Appendix A

FABER MAUNSELL | AECOM

West Lindsey Strategic Flood Risk Assessment
Climate Change Modelling of River Trent

November 2007

BLACK & VEATCH
building a world of difference™

West Lindsey Strategic Flood Risk Assessment
Climate Change Modelling of River Trent

CONTENTS

1. INTRODUCTION 1

2. METHODOLOGY 1
2.1 Existing Model 1
2.2 Boundary Conditions 1
2.3 Modelling Climate Change Flows and Tide Levels 2
2.4 Modelling Considerations 4

3. RESULTS 5
3.1 Flood Levels 5
3.2 Mapping 5

4. CONCLUSIONS 7

5. REFERENCES 8

Document issue details:

B&V project no. 121101 Client's reference no.

Version no.	Issue date	Issue status	Distribution
1	7 Nov 2007	Draft	Faber Maunsell

This page has been intentionally left blank

West Lindsey Strategic Flood Risk Assessment Climate Change Modelling of River Trent

1. INTRODUCTION

As part of a Strategic Flood Risk Assessment carried out for the West Lindsey District Council by Faber Maunsell, it was necessary to predict the impact of climate change and sea level rise on flood levels in the project area for the year 2115. As Black and Veatch had developed a river model for the tidal reach of the River Trent for the Environment Agency, Black & Veatch were commissioned to carry out this study and generate the required results by adapting the hydrology for the appropriate climate changes.

2. METHODOLOGY

2.1 Existing Model

The existing ISIS model of the Tidal Trent had been developed by Black and Veatch in 2005 as part of the Tidal Trent Strategy (Ref. 1). Versions of this model were developed to test the effect of breaches in the major defences in the reach between Cromwell Weir (SK 809 612) and Trent Falls (SE 863 230).

These models were used, unmodified, to generate the water levels used for this study.

2.2 Boundary Conditions

Fluvial

The hydrology for the Tidal Trent Strategy was used as the basis of this study.

As this study was required to generate water levels for 2115, the fluvial flows used for the Tidal Trent Strategy were increased by 20% to simulate climate change.

Tidal

The downstream boundary of the Tidal Trent model is Trent Falls, where the Rivers Trent and Ouse meet and form the River Humber. At this point the River Humber is tidally dominated so the model uses the tidal stage data from the recorder at Blacktoft Jetty on the River Ouse, 2.5km upstream of Trent Falls. The tidal sequence for November 5th, 2000 was used as the basis of most events, with a tidal surge superimposed on the highest tide (see the Tidal Trent Strategy Report for a more detailed discussion, Ref. 1).

Impact of Climate Change

Although the Tidal Trent Strategy contained some information on climate change, Defra have since issued revised climate change guidance. This guidance forms tables B1 and B2 of Planning Policy Statement 25: Development and Flood Risk (Ref 2)

Application of Climate Change to Model Boundaries

Owing to the complexity of the region being studied, it was not appropriate to simply apply a climate change to the tidal boundary of the model and simply select tidal events on the basis of a return period.

In the Tidal Trent Strategy, a report compiled by Posford-Duvivier[1] (Ref. 3) was used as the basis for calculating the water levels in the tidally dominated reach between Gainsborough Rail Bridge (SK 809 881) and Trent Falls. This took 1990 as the base date for its calculation. The Tidal Trent Strategy used the year 2010 as its base year for calculating the tide levels and calculated the increase in tide levels between 1990 and 2010 using information from the Posford report.

The new climate change formula was then used to generate water levels for 2115.

