	Model Ref/ Details	
	Model name:	**Wombwell Wetlands Modelling**
	Purpose:	**Flood risk modelling, wetland design**

Hydraulic roughness values used:

Manning's roughness is used in 1D models to account for a range of features such as channel roughness, vegetation, channel expansion and contraction and sinuosity. The 2009 model used a range of values to represent roughness in channel and on the floodplain. The values are as follows:

River Dove - floodplain (0.100 - 0.060) channel (0.058 - 0.040)

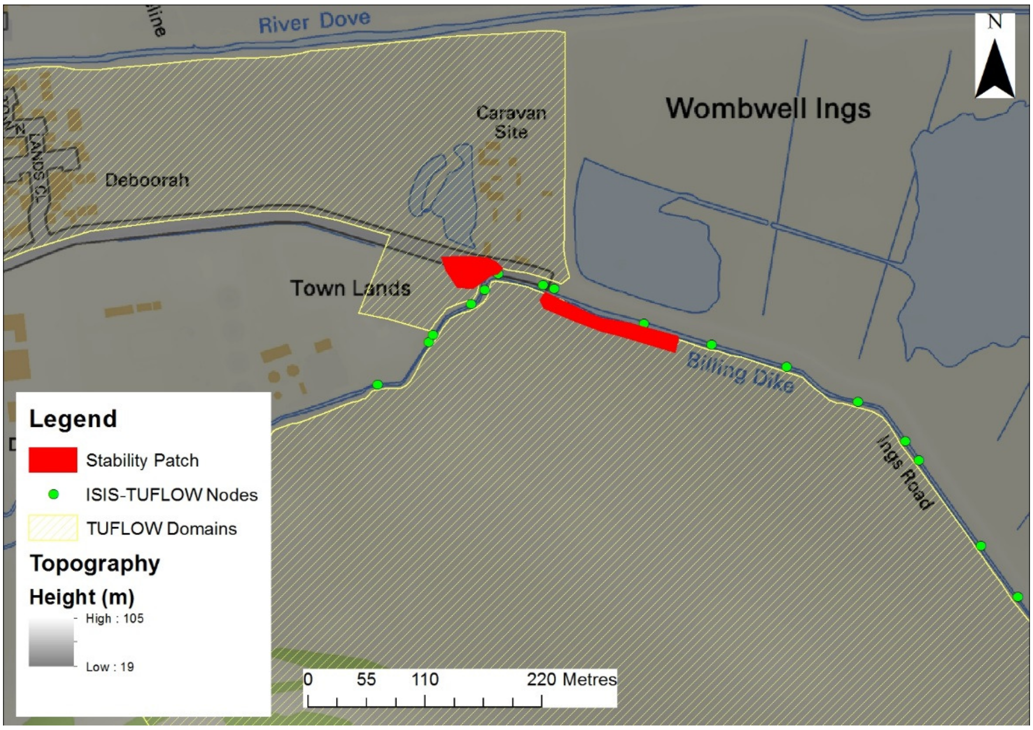
Bulling Dike - floodplain (0.075 - 0.060) channel (0.050 - 0.040)

These values are considered largely sensible and representative of the channel and floodplains of the study area and have therefore not been changed, apart from the reach of the river Dove between the new Pitt Bridge and Stoneyford Lane. Previously in channel roughness values in this reach were of the order of 0.055 to 0.058, which appeared high on the evidence of the site visit and survey undertaken for this study. Values of 0.040 were used for this reach.

2D Manning's n	Comment / Example
0.300	Formal buildings
0.050	General Arable farmland
0.070	Rough pasture and grazing
0.020	Roads and Hardstanding
0.100	Stability patch

In the existing situation model, a stability patch was used in two areas.

- Along the right hand bank of Bulling Dike where water is transferred between Bulling Dike and the floodplain.
- An isolated spot on the left hand bank of the Bulling Dike where a small surface water ditch enters the Dike, the relatively steep changes in levels causes some mass balance instability, which is eased by the patch.

