Appendix B – Risk Assessment: Technical Details

Introduction

Capita Symonds constructed two hydraulic models to represent the study area using TUFLOW (**T**wo Dimensional **U**nsteady **F**low) software (www.tuflow.com – an industry standard hydraulic modelling package for pluvial flooding). Two models of the area were needed to optimise overall model run times and data processing.

The extents of the two models have been based upon catchment boundaries to limit the amount of cross-boundary interaction between the two models. Figure 1 illustrates the extent of the study area and the hydraulic model models. Table 1 indicates the naming convention applied during the modelling process. Abbreviations used and conventions applied are:

- KL – Lyng's Lynn SWMP Model
- KLN – King's Lynn;
- HCM – Heacham;
- DMK – Downham Market;
- SNM – Snettisham
- xxxYR – Rainfall event probability
- 0xx – Version numbers.

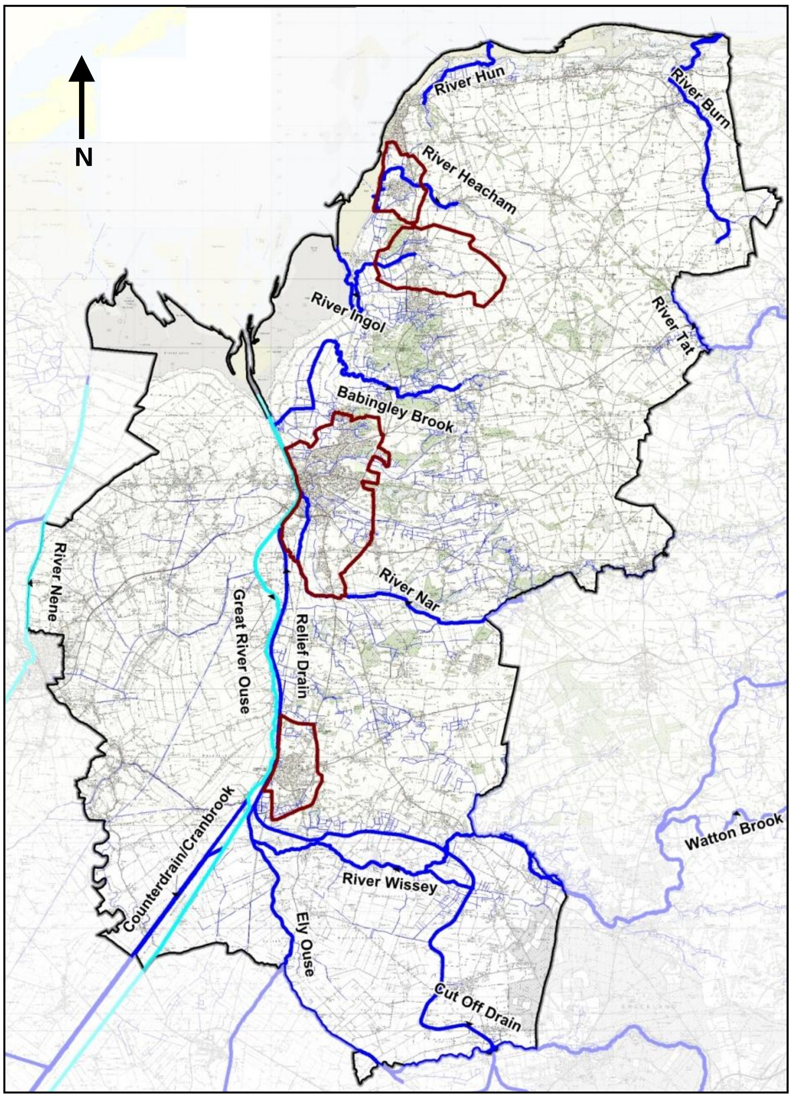


Figure 1: Model Coverage

Table 1: Model Naming Convention

Model Name	Naming Convention (100 year Flood Event example)
King's Lynn	KL_KLN_0100R_016
Heacham	KL_HCM_0100R_014
Downham Market	KL_DMK_0100R_012
Snettisham	KL_SNM_0100R_017

Software Version

All models have been run using TUFLOW build 2010-10-AA-iDP software. All models were run on the 64bit version of this build to take advantage of the faster simulation times and more advanced handling of larger models.

