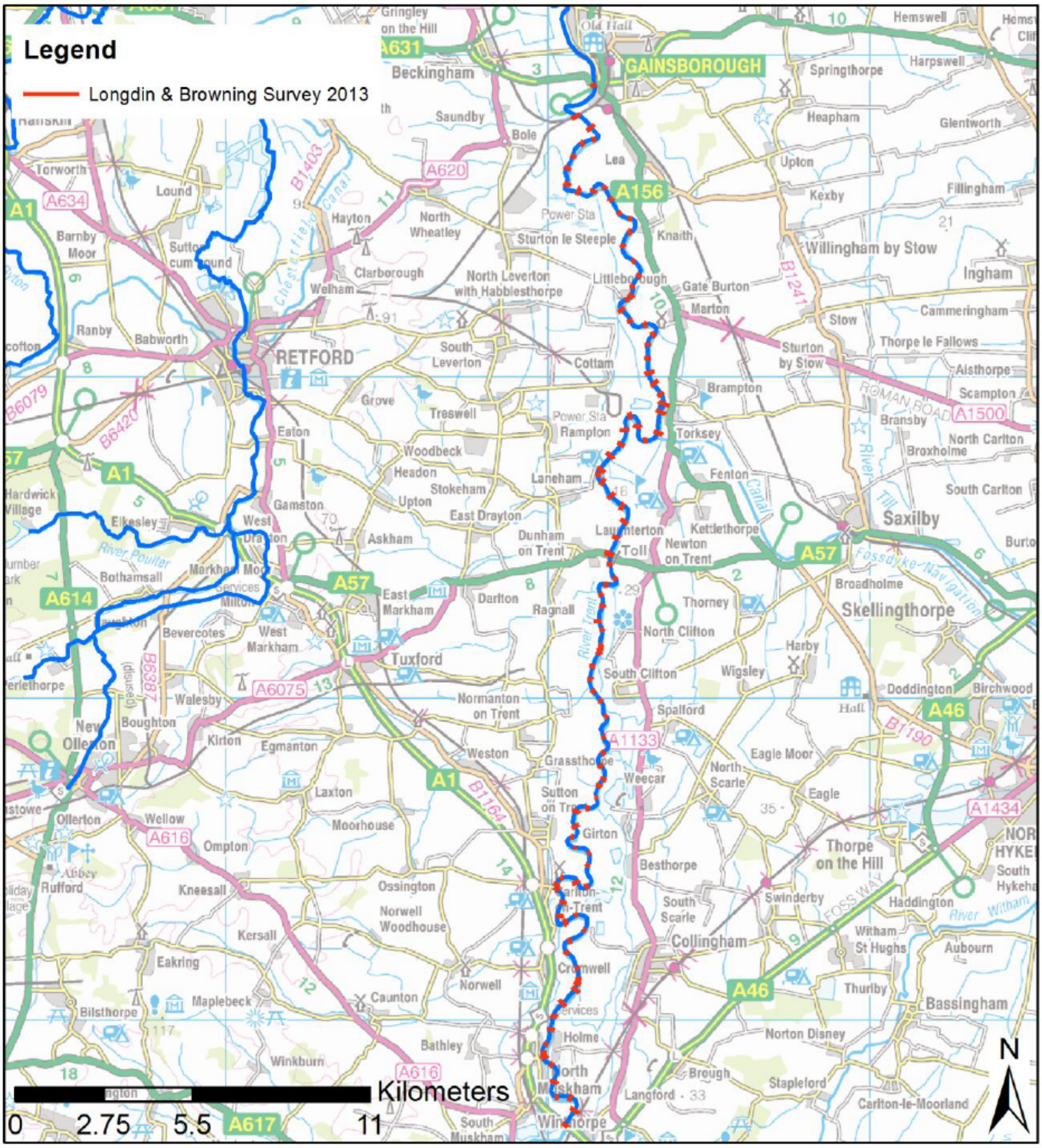
D.2.2.1 Incorporation of New Survey Data

Channel Survey undertaken by Longdin & Browning between November 2012 and March 2013 from Winthorpe Bridge to Gainsborough Road Bridge has been used to replace the existing model cross-sections. The survey was carried out with approximately 500m spacing between sections. This is a coarser spacing than in the original model, however, more suitable for a 1D-2D linked representation.

Downstream of Gainsborough Rail Bridge, bathymetric survey undertaken by the EA Geomatics Group from April to June 2013 has been used at a 5m resolution to extract cross-section data at the locations of the original model cross-sections. A 5m resolution has been used as the river is around 90m wide in its lower reaches, and using a coarser resolution reduced the amount of post-processing required by the Geomatics Group due to the amount of sediment picked up by the depth sensors during the survey.

Figure D.2 shows the location of new survey incorporated into the model.

Figure D.2: Location of Survey Cross-sections



Structures

There are nine structures along the Tidal Trent. The majority of the structures are very large, and unlikely to have a significant impact on the flood risk along the Trent. The structures and how they have been included in the model are given in Table D.1. The various pumping stations at the confluence of the tributaries and the Trent have been described in Section D.3.

Table D.1: Structures along the Tidal Trent

Structure	Comment
Winthorpe Bridge 	Winthorpe Bridge is located at the upstream boundary of the model and therefore has not been included in the model. The A1 embankment constrains most of the flow to the river channel in this location.
Cromwell Weir 	Cromwell Weir is considered the tidal limit of the Trent. It has been represented with a General Purpose Weir unit in ISIS. The curved crest has been taken into account when calculating the breadth of the crest (104m). The crest level used is 5.23mAOD The lock has been represented using a spill section, with a crest level of 8.33mAOD – representing the lock as closed. The land between the lock and the weir has been represented using a spill unit with variable crest levels.

Structure	Comment
Trent Viaduct 	The Trent Viaduct has been represented using a USBPR unit in ISIS. This is because the piers are likely to cause most headloss through the bridge. The bridge does not constrict the flow to a narrower channel, and the soffit of the bridge will not be reached even in extreme flood events. The pier width has been estimated from survey data as 3m each (total of 9m as there are three pairs of piers)
Dunham Road Bridge 	Dunham Road Bridge has been modelled with an arch bridge unit, with a spill representing the over deck flow located in parallel. The pier in the centre of the river is located on a raised section of river bed, represented in the channel section incorporated in the bridge unit. The raised bed section has not been used in the river sections immediately upstream and downstream of the bridge as it is unrepresentative of the general bed levels within 500m of the bridge.

Structure	Comment
Torksey Viaduct  	Torksey Viaduct has two very different construction forms, separated by a small island as shown in the pictures. The model has split the watercourse using a junction into two channels, one for each section of the bridge. Both bridge sections have been represented using arch bridge units. The channels combine again downstream of the bridge and island. The two channels have not been linked laterally to each other, as the water levels in both channels are likely to be very similar without the linking, and linking them would affect the stability of the model. A small section of viaduct on the left bank may get overtopped by extreme events. This has been represented by a spill unit in parallel.
Gainsborough Rail Bridge 	Gainsborough Railway Bridge has been represented using an arch bridge unit. The bridge is composed of a central pier with two large spans either side. There are also three smaller openings represented in the unit, two immediately either side of the river, and one slightly set back from the river.

Structure	Comment
Gainsborough Road Bridge 	Gainsborough Road Bridge is a traditional arched bridge, and has been represented as such in the model.
M180 Motorway 	The M180 Bridge is a very large structure, which was considered to have very little impact on flow, and has therefore not been included in the 1D model. The motorway embankment on either side of the river has been represented in the 2D domain
Keadby Road & Rail Bridge 	Keadby Road & Rail Bridge is a lifting bridge to allow ships to pass up the Trent. There are two piers located in the river channel. It has been modelled as an arch bridge unit in ISIS.

