A63 Castle Street Improvements, Hull
Environmental Statement

Volume 3 Appendix 11.3

ROAD DRAINAGE AND THE WATER ENVIRONMENT – FLOOD RISK MODELLING TECHNICAL REPORT

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A63 Castle Street Improvements, Hull

Environmental Statement

Appendix 11.3 Flood risk modelling technical report

Revision Record

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Contents

1. Introduction

1.1.1 The Sweco-Mott MacDonald joint venture (MMSJV) was commissioned by Highways England to undertake the preliminary design assessment of the A63 Castle Street Improvements in Hull (referred to as “the Scheme”). This supplementary report to Volume 3 Appendix 11.2 Flood risk assessment (FRA) details the approach taken in the production of the hydraulic model.

2. Modelling approach

2.1 General approach overview

2.1.1 A hydraulic model was required in order to demonstrate the flood risk to the site and the surrounding areas, and the potential changes in flood flow paths in the area of the Scheme. A desk study was undertaken utilising results from the most recent flood models obtained from the Environment Agency (EA) and East Riding of Yorkshire Council (ERYC). The general modelling approach included:

- Review of the existing models and model selection
- Development of the baseline and proposed layout models
- Modelling scenarios

2.1.2 The model was used to simulate the agreed flooding scenarios (described in Section 3.4), under existing and proposed development conditions. The results were compared and analysed to determine the extent of flooding under different conditions (flood vulnerability of the Scheme), and the significance of the potential impacts. In addition, detailed analyses were undertaken to assess the potential changes to overland flow routes due to the construction of the Scheme.

2.2 Model review and selection

2.2.1 A review of the available hydraulic models developed for the area of Hull was performed and the different options were analysed. The models used in this study have been described in this section, and a summary of the available models has been presented in Table 2.1.

2.2.2 In 2010 Mott Macdonald was commissioned by the EA to undertake the River Humber North Bank Tidal Modelling Study[1] from Spurn Head, at the mouth of River Humber, to Goole. As part of this study, a two-dimensional (2D) hydrodynamic model was developed to improve the understanding of current and future flood risk from extreme tides and waves along the north bank of River Humber Estuary.

2.2.3 In 2014, the Humber North Bank Tidal Modelling Study was updated and re-run following the December 2013 tidal surge event which caused substantial defence overtopping on the north bank of the Humber. This provided updated design tide levels and overtopping hydrographs which incorporated the 2013 event. The results are referred to as the 2014 Interim Water Level Profile[2].

[1] Mott MacDonald (2011a). The River Humber, North Bank Tidal Modelling Study. Main Report for the Environment Agency. December 2011

[2] Environment Agency (2014). Humber Estuary 2014 Interim Water Level Profile

2.2.4 The River Hull and Holderness Drain Flood Mapping study was commissioned in 2011[3]. The aim of the study was to update the EA's flood map information and to enable better understanding of the impacts of the EA's assets on flood risk in the catchment. The study included the development of a one-dimensional (1D) ISIS and 2D TUFLOW model to represent the River Hull and Holderness Drain system.

2.2.5 Following the significant flooding of the greater Hull area in June 2007, a combined All Hull model was developed containing seven drainage areas which discharge to the Saltend waste water treatment works (WwTW). The All Hull Integrated Catchment Model was developed using the Infoworks ICM hydraulic software and completed in 2012. It was developed for ERYC to understand the hydraulic performance of the sewerage system. A fundamental component of this model is the Infoworks CS 1D Hull Combined Drainage Area Zones (DAZ) model for the combined sewer network serving Hull. The DAZ model was developed by Clear Environmental Ltd working on behalf of ERYC.

2.2.6 In consultation with the EA, it was agreed that the current modelling work will be undertaken using the Infoworks ICM software. Infoworks ICM is an integrated modelling platform which can incorporate both urban and river catchments. The model is also capable of accounting for the impacts of the existing sewer network upon overland flow generation within a catchment area. While the full Infoworks ICM model for Hull was not made available for this study, the Infoworks CS 1D model component of the Hull combined sewer network was provided. The model was considered suitable for use as a starting point in creating an integrated model for the study area to examine flood risk from all sources.

[3] Halcrow (2013). River Hull and Holderness Drain Flood Mapping Study, Modelling Report for Environment Agency. September 2013

Table 2.1: Available hydraulic models for the Hull area

No.	Model	Owner	Developer	Software	Model description
1	River Humber North Bank Tidal Model	EA	Mott Macdonald	TUFLOW / ISIS	Predicts tidal flooding from the Humber Estuary including wave overtopping of existing defences and undefended scenarios for a range of return periods.
2	Hull Surface Water Management Plan model	HCC	Halcrow	TUFLOW	Predicts pluvial flooding for rainfall events for a range of return periods.
3	River Hull Strategic Flood Risk Assessment (SFRA)	Hull City Council	Arup	Various	The SFRA[4] compiles modelling information from a range of studies to consider fluvial, pluvial and tidal flooding. The majority of the modelling information stems from 1D/2D ISIS-TUFLOW models and 1D/2D Infoworks ICM models. A small amount of additional modelling was carried out as part of the SFRA (2016) to update relevant climate change scenarios.
4	River Hull and Holderness Drain Flood Mapping study	EA	Halcrow	TUFLOW / ISIS	Predicts flooding from the River Hull from overtopping or breach of defences. This model considers three main sources of flooding: • Fluvial from storm runoff; • Tidal; • Fluvial from base flow (without rainfall event) from springs upstream

[4] Hull City Council (2016). Strategic Flood Risk Assessment December 2016. Available online at: http://www.hullcc.gov.uk/pls/portal/url/PAGE/HOME/PLANNING/PLANNING%20POLICY/FLOOD%20RISK%20ASSESSMENT/

No.	Model	Owner	Developer	Software	Model description
5	The All Hull Integrated Catchment Model developed for the Willerby and Derringham Flood Alleviation Scheme (WaDFAS) Scheme	ERYC	Clear Environmental	Infoworks ICM	Predicts flooding from multiple flooding sources in the Hull and Haltemprice catchments. The model is 2D in the areas of Willerby and Derringham but 1D in the area the Scheme.
6	All Hull Combined DAZ Model	YW	Mouchel	Infoworks CS 1D	YW drainage / sewerage model. Predicts sewerage network performance and flooding for all of Hull.

3. Modelling the baseline and proposed scenarios

3.1 Previous model build and calibrations

3.1.1 The Infoworks CS 1D Hull Combined DAZ model build is detailed in the All Hull Model Build and Verification Report[5]. The report details how the All Hull Model was built from a combination of seven individual Drainage Area Planning models contributing flow to the Saltend WwTW.

3.1.2 The All Hull Model was verified against a number of flow surveys including both dry weather flow days and storm events. Verification was carried out against full flow survey period data and a number of discrete events.

3.2 Baseline model construction

3.2.1 The Infoworks CS 1D Hull Combined DAZ model was imported into Infoworks ICM in preparation for the creation of the 2D modelling domain near the study area. A preliminary assessment was conducted comparing model predictions for the imported model within Infoworks ICM to predictions for the same model in Infoworks CS. This assessment verified that the transition from CS to ICM has no predictive impact. The extent of the Infoworks CS model can be seen in Figure 3.1, depicted in green.

3.2.2 A 1D model is incapable of fully determining the fate of any flood water that spills out of a manhole at ground level. Therefore, to enable the fate of the flood water to be determined, a 2D element was added to the model after it was imported into ICM. The 1D domain of the DAZ model was linked to a 2D domain via manholes. This enabled a better representation of surface water flooding.

3.2.3 The drainage network within the proposed study area was checked and found to be almost entirely a combined system with only a very small proportion of surface water-only sewers. Therefore, it was deemed that all manholes within the study area can receive and contribute flood flows to and from the 2D domain. As such, all manholes, apart from those designed as ‘Sealed’, within the 2D zone study area were to set to flood type ‘2D’.

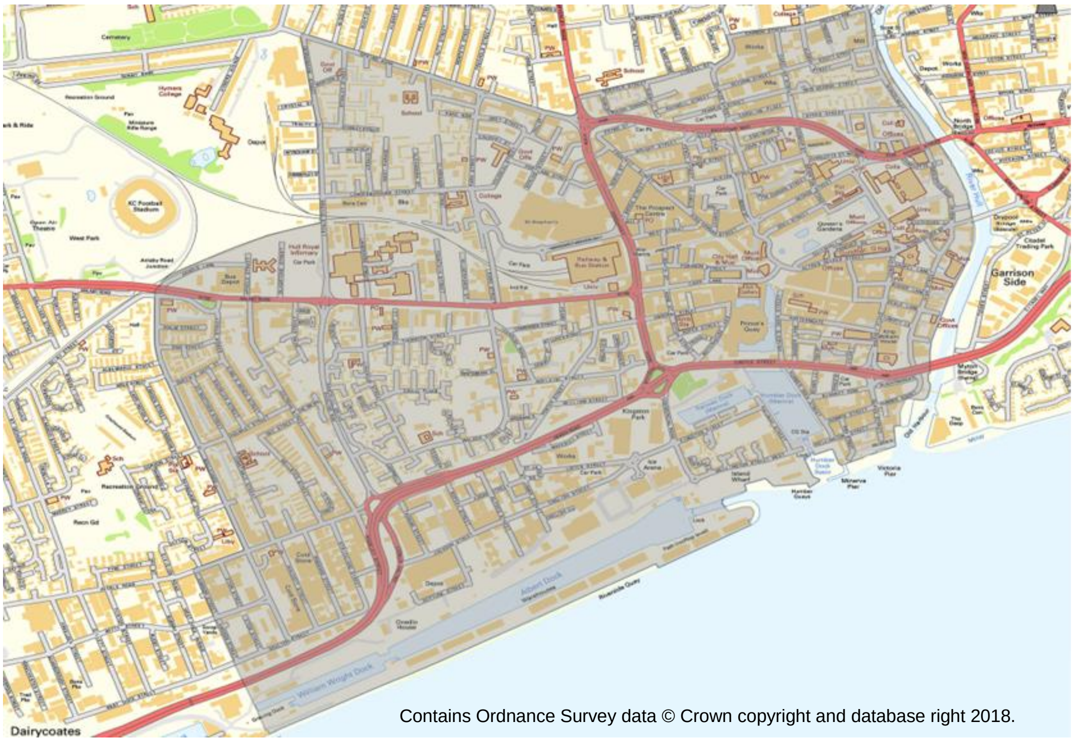
3.2.4 Manholes outside the 2D zone study area were retained as per the supplied All Hull Model. The majority of manhole nodes (71%) outside the 2D zone study area were set to “Stored” flood type with approximately 7% set to “Sealed” and 14% set to “Lost”.