Direct Rainfall Methodology

The purpose of this modelling task is to analyse the impact of significant rainfall events across the study area by assessing flow paths, velocities and catchment response. This method essentially consists of building a virtual representation of the ground topography, then applying water to the surface and using a computational algorithm to determine the direction, depth and velocity of the resulting flows. Further explanation of this industry standard method is available in the Defra SWMP Guidance – Annexes C and D.

Key Assumptions

This method incorporates conservative allowances for the drainage network and infiltration. The following key assumptions were made to generate the model input:

- Initial Loss – None
- Infiltration Loss – None
- Allowance for Drainage System – 0mm/hr for King's Lynn and a constant 3mm/hr for Heacham, Downham Market and Snettisham
- No aerial reduction factor applied
- 'Summer' rainfall profile was used

Runoff Coefficients and Continuous Losses

Runoff Coefficients and continuous losses have been applied to the rainfall profiles as per the table below.

Table 2: Runoff Coefficients and Losses

Feature Code	Descriptive Group	Comment	Runoff Coefficients	Drainage - Continuous Loss (mm/hr) Excluding King's Lynn
10021	Building		0.9	3
10053	General Surface	Residential yards	0.5	3
10054	General Surface	Step	0.8	3
10056	General Surface	Grass, parkland	0.35	0
10062	Building	Glasshouse	0.95	3
10076	Land; Heritage And Antiquities		0.85	3
10089	Water	Inland	1	0
10111	Natural Environment (Coniferous/NonConiferous Trees)	Heavy woodland and forest	0.2	0

Feature Code	Descriptive Group	Comment	Runoff Coefficients	Drainage - Continuous Loss (mm/hr) Excluding King's Lynn
10119	Roads Tracks And Paths	manmade	0.85	3
10123	Roads Tracks And Paths	tarmac or dirt tracks	0.75	3
10167	Rail		0.35	3
10172	Roads Tracks And Paths	Tarmac	0.85	3
10183	Roads Tracks And Paths (roadside)	Pavement	0.85	3
10185	Structures	Roadside structure	0.9	3
10187	Structures	Generally on top of buildings	0.9	3
10203	Water	foreshore	1	0
10210	Water	tidal water	1	0
10217	Land (unclassified)	Industrial Yards, Car parks	0.85	3

Hydrology – Rainfall Events

Rainfall inputs were generated at a standard 10km grid square resolution. Hyetographs for the following rainfall events were generated:

- 1 in 30 year
- 1 in 75 year
- 1 in 100 year
- 1 in 100 year plus climate change (+30%)
- 1 in 200 year

Total rainfall depths at each 10km grid centroid for all required return periods were extracted from the FEH CD-ROM (v3) Depth Duration Frequency (DDF) model. A comparison between the peak rainfall depths in adjacent 10km grid squares was completed to confirm the suitability of the 10km grid resolution for modelling purposes. It was decided that the following points would be used to extract the rainfall information for the models:

- King's Lynn – NGR 561900 319650
- Heacham – NGR 566700 337950
- Downham Market – NGR 560500 304500
- Snettisham – NGR 567000 333000

Hydrology – Critical Duration

Critical duration is a complex issue when modelling large areas for surface water flood risk. The critical duration can change rapidly even within a small area, due to the topography, land use, size of the upstream catchment and nature of the drainage systems. The ideal approach would be to model a wide range of durations. However, this is not always practical or economic when modelling large areas using 2D models which have long simulation times – such as within this study

The standard FEH equation which approximates the critical duration provides a useful starting point for the determination of the critical storm duration. The Time to Concentration (tc) was also used to used to assess the critical duration and provide a range of durations that should be tested.

Two methods were used to calculate an estimate of the critical storm duration for the rainfall profiles used in the model. A summary of these methods is given below:

- The Bransby-Williams formula was used to derive the *time of concentration,* defined as the time taken for water to travel from the furthest point in the catchment to the catchment outfall, at which point the entire site is considered to be contributing runoff; and
- The Flood Estimation Handbook (FEH) equation for critical storm duration - the standard average annual rainfall (SAAR) value for each a catchment has been extracted from the FEH CD-ROM v3 and the Revitalised Flood Hydrograph method (ReFH) model has been used to derive the time to peak (Tp) from catchment descriptors.