In-channel Roughness Values

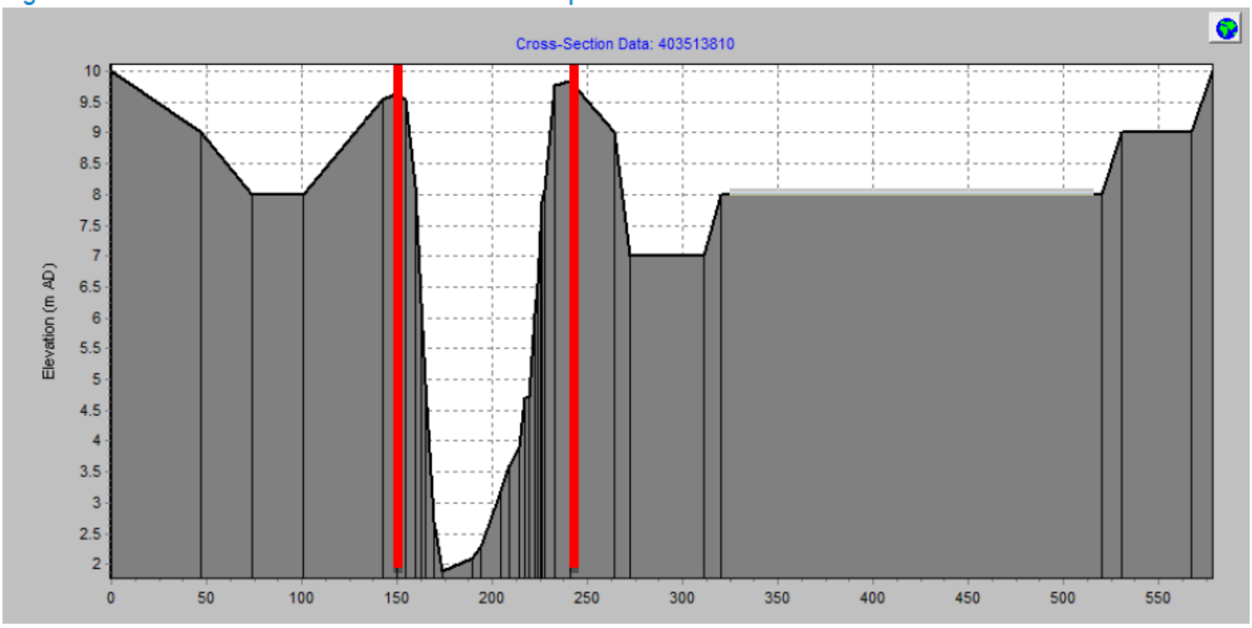
In-channel roughness values have been derived using Chow (1959). The channel is dredged, and has a number of large meanders. Manning's values have been amended during the calibration process and a value of 0.03 used in the upper reaches, and 0.02 in the lower reaches. A Manning's value of 0.02 is considered to be very low for a river, however, the calibration shows that in the lower reaches the model is mostly predicting higher water levels than those observed. Reducing Manning's value further was not considered realistic. On areas of floodplain which are contained within the ISIS river cross-sections, a value of 0.05 has been used to provide consistency with the roughness values used in the 2D floodplain representation.

D.2.2.2 Preparation for Linking to 2D Representation

Truncation of ISIS Cross-sections

The ISIS cross-sections have been truncated to bank-top locations on the left and right banks, to ensure that out-of-bank flow is not represented twice within the model (once within the 1D representation, and once within the 2D representation) as shown in Figure D.3.

Figure D.3: Truncation of Cross-sections to Bank-tops

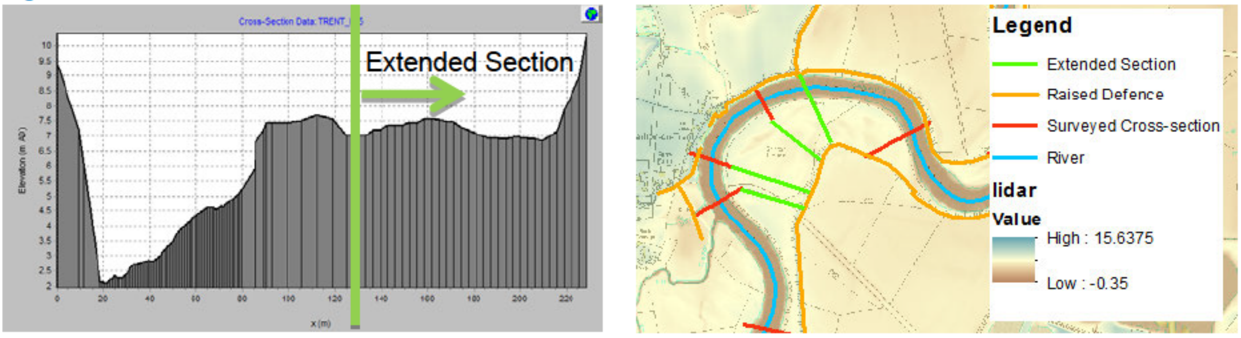


Source: ISIS

Extension of ISIS Cross-sections

In a number of locations the ISIS cross-sections have been extended using LiDAR data. This has been carried out where the surveyed cross-sections do not extend as far as the first flood embankment.

Figure D.4: Extension of Cross-sections



Source: ISIS

Bank Levels

The survey data available for defining the bank levels has been tabulated in Table 4.2 and shown in Figure 4.3. Where multiple data sets were available for a location the source of the data to be used was discussed with the EA. Longsections of each bank of the Tidal Trent with the available bank survey data and the survey data that was chosen to be used are provided in the accompanying data. The levels were enforced using a “z-line” in the 2D domain to ensure that they were accurately represented.

D.3 Schematisation of Tributaries

The tributaries have been incorporated into the model as gully lines to carve a channel into the 2D domain. This representation has been considered acceptable as the tributaries themselves are not the key focus of the study, and for the River Idle, River Torne, Hatfield Waste Drain, North Soak Drain, South Soak Drain and River Eau, 1D representations of the river channels have already been created as part of previous studies and used to inform the flood risk for the surrounding areas.

Details on the representation of each tributary are given below:

D.3.1 River Idle

Bed levels for the River Idle have been extracted from the existing ISIS model cross-sections by JBA Consulting in 2005. The z-line was given a width varying from 20m at the upstream end of the model domain, to 30m at the confluence with the Trent to ensure that the correct width of channel has been carved out. The bank levels were taken from LiDAR data at around 50m intervals, and enforced into the model using z-lines.

The only structure represented on the River Idle is Stockwith Pumping Station which pumps water from the Idle into the Trent. The pumping station was incorporated into the model by including a short reach of ISIS, linked at one end to the 2D gully line to allow flow from the 2D model into the ISIS model, and at the other end to an ISIS abstraction unit.

Stockwith Pumping Station consists of four pumps, two with a pumping capacity of 12.74 m^3/s and two with a pumping capacity of 4.96 m^3/s. The pumps were combined into one abstraction unit.

The abstraction unit contains several rules to control the amount of water pumped from the Idle into the Trent depending on the water level in the Idle. The pumping rules were taken from data provided in the River Idle Flood Risk Mapping Report (JBA, 2005). The rules differ depending on whether the flood is on its rising limb or falling limb.

The rules were initially incorporated as given, however, this led to model instabilities as there were large changes in the pumping capacity for very small changes in water level. The rules were therefore amended to allow for a graduated increase in pumping capacity as the water level increased, particularly for the lower water levels when the pumps are switching between off and on. This is not considered to have an effect on the peak water levels, as the rules corresponding to the higher water levels have been left unchanged. Table D.2 provides details of the pumping rules used, and whether these have been amended from the original representation.

Table D.2: Pumping Rules Used for Stockwith Pumping Station

Rising or Falling Limb	Minimum Level (mAOD)	Maximum Level (mAOD)	Discharge (m^3/s)	Comments
Rising Limb	<2.1	2.1	0	No Pumps Operational
	2.1	2.3	Graduated between 0 and 5	Original rules have an extraction of 5 m^3/s for all water levels between 2.1 and 2.3 mAOD
	2.3	2.5	Graduated between 5 and 10	Original rules have an extraction of 10 m^3/s for all water levels between 2.3 and 2.5 mAOD Data
	2.5	2.7	Graduated between 10 and 12	Original rules have an extraction of 12 m^3/s for all water levels between 2.5 and 2.7 mAOD Data
	2.7	2.9	Graduated between 12 and 17	Original rules have an extraction of 17 m^3/s for all water levels between 2.7 and 2.9 mAOD Data
	2.9	3.1	22	
	3.1	3.3	24	
	3.3	3.5	29	
	3.5	>3.5	34	
Falling Limb	3.3	>3.5	34	
	3.1	3.3	29	
	2.9	3.1	24	
	2.7	2.9	22	
	2.4	2.7	Graduated between 12 and 17	Original rules have an extraction of 17 m^3/s for all water levels between 2.4 and 2.7 mAOD Data
	2.2	2.4	Graduated between 10 and 12	Original rules have an extraction of 12 m^3/s for all water levels between 2.2 and 2.4 mAOD Data
	2.0	2.2	Graduated between 5 and 10	Original rules have an extraction of 10 m^3/s for all water levels between 2.0 and 2.2 mAOD Data
	1.9	2.0	Graduated between 0 and 5	Original rules have an extraction of 5 m^3/s for all water levels between 1.9 and 2.0 mAOD
	<1.9	1.9	0	No Pumps Operational

Source: River Idle Flood Risk Mapping Report (JBA 2005) and Mott MacDonald

D.3.2 Warping Drain and Ferry Drain

Warping Drain and Ferry Drain run in parallel across the floodplain, and discharge into the Trent at Owston Ferry via two pumping stations. The water courses have been carved into the 2D domain using gully lines as explained for the River Idle. The elevations for the gully lines were taken from LiDAR, and then dropped by 1m due to the LiDAR reflecting off the water surface. The two pumping stations were modelled together in one unit, since due to the grid size used in the 2D domain, it was difficult to separate the two watercourses, particularly at their confluence with the Trent, where they run very close to each other.

