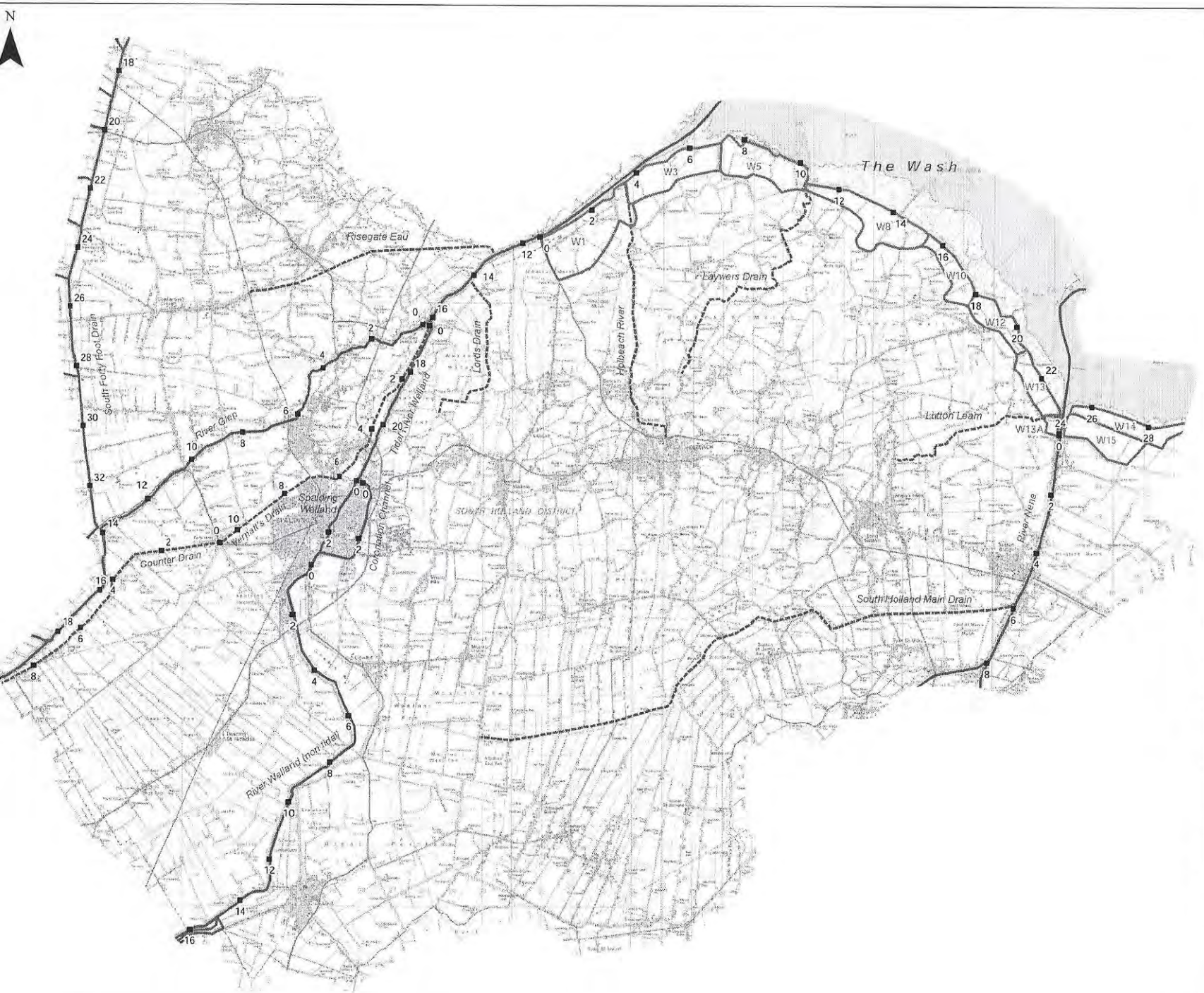
LIN Consulting

APPENDIX C: Flood Mapping



NOTES

Map Legend

- Chainage Points (Km)
- Main River
- IDB Main Drains
- Wash Cells

REV	DATE	REMARKS

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ROYAL HASKONING
RIGHTWELL HOUSE
BRETTON
PETERBOROUGH
PE3 8DW
TEL +44 (0)1733 334455
FAX +44 (0)1733 262243

SOUTH HOLLAND DISTRICT COUNCIL
COUNCIL OFFICES
PRIORY ROAD
SPALDING
LINCOLNSHIRE
PE11 2XE

UPDATE OF STRATEGIC FLOOD RISK ASSESSMENT

Reference Chainages

DATE OF ISSUE: Jan 2010 REV NO:

SCALE: 1:120,000

FIGURE NO: 8

Location	Chainage	Peak 1 in 100 year fluvial flood level (mOD)		Peak 1 in 1000 year fluvial flood level (mOD)		Defence crest level (mOD)	Defence type	Freeboard (m) 1 in 100 Year Level		Freeboard (m) 1 in 1000 Year Level	
	(km)	2007	2055/2115	2007	2055/2115			2007	2055/2115	2007	2055/2115
Little London Bridge	0.0	4.42	4.67	4.43	4.68	5.99	Bank with road on crest	1.57	1.32	1.56	1.31
Sluice	0.1	2.40	3.11	3.18	4.10	5.99	Bank with road on crest	3.59	2.88	2.81	1.89
	0.2	2.40	3.11	3.18	4.10	6.04	Bank with road on crest	3.64	2.93	2.86	1.94
	0.3	2.40	3.11	3.18	4.10	6.09	Bank with road on crest	3.68	2.97	2.91	1.99
	0.4	2.40	3.11	3.18	4.10	6.13	Bank with road on crest	3.73	3.02	2.95	2.03
	0.5	2.40	3.11	3.18	4.10	6.18	Bank with road on crest	3.78	3.07	3.00	2.08
	0.6	2.40	3.11	3.18	4.10	6.11	Bank with road on crest	3.71	3.00	2.93	2.01
	0.7	2.40	3.11	3.18	4.10	6.04	Bank with road on crest	3.64	2.93	2.86	1.94
	0.8	2.40	3.11	3.18	4.10	5.98	Bank with road on crest	3.57	2.87	2.80	1.88
Fen End	0.9	2.40	3.11	3.18	4.10	5.91	Bank with road on crest	3.51	2.80	2.73	1.81
	1.0	2.40	3.11	3.18	4.10	5.84	Bank with road on crest	3.44	2.73	2.66	1.74
	1.1	2.40	3.11	3.18	4.10	5.80	Bank with road on crest	3.40	2.69	2.62	1.70
	1.2	2.40	3.11	3.18	4.10	5.77	Bank with road on crest	3.37	2.66	2.59	1.67
	1.3	2.40	3.11	3.18	4.10	5.73	Bank with road on crest	3.33	2.62	2.55	1.63
	1.4	2.40	3.11	3.18	4.10	5.70	Bank with road on crest	3.29	2.59	2.52	1.60
	1.5	2.40	3.11	3.18	4.10	5.66	Bank with road on crest	3.26	2.55	2.48	1.56
	1.6	2.40	3.11	3.18	4.10	5.74	Bank with road on crest	3.34	2.63	2.56	1.64
	1.7	2.40	3.11	3.18	4.10	5.82	Bank with road on crest	3.41	2.71	2.64	1.72
	1.8	2.40	3.11	3.18	4.10	5.89	Bank with road on crest	3.49	2.78	2.71	1.79
	1.9	2.40	3.11	3.18	4.10	5.97	Bank with road on crest	3.57	2.86	2.79	1.87
	2.0	2.40	3.11	3.18	4.10	6.05	Bank with road on crest	3.65	2.94	2.87	1.95
	2.1	2.40	3.11	3.18	4.10	6.03	Bank with road on crest	3.63	2.92	2.85	1.93
	2.2	2.40	3.11	3.18	4.10	6.01	Bank with road on crest	3.61	2.90	2.83	1.91
	2.3	2.40	3.11	3.18	4.10	5.98	Bank with road on crest	3.58	2.87	2.80	1.88
A16 Road Bridge	2.4	2.40	3.11	3.18	4.10	5.96	Bank with road on crest	3.56	2.85	2.78	1.86
	2.5	2.40	3.11	3.18	4.10	5.94	Bank with road on crest	3.54	2.83	2.76	1.84
	2.6	2.40	3.11	3.18	4.10	5.96	Bank with road on crest	3.56	2.85	2.78	1.86
	2.7	2.40	3.11	3.18	4.10	5.98	Bank with road on crest	3.58	2.87	2.80	1.88
	2.8	2.40	3.11	3.18	4.10	6.01	Bank with road on crest	3.61	2.90	2.83	1.91
	2.9	2.40	3.11	3.18	4.10	6.03	Bank with road on crest	3.63	2.92	2.85	1.93
	3.0	2.40	3.11	3.18	4.10	6.05	Bank with road on crest	3.65	2.94	2.87	1.95
	3.1	2.40	3.11	3.18	4.10	6.02	Bank with road on crest	3.62	2.91	2.84	1.92
	3.2	2.40	3.11	3.18	4.10	5.99	Bank with road on crest	3.59	2.88	2.81	1.89