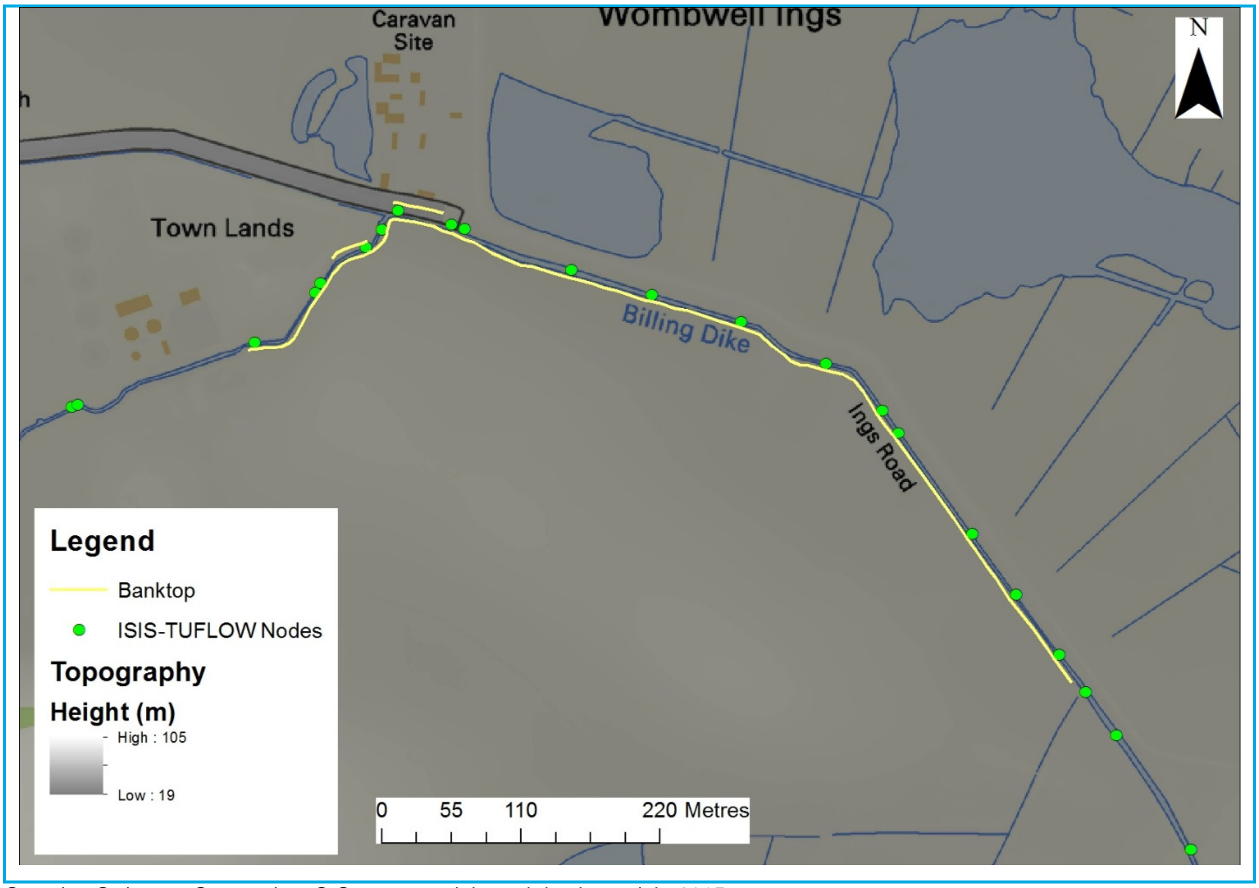


4.2 2D Topographic modifications

Only one modification was made to the 2D domain in the existing situation run (Figure 4-1).

- Bank heights stamped on in certain areas to improve representation of water transfer between the two domains (**2d_zline_BUL_banktop**). The heights used in this analysis were from the JBA survey in 2015. The ditch that runs parallel to the road, and enters Bulling Dike at the apex of the right hand bend, was not surveyed in the bank top survey and so the LIDAR levels were used to control water leaving the 1D domain in this location. Not surveying bed levels of the ditch is considered acceptable because during a flood event, the ditch is likely to contain water and so the LIDAR levels (which can't sample below water) are considered reasonable for use.