The pumping stations at Owston Ferry have been incorporated in the same manner as Stockwith Pumping Station. The EA provided details for the pumping stations as follows:

- Three diesel pumps each with a capacity of 0.95m^3/s;
- Gravity penstock at outfall which closes at around 2mAOD;
- Decision to pump is taken around 2.4mAOD (not automatic pumping);
- For normal conditions, pumping not required;
- Pumps were made operational during floods of July 2007, January 2008 and November 2012.

It has been considered that – since the July 2007 and January 2008 events correspond to a return period of around 1 in 5 to 1 in 7 year on the Trent – it would be acceptable to consider the pumps as being operational for all events modelled, with pumping commencing at a level of 2.4m. The level in the Trent during all modelled flood events is above 2mAOD for the main part of the event, therefore the gravity penstock has not been incorporated into the model.

A graduated increase in pumping capacity has been used between water levels of 2.4 and 2.6mAOD to ensure model stability. A pumping capacity of 2.85m^3/s (all three pumps operational) has been used for water levels above 2.6mAOD.

D.3.3 River Torne, Hatfield Waste Drain, North Soak Drain and South Soak Drain

The River Torne, Hatfield Waste Drain, North Soak Drain and South Soak Drain all combine into what is called "The Three Rivers" approximately 3km upstream of Keadby. This then discharges into the Tidal Trent via Keadby Pumping Station.

The tributaries have been incorporated using gully lines, with the bed levels and bank levels extracted from survey data undertaken by Cartographic Surveys in 2006.

The only structure represented on these tributaries is Keadby Pumping Station which pumps water from The Three Rivers into the Trent. The pumping station was incorporated into the model by including a short reach of ISIS, linked at one end to the 2D gully line to allow flow from the 2D model into the ISIS model, and at the other end to a number of abstraction units.

Keadby Pumping Station consists of six pumps, one with a pumping capacity of 2 m^3/s and five with a pumping capacity of 5.4 m^3/s. Each pump has been given its own abstraction unit, with the rules taken from the River Torne Modelling Study Report (Black & Veatch, 2005). The rules differ depending on whether the flood is on its rising limb or falling limb, and in some cases, whether one of the other pumps is operational or not.

Pumps 2 and 6 also have additional rules depending on whether the level at Candy Farm is greater than 1mAOD. Since the location of Candy Farm is in the 2D domain, and the abstraction units are in the 1D domain, it has not been possible to accommodate this rule explicitly. It has been assumed that since the flood is likely to have progressed from the upper reaches of the Torne and associated tributaries, the level at Candy Farm is likely to be greater than 1mAOD during the rising limb of the flood, and less than 1m during the falling limb of the flood (with rising and falling times determined by the levels at Keadby).

The rules for each pump unit are given in Table D.3.

Table D.3: Pumping Rules Used for Keadby Pumping Station

Rising or Falling Limb		Minimum Level (mAOD)	Maximum Level (mAOD)	Discharge (m^3/s)	Comments
Rising Limb	Pump 1		<0.55	0	Pump 1 is dependent on operating status of Pump 2 (Pump1 turns off if level <0.55 and Pump 2 is on – this is always the case for levels above 0.25m as we assume Candy Farm level is >1mAOD)
		>0.55		2	
	Pump 2		<0.25	0	Pump 2 depends on levels at Candy Farm (assumed >1mAOD on rising limb)
		>0.25		5.4	
	Pump 3		<0.8	0	
		>0.8		5.4	
	Pump 4		<0.85	0	
		>0.85		5.4	
	Pump 5		<0.75	0	
		>0.75		5.4	
	Pump 6		<0.25	0	Pump 6 depends on levels at Candy Farm (Assumed >1mAOD on rising limb)
		>0.25		5.4	
Falling Limb	Pump 1	>0.55		2	See above comment for Pump 1
			<0.55	0	
	Pump 2	>0.1		5.4	
			<0.1	0	See above comment for Pump 2
	Pump 3	>0.3		5.4	Pump 2 depends on levels at Candy Farm (assumed <1mAOD on falling limb)
			<0.3	0	
	Pump 4	>0.4		5.4	
			<0.4	0	
	Pump 5	>0.2		5.4	
			<0.2	0	
	Pump 6	>0.15		5.4	Pump 6 depends on levels at Candy Farm (assumed <1mAOD on falling limb)
			<0.15	0	

Source: River Torne Modelling Study Final Report (Black & Veatch 2005) and Mott MacDonald

D.3.4 River Eau and Bottesford Beck

The River Eau and Bottesford Beck have been incorporated into the model using gully lines. For Bottesford Beck the elevations of the gully line have been taken from survey data taken by Gayler in March 1996. For the River Eau, LiDAR levels have been used to inform the gully elevations.

Both Bottesford Beck and River Eau discharge into the Trent via outfalls which restrict the flow of water passing from the Trent up the tributaries. This has been modelled using a uni-directional culvert in ESTRY, allowing flow to pass only from the Tributaries into the Trent. Dimensions from the culvert have been taken from available survey data.

D.4 Schematisation of Floodplain

D.4.1 Raised Infrastructure

Raised infrastructure has been enforced in the 2D domain using z-lines to ensure that the constriction to the flow is modelled accurately. Examples of where these z-lines have been used are:

- Raised roads
- Railway embankments

The elevations used along the z-lines have been extracted from the LiDAR data.

D.4.2 Minor Channels

Minor channels have been enforced into the 2D domain using gully lines. These ensure that a flow path is carved into the 2D domain allowing the flow of water. The elevations of the points associated with the gully lines have been extracted from the LiDAR data. The gully lines have been read into the TUFLOW geometry control file after the embankments have been read in. This is to ensure that the embankments do not restrict the flow in the minor drains.

D.4.3 Roughness

Mastermap data has been used to classify the 2D floodplain into a variety of land use categories. Each category has been assigned a roughness value through the TUFLOW materials file. The Manning's roughness values used are given in Table D.4.

Table D.4: Manning's n Values Used for Land Classification

Land Type	Manning's n Value
Natural/grassland/river banks/scrub/rough ground	0.06
Roads	0.038
Rail	0.05
Buildings	0.100
Standing water	0.035
Woodland	0.1
Other	0.05

D.5 Design Model Boundaries

Figure D.1 provides a schematic showing the location of the model boundaries. All of the inflows into the 1D domain are represented by a discharge ~ time series and apply the design hydrographs. A stage ~ time series has been applied at the downstream limit of the 2D model using the tidal design hydrographs.

D.6 Undefended Scenario

Following national guidelines to determine ABDs, all raised flood defences were removed from the defended baseline model build. The railway embankment and embanked roads were not removed as their primary purpose is not flood defence. Pumping stations and outfalls were removed from the model allowing free flow of water between the Tidal Trent and the tributaries.

A model was also created removing the minor 1 in 10 year defences along the Tidal Trent to identify the benefit these defences give for the smaller return periods. For this scenario only the minor defences were removed, and the pumping stations and outfalls were kept as in the defended baseline model.

D.7 Breach Scenario

The representation of breaches has been discussed in detail in Appendix F.

D.8 Calibration

D.8.1 Model Calibration Process

The design defended model was calibrated against six historical flood events:

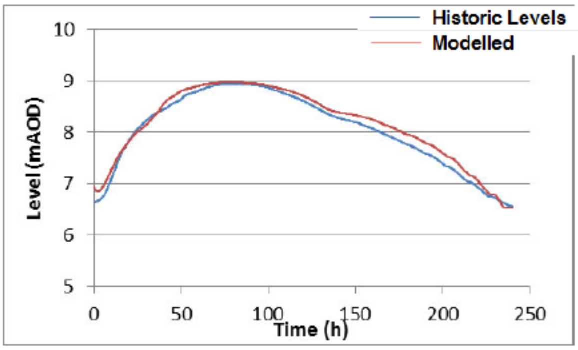
- November 2000;
- January 2005;
- June 2007;
- November 2011;
- July 2012;
- November 2012.

The calibration of the model was focused on matching the observed water levels at Carlton-on-Trent, Torksey Lock, Gainsborough, Keadby and Burton Stather with those modelled. Flood extents from the November 2000 and November 2012 events were also used to aid the calibration of the 2D model. Details of the level of calibration achieved for each event is given below.

