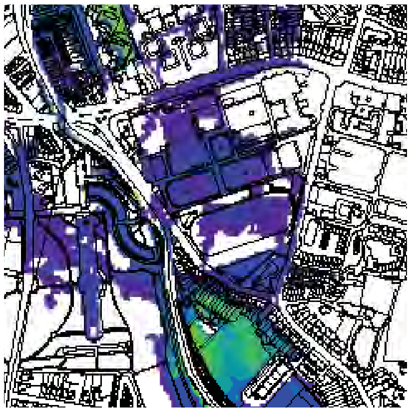
RPS

NORTH WESTERN
NEAGH BANN
CFRAM
STUDY
CATCHMENT FLOOD RISK
ASSESSMENT AND MANAGEMENT

North Western - Neagh Bann CFRAM Study

UoM 06 Hydraulics Report
4.5 Carlingford

IBE0700Rp0012



OPW
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Photographs of flooding on cover provided by Rivers Agency

NWNB CFRAM Study
HA06 Hydraulics Report
Carlingford Model

DOCUMENT CONTROL SHEET

Client	OPW
Project Title	NWNB CFRAM Study
Document Title	IBE0700Rp0012_HA06 Hydraulics Report
Model Name	Carlingford

Rev.	Status	Author(s)	Modeller	Reviewed by	Approved By	Office of Origin	Issue Date
D01	Draft	T. Carberry	C. Lewis	I Bentley	G, Glasgow	Belfast/Limerick	14/03/2014
D02	Draft	T. Carberry	C. Lewis	I Bentley	G, Glasgow	Belfast/Limerick	20/06/2014
F01	Draft	E. Holland	C. Lewis	L. Arbuckle	G. Glasgow	Belfast	12/12/2014
F02	Draft	E. Holland	C. Lewis	L. Arbuckle	G. Glasgow	Belfast	13/08/2015
F03	Draft Final	E. Holland	E. Holland	S. Patterson	G. Glasgow	Belfast	06/07/2016

Table of Reference Reports

Report	Issue Date	Report Reference	Relevant Section
North Western Neagh Bann CFRAM Study Flood Risk Review	**May 2012**	**2011s5232 NW&NB CFRAM FRR Report_Final**	**Executive Summary**
North Western Neagh Bann CFRAM Study UoM06 Inception Report	**March 2013**	**IBE0700Rp0003_UoM 06 Inception Report**	**4.3.2**
North Western Neagh Bann CFRAM Study Hydrology Report UoM06	**October 2013**	**IBE0700Rp0008_UoM 06 Hydrology Report**	**4.2, 8.1**
North Western Neagh Bann CFRAM Study Hydraulics Report	**May 2014**	**IBE0700Rp0012_UoM 06_Hydraulics Report**	**3**
North Western Neagh Bann CFRAM HA01_06_36 Survey Contract Report	**October 2013**	**IBE0700Rp0007_HA01_06_36 NWNB_CFRAM_Survey Contract Report**	**1.6, 1.12, 1.16**

4 HYDRAULIC MODEL DETAILS

4.8 CARLINGFORD MODEL

4.8.1 General Hydraulic Model Information

(1) Introduction:

The NWNB CFRAM Flood Risk Review (2011s5232 NW&NB CFRAM FRR Report_Final_v2.0) highlighted Carlingford as an AFA for fluvial flooding, and coastal flooding - 'mechanism 1 tidal' flooding and 'mechanism 2 wave overtopping' - based on a review of historic flooding and the extents of flood risk determined during the PFRA.

Carlingford AFA is located at the foot of Carlingford Mountain and Slieve Foye and on the shores of Carlingford Lough. Fluvial flood risk emanates from three small watercourses.

The Carlingford River model represents one small steep watercourse which rises in the eastern foothills of Carlingford Mountain/Slieve Foy and flows eastwards to the harbour within the village. The catchment area at the downstream limit HEPs is 0.9km^2.

The Carlingford Commons River modelled reaches includes represents a small steep watercourse from the mountains and its tributary, Liberties of Carlingford, which flows through the relatively flat lands to the south of the village. The catchment area at the downstream limit HEP (where it discharges to the harbour) is 2.7km^2.

There are no gauging station sites within the modelled reaches and as such the model is ungauged for the purposes of flow estimation.

The nearest (hydrologically and geographically) gauging station is Stn no. 06030, Ballygoly. It is located 3km south west of the modelled catchment on the Big River which receives small steep tributaries flowing down the western foothills of Slieve Foy. It is rated as B under FSU so confidence in flow values is limited to a maximum of Q_{med}. However the data from this station was used to adjust initial Q_{med} estimates within the model using an adjustment factor of 1.71 since the Ballygoly station represents data from a small catchment in the Cooley Mountains and drains part of the same land form (Slieve Foy). Refer to UoM 06 Hydrology Report Rp0008_F01, Chapter 4.2, for full details on hydrology estimation for this model.

All three rivers within the Carlingford AFA are HPW and are under tidal influence in their lower reaches. Therefore these watercourses have been modelled as 1D-2D using the MIKE suite software. Channel markers have been located at the right and left banks of all cross-sections. Flow within these markers is calculated by the 1D model component; however when the water level rises sufficiently to meet the bank markers flow can enter the 2D domain which represents the floodplain. These two models are coupled through MIKE FLOOD; refer to Chapter 3.1 for further details. This approach is

<table>
<tr><td colspan="3">also considered the most appropriate given the significant potential for tidal inundation.</td></tr>
<tr><td>(2) Model Reference:</td><td colspan="2">HA06_CARL2</td></tr>
<tr><td>(3) AFAs included in the model:</td><td colspan="2">CARLINGFORD</td></tr>
<tr><td colspan="3">(4) Primary Watercourses / Water Bodies (including local names):</td></tr>
<tr><td colspan="3"><u>Reach ID</u> <u>Name</u>
0630M CARLINGFORD
0631M CARLINGFORD COMMONS
0632M LIBERTIES OF CARLINGFORD
0632A* LIBERTIES OF CARLINGFORD TRIB 1*
*0632A was removed from the model due to lack of data to describe the flow there. Also it is a relatively short reach therefore flow from this tributary has been taken account of in the Top-up flow between 06_515_U and 06_847_3. The storage related to the tributary is taken account of in the 2-D domain.</td></tr>
<tr><td colspan="3">(5) Software Type (and version):</td></tr>
<tr><td>(a) 1D Domain:
MIKE 11 (2012)</td><td>(b) 2D Domain:
MIKE 21 - Rectangular Mesh (2012) ('Mechanism 1 tidal' and fluvial flooding)
MIKE 21 - Flexible Mesh (2012) ('Mechanism 2 wave overtopping' flooding)</td><td>(c) Other model elements:
MIKE FLOOD (2012)</td></tr>
</table>

4.8.2 Hydraulic Model Schematisation

(1) Map of Model Extents:

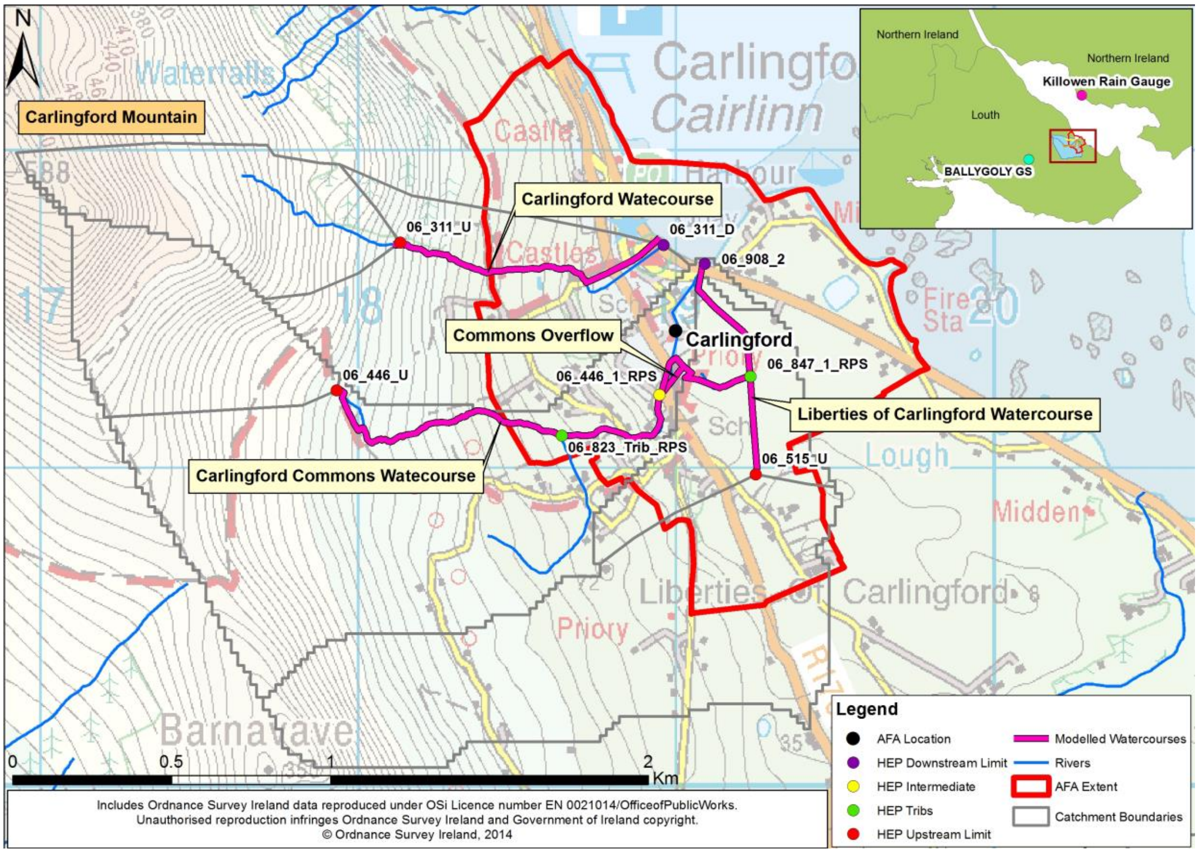


Figure 4.8.1: Map of Model Extent

Figure 4.8.1 illustrates the extent of the modelled catchment, river centre line, HEP locations and AFA extents. The Carlingford, Carlingford Commons and Liberties of Carlingford Catchments are all HPWs.

The Carlingford catchment contains 1no. Upstream Limit HEP, 1no. Downstream Limit HEP and does not have any Tributary HEPs.

The Carlingford Commons modelled reach contains 1no. Upstream Limit HEP, 1no. Tributary HEP and 1no. Intermediate HEP. T

The Liberties of Carlingford modelled reach has 1no. Upstream Limit HEP, 1no. Tributary HEP, (for the Carlingford Commons tributary) and 1no. Downstream Limit HEP.

The figure insert shows the location of the Ballygoly Hydrometric Station (06030) and Killowen hourly rain gauge in relation to the AFA. The Killowen rain gauge, located in County Down has the only rainfall data available of high enough temporal resolution and accuracy for use in verifying the simulated design events (refer to Uom 06 Hydrology Report, Rp0008_F01, Chapter 1)

(2) x-y Coordinates of River (Upstream extent):

Table 4.8.1: Upstream Extent of Rivers within Carlingford AFA

River Name		**Easting**	**Northing**
0630M	CARLINGFORD	318108	311703
0631M	CARLINGFORD COMMONS	317936	311252
0632M	LIBERTIES OF CARLINGFORD	319250	310980

(3) Total Modelled Watercourse Length:		3.5 km	
(4) 1D Domain only Watercourse Length:	0km	**(5) 1D-2D Domain Watercourse Length:**	3.5 km
(6) 2D Domain Mesh Type / Resolution / Area:		Rectangular / 5 metres / 2.1 km^2	

The primary reason for selecting the 5m grid cell size was that the data provided by the LiDAR to describe the topography has a resolution of 5m. Selecting a smaller cell size would not increase the accuracy of the model.

There was also the issue of balancing the requirement to resolve key features within the model domain with practical model set-up issues. Should the grid cell size be reduced further, this creates major stability issues which are difficult to resolve. Reducing the time-step as an initial approach to reducing these instabilities generates unfeasible model runtimes in this case. Therefore the grid cell size selected is considered optimum for the model.

(7) 2D Domain Model Extent:

Figure 4.8.2 below illustrates the modelled extents and the general topography for the Carlingford model. The black lines depict the modelled 1D extent of the Carlingford River to the north, Carlingford Commons and the Liberties of Carlingford to the south. Along the coastline at Carlingford Harbour the flood defence walls are represented by pink lines. Buildings are excluded from the mesh and therefore represented as white spaces. Refer to Chapter 3 for details on representation of buildings in the model.

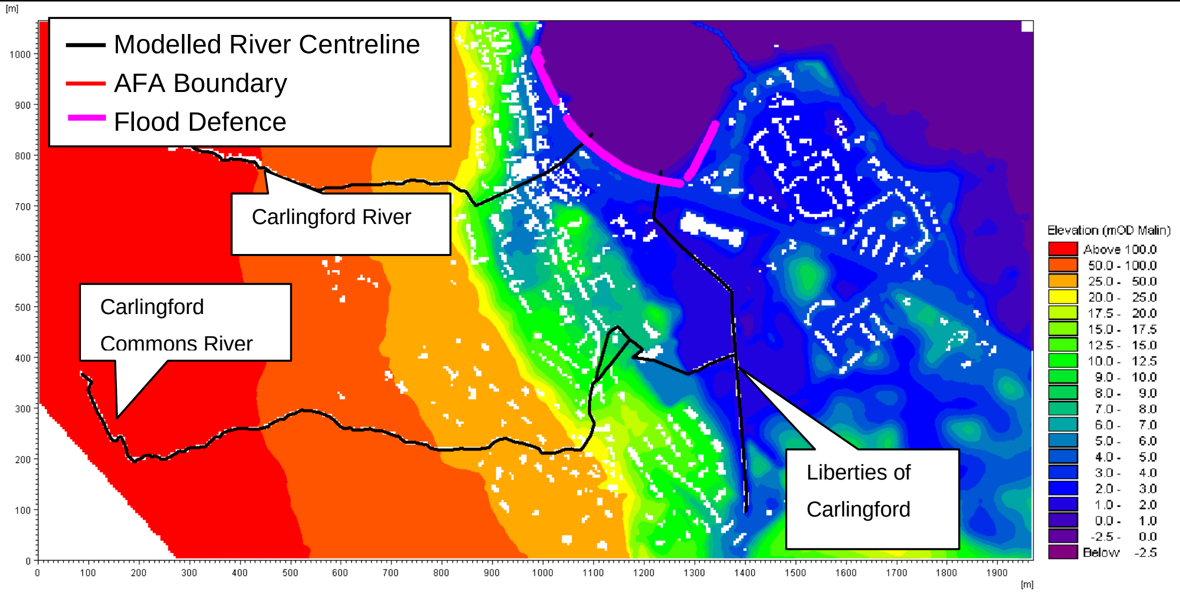


Figure 4.8.2: 2D Model Extent

Figure 4.8.3 shows an overview drawing of the model schematisation. Figure 4.8.4 shows a more detailed view. The overview diagram covers the model extents, showing the surveyed cross-section locations, AFA boundary and river centre line. It also shows the area covered by the 2D model domain. Figure 4.8.4 shows the detailed area where there is the most significant risk of flooding. These diagrams include the surveyed cross-section locations, AFA boundary and river centre. Figure 4.8.4 shows the location of the critical structures as discussed in Section 4.8.3 (1), along with the location and extent of the links between the 1D and 2D models.