Figure 4-1: Existing situation z lines



5. Structures

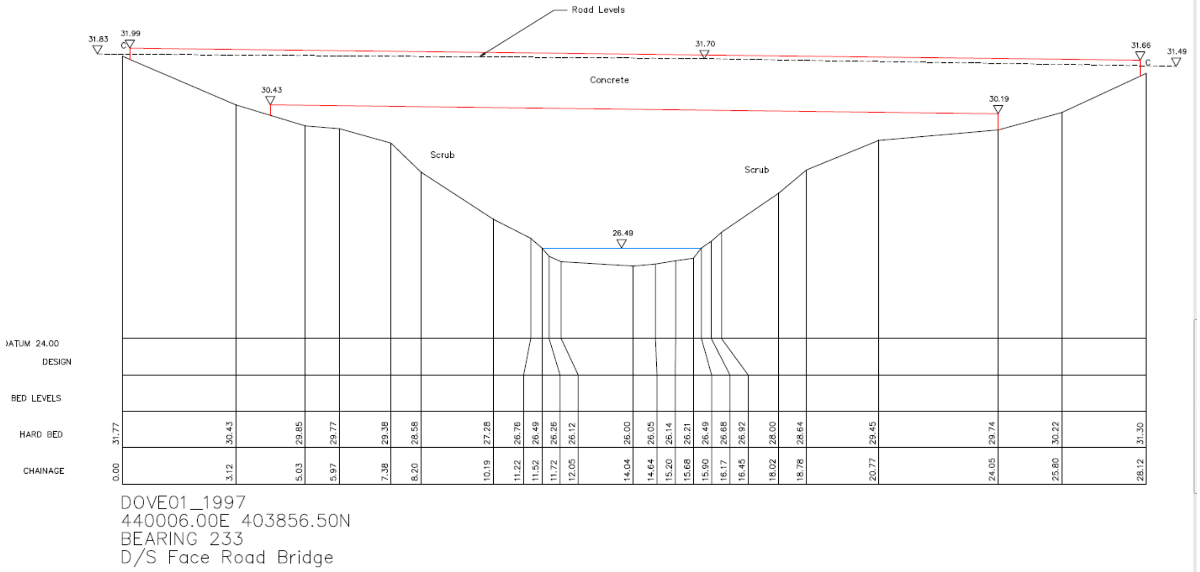
5.1 General procedures for all structures

This section highlights changes to structures made to the 2009 model for the purpose of this study. Where check survey has been undertaken, comparisons will also be made between the 2009 representation and the new survey and any changes to the model will be highlighted,

5.2 New structures

Since the 2009 study, the Pitt Bridge on the River Dove has been replaced with a new bridge (see section 3 of the modelling report).

Name of structure:	New Pitt Bridge (Littlefield Lane)
Location (NGR):	440006 403856
Included in model (state reason if not):	Yes
Model label:	DOVE01_2006u
Type:	USBPR Bridge unit
Additional Information:	-
How has structure been modelled?:	Modelled as a USBPR unit due to flat soffit. Spill over the structure modelled using an inline spill unit.



Name of structure:	New Pitt Bridge (Littlefield Lane)
	

5.3 Check survey comparison

Check survey was undertaken on one structure on the River Dove and two on Bulling Dike. The comparisons between the 2009 model and 2015 survey are outlined below.

DOVE01_1340 Upstream Face	The upstream face of Stonyford Road Bridge on the River Dove, was represented in the 2009 model with an invert of 23.97mAOD, a width of 4.1m, height to springing of 1.40m, and height of crown of 1.33m. The JBA 2015 survey has a surveyed invert level of 23.96mAODm. The width and height to soffit and crown also compare well to the surveyed data, although as the culvert is not uniform, exact comparisons are impossible to make, but the dimensions used in the 2009 model are reasonable. 
BUL01_3064u Upstream Face	In the 2009 model, this structure was modelled using a USBPR bridge unit, with a width of 2.80m and soffit level of 24.84mAOD. The bed level of the upstream section was 23.37mAOD. Below photo taken in 2009.

	 Section BUL01_3088.894 In the 2015 survey, the hard bed level was 23.38mAOD, and a similar width, however the soffit level was surveyed at 24.98mAOD. The soffit level has been adjusted to this level in the current model. Below photo taken in 2015. 
BUL01_2785u Upstream Face	In the 2009 model this culvert was modelled using a symmetrical conduit unit with a low flow 'slot' to improve model stability. The 'true' invert at the upstream face of the culvert is 23.82mAOD, with the invert of the narrow slot set at 23.46mAOD. The soffit of the culvert is 24.76mAOD, with a width of 2.4m. Photograph below taken in 2008.

Section BUL01_2809.304

Similar levels were recorded in the 2015 survey (photograph below).

6. Model modifications for scenario runs

6.1 Summary of proposed scheme

The proposed restoration comprises of two key elements:

1. The redirection of Bulling Dike away from the caravan park by moving the dike across the floodplain away from the dogleg and adding a bund on the left hand bank of the Dike.
2. The creation of a reedbed and wet grassland on the right hand floodplain of Bulling Dike.