D.8.2 November 2000 Calibration Results

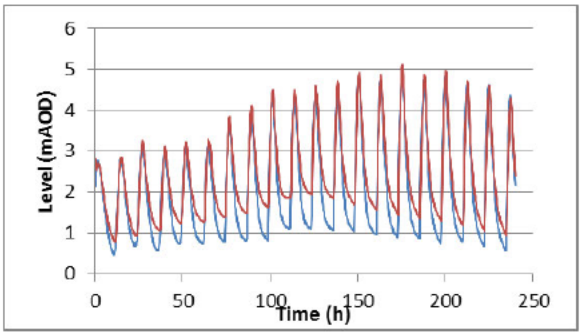
The November 2000 event has been used in a large number of previous studies for calibration purposes due to the widespread flooding that it caused. Observed data is only available at North Muskham and Keadby for this event, however, flood outlines are available and have been compared to the modelled flood extents in Figure 6.1. Figure D.5 and Figure D.6 compare the observed and modelled levels at North Muskham and Keadby and Table D.5 compares the peak levels, and difference in timing of peak at these gauging stations.

Figure D.5: November 2000 Calibration at North Muskham



Source: Mott MacDonald and EA data

Figure D.6: November 2000 Calibration at Keadby



Source: Mott MacDonald and EA data

Table D.5: November 2000 Calibration

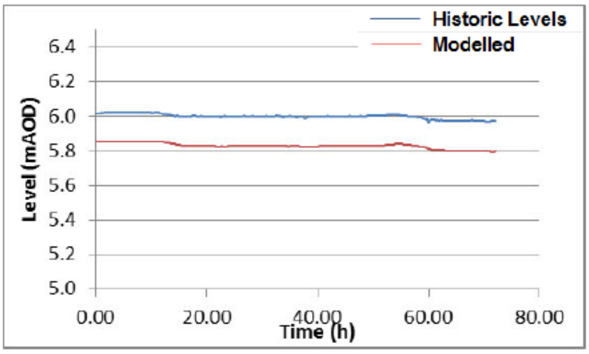
Gauging Station	Historical Data		Modelled Data		Difference in Level (m)	Difference in Time of Peak (h)
	Level (mAOD)	Time of Peak (h)	Level (mAOD)	Time of Peak (h)		
North Muskham	8.95	77.75	8.97	74.75	-0.02	3.00
Keadby	4.99	175.25	5.11	175.5	-0.12	-0.25

The lowest point of the tidal cycle at Keadby is not well represented by the model, however, this is not considered to be a problem as it is the higher water levels that cause the flooding. The flood extents match well with the observed flood extents.

D.8.3 January 2005 Calibration Results

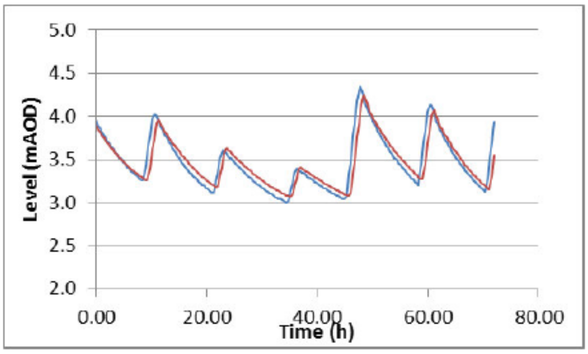
The January 2005 event is a fairly small tidal event where the flow remains in-bank for the duration of the event. Observed data is available at all gauges. Figure D.7 to Figure D.12 compare the observed and modelled levels at each gauge and Table D.6 compares the peak levels, and differences in timing of peak at each gauging station.

Figure D.7: January 2005 Calibration at North Muskham



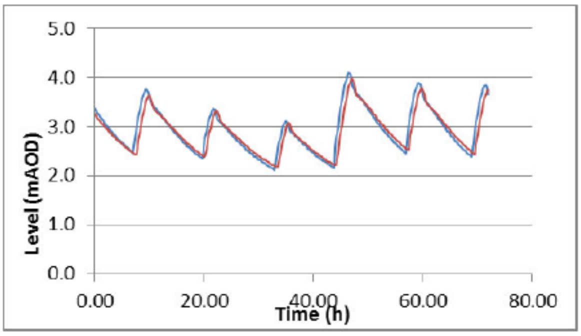
Source: Mott MacDonald and EA data

Figure D.8: January 2005 Calibration at Carlton on Trent



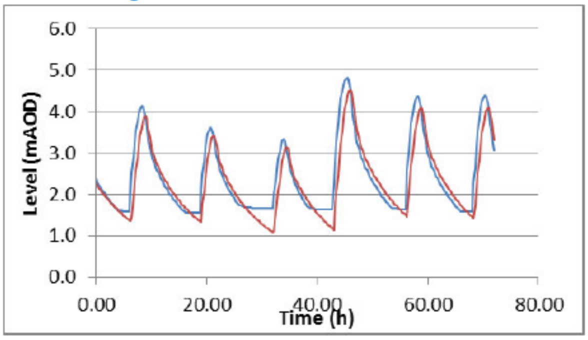
Source: Mott MacDonald and EA data

Figure D.9: January 2005 Calibration at Torksey Lock



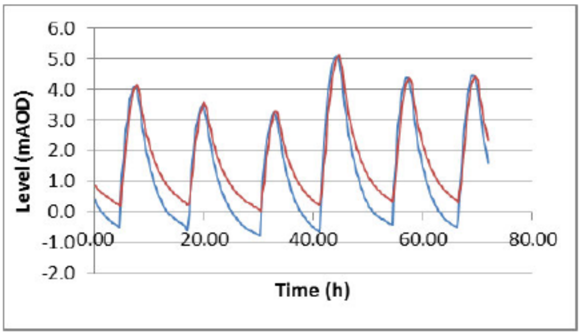
Source: Mott MacDonald and EA data

Figure D.10: January 2005 Calibration at Gainsborough



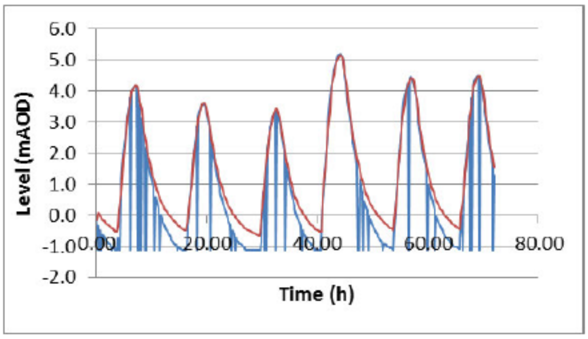
Source: Mott MacDonald and EA data

Figure D.11: January 2005 Calibration at Keadby



Source: Mott MacDonald and EA data

Figure D.12: January 2005 Calibration at Burton Stather



Source: Mott MacDonald and EA data

Table D.6: January 2005 Calibration

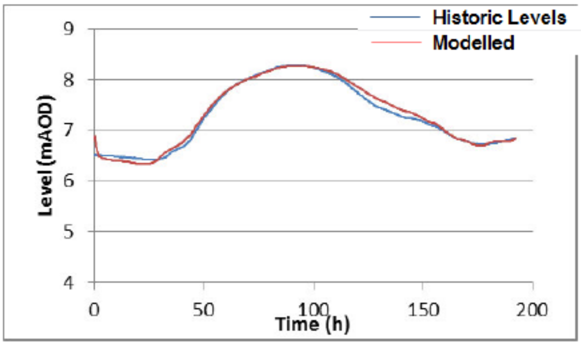
Gauging Station	Historical Data Level (mAOD)	Historical Data Time of Peak (h)	Modelled Data Level (mAOD)	Modelled Data Time of Peak (h)	Difference in Level (m)	Difference in Time of Peak (h)
North Muskham	6.02	3.50	5.86	8.5	0.17	-5.00
Carlton on Trent	4.34	47.75	4.25	48.5	0.09	-0.75
Torksey Lock	4.11	46.50	3.98	47	0.13	-0.50
Gainsborough	4.82	45.50	4.53	46	0.28	-0.50
Keadby	5.10	44.25	5.12	44.75	-0.02	-0.50
Burton Stather	5.20	44.17	5.16	44.25	0.04	-0.08

For this tidal event, the difference in water levels is acceptable at Burton Stather and Keadby. Upstream of Gainsborough the levels do differ, however, it is not expected that tidal events will cause significant flooding upstream of Gainsborough and therefore calibration of the upper sections of the model has focused on the fluvial events. The timing of the peaks and shape of the level hydrographs is good, particularly at the top of the tidal cycles.

D.8.4 June 2007 Calibration Results

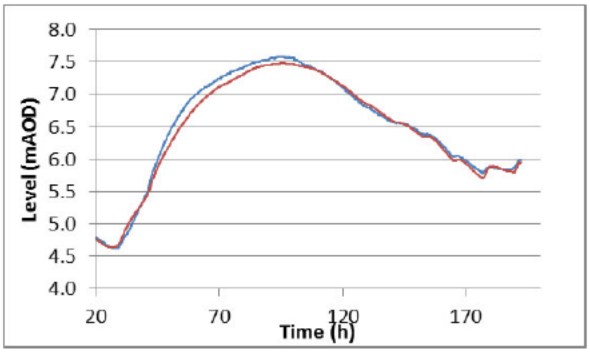
The June 2007 event is a fluvial event which is mainly in-bank for the duration of the event. Observed data is available at all gauges. Figure D.13 to Figure D.18 compare the observed and modelled levels at each gauge and Table D.7 compares the peak levels and differences in timing of peak at each gauging station.