[5] Mouchel (2012). All Hull model, Model Build and Verification Report, July 2012.

Figure 3.1: Extent of the 1D Hull sewer network model (red area highlights 2D model study area)

3.2.5 Bespoke LiDAR data for the area with 1 km radius around the Scheme site was provided by Bluesky in 2014. The data has 0.5 m horizontal and 0.025m vertical resolution. This data was used to represent the existing ground surface in the 2D zone. The area of the available LiDAR data, and subsequently of the 2D zone, covers approximately 4km^2. It is bounded by the River Hull on the east and by the River Humber to the south. It extends to about 1 km to the north and west of the Scheme. Figure 3.2 below presents the extent of the 2D zone.

Figure 3.2:– Extent of study area and 2D zone used in hydraulic modelling



3.2.6 Infiltration zones were not applied in the original CS model. The same approach was adopted for this assessment since the area in and around the Scheme is heavily urbanised and predominantly impermeable.

3.2.7 The 2D zone had the following default characteristics:

- Minimum element area: 5m^2
- Maximum element area: 100m^2
- Boundary condition: Normal depth condition
- Manning's n roughness: 0.025

3.2.8 Terrain sensitive meshing was activated, which allows ICM to increase the resolution of the 2D mesh in areas that have a large variation in height, without increasing the number of mesh elements in relatively flat areas. The preliminary meshing, however, indicated that linear features with vertical or very steep gradients such as the underpass retaining or dividing walls were not well represented in the mesh. This results in ill-defined elevations along linear features resulting in inaccurate flood flow pathways. This was resolved by adding linear breaklines along the underpass and the adjacent slip roads to represent walls. A group of up to three parallel breaklines was required to force them to reflect the level variations in these areas ensuring that mesh vertices align with these features, instead of passing either side of them.

3.2.9 The buildings within the study area were extracted from Ordnance Survey (OS) MasterMap and were included as void polygons. This was done to achieve resolution of flow paths around buildings.

3.2.10 In addition to the above, areas of open green space, large gardens and parks had increased roughness to 0.060 (from default 0.025).

Nodes, conduits and ancillaries

3.2.11 Nodes and conduits for the 1D network were retained from the All Hull Model[5] and these were based on a number of smaller models and incorporated a degree of manhole survey. All ancillaries within the original All Hull Model were based on surveyed or as-built information and these included a number of sewage pumping stations, CSOs and the Hull transfer tunnel.

3.2.12 A check was carried out of node cover levels against 2D mesh levels. There were a small number of discrepancies but this was not expected to have a significant impact on predicted flooding.

Sub-catchment inflows

3.2.13 Current hydraulic modelling techniques do not represent the full extent of entry points for drainage into the sewer. The current hydraulic model does not represent the road gullies and secondary network elements that collect runoff from the surface into the drainage network. To simulate inflows at each node/manhole, the sub-catchments approach was used which acts to route rainfall into runoff across an area contributing to an individual node or manhole. As such, the interface between the 2D surface model element and the sewer network is limited to manhole locations, where all ‘non-sealed’ manholes permit flows either into or out of the sewer. This exchange of flow depends on predicted water levels within the sewer exceeding predicted 2D water levels at the manhole location, or vice versa.

3.2.14 When applying direct rainfall to an urban area, network models tend to overpredict the volumes of surface water in the upper catchments where surface water cannot find the network, and under predict downstream where the network is not able to redistribute flows from the upper catchment. The study area for the Scheme is at the lower end of the network. No rainfall was applied directly to the entire 2D zone.

3.2.15 Details on contributing areas and impermeable area allocations for the sub-catchments are detailed in the All Hull Model Build & Verification Report[5]. Contributing areas were refined through the amendment of impermeable area layers and the area take-off process following model verification[5].

3.2.16 The default sub-catchments from the All Hull Model had a range of surfaces depending on the pervious or impermeable nature. Soil types were identified from a digitised Wallingford UK soil (WRAP) map[5]:

- Runoff surface 1 represented standard paved areas with a fixed percentage runoff of 75%
- Runoff surface 2 represented standard roof areas with a fixed percentage runoff of 95%
- Runoff surface 3 represented urban creep with a fixed percentage runoff of 100%
- Runoff surface 5 represented pervious areas using the New UK Runoff model. Five different surfaces were included to represent WRAP SOIL classes 1 to 5.
- Runoff surface 99 represented ground infiltration for a range of ground conditions throughout the model areas using overlapping sub-catchments. The total area of ground infiltration surfaces was approximately 1,581ha.

3.2.17 The total sub-catchment area within the entire model was approximately 7,601ha with a total contributing area of approximately 6,163ha which is equivalent to 81%. The total area of ground infiltration areas was approximately 1,581ha equivalent to approximately 21% of the whole model area.

3.2.18 A test was carried out where missing contributing area was assigned to the relevant pervious runoff surfaces within each sub-catchment where the contributing area was less than the total area. This test showed no appreciable difference in flood extent within the study area (see

3.2.19 Figure 3.3). The sub-catchment boundaries within the study area are shown in Figure 3.4 below.

Defence schematisation

3.2.20 The flood defences along River Humber and River Hull were represented in the model as a series of separate linear defence sections. The coastal flood defences along the north bank of River Humber adjacent to the Scheme were represented using 23 separate sections, based on the information provided in the River Humber North Bank Tidal Modelling Report Appendix D[6] and by the Environment Agency for the upgraded Albert Dock defences. The locations of the River Humber defences are presented in Figure 3.5 below. The flood defences along the River Hull adjacent to the Scheme were represented using 14 separate sections. Their locations were based on information provided in the River Hull and Holderness Flood Mapping study[3] and are presented in Figure 3.6.

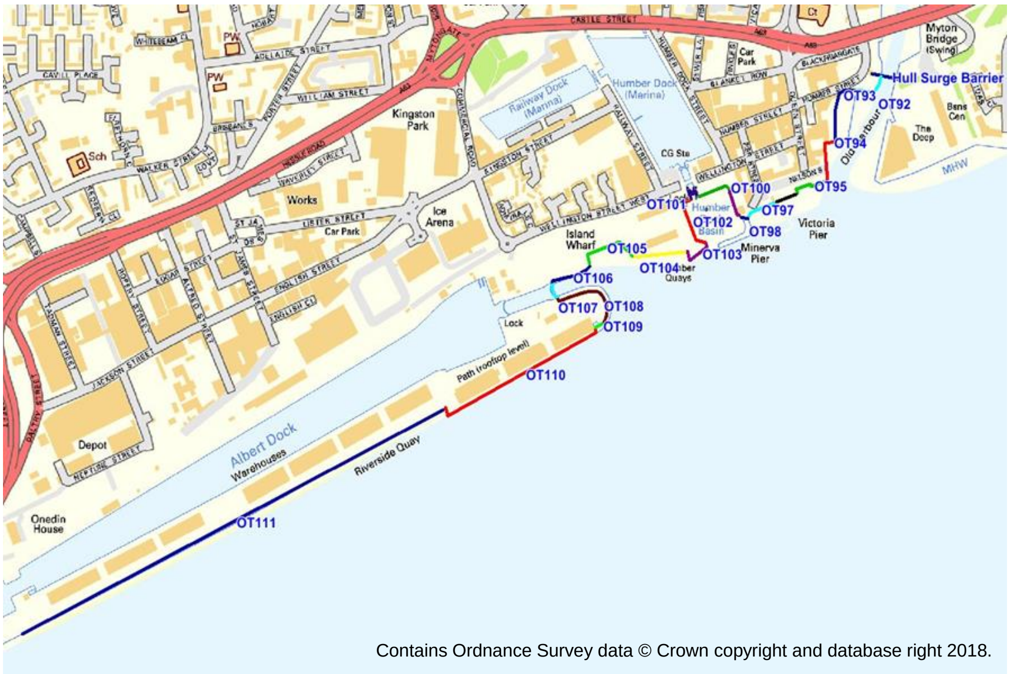
[6] Mott MacDonald (2011c). The River Humber, North Bank Tidal Modelling Study. Flood Defence Conceptualisation Report. December 2011.

Figure 3.3: Sensitivity (flood depth difference) to permeable catchment area increase

Figure 3.4: Sub-catchment layout within the study area

3.2.21 Defences within the urban area of Hull are generally flood walls with toe protection with a generally shallow foreshore slope. This area also includes a number of dock gates and the Hull Tidal Barrier. The average defence elevation is 5.85m AOD. A number of sections also have redundant jetties and piers which would act to deflect incoming waves and lessen the impact of wave attack on the flood defences.