Based on the results from the following critical storm durations were used within the direct rainfall models:

- Kings Lynn – 3.4 hours
- Downham Market – 1hour
- Snettisham – 1.4hours
- Heacham – 1.3hours

The catchment descriptors, from the centre of each catchment, were exported from the Flood Estimation Handbook (FEH) into the rainfall generator within Infoworks CS, which was used to derive rainfall hyetographs for a range of return periods. An example of the hyetograph used in the King's Lynn settlement model is located below in Figure 2.

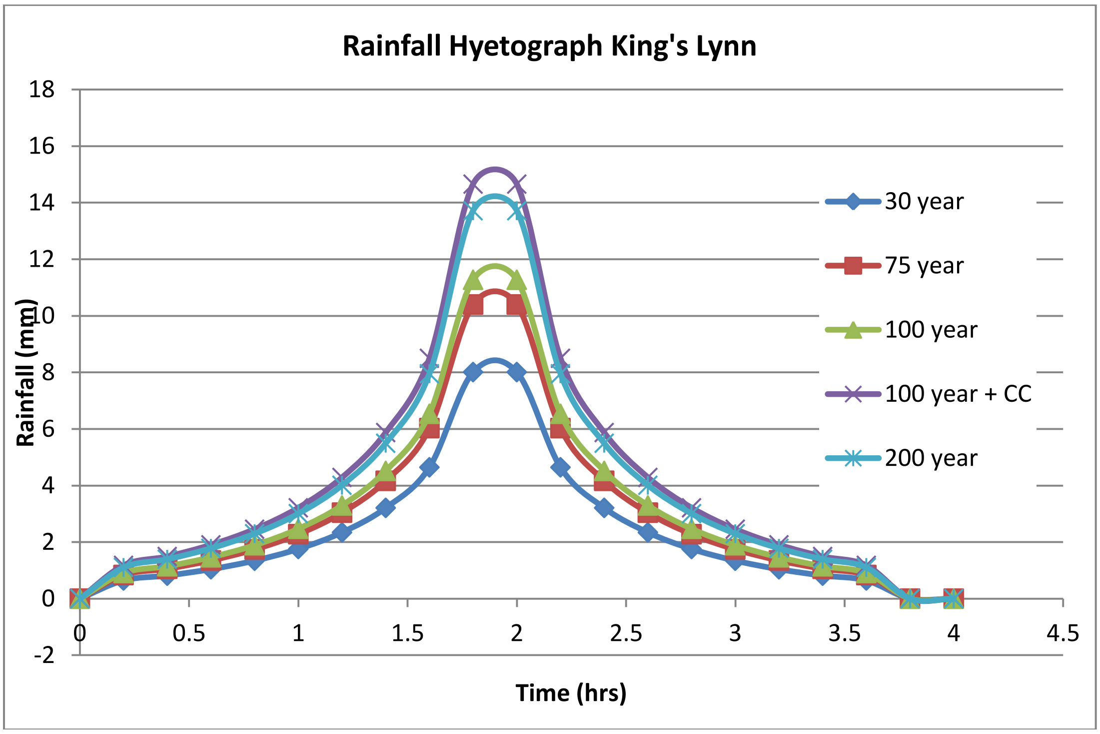


Figure 2. Hyetograph used in the King's Lynn Settlement Direct Rainfall Model

Grid Size

The models were constructed with a 5m grid size. This grid size was chosen as it represented a good balance between the degree of accuracy (i.e. ability to model overland flow paths along roads or around buildings) whilst maintaining reasonable model run ("simulation") times. For example, refining the grid size from a 5m grid to a 2m grid is likely to have a significant increase a model simulation time.

Topography

LiDAR data was available at a 1m resolution for the majority of the study area, and in the few small areas it was missing 2m resolution LiDAR. Where 2m LiDAR was not available, IFSAR was used (in particular the upper catchment of Snettisham) to assist in creating the DTM. Filtered LiDAR (and IFSAR) data (in preference to unfiltered) has been used as the base topography to provide the model with a smoother surface to reduce the potential instabilities in the model and areas of unexpected ponding.