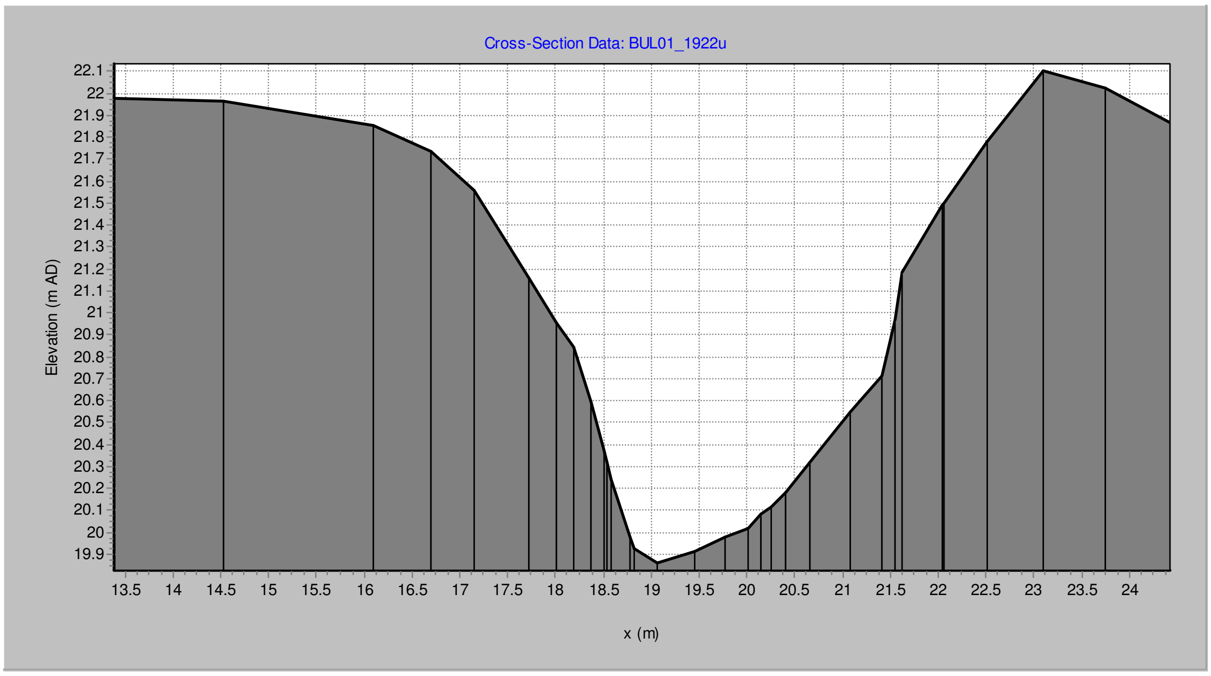
The detailed design drawings are in Appendix B. From a flood risk perspective, the key mechanism, which inundates the caravan Site, is the overtopping of Bulling Dike near the dogleg, which forces water on to the Caravan Site and surrounding land. By filling in the existing course of Bulling Dike and redirecting the Dike away from the Caravan Site, it is hoped to mitigate against that flood risk mechanism. Lowering floodplain levels to create the reedbed and wet grassland, will increase storage on the floodplain, but is thought to be a secondary mechanism.

A suitably sized flapped culvert will be used to move water from the surface water ditch on the caravan site side of the bund back into Bulling Dike.

6.2 1D modifications

Figure 6-1 shows that in the proposed situation, Bulling Dike is redirected away from the dog-leg and the Caravan Site. Channel cross sections for the reach were interpolated using HEC-RAS from neighbouring sections (2106 and 1833) and channel chainage adjusted to match the new channel length (Figure 6-1).