Figure 3.5: Flood defences along the River Humber north bank



Contains Ordnance Survey data © Crown copyright and database right 2018.

Figure 3.6: Flood defences along the River Hull west bank

Contains Ordnance Survey data © Crown copyright and database right 2018.

3.2.22 Detailed information related to the physical characteristics of the defences along River Humber was provided with the Humber tidal modelling report Appendix D[6]. Additional information was supplied by the Environment Agency in 2016 including details of the upgraded defences along Albert Dock. The relevant details of the defences within the model area are presented in Table 3.1. No specific information was provided regarding the levels of the defences along the River Hull. The location of the defences was identified based on the location of modelled river cross sections on the upstream and downstream ends of each defence section[3]. The defences were delineated between the respective cross sections.

3.2.23 Flood defence overtopping due to wave surge and extreme tides was not explicitly predicted as a component of the present study, since this analysis has been previously conducted by Mott Macdonald[1], Halcrow[3] and the Environment Agency[2]. For a given "defences operating" scenario, simulated flows over each section of the flood defences obtained from previous modelling were applied as inflows at the respective defence location in this study. For undefended scenarios, the defence locations act as level/head-type boundaries for the 2D mesh, with River Humber water levels as a function of time applied at these locations. This approach is explained further in Section 3.3.2.

Table 3.1: Physical characteristics of Humber defences

Defence Section	Physical parameters				
	Crest elevation (mAOD)	Wall height (m)	Total Defence Elevation (mAOD)	Section Length (m)	Schematisation
OT90	5.88	0.35	6.23	110	Vertical wall
OT91[1]	6.30	0.00	6.30	37	Vertical wall
OT92	5.69	0.17	5.86	59	Vertical wall
OT93	4.25	2.87	7.12	138	Vertical wall
OT94	5.85	1.30	5.85	73	Vertical wall
OT95	4.71	1.11	5.82	80	Vertical wall - promenade
OT96	4.81	1.00	5.81	36	Vertical wall - promenade
OT97	4.87	1.00	5.87	46	Vertical wall - promenade
OT98	4.87	1.04	5.91	19	Vertical wall - promenade
OT99	4.82	1.02	5.84	61	Vertical wall - promenade
OT100	4.87	0.98	5.85	62	Vertical wall - promenade
OT101[2]	5.96	0.00	5.96	46	Lock
OT102	6.17	1.12	6.17	111	Vertical wall - promenade

Defence Section	Physical parameters				
	Crest elevation (mAOD)	Wall height (m)	Total Defence Elevation (mAOD)	Section Length (m)	Schematisation
OT103	6.17	1.12	6.17	60	Vertical wall
OT104	5.11	1.07	6.18	108	Vertical wall with rock armour and wave return wall
OT105	5.11	0.8	5.91	129	Vertical wall - promenade
OT106	4.97	0.74	5.71	74	Vertical wall - promenade
OT107[3]	5.69	0.00	5.69	50	Lock
OT108	4.93	1.02	5.95	129	Vertical wall - promenade
OT109	4.92	1.10	6.02	9	Vertical wall - promenade
OT110	5.60	0.37	5.97	358	Vertical wall
OT111	4.84	1.38	6.22	932	Vertical wall - promenade
OT112	4.96	1.08	6.04	386	Smooth concrete apron with wave return wall

1. Defence OT91 is the Hull Tidal Surge Barrier
2. Defence OT101 is the Humber Dock Marina entrance gates
3. Defence OT107 is the Albert Dock entrance gates

3.3 Proposed layout model construction

3.3.1 The ground elevation model of the proposed layout of the Scheme was generated from a three-dimensional (3D) contour AutoCAD design drawing. The drawing was converted to a surface raster using ArcGIS, and subsequently merged with the existing layout raster (generated from the available digital terrain model) utilising the 'mosaic to new raster' tool. The 2D zone mesh was calculated by sampling elevations from the proposed ground elevation model.

3.3.2 A detailed representation of the proposed highway drainage network was not included in the model for two reasons; firstly, the lack of existing highway drainage in the YW Infoworks CS sewerage network model would not allow a true comparison of the impact; and secondly, the proposed highway drainage was modelled independently in MicroDrainage for drainage design purposes. However, a dummy outfall was placed in the lowest part of the underpass to simulate the discharge with a proposed pump capacity of 100 l/s. In the pluvial scenarios, the discharge rate of the outfall was not restricted to compensate for the lack of attenuation storage in the model (as the proposed drainage network is not represented) and to avoid flooding in the underpass. However, for the tidal scenarios, the restricted pump capacity was applied. This provided an accurate representation of the extent of flooding of the underpass under extreme conditions when the enclosed volume of water can reach 30,000m^3 (which is predicted to occur due to wave overtopping from the River Humber in response to the 1 in 1000-year tide). It also gave an indication of the time required for the road to be drained after such events. For an event of this magnitude, it will take more than 3 days to drain the underpass.

3.3.3 The Scheme would require the diversion of two existing sewers. While the proposed diversions will be designed by YW, MMSJV provides an indicative design based on discussions with YW. This design is presented in the At Grade Drainage System Strategy Report[7]. The proposed diversions are incorporated into the ICM model.

3.3.4 The proposed model also includes the removal of 3 no. buildings to be demolished as part of the Scheme, namely:

- 13-14 Castle Street
- Earl de Grey public house
- The Myton Centre at William Street

3.3.5 The above buildings were removed as void polygons from the proposed mesh to represent their demolition and to model the revised flow paths in these areas.

3.4 Input data sources

Rainfall and evaporation

3.4.1 The design rainfall parameters, derived for the original CS model for the Hull catchment area, were provided and were used for the generation of different rainfall events. These parameters are based on the FEH99 dataset and are presented in Table 3.2 below. An areal reduction factor of 0.86 was applied to the total rainfall catchment area of 7,100ha. Derivation of API30 (summer and winter) were carried out using the ‘if the NAPI fits’ technique[5].

3.4.2 Figure 3.10 shows the design rainfall hyetographs used in the model.

3.4.3 A sensitivity assessment was carried out using the most up-to-date FEH13 dataset to evaluate the impact of this dataset on flood depths. Figure 3.8 shows the impact of using FEH13 rainfall on maximum predicted flood depths for a 1 in 100-year plus climate change pluvial flooding event. The figure shows this dataset has minor effects (0.05 to 0.10m difference in flood depths) in areas remote from the Scheme around Scott Street and Portland Street to the north and the Blackfriargate underpass to the east.

[7] Mott MacDonald Grontmij Joint Venture (2014b). A63 Castle Street Improvements; At Grade Drainage System Strategy. Report for Highways Agency. Doc Ref: 1168-08-005-RE-001 A2. March 2014

Table 3.2: Design rainfall parameters taken from the Hull model verification report[5]

Catchment descriptor	Value
SAAR	= 643mm
C	= -0.023
D1	= 0.356
D2	= 0.307
D3	= 0.255
E	= 0.302
F	= 2.404
UCWI (summer)	= N/A - API 30 has been used
UCWI (winter)	= N/A - API 30 has been used
API30 (summer)	Soil type 2 = 0.10 Soil type 4 = 5.5
API30 (winter)	Soil type 2 = 0.75 Soil type 4 = 11.2
Drainage Network Catchment Area	= 7100ha
Depression Storage	= 10mm
Evaporation (summer)	= 2.4
Evaporation (winter)	= 1.0
Areal Reduction Factor	= 0.87

Figure 3.7: Design hyetographs

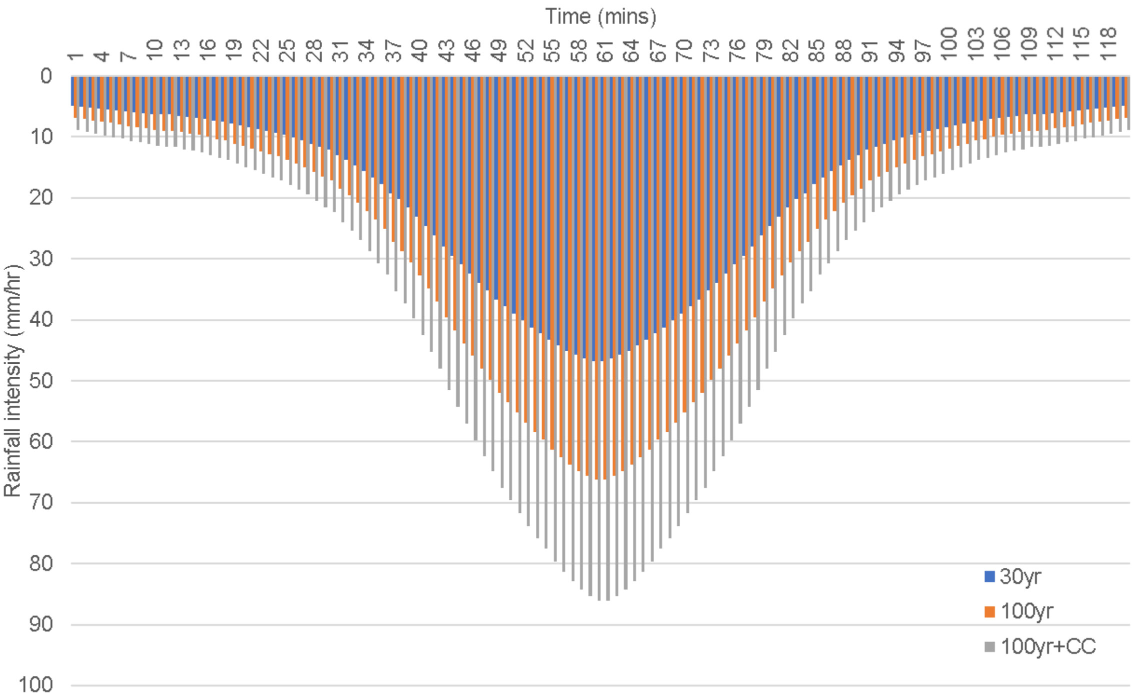


Figure 3.8: FEH13 sensitivity (flood depth differing for a 1 in 100-year plus climate change) flood event

Sewage and trade effluent

3.4.4 Foul sewage and trade effluent event files, representing daily patterns of domestic and trade waste discharged in the system, were also provided with the Infoworks CS model[5]. These were not changed.