Structures

Structures within the study area were modelled in 2D, an approach consistent with the strategic nature of this project. Structures modelled in 2D include those on watercourses and underpasses or culverts within the floodplain. The structures were modelled by using the ZSHP function in TUFLOW which allows the user to specify the object width representing the structure opening. Invert levels were determined by inspecting the LiDAR DTM (and aerial/site photograps) with widths of structures either observed on site visits, from Google Maps, or also derived from the LiDAR DTM.

Initially, a base hydraulic model was simulated without the structures to identify where structures should be included or not represented at all. Based on this output, the hydraulic model was then amended to better represent the key structures (large culverts, road underpasses etc).

Manning's Values

The following Manning's roughness coefficient values were used across both hydraulic models.

Feature Code	Descriptive Group	Comment	Mannings Roughness
10021	Building		0.500
10053	General Surface	Residential yards	0.040
10054	General Surface	Step	0.025
10056	General Surface	Grass, parkland	0.030
10062	Building	Glasshouse	0.500
10076	Land; Heritage And Antiquities		0.500
10089	Water	Inland	0.035
10111	Natural Environment (Coniferous/NonConiferous Trees)	Heavy woodland and forest	0.100
10119	Roads Tracks And Paths	manmade	0.020
10123	Roads Tracks And Paths	tarmac or dirt tracks	0.250
10167	Rail		0.050
10172	Roads Tracks And Paths	Tarmac	0.020
10183	Roads Tracks And Paths (roadside)	Pavement	0.020
10185	Structures	Roadside structure	0.030

Feature Code	Descriptive Group	Comment	Mannings Roughness
10187	Structures	Generally on top of buildings	0.500
10203	Water	foreshore	0.040
10210	Water	tidal water	0.035
10217	Land (unclassified)	Industrial Yards, Car parks	0.035
10096	Land, (Cultivation lands)	Dense vegetation, Cliff, Cultivation areas	0.100

Building Representation

In order to determine the influence raised building pads will have within the model, the following approach has been used for the representation of buildings in the models through the coding of the TUFLOW Materials File (*.tmf) file. The method is also described in Figure 3.

- A GIS layer containing the locations of all 'buildings' was created based on the buildings polygons in the OS Mastermap dataset;
- The LiDAR DTM was then interrogated to obtain an average 'bare earth' ground level for each building polygon.
- This average ground level was applied to the building polygons to give them their base elevation in the Tuflow model;
- The building polygons were then raised 100mm above their average 'bare earth' ground level to create stubby building pads (reflecting an average building threshold level). This ensures that the buildings form an obstruction to flood water and that shallow flows must pass round the buildings (and not flow through them).

A high Manning's n value (n = 0.5) was applied to the buildings to represent the high resistance that buildings have to flow. However, for very shallow depths of flow (up to 30mm) a lower Manning's n value (n = 0.015) ensure shallow flows did not incorrectly accumulate within the building footprint.

The TUFLOW model used is a direct rainfall model which applies a rainfall hyetograph to every active cell within the 2D model extent. This includes the cells representing buildings. The Manning's n value for buildings is reduced for these very shallow depths so that the flow which is created on buildings as a consequence of the application of direct rainfall is able to flow away from the building. If the Manning's n value was not reduced for these shallow depths, the rainfall applied to the building cells would pond here in an unrealistic manner.

The only exception to this method was in situations where the polygon representing the building was large or long. In these locations, the use of a single elevation to represent the floor level resulted in parts of the building being raised metres above the surrounding ground level.