Location	Chainage	Peak 1 in 100 year fluvial flood level (mOD)		Peak 1 in 1000 year fluvial flood level (mOD)		Defence crest level (mOD)	Defence type	Freeboard (m) 1 in 100 Year Level		Freeboard (m) 1 in 1000 Year Level	
	(km)	2007	2055/2115	2007	2055/2115			2007	2055/2115	2007	2055/2115
Marsh Road Sluice	0.0	4.32	4.69	4.34	4.69	5.84	Earth bank	1.52	1.15	1.50	1.15
	0.1	4.32	4.69	4.34	4.69	6.99	Earth bank	2.67	2.30	2.65	2.30
Springfields	0.2	4.32	4.69	4.34	4.69	7.19	Earth bank	2.87	2.50	2.85	2.50
A151 Bridge	0.3	4.32	4.69	4.34	4.69	6.37	Earth bank	2.05	1.68	2.03	1.68
	0.4	4.32	4.69	4.34	4.69	6.16	Earth bank	1.84	1.47	1.82	1.47
	0.5	4.32	4.69	4.34	4.69	6.13	Earth bank	1.81	1.44	1.79	1.44
	0.6	4.32	4.69	4.34	4.69	6.10	Earth bank	1.78	1.41	1.76	1.41
	0.7	4.33	4.69	4.35	4.69	6.06	Earth bank	1.73	1.37	1.71	1.37
	0.8	4.33	4.69	4.35	4.69	5.92	Earth bank	1.59	1.23	1.57	1.23
	0.9	4.33	4.69	4.35	4.69	5.64	Earth bank	1.31	0.95	1.29	0.95
	1.0	4.34	4.69	4.36	4.69	5.58	Earth bank	1.24	0.89	1.22	0.89
	1.1	4.34	4.69	4.36	4.69	5.38	Earth bank	1.04	0.69	1.02	0.69
	1.2	4.34	4.69	4.36	4.69	5.35	Earth bank	1.01	0.66	0.99	0.66
B1165 Bridge	1.3	4.34	4.69	4.36	4.69	5.35	Earth bank	1.01	0.66	0.99	0.66
	1.4	4.34	4.69	4.36	4.69	5.46	Earth bank	1.12	0.77	1.10	0.77
	1.5	4.34	4.69	4.36	4.69	6.00	Earth bank	1.66	1.31	1.64	1.31
	1.6	4.34	4.69	4.36	4.69	5.72	Earth bank	1.38	1.03	1.36	1.03
	1.7	4.35	4.69	4.37	4.69	5.63	Earth bank	1.28	0.94	1.26	0.94
	1.8	4.35	4.69	4.37	4.69	5.35	Earth bank	1.00	0.66	0.98	0.66
	1.9	4.35	4.69	4.37	4.69	5.14	Earth bank	0.79	0.45	0.77	0.45
Disused Railway bridge	2.0	4.35	4.69	4.37	4.69	5.37	Earth bank	1.02	0.68	1.00	0.68
	2.1	4.36	4.69	4.37	4.69	5.40	Earth bank	1.04	0.71	1.03	0.71
Road bridge	2.2	4.36	4.69	4.37	4.69	5.70	Earth bank	1.34	1.01	1.33	1.01
	2.3	4.36	4.68	4.38	4.69	5.56	Earth bank	1.20	0.88	1.18	0.87
	2.4	4.36	4.68	4.38	4.69	5.41	Earth bank	1.05	0.73	1.03	0.72
Road bridge	2.5	4.36	4.68	4.38	4.69	5.33	Earth bank	0.97	0.65	0.95	0.64
	2.6	4.36	4.68	4.38	4.69	5.91	Earth bank	1.55	1.23	1.53	1.22
	2.7	4.36	4.68	4.38	4.69	5.37	Earth bank	1.01	0.69	0.99	0.68
	2.8	4.36	4.68	4.39	4.69	5.80	Earth bank	1.44	1.12	1.41	1.11
	2.9	4.37	4.68	4.39	4.69	5.89	Earth bank	1.52	1.21	1.50	1.20
Spalding Drove bridge	3.0	4.37	4.68	4.39	4.69	5.97	Earth bank	1.60	1.29	1.58	1.28
	3.1	4.37	4.68	4.39	4.69	5.77	Earth bank	1.40	1.09	1.38	1.08
	3.2	4.37	4.68	4.39	4.69	5.85	Earth bank	1.48	1.17	1.46	1.16

A P P E N D I X F

MASTERPLAN LAYOUT

REPORT

2016 Update of South Holland Strategic Flood Risk Assessment - Modelling and Mapping Note

2016 Modelling and mapping Update Note

Client: South Holland District Council

Reference: WATPB3271R001D01

Revision: 01/Final

Date: 28 February 2017

Royal HaskoningDHV

Enhancing Society Together

HASKONINGDHV UK LTD.

Rightwell House
Rightwell East
Bretton
Peterborough
PE3 8DW
Water
VAT registration number: 792428892

+44 1733 334455 **T**
+44 1733 262243 **F**
email **E**
royalhaskoningdhv.com **W**

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1 Introduction

1.1 General

This report sets out the process and parameters used in generating additional 2D flood modelling outputs that have been used in the update (2016) of the South Holland Strategic Flood Risk Assessment. This report is supplementary to the June 2009 Modelling Report[1] of the previous SFRA study. The information presented here is supplementary to that in the main SFRA report. The outputs from the modelling study have been used to map maximum flood depth, velocity, hazard and extent for a range of flood probabilities. To achieve these outputs, two new detailed TUFLOW models have been developed to represent likely flood extents as a result of breaching of the defences from the Crowland and Cowbit Washes and from the River Glen at Surfleet. This has been presented in addition to the detailed modelling for Spalding and Sutton Bridge developed as part of the 2010 SFRA. Only fluvial flooding has been considered in this modelling update. Fluvial boundaries have been generated utilising the Environment Agency's 2007 version of the MIKE11 River Welland and Glen Catchment Strategic Model[2]. Further details of these inputs are discussed below.

In addition to the new modelling outlined above, a review of the detailed modelling for Spalding was carried out to address anomalies identified in the results of the previous SFRA outputs. This led to an update of a couple of breaches where they were not applied consistently across different flood probabilities. A location plan showing all breach locations is provided as a separate Map, Figure MA1.

The whole of the tidal flooding information has been replaced by the mapping from the latest Environment Agency Tidal Hazard mapping. Where the mapping for an area contains both fluvial and tidal components, the more severe of the two has been presented.

1.2 Methodology

TUFLOW modelling has been utilised to simulate flood propagation in the South Holland District from the new fluvial breaching of defences. The sources of fluvial flooding considered are the Rivers Glen and Welland, including the Crowland to Cowbit Washes. No new or updated information from Internal Drainage Boards were used within this update.

The previous study and update undertook TUFLOW modelling in two forms. A District-wide assessment was undertaken for present-day (2006) and year 2115 scenarios (the latter allowing for the prospective impact of climate change) considering a fluvial flood event of 1% Annual Probability of Exceedance (AP) or a tidal event of 0.5% AP as appropriate to location. 0.1% modelling was not carried out at the District-wide scale. The District-wide modelling used a 50m terrain grid. Additionally, more detailed assessments were made for both the Spalding/Pinchbeck area and the Sutton Bridge area. These were expected to be the principal areas for future development in the District. The detailed modelling used a10m terrain grid. As well as considering the same scenarios taken for the District-wide modelling, it also considered fluvial and tidal events of 0.1% AP for the present-day and year 2115.

This study has utilised a similar approach to the former detailed modelling (10m grid resolution) for the new modelling for Crowland and Surfleet.

