	study, however, it will provide limited information on local flow patterns or inundation depths on the floodplain.
Manning's Roughness	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 existing model uses 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 - 0.055)** **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. In-channel roughness values of 0.55 are used in the Dove upstream of Stoneyford Bridge. Compared to site observations, these values seem high.
Timestep	The model runs using a minimum timestep of 1.5 seconds - this is low for a 1D only model but reasonable and given the complexity of the system.
Catchment Changes	The main changes identified from discussions with Jeff Lunn (Garganey Trust), Derek Bell (BMBC) and from what was observed during the site visit (30 January 2015) in the catchment area as follows: • River Dove - Pit Bridge (Littlefield Lane). Old bridge removed and replaced with a flat deck concrete bridge with no abutments in the channel. • River Dove - The Stonyford Bridge "dogleg". Gabion baskets filled with large aggregate added along the right bank immediately upstream of the Stonyford Bridge "dogleg". Narrows the channel and increases the right bank crest level by approximately 250 - 300mm.
Fit for purpose?	The existing model does not represent the changes that are listed above. The changes along the River Dove may directly affect the flooding mechanisms within Bulling Dike due to the linked relationship between the two watercourses. In the existing model Bulling Dike receives flood waters from the River Dove via right bank overtopping that travels south as overland flow. It is fair to assume that the changes to the River Dove would decrease the volume of linked floodwater. Replacing the dilapidated Pitt Bridge would reduce the potential for right bank overtopping. This bridge previously had abutments and an arch shape that constricted the channel and was a known source of flooding, causing overtopping that contributed to the Bulling Dike's flow volume during the June 2007 event. Increasing the right bank crest level upstream of the Stonyford Bridge "dogleg" may provide some protection to the right bank, possibly reducing overtopping of the bank at this location.

2.3 Proposed changes

As highlighted in section 3.4.2 the reach, which includes the proposed wetland, is modelled using extended ISIS sections, with three sections only in the reach of interest. In order to better understand the potential inundation areas and depths of the proposed scheme, it is proposed to convert a small area of the model, (which covers the site area), into a linked 1D-2D model using ISIS-TUFLOW.

Most of the flooding mechanisms identified in the 2007 event are still relevant today. However, from discussions with Derek Bell at BMBC (Barnsley Metropolitan Borough Council) and from visiting the site (30 January 2015) it was established that some revisions and updates are required to the wider catchment model. These are listed below:

- River Dove - Pit Bridge (Littlefield Lane). Pit Bridge at this location has been replaced. The new bridge comprises of a flat concrete deck with no abutments, which encroaches in to the channel. Representing the new structure in the model will improve the representation of any overtopping of the right bank at the previously dilapidated Pit Bridge on Littlefield Lane.
- River Dove - The Stonyford Bridge "dogleg". Since the 2009 JBA 1D ISIS model and pre-feasibility study, gabion baskets filled with large aggregate have been added along the right bank immediately

upstream of the Stonyford Bridge "dogleg". The gabion baskets, (installed between 2009 to 2010), provide protection from scour and have raised the right bank crest level by 250 - 300mm. Updating the model to include the raised bank levels would provide and better understanding of the current flood mechanisms.

3. Modelling approach

3.1 Modelling rationale

The Do-minimum (i.e. baseline model) from the 2009 study was used as the basis for this study, as that model is the best available representation of the system. Further survey has been commissioned in a number of places to improve the detail in the model, and to provide checks on the dimensions of the structures in the 2009 model. The combination of using the best available catchment wide model, combined with site specific survey to improve detail in and around the areas of interest will lead to a model fit for purpose in understanding the flood risk benefits of the proposed wetland.

3.2 Available data

Item	Comments
Cross-section survey:	Cross section survey data associated with the 2009 flood mapping model. Site specific survey data was collected by JBA in 2015 which included, 1. Key structures and features were surveyed where levels may have changed since the previous modelling (e.g. the Pit Bridge and the right hand bank upstream of Stoneyford bridge where gabions have been introduced. 2. A topographical survey was carried out in the vicinity of the proposed wetland site in order to provide further detail. The survey at this location covered both bank top crest levels and general ground levels within the site. 3. Check survey at four structures.  Contains Ordnance Survey data. Crown copyright 2015.
LIDAR & other Topographic Data:	1m resolution LIDAR was supplied by EA Geomatics. The LIDAR was flown in December 2014 and processed before the filtered and unfiltered datasets were supplied to JBA Consulting in August 2015. Spot levels (as above).
Map Data:	Master Map data were provided by the Environment Agency for the study area.

Gauging station flows /levels:	No gauged data were available in the catchment.
Gauging station rating curves:	There were no available gauging station rating curves in the model reach.