Figure D.13: June 2007 Calibration at North Muskham



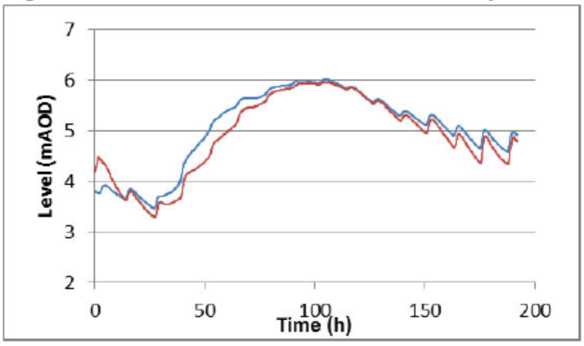
Source: Mott MacDonald and EA data

Figure D.14: June 2007 Calibration at Carlton-on-Trent



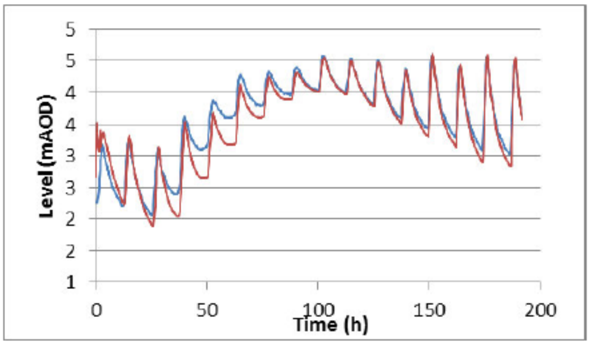
Source: Mott MacDonald and EA data

Figure D.15: June 2007 Calibration at Torksey Lock



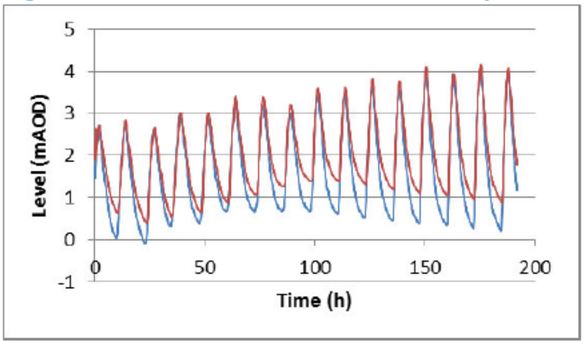
Source: Mott MacDonald and EA data

Figure D.16: June 2007 Calibration at Gainsborough



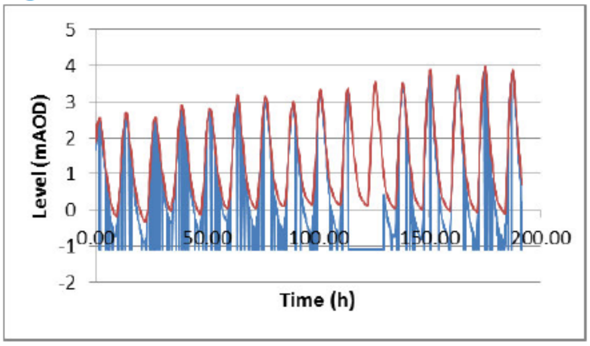
Source: Mott MacDonald and EA data

Figure D.17: June 2007 Calibration at Keadby



Source: Mott MacDonald and EA data

Figure D.18: June 2007 Calibration at Burton Stather



Source: Mott MacDonald and EA data

Table D.7: June 2007 Calibration

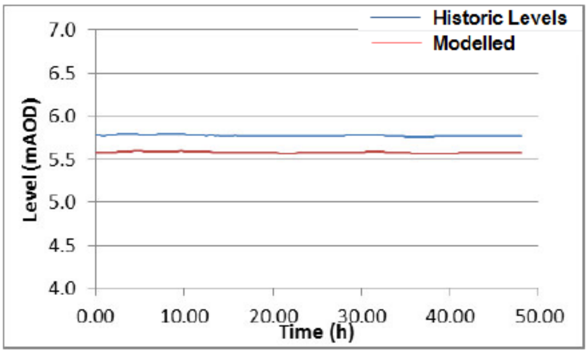
Gauging Station	Historical Data		Modelled Data		Difference in Level (m)	Difference in Time of Peak (h)
	Level (mAOD)	Time of Peak (h)	Level (mAOD)	Time of Peak (h)		
North Muskham	8.30	94	8.28	92	0.02	2.00
Carlton-on-Trent	7.59	95	7.48	89.5	0.11	5.50
Torksey Lock	6.01	105	5.95	104.25	0.05	0.75
Gainsborough	4.58	151.25	4.61	151.5	-0.03	-0.25
Keadby	4.02	175.25	4.16	175.5	-0.13	-0.25
Burton Stather	3.90	175.00	3.98	175.25	-0.08	-0.25

The peak of the event is well represented by the model, however, the level profile at Torksey Lock suggests that the model is attenuating the flow slightly less, resulting in a shorter event. Peak levels match well, although they are underestimated at the top end of the model and overestimated at the bottom end.

D.8.5 November 2011 Calibration Results

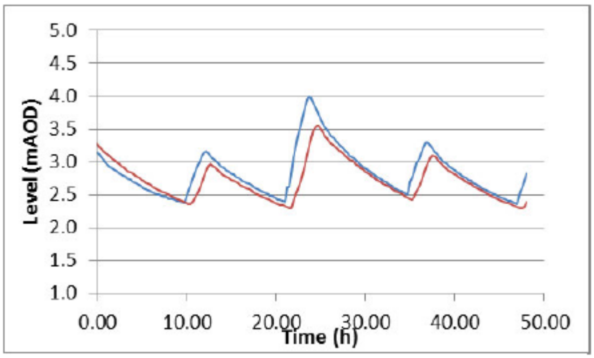
The November 2011 event is a tidal event which is mainly in-bank for the duration of the event. Observed data is available at all gauges. Figure D.19 to Figure D.24 compare the observed and modelled levels at each gauge and Table D.8 compares the peak levels and differences in timing of peak at each station.