Inflows and flood level data

River Humber north bank tidal model

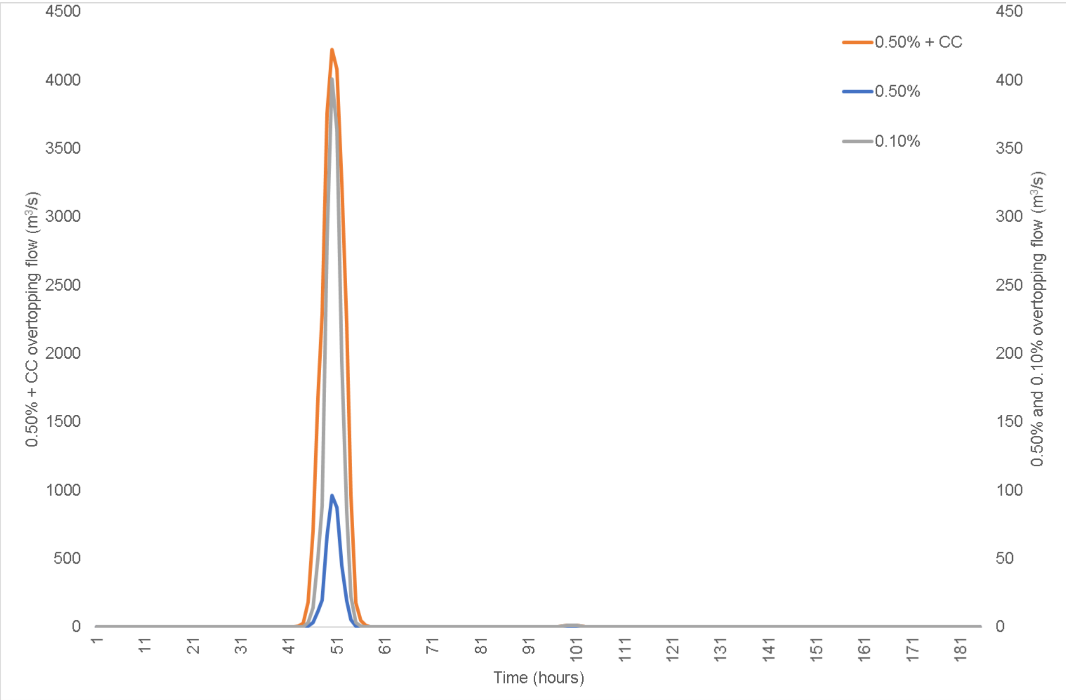
3.4.5 A range of input data and modelling results from the River Humber North Bank Tidal Modelling Study were made available by the EA for the A63 FRA.

3.4.6 The Water Level, Tide, Surge and Wave Analysis Report of the River Humber Tidal Modelling study[8] states that Associated British Ports (ABP), in their 2007 report, presented design water levels for a range of return periods for 15 locations along the north bank of the River Humber from Kilnsea to Saltmarsh. These levels were adopted in the River Humber model as recommended baseline design water levels at the specified locations.

[8] Mott MacDonald (2011b). The River Humber, North Bank Tidal Modelling Study. Water Level, Tide, Surge and Wave Analysis. December 2011

3.4.7 However, these levels were updated following the December 2013 surge event which caused overtopping of the Humber defences along the north bank. Peak tide levels were provided by the Environment Agency as part of the 2014 Interim Water Level Profiles[2]. The Environment Agency also supplied overtopping hydrographs for the revised design tidal events over the raised defences at Albert Dock. The revised overtopping hydrographs are summarised in Figure 3.9 below and are presented as total flow along the whole 2D boundary at the Humber north bank.

Figure 3.9: River Humber defence overtopping hydrographs



3.4.8 The design water levels for a range of return periods at several locations situated within and close to the Scheme study area were extracted from the 2014 Interim Water Level Profile[2] and are presented in Table 3.3 below.

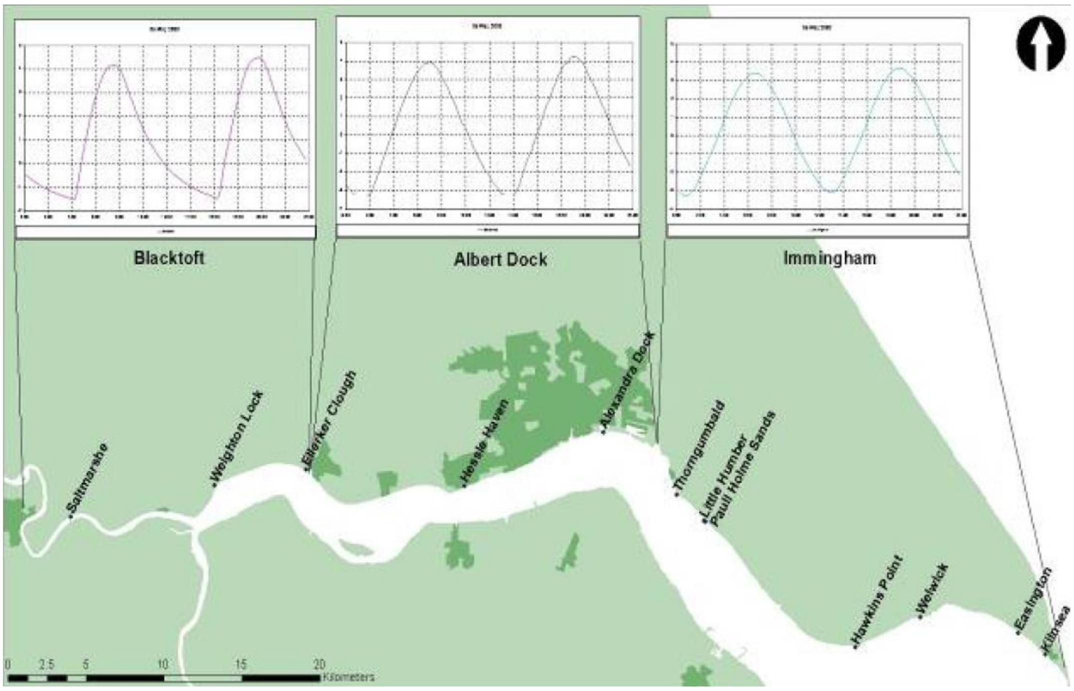
Table 3.3: Design water levels for present day and including Climate Change (to 2115)[2]

Location	Easting	Northing	10-yr	50-yr	100-yr	200-yr	200-yr (2115)
Thorngumbald	517100	425100	4.89	5.18	5.31	5.45	6.58
Paull	516486	426564	4.94	5.23	5.37	5.51	6.64
Saltend	515946	427357	4.91	5.20	5.34	5.48	6.61
Albert Dock Bridge	509482	427809	5.07	5.36	5.49	5.62	6.75
Hessle Haven	503467	425604	5.35	5.62	5.73	5.83	6.96
Hull Barrier	510194	510194	5.17	5.46	5.59	5.72	6.85

3.4.9 The above design water levels were based on the variation of the typical shape of the astronomical tide curve, which in turn was based on observed data around 5th May 2000. The shape of these tide curves as outlined in the River Humber North

Bank Tidal Modelling Main Report[1] are reproduced in Figure 3.10 below. For this study, the astronomical tide curve for the Albert Dock reach was used.

Figure 3.10: Selected representative astronomical tide curves (reproduced from Mott Macdonald[1])



3.4.10 The River Humber Modelling Report[8] and the 2014 Interim Water Level Profile[2] upon which the above results are ultimately derived, describes the process of derivation of the design tide hydrographs used as input in the tidal scenarios modelling. The hydrographs consider both the astronomical tide and the surge element. The surge profile in the Humber tidal study was based on the extreme 1953 event. This surge profile was combined with the astronomical tidal curve, with the peak of the surge and the peak of the spring astronomical high tide assumed to be coincident.

3.4.11 The combined design hydrographs were derived by scaling the surge element to achieve the pre-defined design peak water levels (Table 3.3). For the climate change scenarios, the astronomical tidal cycle was shifted upwards by 1.125 m to represent the 2115 climate change horizon before being combined with the storm surge profile. The 1953 surge profile was adopted from the River Humber Modelling Report[8] and is reproduced below for reference.