Figure 6-1: Cross section of new Bulling Dike Reach

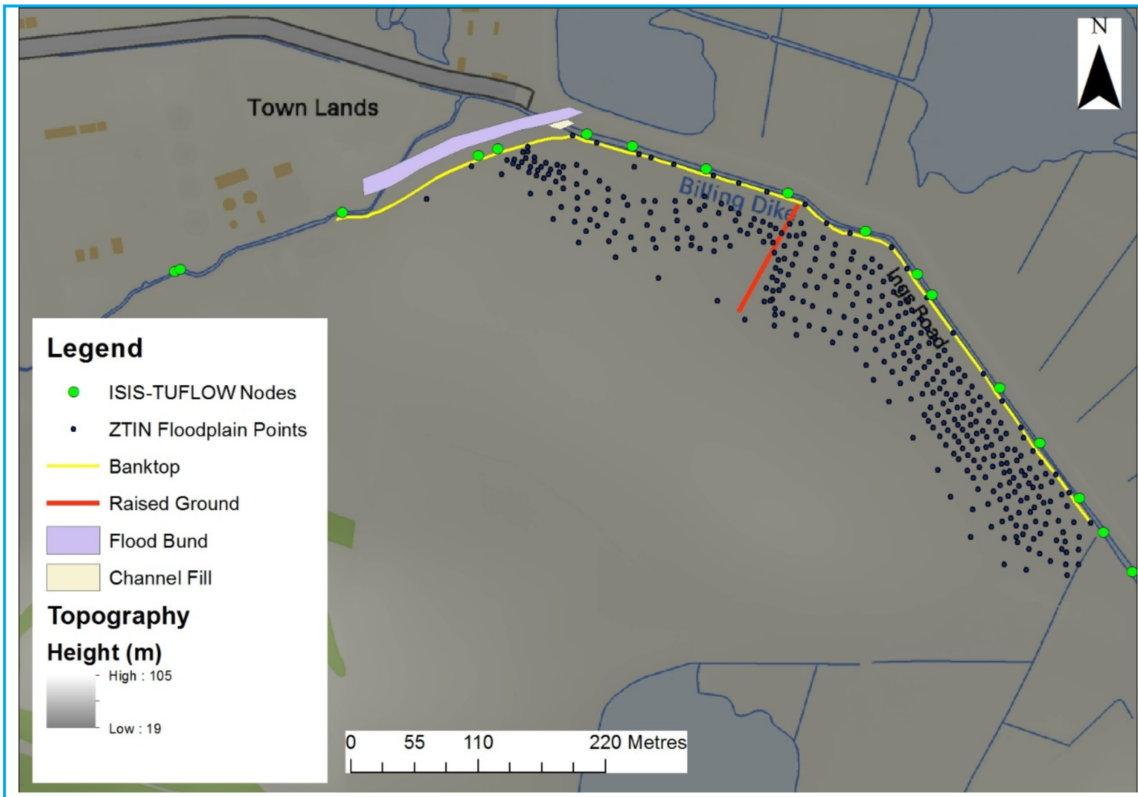


6.3 2D modifications

A number of 2D topographic modifications were required in the post-change scenario (Figure 6-2):

- Banktop levels were again defined using a z line (minimal changes were made to right hand bank-top levels in the post-change scenario) – **2d_zline_BUL_banktop_POST**.
- A z tin was used to define the modified floodplain levels which form the proposed wetland (**2d_ztin_Floodplain_POST**).
- A z line representing raised ground between the reed bed area and the shallow wet grassland area (for more information see the main report) – **2d_zline_BUL_Raised_ground**.
- The proposed flood bund was modelled using a z shape file (**2d_zshp_BUL_BUND**).
- A small area of the existing channel, which subsequently formed a backwater, was infilled to improve model stability (**2d_zshp_fill_channel**).

Figure 6-2: Post change model schematisation



It is not possible to model the full detail of the proposed wetland scheme in the hydraulic model, therefore, some simplifications were made:

Intake sluice	A sluice or tilting weir is proposed to control the flow split between Bulling Dike and the reed bed. It is assumed that in a flood event that the sluice will be opened to make best use of floodplain storage and so rather than a sluice gate this structure is modelled by lowering bank levels.
Raised ground – 'Saddle'	The raised ground between the reed bed and the shallow wet grassland will have a low spot or 'saddle' to allow water to pass into the shallow grassland from the reed bed once water reaches a particular level in the reed bed. This level of this saddle is proposed to be 21.2mAOD. This has been modelled as lower points in the z line that delineates the raised ground.
Outflow	The wet grassland will flow out into the existing ditch to the south east. This drainage ditch has not been explicitly modelled using in the model but is included in the 2D domain as by virtue of being sampled in the LIDAR. In the post-change scenario, water is allowed to return to that ditch in the 2D domain as represented in the pre-change model.

Flood Bund	The bund links into high ground upstream of the site and into the existing Wombwell Ings embankment. Currently modelled as a high block at 25mAOD to act as a glass wall to determine water levels in Bulling Dike at a range of return periods to guide the design of the bund.