[1] *Update of Strategic Flood Risk Assessment, Modelling Report, June 2009, Royal Haskoning*
[2] *Welland and Glen Catchment Strategic Model – 2007. Environment Agency*

1.3 Model Inputs

To derive the various outputs for the study, a series of breaches have been modelled in the embankment of the Crowland Washes (to assess risk at Crowland) and from the River Glen (to assess risk at Surfleet). Only fluvial breaching has been considered. A modified reservoir breach methodology has been adopted in order to determine risk at Crowland.

The flows through the breaches for the River Glen and Crowland Washes have been used as inputs in the TUFLOW models. For Surfleet, the flows have been derived using the River Welland and Glen Mike11 model. Details of the Mike11 modelling are described in *Section 2*. For Crowland Washes, breach modelling at Crowland has been carried out as described in *Section 3*. The flood propagation is described in *Section 4* and the creation of the mapping outputs is described in *Section 5*.

The 2007 River Welland Glen Catchment strategic Model and results have been utilised in this study as an ongoing study updating the hydrology and geometry of the various watercourses had not been completed. The intention of this study was that the updated version of the model and its results would have been utilised in this study however the Environment Agency were happy that the older model and results would be suitable for use in this study, as any difference in channel levels was likely to be small and unlikely to have a significant impact on hazard mapping results.

The outputs presenting climate change considerations within this study are represented as the 2115 scenarios. The modelling and mapping represent the outputs from the previous modelling which is in line with the previous PPS 25 guidance and therefore is not in line with the latest guidance published by the Environment Agency in 2016. The new modelling also used the previous guidance for consistency.

The table below shows the comparison between the PPS 25 increases used to account for 100 years of climate change (Year 2115) in this update compared to the present day (2006) and the current Environment Agency 2016 guide.

Parameter	Climate change increases for Year 2115 (Pre 2016 guidance applied in this SFRA)	New climate change increases (Environment Agency guidance - April 2016)
Sea level rise (m)	+1.14m	1.21m
Extreme wave height	+10%	+10% and +10% sensitivity
Peak river flow and volume	+20%	A range from 20% to 65% depending on Flood Zone and type (vulnerability) of development
Peak rainfall intensity	+30%	Test for 20% and 40%

Where flows arise from pumping rather than natural run-off, notably in the Vernatt's Drain and for the Fenland sub-catchments of the South Forty Foot Drain, peak flow rates for future eras have been taken as equal to current rates since this SFRA assumes all flood risk management measures will remain in their current state, as per the assumptions for the 2010 SFRA modelling.

To enable different policies to be applied for climate change for fluvial and tidal/sea levels, a new map has been created and provided with this update titled "Extent of Fluvial and Tidal Domination" which shows areas where the fluvial and tidal conditions are dominating the peak flood levels for the 1% fluvial and 0.5% tidal/sea levels for the 2115 scenario.

2 Mike11 Modelling - Surfleet

2.1 Methodology

As agreed with the Environment Agency, the methods outlined in Sections 2.1 to 2.4 of the June 2009 modelling report have been utilised in this study to determine breach flow parameters for the Surfleet River Glen models. Figure 1 shows the locations at which breaches have been considered along the River Glen in the Mike11 model.

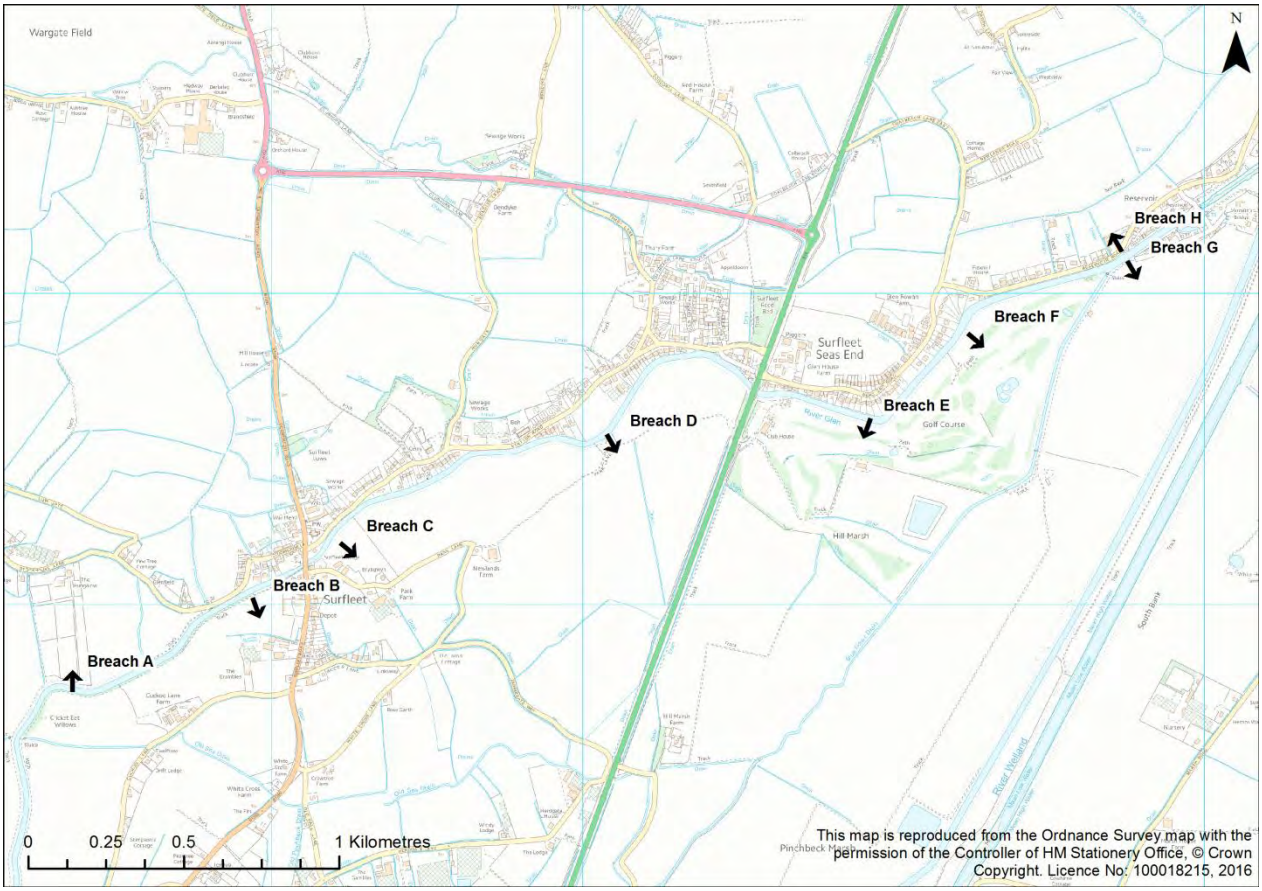


Figure 1 - Mike11 Breach Locations at Surfleet

In addition to the above methodology, additional logic has been applied in determining breach inputs for breach location C. The 'normal' breach method assumed that if a breach occurs, water is able to flow unobstructed into the floodplain (water spills from a high breach base into a lower floodplain). However, in breach location C, although the floodplain immediately landward of the defence is low, there is a ridge of higher ground a short distance from the defence at an elevation of 4.38m AOD (estimated from LiDAR) which water would build up behind and then spill over. For return periods where the maximum water level in the watercourse would be lower than the ridge of high land, the typical assumption of unobstructed flow would therefore be an incorrect assumption. Therefore, the stage and not flow from the 1D model has been utilised as the boundary condition. For breaches where the maximum water level is higher than 4.38m AOD, a flow hydrograph has been produced as per the methodology outlined in the June 2009 report.

2.2 Surfleet Breach Parameters

Table 1 outlines the locations and parameters used in the breach models of this study along the River Glen. The locations of the breaches can be seen in Figure 1.

Table 1 - Mike11 Model Breach Parameters

River	Model Node Chainage Used	Chainage (used in SFRA report)	Location	Breach Base m AOD	Breach Width m	Start Time Present-day Scenario	Start Time 2115 Scenario
Glen	4700	5.1	A – Left Bank	3.5	40	Peak	Peak
Glen	3900	3.5	B – Right Bank	3.7	40	Peak	Peak
Glen	3600	3.2	C – Right Bank	4.38*	40	Peak	Peak
Glen	2400	2.0	D – Right Bank	3.8	40	Peak	Peak
Glen	1400	1.1	E – Right Bank	3.5	40	Peak	Peak
Glen	1400	0.9	F – Right Bank	3.8	40	Peak	Peak
Glen	600	0.2	G – Right Bank	3.8	40	Peak	Peak
Glen	600	0.2	H – Left Bank	4.0	40	Peak	Peak

* Breach base has been assumed as the raised ground level and not the lowest level of the floodplain

2.3 Mike11 Model Runs

Table 2 lists the names of the Mike11 model runs which contain the individual breaches for locations A to G on the River Glen. Flow has been extracted from the weir units that have been used to model the breaches and the resulting flows have been added to a database to be inputs into the various TUFLOW models for Surfleet.