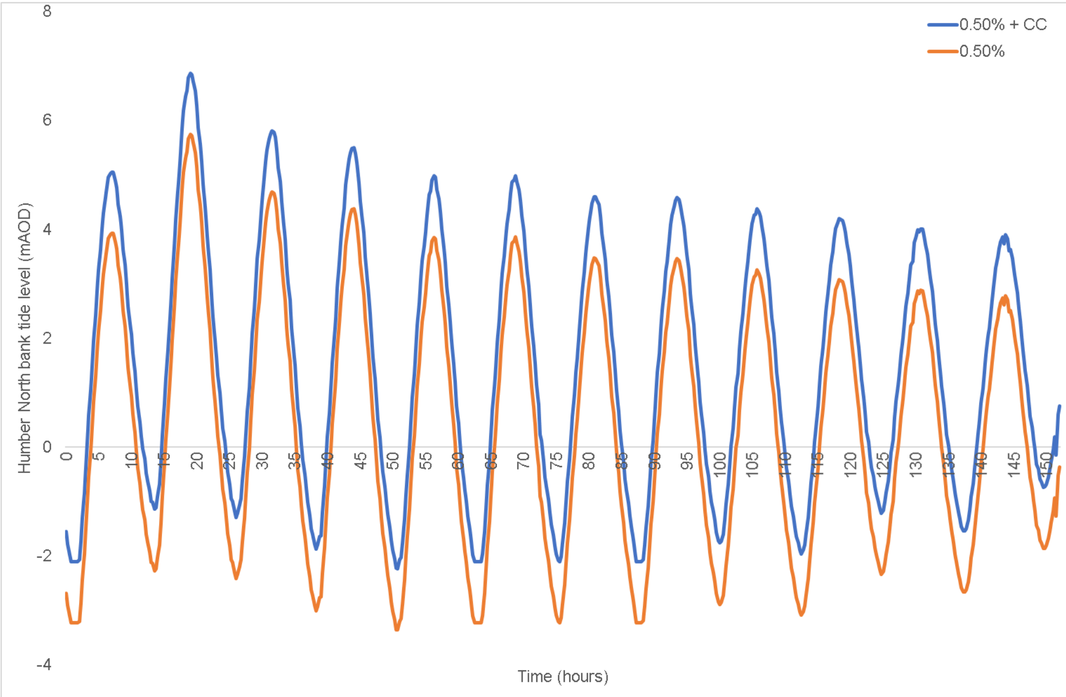
Figure 3.11: 1953 Design storm surge profile (reproduced from Mott Macdonald[8])

Source: Based on smoothed 1953 surge profile

3.4.12 The overtopping discharge hydrographs were used as flow-time boundary conditions in the River Humber Tidal Model. Nevertheless, it must be recognised that the wave overtopping is not a constant flow and some flood water is able to flow back out to sea when the water level on the floodplain is above the defence crest level and the water level in Humber is below the defence crest level. To enable flow to exit the model under these conditions, synthetic weirs were set along the flood defence crest in the Humber Tidal Model[1]. However, it was not possible to apply the same modelling technique within Infoworks ICM, and if the same overtopping discharge hydrographs were used as input to the model it would have resulted in marginal overestimating of the flows. Therefore, the output flow hydrographs for the wave overtopping scenarios from the Humber model for a range of return periods including climate change were also requested and provided by the EA. The model outputs were extracted from the River Humber baseline scenario assuming a wave attack angle of 120 degrees[1].

3.4.13 Most of the floodplain along the north bank of the Humber is below the 1 in 200-year event design peak water levels. For the undefended scenarios, water level (head-time) boundary conditions, as derived for the River Humber tidal model along the north bank of River Humber, were provided by the EA for return periods of 1 in 200-years and 1 in 200-years including climate change. The effect of waves was not considered for the undefended scenarios. The head-time boundaries were calculated based on the astronomical tidal curve and the design surge profile at key locations[1]. Head-time boundary conditions were applied to the model for 11 cycles, including one tidal cycle before the peak surge, the peak tidal cycle and 9 cycles after. The tidal level head-time boundary conditions are given in Figure 3.12 below.

Figure 3.12: River Humber undefended head-time boundary conditions



River Hull and Holderness Drain flood mapping study

3.4.14 In the River Hull and Holderness Drain Flood Mapping study, different “with defences” and “without defences” scenarios were modelled for a range of return periods, for fluvial and tidal flooding, and the results were made available for the A63 FRA.

3.4.15 Following a review of the River Hull modelling results[3], fluvial flooding from the River Hull predominantly affects the upper reaches, the land-drainage network and low-level drainage system, as well as inflows from the eastern side of the catchment. The downstream River Hull reaches, and in particular the reach adjacent to the city of Hull, is not affected by fluvial flooding (assuming the river is not tidally influenced, i.e. the Hull Tidal Barrier is closed).

3.4.16 Most of the scenarios with ‘single asset removal’, such as pumps and outfalls, also affected the drains and the upper reaches of River Hull. The only flooding scenario predicted to affect the area near to the Scheme is the failure of the Hull Tidal Surge Barrier to close (with all other flood defences operating as per specification).

3.4.17 In consultation with the EA, it was agreed to consider the following River Hull flooding scenarios:

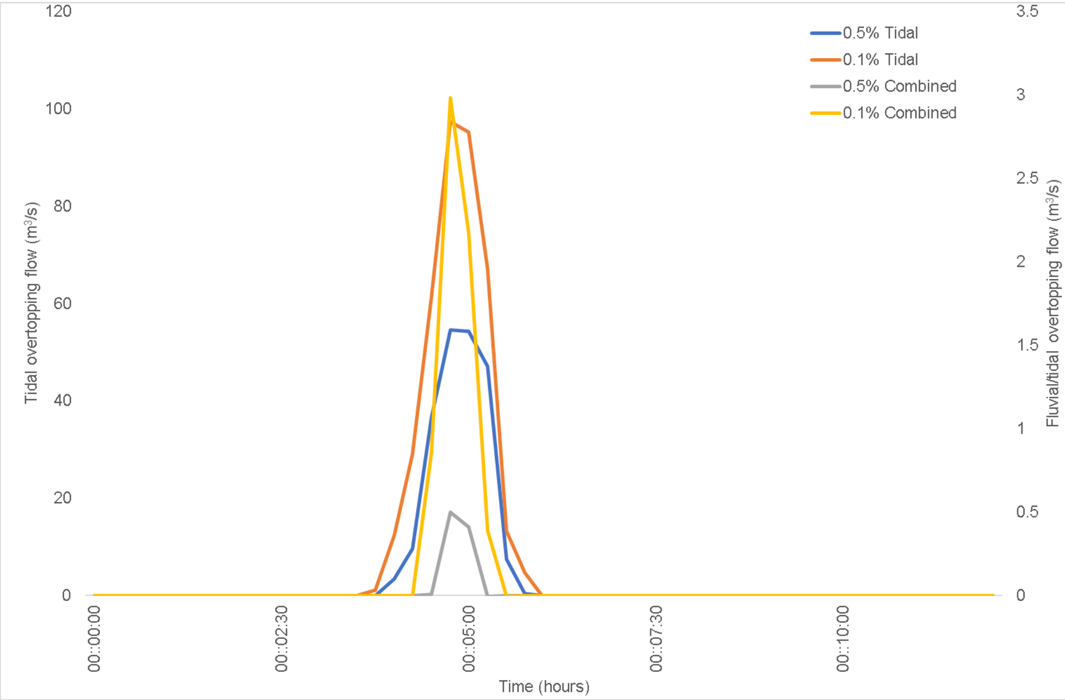
- Tidal flooding with Hull Tidal Surge Barrier open
- Combined tidal and River Hull fluvial flooding

3.4.18 The tidal and fluvial flow flooding scenarios had combined return periods as follows:

- Fluvial return period 1 in 5-years and tidal return period 1 in 2-years for an overall combined return period of 1 in 200-years
- Fluvial return period 1 in 10-years and tidal return period 1 in 5-years for an overall combined return period of 1 in 1000-years.

3.4.19 The hydrographs of the flows overtopping the Hull defences for the relevant scenarios were extracted from the River Hull modelling outputs and were applied to the respective River Hull defence element as flow-time (hydrograph) boundaries. These hydrographs are summarised in Figure 3.13 below as total flow along the full boundary adjacent to the River Hull.

Figure 3.13: River Hull tidal, fluvial and combined inflow hydrographs



3.5 Flood risk scenarios

3.5.1 The existing and the proposed case flood risk scenarios to be tested in the A63 model were discussed and agreed in consultation with the EA. The agreed scenarios are listed in Table 3.4 below and are discussed in detail in the following section.

Table 3.4: Agreed modelling scenarios

Source of flooding	Return periods modelled (years)
Pluvial	1 in 30 1 in 100 1 in 100 plus climate change
Tidal from the River Hull (with Hull Tidal Surge Barrier open)	1 in 200 1 in 1000 (surrogate for a 1 in 200 with climate change event)
Combined fluvial and tidal from the River Hull (with Hull Tidal Surge Barrier open)[1]	1 in 200 1 in 1000 (surrogate for a 1 in 200 with climate change event)
Wave overtopping (defended) from the River Humber	1 in 200 1 in 1000 1 in 200 plus climate change
Tidal (undefended) from the River Humber	1 in 200 1 in 200 plus climate change

1. The combined events have the following joint probability conditions:
a. Fluvial return period 1 in 5yrs, tidal return period 1 in 2yrs: Overall return period 1 in 200yrs
b. Fluvial return period 1 in 10yrs, tidal return period 1 in 5yrs: Overall return period 1 in 1000yrs

3.6 Climate change

3.6.1 The NPPF Guidance advises on a sensitivity range to be taken into consideration when assessing the impact of climate change on flooding from the land, rivers and sea as part of flood risk assessment. This range may provide an appropriate precautionary response to the uncertainty associated with climate change impacts upon rainfall intensities, river flow, wave height and wind speed. The sensitivity ranges and climate change allowances were published and updated by the Environment Agency[9]. The relevant climate change allowances are listed in Table 3.5 below.