3.3 Model build-up

Item	Notes	Comments
What software & reason for choice:	ISIS-TUFLOW Linked 1D/2D Model.	ISIS is used to represent the river channel and hydraulic structures in the study area. This links dynamically with TUFLOW for some areas of the model. The double precision version of TUFLOW has been used as predicted water depths can be very low.
Grid size selection:	Outline the reasons behind selection of grid sizes for the 2D domain	The model domain has been defined to include the 1,000-year extent from the previous study. A grid size of 2m was used as the size of the TUFLOW domains is relatively small given the localised nature of the 2D domains.
Coefficients:	State documentary sources.	Manning's n values are based on industry standard documentation [Chow (1959), Hicks & Mason (1998), HEC-RAS Reference Manual (January 2010)].
Model Proving:	Outline the test to be applied with the reason, the target accuracy and method of calculation	*Sensitivity:* The model was tested for sensitivity to the following parameters in the 100-year run: • Model Inflows (by including an allowance for climate change) • Manning's n roughness ±20% • Downstream boundary (by increasing and decreasing flows in the Dearne by 20%)
Any limitations in the method of modelling used:	E.g. If model is used for other flow rates would it require modification?	Since there is also no flow gauging in the catchment, the confidence bounds on flow estimates used in this model are wide. Further limitations are detailed in the Main Report and FEH check file.

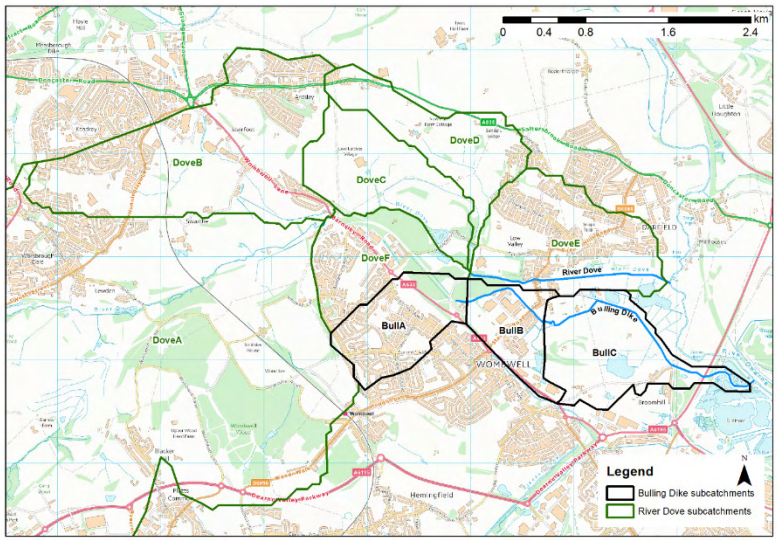
4. Overview

This section summarises the schematisation of the model.