7. Sensitivity testing

The table below details the sensitivity analysis undertaken. Sensitivity tests were carried out on the baseline model for the 100-year return period event.

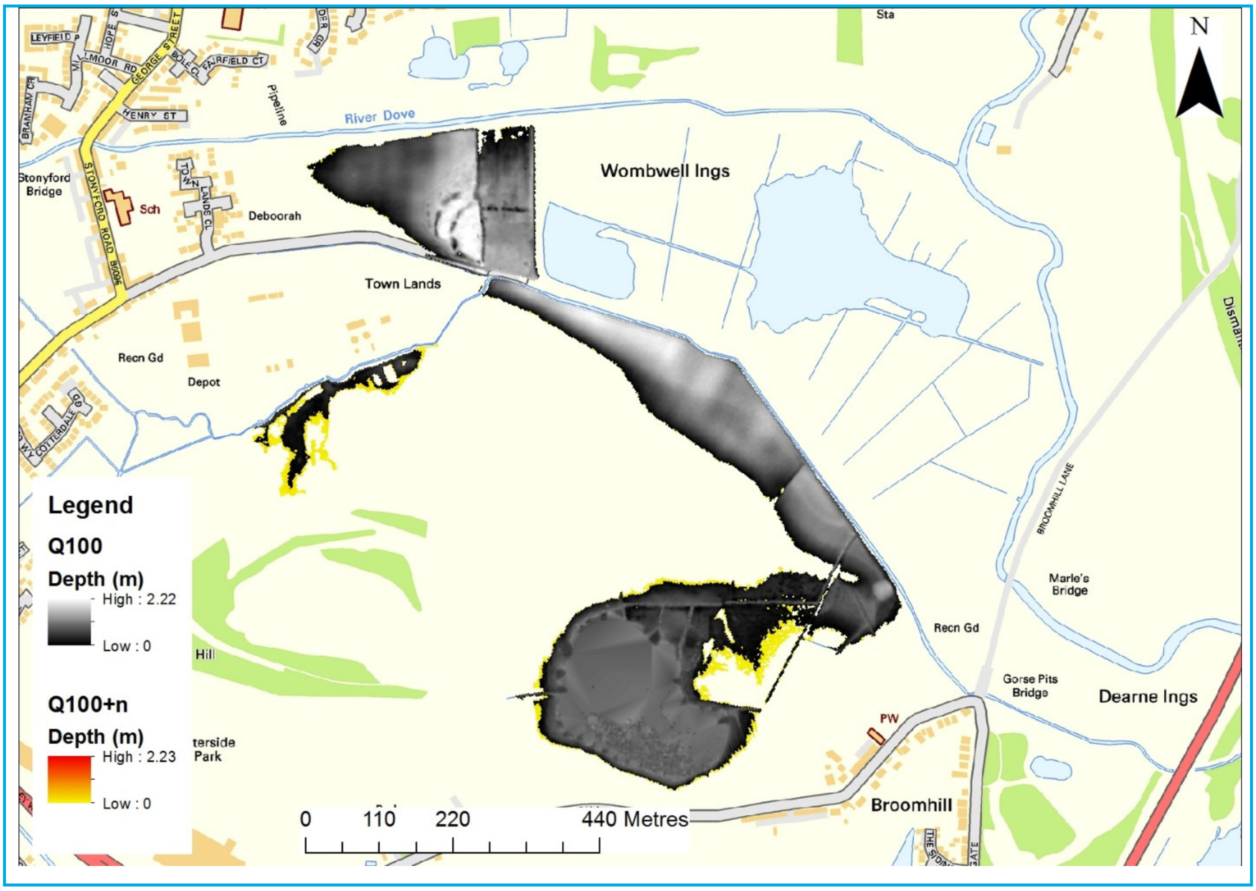
Parameter	Variance
Flow rates	Flow rates were varied to include an allowance for climate change
Manning's n roughness coefficients	+/- 20% in both the channel and the floodplain. This includes culvert roughness.
Downstream boundaries	Increasing and decreasing the inflow into the Dearne by 20% and changing the timing of the inflow of the Dearne.