Table 3.5: Flood risk assessment - climate change allowances

Parameter	Total potential change anticipated for the '2080s' (2070 to 2115)
Peak river flow[1]	20% Central 30% Higher central 50% Upper end[2]
Peak rainfall intensity	20% Central 40% Upper end
Offshore wind speed	10%
Extreme wave height	10%

[9] Environment Agency (2017). Flood risk assessments: climate change allowances. Available online at: https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

Parameter	Total potential change anticipated for the '2080s' (2070 to 2115)
Sea level allowance[3]	0.99m/1.125m

1. Values are for Humber river basin district
2. Guidance states for 'essential infrastructure' in Flood Zone 3a to use the upper end allowance
3. 0.99m values for the 'North west, north east' area of England. However, value adopted in previous studies (from which data for this assessment is derived, was 1.125m)

3.6.2 In this assessment, the impact of climate change is considered for all potential sources of surface water flooding. For the pluvial flooding assessment, a 30% increase in rainfall intensity is applied as per a previous agreement with the EA.

3.6.3 Based on Mott McDonald's River Humber study[8], climate change impacts upon tidal levels in the Humber are assumed to raise peak water level predictions at any given location by 1.125 m by 2115 (relative to 2010 values). Therefore, for the climate change scenarios, the whole astronomical tide curve was shifted up by 1.125 m before being combined with the surge profile and scaled to the design peak water level (presented in Table 3.3). This represents a conservative approach when compared to the 0.990m sea level rise from NPPF guidance. Based on NPPF guidance, an increase of 10% was applied to wave heights to represent the impact of climate change.

3.6.4 In the River Hull and Holderness Drain Flood Mapping Study[3] the effect of climate change was not modelled for the 1 in 200-year return period for the tidal flooding scenario. Therefore, in consultation with the EA, it was agreed that the results of the 1 in 1000-year return period simulation will be used to approximately represent the 1 in 200-year tidal event with climate change. The 1 in 1000-year peak flow was approximately 80% greater than the 1 in 200-year peak flow; as such this represents a conservative assessment.

Pluvial flooding

3.6.5 Pluvial flooding was simulated for return periods of 1 in 30, 100, and 100 years including 30% climate change. A critical storm duration analysis was performed to establish the worst case pluvial flooding that may occur in the area of interest. Simulations for each return period were conducted for a range of design event durations ranging from 15 to 960 minutes for both summer and winter storm profiles. The severity of the pluvial flooding was assessed based on analysis of the flood depth over the modelled area. Using this metric, the critical storm duration was estimated to be 120 minutes with a winter storm profile. The results for the events with duration 60, 120 and 240 minutes winter profile are presented in Table 3.6.

Table 3.6: Flood risk assessment: climate change allowances

Event duration (min)	Area inundated for respective flood depth (m)				
	0.05-0.15	0.15-0.30	0.30-0.60	>0.60	Total
60	581,596	107,252	15563	2876	707,287

Event duration (min)	Area inundated for respective flood depth (m)				
	0.05-0.15	0.15-0.30	0.30-0.60	>0.60	Total
120	567,183	125,691	25520	3970	722,364
240	532,342	130,873	35134	5090	703,439

3.6.6 In addition, tidal lock sensitivity simulations were performed to assess the sensitivity of the model to variations in tidal boundary conditions during pluvial events. The design water levels for the 1 in 10-year return period at the locations of the drainage system outfalls were used to produce level files. These files were used as boundary conditions, applied to the existing sewer network outfalls in the pluvial flooding assessment to account for tidal impacts upon sewer network discharge. Results indicate that predicted flooding is not sensitive to variations in the tidal boundary conditions applied to the outfalls, i.e. the 1 in 100-year return period pluvial event (with climate change) combined with either a 1 in 1 year or 1 in 10-year tidal event as boundary conditions produced equivalent predictions.

Tidal and fluvial flooding

Flooding from the Humber Estuary

3.6.7 Tidal flood risk in the area is posed directly by the River Humber, which is tidally dominated in the reach bordering the Scheme. Flood risk may be posed via tidal wave overtopping the banks or defences, or by high tidal levels in case of defence failure.

3.6.8 Flow hydrographs for each defence element were applied as a boundary condition for the wave overtopping defended scenario in the model. Wave overtopping was simulated for the following return periods: 1 in 200 and 1 in 1000-years under 2010 climate conditions and 1 in 200-year under 2115 climate conditions (i.e. with climate change impacts considered).

3.6.9 The River Humber North Bank Tidal Modelling Report[1] states that the flood risk beyond Albert Dock was sensitive to the initial water level in the dock prior to the storm surge. The water level in the dock at the time of the Bluesky aerial survey was 2.7m AOD. However, ABP advised that Albert Dock is a tidal dock and as such the water level within it depends on the height of tide and operational activity. The working range of water levels in Albert Dock is between 1.9m AOD to 4.3m AOD, which is from the lowest water level retained in the dock to the height of tide at which the flood defence gates are put in place. The level from the aerial survey of 2.7m AOD falls within the lower end of the inter-quartile range of operating levels reported by ABP.

3.6.10 All the Humber wave overtopping scenarios (Table 3.4) were modelled with an initial water level of 3.9m AOD in Albert Dock. This is the water level used in the River Humber North Bank Tidal Modelling Study[1] and is above the Mean High-Water Springs level of 3.7m AOD.

3.6.11 The predicted water level data from the Humber tidal model along the defences for the undefended scenarios with a return period of 1 in 200-years and 1 in 200-years plus climate change was used as a boundary condition for the model. Note that, in the area of the Scheme, only the levels along defences OT110 and OT111 (along Albert Dock – see Figure 3.3) were derived and these were applied along all Humber defences in the model. This approach is conservative and assumes an average water level along the boundaries of the study area with a constant rise in water levels. Climate change levels were increased by 1.125m, as described in Section 3.4.11 and Table 3.5.

Flooding from the River Hull

3.6.12 The flow hydrographs along the River Hull defences for the relevant scenarios were applied as inflow boundary conditions at the 2D zone of the ICM model. The scenarios were simulated for the following return periods:

- Tidal flooding from River Hull (Hull Tidal Surge Barrier open) for a 1 in 200 and a 1 in 1000-year return period.
- Combined flooding from River Hull (fluvial and tidal with Hull Tidal Surge Barrier open) for a 1 in 200 and a 1 in 1000-year combined return period.

3.6.13 Climate change was not explicitly considered for flooding from the River Hull due to the lack of available climate change scenarios in the supplied source modelling information. However, the 1 in 1000-year scenario was used as a surrogate for the 1 in 200-year plus climate change event (see Section 3.6.4).

3.7 Joint probability analysis

3.7.1 Flooding can arise not only from individual sources but also from contribution of more than one source, e.g., high sea levels during high fluvial baseflow conditions.

3.7.2 Chapter 7 of the Hull Hydrology and Data Investigation Study Report Technical Note [10] discusses the joint probability methods detailed in the Defra Report FD2308/TR1[11] and the dependence between pairs of variables published in the Halcrow study. The document states that based on the approach provided in the FD2308 it is reasonable to assume independence between flood sources for the River Hull catchment and summarises justification for this assumption in Table 3.7.

[10] Halcrow (2011) Hull Hydrology and Data Investigation Study Report, Technical Note. March 2011

[11] Defra (2005). R&D Technical Report FD2308/TR1 Joint probability: Dependence mapping and best practice: Technical report on dependence mapping. March 2005

Table 3.7: Correlation between flood parameters for the River Hull (adapted from Halcrow[10])

Variable pair	Justification for assuming independence
Baseflow and sea level	Very low correlation ('near independence') between flow recorded at Hempholme Weir and surge recorded at Immingham. The apparent slight dependence is probably explained by seasonality. This indicates independence for groundwater base flows and sea levels.
Rapid runoff and sea level	Very low correlation between intense rainfall and surge recorded at Immingham. This shows independence between fluvial flows and sea levels
Baseflow and rapid runoff	Baseflow in the River Hull permeable catchment is a response to seasonal rainfall, whilst rapid runoff is a response to short duration rainfall events. It is assumed that rainfall at these different timescales is essentially independent.

3.7.3 Joint probability combined scenario conditions were also estimated as part of the River Hull and Holderness Drain Flood Mapping Study[3]. Combined scenario conditions for several of the different flooding source combinations are listed in the Study report and those for the Hull Tidal Surge Barrier combined scenario conditions applicable to this assessment are presented in Table 3.8.

Table 3.8: Combined scenario conditions (adapted from Halcrow[3])

Structure State	Fluvial Runoff return period	Fluvial Baseflow return period	Tidal return period	Overall return period
Failed Open	Nominal	1:2 year	5:1 year	1:10 year
Failed Open	Nominal	1:2 year	1:2 year	1:100 year
Failed Open	Nominal	1:5 year	1:2 year	1:200 year

3.7.4 The dependency between sea level and short term (two hourly) high-intensity rainfall on an urbanised catchment are also considered using the joint probability methods described in FD2308/TR2[12]. There was no suitable long-term rainfall data available in the study area, therefore the simplified method outlined in Section 3.5.2 of the FD2308/TR2[12] was applied. The simplified method uses a 'correlation factor' (CF), not originally intended as the basis of a probability model, but as a descriptive representation of actual dependence relative to independence and full dependence. CF values of 2, 20, 100 and 500 represent levels of dependence 'none', 'modestly correlated', 'well correlated' and 'strongly correlated', respectively. Defra provide figures with colour-coded dependence bands and the figure presenting dependency between sea level and rainfall is shown in Figure 3.14. The figure indicates that the CF for these two variables along Britain's east coast is 2 (CF = 2), corresponding to 'independent'.