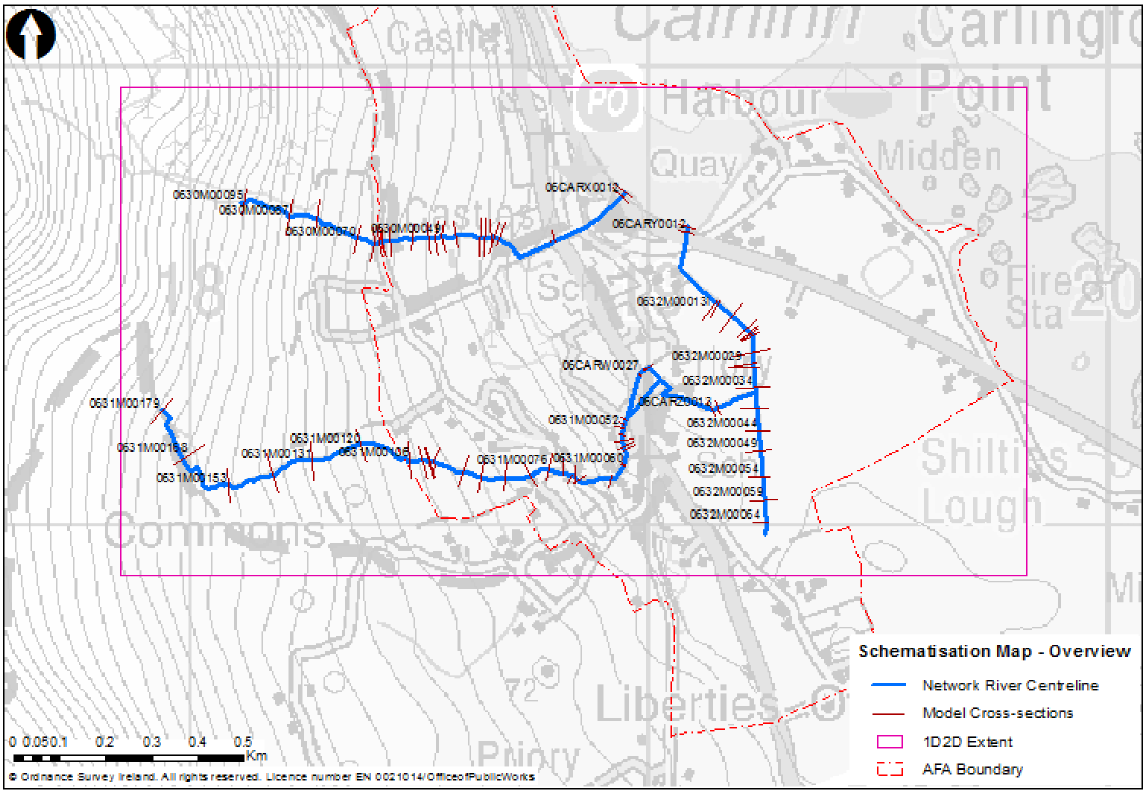


Figure 4.8.3: Overview Drawing of Model Schematisation

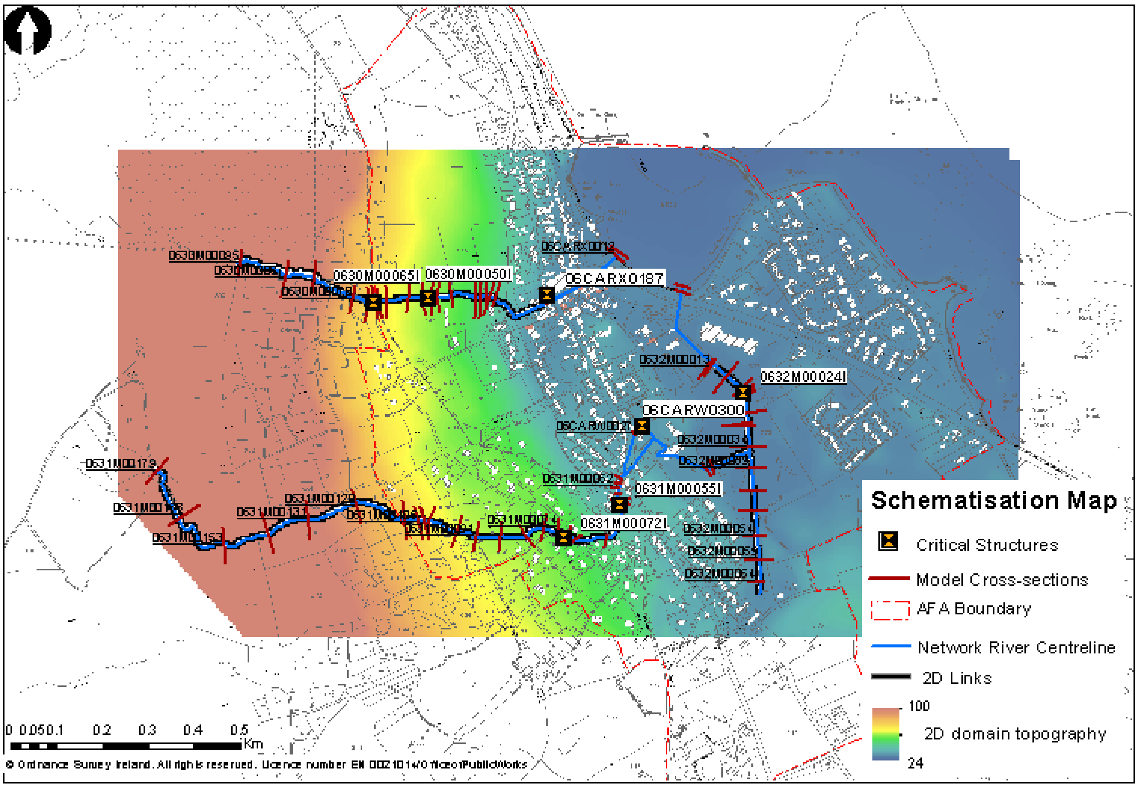


Figure 4.8.4: Detailed Area of Model Schematisation showing Critical Structures

Wave Overtopping Model

Figure 4.8.5 illustrates the extents of the specific 2D domain used during the wave overtopping runs to analyse 'mechanism 2 wave overtopping' flooding in the Carlingford AFA. There are two ICWWS CAPO Prediction Locations applicable to the coastline as labelled and shown as a red line in Figure 4.8.5. It should be noted that this model area is considerably smaller than the overall model for analysing fluvial and 'mechanism 1 tidal' flooding since the area of interest is much more localised.

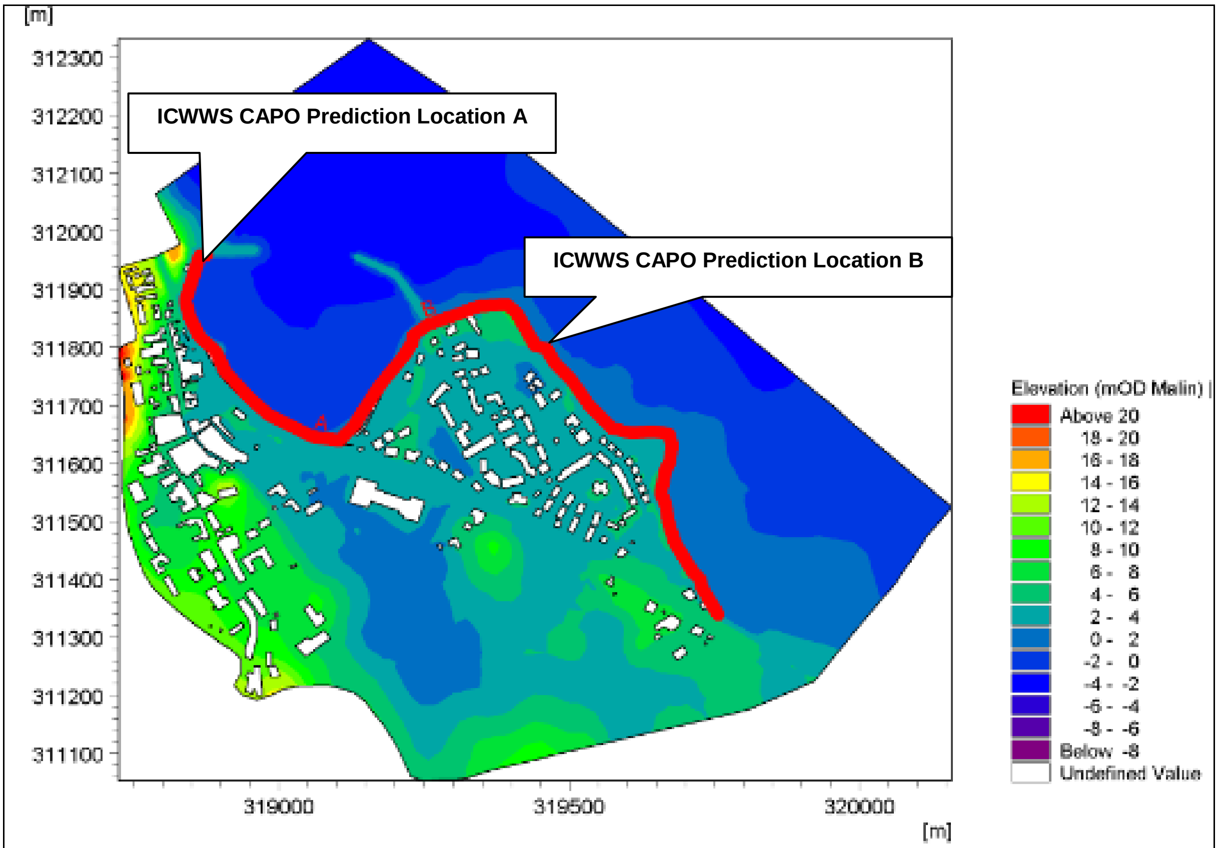


Figure 4.8.5: 2D Domain Model Extent - Wave Overtopping

(8) Survey Information		
(a) Survey Folder Structure:		
First Level Folder	**Second Level Folder**	**Third Level Folder**
Murphy_NW6_M02_WP6A3_0630M_V1_130215 *Carlingford* Murphy: Surveyor Name NW6: North Western CFRAM Study Area, Hydrometric Area 6 M02: Model Number 2 0630M: River Reference WP6A3: Work Package 6A3 Version: V1 *130215*: Date Issued (15th FEB 2013)	V0_20130215_ASCII	
	V0_20130215_Other	FP Photos
	V1_20130222_Dwg	5921_0630M_Carlingford_V1
	Photos *(Naming convention is in the format of Cross-Section ID and orientation - upstream, downstream, left bank or right bank)*	

(b) Survey Folder References:

Table 4.8.2

Reach ID	**Name**	**File Ref.**
0630M	CARLINGFORD	*Murphy_NW6_M02_WP6A3_0630M_V1_130215*
0631M	CARLINGFORD COMMONS	Murphy_NW6_M02_WP6A3_0631M_V1_130215
0632M	LIBERTIES OF CARLINGFORD	Murphy_NW6_M02_WP6A3_0632M_V1_130215

The bathymetry of the 2D model used depth information extracted from CMAP, LiDAR and the topographic surveys carried out for this study. CMAP data provided depth information for the Carlingford Lough area of the domain. Further details on the bathymetry data sources are presented in Chapter 2.2.3.

(9) Survey Issues:

(a)Survey Issue Raised

Watercourse Name:
Carlingford Commons (0631M)
Liberties of Carlingford (0632M)

Grid ref:
319100 311500 (approx).

Location:
Downstream extents of Carlingford Commons and Liberties of Carlingford watercourses.

RPS Comments:
At Carlingford, the downstream extents of Carlingford Commons (0631M) and Liberties of Carlingford (0632M) have incorrect centrelines, see Figure 4.8.6, and require extra sections. Barry Woods (Area Engineer) was contacted about the watercourses and his response was as follows:

"The Carlingford Commons “watercourse” exits St Michaels terrace and is culverted across Dundalk Street before discharging into the old Mill Race that runs parallel to the school boundary wall. This mill race then flows towards the site of the old mill, (now long gone) before making its way into the Carlingford Liberties “watercourse” somewhere to the rear of the Four Seasons Hotel Site. This watercourse then makes its way towards the Ghan House property, where it is culverted and exits at the chamber at the Ghan Road, just at the rear of the collapsed wall. (It is my understanding that these watercourses do not discharge to the lake near Ghan House.) From here it flows into the old Railway Culvert which crosses the Ghan Road and the R176 before discharging into the harbour."

Screen Shot of Location:

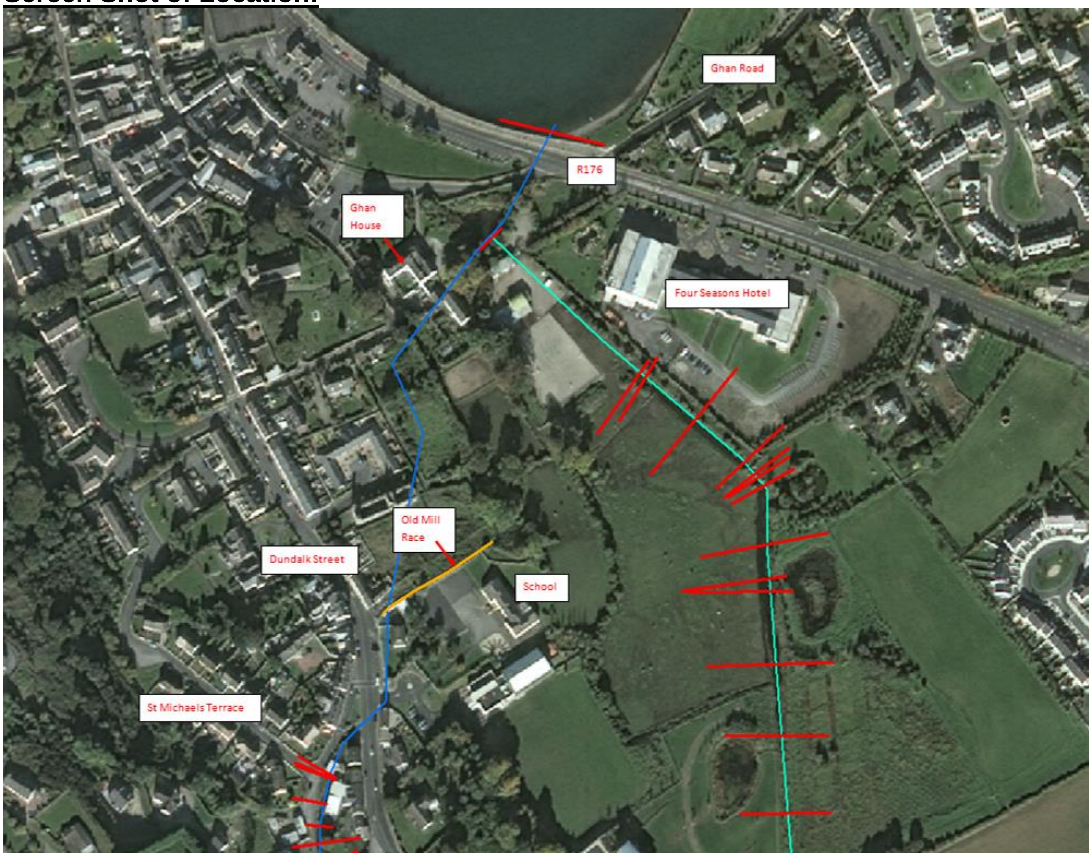


Figure 4.8.6: Screenshot of Survey Query with the Original River Centrelines

Survey Requirements:

It is not possible to establish the exact route of the watercourses from aerial photography, so we require the centrelines of both Carlingford Commons and Liberties of Carlingford watercourses to be located, and sections to be taken in accordance with the survey specification for HPWs.

Outcome of Infill Survey

April 2014, Six West Ltd carried out an infill survey of the lower reaches of three watercourses within the Carlingford AFA the Carlingford (0630M), the Carlingford Commons (0631M) and the Liberties of Carlingford (0632M). The aim of the survey was to determine the definite centrelines of the lower reaches and to confirm the presence and type of any structures at these surveyed sections.

The Carlingford Watercourse (0630M) downstream extent was found to have a new centreline (ID: 06CARX) while the downstream open boundary remained the same, see Figure 4.8.7. The twin culvert, 06CARX0187I, at 318791E and 311631N was surveyed and cross-sections were provided for both the inlet and outlet of the structure.

The Carlingford Commons Watercourse (0631M) downstream extent was found to have a new centreline (ID: 06CARZ) , see Figure 4.8.7.. The Carlingford Commons was also found to have a

different downstream extent than that originally considered. The Carlingford Commons watercourse was found to discharge into the Liberties of Carlingford at chainage 311.245.

The twin culvert, 06CARZ0300I, at 318945E and 311253N was surveyed and cross-sections were provided for both the inlet and outlet of the structure. The survey also revealed an overflow route (ID: 06CARW) that branches off from the main watercourse at 318945E and 311253N and links back into the main watercourse again at 319019E and 311253N. This section of the watercourse is the open channel described by Barry Woods prior to the survey as the watercourse "that is culverted across Dundalk Street before discharging into the old Mill Race that runs parallel to the school boundary wall. This Mill race then flows towards the site of the old mill, (now long gone) before making its way into the Carlingford Liberties “watercourse” somewhere to the rear of the Four Seasons Hotel Site".

The Liberties of Carlingford Watercourse (0632M) downstream extent was found to have a new centreline (ID: 06CARY) while the downstream open boundary remained the same, see Figure 4.8.7. There were no additional structures surveyed.