Table 2.1 Tidal Climate Change Factors for 2115

	Base date	Sea Level Rise, mm
Posford Data	1990	1142.5

Table 2.2 Fluvial Flows for 2115

Return Period	Fluvial Flows, m^3/s		
Fluvial Flow	**Original**	**Factor (20%)**	**2115**
MDF	85	1.2	102
5 year	680	1.2	816
10 year	815	1.2	978
25 year	990	1.2	1188
50 year	1110	1.2	1332
100 year	1220	1.2	1464
200 year	1320	1.2	1584
1000 year	1540	1.2	1848

2.3 Modelling Climate Change Flows and Tide Levels

ISIS has the facility to allow different boundary conditions to be applied to a single model to generate different water levels. These boundary conditions are usually inflows and different types of downstream boundary conditions. For the Tidal Trent model, the downstream boundary consisted of a Head-Time boundary unit to simulate the tide at Trent Falls; the maximum water level being determined by the return period of the tidal surge being considered. These boundary conditions are held in the event files.

Breach models had been developed as part of the Tidal Trent Strategy, to allow flooding onto selected areas protected by major flood defences. As the tidal boundary has no significant affect on water levels upstream of Gainsborough Rail Bridge, determining the possible flood levels in 2115 due to the River Trent could be obtained by running the appropriate breach model with the fluvial flows from Table 2.2.

[1] Posford-Duvivier (now Royal Haskoning) will be referred to as Posford for the remainder of this report.

From Gainsborough downstream, however, the hydraulics become complicated by the triple interaction of the fluvial flow, the tide and the action of Beckingham Marshes; the flood storage area to the west of Gainsborough. Therefore, selecting an appropriate fluvial-tidal combination to represent the 25, 200 and 1000 year return periods was not a straightforward matter. Due to the hydraulic complexity at Gainsborough, simply selecting a combination of fluvial and tidal events to represent a given return period was not a simple matter of multiplying the event probabilities. Nor would a Joint Probability approach work (as discussed in the Tidal Trent Strategy Report, Ref. 1).

The Posford report (Ref. 3) calculated water levels at Blacktoft, Keadby, Owston Ferry and Gainsborough for selected return periods based on 1990 data. These levels were then raised by 1142.5mm (see Table 2.1) and plotted. Next, a number of event files were built which contained combinations of different fluvial and tidal return periods. These event files were run through the "glass walled" model[2] and the results of each event were plotted on top of the raised Posford levels. Where a modelled level coincided with both the Posford graph and the location of a breach, that combination was subsequently used to generate water levels in the appropriate breach model (the Tidal Trent Strategy Report has a more detailed description of this process, Ref. 1).

Table 2.3 Event Files Used

<table>
<tr><th></th><th colspan="3">Event Combination (Fluvial + Tidal)</th></tr>
<tr><th>Breach model</th><th>25 year</th><th>200 year</th><th>1000 year</th></tr>
<tr><td>6d</td><td rowspan="11">25yrQ+MHWS</td><td rowspan="11">200yrQ+MHWS</td><td rowspan="11">1000yrQ+MHWS</td></tr>
<tr><td>7</td></tr>
<tr><td>7a</td></tr>
<tr><td>8a</td></tr>
<tr><td>8b</td></tr>
<tr><td>8c</td></tr>
<tr><td>8d</td></tr>
<tr><td>12a</td></tr>
<tr><td>12b</td></tr>
<tr><td>13a</td></tr>
<tr><td>13b</td></tr>
<tr><td>A3</td><td>25yrQ+50yrTide</td><td>50yrQ+20yrTide</td><td>200yrQ+MHWS</td></tr>
<tr><td>A1</td><td>25yrQ+50yrTide</td><td>50yrQ+20yrTide</td><td>200yrQ+MHWS</td></tr>
<tr><td>B</td><td>100yrQ+1yrTide</td><td>100yrQ+5yrTide</td><td>Extrapolate from 25yr & 200yr results</td></tr>
<tr><td>C</td><td>Interpolate between 10yrQ+20Tide & 100yrQ+1Tide</td><td>100yrQ+1yrTide</td><td>Interpolate between 100yrQ+1Tide & 100yrQ+5Tide</td></tr>
<tr><td>D</td><td>MDF+250yrTide</td><td>MDF+1000yrTide</td><td>100yrQ+1yrTide</td></tr>
</table>

MHWS = Mean High Water Spring
MDF = Mean Daily Flow

Getting a combination of flow and tide to exactly match the water levels required at each breach location was not usually possible, so the nearest match was used. It was assumed that any errors in this approach would decrease the further away from the river the water flows; i.e. a given change in water level in the river will result in a smaller change in water level in the flood cells connected to the breach.