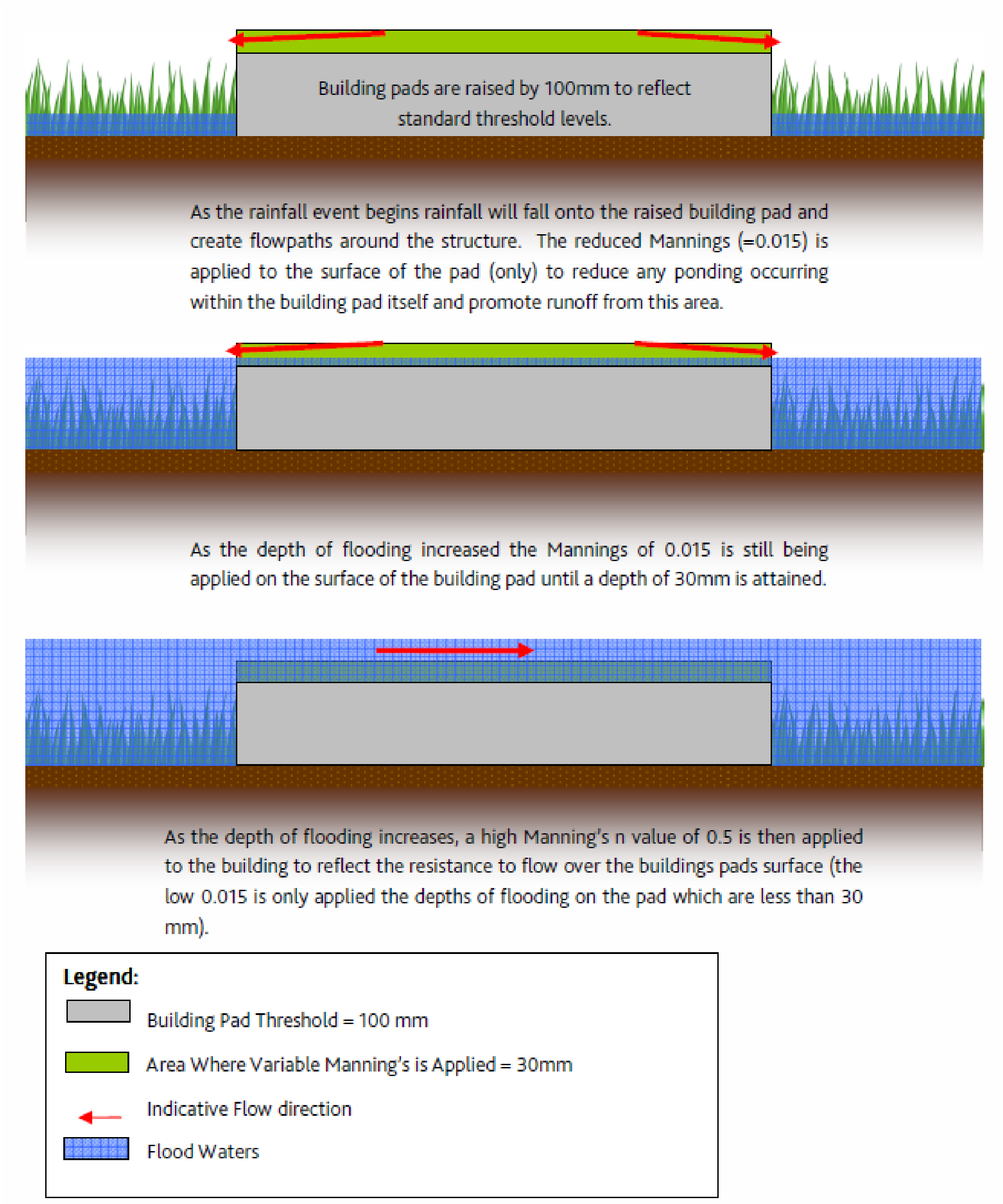


Figure 3 Building Pad Methodologies

Formal and Informal Defences

A GIS layer containing defences from the Environment Agency's NFCDD dataset was provided. These defences have been included in all models.

Model Boundaries

Downstream boundaries in the models were included where it was observed that water was able to flow outside of the model extent. The type of downstream boundary used was a flow vs. stage (level) relationship, or HQ boundary.

Simulation Time

The models were run for double the critical durations. The simulation times for each of the models are listed below in Table 4:

Table 4: Model simulation times

Model Name	Model Simulation Time (hrs)
Kings Lynn	6.8
Downham Market	2
Heacham1	2.6
Snettisham	2.8

Model Parameters

Time Step

The model was initially simulated with the 1 second time step. This resulted in the model reporting anomalous flood depths around steep topographic gradients, particularly around:

Other Tuflow Parameters

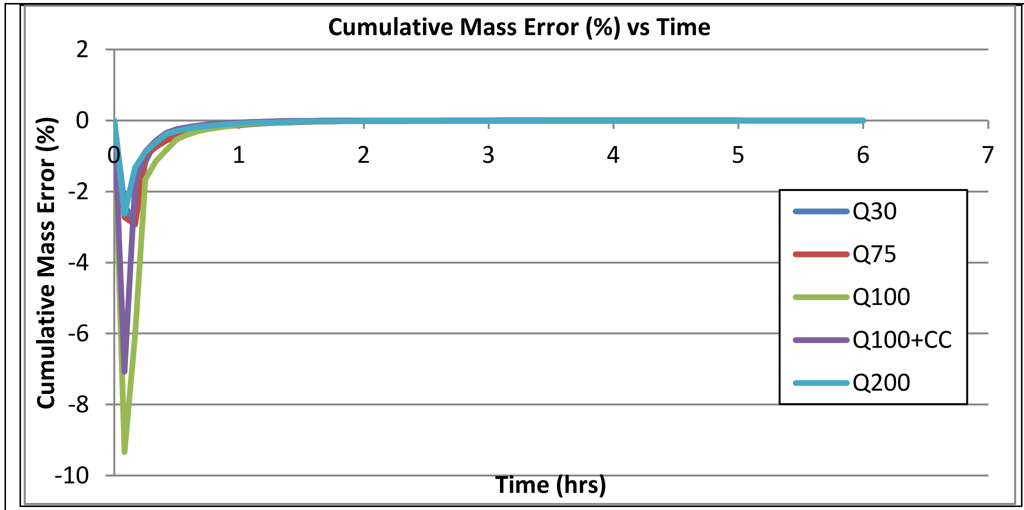
Table 2 describes other key Tuflow parameters that have been used in the study.

Table 2: Changes to Default TuFlow Parameters

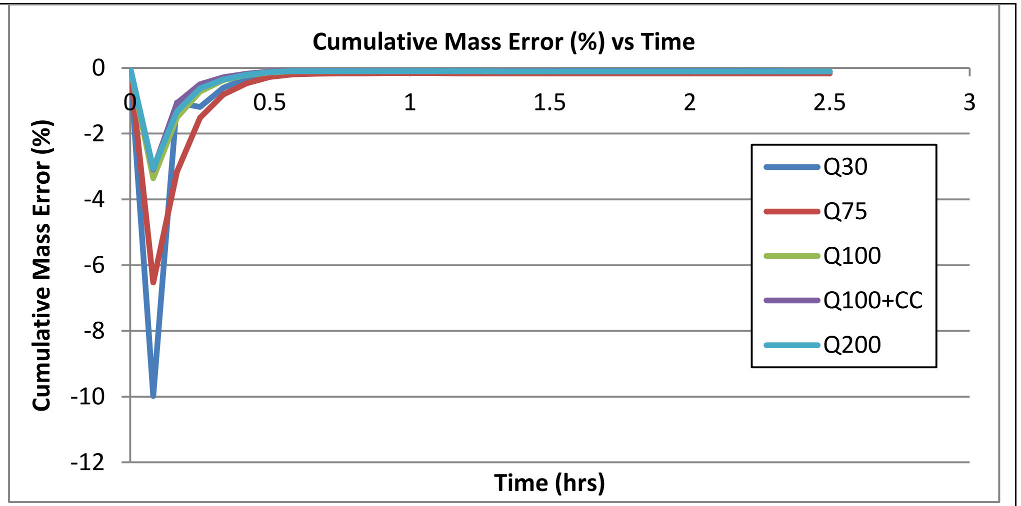
Parameter	Value
Cell Wet/Dry Depth	0.001m
Maximum Velocity Cut-off Depth	0m/s