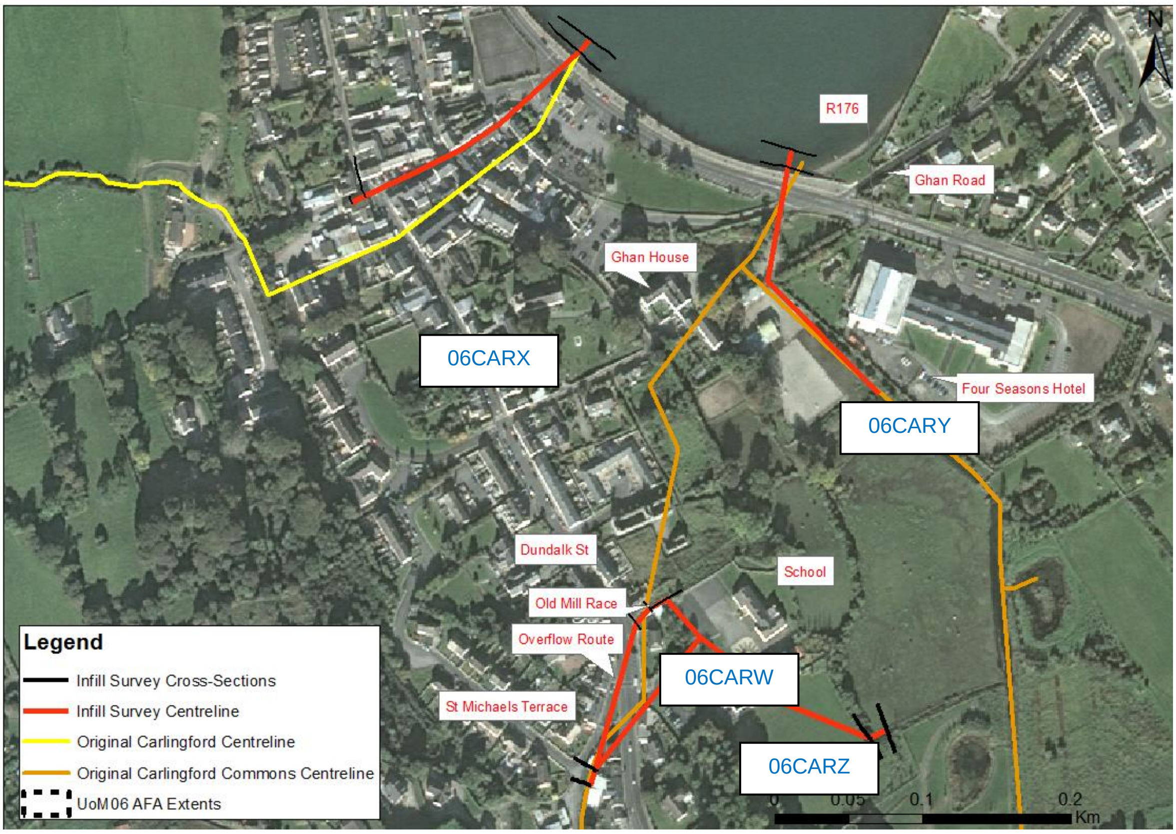


Figure 4.8.7: Screenshot of Survey Query with Infill Survey River Centrelines and Cross-Sections

(b)Infill Survey Structure:		
First Level Folder	**Second Level Folder**	**Third Level Folder**

69WEST_NW6_M02_INFILL_ Culverts_FINAL_140519 Murphy: Six West NW6: North Western CFRAM Study Area, Hydrometric Area 6 M02: Model Number 2 06CARW: River Reference WP6A3: Work Package 6A3 Version: V1 *130519*: Date Issued (19th MAY 2014)	V2_20140519_ASCII V0_20140519_Photos V2_20140519_Dwg Photos *(Naming convention is in the format of Cross-Section ID and orientation - upstream, downstream, left bank or right bank)*	

(c) Infill Survey Folder References:

Reach ID **Name**	**File Ref.**
06CARW Carlingford Commons Overflow	*69WEST_NW6_M02_INFILL_Culverts_FINAL_140519*
06CARX Carlingford	69WEST_NW6_M02_INFILL_Culverts_FINAL_140519
06CARY Liberties of Carlingford	69WEST_NW6_M02_INFILL_Culverts_FINAL_140519
06CARZ Carlingford Commons	69WEST_NW6_M02_INFILL_Culverts_FINAL_140519

4.8.3 Hydraulic Model Construction

(1) 1D Structures (in-channel along modelled watercourses):	See Appendix A.1 Number of Bridges and Culverts: 13 Number of Weirs: 1

The survey information recorded includes a photograph of each structure, which has been used to determine the Manning's n value. Further details are included in Chapter 3.5.1. A discussion on the way structures have been modelled is included in Chapter 3.3.4.

The location of critical structures included in the model is presented in Figure 4.8.5. Details of these structures are also presented in Appendix A.1.

On the Carlingford Branch 0630M, culvert 0630M00065I (Figure 4.8.8) at chainage 337.857m contributes to fluvial flooding. This is attributed to the insufficient capacity of culvert, which causes the flow to back up and breach mainly the left bank for fluvial dominated 1% and 0.1% AEP events

Figure 4.8.8: 0630M00065I (Upstream Face) 0630M00067 (Downstream Face)

On the Carlingford Branch 0630M, culvert 0630M00050I (Figure 4.8.9) at chainage 577.671m contributes to fluvial flooding. This is attributed to the insufficient capacity of culvert, which causes the flow to back up and breach both left and right banks during fluvial dominated 0.1%AEP event.

Figure 4.8.9: 0630M00050I (Upstream Face) 0630M00049 (Downstream Face)

On the Carlingford Branch 0630M, culvert 06CARX0187 (Figure 4.8.10) at chainage 753.5 m is critical to the fluvial flooding in the area. Flooding upstream of the culvert is attributed to the insufficient capacity of culvert and blockage (see trash screen), which causes the flow to back up and breach mainly the left bank during all modelled fluvial dominated AEP events.

Figure 4.8.10: 06CARX0187 (Upstream Face) 06CARX0012I (Downstream Face)

On the Carlingford Commons Branch 0631M, culvert 0631M00072I (Figure 4.8.11) at chainage 1097.65 m contributes to fluvial flooding. Flooding upstream of this culvert is attributed to the insufficient capacity of culvert, which causes the flow to back up and flood out both left and right banks during a fluvial dominated 10% AEP simulated event.

Figure 4.8.11: 0631M00072I (Upstream Face) 0631M00069J (Downstream Face)

On the Carlingford Commons Branch 0631M, culvert 0631M00055I (Figure 4.8.12) at chainage 1280.465 m contributes to fluvial flooding. Flooding upstream of this culvert is attributed to the insufficient capacity of culvert, which causes the flow to back up and flood out both left and right banks during a fluvial dominated 10% AEP simulated event.

Figure 4.8.12: 0631M00055I (Upstream Face) 0631M00054J (Downstream Face)

On the Carlingford Commons Branch 0631M, culvert 06CARW0300I (Figure 4.8.13) at chainage 1348 m is critical to the fluvial flooding in the area. Flooding upstream of the culvert is attributed to the insufficient capacity of culvert and blockage (see trash screen), which causes the flow to back up and flood out both left and right banks during all fluvial dominated AEP events simulated.

Figure 4.8.13: 06CARW0300I (Upstream Face) 06CARW0013I (Downstream Face)

On the Liberties of Carlingford Branch 0632M, culvert 0632M00024I (Figure 4.8.14) at chainage 442.821 m is critical to the fluvial flooding in the area. Flooding upstream of the culvert is attributed to the insufficient capacity of culvert which causes the flow to back up and flood out both left and right banks during all fluvial dominated AEP events simulated.

Figure 4.8.14: 0632M00024I (Upstream Face) 0632M00022J (Downstream Face)

(2) 1D Structures in the 2D domain (beyond the modelled watercourses):	None
(3) 2D Model structures:	None

(4) Defences:

Type	Watercourse	Bank	Model Start Chainage (approx.)	Model End Chainage (approx.)
WALL	COASTAL	COASTAL FRONT	-	-

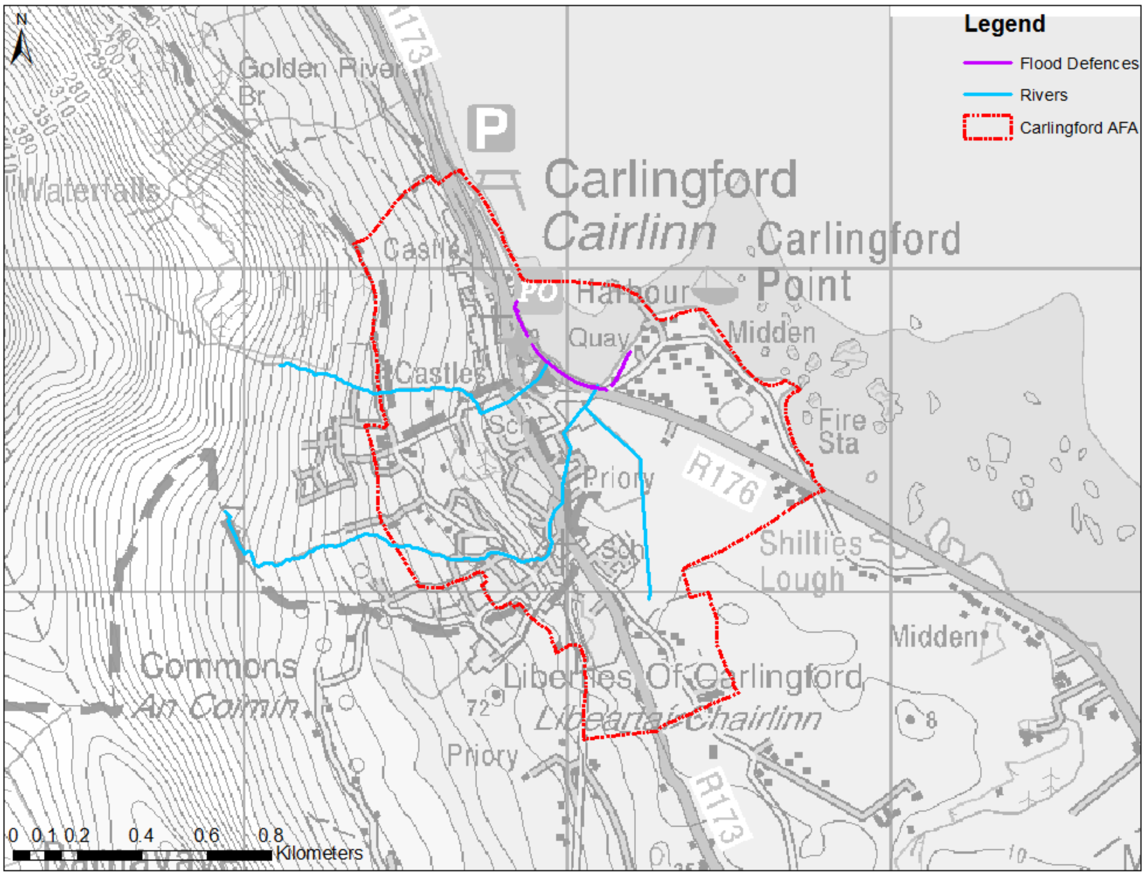


Figure 4.8.15: Coastal Walls at Carlingford Harbour

Figure 4.8.16: Carlingford Coastal Wall

(5) Model Boundaries - Inflows:

Full details of the flow estimates are provided in the Hydrology Report (IBE0700Rp0008_UoM06 Hydrology Report_D01 - Section 4.2 and Appendix D). The boundary conditions implemented in the model are in Table 4.8.3.

Table 4.8.3: MIKE11 Model Boundary Conditions

	Boundary Description	Boundary Type	Branch Name	Chainage	Chainage	Gate ID	Boundary ID
1	Open	Inflow	Carlingford	0	0		06_311_U
2	Distributed Source	Inflow	Carlingford	0	738		Top-up flow between 06_311_U & 06_311_D
3	Open	Inflow	Carlingford Commo	0	0		06_446_U
4	Distributed Source	Inflow	Carlingford Commo	0	1334		Top-up flow between 06_446_U & 06_446_1_RPS
5	Point Source	Inflow	Carlingford Commo	893.89496	0		06_823_Trib_RPS
6	Open	Inflow	Liberties of Carlingfo	0	0		06_515_U
7	Distributed Source	Inflow	Liberties of Carlingfo	0	311.6		Top-up flow between 06_515_U & 06_847_1_RPS
8	Distributed Source	Inflow	Carlingford Commo	1620.6	1718		Top-up flow between 06_446_1_RPS & 06_847_1_RPS
9	Distributed Source	Inflow	Liberties of Carlingfo	311.6	728.57		Top-up flow between 06_847_1_RPS & 06_908_2
10	Open	Water Level	Carlingford	929.89	0		-0.45m
11	Open	Water Level	Liberties of Carlingfo	734	0		0.38m

The upstream boundary of the Carlingford catchment is located at HEP 06_311_U; the model node ID at this location is 0630M00095. A point inflow was therefore applied at this node to account for flow entering the Carlingford watercourse upstream of this location. A distributed source has been applied evenly to all nodes downstream of this point to account for flow entering the Carlingford watercourse downstream of the Upper Limit HEP.

The upstream boundary of the Carlingford Commons catchment is located at HEP 06_446_U; the model node ID at this location is 0631M00179. A point inflow was therefore applied at this node to account for flow entering the Carlingford Commons watercourse upstream of this location. A distributed source has been applied evenly to all nodes downstream of this point to account for flow entering the Carlingford Commons watercourse downstream of the Upper Limit HEP.

The upstream boundary of the Liberties of Carlingford catchment is located at HEP 06_515_U; the model node ID at this location is 0632M00064. A point inflow was therefore applied at this node to account for flow entering the Liberties of Carlingford watercourse upstream of this location. A distributed source has been applied evenly to all nodes downstream of this point to account for flow entering the Liberties of Carlingford watercourse downstream of the Upper Limit HEP.

Figure 4.8.17 shows the associated 1% AEP upstream hydrographs generated and used.

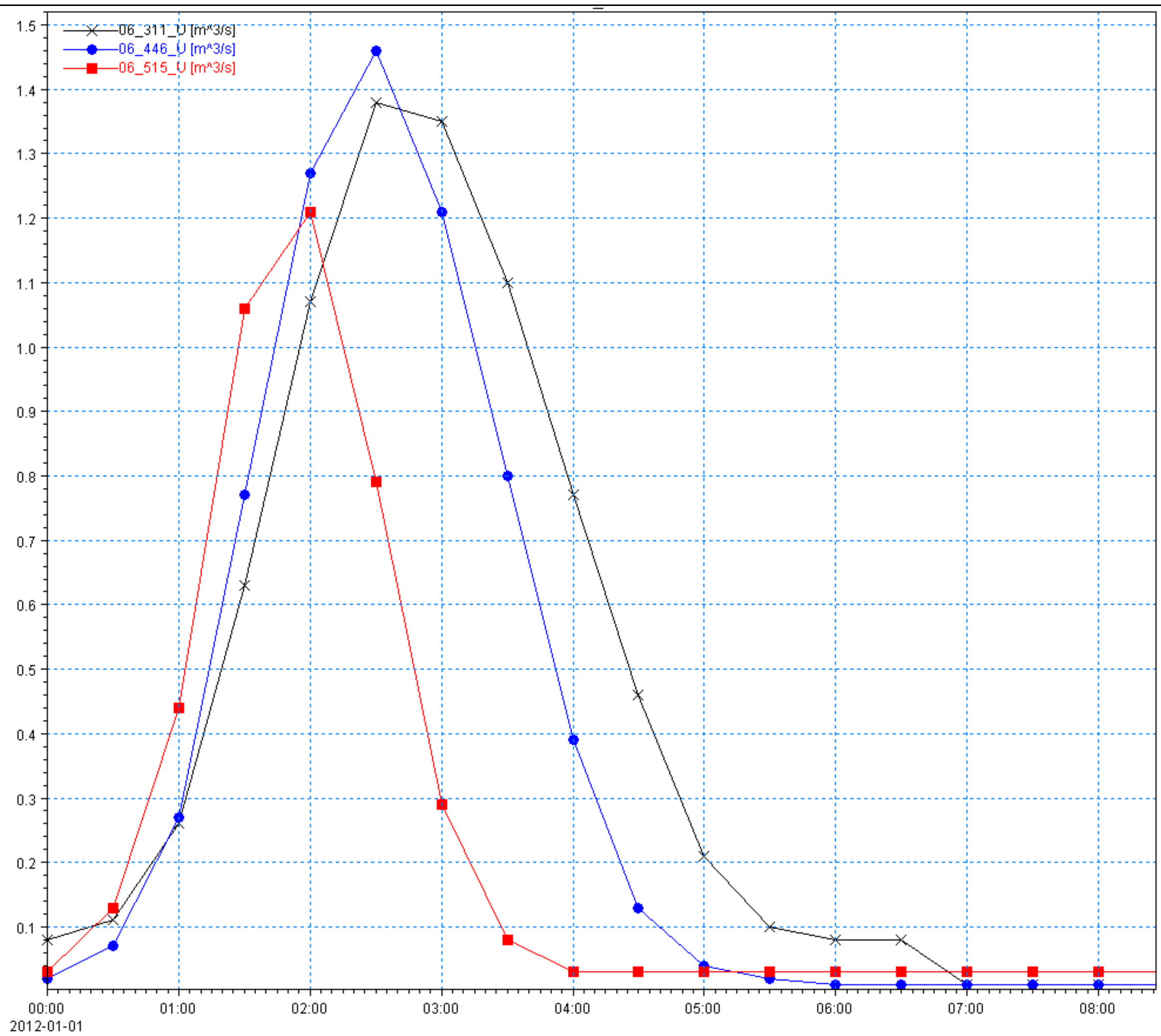


Figure 4.8.17: 1% AEP Inflow Hydrograph for the all watercourses included in the 1D domain

No changes to the magnitude of the flows provided in the hydrology report have been made i.e. there was no increase / reduction of initial flows to achieve model calibration. The timing of fluvial hydrographs was shifted to ensure peak flows occur at the same time as the peak tide water levels. This approach was adopted to ensure simulation of the highest volumes of water from both sources of flooding at the same time for each scenario.