Table 2 - Surfleet Mike11 Model Runs

Surfleet 1% Mike11 Models	Surfleet 1%+CC Mike11 Models	Surfleet 0.1% Mike11 Models	Surfleet 0.1%+CC Mike11 Models
Breach_A 100.sim11	Breach_A 100CC.sim11	Breach_A 1000.sim11	Breach_A 1000CC.sim11
Breach_B 100.sim11	Breach_B 100CC.sim11	Breach_B 1000.sim11	Breach_B 1000CC.sim11
Breach_C 100.sim11	Breach_C 100CC.sim11	Breach_C 1000.sim11	Breach_C 1000CC.sim11
Breach_D 100.sim11	Breach_D 100CC.sim11	Breach_D 1000.sim11	Breach_D 1000CC.sim11
Breach_E 100.sim11	Breach_E 100CC.sim11	Breach_E 1000.sim11	Breach_E 1000CC.sim11
Breach_F 100.sim11	Breach_F 100CC.sim11	Breach_F 1000.sim11	Breach_F 1000CC.sim11
Breach_G 100.sim11	Breach_G 100CC.sim11	Breach_G 1000.sim11	Breach_G 1000CC.sim11

2.4 Surfleet Overtopping Modelling

The risk of flooding from overtopping of the River Glen embankments has been assessed for the 4km of watercourse upstream of the Surfleet Reservoir, covering Surfleet and Surfleet Seas End. The Mike11 model has not been dynamically linked to TUFLOW to produce these outputs as this was outside the

scope of the study. The 2D modelling utilised stage hydrographs extracted at 500m intervals from the updated Mike11 Strategic Model (which includes spills to floodplain channels). The peak water elevations of the hydrographs are selected nodes as published in Appendix A of the 2010 SFRA report. Flood extents have been produced for the 1% AEP (Year 2115), 0.1% AEP (present day) and 0.1% AEP (Year 2115). No overtopping occurs during the present day 1% AEP.

3 Crowland to Cowbit Breaching

3.1 Methodology

In order to determine flow hydrographs from breaches of the eastern embankment of the Crowland to Cowbit Washes, a modified version of the method (Froehlich) described in the reservoir flood mapping guidance[3] was utilised. Figure 2 shows the methodology as outlined in the guidance.

[3] *Reservoir Flood Maps (RFM) Guide, Environment Agency January 2016*

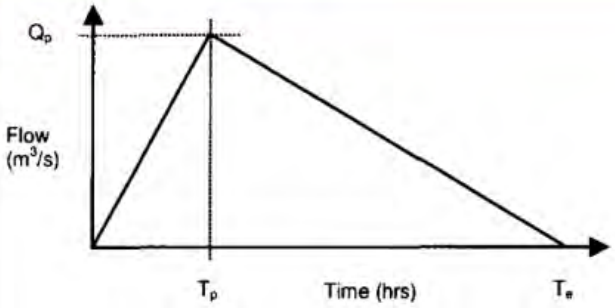
<table>
<tr><th>Step</th><th>Action</th><th>Explanation</th></tr>
<tr><td>1</td><td>Assume the hydrograph shape is triangular as follows</td><td>
</td></tr>
<tr><td>2</td><td>Calculate peak discharge (Qp) using the following equations which depend on the type of dam</td><td>
<table>
<tr><th>Dam type</th><th>Equation to estimate Q_p</th><th>Reference</th></tr>
<tr><td>Earthfill embankment</td><td>$Q_p = FOS\left[0.607(V_w^{0.295} H_w^{1.24})\right]$</td><td>Froehlich (1995)</td></tr>
<tr><td>Concrete/masonry</td><td>$Q_p = cLH_w^{1.5}$</td><td>CIRIA C542</td></tr>
</table>
where:
FOS = factor of safety (equal to 1.5)
V_w = Reservoir volume at top water level (m^3)
H_w = Maximum dam height (m)
c = Coefficient of discharge (depends on dam construction type)
L = Length of dam crest across the valley
</td></tr>
<tr><td>3</td><td>Estimate time to peak discharge (T_p) based on the following guidelines</td><td>
<table>
<tr><th>Dam type</th><th>Equation to estimate T_p (s)</th><th>Reference</th></tr>
<tr><td>Earthfill embankment</td><td>$T_p = 120H_w$</td><td>Brown & Gosden (2004)</td></tr>
<tr><td>Concrete/ masonry</td><td>T_p = 30s or 720s (dependent on construction type)</td><td>CIRIA C542</td></tr>
</table>
</td></tr>
<tr><td>4</td><td>Estimate time to end discharge (T_e) so that the volume under the hydrograph is equal to the reservoir volume</td><td>$V_w = ½ (Q_p \times T_P) + ½(Q_p \times (T_e - T_p)$</td></tr>
</table>

Figure 2 - Reservoir Flood Maps Hydrograph Methodology

For the analysis undertaken in this study, the following has been assumed:

V_w = Volume for the area shown in Figure 3 between maximum water elevation (H_w) and LiDAR
H_w = Water level minus breach base elevation

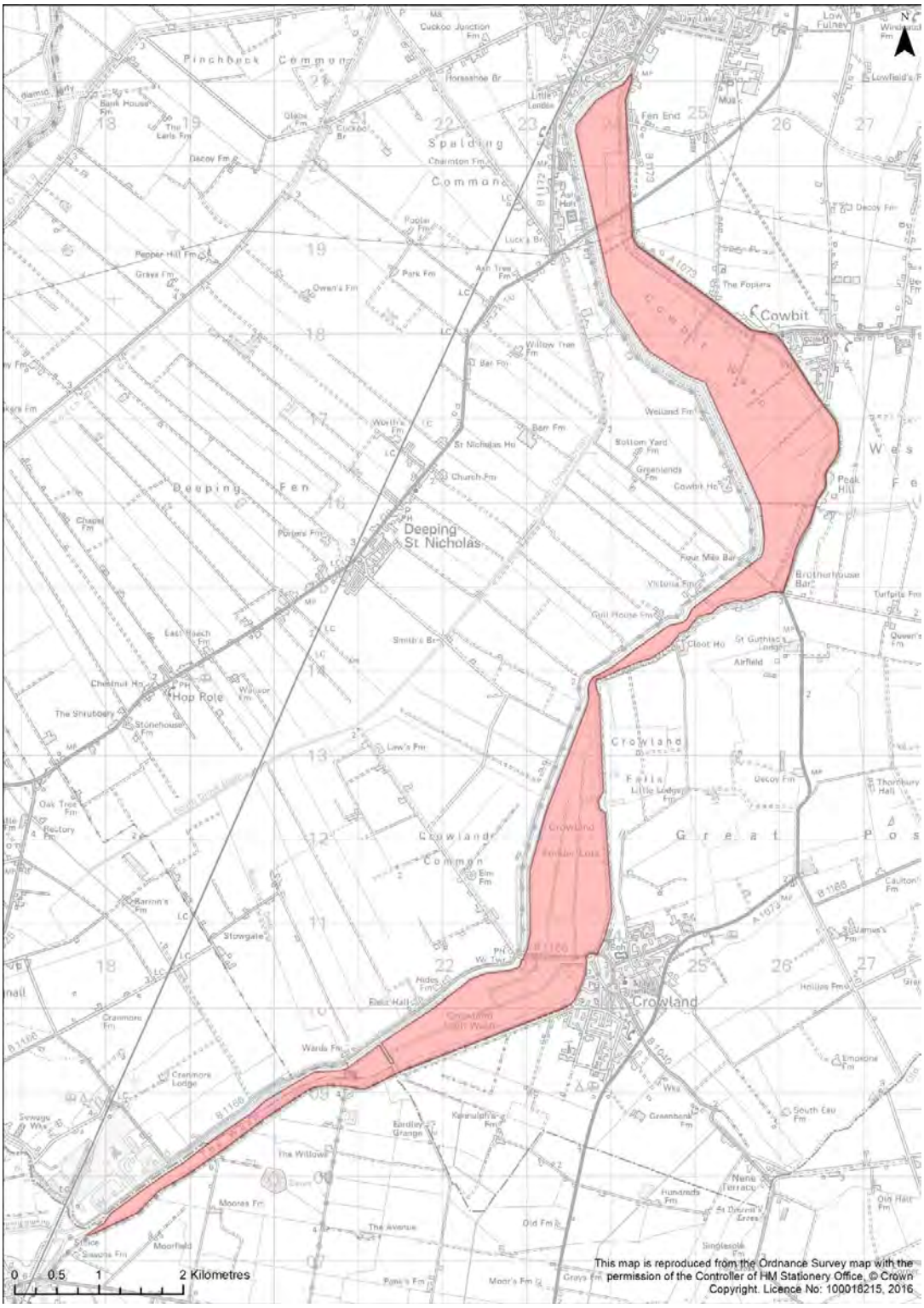


Figure 3 - Extent of Crowland to Cowbit Washes

LiDAR has been used to determine the volume of the washlands as shown in *Figure 3* between the maximum water levels and the various breach base elevations.