Model Stability

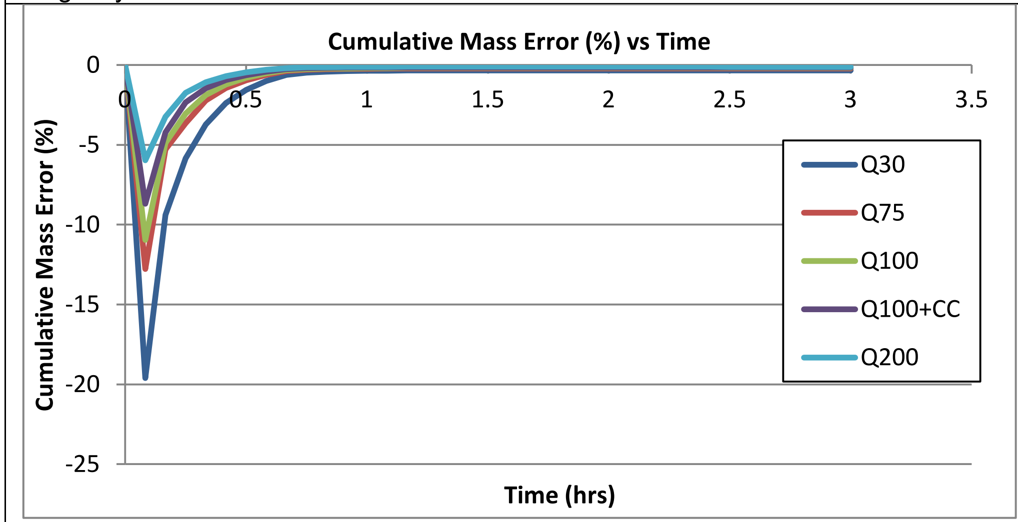
Assessing the stability of a model is a critical step in understanding the robustness of a model and its ability to simulate a flood event accurately. Stability in a TUFLOW model is assessed by examining the cumulative error (or mass balance) of the model as well as the warnings outputted by the model during the simulation. Figures 4 overleaf, illustrates the cumulative error of the models are within the recommended range of +/-1% throughout the simulation.



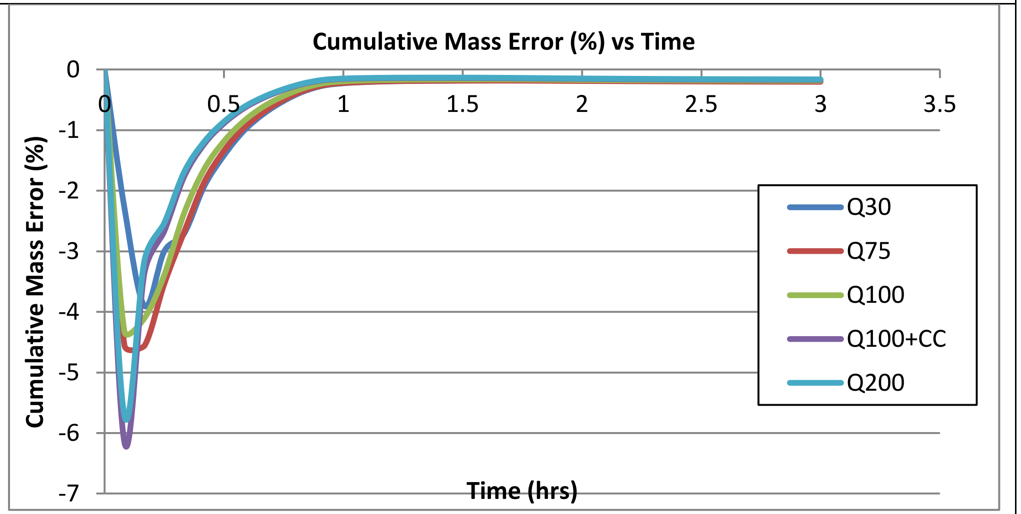
King's Lynn



Downham Market



Heacham



Snettisham

Figure 4: Mass Balance per Model

Conclusions and Recommendations

The hydraulic models constructed for Phase 2 of the Borough Council of King's Lynn and West Norfolk Surface Water Management Plan represents an 'intermediate' approach to identify areas at risk of surface water flooding. It represents a significant refinement on the previously available information on surface water flooding in the study area. Recommendations for future improvements to the models include (but are not limited) to the following:

- Explicitly model the existing drainage network in key areas of risk;
- Inclusion of survey data for critical structures;
- Inclusion of river flows and channel capacity (where applicable);
- Reduction in model grid size in key areas of risk;
- The use of better quality or more up to date topographic information particularly in areas of recent development
- It is recommended that the large ordinary watercourses (e.g. Gaywood River etc) undertake a separated 1d2d hydraulic model to determine the impacts from these watercourses (based on survey information and other sources of DTM) can be quantified throughout the affected settlements.