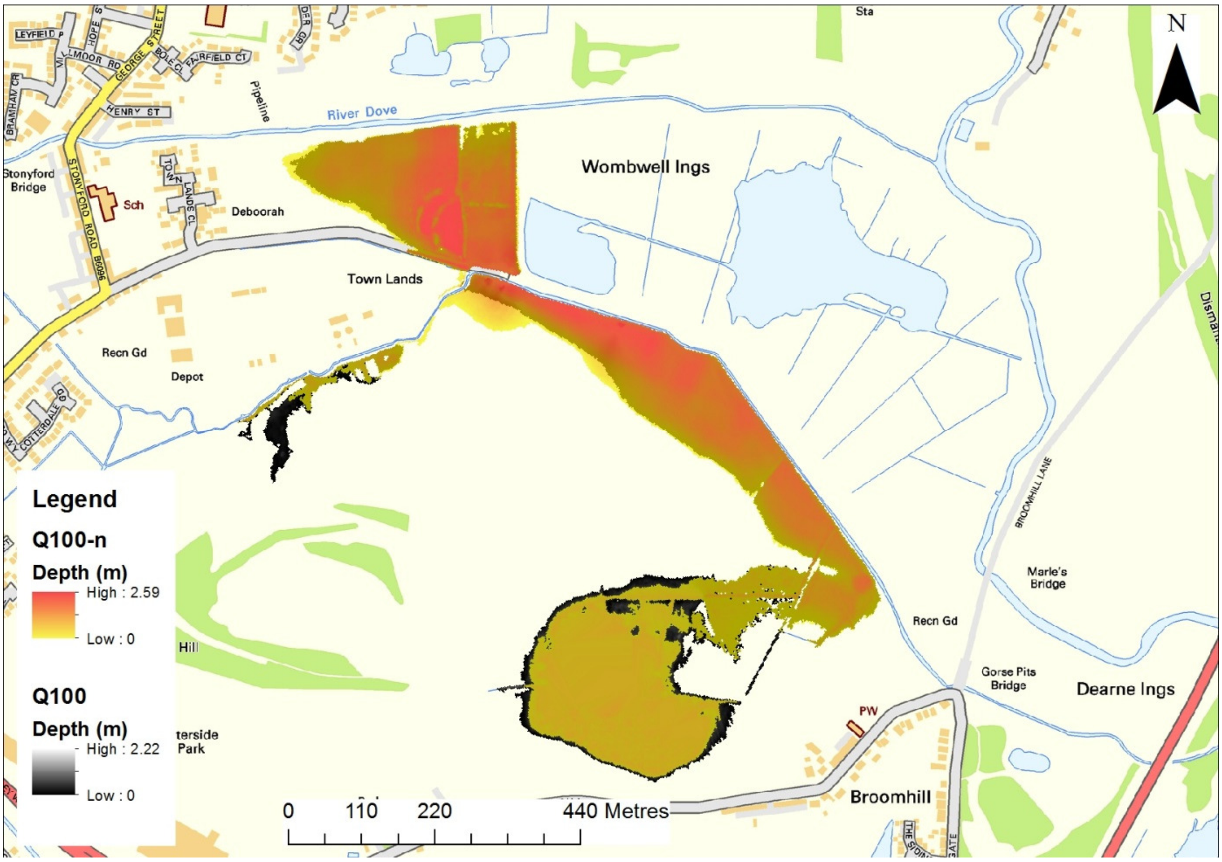
Increasing Manning's roughness by 20% (i.e. a Manning's value of 0.040 is increased to 0.048) led to an increase in flood extent (**Error! Reference source not found.**) in all areas of the 2D domain. This is likely to be due to the increased roughness leading to higher water levels for a given flow in the 1D model, hence increasing the volumes of water being exchanged onto the 2D domain.

Error! Reference source not found. also shows that a decrease in Manning's roughness by 20% leads to a slight decrease in the modelled outline in most areas (apart from on a small area on the right hand floodplain opposite the caravan site). This will be a result of the lower Manning's in the 1D model leading to a lower stage per given flow.

Changing the Manning's roughness values led to no change in the number of properties inundated in the study area.

Figure 7 1: Manning's roughness sensitivity results





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The downstream boundary at the bottom Bulling Dike and the River Dove is formed by water levels in the River Dearne, a small stretch of which is also modelled. The inflow to this stretch of the Dearne was the 100-year flood event. In the design scenario, the flood event on Bulling Dike is timed to occur early and on the rising limb of this hydrograph. As a first sensitivity test, the modelled inflows to the Dearne were increased and decreased by 20% (akin to increasing baseflows).

Lowering the downstream water level (i.e. water levels in the Dearne) leads to a slight decrease in the flood extent around Broomhill Flash (Figure 7-2). Increasing water levels in the Dearne led to no changes in modelled water levels.