Water levels were supplied by the Environment Agency for the Crowland and Cowbit washlands for flood events with 1% and 0.1% chances of occurring in any year inclusive of climate change. In order to determine water levels for these return periods without climate change, levels were interpolated using data from the existing Mike11 model. Table 3 shows how the water levels have been derived.

Table 3 - Crowland to Cowbit Maximum Water Levels

	Return Period Peak Water Level (m AOD)			
Model	**1%**	**1% + CC**	**0.1%**	**0.1% + CC**
Mike11 Main Model	2.42	3.11	3.20	4.13
Washlands Model	3.74*	4.43 (including waves)	4.44**	5.37 (including waves)

* Estimate based on 1%+CC Washlands model estimate, minus difference in Mike11 main model results for 1% and 1%+CC (as agreed with the Environment Agency)
** Estimate based on 0.1%+CC Washlands model estimate, minus difference in Mike11 main model results for 0.1% and 1%+CC (as agreed with the Environment Agency)

Table 4 lists the breach base elevation and peak water levels that have been assumed for the various return periods assessed and Figure 4 shows the location of the breaches.

Table 4- Crowland to Cowbit Washes Breach Parameters

Breach Location	Breach Base Elevation (m AOD)	Maximum Water Level (m AOD) 1%	Maximum Water Level (m AOD) 1% + Climate Change	Maximum Water Level (m AOD) 0.1%	Maximum Water Level (m AOD) 0.1% + climate Change
A	2.1	3.74	4.43	4.44	5.37
B	2.3	3.74	4.43	4.44	5.37
C	3.3	3.74	4.43	4.44	5.37
D*	4.1	3.74	4.43	4.44	5.37
E	1.5	3.74	4.43	4.44	5.37
F	1.6	3.74	4.43	4.44	5.37

*Breach base taken as high ground level landward of defence (North Street)

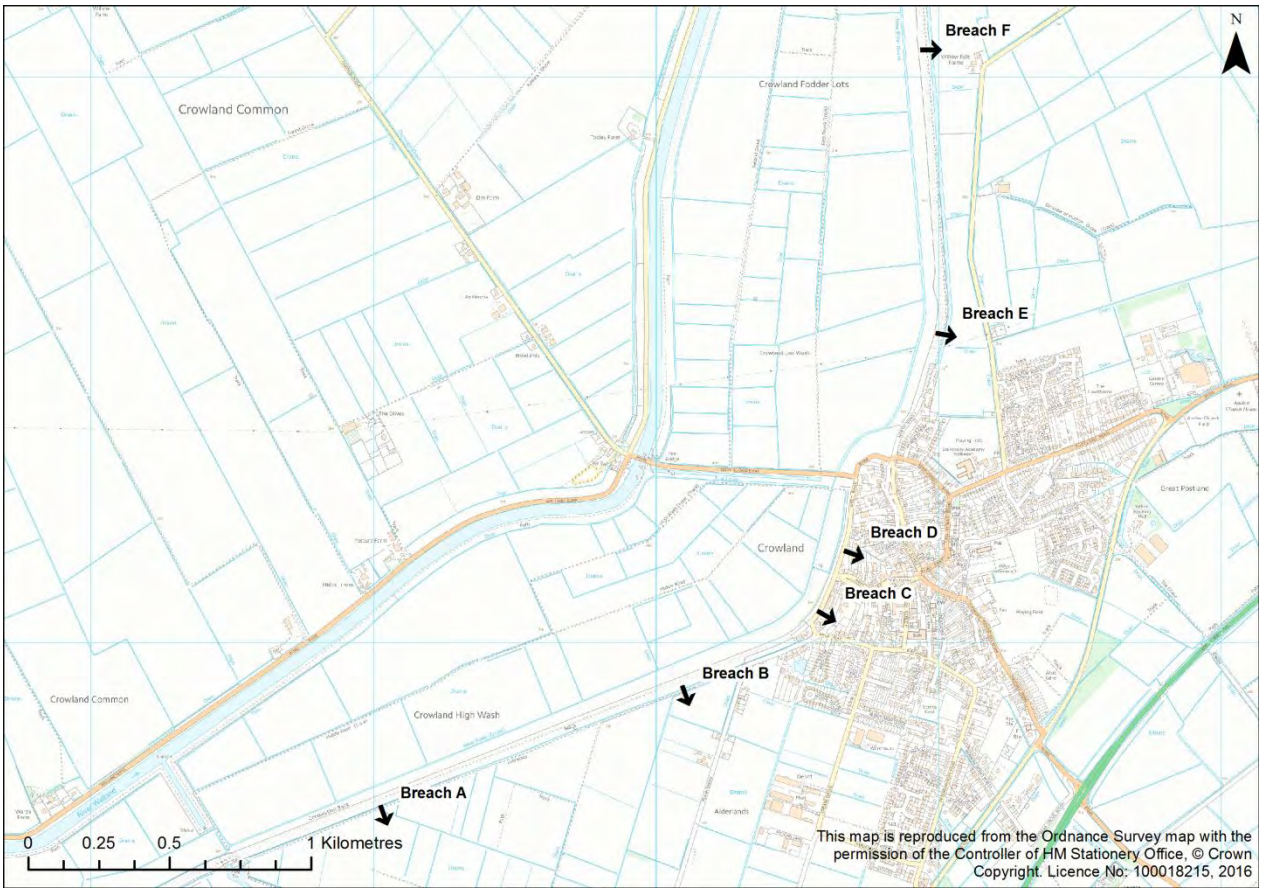


Figure 4 - Crowland Breach Locations

For breach location D, a similar approach to that at Surfleet Breach location C has been applied. This is because the water level in the washlands is below the elevation of North Street which is set some way back from the breach. As the volume of the floodplain between the breach and the road is very small in comparison to the volume of water in the washlands, a fixed stage hydrograph has been used for the boundary condition. This would allow depth, velocity and associated hazard to be calculated by the hydraulic model.

4 TUFLOW Modelling

4.1 General

TUFLOW models of the floodplain at Crowland and Surfleet have been created to assess flood risk.

4.2 2D Domains

The extent of the 2D domain of the Crowland model can be seen in Figure 5, represented by the green boundary line with breach locations shown as blue triangles. For Surfleet two separate models (one on each bank) were created as breaches have been assessed on both the left and right hand banks. The extent of these models can be seen in Figure 6 represented by the green outlines.