3.7.5 Based on the above results, the joint probability of intense rainfall and high sea levels was not considered further as part of this FRA.

[12] Defra and Environment Agency (2006). Guidance Document FD2321/TR2. Flood Risks to People, Phase 2. March 2006.

3.7.6 In consultation with the EA, it was agreed that the joint probability combination of baseflow and sea level will be considered for the A63 FRA. The River Hull and Holderness Drain Flood Mapping study model uses, for their joint probability scenarios, the combined joint probability conditions as presented in Table 3.8. The resulting flow hydrographs along the River Hull defences from these scenarios were applied as inputs at the relevant defence locations into the A63 FRA ICM model.

Figure 3.14: Summary dependence information for rainfall and sea level (reproduced from Defra[11])

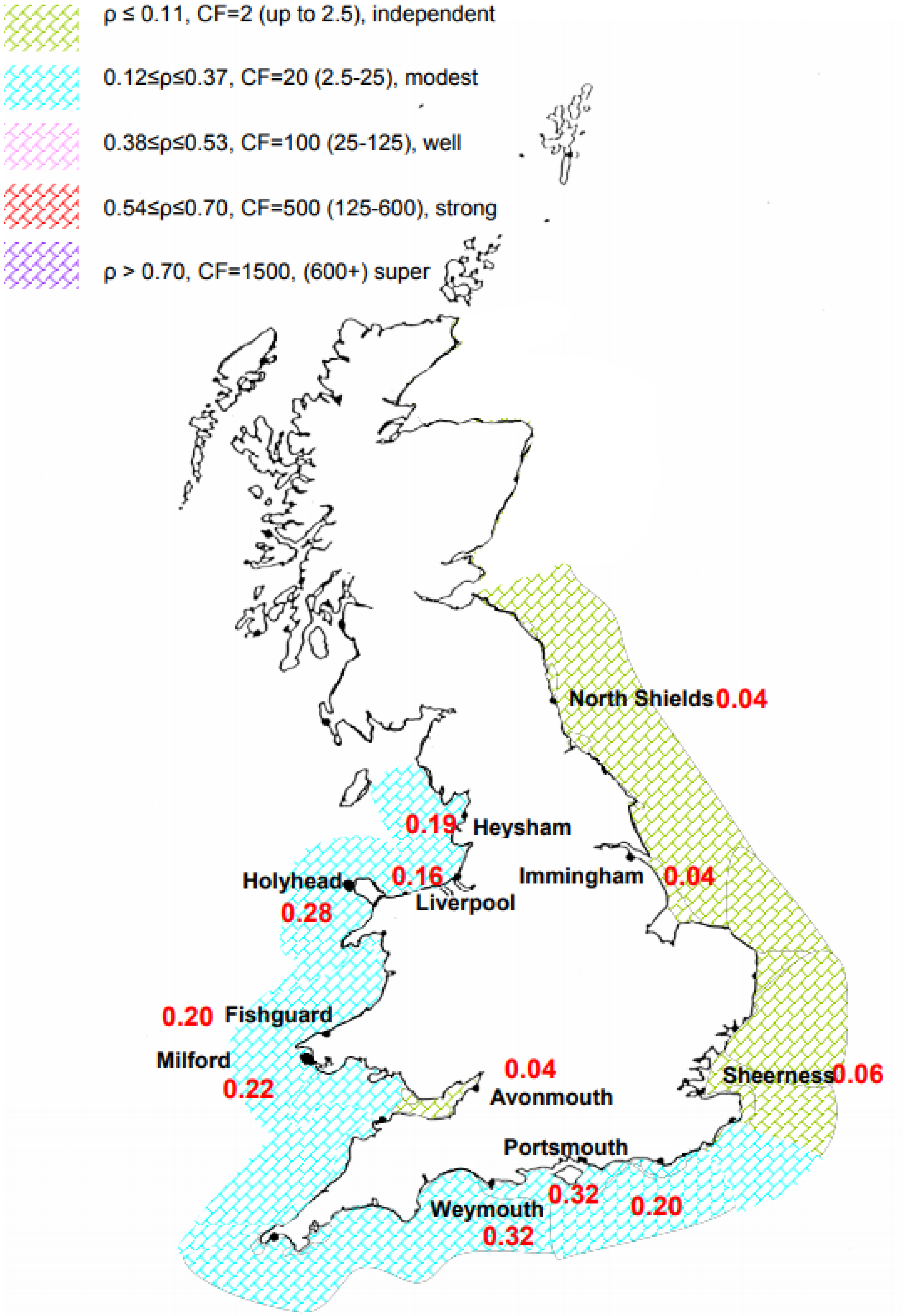


Figure 3 Summary dependence information for rainfall and sea level

4. Model summaries

4.1.1 Table 4.1 provides a summary of model files required to run the model.

Table 4.1: Model file structure

Element	Name
Master Database	A63_2018_FRA_070318.icmm
Model Network	2018 Network (scenarios)
Ground models	Baseline DTM Proposed DTM
Trade Waste Group	Hull Overall v2
Waste Water Group	All_Hull_Waste Water_v2
Flow Group	200yr Tidal Hull_short 2017 1000yr Tidal Hull_short 2017 200yr Comb Td&Fl Hull_short 2017 1000yr Comb Td&Fl Hull_short 2017 1000yr Tidal Humber 2017 200yr Tidal Humber 2017 200yr CC Tidal Humber 2017
Level Group	10yr tide (2010 CSOs only)_6hr_init 200yr CC Humber Tidal 2017 (for undefended) 200yr Humber Tidal 2017 (for undefended)
Rainfall Group	Winter 100yrCC (120min) Winter 30yr (120min) Winter 100yr (120min)

Run Group	Pluvial Only:
	• Pluvial Existing:
	    ○ 100CC
	    ○ 30
	    ○ 100
	• Pluvial Proposed
	    ○ 100CC
	    ○ 30
	    ○ 100
	Humber:
	• Defended:
	    ○ Existing
	        ▪ Existing Tidal Humber 1000yr
	        ▪ Existing Tidal Humber 200yr
	        ▪ Existing Tidal Humber 200yr + CC
	    ○ Proposed
	        ▪ Proposed Tidal Humber 1000yr
	        ▪ Proposed Tidal Humber 200yr
	        ▪ Proposed Tidal Humber 200yr + CC

Element	Name
	• Undefended: ○ Existing ▪ Existing Tidal Humber Undefended 200yr ▪ Existing Tidal Humber Undefended 200yr + CC ○ Proposed ▪ Proposed Tidal Humber Undefended 200yr ▪ Proposed Tidal Humber Undefended 200yr + CC Hull: • Existing ○ Existing Tidal/Fluvial Hull 200yr ○ Existing Tidal/Fluvial Hull 1000yr ○ Existing Tidal Hull 200yr ○ Existing Tidal Hull 1000yr • Proposed ○ Proposed Tidal/Fluvial Hull 200yr ○ Proposed Tidal/Fluvial Hull 1000yr ○ Proposed Tidal Hull 200yr ○ Proposed Tidal Hull 1000yr
Timestep	Pluvial runs: 5 All other runs: 10
Results timestep multiplier	Pluvial runs: 200 All other runs: 90

4.1.2 Table 4.2 provides a summary of model timestep, run time and mass balance errors.

Table 4.2: Model run summaries

Source of Flooding	Return Periods Modelled (years)	Baseline			Scheme		
		Timestep (s)	Runtime (min)	Volume balance Error (%)	Timestep (s)	Runtime (min)	Volume balance Error (%)
Pluvial	1 in 30	5	43	0.00	5	75	0.00
	1 in 100	5	72	0.00	5	80	0.00
	1 in 100 + CC	5	72	0.00	5	52	0.00
Tidal from the River Hull	1 in 200	10	95	0.02	10	218	0.07
	1 in 1000	10	175	0.14	10	664	0.12
Combined fluvial and	1 in 200	10	58	0.03	10	52	0.03
	1 in 1000	10	66	0.03	10	60	0.03

Source of Flooding	Return Periods Modelled (years)	Baseline			Scheme		
		Timestep (s)	Runtime (min)	Volume balance Error (%)	Timestep (s)	Runtime (min)	Volume balance Error (%)
tidal from the River Hull							
Humber wave overtopping (defended)	1 in 200	10	115	-0.05	10	84	-0.12
	1 in 1000	10	218	0.28	10	155	0.27
	1 in 200 + CC	10	226	-0.02	10	239	-0.01
Humber tidal (undefended)	1 in 200	10	399	-0.04	10	234	-0.04
	1 in 200 + CC	10	411	-0.04	10	246	-0.05

5. Results preparation and presentation

5.1.1 The modelling results were presented in the form of maps indicating flood depth across the modelled area for each scenario. The flood maps from the wave overtopping scenarios were compared to the maps representing the flood extent of the 5 December 2013 flood event in Hull. The return period of this event has not been estimated, however, the extent of the flooded area falls between the modelled 1 in 200 and 1 in 1000-year wave overtopping events.

5.1.2 The predicted behaviour of the flood propagating northwards from Albert Dock during the wave overtopping events was also presented in maps indicating the flow direction and velocity. In consultation with the EA and HCC it was agreed that the predicted flow directions compare well with the observed behaviour of the December 2013 flood.