[2] This refers to a model in which all the water is confined to the river channel or selected washlands.

The 1000 year water level assigned to the reservoir cells for breach run B were determined by linear extrapolation of the 25 and 200 year results. The river levels at the breach location were read off a plot of the projected Posford levels and tabulated alongside the reservoir levels for each return period. The data values were plotted on a graph and the 1000 year water levels were simply adjusted to fit to a straight line drawn through the other two points. As the highest 1000 year water levels in flood cell B that were generated by the breach in flood cell A were much higher than those predicted by this extrapolation, any inaccuracy in this method is not significant.

2.4 Modelling Considerations

The original Tidal Trent breach analysis was carried out by assuming that all the major flood defences were high enough to constrain the fluvial flows to the channel and washlands. As such, the breach models were built from the 'glass walled' model and the only water that was allowed to *escape* from the model was through the breach under consideration. While this approach was acceptable for the Tidal Trent Strategy, the requirement to use the 1000 year return period plus climate change for the year 2115 means that the model was being given far more flow than previously used. The consequence of this approach was that the modelled water levels could be higher than those that would actually occur in the river (assuming the defences remain at their current height).

3. RESULTS

3.1 Flood Levels

The breach runs give maximum water levels in each of the flood cells behind the major flood defences. As breaches in different locations along the river generate different water levels in each flood cell, the results were compared and only the maximum value is given in Table 3.1. The locations of the flood cells are shown in Figures 3.1 & 3.2.

Table 3.1 Maximum Water Levels in Flood Cells

	Maximum Water Level from all model runs, m OD		
Cell Name	**25 year**	**200 year**	**1000 year**
Breach_6d	6.8	7.7	8.2
Breach_10	6.9	7.5	7.9
Breach_11	6.9	7.5	7.9
Breach_12	6.9	7.5	7.9
Breach_13	7.5	8.2	8.7
Breach_14	6.9	7.5	7.9
res_A	5.1	5.4	5.7
res_B	5.1	5.4	5.7
res_C	5.1	5.4	5.7
res_D	5.1	5.4	5.7

A list of the maximum water levels in the river channel is tabulated in the Appendix. The Black & Veatch model results have been used for the reach upstream of Gainsborough Rail Bridge and the raised Posford levels for the downstream reach.

3.2 Mapping

LiDAR data were not available for the whole of the West Lindsey Council area. Therefore, to ensure consistency, ground levels were taken from NextMap data. NextMap data are only accurate to 1m in the vertical plane, so the flood outlines must be read with extreme caution, especially in those areas where the ground is generally flat.

For the purposes of this study, much higher fluvial flows have been routed through the model than those for which it was designed. The consequence of using the Tidal Trent breach models is that all the additional water has been constrained to the river, raising the peak water level above that which would actually happen. This means that, for small isolated flood cells, such as Breach_6d near Gainsborough, a significantly higher water level has been reached in the model compared with other model results. This accounts for some of the apparently inconsistent *steps* in some of the flood outlines.

Figures 3.3 and 3.4 show the flood outlines for the 25, 200 and 1000 year flood events.

There are several locations where the reliability of the flood cell boundaries is in doubt:

- Along the line of the railway at:
    - Stow Park
    - Sykes Farm
    - Saxilby
- And, adjacent to the A46 at Skellingthorpe.

In the original model, flood cell Breach_10 stopped at the A46, however, there is evidence of a possible flow route under the road. Should a flow route exist, water would be able to flow out of the flood cell, lowering its maximum level. However, without modelling both the culvert and the receiving area, it is not possible to determine what effect it would have on the flood levels. As the model is currently schematised, the flood levels will be *pessimistic*, i.e. higher than they might be in reality.