Figure 7 2: Downstream boundary sensitivity results

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A further test was undertaken by revising the timing of the Dearne inflow hydrograph, much closer to the peak of the flood event in Bulling Dike. An exact correspondence of the flood peaks in Bulling Dike and the Dearne is unlikely due to the very different catchment characteristics of the two rivers. The difference in water levels between the design scenario and the scenario with revised timings is shown in Figure 7-3, which shows that with the revised timings, the water levels at the confluence increase by around 0.55m.

Figure 7-4 shows that near the Caravan site, the peak modelled water level remains the same under both downstream boundary conditions, however, the wetland takes longer to drain under the higher downstream boundary conditions. This analysis shows, that even under an extreme and unlikely scenario, water levels in the Dearne do not greatly impact upon water levels in Bulling Dike.

Figure 7 3: Modelled water levels at the confluence between Bulling Dike and Dearne

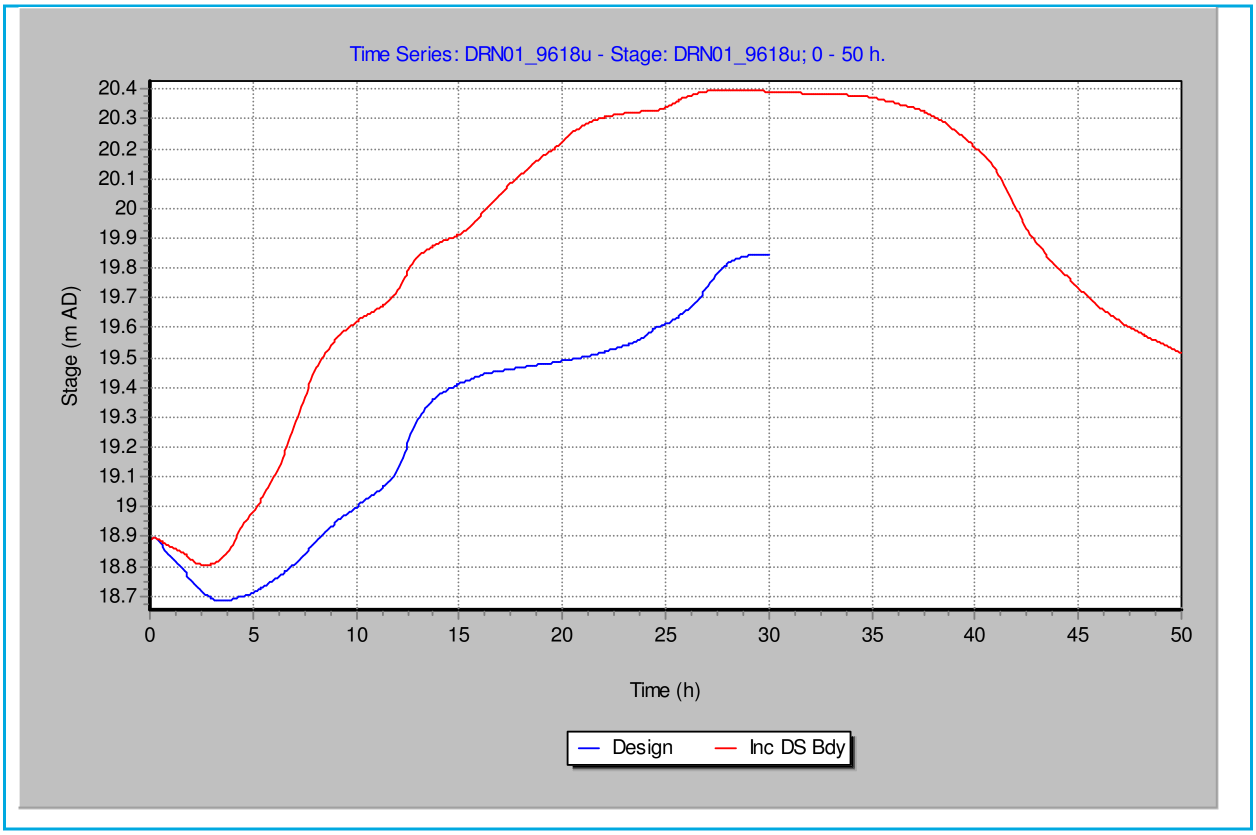

Figure 7 4: Modelled water levels at the confluence between Bulling Dike and Dearne