Boundary conditions for the MIKE21 open boundaries were generated by combining storm surge and tidal elevation data. Outputs from the Irish Coastal Protection Strategy Study (ICPSS) have resulted in extreme tidal and storm surge water levels being made available around the Irish Coast for a range of AEPs. The locations of the ICPSS nodes along with the relevant AFA locations are shown in Figure 4.8.18.

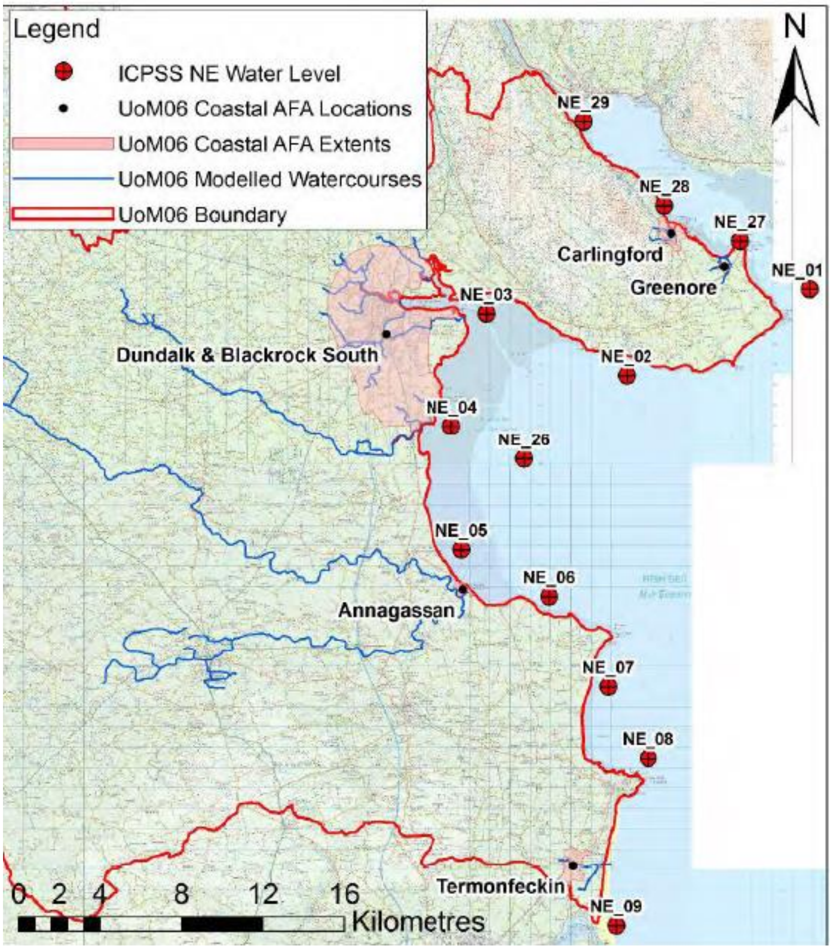


Figure 4.8.18: ICPSS Node Locations (IBE0700Rp0008_UoM06 Hydrology Report_F01)

The associated AEP water levels for node NE28, those used for the Carlingford AFA, are contained in the Table 4.8.4. It should be noted that the water levels listed below are 'still' water levels, as this model does not account for wave run-up or overtopping.

Table 4.8.4: ICPSS AEP Total Water Levels for Relevant Model Nodes

ICPSS Node	AFA/HPW	Annual Exceedance Probability (AEP) %							
		2	5	10	20	50	100	200	1000
		Highest Tidal Water Level to OD Malin (m)							
NE28	Carlingford	3.14	3.26	3.36	3.45	3.58	3.68	3.77	3.99

The ICPSS water levels are total water levels, comprising tidal and surge components which together yield a joint probability event of a particular AEP.

Using information from the Secondary Port of Cranfield Port in the Admiralty Tide Tables, a tidal water level was established which was based on MHWS. Using this water level a tidal curve was generated by fitting it to a sinusoidal curve. Also the resultant magnitude of the surge component required to produce a total water level for the relevant AEP was deduced, see Chapter 3.9.1. The tidal curve was

combined with the appropriate scaled residual surge profile of 48 hours duration to obtain the total combined water level time series as required for the relevant AEPs.

Figure 4.8.19: Carlingford Coastal Boundary illustrates the tidal profile, storm surge profile and resultant total water level profile for a 0.5% AEP design event. The total water profile was applied as a level boundary to the northern and eastern boundaries of the 2D domain.

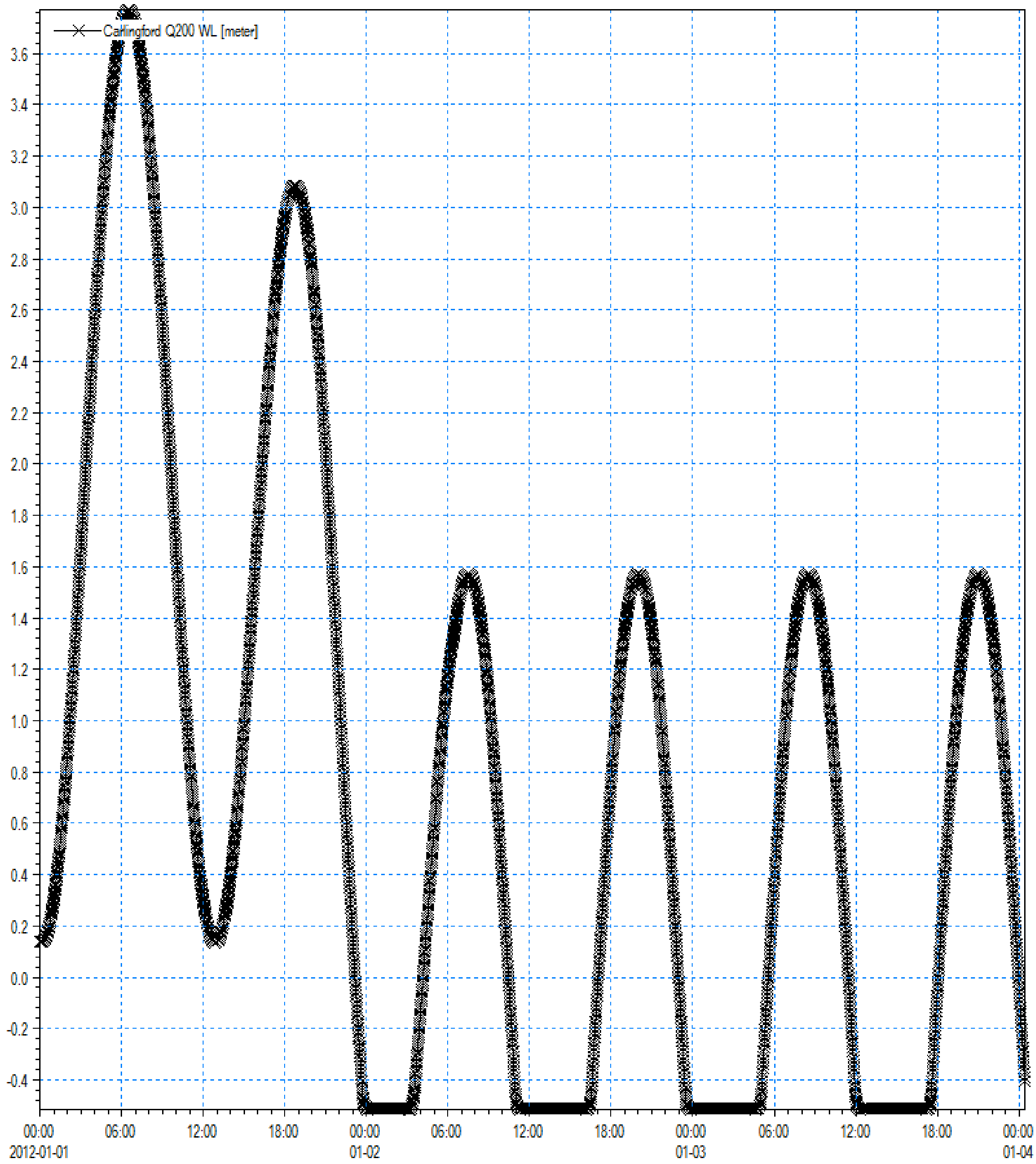


Figure 4.8.19: Carlingford Coastal Boundary

Wave Overtopping Model

To simulate 'mechanism 2 wave overtopping' flooding at the Carlingford AFA, data from the ICWWS was used including peak shoreline water levels and wave heights, periods and directions for each AEP event. The locations at Carlingford for which this data was calculated is shown in Figure 4.8.20. An example of this data for the Carlingford AFA is shown below in Table 4.8.5

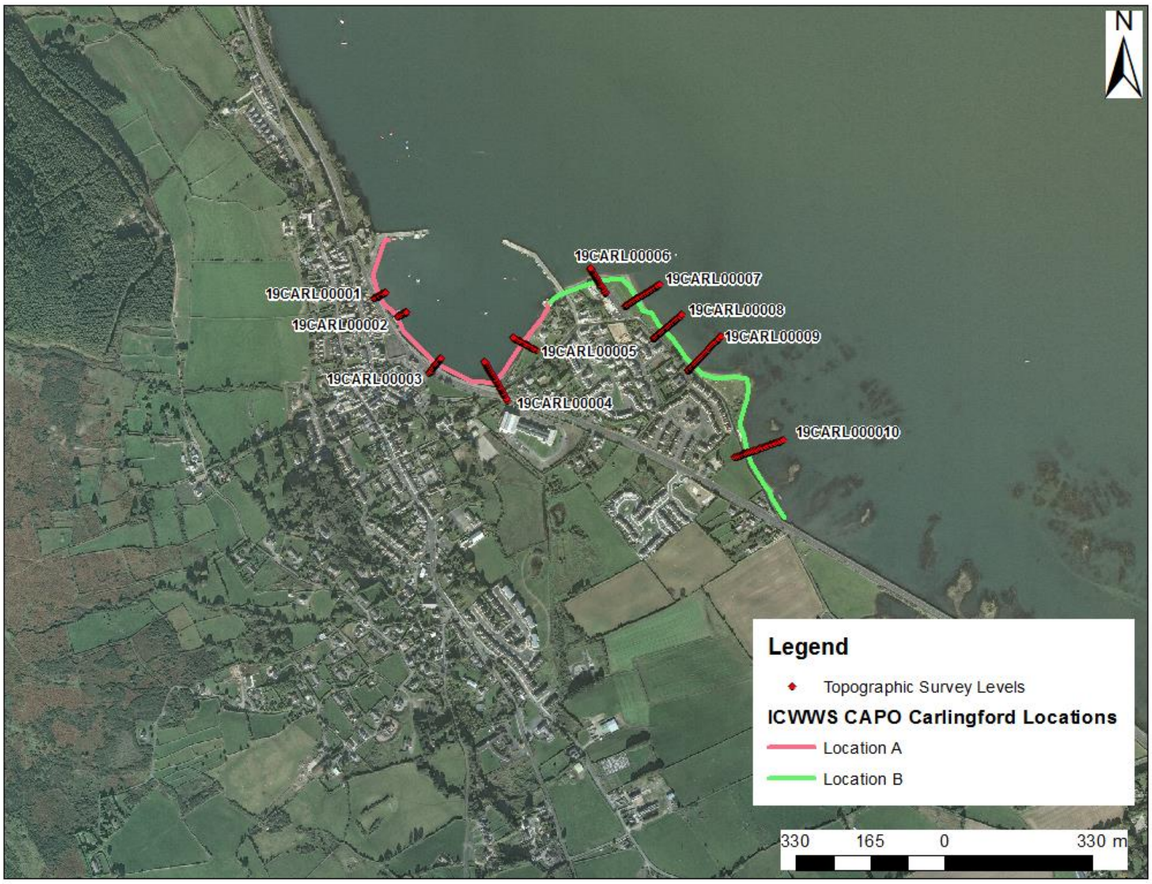


Figure 4.8.20: ICWWS CAPO Carlingford Prediction Location and Topographic

Table 4.8.5: ICWWS CAPO Carlingford Wave Climate and Water Level Data

Prediction Location Reference: Carlingford_Location A				
Bed Level 0.26m OD Malin				
		Combined Wave Component		
AEP	WL (OD Malin)	Hm0 (m)	Tp (s)	MWD (°)
0.1%	2.91	0.49	4.72	67
0.1%	3.10	0.48	4.78	66
0.1%	3.32	0.42	5.06	65
0.1%	3.54	0.36	5.40	63
0.1%	3.64	0.34	5.52	62
0.1%	3.73	0.31	5.68	62

To calculate the overtopping discharge rate for each scenario at various locations along the shoreline, the empirical overtopping calculator tool outlined by the EurOtop manual was used. There was a mixture of structure types to overtop at Carlingford. There were 10 beach profiles surveyed, each corresponding to a change in the nature or character of a particular section of the coastline. Where these differences were observed, both ICWWS locations were subdivided accordingly to describe the overtopping discharge for that section.

Within ICWWS Location A there are five beach profiles, see Figure 4.8.20. Profiles 19CARL00001, 19CARL00003 and 19CARL00005 describe the dimensions of the main flood defence walls at Carlingford Harbour and were all classified as composite slope structures. Profile 19CARL00002 describes the dimensions of the pier seaward of the flood defence wall that runs parallel to the R173. While it is evident that there would be no wave overtopping along that surveyed profile, there is a wave overtopping discharge to be accounted for at the location immediately east of that profile. Therefore dimensions to describe this vertical wall structure, 19CARL00002A, were approximated from 19CARL00002 and 19CARL00003. These assumptions are discussed further in Section 4.8.6 (1). There is no structure at location 19CARL00004. This is open public access to the beach at the harbour. Rather than fitting EurOTop to this natural beach profile the 'mechanism 2 wave overtopping' flooding experienced here was accounted for by the offshore water levels boundaries.

Within ICWWS Location B there are a further five beach profiles, see Figure 4.8.20. There are no structures at 19CARL00006 and 19CARL000010. At both these sections of the coast the 'mechanism 2 wave overtopping' flooding experienced here was accounted for by the offshore water levels boundaries. Profiles 19CARL00008 and 19CARL00009 were classified as armoured simple slopes. While there is no structure at 19CARL00007 it was classified as a composite structure due the steep nature of the upper slope. Also the crest level of this slope is 1.82 m above the peak water level of the 0.1% AEP event. For profiles 19CARL00002A and 19CARL00008 when the water level exceeds the crest level discharges were calculated with a freeboard value of 0.01m.

The remaining, intermittent sections of the coastline within Carlingford AFA that are not described by the survey but subject to 'mechanism 2 wave overtopping' flooding were accounted for by the offshore water levels boundaries.

The largest calculated discharge rate out of the six possible combinations of water levels and wave heights, periods and directions was used for each design AEP event for each section. The sections that were included in the wave overtopping model are shown in Figure 4.8.21. It should be noted that when the peak discharge rate was less than 0.03l/s/m, no further analysis was required.

Even with this conservative approach, the discharge rate computed was still below the threshold, thus ruling out profiles 19CARL00003, 19CARL00005 and 19CARL00008 from further analysis and subsequent modelling for the 10% AEP event. All other locations returned discharge rates above this threshold.

Once the discharges for simulation were ascertained, a water level profile was produced using predicted tidal heights from Cranfield Point to calculate the discharge rate across the tidal cycle. This is because the rate determined by EurOtop was specific to the peak water level only. A storm duration of 12 hours beginning and ending at low-water was assumed. The discharge rate profile was then scaled based on the length of the exposed shoreline in order to produce a discharge profile in m^3/s. Some example discharges for a given wave condition are presented in Table 4.8.6 and an example discharge curve is presented in Figure 4.8.22.