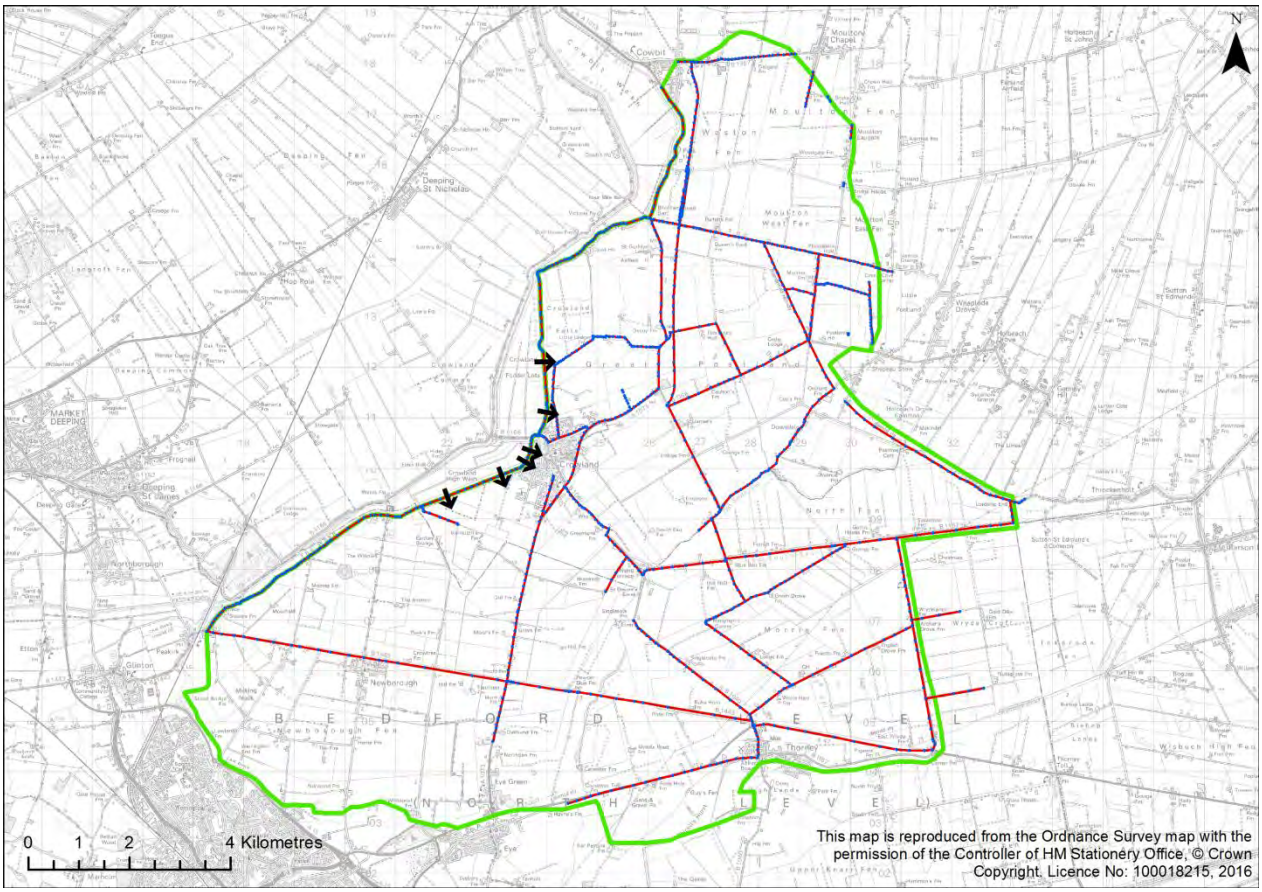


Figure 5 - Crowland 2D Model Extent

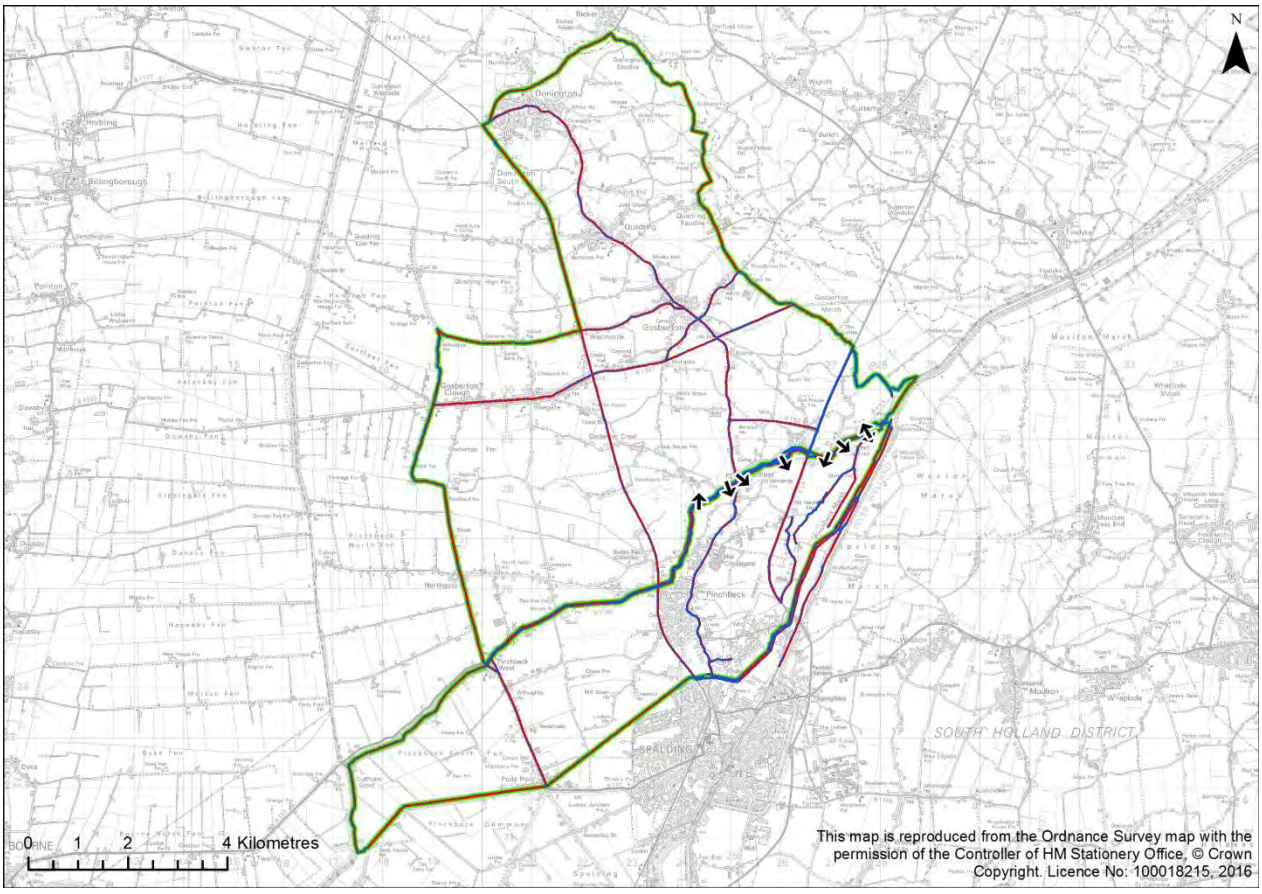


Figure 6 - Surfleet Model Locations

The three models have been created utilising a fixed 10m size grid. The grid size utilised matches that of the detailed models in the previous study. Although the models incorporate urban area where detail is required to depict flow routes, as the extent of flooding was also required it was not possible to utilise a smaller grid without extremely long model run times.

4.3 Topography

The hydraulic models underlying topographic data has been generated from 2m resolution LiDAR data. Although 0.25, 0.5 and 1m resolution data were also collected for the study, only the 1m and 2m resolution LiDAR fell within the extents of the models. A comparison of the 1m and 2m resolution LiDAR showed that the two data sets were very similar, but the models ran significantly more slowly across the 1m resolution. Therefore the 2m LiDAR has been used across all models.

During initial testing of the Crowland hydraulic model, the model crashed due to rapid changes in model topography. In order to negate such instances, the command 'Interpolate ZHC ALL' has been utilised, this command smooths the underlying topography and improves model stability. Following more detailed inspection of the model, an isolated but deep depression still existed within the topography. Therefore a Zshape has been used to 'fill' this depression by interpolating surround elevations. This was the only instance where this has been required.

4.4 Raised Features and Buildings

Raised features such as roads and flood embankments have been included in the model as zlines to ensure that crest heights are included in the model, the 10m grid allows for a point in the floodplain to be depicted every 5m and therefore this approach ensured that the topography was accurately represented. The location of roads and embankments are shown as red lines and dots in Figure 5 and Figure 6. Buildings have been raised from the underlying grid by an elevation of 0.3m. Mastermap building polygons have been used to depict the extent of buildings within the models.

4.5 Roughness Coefficients

Roughness coefficients consistent with those from the previous study have been utilised in this study as agreed with the Environment Agency. Mastermap data has been utilised to delimit differing land uses and roughness coefficients. The roughness coefficients utilised can be seen in Table 5, and an extract of how the data has been applied can be seen in Figure 7.

Table 5 - Model Roughness Coefficients

Material	Model Roughness Coefficient
Buildings	0.5
Roads	0.024
Gardens	0.12
Other	0.09



Figure 7 - Delineation of Mastermap Data (Left) and Associated Model Roughness Coefficient Delineation (Right)

4.6 Model Runs

Table 6 lists the TUFLOW model runs undertaken for the study.