5.1.3 The results from the existing and proposed case scenarios were compared and maps illustrating the difference in flood depth between the two scenarios were also produced. This made it possible to visually assess the flooding risk impact of the Scheme.

5.1.4 The Infoworks ICM software can estimate the maximum Flood Hazard Rating (HR) value for each mesh element during a simulation. The model calculates the HR using the Defra Hazard formula as presented in the Defra & EA FD2308/TR1[11] and Defra & EA FD2321/TR2[12]:

$$HR = d.\ (v + 0.5) + DF$$

Where:

d = depth of flooding (m)

v = velocity of floodwaters (m/s)

DF = Debris Factor

Where Debris Factor is assumed to be:

0.5 for depths < 0.25m and 1.0 for depths > 0.25m as used in Table 4 of the Explanatory Note for FD2320 and FD2321[13].

5.1.5 Table 5.1 represents the Hazard to People Classification related to each HR value. The figure has been extracted from the Supplementary Note on Flood Hazard Rating FD2320/TR2[13]. Maps illustrating the HR across the area were also generated.

5.1.6 All flood depth, hazard and velocity maps are presented in Appendix A of Volume 3 Appendix 11.2 Flood risk assessment.

[13] Defra and Environment Agency (2008). Supplementary Note on flood hazard rating and thresholds for development planning and control purpose; Clarification on Table 13.1 of FD2320/TR2 and Figure 3.2 of FD2321/TR1. May 2008.

5.1.7 In addition, numerical values from the modelling results were extracted and information regarding the size of the flooded areas by depth under different conditions was calculated. This is presented in tabulated format in Tables 10.1 and 10.2 in Volume 3 Appendix 11.2 Flood Risk Assessment.

Table 5.1: Hazard classification based on Hazard Rating (reproduced from Defra & EA[13])

HR	Depth of flooding - d (m)												
	DF = 0.5				DF = 1								
Velocity v (m/s)	0.05	0.10	0.20	0.25	0.30	0.40	0.50	0.60	0.80	1.00	1.50	2.00	2.50
0.0	0.03 + 0.5 = 0.53	0.05 + 0.5 = 0.55	0.10 + 0.5 = 0.60	0.13 + 0.5 = 0.63	0.15 + 1.0 = 1.15	0.20 + 1.0 = 1.20	0.25 + 1.0 = 1.25	0.30 + 1.0 = 1.30	0.40 + 1.0 = 1.40	0.50 + 1.0 = 1.50	0.75 + 1.0 = 1.75	1.00 + 1.0 = 2.00	1.25 + 1.0 = 2.25
0.1	0.03 + 0.5 = 0.53	0.06 + 0.5 = 0.56	0.12 + 0.5 = 0.62	0.15 + 0.5 = 0.65	0.18 + 1.0 = 1.18	0.24 + 1.0 = 1.24	0.30 + 1.0 = 1.30	0.36 + 1.0 = 1.36	0.48 + 1.0 = 1.48	0.60 + 1.0 = 1.60	0.90 + 1.0 = 1.90	1.20 + 1.0 = 2.20	1.50 + 1.0 = 2.55
0.3	0.04 + 0.5 = 0.54	0.08 + 0.5 = 0.58	0.15 + 0.5 = 0.65	0.19 + 0.5 = 0.69	0.23 + 1.0 = 1.23	0.30 + 1.0 = 1.30	0.38 + 1.0 = 1.38	0.45 + 1.0 = 1.45	0.60 + 1.0 = 1.60	0.75 + 1.0 = 1.75	1.13 + 1.0 = 2.13	1.50 + 1.0 = 2.50	1.88 + 1.0 = 2.88
0.5	0.05 + 0.5 = 0.55	0.10 + 0.5 = 0.60	0.20 + 0.5 = 0.70	0.25 + 0.5 = 0.75	0.30 + 1.0 = 1.30	0.40 + 1.0 = 1.40	0.50 + 1.0 = 1.50	0.60 + 1.0 = 1.60	0.80 + 1.0 = 1.80	1.00 + 1.0 = 2.00	1.50 + 1.0 = 2.50	2.00 + 1.0 = 3.00	2.50 + 1.0 = 3.50
1.0	0.08 + 0.5 = 0.58	0.15 + 0.5 = 0.65	0.30 + 0.5 = 0.80	0.38 + 0.5 = 0.88	0.45 + 1.0 = 1.45	0.60 + 1.0 = 1.60	0.75 + 1.0 = 1.75	0.90 + 1.0 = 1.90	1.20 + 1.0 = 2.20	1.50 + 1.0 = 2.50	2.25 + 1.0 = 3.25	3.00 + 1.0 = 4.00	3.75 + 1.0 = 4.75
1.5	0.10 + 0.5 = 0.60	0.20 + 0.5 = 0.70	0.40 + 0.5 = 0.90	0.50 + 0.5 = 1.00	0.60 + 1.0 = 1.60	0.80 + 1.0 = 1.80	1.00 + 1.0 = 2.00	1.20 + 1.0 = 2.20	1.60 + 1.0 = 2.60	2.00 + 1.0 = 3.00	3.00 + 1.0 = 4.00	4.00 + 1.0 = 5.00	5.00 + 1.0 = 6.00
2.0	0.13 + 0.5 = 0.63	0.25 + 0.5 = 0.75	0.50 + 0.5 = 1.00	0.63 + 0.5 = 1.13	0.75 + 1.0 = 1.75	1.00 + 1.0 = 2.00	1.25 + 1.0 = 2.25	1.50 + 1.0 = 2.50	2.00 + 1.0 = 3.00	3.50	4.75	6.00	7.25
2.5	0.15 + 0.5 = 0.65	0.30 + 0.5 = 0.80	0.60 + 0.5 = 1.10	0.75 + 0.5 = 1.25	0.90 + 1.0 = 1.90	1.20 + 1.0 = 2.20	1.50 + 1.0 = 2.50	1.80 + 1.0 = 2.80	3.40	4.00	5.50	7.00	8.50
3.0	0.18 + 0.5 = 0.68	0.35 + 0.5 = 0.85	0.70 + 0.5 = 1.20	0.88 + 0.5 = 1.38	1.05 + 1.0 = 2.05	1.40 + 1.0 = 2.40	1.75 + 1.0 = 2.75	3.10	3.80	4.50	6.25	8.00	9.75
3.5	0.20 + 0.5 = 0.70	0.40 + 0.5 = 0.90	0.80 + 0.5 = 1.30	1.00 + 0.5 = 1.50	1.20 + 1.0 = 2.20	1.60 + 1.0 = 2.60	3.00	3.40	4.20	5.00	7.00	9.00	11.00
4.0	0.23 + 0.5 = 0.73	0.45 + 0.5 = 0.95	0.90 + 0.5 = 1.40	1.13 + 0.5 = 1.63	1.35 + 1.0 = 2.35	1.80 + 1.0 = 2.80	3.25	3.70	4.60	5.50	7.75	10.00	12.25
4.5	0.25 + 0.5 = 0.75	0.50 + 0.5 = 1.00	1.00 + 0.5 = 1.50	1.25 + 0.5 = 1.75	1.50 + 1.0 = 2.50	2.00 + 1.0 = 3.00	3.50	4.00	5.00	6.00	8.50	11.00	13.50
5.0	0.28 + 0.5 = 0.78	0.60 + 0.5 = 1.10	1.10 + 0.5 = 1.60	1.38 + 0.5 = 1.88	1.65 + 1.0 = 2.65	3.20	3.75	4.30	5.40	6.50	9.25	12.00	14.75

Flood Hazard Rating (HR)	Colour Code	Hazard to People Classification
Less than 0.75		Very low hazard - Caution
0.75 to 1.25		Danger for some – includes children, the elderly and the infirm
1.25 to 2.0		Danger for most – includes the general public
More than 2.0		Danger for all – includes the emergency services

6. Model limitations

6.1.1 The following section discusses assumptions and limitations relating to the modelling process.

6.1.2 As discussed in Section 3.1.3, the modelled 2D zone covers an area of 1 km radius around the Scheme site. While the drainage network beyond the 2D zone is included in the 1D sewer network component of the model, the overland flow coming from or flowing towards this area is not accounted for. However, it is considered that 1 km radius around the Scheme site is sufficient to represent the flood risk to the site and the surrounding areas, and the potential changes in flood flow paths around the Scheme.

6.1.3 As mentioned in Section 3.1.4, infiltration areas were not applied in the model, since the area in and around the Scheme is heavily urbanised and predominantly impermeable.

6.1.4 There is uncertainty around the choice of runoff model applied to the sub-catchments for the pluvial flooding scenarios.

6.1.5 The details of the proposed highway drainage are not included in the model. The reasons for adopting this conservative approach are discussed in Section 3.2.8.

6.1.6 One of the main areas of uncertainty was related to the use of third party data in the modelling assessment. The use of a combination of data from different sources could increase the risk of data inconsistency and the propagation of errors. Nonetheless the results from the A63 FRA modelling work show consistency with the results from previous studies, which give confidence in the modelling approach and input data selection.

6.1.7 There is uncertainty resulting from the processing of the proposed ground elevation model data. The ground elevation model for the Scheme was developed as a detailed 3D contour design drawing. However, the process of generating a ground mesh used in Infoworks ICM involves multiple steps, such as creating surface rasters for the proposed section of the road and merging it with the existing raster prior to importing it into the ICM software, to produce a surface mesh. These multiple transformations may to some extent decrease the integrity of the final ground elevation model, and although every care was taken to identify errors, some fine details may not be represented accurately. Nevertheless, it is considered that the generated existing and proposed ground surface models are suitable for the purposes of this assessment.