Between North Clifton and Trent Port, the flood outlines have been generated from the maximum water levels in the Breach_10 to Breach_14 flood cells.. From Trent Port to Lea Marshes the right bank is bounded only by high ground and the outline was drawn from the river levels and levels in the washlands generated by the 'glass-walled' model. The small flood cell next to Gainsborough Rail Bridge is behind a major embankment and was mapped using the Breach_6d model results. From Gainsborough Rail Bridge to just downstream of the A631 bridge at Gainsborough, the Posford river levels have simply been extended to meet the ground, on the assumption that the area is small and there would be sufficient volume in the flood to fill this area and not significantly affect water levels. From this latter point down to North Ewster, the maps have been drawn using the breach model results.

Table 3.2 Summary of Mapping Methods used

Reach	Mapping method
North Clifton to Trent Port	Breach model results
Trent Port to Lea Marshes	'glass-walled' model results
Breach_6d	Breach model results
Gainsborough Rail Bridge to just downstream of the A631 bridge at Gainsborough	Increased Posford predictions extended from river
Gainsborough to North Ewster	Breach model results

4. CONCLUSIONS

Owing to the fact that the breach models used to prepare this report were not designed for fluvial flows which exceeded the flood defences, the use of the models for future 200 and 1000 year events means that the results must be treated with caution. The water levels in the flood cells will be higher than those which might be expected if the flood defences remain at their present day levels. As such, it could be considered that the predicted water levels are *pessimistic*, depending on the purpose for which they are to be used.

The river levels in the reach between Gainsborough Rail Bridge and North Ewster have been predicted from historic trends, as catalogued in the Posford report (Ref. 3), so might be considered more reliable than the results in the fluvial reach. However, due caution still needs to be applied as the water levels in the flood cells behind the defences in this downstream reach were calculated by the ISIS model, though with due reference to the river levels, as described in Section 2.3.

5. REFERENCES

1. **Black & Veatch**, "Tidal Trent Flood Risk Management Strategy", Environment Agency, July 2005.

2. **Department of Communities and Local Government,** "Planning Policy Statement 25: Development and Flood Risk", 2006

3. **Posford-Duvivier,** "Humber Estuary Tidal Defences Data Collection & Analysis", National Rivers Authority, May 1991.

APPENDIX

Table 1: Table of Maximum Water Levels in the river; upstream of Gainsborough Rail Bridge (Trent44860U) using results from the AllSpills[3] model (TT_57_AllSpills.dat), then the downstream values from the Posford's predicted values increased by the DEFRA climate change formula.

River Node	Location	25 year	200 year	1000 year
Trent68680	North Clifton	8.066	8.417	8.515
Trent68040		8.069	8.422	8.519
Trent67680		8.063	8.414	8.511
Trent67380		8.058	8.412	8.509
Trent67250		8.059	8.417	8.516
Trent67080		8.038	8.390	8.488
Trent66780		7.991	8.323	8.416
Trent66230		7.834	8.110	8.182
Trent66010U	Dunham Bridge	7.862	8.136	8.206
Trent66010D		7.798	8.039	8.098
Trent65550		7.794	8.039	8.099
Trent65230		7.792	8.032	8.090
Trent64930		7.805	8.056	8.116
Trent64530		7.756	7.987	8.045
Trent64320		7.731	7.947	8.004
Trent63760		7.749	7.976	8.035
Trent63090	Laneham	7.730	7.948	8.005
Trent62620		7.741	7.966	8.024
Trent61880		7.709	7.919	7.978
Trent61450		7.720	7.936	7.994
Trent61120		7.713	7.925	7.983
Trent60940		7.714	7.926	7.984
Trent60840		7.711	7.921	7.978
Trent60620		7.714	7.927	7.986
Trent60130		7.705	7.918	7.978
Trent59890		7.707	7.921	7.981
Trent59290		7.616	7.795	7.870
Trent58830		7.600	7.772	7.850
Trent58460	Torksey Bridge	7.563	7.721	7.808
Trent58360		7.544	7.694	7.785
Trent58290		7.557	7.713	7.802
Trent57680		7.520	7.667	7.768
Trent57420		7.503	7.644	7.750
Trent56550		7.465	7.599	7.723
Trent56080		7.447	7.580	7.715
Trent55800	Trent Port	7.431	7.563	7.709
Trent55460		7.410	7.540	7.699
Trent55020		7.360	7.487	7.682
Trent54640		7.353	7.475	7.668
Trent54470		7.360	7.485	7.677
Trent54290		7.362	7.488	7.679
Trent54010		7.358	7.483	7.678

[3] This model has the major defences modelled as spill units with interconnected reservoir units representing the protected areas behind the defences.