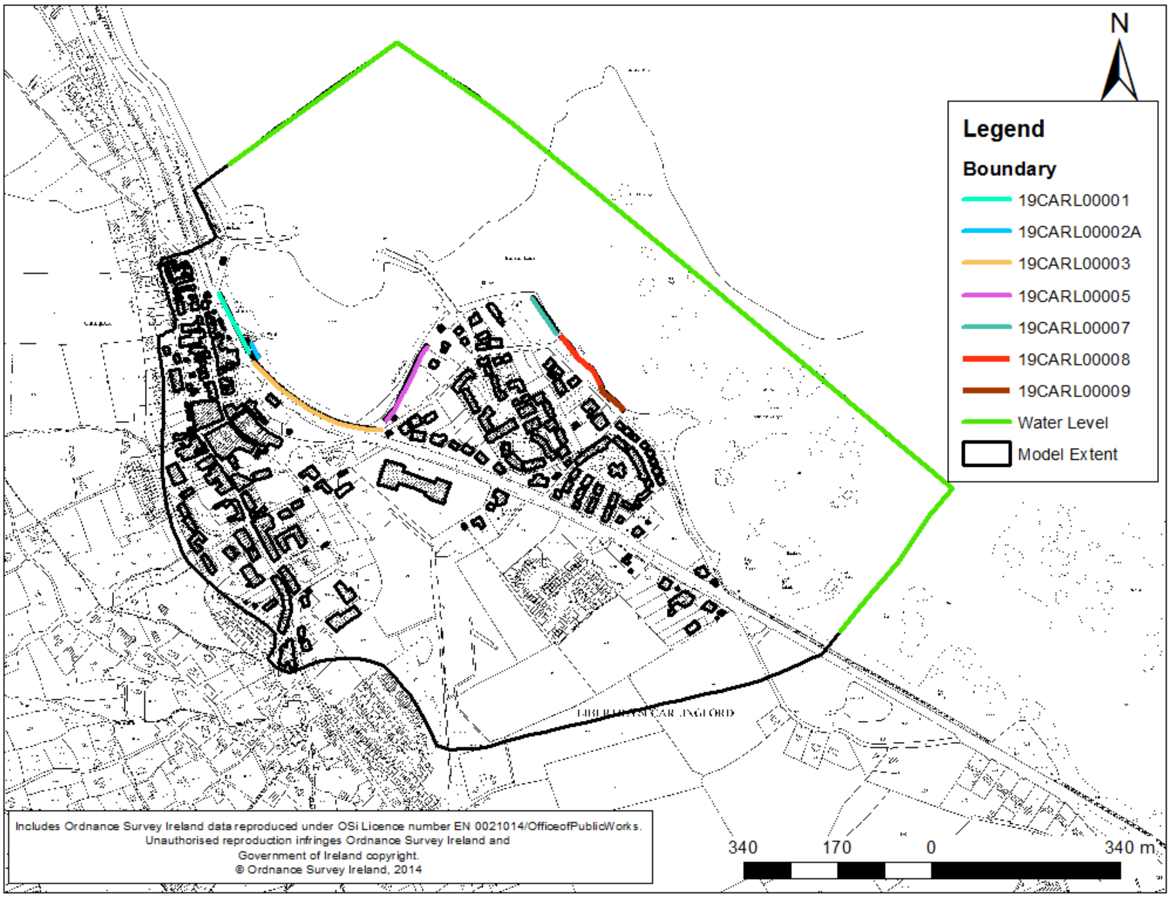


Figure 4.8.21: Carlingford Modelled Wave Overtopping Locations

Table 4.8.6: Peak Wave Climate and associated Wave Overtopping Discharges for Modelled Sections

Section	AEP	WL (mOD Malin)	Hm0 (m)	Tp (s)	MWD (°)	Discharge Rate (l/s/m)	Discharge (m^3/s)
19CARL00001	10%	3.73	0.31	5.68	61.70	0.33	0.03
19CARL00001	0.50%	3.73	0.23	6.00	59.53	2.91	0.24
19CARL00001	0.10%	3.32	0.17	5.83	58.13	9.30	0.78
19CARL00002A	10%	3.73	0.31	5.68	61.70	1.90	0.05
19CARL00002A	0.50%	3.73	0.23	6.00	59.53	4.46	0.11
19CARL00002A	0.10%	3.32	0.17	5.83	58.13	9.35	0.23
19CARL00003	10%	3.73	0.31	5.68	61.70	N/A	N/A
19CARL00003	0.50%	3.73	0.23	6.00	59.53	0.55	0.15
19CARL00003	0.10%	3.32	0.17	5.83	58.13	1.81	0.49
19CARL00004	10%	N/A	N/A	N/A	N/A	N/A	N/A
19CARL00004	0.50%	N/A	N/A	N/A	N/A	N/A	N/A
19CARL00004	0.10%	N/A	N/A	N/A	N/A	N/A	N/A
19CARL00005	10%	3.73	0.31	5.68	61.70	N/A	N/A
19CARL00005	0.50%	3.73	0.23	6.00	59.53	1.06	0.17
19CARL00005	0.10%	3.32	0.17	5.83	58.13	3.07	0.48
19CARL00006	10%	N/A	N/A	N/A	N/A	N/A	N/A
19CARL00006	0.50%	N/A	N/A	N/A	N/A	N/A	N/A
19CARL00006	0.10%	N/A	N/A	N/A	N/A	N/A	N/A
19CARL00007	10%	2.91	0.53	6.12	55.33	0.06	0.01
19CARL00007	0.50%	3.22	0.68	6.01	59.90	0.48	0.04
19CARL00007	0.10%	3.73	0.60	6.43	62.77	1.94	0.16
19CARL00008	10%	2.68	0.32	5.16	62.41	N/A	N/A
19CARL00008	0.50%	3.73	0.46	6.55	61.81	3.65	0.41
19CARL00008	0.10%	3.73	0.60	6.43	62.77	13.75	1.55
19CARL00009	10%	2.68	0.32	5.16	62.41	27.62	1.52
19CARL00009	0.50%	3.73	0.46	6.55	61.81	195.44	10.75
19CARL00009	0.10%	3.73	0.60	6.43	62.77	291.13	16.01
19CARL000010	10%	N/A	N/A	N/A	N/A	N/A	N/A
19CARL000010	0.50%	N/A	N/A	N/A	N/A	N/A	N/A
19CARL000010	0.10%	N/A	N/A	N/A	N/A	N/A	N/A

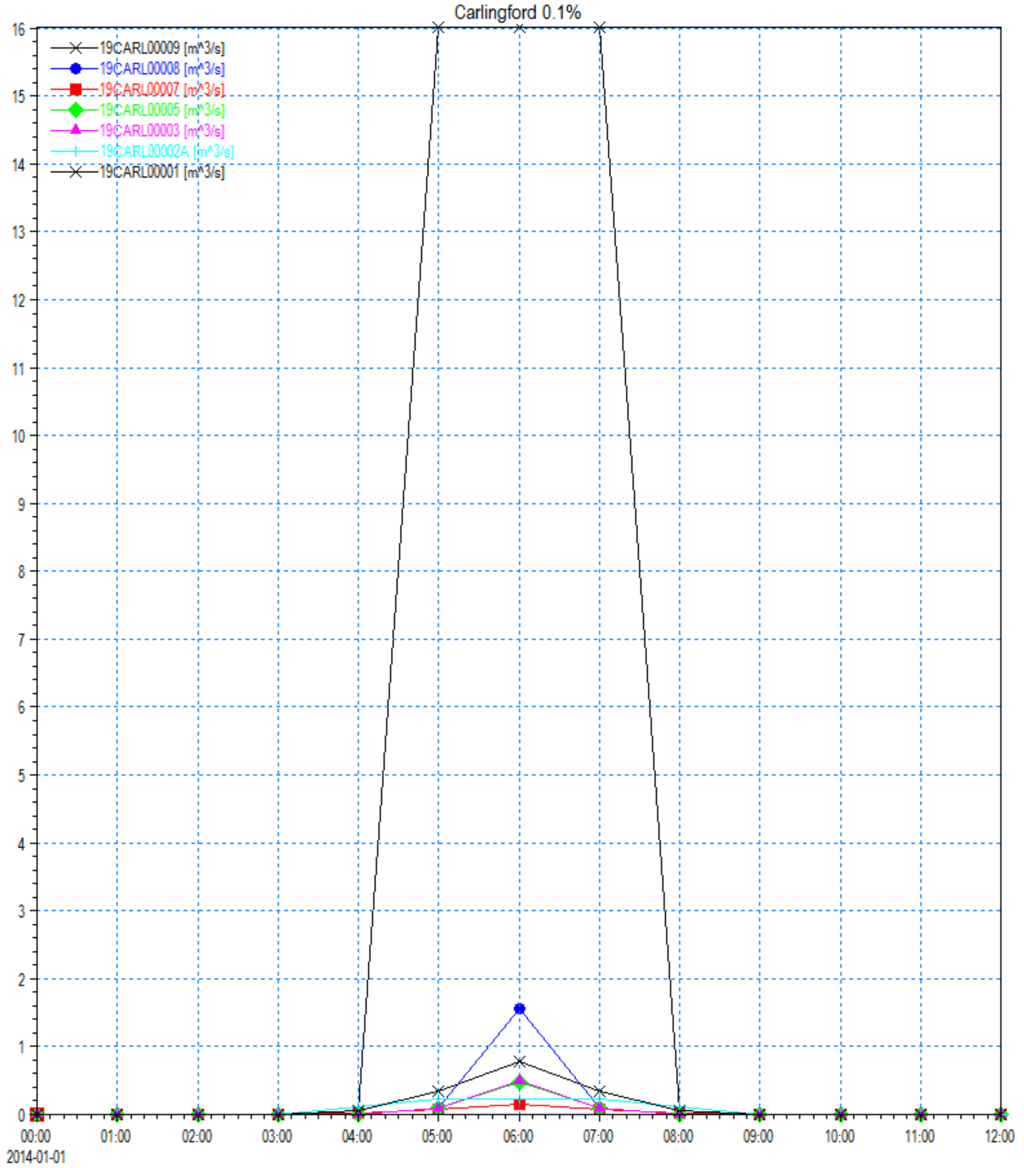


Figure 4.8.22: Wave Overtopping Discharge Profiles at Carlingford for the 0.1% AEP event

(6)Model Boundaries – Downstream Conditions:	Water level boundaries were applied at the downstream extent of the Carlingford and the Liberties of Carlingford watercourses where it discharges to the 2D model domain (chainage 929.89m and 734m respectively). It should be noted that this boundary is given a 'dummy' water level value of -0.45mOD Malin and 0.38mOD Malin respectively. However this value is ignored once the simulation commences and the level of this boundary varies in time based on dynamic calculations driven by the water levels in the Carlingford and the Liberties of Carlingford and Carlingford Harbour.

(7) Model Roughness: (see Chapter 3.6.1 'Roughness Coefficients')		
(a) In-Bank (1D Domain)	Minimum 'n' value: 0.040	Maximum 'n' value: 0.050
(b) MPW Out-of-Bank (1D)	Minimum 'n' value: N/A	Maximum 'n' value: N/A
(c) MPW/HPW Out-of-Bank (2D)	Minimum 'n' value: 0.033 (Inverse of Manning's 'M')	Maximum 'n' value: 0.060 (Inverse of Manning's 'M')

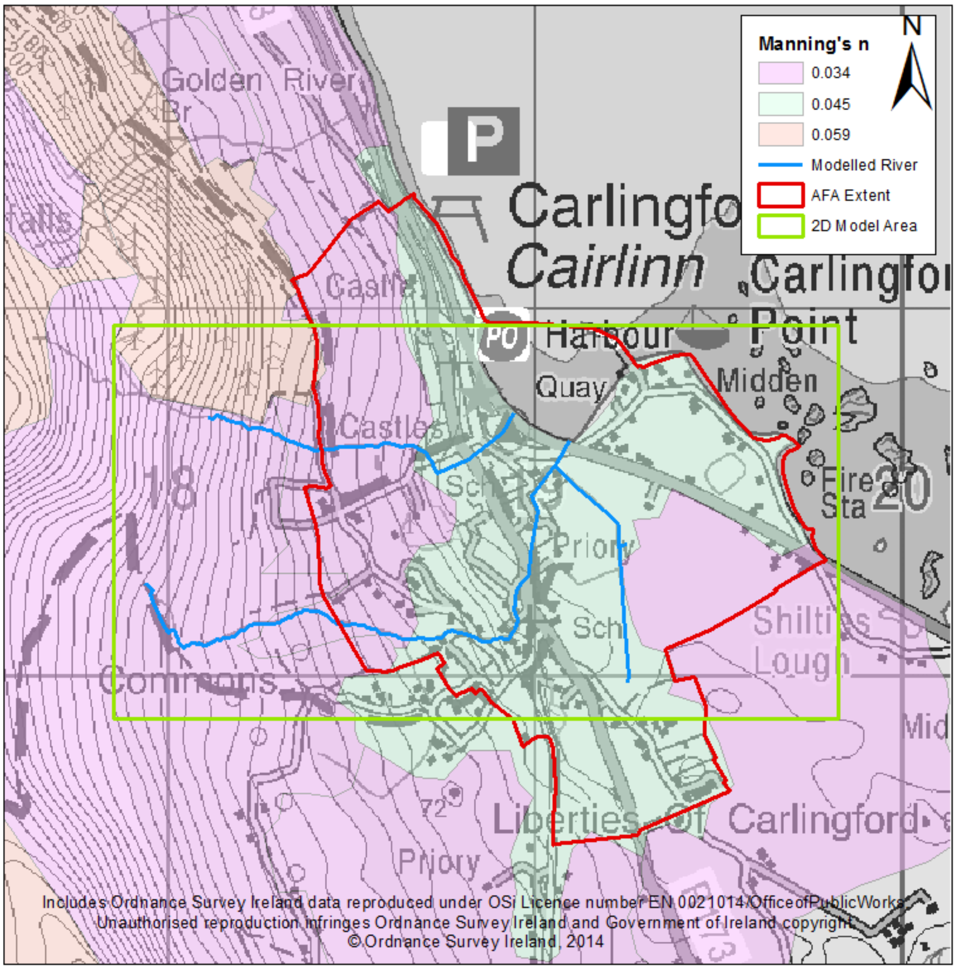


Figure 4.8.23: Map of 2D Roughness (Manning's n)

Figure 4.8.23 illustrates the roughness values applied within the 2D domain of the model. Roughness in the 2D domain was applied based on land type areas defined in the Corine Land Cover Map with representative roughness values associated with each of the land cover classes in the dataset.

(d) Examples of In-Bank Roughness Coefficients

 **Figure 4.8.24: Carlingford Watercourse – 0630M00054_UP** Manning's n = 0.050 Mountain stream in stable condition; some cobbles on bed	 **Figure 4.8.25: Carlingford Commons (Upper) – 0631M00103W_UP** Manning's n = 0.050 Mountain stream in stable condition; some cobbles on bed
 **Figure 4.8.26: Carlingford Commons (Lower) – 0631M00055I_UP** Manning's n = 0.040 Modified channel in stable condition; some cobbles on bed	 **Figure 4.8.27: Liberties of Carlingford – 0632M00021_DN** Manning's 0.045 Standard natural channel in stable condition; some weeds and stones

4.8.4 Sensitivity Analysis

To be completed for final version of report.

4.8.5 Hydraulic Model Calibration and Verification

(1) Key Historical Floods (From IBE0700Rp0003_UoM 06 Inception Report unless otherwise specified):

(a) **AUG 2008.**

Information was found on a website (www.dundalkdemocrat.ie) during the internet search which indicated that roads were flooded in the Carlingford area on 16th August 2008. No details on flood depths or extents were available within the Carlingford AFA.

The flood event as recorded at the Ballygoly hydrometric station (Stn no. 06030, refer to Section 4.8.1) and UoM 06 Hydrology Report Rp0008_F01, has an estimated frequency of 10% AEP.

The Killowen hourly rain gauge in Co. Down (approx. 3.5 km from Carlingford), recorded 39mm of rainfall over eight hour duration on 16th August 2008. This event has a frequency of 30.3% AEP using the FSU DDF model (FSU WP 1.2 'Estimation of Point Rainfall Frequencies').

No further information on source, flows, levels or AEP is available; however model results do indicate flooding of some roads as reported. Based on the model, the roads that are predicted to flood during a fluvial 10% AEP event with coastal 50% AEP are the R173, the Old Quay Lane, Newry St. and River St, see Figure 4.8.28. This provides qualitative support for the model.