Table 6 - Model Runs

Surfleet TUFLOW Models	Surfleet TUFLOW Models With Climate Change	Crowland TUFLOW Models	Crowland TUFLOW Models With Climate Change
Surf_T100_A.tcf	Surf_T100CC_A.tcf	Crow_T100_A.tcf	Crow_T100CC_A.tcf
Surf_T100_B.tcf	Surf_T100CC_B.tcf	Crow_T100_B.tcf	Crow_T100CC_B.tcf
Surf_T100_C.tcf	Surf_T100CC_C.tcf	Crow_T100_C.tcf	Crow_T100CC_C.tcf
Surf_T100_D.tcf	Surf_T100CC_D.tcf	Crow_T100_D.tcf	Crow_T100CC_D.tcf
Surf_T100_E.tcf	Surf_T100CC_E.tcf	Crow_T100_E.tcf	Crow_T100CC_E.tcf
Surf_T100_F.tcf	Surf_T100CC_F.tcf	Crow_T100_F.tcf	Crow_T100CC_F.tcf
Surf_T100_G.tcf	Surf_T100CC_G.tcf	Crow_T1000_A.tcf	Crow_T1000CC_A.tcf
Surf_T1000_A.tcf	Surf_T1000CC_A.tcf	Crow_T1000_B.tcf	Crow_T1000CC_B.tcf
Surf_T1000_B.tcf	Surf_T1000CC_B.tcf	Crow_T1000_C.tcf	Crow_T1000CC_C.tcf
Surf_T1000_C.tcf	Surf_T1000CC_C.tcf	Crow_T1000_D.tcf	Crow_T1000CC_D.tcf
Surf_T1000_D.tcf	Surf_T1000CC_D.tcf	Crow_T1000_E.tcf	Crow_T1000CC_E.tcf
Surf_T1000_E.tcf	Surf_T1000CC_E.tcf	Crow_T1000_F.tcf	Crow_T1000CC_F.tcf
Surf_T1000_F.tcf	Surf_T1000CC_F.tcf		
Surf_T1000_G.tcf	Surf_T1000CC_G.tcf		

5 Mapping

5.1 General

The outputs from the new modelling exercise was combined with outputs from the previous SFRA and the Environment Agency's tidal flood hazard mapping to produce a revised set of maps for residual flooding for the present day and 2115. It was agreed with the Environment Agency that the Actual Flood Risk maps for both the South Holland District Council district wide and the more detailed location specific areas were not to be updated as they do not use them to support development planning decisions. The Residual Flood Risk Maps for the South Holland District Council broad scale 2055 maps were also not updated for the same reasons. The colour scheme/bandings of all the maps have been changed within this update to match that used by the Environment Agency for their Tidal Hazard Mapping. This enables consistency with other SFRAs, including Boston Borough Council SFRA. This is particularly important as a new Local Plan is being prepared for South East Lincolnshire (the areas of Boston Borough Council and South Holland District Council). A new map has been created and provided with this 2016 SFRA Modelling and mapping Update titled "Fluvial and Tidal Source Mapping". This map shows where the source of the information used for the mapping is from South Holland District Council modelling and where it is from the Environment Agency's Flood Hazard mapping.

For the area covered by the Environment Agency Tidal Hazard Mapping, the hazard maps were reproduced as provided by the Environment Agency.

For the areas not covered by the Environment Agency Tidal Hazard Mapping, the hazard maps were derived by combining the peak velocity and depth information from the modelling results within GIS. This enabled adherence to the FD2320 methodology and avoids the different factors used in the direct calculation by TUFLOW which does not fully conform to FD2320 guidance. The method is outlined below:

- Using a raster calculator within GIS software we calculated a debris factor for the four scenarios (present day and climate change) in compliance with the FD2320 (page 117) adopting a debris factor of 0.5 for depths below and equal to 0.25 m and a debris factor of 1.0 for depths above 0.25m.
- The hazard was then calculated (using raster calculator within GIS software) based on the hazard formula FD2320 (page 117), utilising the maximum depth and velocity layers and the created debris factor layers.
- In the areas where velocity results were not available (IDB drains, etc.) a velocity = 0 was assigned.
- Resulting hazard layers were then combined with those from the Environment Agency Tidal Hazard Mapping and classified according to the legend provided by the Environment Agency.

5.2 Detailed Residual Mapping for Selected Settlements

Detailed Residual Flood Risk Maps were developed for Spalding, Sutton Bridge, Surfleet and Crowland, where significant developments are planned. The detailed maps for Surfleet and Crowland maps are completely new, while those for Spalding and Sutton Bridge are updates to the 2010 SFRA mapping. For each of these settlements, the following maps were developed for both the present day and Year 2115:

- Residual Flood Risk Extent Maps for 1% fluvial / 0.5% tidal event probability
- Residual Flood Risk Extent Maps for the 0.1% event probability
- Residual Flood Peak Depth Maps for 1% fluvial / 0.5% tidal event probability

- Residual Flood Peak Depth Maps for the 0.1% event probability
- Residual Flood Peak Velocity Maps for 1% fluvial / 0.5% tidal event probability
- Residual Flood Peak Velocity Maps for the 0.1% event probability
- Residual Flood Hazard Maps for 1% fluvial / 0.5% tidal event probability
- Residual Flood Hazard Maps for the 0.1% event probability

The development of the updated detailed residual flood mapping for each of the four settlements is described below:

Spalding (including Pinchbeck)
The mapping was an amalgamation of the 2D-breach modelling and mapping from the 2010 SFRA and the Environment Agency's Tidal Hazard Mapping sources. The maps were amalgamated, with the worst case situation from each source used per point on the map. Some anomalies had been identified within the 2010 modelling outputs, as a result, a quality review of the result files were carried out to ensure the appropriate files had been used in the mapping. A few anomalies were corrected by turning on spills and replacing missing or erroneous files with the correct ones. The result files were then recombined to produce the updated flood maps. As a result, inconsistencies were removed from the results, but in some cases, the flood outlines for the 2016 update were different from the 2010 ones. Some of these were due to the removal of post modelling adjustments made during the 2010 mapping process.

Sutton Bridge
The Environment Agency's Tidal Hazard Mapping was used for Sutton Bridge. The previously modelled and mapped output used within the 2010 SFRA was therefore completely replaced by the Environment Agency's Tidal flood maps as the Environment Agency regards this as more up to date.

Surfleet
The mapping was an amalgamation of the new 2D-breach and overtopping modelling of the River Glen near Surfleet (See Section 2 above) and the Environment Agency's Tidal Hazard Mapping. The maps were amalgamated, with the worst case situation from each source used per point on the map.

Crowland
The mapping was based on the outputs of the breach modelling of the Crowland Washes barrier banks at Crowland as described in Section 3.

5.3 District-wide Residual Flood Risk Mapping

The district wide mapping covered the whole of the South Holland District Council area. The following maps were developed for both the present day and Year 2115:

- Residual Flood Risk Extent Maps for 1% fluvial / 0.5% tidal event probability
- Residual Flood Peak Depth Maps for 1% fluvial / 0.5% tidal event probability
- Residual Flood Peak Velocity Maps for 1% fluvial / 0.5% tidal event probability
- Residual Flood Hazard Maps for 1% fluvial / 0.5% tidal event probability

The new district-wide maps were created by incorporating the four detailed maps into the 2010 district wide maps. The district-wide flood hazard maps have been provided for this update, even though not for the 2010 SFRA as all parameters were available to enable this. However as the 0.1% mapping was not

carried out at a district level in 2010, it was agreed with the Environment Agency that this will not be carried out in this update as well as it would have required new modelling.