River Node	Location	25 year	200 year	1000 year
Trent53570	Littleborough	7.340	7.465	7.669
Trent52930		7.287	7.411	7.663
Trent52310		7.143	7.264	7.638
Trent51650		7.076	7.216	7.633
Trent51330	Knaith	7.000	7.161	7.628
Trent51000		6.984	7.148	7.626
Trent50620		6.874	7.065	7.613
Trent50110		6.856	7.051	7.619
Trent49470		6.849	7.046	7.613
Trent49260		6.849	7.047	7.614
Trent49060		6.852	7.049	7.616
Trent48630		6.849	7.048	7.618
Trent48470		6.851	7.048	7.614
Trent48310		6.849	7.047	7.613
Trent48200		6.848	7.046	7.612
Trent48070		6.843	7.042	7.610
Trent47930		6.836	7.036	7.607
Trent47540		6.835	7.035	7.614
Trent47220		6.835	7.039	7.614
Trent46960		6.836	7.036	7.607
Trent46700		6.832	7.034	7.607
Trent46390		6.812	7.016	7.591
Trent46180		6.793	6.997	7.571
Trent45880	Lea STW	6.726	6.928	7.487
Trent45560		6.676	6.879	7.435
Trent45310		6.642	6.847	7.411
Trent44950		6.583	6.788	7.337
Trent44860U	Rail Bridge	6.577	6.780	7.324
Trent42400	A631, Gainsborough	6.908	7.130	7.248
Trent40130	Morton	6.910	7.112	7.216
Trent38830		6.912	7.102	7.199
Trent36310		6.915	7.082	7.164
Trent35640		6.916	7.077	7.155
Trent35320	East Stockwith	6.916	7.074	7.151
Trent33550	Heckdyke	6.918	7.061	7.127
Trent32300		6.920	7.051	7.109
Trent29300	Owston Ferry	6.923	7.028	7.069
Trent26490		6.904	7.005	7.044
Trent25070	South Ewster	6.895	6.993	7.031
Trent24030	North Ewster	6.888	6.985	7.022

Table 2: Table of Maximum Water Levels in the river; upstream of Gainsborough Rail Bridge (Trent44860U) using results from the 'glass-walled' model (TTrent_57.dat), then the downstream values from the Posford's predicted values increased by the DEFRA climate change formula.

River Node	Location	25 year	200 year	1000 year
Trent68680	North Clifton	8.157	9.004	9.572
Trent68040		8.160	9.009	9.577
Trent67680		8.155	9.003	9.570
Trent67380		8.151	9.002	9.570
Trent67250		8.153	9.007	9.576
Trent67080		8.133	8.995	9.568
Trent66780		8.085	8.939	9.506
Trent66230		7.937	8.805	9.376
Trent66010U	Dunham Bridge	7.961	8.805	9.363
Trent66010D		7.897	8.719	9.260
Trent65550		7.894	8.726	9.269
Trent65230		7.891	8.715	9.256
Trent64930		7.905	8.734	9.275
Trent64530		7.859	8.697	9.245
Trent64320		7.834	8.669	9.214
Trent63760		7.852	8.691	9.239
Trent63090	Laneham	7.834	8.671	9.218
Trent62620		7.845	8.686	9.235
Trent61880		7.814	8.656	9.205
Trent61450		7.825	8.668	9.218
Trent61120		7.818	8.661	9.210
Trent60940		7.819	8.663	9.212
Trent60840		7.817	8.659	9.209
Trent60620		7.819	8.662	9.212
Trent60130		7.812	8.659	9.209
Trent59890		7.814	8.661	9.212
Trent59290		7.726	8.576	9.126
Trent58830		7.710	8.559	9.109
Trent58460	Torksey Bridge	7.676	8.523	9.072
Trent58360		7.658	8.503	9.052
Trent58290		7.670	8.520	9.070
Trent57680		7.637	8.488	9.041
Trent57420		7.621	8.473	9.025
Trent56550		7.586	8.442	8.996
Trent56080		7.569	8.428	8.981
Trent55800	Trent Port	7.554	8.414	8.970
Trent55460		7.535	8.395	8.953
Trent55020		7.488	8.352	8.912
Trent54640		7.481	8.345	8.905
Trent54470		7.488	8.350	8.908
Trent54290		7.490	8.352	8.912
Trent54010		7.486	8.346	8.904
Trent53570	Littleborough	7.472	8.347	8.911
Trent52930		7.418	8.280	8.835
Trent52310		7.273	8.126	8.674