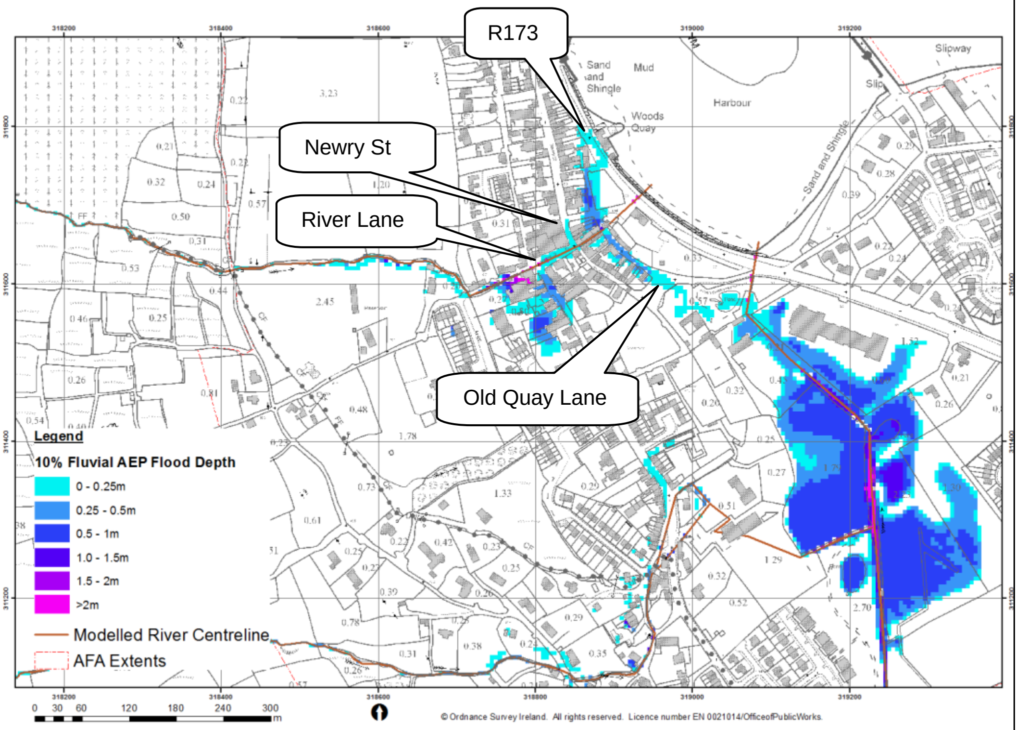
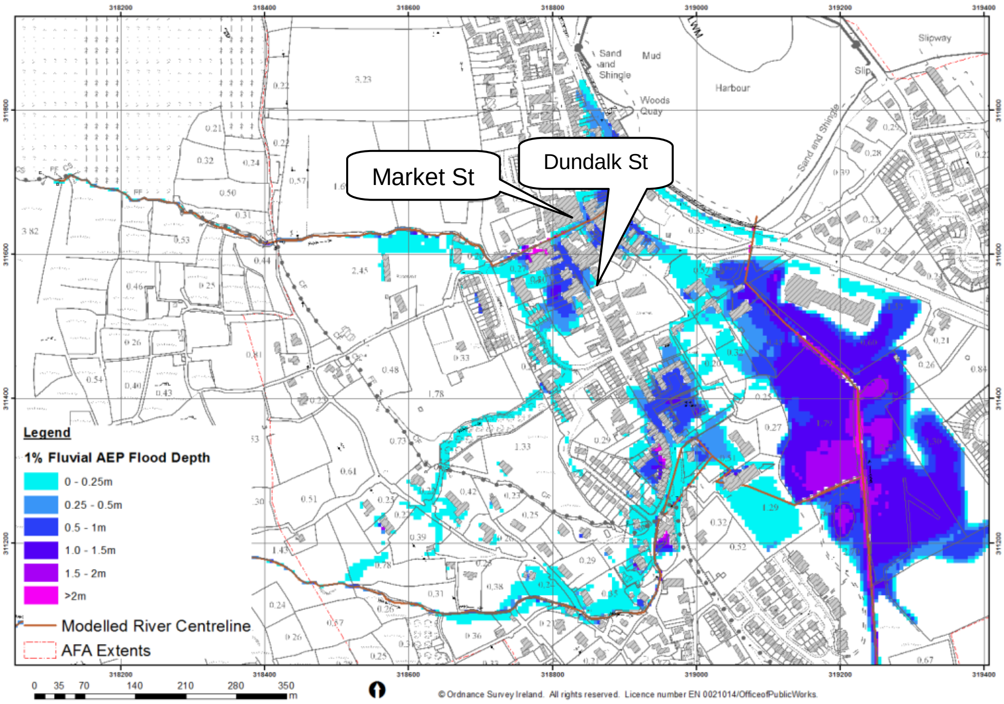
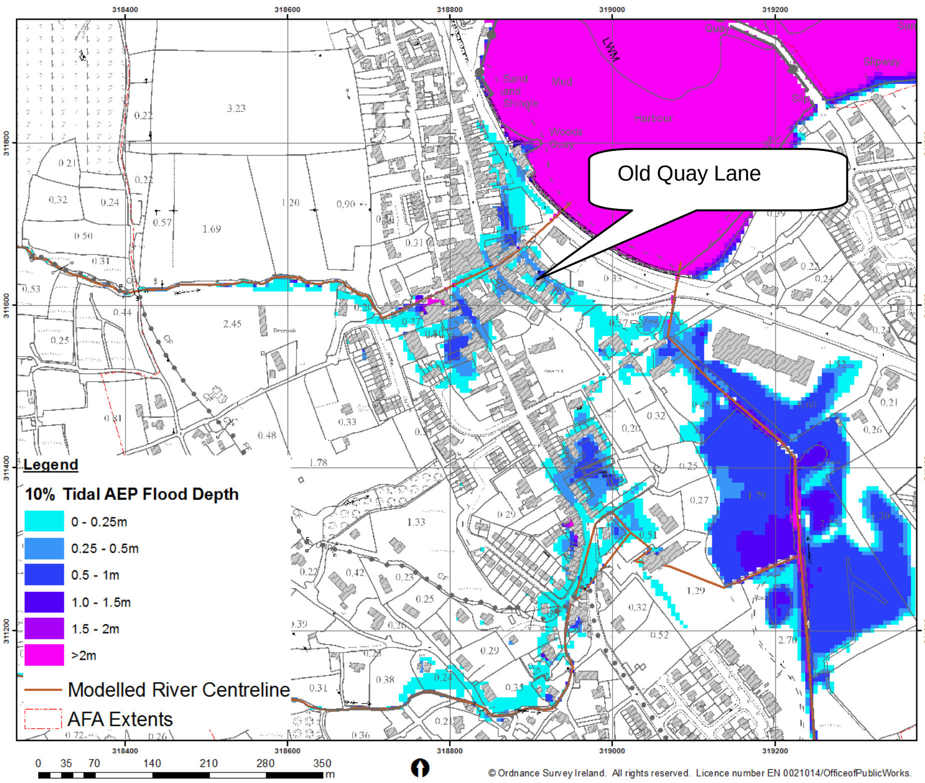


Figure 4.8.28: Water Depths resulting from fluvial 10% AEP event with coastal 50% AEP event

(b) **OCT 2005.**	Information was found on www.floodmaps.ie which indicated that flooding occurred in Carlingford on 24th October 2005. Landscaping works and realignment of the channel of the Mountain river was taking place at the time of this particular rainfall event. Heavy rainfall washed material from landscaping works downstream which blocked grills on the river channel, causing the river to spill onto the public roads and flood adjacent buildings. In addition, photos indicate that the flood waters washed silt/gravels onto roads. It was not possible to determine conclusively which watercourse the description "Mountain river" is referring to. However conclusions were drawn after reviewing the nature of the flooding within the model to make the assumption that this river is the modelled Carlingford watercourse. No details on flood depths or extents were available within the Carlingford AFA. The flood event as recorded at the Ballygoly hydrometric station (Stn no. 06030) has an estimated frequency of 5% AEP. The Killowen hourly rain gauge recorded 69 mm of rainfall with duration of 10 hours on 24th October 2005. This event has a frequency of 1.9% AEP, using the FSU DDF model. No further information on source, flows, levels or AEP is available; however model results do indicate flooding of some roads as reported. Each scenario modelled was run with the assumption that all structures and trash screens are free of debris therefore a direct comparison cannot be drawn with the information sourced from the report. The roads that are predicted to flood during a fluvial 1% AEP event with coastal 50% AEP are the R173, the Old Quay Lane, Market St., Dundalk St. and River Lane, see Figure 4.8.29. This provides qualitative support for the model.

	 **Figure 4.8.29: Water Depths resulting from fluvial 1% AEP event with coastal 50% AEP event**
(c) **FEB 2002.**	Information was found on www.floodmaps.ie indicating that flooding occurred on 2nd February 2002 in Annagassan, Carlingford and Dundalk & Blackrock South due to heavy rain, high tides and strong easterly winds. An Irish Times article contained reports of houses being flooded in Carlingford. No details on flood depths or extents were available within the Carlingford AFA. The flood event as recorded at the Ballygoly hydrometric station (Stn no. 06030) has an estimated frequency of 76% AEP. The Killowen hourly rain gauge has no reliable data for this event. No further information on source, flows, levels or AEPs is available so this event is not suitable for model calibration. A review of the tidal 10% AEP event with a fluvial 50% AEP event results indicate flooding of buildings as reported predominantly along Old Quay Lane, see Figure 4.8.30. More frequent events (higher AEPs) will be simulated for final modelling therefore a more direct comparison of the recorded information and the model results will be made.

	 **Figure 4.8.30: Water depths resulting from Tidal 10%AEP event with a Fluvial 50% AEP**
(d) **NOV 2000.**	The review indicated that a flood event occurred in Ardee, Carlingford, Dundalk and Termonfeckin in November 2000. Correspondence from the Louth County Secretary to the Department of Environment and Local Government, dated 10th November 2000, indicated that on 2nd November in Carlingford, heavy rainfall and run-off from the Cooley Mountains caused flooding which damaged roads including the N1. The letter estimated that, in the Dundalk/Carlingford engineering area, approximately IR£100,000 worth of damage was done when the edge of c. 20 miles of road was washed away. In addition, a further IR£100,000 would be required to repair culverts. No details on flood depths or extents were available within the Carlingford AFA. No reliable data was recorded at Ballygoly hydrometric station. The Killowen hourly rain gauge recorded 36 mm of rainfall with duration of 11 hours on 2nd November 2000. This event has a frequency of 52.6% AEP, using the FSU DDF model. No further information on source, flows, levels or AEPs is available so this event is not suitable to facilitate model calibration. More frequent events (higher AEPs) will be simulated for final modelling therefore a more direct comparison of the recorded

	information and the model results will be made.
(e) **DEC 1981.**	Flooding occurred in Annagassan, Carlingford and Dundalk & Blackrock South on 3rd December 1981 due to heavy rainfall, high tides and strong winds. The Dundalk Democrat stated reported that waves came over the wall at Carlingford; however only minor damage was caused. No further information on source, flows, levels or AEPs is available so this event is not suitable to facilitate model calibration.

Summary of Calibration

Hydrometric data is available from Ballygoly hydrometric station (06030) 4.5km southwest of Carlingford. Hourly rainfall data is available from Killowen gauging station to the east of Carlingford Lough in County Down, see Figure 4.8.1. No data could be found relating to specific historical flood events at Carlingford, so it was therefore not possible to use data to calibrate the model. However where possible the model has been validated against flow data recorded at Ballygoly and rain gauge data recorded Killowen. Model results were reviewed to ascertain whether areas in the Carlingford domain are flooding as documented under model simulation.

Model flows were checked against the estimated flows at HEP check points where possible to ensure the model is well anchored to the hydrological estimates. For example at HEP 06_311_D on the Carlingford watercourse, the estimated flow during the 1% AEP event is 3.72 m^3/s (IBE0700Rp0008_UoM 06 Hydrology Report_F01, Appendix D) and the modelled flow is 4.29 m^3/s. Full flow tables and discussion of comparison results are in Appendix A.3

A mass balance check has been carried out on the model to make sure that the total volume of water entering and leaving the model at the upstream and downstream boundaries balances the quantity of water remaining in the model domain at the end of a simulation. Refer to Chapter 3.11 for details of acceptable limits. Table 4.8.7 summarises the mass errors for each model run:

Table 4.8.7: Model Mass Balance

Model	1D Mass Error	2D Mass Error
10% AEP Fluvial	-0.03%	0.00%
1% AEP Fluvial	-0.02%	0.00%
0.1% AEP Fluvial	-0.01%	0.00%
10% AEP Coastal	-0.04%	0.00%
0.5% AEP Coastal	-0.04%	0.00%
0.1% AEP Coastal	-0.03%	0.00%

There are minor instabilities along each watercourse for all events though they occur predominantly in the upper reaches of the Carlingford and Carlingford Commons watercourses which are outside of the AFA. This is due to the steepness of the catchment which has an approximate slope of 1 in 2 from source to flood plain (see Carlingford Long Section Profile, Appendix A.2) as well as the number and nature of structures in succession along these watercourses. For instance there is a model instability on the Carlingford watercourse (chainage 642.845m) where there is also the culvert 0630M00065I present.

The dynamic results at the lower reaches of all watercourses within the 2D domain were also reviewed to investigate these instabilities. The out-of-bank flood flows are very complex due to the low-lying topography and the presence of the flood defence walls at Carlingford Harbour. The impact of these instabilities were reviewed and it was concluded that it does not cause erroneous out-of-bank flooding as they are a reflection of the volatile flow patterns within the catchment. The mass balance for these design runs was found to be close to zero, which supports the conclusion that these instabilities have a relatively minor impact upon the model results.

The mass error in the model simulations is very small, showing good conservation of mass and momentum throughout.

A limited verification exercise has been undertaken based on the data available, however due to the lack of data the accuracy of this model is somewhat unknown. Despite the lack of calibration and verification data, the model is considered to be performing satisfactorily for design event simulation.

(2) Post Public Consultation Updates

Following informal public consultation and for S.I public consultation periods in 2015, general model updates were applied to refine model resolution and improve model stability, mapping issues as Final reflects these changes.

(3) Standard of Protection of Existing Formal Defences:

Defence Reference	Type	Watercourse	Bank	Modelled Standard of Protection (AEP)
1)	WALL	COASTAL	COASTAL FRONT	10% to 0.5% AEP Tidal

There is a coastal retaining wall located along the coastline edge of Carlingford harbour, see Figure 4.8.31. The retaining wall is approximately 0.55km in length. The crest level of the wall ranges from 4.25-4.60m OD Malin with the lowest section at the south-east corner where there is a gap in the wall for access to the water. The structure was not recognised in the LiDAR as it has a 5m rectangular mesh and so the cells at this location were raised to the correct crest level to represent the sea wall.

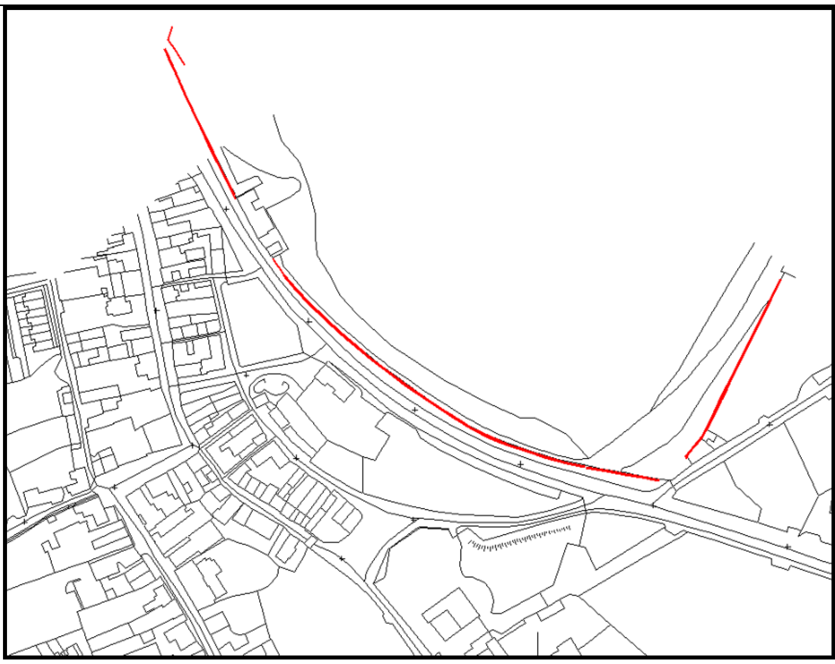


Figure 4.8.31: Flood Defence at Carlingford Harbour (shown as red line)

Figure 4.8.32 shows that the flood defence would reduce the risk of an area from flooding during a flood event. The hatched area, (highlighted within the red circles on the Figures, please see maps accompanying this report and Appendix A.4 for file references) identifies the additional area that would flood during 10% AEP and 0.5% AEP tidal events if the defence was removed.