Figure D.19: November 2011 Calibration at North Muskham



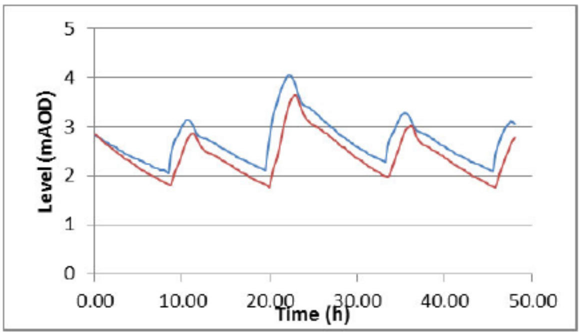
Source: Mott MacDonald and EA data

Figure D.20: November 2011 Calibration at Carlton-on-Trent



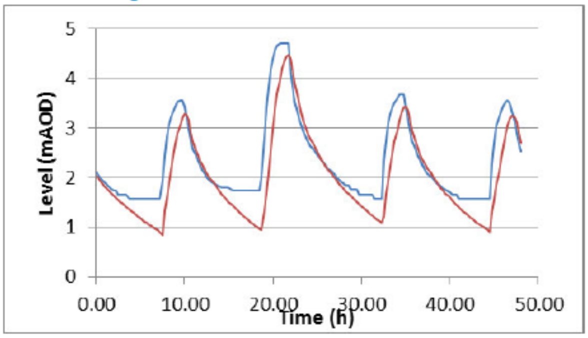
Source: Mott MacDonald and EA data

Figure D.21: November 2011 Calibration at Torksey Lock



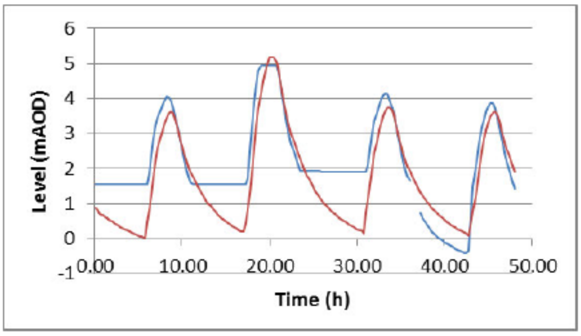
Source: Mott MacDonald and EA data

Figure D.22: November 2011 Calibration at Gainsborough



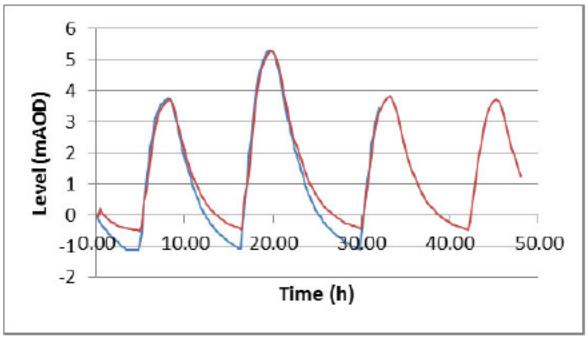
Source: Mott MacDonald and EA data

Figure D.23: November 2011 Calibration at Keadby



Source: Mott MacDonald and EA data

Figure D.24: November 2011 Calibration at Burton Stather



Source: Mott MacDonald and EA data

Table D.8: November 2011 Calibration

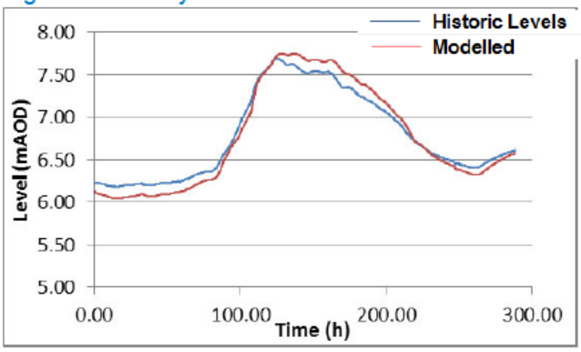
Gauging Station	Historical Data		Modelled Data		Difference in Level (m)	Difference in Time of Peak (h)
	Level (mAOD)	Time of Peak (h)	Level (mAOD)	Time of Peak (h)		
North Muskham	5.79	3.00	5.60	4.75	0.20	-1.75
Carlton-on-Trent	4.00	23.75	3.55	24.75	0.44	-1.00
Torksey Lock	4.05	22.25	3.64	22.75	0.41	-0.50
Gainsborough	4.72	21.00	4.47	21.75	0.25	-0.75
Keadby	4.96	19.00	5.20	20.5	-0.24	-1.50
Burton Stather	5.30	19.67	5.31	19.75	-0.01	-0.08

The shape of the tidal hydrograph is well represented as it progresses up the river, however, the water levels upstream of Gainsborough are under-predicted, similar to the January 2005 event. The level at Keadby is over-predicted by 0.24m, however, the observed stage hydrograph suggests a flat peak. This is considered unlikely and has not been replicated by the model.

D.8.6 July 2012 Calibration Results

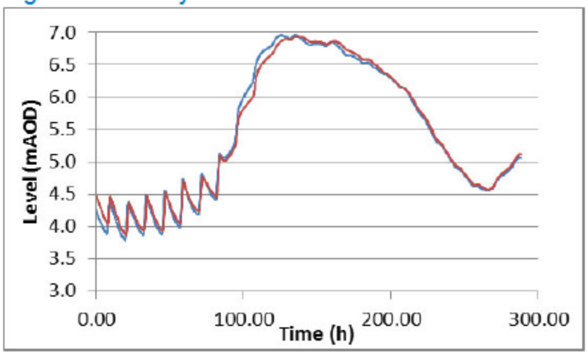
The July 2012 event is a fluvial event which is in-bank for the majority of the modelled reach. Observed data is available at all gauges. Figure D.25 to Figure D.30 compare the observed and modelled levels at each gauge and Table D.9 compares the peak levels and differences in timing of peak at each gauging station.

Figure D.25: July 2012 Calibration at North Muskham



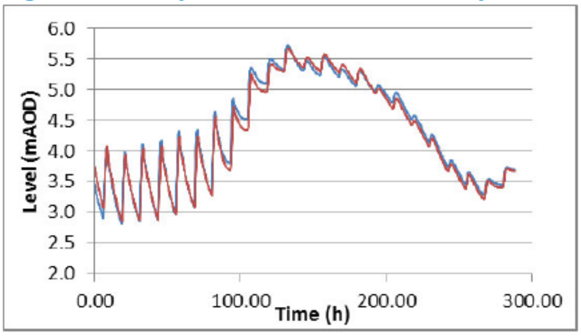
Source: Mott MacDonald and EA data

Figure D.26: July 2012 Calibration at Carlton-on-Trent



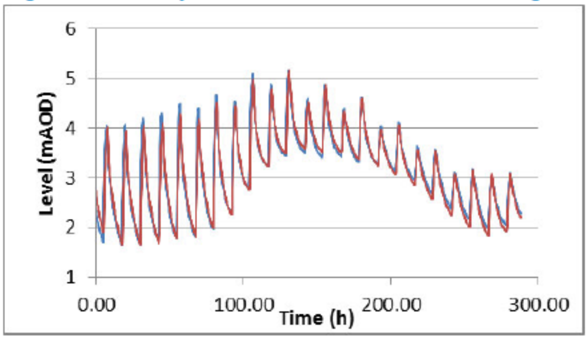
Source: Mott MacDonald and EA data

Figure D.27: July 2012 Calibration at Torksey Lock



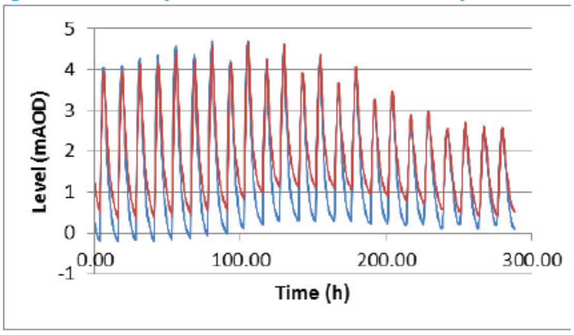
Source: Mott MacDonald and EA data

Figure D.28: July 2012 Calibration at Gainsborough



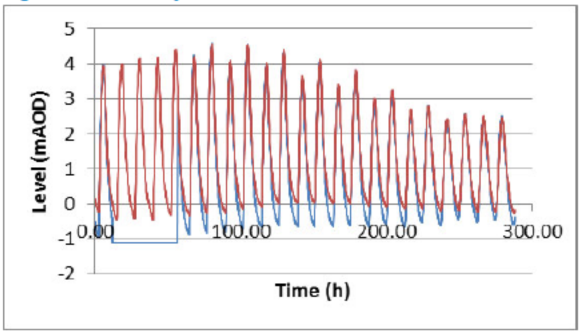
Source: Mott MacDonald and EA data

Figure D.29: July 2012 Calibration at Keadby



Source: Mott MacDonald and EA data

Figure D.30: July 2012 Calibration at Burton Stather



Source: Mott MacDonald and EA data

Table D.9: July 2012 Calibration

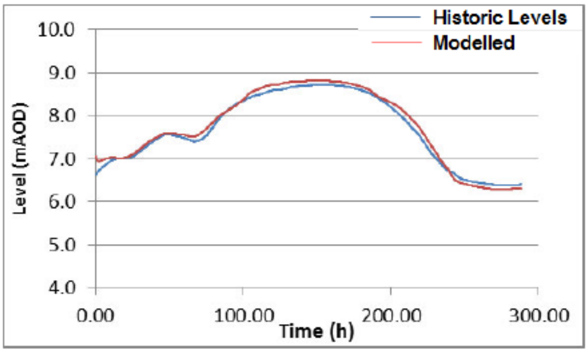
Gauging Station	Historical Data		Modelled Data		Difference in Level (m)	Difference in Time of Peak (h)
	Level (mAOD)	Time of Peak (h)	Level (mAOD)	Time of Peak (h)		
North Muskham	7.69	125.50	7.75	128	-0.06	-2.50
Carlton-on-Trent	6.96	125.75	6.94	137.5	0.02	-11.75
Torksey Lock	5.72	132.50	5.69	132.5	0.04	0.00
Gainsborough	5.17	130.75	5.16	131	0.02	-0.25
Keadby	4.70	80.75	4.67	105.5	0.03	-24.75
Burton Stather	4.58	80.33	4.57	80.5	0.01	-0.17

The calibration for this event is particularly good, suggesting that the 1D model represents the in-bank flows of the Tidal Trent very well for fluvial events. The modelled time of peak is 24 hours different from that observed at Keadby. This is due to some very small differences in water levels, giving the peak level two tidal cycles later than that observed.

D.8.7 November 2012 Calibration Results

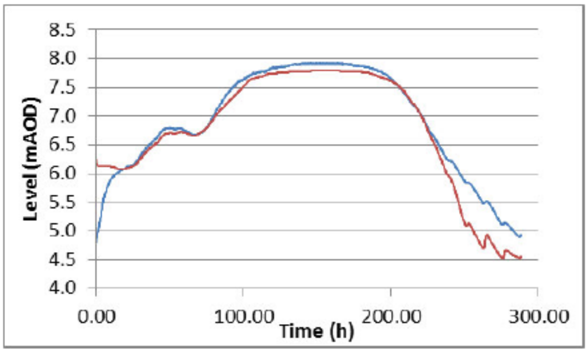
The November 2012 event is a very large fluvial event with extensive out-of-bank flooding, particularly upstream of Gainsborough. Observed data is available at all gauges, and in addition flood extents were available. The observed flood extents have been compared with the modelled flood extents in Figure 6.2. Figure D.31 to Figure D.36 compare the observed and modelled levels at each gauge and Table D.10 compares the peak levels and differences in timing of peak at each gauging station.

Figure D.31: November 2012 Calibration at North Muskham



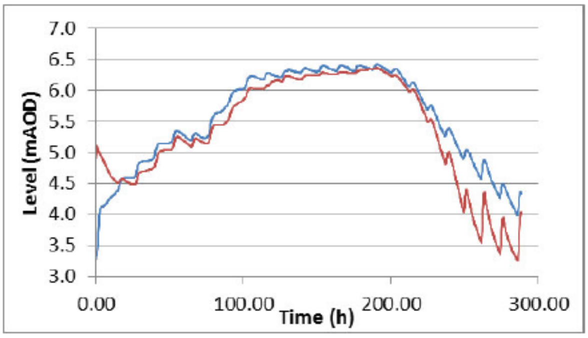
Source: Mott MacDonald and EA data

Figure D.32: November 2012 Calibration at Carlton-on-Trent



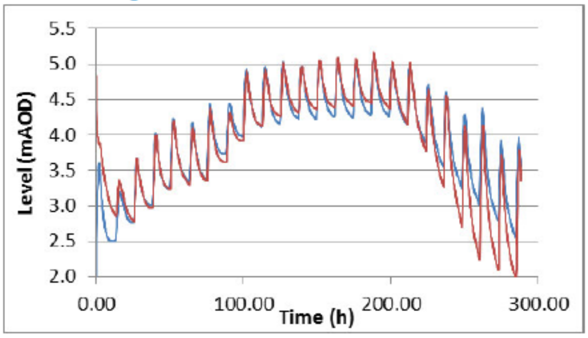
Source: Mott MacDonald and EA data

Figure D.33: November 2012 Calibration at Torksey Lock



Source: Mott MacDonald and EA data

Figure D.34: November 2012 Calibration at Gainsborough



Source: Mott MacDonald and EA data

Figure D.35: November 2012 Calibration at Keadby

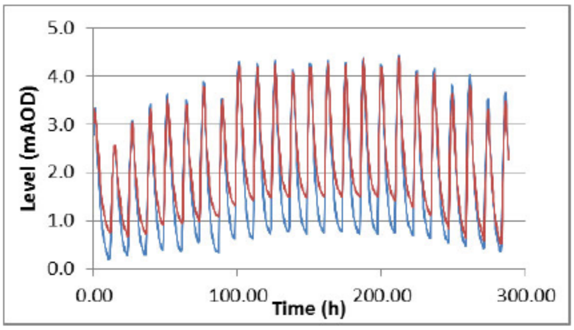
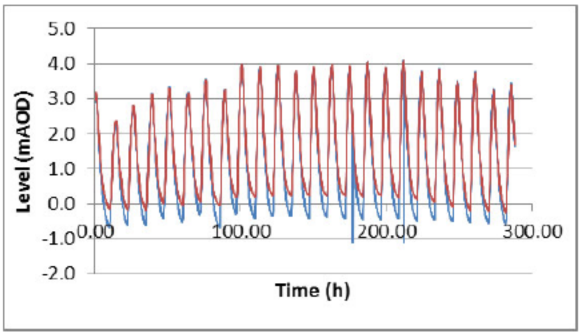


Figure D.36: November 2012 Calibration at Burton Stather



Source: Mott MacDonald and EA data

Source: Mott MacDonald and EA data

Table D.10: November 2012 Calibration

Gauging Station	Historical Data		Modelled Data		Difference in Level (m)	Difference in Time of Peak (h)
	Level (mAOD)	Time of Peak (h)	Level (mAOD)	Time of Peak (h)		
North Muskham	8.72	152.00	8.81	151.5	-0.09	0.50
Carlton-on-Trent	7.92	161.00	7.79	154.5	0.13	6.50
Torksey Lock	6.43	190.75	6.36	190	0.07	0.75
Gainsborough	5.12	188.50	5.16	188.5	-0.04	0.00
Keadby	4.43	212.00	4.39	212	0.05	0.00
Burton Stather	4.09	211.67	4.09	211.75	0.01	-0.08

The calibration for this event is also fairly good, with a slight under-estimate of the flood levels at Carlton-on-Trent. However, levels matched well here for the June 2012 event and therefore no changes have been made. The timing of the peak levels is also very good, particularly along the lower stretch of the river.

D.8.8 Calibration Overview

The model has been successfully calibrated throughout the modelled reach for four fluvial events, including both in-bank and out-of-bank flows. The model has also been run for two tidal events and the levels compared with observed levels.

The calibration for the tidal events is of a lower quality than that for the fluvial events and has focused primarily on downstream of Gainsborough. In consultation with the EA, it was decided to leave the calibration as it is because of the close match with observed data for the fluvial events. It was not considered beneficial to the study to amend the model to increase the level of calibration for the tidal events upstream of Gainsborough if this was to lower the model accuracy for fluvial events in this reach.

The differences between the observed and modelled levels in the six calibration events should be kept in mind when assessing and reviewing the design run results.

Appendix E. Model Results

E.1 Model Predicted Water Levels and Flows

Maximum model predicted water levels and flows for each model run at every model node have been extracted from the results and are provided in the accompanying digital data.

E.2 Flood Mapping

The Environment Agency is responsible for preparing and updating flood maps across England and Wales for various purposes. The flood maps from this study will help to inform the Agency on the flood risk along the Tidal Trent. All such outputs follow a standard format to ensure consistency nationally. The compilation of the maps and the mapping outputs follow the latest 'Guidance for Identification of Areas Benefiting from Flood Defences and Producing the Flood Map'.

Flood depth and velocity maps depict the maximum depth of flooding and maximum velocity across the floodplain for each of the events modelled (Table A.3). Flood depth is a direct output from the TUFLOW model and has been converted to grid files and mapped for each of the design events.

Flood hazard maps have also been produced for all the specified design events as part of this study. Flood hazard describes the flood conditions in which people are at risk of death or serious injury from being swept away by, and/or drowning in, flood waters. Flood hazard categorises this risk to people based on the combination of flood depth, velocity and the presence of debris in the water.

The calculation of flood hazard is based on the following formula:

$$FloodHazard = d\left(V + \frac{1}{2}\right) + DF$$

Where:

- *d* is the maximum depth of flooding;
- *V* is the maximum velocity of flood waters; and
- *DF* is the debris factor.

The presence of debris can have a significant impact on hazard level varying with depth and velocity. However, the application of debris factors can be subjective. For the purposes of this study, conservative estimates were used for the presence of debris as per guidance in FD2321/TR1 and FD2320/TR2 (Defra, 2008) and summarised in Table E.1. The resultant flood hazard categories are summarised in Table E.2.

Table E.1: Debris Factors for Different Depths with Dominant Land Use

Depth (m)	Debris Factor by Dominant Land Use			
	Pasture	Woodland	Urban	Conservative
0 - 0.25	0	0	0	0.5
0.25 – 0.75	0	0.5	1	1
> 0.75 (or velocity > 2m/s)	0.5	1	1	1

Source: Table 1. SUPPLEMENTARY NOTE ON FLOOD HAZARD RATINGS AND THRESHOLDS (May 2008)

Table E.2 outlines the flood hazard categories as specified by FD2320/TR2 (Defra, 2008).

Table E.2: Flood Hazard Categories

Flood Hazard Rating Value	Degree of Flood Hazard	Description
0 - 0.75	Low	Caution: Flood zone with shallow flowing water or deep standing water
0.75 - 1.25	Moderate	Dangerous for some (vulnerable): Flood zone with deep or fast flowing water
1.25 – 2.0	Significant	Dangerous for most: Flood zone with deep or fast flowing water
> 2.0	Extreme	Dangerous for all: Extreme danger flood zone with deep or fast flowing water

Source: Table 2. SUPPLEMENTARY NOTE ON FLOOD HAZARD RATINGS AND THRESHOLDS (May 2008)

All flood maps have been provided in digital format on the accompanying hard drive as detailed in Appendix B.