River Node	Location	25 year	200 year	1000 year
Trent51650		7.206	8.066	8.607
Trent51330	Knaith	7.134	8.016	8.576
Trent51000		7.119	7.997	8.557
Trent50620		7.015	7.884	8.448
Trent50110		6.998	7.865	8.430
Trent49470		6.993	7.862	8.428
Trent49260		6.993	7.861	8.427
Trent49060		6.996	7.865	8.431
Trent48630		6.992	7.861	8.427
Trent48470		6.994	7.865	8.431
Trent48310		6.993	7.862	8.428
Trent48200		6.991	7.863	8.428
Trent48070		6.986	7.860	8.429
Trent47930		6.979	7.851	8.420
Trent47540		6.979	7.850	8.418
Trent47220		6.979	7.851	8.419
Trent46960		6.979	7.850	8.418
Trent46700		6.976	7.852	8.421
Trent46390		6.958	7.837	8.408
Trent46180		6.938	7.817	8.390
Trent45880	Lea STW	6.869	7.729	8.296
Trent45560		6.819	7.676	8.243
Trent45310		6.786	7.649	8.217
Trent44950		6.726	7.586	8.147
Trent44860U	Rail Bridge	6.718	7.573	8.128
Trent42400	A631, Gainsborough	6.908	7.130	7.248
Trent40130	Morton	6.910	7.112	7.216
Trent38830		6.912	7.102	7.199
Trent36310		6.915	7.082	7.164
Trent35640		6.916	7.077	7.155
Trent35320	East Stockwith	6.916	7.074	7.151
Trent33550	Heckdyke	6.918	7.061	7.127
Trent32300		6.920	7.051	7.109
Trent29300	Owston Ferry	6.923	7.028	7.069
Trent26490		6.904	7.005	7.044
Trent25070	South Ewster	6.895	6.993	7.031
Trent24030	North Ewster	6.888	6.985	7.022

AECOM

Appendix B

Appendix B - 2D Breach Modelling Methodology

The 2D modelling package Tuflow, version 2007-07-AF, was used the model the impact of breaches in the defences of two major Rivers in West Lindsey at two locations – Gainsborough and Bardney. The modelling methodology and any model assumptions are described below.

Gainsborough Breach Analysis Methodology

Three breach models were constructed on the right bank of the River Trent at Gainsborough to determine the impact of a breach in the defences on the town of Gainsborough. The locations of the breaches were:

1 The earth embankment defence at the allotment gardens to the south of North Warren Road (SK 480 390).

2 The concrete flood wall at the supermarket carpark near the Ropery Road / Caskgate Street junction (SK 481 389).

3 The earth embankment with open grassland on the landward side to the south of River Trent railway bridge (SK 481 388).

Tuflow Model Structure

The model build involved generating a series of MapInfo GIS layers, which are input into the TUFLOW computational engine through a series of control files in Textpad. An example of the GIS layers used in this study are shown in Table B.1.

Layer Name	Layer Type	Description
Gains_Factory_Projection		Sets the projection of the model
2d_loc_Gains_Factory	LOC	Layer defining the grid location and orientation
2d_zpt_SAR_Terrain	ZPT	10m grid point containing topography
2d_code_Gains_Factory		Layer defining the active cells
2d_mat_Gains_Factory	MAT	Polygons defining Mannings ‘n’ roughness
2d_bc_hydrograph	BC	Layer defining the location and the characteristics of the river hydrograph
2d_bc_breach	BC	Layer defining the location and characteristics of the breach
2d_zln_roads	ZLN	Elevation lines of the roads

Table B.1 - Tuflow GIS Layers.

Ground Model

There was no LIDAR data available in the locations undertaken for the breach scenarios. SAR data was compared with LIDAR data to the north of Gainsborough and it was found that SAR was 0.63m higher than the LIDAR data based on the average-square mean methodology. The SAR data was therefore lowered by 0.63m before being used in the Tuflow modelling.

The ground level grid resolution used was 10m. This was deemed satisfactory enough to produce accurate results in the urban areas.

Roughness coefficients

Bed friction in hydraulic models is represented by Manning’s ‘n’ roughness coefficients. Polygons were used to define the locations of different Mannings ‘n’ values. The materials were assigned roughness values as shown in Table B.2.

Material Description	Manning's 'n'
Default (Grazed fields/ short grass)	0.05
Roads, concrete	0.02
Kept fields (playing fields etc)	0.04
Urban: primarily accounts for gardens, fences etc.	0.08
Scrubland	0.055
Trees/Wooded	0.10
River channel	0.035
Urban including housing	0.15

Table B.2 - Manning's 'n' Roughness Values.

Boundary Conditions

The Tuflow model contained a boundary to represent the River Trent and a boundary to represent the breach through the defence structure. The River Trent boundary was a stage hydrograph for a 1 in 200 year event. The stage hydrograph was provided specifically for this study by Black & Vetach Consultants and was based on the model results from the V57 version of the River Trent model for a 200 year with a MHWS design tide event. The maximum stage was 6.84mOD.

The breach scenario assumed that the breach occurred in the defence at the peak stage during the event. The breach was modelled based on the conservative assumption that half an hour after the peak stage had occurred, the level of the defence would have dropped by 1m and after two hours the level of the defence would be 2m below its original height. This was assumed to occur until the level of the defence reached the landward level behind the embankment. At this point the defence was assumed to stay at this level for 48 hours – the time taken before the breach would be repaired. After 48 hours the breach was assumed to close at the same rate at which it first developed.

The width of the breach was based on the guidelines provided in the Brief – 50m width for an earth embankment and 20m width for a flood wall.

Model Extents

The 2D domain flood cell extents varied for each of the breach scenarios depending upon the geographical features that would potentially obstruct flood flows resulting from the breach. The model extent for each of the breach locations are described below:

1. Carr Lane/Wharton Road and the railway line formed the northern and eastern boundaries of the flood cell. Lord Street and Market Street formed the southern boundary.
2. The A631 main road and the railway line formed the southern and eastern boundaries. Carr Lane and Wharton Road in the fenland area formed the northern boundary.
3. Lord Street and Market Street formed the northern boundary. The flood cell was limited southwards by the flood embankments and eastwards by the railway line embankment and the higher ground of the scarp slope.

Timestep

The timestep for the Tuflow model was calculated based on the guidelines in the Tuflow manual. This states that the timestep of the Tuflow model should be between a quarter and a half of the grid size of the terrain. The timestep of the Tuflow model is therefore 5.0s.

Cumulative mass errors were monitored throughout the simulation and were generally less than 1%. This indicated that the chosen timestep is sufficiently short. Higher mass errors occurred at the start of the model run period but were reduced shortly after simulations were underway. This is normal and indicates an acceptable model performance.

Bardney Breach Analysis Methodology

A breach scenario through the earth embankment downstream of the Sugar Factory at Bardney was investigated by creating a linked ISIS-TUFLOW model of the River Witham and the left bank floodplain near Bardney.