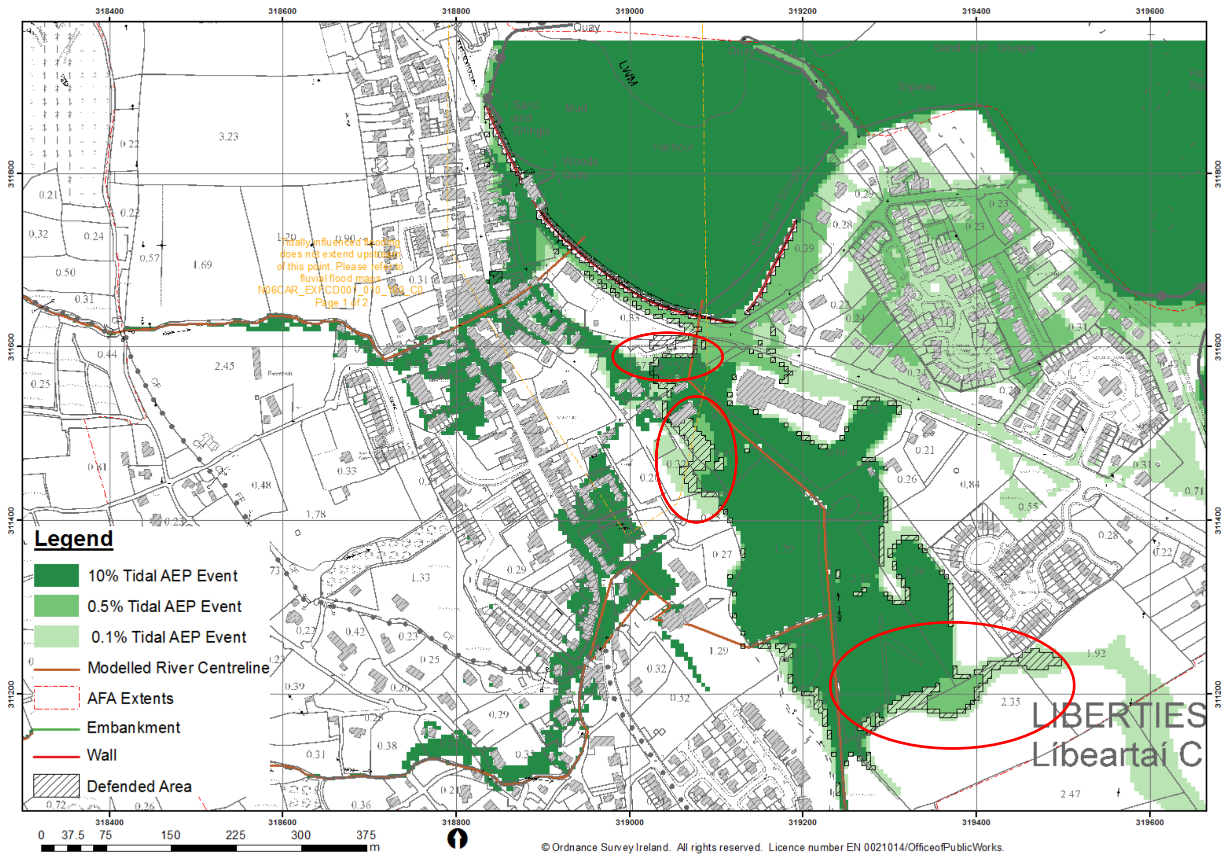


Figure 4.8.32: Carlingford Coastal Dominated Flood Extents

(4) Gauging Stations:
None within model.
(5) Other Information:
At an informal workshop Local Authority representatives provided information about culvert works that had been undertaken on the complex and aged drainage system in the town. Additional survey information has been incorporated into the draft final version of the mapping, see Section 4.8.2(9).

4.8.6 Hydraulic Model Assumptions, Limitations and Handover Notes

(1) Hydraulic Model Assumptions:
(a) The in-channel roughness coefficients were selected based on normal bounds using photos received from the channel and structure survey. Using CIRIA's (1997) Manning's n values for culverts as a reference it is assumed that the final selected values are representative, see Chapter 3.6.1. (b) The peak of the fluvial hydrographs generated during the hydrological analysis was reviewed during the development of the model. The original time series files were edited so all fluvial peaks coincide with both each other and the peak flow of the tidal boundary to ensure the AFA was subjected to the highest volumes of water from both sources of flooding at the same time for each scenario. (c) For all simulations it has been assumed that all culverts and screens are free of debris and sediment. (d) On the Commons Overflow Branch an open cross-section had to be included at the downstream extent of the branch to enable the branch to be linked to the Carlingford Commons Branch. MIKE11 does not link branches from one closed section to another closed section. (e) No overtopping structure (weir) was included for the 06CARX0187 culvert (Carlingford), the 06CARZ0300I culvert (Carlingford Commons) and the 0632M00013I culvert (Liberties of Carlingford) as the headwalls are considerably higher than the culvert soffit and surrounding banks (see photograph in Section 4.8.3(1)). When linked to the 2D model domain waters spill through lateral links before continuing downstream. (f) A small tributary of the Liberties of Carlingford watercourse has been left out of the model as there is very little survey information (only 2 XN's provided) and no inflow was provided. As it may act as a storage area, it has been taken into consideration in the 2-D model. (g) Sections of all three watercourses (Carlingford, Carlingford Commons and Liberties of Carlingford) included in the 1D model represented by long culverts (>20m) have not been ‘blocked out’ or linked to the 2-D model (via lateral links) to improve representation of possible cross-flow over the structure in the 2-D modal during high flow events. (h) The 2-D model has two open boundaries as the estimated high tide levels could overtop adjacent land along Greenore Road (R176) and the Ghan Road development. (i) The dimensions required to calculate the wave overtopping discharge experienced at 19CARL00002A

were the crest level of the vertical wall and the topographic level at the toe of the structure. The crest level was ascertained interpolating the LiDAR data landward of the crest. The topographic level at the toe of the structure was ascertained by interpolating the levels at the toe of the structures at 19CARL00001, 19CARL00002 and 19CARL00003.	
(2) Hydraulic Model Limitations and Parameters:	
(a) A 0.5 second time-step for both the MIKE 11 and MIKE 21 models has been selected in order to achieve a successful model simulation for all return periods. (c) The lateral links on the Carlingford Common watercourse require an exponential smoothing factor of 0.8 for improved stability. Depth tolerance has been increased to 0.2m (from 0.1m) along the Carlingford Commons watercourse. (d) A 5m grid DTM was used with buildings excluded from the floodplain. Given the heavily urban area of Carlingford, the grid resolution may result in poorly defined potential flow routes. This was deemed acceptable as this resolution adequately resolved the HPWs and MPWs. Also when blocking out the watercourse channels in preparation for joining the 1-D and 2-D models, the 'minimum of one grid cell' has been applied. This approach may give some mass balance issues where the channel width is less than the grid size (<5m). (e) Courant numbers are generally <1. Some peaks of high Courant number remain on the Carlingford Commons (1.5) watercourse near structure 0631M00059I_CUL. However model output data (discharge and water level) extracted from nearby nodes are stable. Courant could be lowered by further reduction in time step.	
Hydraulic Model Parameters:	
MIKE 11	
Timestep (seconds)	0.5
Wave Approximation	Fully Dynamic
Delta	0.75
Inter1Max factor	100
MIKE 21	
Timestep (seconds)	0.5
Drying / Flooding	0.02/0.03
Eddy Viscosity (and type)	Constant eddy formulation varying in space based on equation $0.02\Delta x^2/\Delta t$.
MIKE FLOOD	
Link Exponential Smoothing Factor	All default (1)

(where non-default value used)	

(3) Design Event Runs & Hydraulic Model Handover Notes:

(a) The coastal boundary total water level is based on tide levels at Cranfield Point and ICPSS point NE28.

(b) The parameters within the HD parameter file are identical for all design run scenarios.

(c) Steady state initial conditions have been used in the 1D model component during all design runs.

(d) Global surface elevation initial conditions of -0.43mOD Malin in the 2D domain have been used during all design runs. This value was chosen to match the water level of the first timestep at the coastal boundary to reduce instabilities during model start-up.

(e)This model is influenced by both coastal and fluvial sources, as such a range of events were simulated with fluvial or tidal influences dominating flows. The 10% AEP, 1% AEP and 0.1% AEP fluvial return periods were simulated, all coinciding with the 50% AEP tidal event. The 10% AEP, 0.5% AEP and 0.1% AEP tidal events were also simulated, all coinciding with the 50% AEP fluvial event.

Fluvial Simulations

During the fluvial events (coinciding with the 50% AEP tidal event) in Carlingford town, all watercourses considered are shown to flood for all events simulated (10% AEP, 1% AEP, 0.1% AEP). The primary reason for this is the tide lock effect on the main culverts through Carlingford (0630M00037I Carlingford; 0631M00049IB Carlingford Commons - see photographs in section 1.1.3) which prevent fluvial flows discharging during periods of high tidal water levels. The 50% AEP tide is sufficient to cause a tide lock scenario when the fluvial peaks are aligned with the peak tide levels.

During the 10% AEP event there is some shallow depth flooding along both the Carlingford and Carlingford Commons watercourses in sections upstream of the main culverts mentioned above. The subsequent spill water, once out of channel, follows the general topography of the area down towards Carlingford centre and the sea front along sections of River Lane and Dundalk Street. A number of properties along these routes (Abbey Court) are shown to be at risk. During both the 1% AEP and 0.1% AEP event simulations this spill is more pronounced with flooding spreading to Trinity Close and Tholsel Street.

The majority of the Liberties of Carlingford watercourses is low lying and (<3m) and so is heavily tidally influenced. As such this watercourse is shown to experience significant flooding during the 50% AEP tide event; a longitudinal section is included in Appendix A2. Flooding is made worse by the tide lock effect of the main culvert preventing fluvial flows discharging during periods of high tidal water levels – this culvert does not have a tide flap to prevent flow into these areas. However this area is predominantly open fields with few properties shown to be at risk.

Tidal Simulations

During each of the tidal dominated scenarios considered some flooding of Carlingford was shown. During the 10% AEP tidal event the majority of Carlingford remain flood free with flooding isolated to sections of Dundalk Street, Abbey Court and the low lying areas of the Liberties of Carlingford catchment.

During the 0.5% AEP and 0.1% AEP tidal events extensive tidal flooding is experienced along Greenore

Road (R176) and throughout the Ghan Road development. The primary cause of this flooding is the peak tide levels exceeding adjacent coastal land levels. Within Carlingford centre, widespread flooding is shown along Old Quay Lane and Tholsel Street.	
(4) Hydraulic Model Deliverables:	
Please see Appendix A.4 for a list of all model files provided with this report.	
(5) Quality Assurance:	
Model Constructed by: Model Reviewed by: Model Approved by:	Chris Lewis Stephen Patterson Malcolm Brian

APPENDIX A.1

TABLE OF STRUCTURES

1D Structures modelled in the 1D domain								
Structure Details - Bridges and Culverts:								
RIVER BRANCH	CHAINAGE	ID**	LENGTH (m)	OPENING SHAPE	HEIGHT (m)	WIDTH (m)	SPRING HEIGHT FROM INVERT (m)	MANNING'S n
Carlingford	337.857	0630M00065I	3.8	Irregular	0.87	1.642	N/A	0.013
Carlingford	460.2	0630M00050I	4.4	Circular	0.5	0.5	N/A	0.013
Carlingford	577.671	0630M00041I	13.14	Circular	1.2	1.2	N/A	0.013
Carlingford	753.5	06CARX0187J	176.4	*Circular X2	0.3, 0.3	0.3, 0.3	N/A	0.013
Carlingford Commons	1097.65	0631M00072I	8	Irregular	0.646	1.678	N/A	0.013
Carlingford Commons	1246.75	0631M00059I	33	Irregular	1.12	1.208	N/A	0.015
Carlingford Commons	1280.465	0631M00055I	14	Circular	1.2	1.2	N/A	0.013
Carlingford Commons	1302.5	0631M00053D	4.2	Irregular	0.442	3.902	N/A	0.013
Carlingford Commons	1348	06CARZ0300I	286.7	*Circular X2	0.9, 0.9	0.9, 0.9	N/A	0.013
Liberties of Carlingford	442.821	0632M00024I	2.87	Circular	0.6	0.6	N/A	0.013
Liberties of Carlingford	526.83	0632M00013I	186.6	*Circular	0.5	0.5	N/A	0.013
Commons Overflow	139.76	06CARW0000I	34.9	*Irregular	0.74	1.16	N/A	0.025

Structure Details - Weirs					
RIVER BRANCH	CHAINAGE	ID	MANNING'S n	TYPE	
Carlingford Commons	766.328	0631M00103W	0.05	Broad Crested Weir	
1D Structures modelled in the 2D domain					
Structure Details - Bridges and Culverts:					
None					
Structure Details - Weirs:					
None					

* Denotes structures incorporated as closed cross-sections only (and therefore not included in the Network file).