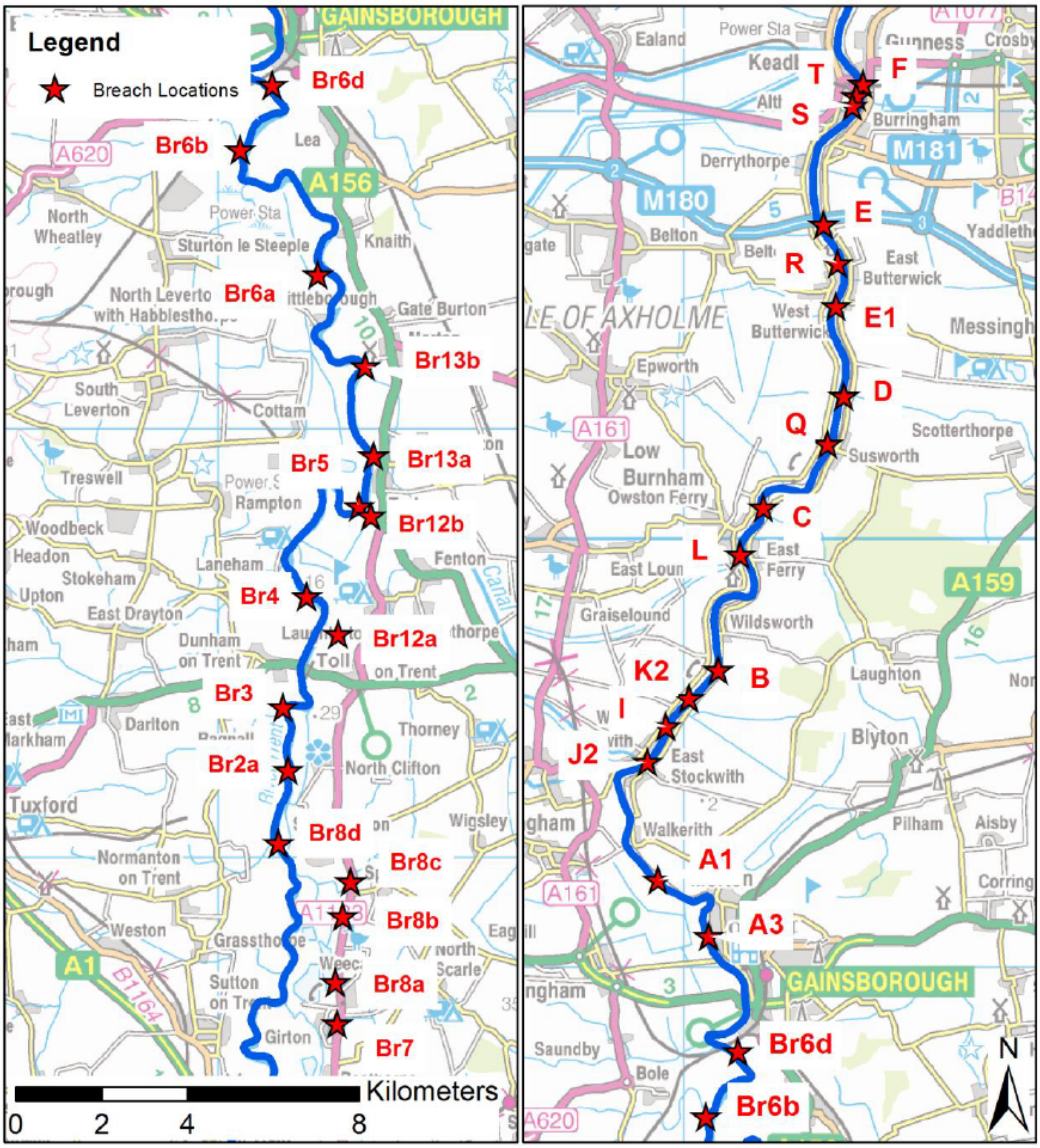
Flood progression maps, maximum depth, velocity and hazard maps, and composite maximum depth, velocity and hazard maps have been produced for each of the breach models. These are explained in more detail in Appendix F.

Appendix F. Breach Analysis

F.1 Breach Locations

Breach analysis has been undertaken at 32 locations between Girton and Keadby . The locations are those previously used as part of the Tidal Trent Strategy Study and were chosen based on historical records of breaching. Figure F.1 shows the location of the modelled breaches.

Figure F.1: Location of Breaches along Tidal Trent



Source: Mott MacDonald. This map is reproduced by permission of Ordnance Survey on behalf of The Controller Of Her Majesty's Stationary Office. © Crown Copyright. All rights reserved. Environment Agency 100026380, 2013.

F.2 Classification of Breach Characteristics

Key topographic data used to determine breach characteristics was taken from NFCDD data, defence crest level survey data and LiDAR data. The NFCDD data was used to determine the type of defence present at each location (Hard or Soft), the defence crest level data, the crest level at each location and the LiDAR data of the surrounding floodplain level.

F.2.1 Breach Width and Duration

The EA's Northern Area Requirements for Hazard Mapping guidance has been used to determine the breach width and duration for each location. This is summarised in Table F.1.

Table F.1: Breach Width and Duration Specification

Scenario	Defence Types	Breach Width	Time to Closure
Fluvial	Hard	20m	36h
	Soft (earth bank)	40m	36h
Tidal	Hard	20m	72h
	Soft (earth bank)	50m	72h

In consultation with the EA it was agreed that breaches upstream of Gainsborough would be considered to be on a fluvial river, and breaches downstream of Gainsborough on a tidal river.

F.2.2 Breach Level

To derive the breach level, the floodplain level behind the defence was calculated based on the Digital Terrain Model (DTM). The floodplain level has been taken as the general level of the floodplain behind the defence, not counting any small ditches that may run directly behind the defence.

The ground level within the 2D domain at the defence has been reduced to the appropriate breach level, along the whole breach width, to enable the flood water to pass through once the breach has been initiated.

F.3 Representation of Breaches in Model

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 variable z-shape file is referenced in the TUFLOW geometry control file (.tgc file), and therefore there is a separate .tgc file for each breach run.

The same variable z-shape file has been used for all breach runs, with the time of initiation set to 10,000 hours for the breaches not being simulated, and the time of initiation of the breach of interest set to the relevant time. This ensures that a consistent approach is used across all the breaches and helped in the batch-processing of multiple breach runs.

Within the variable z-shape file there is an option to specify the duration over which the breach collapses, and the duration over which the breach is restored. This has been set to 0.1 hours in both cases, as an instantaneous breach would be likely to cause significant instabilities within the model and lead to a lower level of confidence in the model results.

F.4 Breach Initiation Time

The EA guidance for determining breach initiation time recommends initiating the breach for fluvial events when the water levels reach the crest level of the river bank to be breached. If this level is never attained, then the peak water level should be used instead. For tidal events, the breach should occur 1 hour prior to High Water on the peak surge at the location of the breach.

The defended baseline design runs have been used to identify when the time of initiation should occur and the relevant time included in the variable z-shape file.

A number of the breaches which are set back from the main water-course have not been modelled for the two tidal scenarios as the adjacent floodplain is not shown to be flooded during the standard design runs. Breaching the defences would therefore not lead to any increase in flooding. The breach locations where this occurs are:

- Br7 – Across A1133, East of Girton;
- Br8a – Across A1133, between Home Farm (Trent Lane) and Highfields;
- Br8b – Across A1133, 300m north of Girton Grange;
- Br12a – Behind Caravan Park, between Laughterton and Newton-on-Trent;
- Br 12b – Near Caravan Park, Torksey Lock.

F.5 Breach Mapping

The following maps have been produced for each flood event scenario at each individual breach location:

- maximum depth, velocity and hazard maps;
- depth progression maps,
  - for fluvial events these show depths at 1, 2, 3, 4, 8, and 12 hours after breach,
  - for tidal events these show depths at 2,4, 6, 8, 12, and 24 hours after breach.

A composite map of the flooded area has been produced for each return period modelled. These maps are provided in the accompanying digital data. They are useful for asset management and strategic planning, including the prioritisation of flood defence works for maintenance or improvement.

Breach origin maps have also been produced. These maps show which breach location produces the largest flood depths across the combined flood extent for each return period modelled. The breach origin maps have been produced to help identify the significance of each breach. These maps will be useful for asset management and strategic planning, including the prioritisation of flood defence works, for maintenance or improvement. The final maps are provided in full in the accompanying digital data and in Figure 7.7 to Figure 7.10.

The breach origin maps also indicate areas where none of the breaches cause an increase greater than 1cm above the baseline defended scenario. The threshold of 1cm was chosen so that any 'ripples' caused by model instabilities due to the breaching of defences were not picked up and identified in the breach origin maps.

Significant findings from the breach analysis are discussed in Section 7.4.

Full details of the breach parameters used and the modelled flood extents for each breach are provided in the form of Breach Summary Sheets in Appendix G.

Appendix G. Breach Summary Sheets

Appendix H. Flood Maps