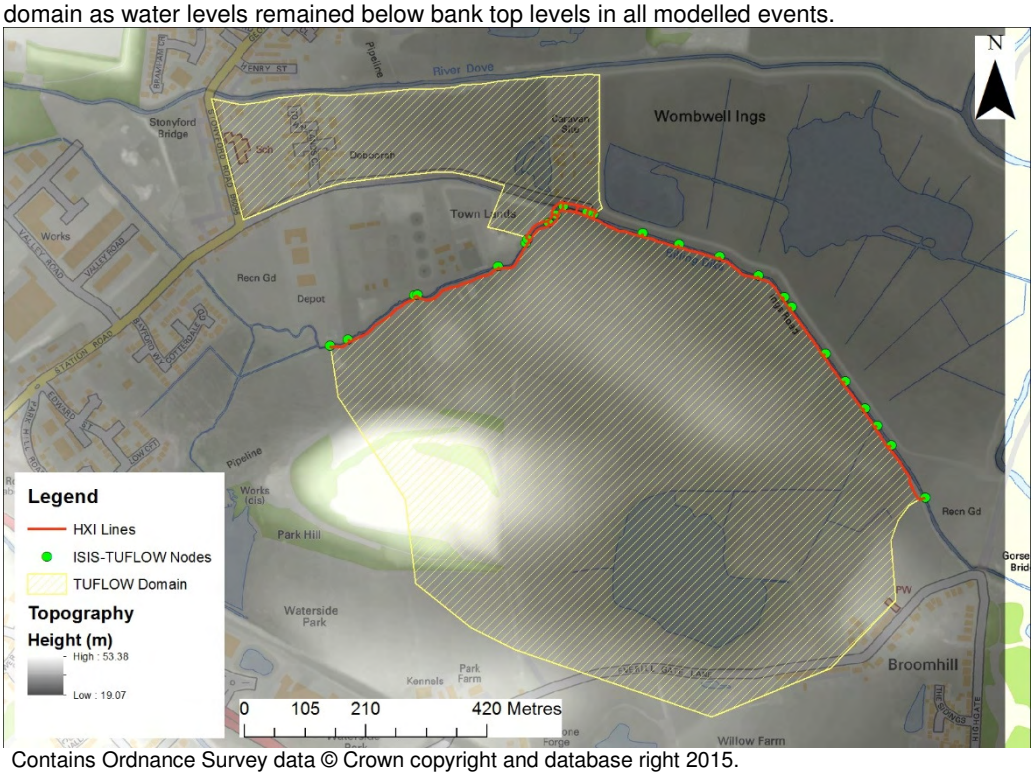
4.1 Overview of models

<table>
<tr><th rowspan="3"></th><th colspan="2">Model Ref/ Details</th></tr>
<tr><th>Model name:</th><th>Wombwell Wetlands Modelling</th></tr>
<tr><th>Purpose:</th><th>Flood risk modelling, wetland design</th></tr>
<tr><td>Inflow Boundaries:</td><td></td><td>All inflows to the model are flow-time hydrographs, applied to the 1D domain using an ISIS 1D QT model boundary. Inflows were derived using Urban ReFH method.

There are two flow-time boundaries which correspond to inflows at the top of the River Dove and Bulling Dike, and lateral inflows along the length of each watercourse to account for diffuse inputs to the watercourse.

<table>
<tr><th>Site code</th><th>Type of estimate
L: lumped catchment
S: Sub-catchment</th><th>Watercourse</th><th>Name or description of site</th></tr>
<tr><td>BullA</td><td>S</td><td>Bulling Dike</td><td>Littlefield Lane, Wombwell</td></tr>
<tr><td>BullB</td><td>S</td><td>Bulling Dike</td><td>D/s of Cotterdale Gardens off B6096 Station Road, Wombwell</td></tr>
<tr><td>BullC</td><td>S</td><td>Bulling Dike</td><td>River Dearne confluence</td></tr>
<tr><td>DoveA</td><td>S</td><td>River Dove</td><td>Aldham Bridge, u/s of A633 Wombwell Lane.</td></tr>
<tr><td>DoveB</td><td>S</td><td>River Dove</td><td>Tributary joining River Dove at Aldham Bridge</td></tr>
<tr><td>DoveC</td><td>S</td><td>River Dove</td><td>Rural area north-east of A633 including Low Laithes</td></tr>
<tr><td>DoveD</td><td>S</td><td>River Dove</td><td>Tributary draining rural area west of Darfield north to A635</td></tr>
<tr><td>DoveE</td><td>S</td><td>River Dove</td><td>Urban area of Darfield to R.Dearne confluence</td></tr>
<tr><td>DoveF</td><td>S</td><td>River Dove</td><td>North-western part of Wombwell, off A633 Barnsley Road</td></tr>
</table>


Contains Ordnance Survey data © Crown copyright and database right 2015.</td></tr>
<tr><td>Outflow Boundary:</td><td>DRN01_6552</td><td>The downstream boundaries of the Dove and Bulling Dike are modelled by including a section of the Dearne model with an inflow scaled to the return period of interest. This ensures that the water levels at the downstream boundary of Bulling Dike and the River Dove are representative.</td></tr>
<tr><td>Length of Model (km):</td><td colspan="2">River Dove: Total Length is 3,722m.
Bulling Dike: Total Length is 3,512m.</td></tr>
<tr><td>Total Number of nodes and structures:</td><td colspan="2">401 1D nodes in the model, of which 143 are river units.
6 culverts and 15 bridges represented in the model.
1 weir and 3 loss units (representing trash screens).</td></tr>
</table>

	Model Ref/ Details	
	Model name:	**Wombwell Wetlands Modelling**
	Purpose:	**Flood risk modelling, wetland design**
	4 weirs modelled using inline spill units 1 general purpose weir.	
Model schematic:	The extent of the 1D ISIS model was unchanged compared to the 2009 model. Two key floodplain areas in the model were converted to ISIS-TUFLOW, the floodplain where the proposed wetland will be located and the area where the caravan site is situated. Care was taken to locate the boundaries of the 2D domains at locations where the water was in channel and so ensure a reasonable transition between the 1D and 2D domains. The remainder of the model was modelled using 1D extended sections and storage areas (unchnaged from the 2009 model). No change was made to the spills or storage areas in the 1D floodplain, as those elements are upstream of our area of interest, and their key function is to route water to the study area relating to this project, rather than detailed flood mapping study of that area. HXI lines are used to control water spilling from Bulling Dike into the 2D domain with bank levels defined by surveyed bank top levels. No links were required between the River Dove and the 2D domain as water levels remained below bank top levels in all modelled events.  Contains Ordnance Survey data © Crown copyright and database right 2015.	
Labelling/ Numbering System Used:	The cross sections used in the model were labelled in the format DOVE01_#### and BUL_####, where the prefix denotes either River Dove or Bulling Dike, and the four digit code corresponds to chainage number.	