** Structure ID Key:

D – Bridge Upstream Face

E – Bridge Downstream Face

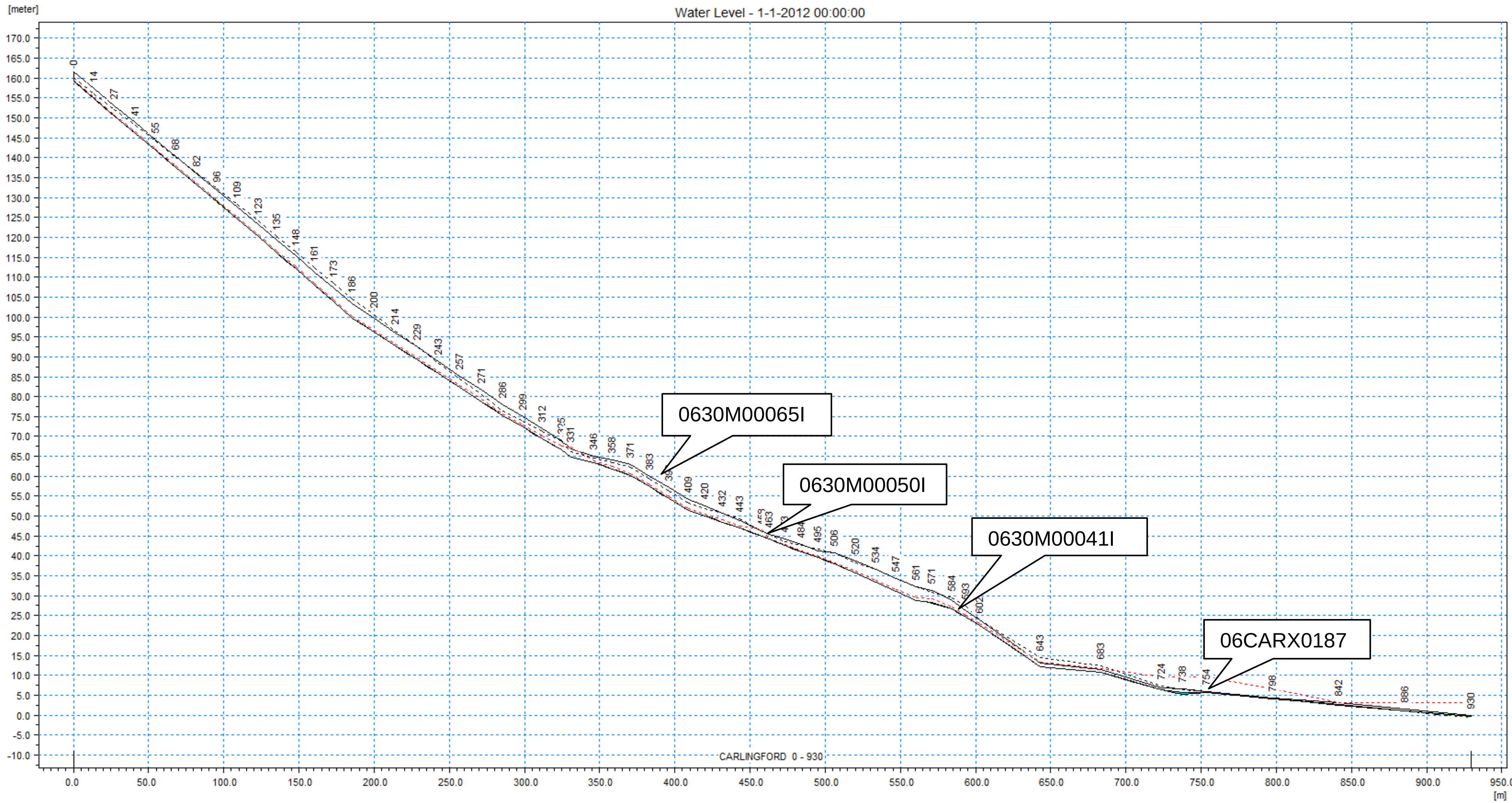
I – Culvert Upstream Face

J – Culvert Downstream Face

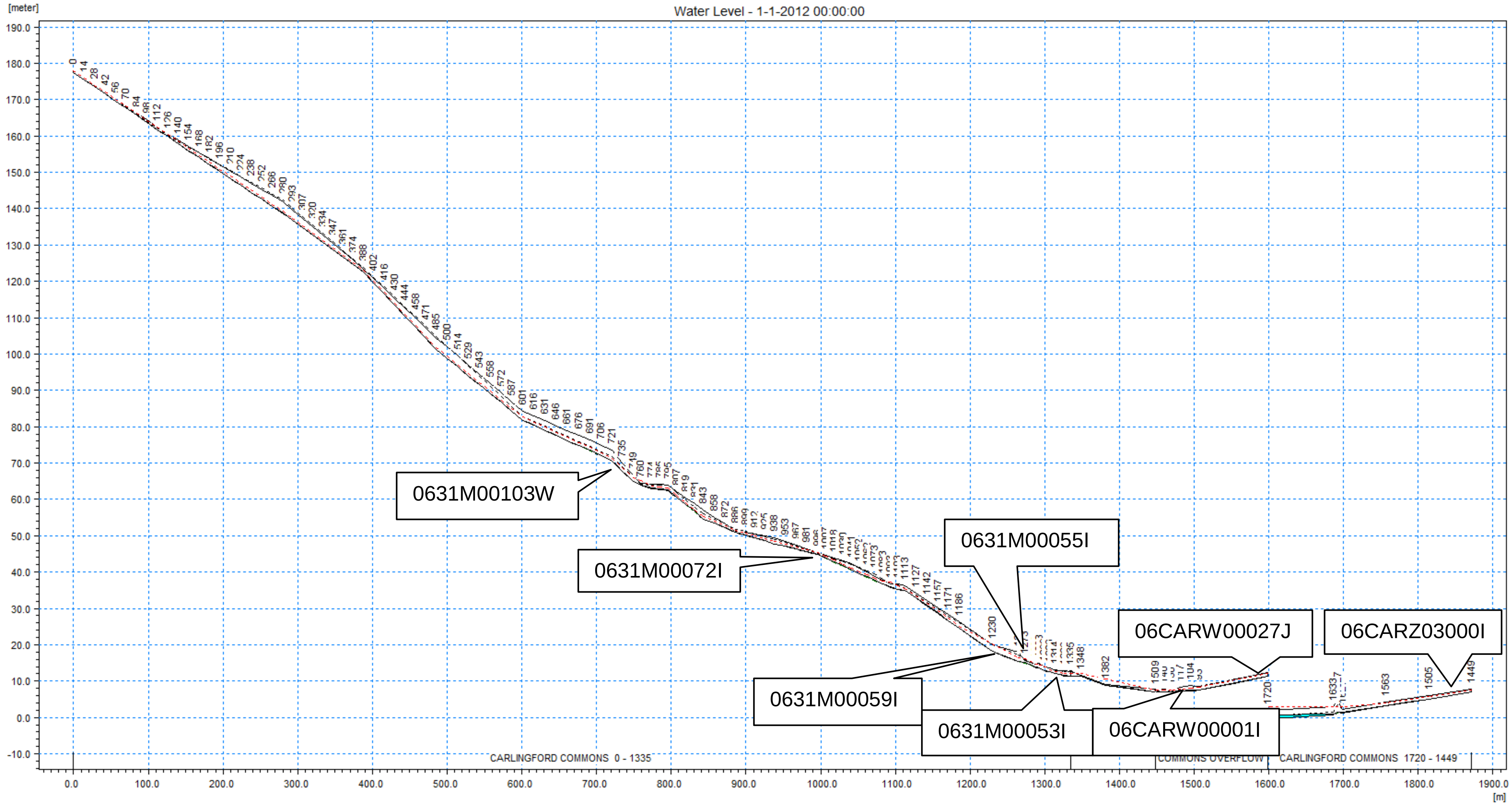
NB: Weirs not reported are weirs included in the Network file to form part of a composite structure with the culvert/bridge.

APPENDIX A.2

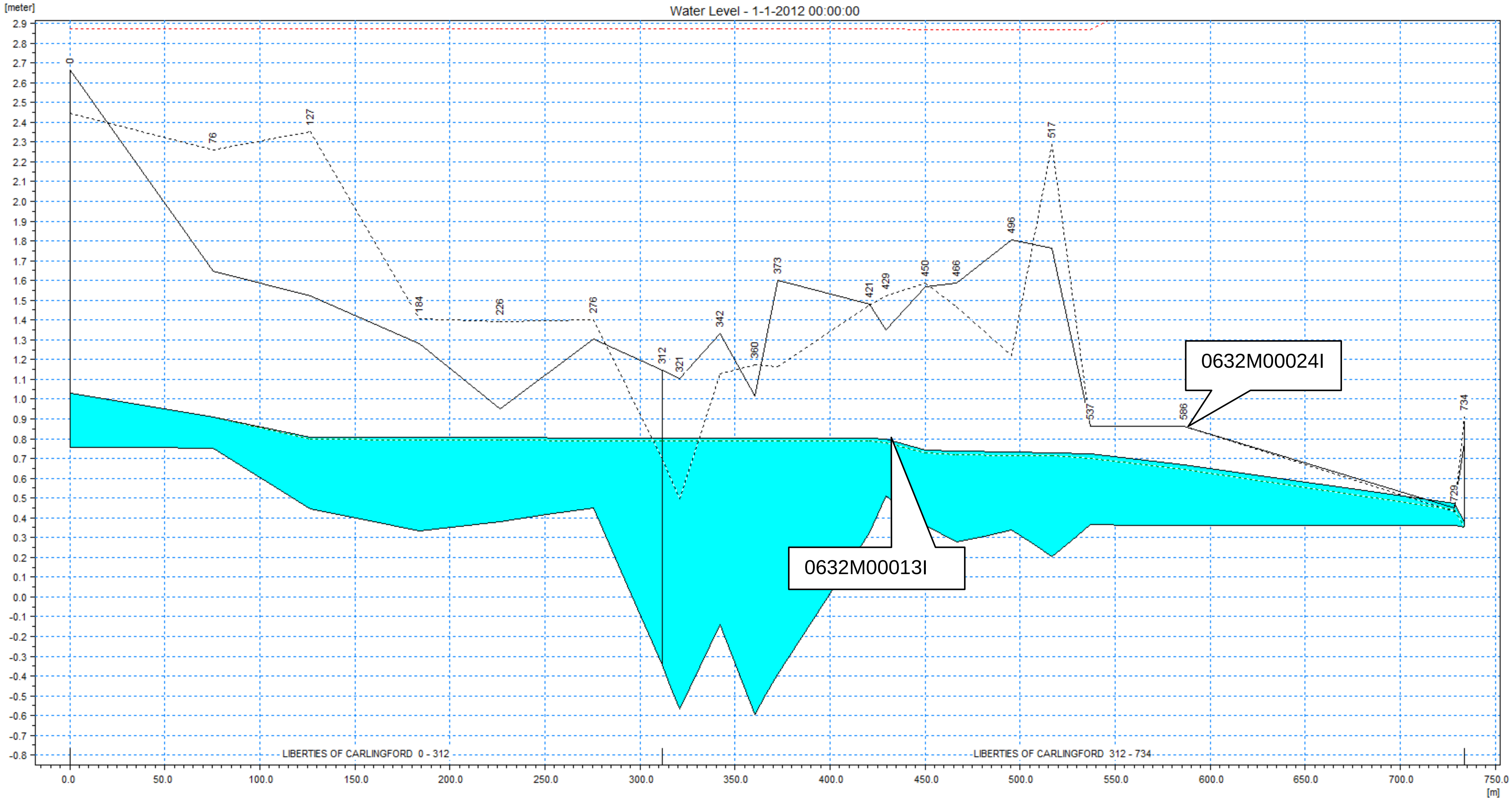
LONG SECTION PROFILES



Long Section Profile, Fluvial Dominated 0.1% AEP event in the Carlingford watercourse



Long Section Profile, Fluvial Dominated 0.1% AEP event in the Carlingford Commons with Overflow Route



Long Section Profile, Fluvial Dominated 0.1% AEP event in the Liberties of Carlingford

APPENDIX A.3

	Peak Water Flows			
River Name & Chainage	**AEP**	**Check Flow (m^3/s)**	**Model Flow (m^3/s)**	**Diff (%)**
CARLINGFORD 730.81	10%	2.01	2.26	+12.44
06_311_D	1%	3.72	5.50	+47.85
	0.1%	6.58	8.08	+22.80
CARLINGFORD COMMONS 1334.33	10%	3.21	3.15	-1.87
06_446_1_RPS	1%	5.93	5.10	-14.00
	0.1%	10.49	11.78	+12.33
LIBERTIES OF CARLINGFORD 205.26	10%	1.47	1.50	+2.04
06_847_1_RPS	1%	2.71	2.79	+2.95
	0.1%	4.79	4.50	-5.97
LIBERTIES OF CARLINGFORD 506.179	10%	5.88	2.72	-53.78
06_908_2	1%	10.86	3.57	-67.13
	0.1%	19.22	6.09	-68.31

The table above provides details of flow in the model at every HEP inflow, check point and modelled tributary. These flows have been compared with the hydrology flow estimation and a percentage difference provided.

The difference between modelled peak flows and estimated check flows in Carlingford River, Carlingford Commons River and Liberties of Carlingford River ranges from 2% to 68%. This model has both fluvial and tidal influences and so the downstream boundaries of this model are set as tidal hydrographs. The estimated flows are based on fluvial inputs only and do not account for this tidal influence, as such there is a large difference shown during all events simulated in the River Carlingford, River Carlingford Commons and the River Liberties of Carlingford.

Also, due to the low lying topography in the area as well as the presence of the coastal walls at Carlingford Harbour the downstream fluvial flows are very complex. Simulated out-of-bank flooding from the Carlingford River was observed to back up behind the coastal walls and continue east to the lower reaches of the Liberties of Carlingford. Simulated out-of-bank flooding from the Carlingford Commons and Liberties of Carlingford also interact with each other. This fluvial-fluvial and fluvial-tidal interaction of flow makes reconciling these flows using these 1-dimensional check flow values difficult. There have been updates made to the hydrological flow estimates, see Hydrological Report, Appendix D and the modelled river network nee, see Section 4.8.2(9)(a). Implementing these updates to the model has improved the modelled flows and flood extents therefore the model is now considered to be behaving reasonably.

APPENDIX A.4

MODEL FILES AND GIS FILES

MIKE FLOOD	MIKE 21	MIKE 21 RESULTS
HA6_CARL2_MF_DEF_5_F_Q10	HA6_CARL2_M21_DEF_5_F_Q10	HA6_CARL2_M21_DEF_5_F_Q10.dfs2
HA6_CARL2_MF_DEF_7_F_Q100	HA6_CARL2_M21_DEF_7_F_Q100	HA6_CARL2_M21_DEF_7_F_Q100.dfs2
HA6_CARL2_MF_DEF_7_F_Q1000	HA6_CARL2_M21_DEF_7_F_Q1000	HA6_CARL2_M21_DEF_7_F_Q1000.dfs2
HA6_CARL2_MF_DEF_5_T_Q10	HA6_CARL2_M21_DEF_5_T_Q10	HA6_CARL2_M21_DEF_5_T_Q10.dfs2
HA6_CARL2_MF_DEF_5_T_Q200	HA6_CARL2_M21_DEF_5_T_Q200	HA6_CARL2_M21_DEF_5_T_Q200.dfs2
HA6_CARL2_MF_DEF_5_T_Q1000	HA6_CARL2_M21_DEF_5_T_Q1000	HA6_CARL2_M21_DEF_5_T_Q1000.dfs2

MIKE 11 - SIM FILE & RESULTS FILE	**MIKE 11 - NETWORK FILE**	**MIKE 11 - CROSS-SECTION FILE**	**MIKE 11 - BOUNDARY FILE**
HA06_CARL2_M11_DEF_5_F_Q10 HA06_CARL2_M11_DEF_5_F_Q10.res11 HA06_CARL2_M11_DEF_7_F_Q100 HA06_CARL2_MF_DEF_7_F_Q100.res11 HA06_CARL2_M11_DEF_7_F_Q1000 HA06_CARL2_MF_DEF_7_F_Q1000.res11 HA06_CARL2_M11_DEF_5_T_Q10 HA06_CARL2_MF_DEF_5_T_Q10.res11 HA06_CARL2_M11_DEF_5_T_Q200 HA06_CARL2_MF_DEF_5_T_Q200.res11 HA06_CARL2_M11_DEF_5_T_Q1000 HA06_CARL2_MF_DEF_5_T_Q1000.res11	HA06_CARL2_NWK_DES_1	HA06_CARL2_XNS_DES_1	HA06_CARL2_BND_DEF_5_F_Q10 HA06_CARL2_BND_DEF_5_F_Q100 HA06_CARL2_BND_DEF_5_F_Q1000 HA06_CARL2_BND_DEF_5_F_Q2
MIKE 11 - DFS0 FILE		**MIKE 11 - HD FILE & RESULTS FILE**	
CARL2_DFS0_2_F_Q2 CARL2_DFS0_2_F_Q10 CARL2_DFS0_2_F_Q100 CARL2_DFS0_2_F_Q1000 CARL2_DFS0_2_F_Q2 CARL2_DFS0_T_Q10 CARL2_DFS0_T_Q200 CARL2_DFS0_T_Q1000		HA06_CARL2_HD_DEF_5_F_Q10 HA6_CARL2_MF_DEF_5_F_Q10.dfs2 HA06_CARL2_HD_DEF_7_F_Q100 HA6_CARL2_MF_DEF_7_F_Q100.dfs2 HA06_CARL2_HD_DEF_7_F_Q1000 HA6_CARL2_MF_DEF_7_F_Q1000.dfs2 HA06_CARL2_HD_DEF_5_T_Q10 HA6_CARL2_MF_DEF_5_T_Q10.dfs2 HA06_CARL2_HD_DEF_5_T_Q200 HA6_CARL2_MF_DEF_5_T_Q200.dfs2 HA06_CARL2_HD_DEF_5_T_Q1000 HA6_CARL2_MF_DEF_5_T_Q1000.dfs2	

'Mechanism 2 Wave Overtopping' Model Files		
MIKE 21	**MIKE 21 - DFS0 FILE**	**MIKE 21 RESULTS**
HA06_CARL2_M21FM_WAV_13_Q10 HA06_CARL2_M21FM_WAV_13_Q200 HA06_CARL2_M21FM_WAV_13_Q1000 HA06_CARL2_DEV13_mesh1	HA06_CARL2_100AEP HA06_CARL2_005AEP HA06_CARL2_001AEP	HA06_CARL2_M21FM_WAV_13_Q10 HA06_CARL2_M21FM_WAV_13_Q200 HA06_CARL2_M21FM_WAV_13_Q1000

GIS Deliverables - Hazard		
Flood Extent Files (Shapefiles)	**Flood Depth Files (Raster)**	**Water Level and Flows (Shapefiles)**
<u>Fluvial</u> N06CAR_EXFCD001_010_100_F0 Page 1 of 2 N06CAR_EXFCD001_010_100_F0 Page 2 of 2 <u>Coastal</u> N06CAR_EXCCD001_005_100_F0 Page 1 of 2 N06CAR_EXCCD001_005_100_F0 Page 2 of 2	<u>Fluvial</u> N06CAR_DPFCD001_F0 N06CAR_DPFCD010_F0 N06CAR_DPFCD100_F0 <u>Coastal</u> N06CAR_DPCCD001_F0 N06CAR_DPCCD005_F0 N06CAR_DPCCD100_F0	<u>Fluvial</u> N13NFCDF0 <u>Coastal</u> N13NCCDF0
Flood Zone Files (Shapefiles)	**Flood Velocity Files (Raster)**	**Flood Defence Files (Shapefiles)**
<u>Fluvial</u> To be issued with final version of this report	<u>Fluvial</u> N06CAR_VLFCD001_F0 N06CAR_VLFCD010_F0 N06CAR_VLFCD100_F0 <u>Coastal</u> N06CAR_VLCCD001_F0 N06CAR_VLCCD005_F0 N06CAR_VLCCD100_F0	N/A
GIS Deliverables - Risk		
Specific Risk - Inhabitants (Raster)	**General Risk - Economic (Shapefiles)**	**General Risk-Environmental (Shapefiles)**
<u>Fluvial</u> To be issued with final version of this report <u>Coastal</u> To be issued with final version of this report		