<u>ISIS Model</u>

The Lower Witham ISIS Hydraulic Model was trimmed prior to being used for the ISIS-Tuflow modelling, both for the purposes of creating the combined model and to improve the model's stability. The trimmed model extended from upstream of Branston Island (approximately 11km downstream of Lincoln) on the River Witham to its downstream extent at the Wash. The South Delph which flows parallel to the south of the river was included. The Barlings Eau, a tributary of the River Witham, was modelled to 1.6km upstream of its confluence at Branston Island and the River Bain was modelled up to 2.3km from its confluence with the Witham south of Tattershall.

The upstream boundary of the ISIS model is a flow-time hydrograph, and the downstream boundary is a head-time boundary representing the tide. Various flow-time hydrographs are input into the River Witham to model its various tributaries.

Initial conditions have been created in order for the model to begin at 45 hours into the simulation (two hours before the start of the breach).

<u>Tuflow Model</u>

The 2-dimensional model extent covers the left bank floodplain of the River Witham from immediately north of the of the Sugar Factory to 5.3km downstream of the factory including all of the land below 6m from the river embankment to approximately 4km east,

In order to avoid repetition, the model structure, ground model and roughness coefficients are the same as outlined above in the Gainsborough Breach Analysis scenario.

A 50 metre breach was modelled as a variable geometry in MapInfo. The breach occurs at the peak stage in the River Witham and the embankment level decreases to the level of the land behind the embankment. Half an hour after the peak stage the breach has been fully developed. After 48 hours the breach is closed at the same rate at which it was developed.

<u>ISIS-TUFLOW</u>

There are three different types of connection between the ISIS and Tuflow domains. The primary link is an HX boundary linking node 'with45' to the area of the breach. There are also SX links which transfer any flows over the spills formerly leading to a reservoir unit in to the 2D domain. SX boundaries were used instead of HX boundaries because there was greater confidence in the level of the spills in the model than in the embankment heights from the SAR data. A point SX boundary was also used to connect pump unit 'c1p' to the 2D domain.

The ISIS-Tuflow model was run for a simulation period of 45-120 hours using ISIS-Tuflow version 2.4 with Tuflow version 2006-06-BF.

AECOM

Appendix C

Appendix C – Skeleton Outline of a FRA

All Flood Risk Assessments should be written in accordance with the guidance PPS 25, in particular Annex E. Guidelines to potential chapter headings within a Flood Risk Assessment are outlined below.

1. Introduction
    i. General introduction to the FRA report. States what will be included in the FRA.
2. Location of the site
    i. Describes the site location.
3. Description of the site
    i. Identifies the key features of the site.
4. Topography and site cross-sections
    i. Describes the topography of the land in and surrounding the site. A topographical survey of the site is required.
5. Potential sources of flooding
    i. Identifies all the sources from where potential flood water could impact on the site.
6. Flood alleviation measures
    i. Identifies any flood alleviation measures on any of the sources of flooding.
7. Records of flooding
    i. Describes any historical flooding on or in the immediate vicinity of the development site.
8. Probabilities and trends of flooding
    i. Reviews the likelihood of flooding occurring and how the probability of flooding will change in the future.
9. Impacts of flooding
    i. Reviews the impact of any flood water on the development site. Describes mitigation measures that could be incorporated into the site layout to reduce the impact of flooding.
10. Drains and sewers
    i. Describes any drains/ditches or any public sewers in the vicinity of the development site.
11. Increased runoff
    i. Identifies whether the proposed development will increase or decrease surface water runoff from the site.
12. Displaced water
    i. Identifies the issue of displaced water, i.e. will the development cause flooding to adjacent properties or land.
13. Morphology
    i. Describes any morphological features within the site or any local drains.
14. Residual risks
    i. Describes any other risks of flooding to the site that are not thought to be significant.
15. Conclusions and recommendations
    i. Summary of findings and points to consider.

Photographs of the site should also be included as part of the report.