5.4 Comparison of Mapped Outputs for 2016 and 2010 Updates

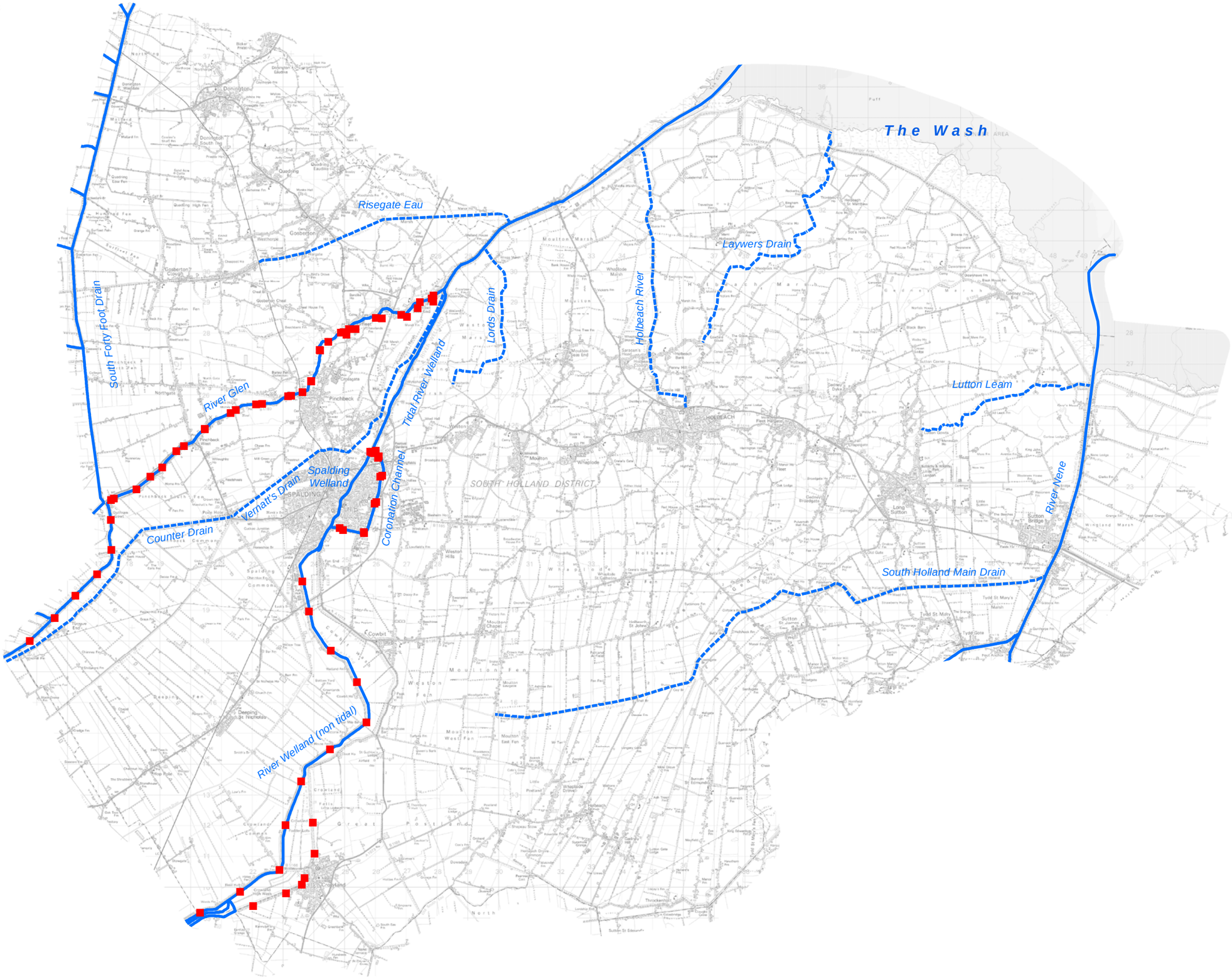
As outlined above, a number of mapping information has not been updated as part of this update. Table 7 below provides a summary of maps which were provided in 2010 and retained in the 2016 update (blue ✓); provided in 2010, but not retained in the 2016 update (red ✓); and Figures newly developed for the 2016 update (green ✓).

Table 7 – Comparison of 2010 and 2016 Mapped Outputs

Residual Risk							
Parameter	**Flood event Annual Probability Tidal/Fluvial**	Spalding, Sutton Bridge, Crowland and Surfleet Areas (new for 2016)			Remainder of the District		
		Present Day (2006)	2055	2115	Present Day (2006)	2055	2115
Maximum flood extent	0.5%/1% 0.1%/0.1%	✓ ✓	✓	✓ ✓	✓	✓	✓
Maximum flood depth	0.5%/1% 0.1%/0.1%	✓ ✓		✓ ✓	✓		✓
Maximum flood flow velocity	0.5%/1% 0.1%/0.1%	✓ ✓		✓ ✓	✓		✓
Maximum flood hazard	0.5%/1% 0.1%/0.1%	✓ ✓		✓ ✓			
Flood extent time contours	0.5%/1% 0.1%/0.1%	✓ ✓		✓ ✓			
Rapid inundation zone	0.5%/1% 0.1%/0.1%	✓ ✓		✓ ✓	✓		✓
Actual Risk							
Parameter	**Flood event Annual Probability Tidal/Fluvial**	Spalding and Sutton Bridge Areas			Remainder of the District		
		Present Day (2006)	2055	2115	Present Day (2006)	2055	2115
Maximum flood extent	0.5%/1% 0.1%/0.1%	✓ ✓	✓	✓ ✓	✓	✓	✓
Maximum flood depth	0.5%/1% 0.1%/0.1%	✓ ✓		✓ ✓	✓		✓
Maximum flood flow velocity	0.5%/1% 0.1%/0.1%	✓ ✓		✓ ✓	✓		✓
Maximum flood hazard	0.5%/1% 0.1%/0.1%	✓ ✓ ✓		✓ ✓ ✓			

Flood extent time contours	0.5%/1% 0.1%/0.1%	✓		✓			
Other Maps from 2010 SFRA							
Map Number	**Map Title**	**2016 update status**					
MA1	Breach locations				✓		
1	Plan of District				✓		
2	IDB Systems				✓		
3	Flood Zones				✓		
4	Development Sites and Key Infrastructure				✓		
New Maps from 2016 Update							
Description	**Map Title**	**2016 update status**					
	Extent of Fluvial and Tidal Domination				✓		
	Fluvial and Tidal Source Mapping				✓		

N



NOTES

Map Legend

- Breach Locations
- Main River
- IDB Main Drains

0 2.5 5 Kilometers

REV	DATE	REMARKS
2	Feb 17	Modelling and Mapping Update
1	Jan 17	Modelling and Mapping Update

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Royal HaskoningDHV
Enhancing Society Together
ROYAL HASKONINGDHV
RIGHTWELL HOUSE
BRETTON
PETERBOROUGH
PE3 8DW
TEL +44 (0)1733 334455
FAX +44 (0)1733 262243

SOUTH HOLLAND DISTRICT COUNCIL
COUNCIL OFFICES
PRIORY ROAD
SPALDING
LINCOLNSHIRE
PE11 2XE

UPDATE OF STRATEGIC FLOOD RISK ASSESSMENT

Breach Locations

DATE OF ISSUE: Feb 2017 **REV NO:** 2

SCALE: 1:125,000

FIGURE NO: MA1

N

NOTES

1. The potential flooding consequences shown on this map primarily relate to flooding from the sea and main rivers taking into account the presence of current flood risk management measures such as flood defences.

2. This update only included new flood risk information from River Welland (Fluvial), River Glen (Fluvial) and Tidal hazard mapping (River Welland, River Nene and the Wash sea defences). No new information from the Internal Drainage Boards and associated systems was used for this update.

3. In addition to the potential flood extents shown on this map, there may be shallow flooding in low-lying rural areas

4. The consequences designated as being a Residual Risk arise from direct overtopping of defences, where this would occur, together with breach failure which is assumed could occur at any point along the defences.

5. Functional Floodplain encompasses areas where water is intended to flow or be stored in times of flood.

6. Land outside South Holland District is not considered.

7. This map shows the extents only of the flooding probability bands relevant to the map Title

Map Legend

Peak Depth

- 0m - 0.25m
- 0.25m - 0.5m
- 0.5m - 1m
- 1m - 2m
- 2m +
- Functional Floodplain
- South Holland District Boundary

REV	DATE	REMARKS
2	Feb 17	Modelling and Mapping Update
1	Dec 16	Modelling and Mapping Update

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Royal HaskoningDHV
Enhancing Society Together

ROYAL HASKONINGDHV
RIGHTWELL HOUSE
BRETTON
PETERBOROUGH
PE3 8DW
TEL +44 (0)1733 334455
FAX +44 (0)1733 262243

SOUTH HOLLAND DISTRICT COUNCIL
COUNCIL OFFICES
PRIORY ROAD
SPALDING
LINCOLNSHIRE
PE11 2XE

UPDATE OF STRATEGIC FLOOD RISK ASSESSMENT

Residual Peak Depth
District - Year 2115
1% Fluvial / 0.5% Tidal Event Probability

DATE OF ISSUE: Feb 2017 **REV NO:** 2

SCALE: 1 : 60,000 @ A1

MAP NO: