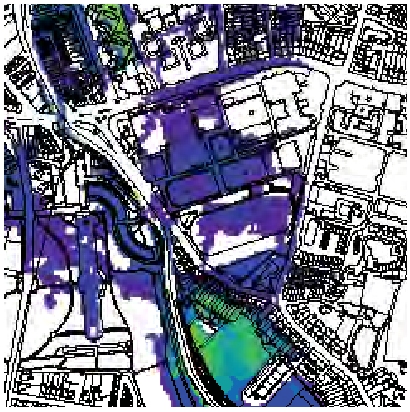
RPS

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

North Western - Neagh Bann CFRAM Study

UoM 06 Hydraulics Report
4.7 Dundalk and Blackrock South

IBE0700Rp0012



OPW
The Office of Public Works
Oifig na nOibreacha Poiblí

Photographs of flooding on cover provided by Rivers Agency

NWNB CFRAM Study

HA06 Hydraulics Report – Dundalk & Blackrock South Model

DOCUMENT CONTROL SHEET

Client	OPW
Project Title	NWNB CFRAM Study
Document Title	IBE0700Rp0012_ HA06 Hydraulics Report
Model Name	Dundalk/ Blackrock South

Rev.	Status	Author(s)	Modeller	Reviewed by	Approved By	Office of Origin	Issue Date
D01	Draft	T.Carberry	C. Neill	S. Patterson	G. Glasgow	Belfast/Limerick	03/07/2014
F01	Draft Final	C. Neill	C. Neill	L. Arbuckle	G. Glasgow	Belfast	18/12//2014
F02	Draft Final	C. Neill	C. Neill	L. Arbuckle	G. Glasgow	Belfast	13/08/2015
F03	Draft Final	C. Neill	C. Neill	S. Patterson	G. Glasgow	Belfast	07/07/2016

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	N/A
North Western Neagh Bann CFRAM HA01_06_36 Survey Contract Report	October 2013	IBE0700Rp0007_HA01_06_36 NWNB_CFRAM_Survey Contract Report	N/A
North Western Neagh Bann CFRAM Study UoM06 Inception Report	March 2013	IBE0700Rp0012_UoM06 Hydrology Report	4, 4.3.2, 5, 6.2, 6.3
North Western Neagh Bann CFRAM Study Hydrology Report UoM06	October 2013	IBE0700Rp0012_UoM 06 Hydrology Report	4.4

4 HYDRAULIC MODEL DETAILS

4.7 DUNDALK & BLACKROCK SOUTH

4.7.1 General Hydraulic Model Information

(1) Introduction:

The NWNB CFRAM Flood Risk Review (2011s5232 NW&NB CFRAM FRR Report_Final_v2.0) highlighted Dundalk and Blackrock South 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.

The AFA encompasses the Dundalk Harbour area, extending southwards along the shores of Dundalk Bay to include the coastal village of Blackrock. Its western boundary is such that Dundalk and its environs are included within the overall AFA. The Castletown River is the largest river within the model which originates as the White Water and Tullyvallan Rivers approximately 25km north in Newtownhamilton, County Armagh. The Castletown River flows in a south-westerly direction before entering Castletown Estuary in Dundalk north. It is tidally influenced as far upstream as HEP 06_1087_13_RA. Its total catchment area at the downstream limit is 239km^2. Pasture is the predominant land use at over 95% coverage.

The Dundalk and Blackrock South model is termed 'Model 4' within the CFRAM Study hydrology analysis (refer to UoM06 Hydrology Report Rp0012, Chapter 4.4) and the hydraulic modelling programme. It has been divided into six sub models, Models 4a to 4f to discuss the hydraulically separate models for simulating flood risk to Dundalk AFA.

Models 4a and 4b represent the Aghaboys and Ballynahattin watercourses which rise in the Tievecrom and Daaikilmore Mountains near Forkhill in County Armagh. They flow in a south easterly direction beneath the M1 motorway, and north of Dundalk Racecourse before reaching Ballymascanlan Estuary. The catchment areas at the downstream limits for Model 4a and 4b are 5.5km^2 and 10km^2 respectively.

Model 4c represents the watercourses that potentially pose fluvial flood risk to Dundalk north. This includes the aforementioned Castletown River and all urban tributaries which enter it before it reaches Castletown estuary. The Kilcurry, Stranacarry and Acarreagh watercourses are all tributaries of the Castletown River that are included in Model 4c.

Model 4d represents the watercourses that potentially pose fluvial flood risk to Dundalk south. This includes the Blackwater River which flows through the Marshes Upper and Lower before discharging to Dundalk Bay (catchment area 23km^2); and the Marshes Lower urban watercourse and tributaries which flow through Marshes Lower before discharging to Castletown Estuary (catchment area 17.5km^2).

Model 4e represents two watercourses that potentially pose fluvial flood risk to Blackrock. Model 4e flows through the townlands of Haggardtown Cross and Green Gates before flowing through Blackrock and

discharging to Dundalk Bay. It is a small and very flat watercourse which drains agricultural lands and has a catchment area of 2.8km^2 at the downstream limit of the model. The Blackrock watercourse drains an area of mixed industrial and agricultural land in south Dundalk before flowing through residential areas of Blackrock and discharging to Dundalk Bay. This watercourse is also flat and drains a largely urbanised catchment area of 3.2km^2.

There are two staff gauge stations located at Ladyswell and St.John's Bridge within the Dundalk model; however both record water level only and have no flow data available.

There are no models located upstream or downstream of Model 4.

All watercourses in this model are HPWs, and so have been modelled as 1D-2D using the MIKE suite of software.

(2) Model Reference:	HA06_DUND4
(3) AFAs included in the model:	Dundalk & Blackrock South

(4) Primary Watercourses / Water Bodies (including local names):

Name	**Reach ID**
BLACKROCK	0616A
GREEN GATES	0616M
FAIRHILL RIVER	0617A
CAMBRICKVILLE TRIB 1	0617B
DUNDALK_TRIBUTARY	0617C
DUNDALK_BLACKWATER	0617M
DUNDALK	0617M_B
PRIORLAND	0618M
FAIRHILL TRIBUTARY	0619A
FAIRHILL_TRIBUTARY_2	0619B
FAIRHILL	0619M
KILALLY	0620M
DONAGHMORE	0621M
MARSHES LOWER	0622M
CASTLETOWN_RIVER	0623M
ACARREAGH	0624M
CASTLETOWN	0625M
STRANACARRY	0626M
KILCURRY RIVER TRIBUTARY 1	0627A
KILCURRY RIVER TRIBUTARY 2	0627B
KILCURRY_RIVER	0627M
BALLYNAHATTIN	0628M
AGHABOYS	0629M

(5) Software Type (and version):		
(a) 1D Domain: MIKE 11 (2012)	**(b) 2D Domain:** MIKE 21 - Flexible Mesh (2012)	**(c) Other model elements:** MIKE FLOOD (2012)

4.7.2 Hydraulic Model Schematisation

(1) Map of Model Extents:

The maps in Figure 4.7.1 to Figure 4.7.5 illustrate the extent of the modelled catchment, river centre line, HEP locations and AFA extents. The watercourses within the Dundalk & Blackrock South AFA extent are HPWs. The model contains 14no. Upstream Limit HEPs, 9no. Intermediate HEPs of which 2 are gauging stations with no data, 9no. Tributary HEPs and 7no. downstream limit HEPs. All of the tributary HEP points represent modelled tributaries with the exception of 06_1059_Trib_RPS which represents an unmodelled tributary.

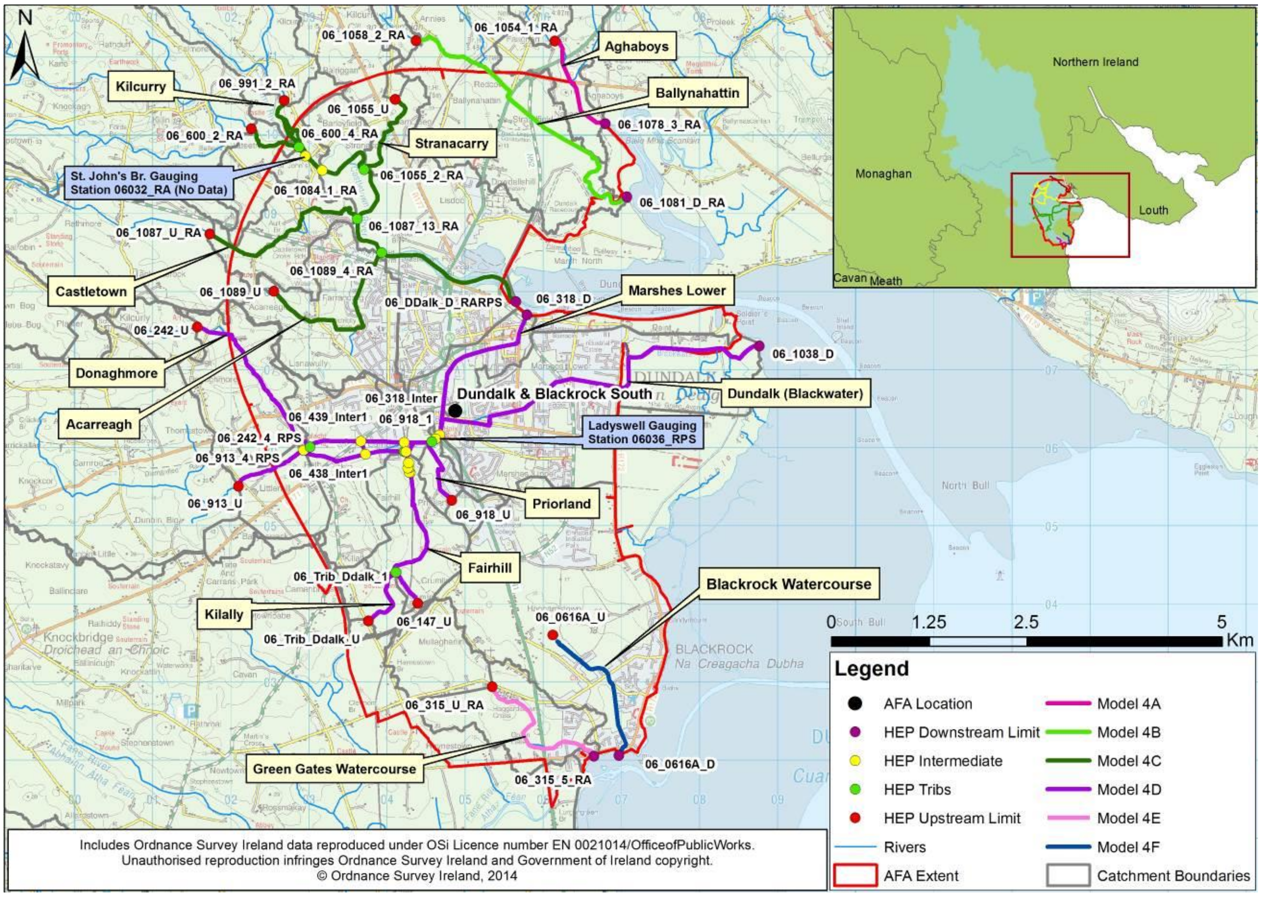


Figure 4.7.1: Map of Model Extents - Overview

The extent contains six models named 4a to 4f inclusive. The extent of these and their model specifics are as follows.

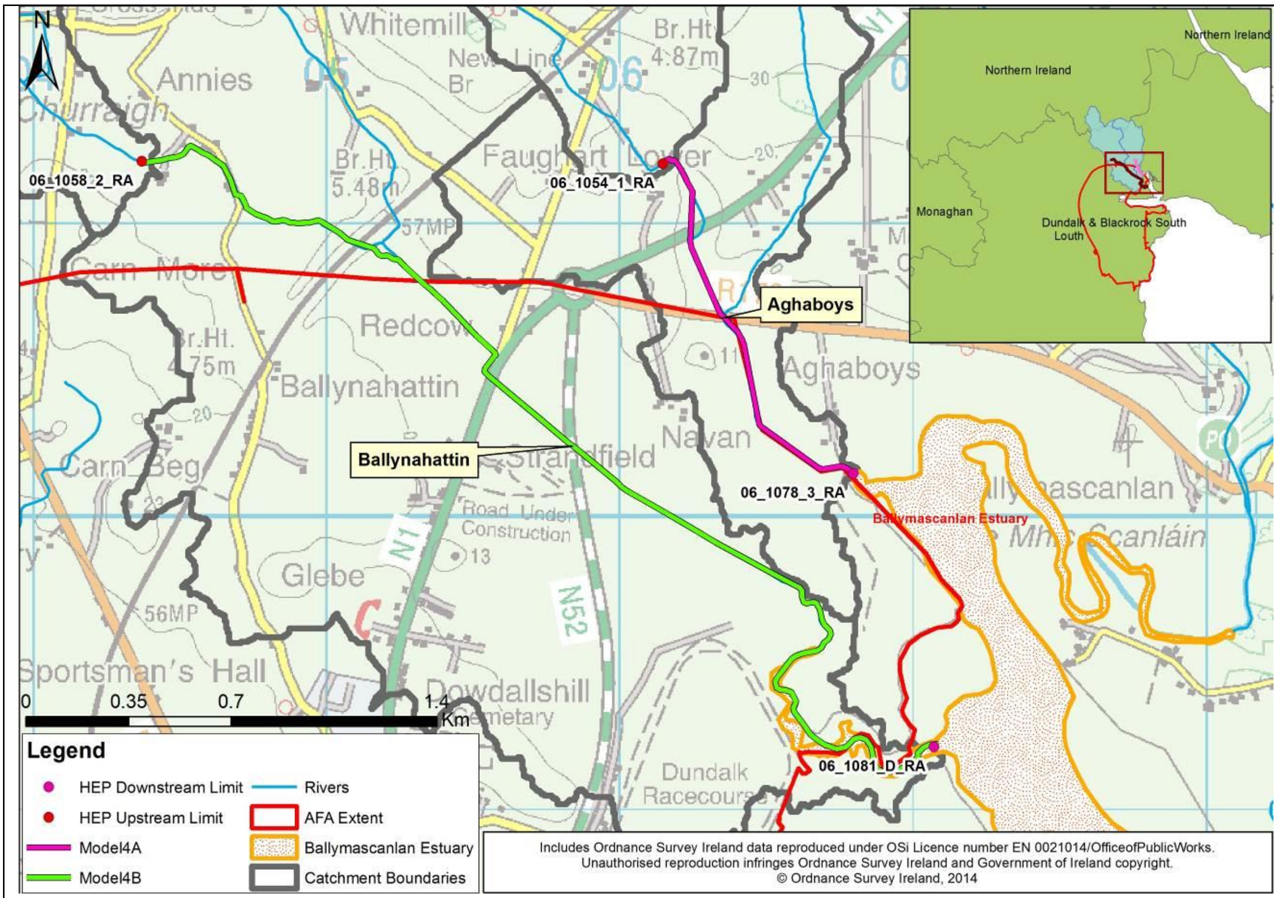


Figure 4.7.2: Map of Model Extents - 4a and 4b

Model 4a, (Figure 4.7.2) Aghaboys, has 1no. Upstream limit HEP (06_1054_1_RA), 1no. Tributary HEP, (the tributary has not been modelled), and 1no. Downstream limit HEP (06_1078_3_RA).

Model 4b, (Figure 4.7.2) Ballynahattin has 1no. Upstream limit HEP (06_1058_2_RA) and 1no. Downstream (06_1081_D_RA).

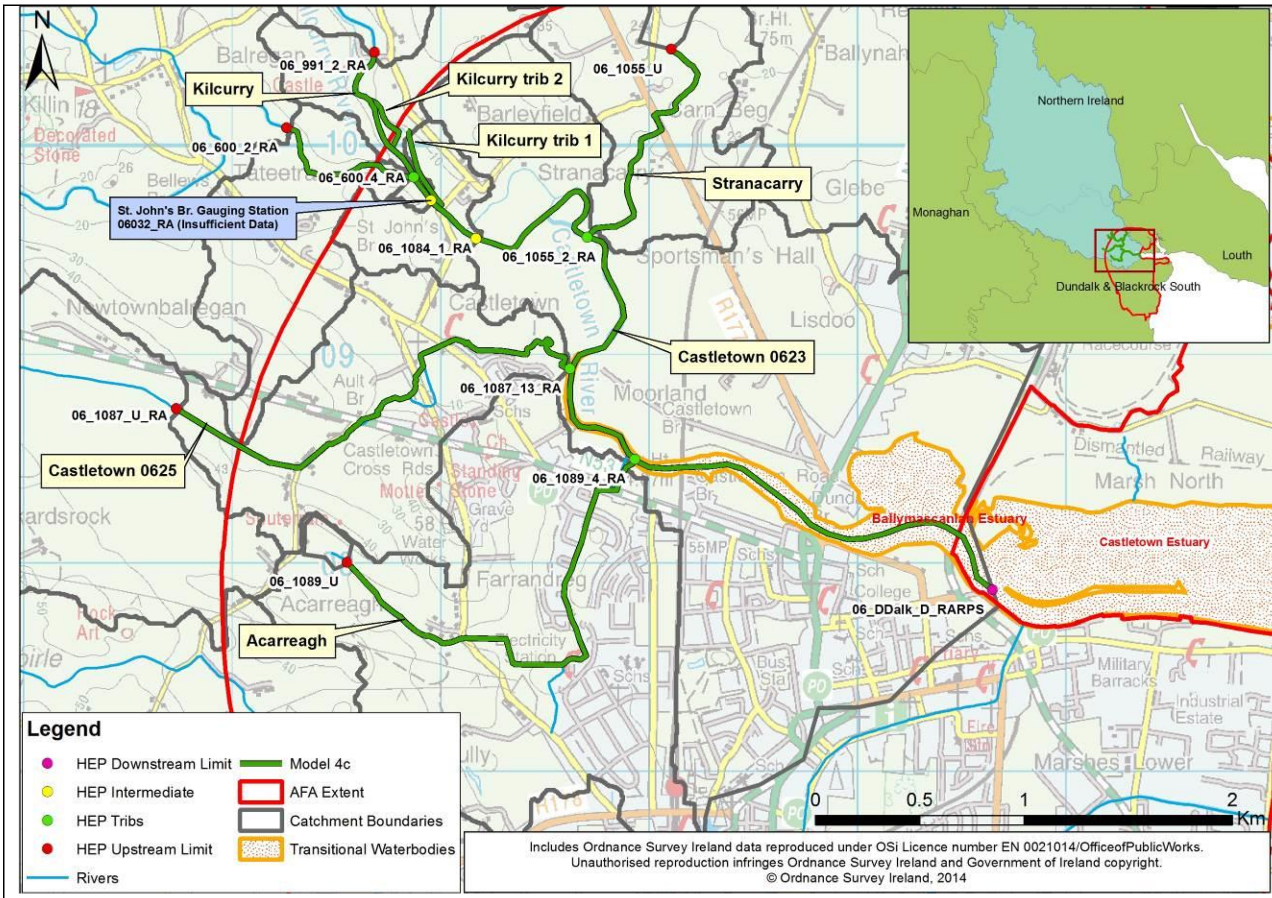


Figure 4.7.3: Map of Model Extents - 4c

Model 4c (Figure 4.7.3) has 12 HEP nodes which include 5no. Upstream limit HEPs, 4no. Tributary HEPs all of which have been modelled, 2no. Intermediate HEPs (of which one is a gauging station 06032 with no data), and 1no. Downstream limit HEP. Gauging station 06032 is a staff gauge with insufficient data recorded to be used effectively and so was redefined as an Intermediate HEP.

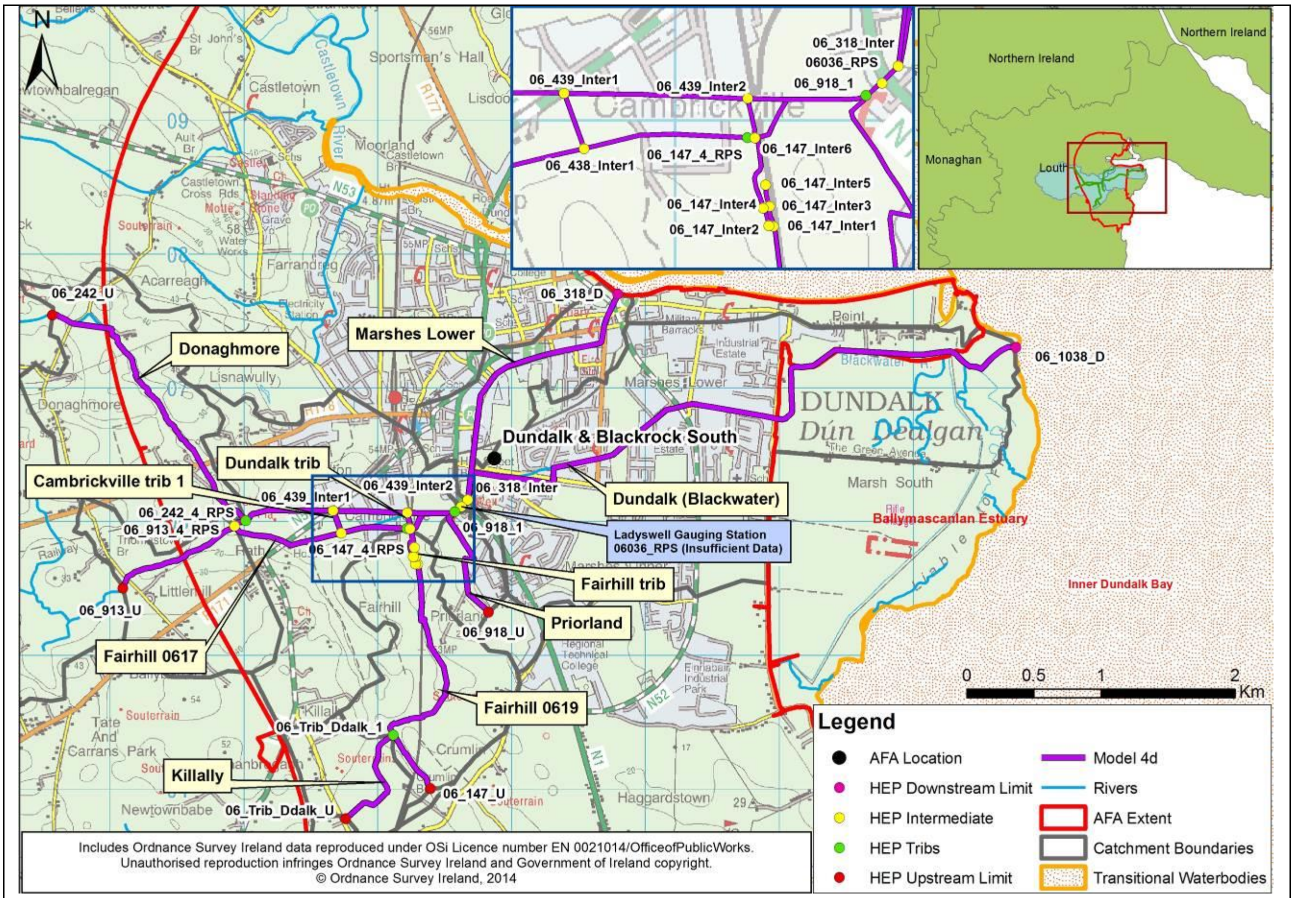


Figure 4.7.4: Map of Model Extents - 4d

Model 4d (Figure 4.7.4) has 5no. Upstream Limit HEPs, 4no. Tributary HEPs all of which have been modelled, 7no. Intermediate HEPs, (one of which is a gauging station with no data), and 2no. Downstream Limit HEPs. Gauging station 06036 is a water level recorder gauge with insufficient data to be used in the study and so was redefined as an Intermediate HEP.

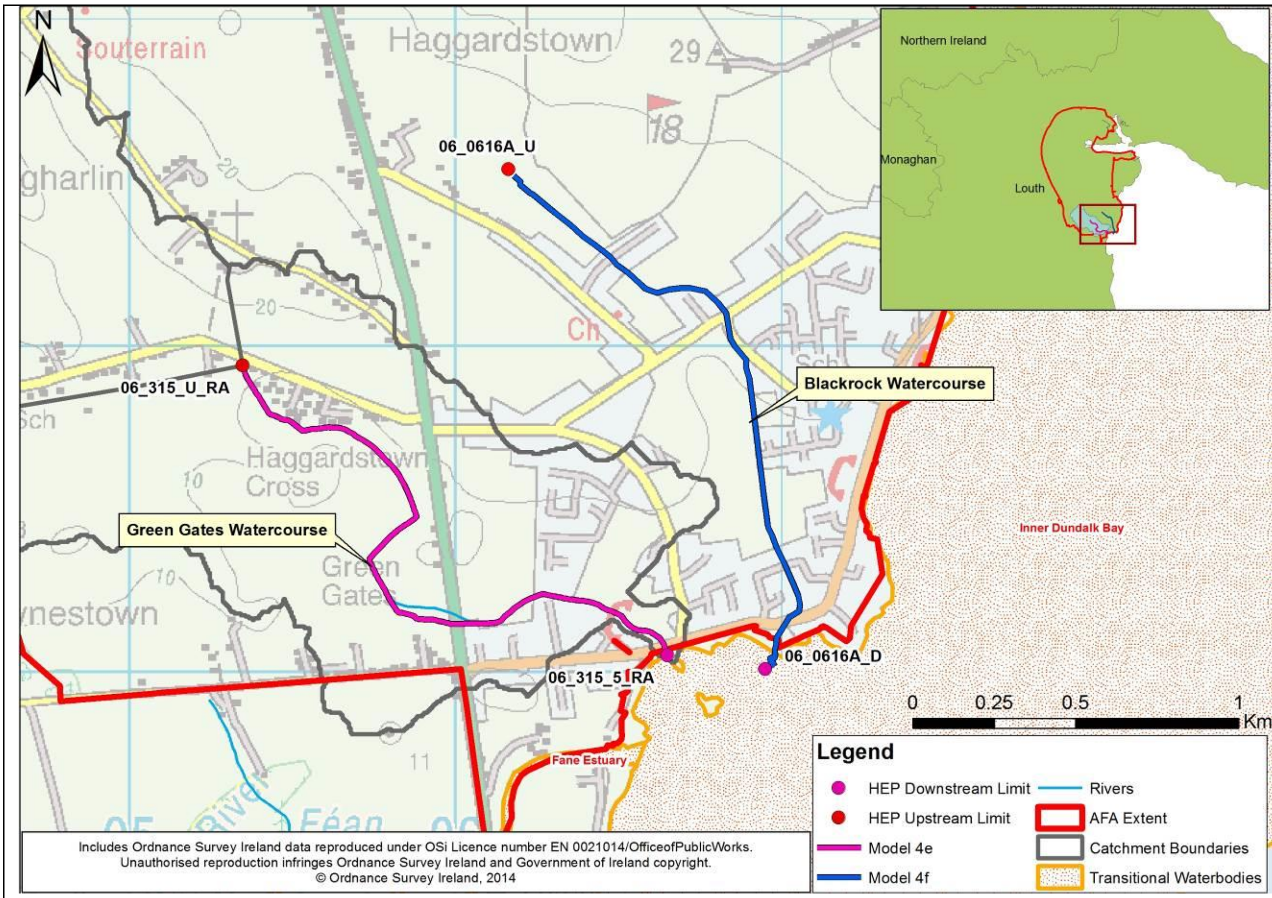


Figure 4.7.5: Map of Model Extents - 4e and 4f

Models 4e and 4f (Figure 4.7.5) each contain 1no. Upstream HEP and 1no. Downstream HEP.

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

River Name		x	y
0616A	BLACKROCK	306175	303521
0616M	GREENGATES	305353	302914
0617A	FAIRHILL RIVER	302937	305960
0617B	CAMBRICKVILLE TRIB 1	303725	305916
0617C	DUNDALK TRIBUTARY	304239	305948
0617M	DUNDALK	302090	305506
0617M_B	DUNDALK B	304691	306254
0618M	PRIORLAND	304813	305339
0619A	FAIRHILL TRIBUTARY	302844	310056
0619B	FAIRHILL_TRIBUTARY_2	302662	310213
0619M	FAIRHILL	304393	304004
0620M	KILLALLY	303780	303801
0621M	DONAGHMORE	301567	307545
0622M	MARSHES LOWER	304670	306164
0623M	CASTLETOWN RIVER A	302260	310085
0624M	ACARREAGH	302572	307976
0625M	CASTLETOWN	301723	308743
0626M	STRANACARRY	303704	309563
0627A	KILCURRY RIVER TRIBUTARY 1	302844	310056
0627B	KILCURRY RIVER TRIBUTARY 2	302687	310204
0627M	KILCURRY_RIVER	302682	310448
0628M	BALLYNAHATTIN	304366	311210
0629M	AGHABOYS	306143	311209

(3) Total Modelled Watercourse Length:		40.7 km	
(4) 1D Domain only Watercourse Length:	0 km	**(5) 1D-2D Domain Watercourse Length:**	40.7 km
(6) 2D Domain Mesh Type / Resolution / Area:		Flexible / 5-150 metres / 135 km^2 (approx.) A smaller mesh size was used in areas of greatly varying topography and adjacent to all 1D-2D connections. Larger cells were used in flatter areas and in the bay area towards the boundary.	

(7) 2D Domain Model Extent:

Figure 4.7.6 and Figure 4.7.7 illustrate the modelled extents, general topography and bathymetry. The spatial extent of the AFA boundary is outlined in pink. The reach centre-lines are presented in red which also represents the 1D modelled extent that is within the 2D area. Buildings are excluded from the mesh and therefore represented as white spaces, refer to Section 3 for details on representation of buildings in

the model.

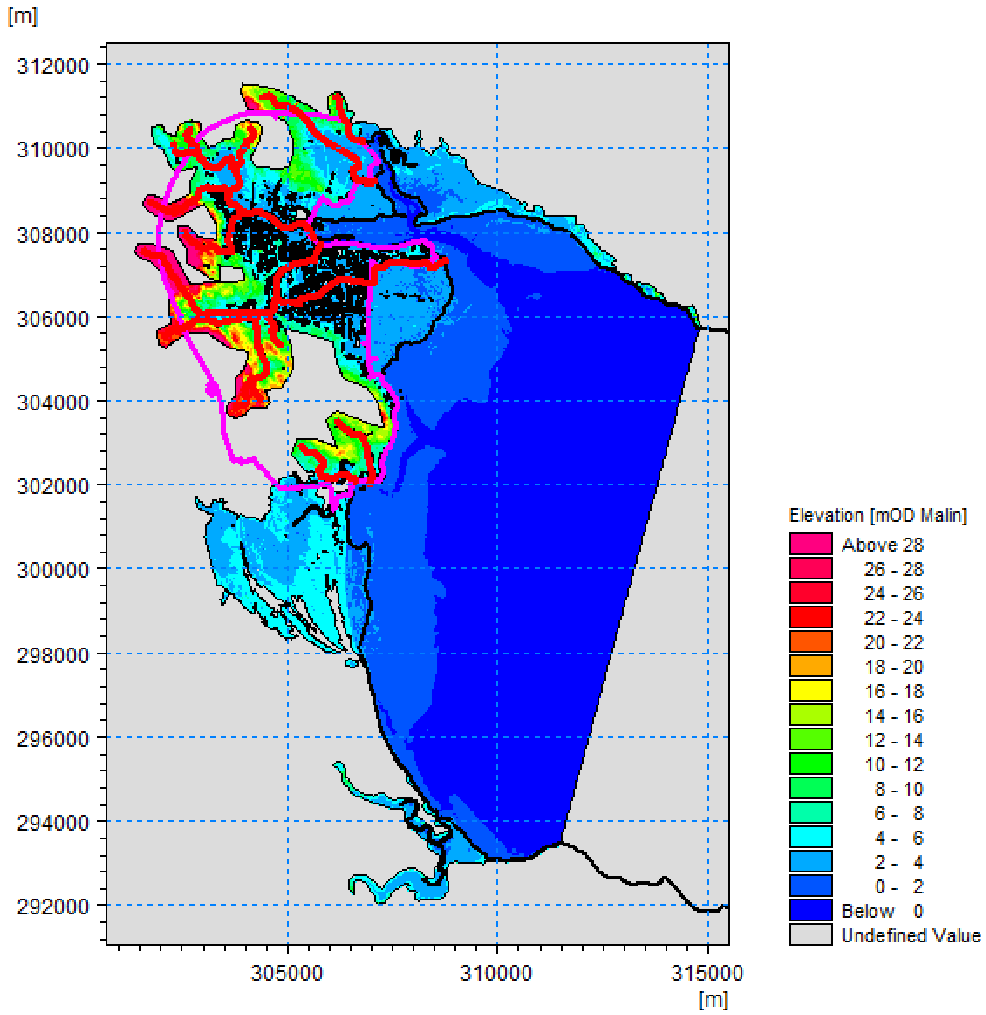


Figure 4.7.6: 2D Domain Model Extent

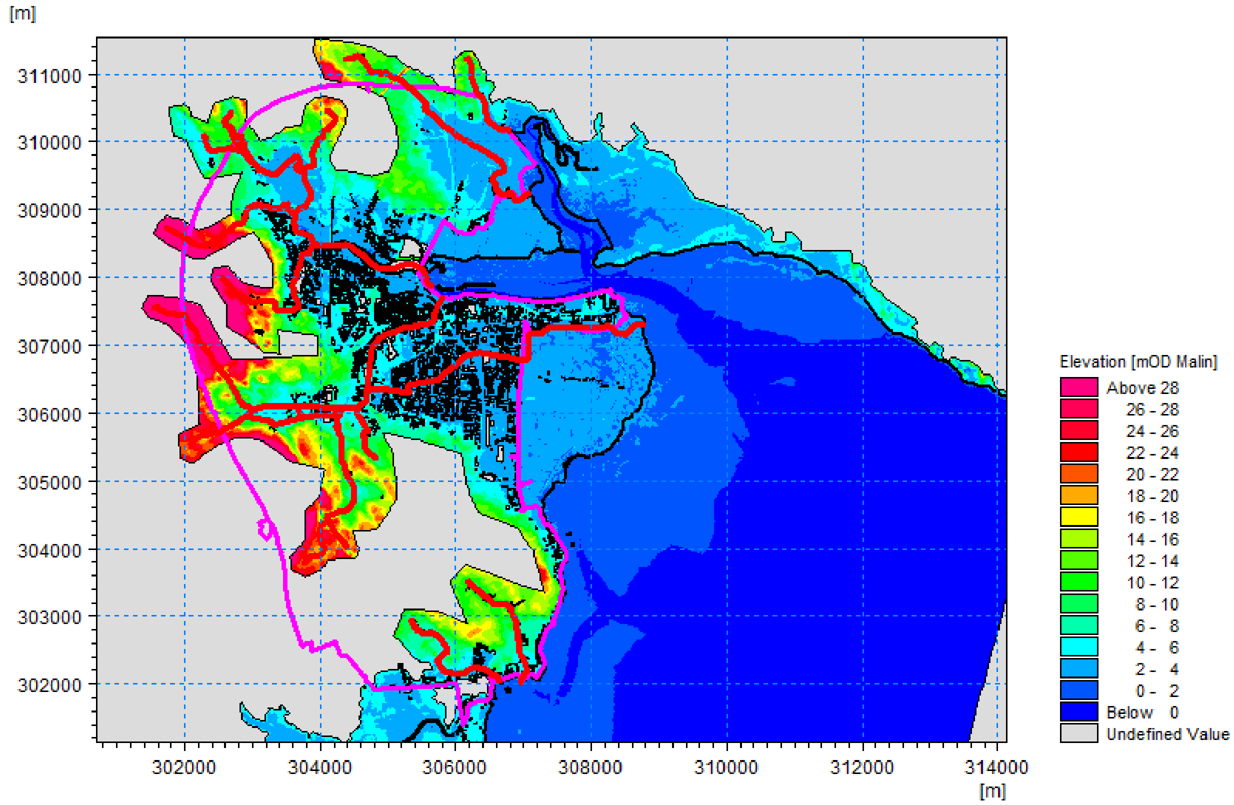


Figure 4.7.7: 2D Domain Model Extent - Detail in AFA vicinity

Figure 4.7.8 and Figure 4.7.9 below show overview drawings of the model schematisation. Figure 4.7.10 to Figure 4.7.12 show detailed views. 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 4.7.10 to Figure 4.7.12 are samples of where there is significant risk of flooding. These diagrams include the surveyed cross-section locations, AFA boundary and river centre. They also show the location of the critical structures as discussed in Section 4.7.3 along with the location and extent of the links between the 1D and 2D models. For clarity in viewing cross-section locations, the detail diagrams show the full extent of the surveyed cross-sections. Note that the 1D model considers only the cross-section between the 1D-2D links.

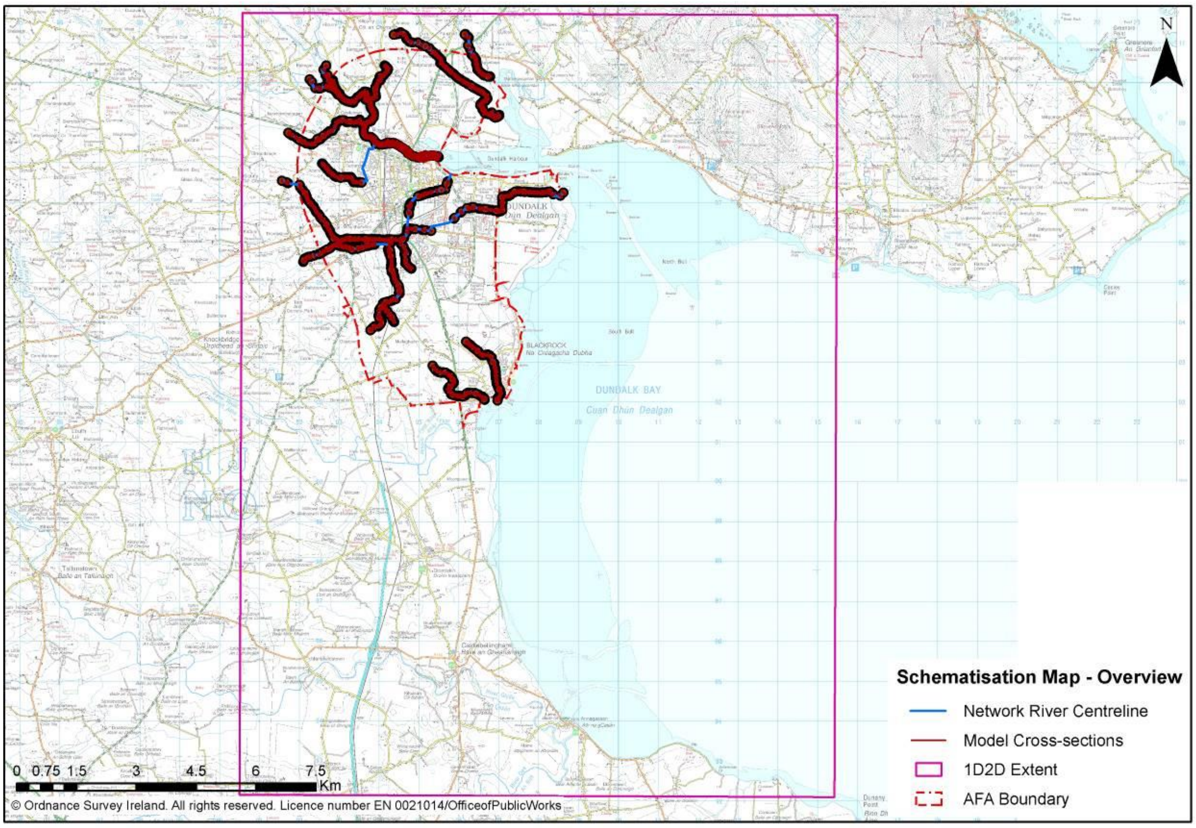


Figure 4.7.8: Overview of Model Schematisation

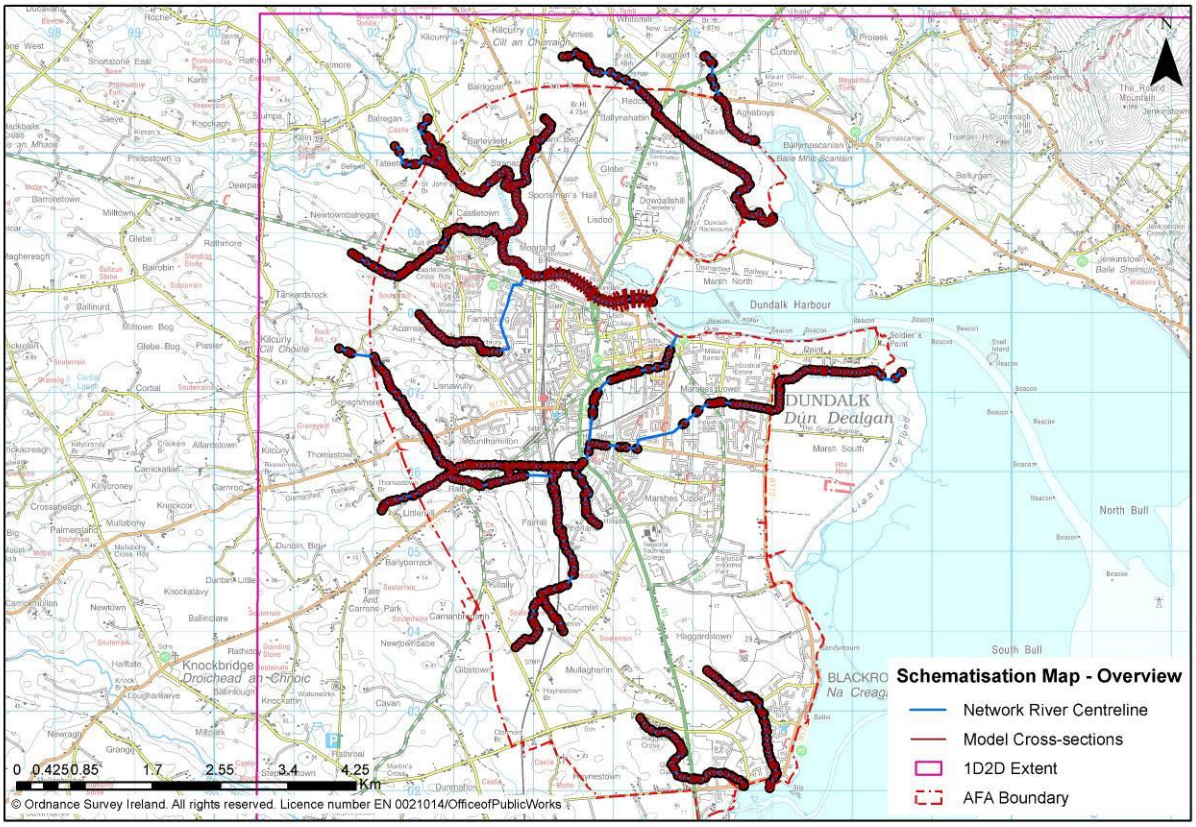


Figure 4.7.9: Overview of Model Schematisation - AFA Extent

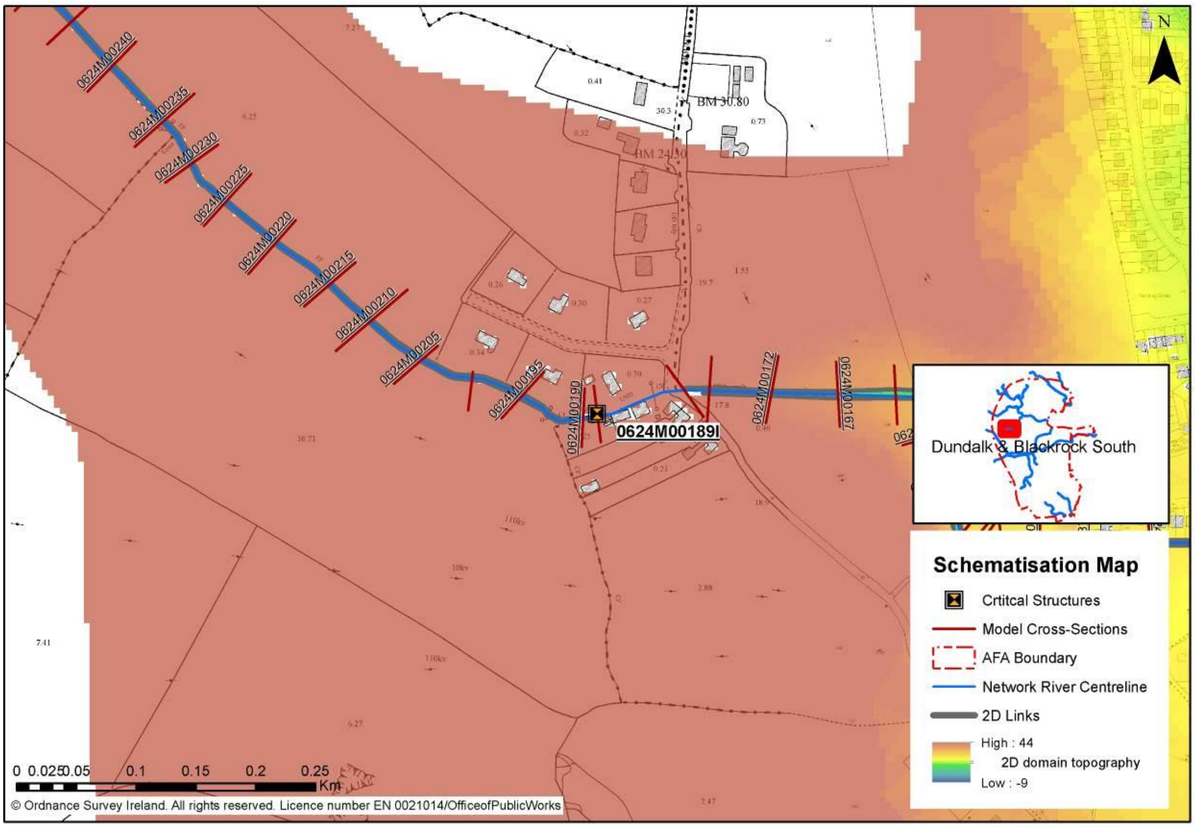


Figure 4.7.10: Model Schematisation of Acarreagh River

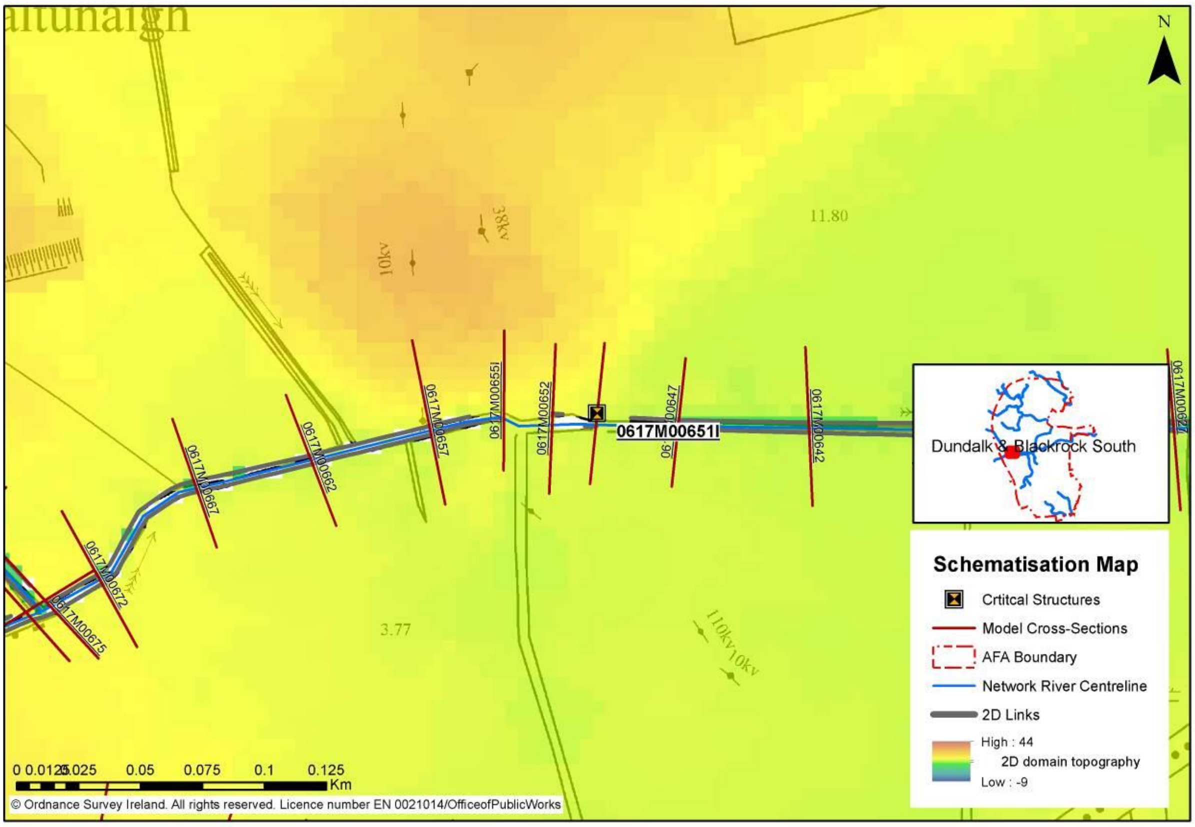


Figure 4.7.11: Model Schematisation of Dundalk River

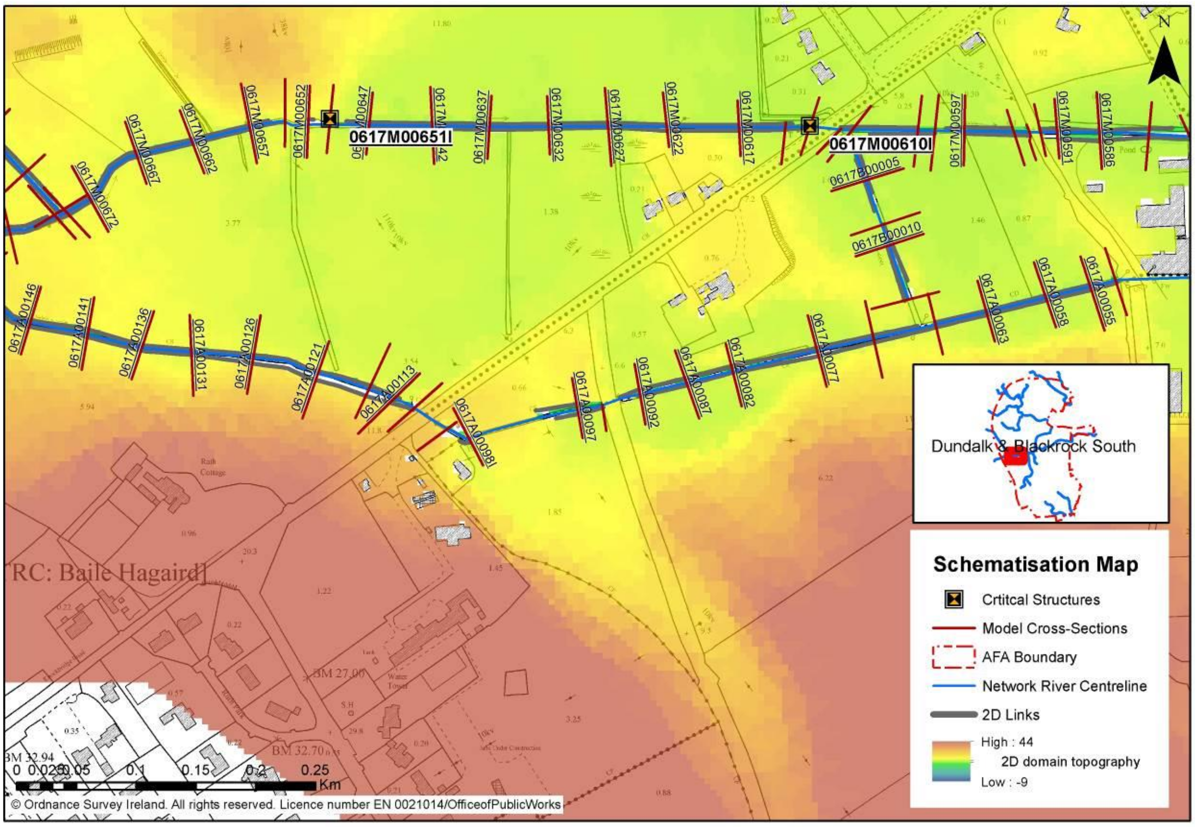


Figure 4.7.12: Model Schematisation of Dundalk River, Fairhill River and Cambrickville Tributary

Figure 4.7.13 illustrates the extents of the specific 2D domain used during model runs to analyse ‘mechanism 2 wave overtopping’ flooding at the Dundalk/Blackrock AFA. There are four distinct ICWWS CAPO Prediction Locations within the AFA, which have been analysed and modelled where appropriate. On final analysis it was deemed appropriate to produce ‘Mechanism 2’ mapping for one location only, although this location is complex and has been split into several lengths of coastline for analysis and modelling. These lengths of coastline are labelled as E1-E5 in Figure 4.7.13. Coastline sections were determined based on the variation of the geometry of the structures to be overtopped and their orientation. It should be noted that this mesh is considerably smaller than the overall mesh for analysing fluvial and ‘mechanism 1 tidal’ flooding as the area of interest is much more localised.

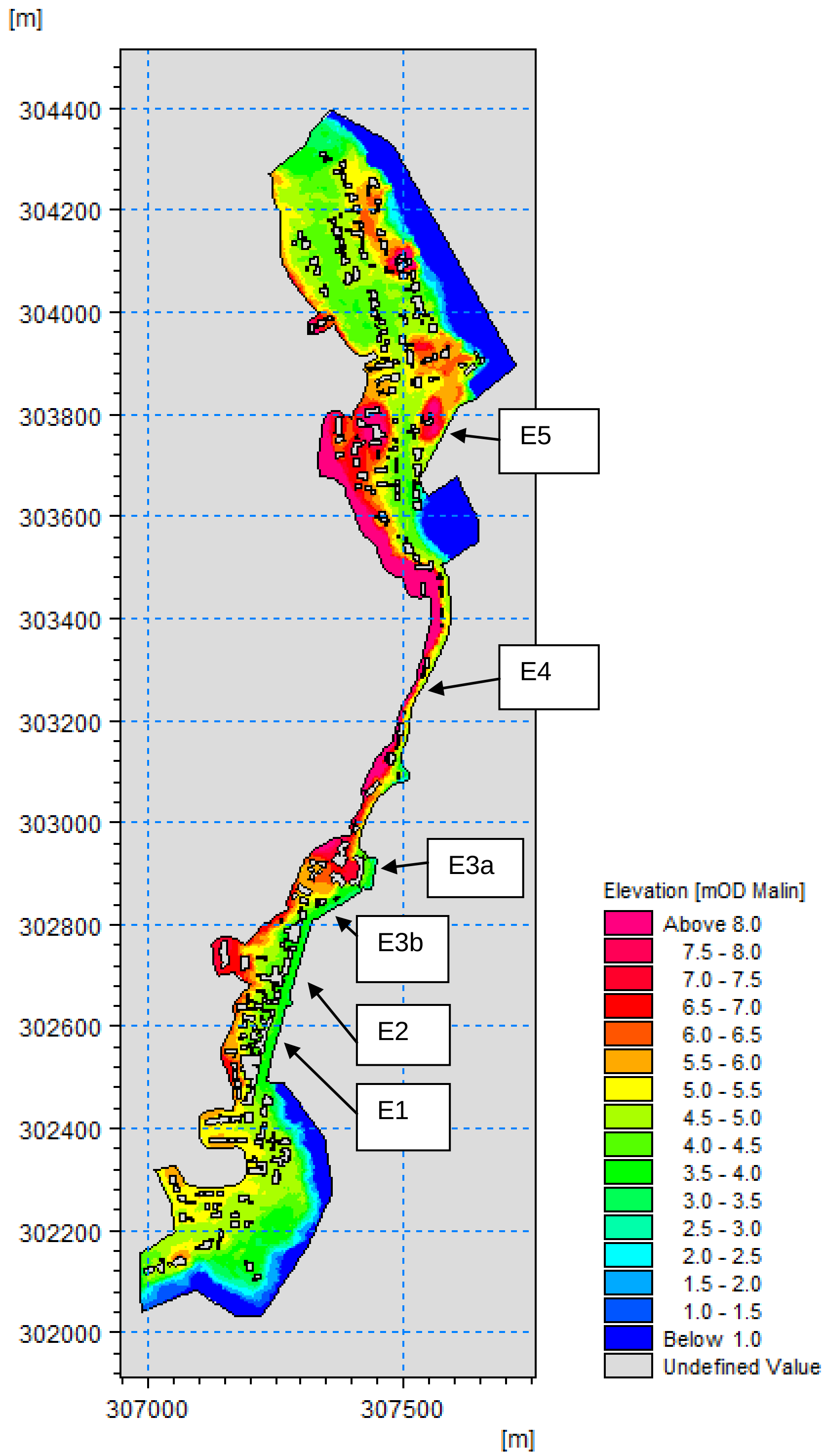


Figure 4.7.13: 2D Domain Model Extent - Wave overtopping

(8) Survey Information

(a) Survey Folder Structure:

First Level Folder	**Second Level Folder**	**Third Level Folder**
Murphy_NW6_M04_ WP6 _0616M_A _V0_130320	V0_20130320_Ascii	
	V0_20130320_GIS	Floodplain_Photos_and_

Dundalk and Blackrock South Murphy: Surveyor Name NW6–North Western CFRAM Study Area, Hydrometric Area 6 M04– Model Number 4 0616M– River Reference WP6 – Work Package 6 Version: V0 *130320*– Date Issued (20 MAR 2013	 V0_20130320_Photos Photos *(Naming convention is in the format of Cross-Section ID and orientation - upstream, downstream, left bank or right bank)*	Shapefile 0616M00001_DN

(b) Survey Folder References:

Reach ID	**Name**	**File Ref.**
0616M	GREENGATES	Murphy_NW6_M04_ WP6 _0616M_A _V0_130320
0616A	BLACKROCK	Murphy_NW6_M05_ WP6 _0616A _V1 _130329
0617M_B	DUNDALK	Murphy_NW6_M04_WP6_0617M_B_V2_130405
0617M	DUNDALK BLACKWATER	Murphy_NW6_M04_WP6_0617M_A_V1_130220
0617B	CAMBRICKVILLE TRIB 1	Murphy_NW6_M04_WP6_0617B_V1_130206
0617C	DUNDALK TRIBUTARY	Murphy_NW6_M04_WP6_0617C_V1_130206
0617A	FAIRHILL RIVER	Murphy_NW6_M04_WP6_0617A_V1_130206
0619A	FAIRHILL TRIBUTARY	Murphy_NW6_M04_WP6_0619A_V1_130220
0619B	FAIRHILL_TRIBUTARY_2	Murphy_NW6_M04_WP6_0619B_V1_130220
0618M	PRIORLAND	Murphy_NW6_M04_WP6_0618M_V1_130220
0619M	FAIRHILL	Murphy_NW6_M04_WP6_0619M_V1_130220
0620M	KILLALLY	Murphy_NW6_M04_WP6_0620M_V1_130206
0621M	DONAGHMORE	Murphy_NW6_M04_WP6_0621M_V1_130206
0622M	MARSHES LOWER	Murphy_NW6_M04_WP6_0622M_V1_130220
0623M	CASTLETOWN RIVER	Murphy_NW6_M04_WP6_0623M_B_V1_130206 Murphy_NW6_M04_WP6_0623M_A_V2_130227
0624M	ACARREAGH	Murphy_NW6_M04_WP6_0624M_V1_130206
0625M	CASTLETOWN	Murphy_NW6_M04_WP6_0625M_V1_130208
0626M	STRANACARRY	Murphy_NW6_M04_WP6_0626M_V1_130220
0627M	KILCURRY_RIVER	Murphy_NW6_M04_WP6_0627M_V1_130220
0627A	KILCURRY RIVER TRIBUTARY 1	Murphy_NW6_M04_WP6_0627A_V1_130220

0627B	KILCURRY RIVER TRIBUTARY 2	Murphy_NW6_M04_WP6_0627B_V1_130220
0628M	BALLYNAHATTIN	Murphy_NW6_M04_WP6_0628M_V2_131218
0629M	AGHABOYS	Murphy_NW6_M04_WP6_0629M_V1_130206

(9) Survey Issues:

A number of minor survey queries were raised for the Dundalk model. All queries were resolved, as outlined below.

- Variation of downstream invert levels of bridges on cross sections were queried in some locations, as these differed from the values provided on the long sections. The surveyors confirmed that the cross section invert levels are correct.
- There was also a query over inconsistent widths provided for certain structures. The surveyors confirmed that this was dependent upon the alignment of the cross section and should be minimal.
- An inconsistent pipe dimension was noted at 0625M00177J on the Castletown River. Surveyors confirmed the pipe diameters as 700mm.
- There were two river centreline shapefiles provided for the Dundalk Blackwater. The surveyors confirmed the correct and most up to date shapefile for use in the model.
- On the Castletown River, the depiction of the weirs on the long section for 0623M_B was queried. The surveyors adjusted the error.
- On the Acarreagh River, the diameter of the pipe at 0624M00002J was queried. The surveyors confirmed the diameter of the pipe as 800mm.
- On the Dundalk River, the diameter of the culvert 0617M00445J was queried. The surveyors confirmed the diameter and adjusted the survey drawings accordingly.
- On the Ballynahattin River, the dimensions of the culvert 0628M0380I were queried. Surveyors confirmed the appropriate dimensions and provided updated drawings.
- The connection of the rivers in the Fairhill area was not clear from the survey report and clarity was sought from the surveyors at the area shown in Figure 4.7.14. Surveyors provided more information: "The area on the west side of the railway line was a wooded swamp in this area. It was impossible to discern where the watercourses flowed to or from. Further south, Reach 0619m did not flow from the east side of the railway line 0619m00059i to the west side of the railway line 0619m00056j. There was very little flow in the reach downstream of 0619m00056j. The water was stagnant and appeared to pool in this area."

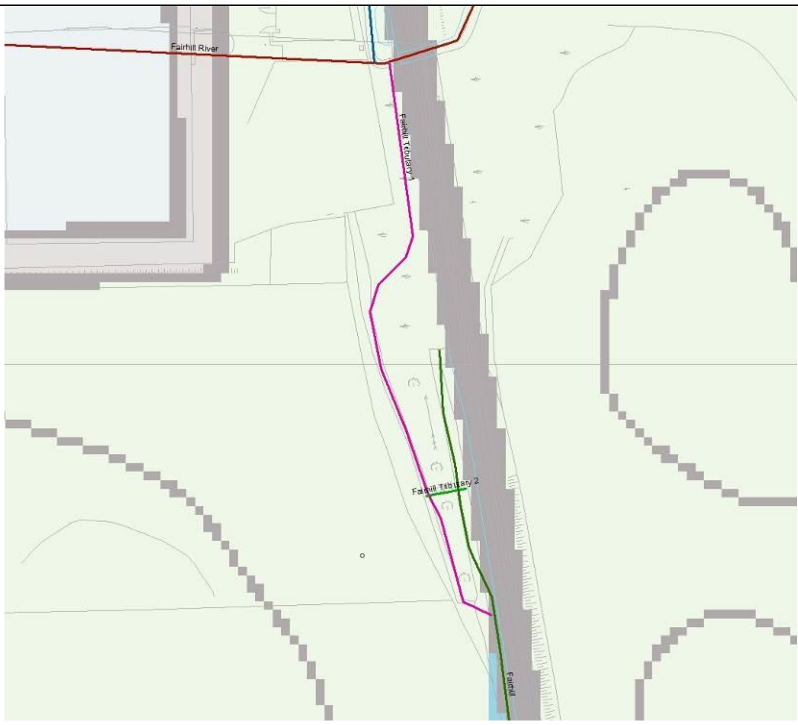


Figure 4.7.14: Fairhill River connections

As the CFRAM LiDAR data was not flown at low water, cleaning had to be undertaken to remove any areas which represented a water surface rather than bathymetry. In the case of the Dundalk model, this was achieved in GIS using the OSI high water mark.

Coastal bathymetry was acquired from Infomar, ICPSS LiDAR, CMAP and various hydrographic surveys. Where necessary, this bathymetry was manually adjusted where data was limited, to ensure representative flows and levels within the model domain. Care was taken to ensure the deep channels within the bay were adequately represented, making use of available Infomar data.

4.7.3 Hydraulic Model Construction

<table>
<tr><td>(1) 1D Structures (in-channel along modelled watercourses):</td><td>See Appendix A.1
Number of Bridges and Culverts: 150
Number of Weirs: 6</td></tr>
<tr><td colspan="2">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.

Buildings have been represented as voids, effectively being blocked out of the 2D domain and providing no floodplain storage, as explained in Section 3.3.2 of this report.

On the Acarreagh River, culvert 0624M00189I (Figure 4.7.15) at Chainage 683 under Mount Avenue causes</td></tr>
</table>

some back up of flow during simulations of large fluvial events. As can be seen in the photo below, the bridge may be prone to blockage due to debris, which would cause more significant backing up and subsequent flooding.

Figure 4.7.15: Culvert 0624M00189I

On the Dundalk Blackwater river, flooding occurs from the 10% AEP and above due to the back up of flow at a long culvert 0617M00420I (Figure 4.7.16), commencing at Chainage 3629 and concluding at Chainage 4357, along the Avenue Road and Greenacres/Lisnaree. This results in flow exceeding bank limit between Chainages 2923 and 3629. Care should be taken to ensure vegetation does not cause blockage of this culvert.

Figure 4.7.16: Culvert 0617M00420I

Significant fluvial flooding occurs at all modelled AEPs in the Cambrickville area mainly due to low lying banks on the Dundalk River and the presence of two culvert structures at Chainages 1346 and 1750 (Figure 4.7.17 and Figure 4.7.18 respectively. As can be seen from the photos, the overgrowth of these culverts by vegetation and debris is a risk factor. Should these culverts become entirely blocked, significant fluvial flooding would also occur at the less extreme events.

Figure 4.7.17: Culvert 0617M00651I

Figure 4.7.18: Culvert 0617M00610I

Another set of structures critical to fluvial flooding in the Marshes Lower area are the chambers located downstream of Ladywell Bridge on the Dundalk (Ramparts) River. These are known to regulate the flow in this area; however no survey details of these chambers were available for modelling. As such, information was extracted from a report 'Dundalk South and West Sector Surface Water Drainage' by Tobin Consulting Engineers (March 2007) which indicated that all the flow from the Dundalk River should be redirected down the Marshes Lower River, with the Dundalk Blackwater being treated as an entirely separate watercourse, with a nominal point inflow. The text in this report indicates that under the Dundalk Sewerage Scheme Contract No.3, the overflow in one chamber was raised so as to reduce the amount of water overflowing to the Dundalk Blackwater River. Pipes were introduced to allow a small continuous flow from the chamber to the Dundalk Blackwater River, to ensure there was always a certain flow in the river. A point inflow at the upstream end of the river was added to account for this small amount of flow in the model.

(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.)**
EMBANKMENT	Dundalk Harbour (307300,310328 - 305532,308202)	N/A	N/A	N/A

EMBANKMENT	Dundalk Bay (306955,304932 - 308273,307253)	N/A	N/A	N/A
WALL	Dundalk Bay (307430,302932 - 307235,302484)	N/A	N/A	N/A
WALL	Castletown River (304819,308123 - 305080-308034)	RB	5439.8	4807
WALL	Dundalk Harbour (306615,307721 - 307898,307736)	N/A	N/A	N/A
Hydraulically significant structures				
EMBANKMENT	Castletown River (304193,309200 - 304126,307267)	N/A	N/A	N/A
(5) Model Boundaries - Inflows:				
Full details of the flow estimates are provided in the Hydrology Report (IBE0700Rp0012_HA06 _UoM06 Hydrology Report_D01- Section 4.4 And Appendix D).The boundary conditions implemented in the model are shown in Table 4.7.1.				

Table 4.7.1: Model Boundary Conditions

	Boundary Description	Boundary Type	Branch Name	Chainage	Chainage	Gate ID	Boundary ID
1	Open	Inflow	DONAGHMORE	16.102	0		06_242_U-u/s inflow
2	Distributed Source	Inflow	DONAGHMORE	16.102	2268.199		Top-up between 06_242_U & 06_242_4_RPS
3	Open	Inflow	KILALLY	29.295	0		06_Trib_Ddalk_U-u/s inflow
4	Distributed Source	Inflow	KILALLY	29.295	902.146		Top-up between 06_Trib_Ddalk_U & 06_Trib Ddalk_1
5	Open	Inflow	FAIRHILL	0	0		06_147_U-u/s inflow
6	Distributed Source	Inflow	FAIRHILL	0	2266.333		Top-up between 06_147_U &
7	Open	Inflow	PRIORLAND	19.915	0		06_918_U
8	Distributed Source	Inflow	PRIORLAND	19.915	961.835		Top-up between 06_918_U & 06_918_1
9	Distributed Source	Inflow	FAIRHILL RIVER	17.277	1523.693		Top-up flow between 06_913_4_RPS & 06036_2
10	Open	Inflow	DUNDALK	0	0		06_913_U-u/s inflow
11	Distributed Source	Inflow	DUNDALK	0	975.913		Top-up between 06_913_U & 06_913_4_RPS-617A
12	Distributed Source	Inflow	DUNDALK	1002.07	2757.657		Top-up between 06_913_4_RPS & 06036_RPS-617M
13	Open	Water Level	MARSHES LOWER	2211.004	0		06318_D_d/s
14	Open	Water Level	DUNDALK_BLACKWATER	7687.898	0		06_1038_D-d/s
15	Open	Inflow	DUNDALK_BLACKWATER	2913.101	0		Dundalk Blackwater constant inflow u/s
16	Distributed Source	Inflow	DUNDALK_BLACKWATER	2913.101	7630		Top-up between U/S inflow & 06_1038_D
17	Distributed Source	Inflow	MARSHES LOWER	0	2006.187		Top-up between U/S Marshes Lower & 06_318_D
18	Open	Inflow	AGHABOYS	0	0		06_1054_1_RA-u/s inflow
19	Distributed Source	Inflow	AGHABOYS	0	1372		Top-up flow between 06_1054_1 & 06_1078_3
20	Open	Water Level	AGHABOYS	1384.45	0		06_1078_3_RA-d/s
21	Open	Inflow	BALLYNAHATTIN	0	0		06_1058_2_RA-u/s inflow
22	Distributed Source	Inflow	BALLYNAHATTIN	0	4103.5		Top-up flow between 06_1058_2 & 06_1081_D
23	Open	Water Level	BALLYNAHATTIN	4123.77	0		06_1081_D_RA-d/s
24	Open	Inflow	BLACKROCK	0	0		06_0616A_U-u/s inflow
25	Distributed Source	Inflow	BLACKROCK	0	1940		Top-up between 06_0616A_U & 06_616A_D
26	Open	Water Level	BLACKROCK	1969.75	0		Model end_06_616A_D
27	Open	Inflow	GREEN GATES	27.338	0		06_315_U_RA-u/s inflow
28	Distributed Source	Inflow	GREEN GATES	27.5	2070		Top-up between 06_315_U_RA & 06_315_5_RA
29	Open	Water Level	GREEN GATES	2080.92	0		Model end_06_315_5_RA
30	Open	Inflow	KILCURRY_RIVER	0	0		06_991_2_RA-u/s inflow
31	Open	Inflow	CASTLETOWN_RIVER	0	0		06_600_2_RA-u/s inflow_used d/s flow-small difference
32	Distributed Source	Inflow	CASTLETOWN_RIVER	0	942.64		Top-up between 06_600_2_Ra & 06032_RA
33	Distributed Source	Inflow	CASTLETOWN_RIVER	942.64	1212.289		Top-up between 06032_RA & 06_1084_1_RA
34	Open	Inflow	STRANACARRY	46.074	0		06_1055_U-u/s inflow
35	Distributed Source	Inflow	STRANACARRY	46.074	1335.756		Top-up between 06_1055_U & 06_1055_2_RA
36	Open	Inflow	CASTLETOWN	0	0		06_1087_U_RA-u/s inflow
37	Distributed Source	Inflow	CASTLETOWN	0	2539.774		Top-up between 06_1087_U_RA & 06_1087_13_RA
38	Open	Inflow	ACARREAGH	33.234	0		06_1089_U-u/s inflow
39	Distributed Source	Inflow	ACARREAGH	33.234	1259.452		Top-up between 06_1089_U & 06_1089_4_RA
40	Distributed Source	Inflow	CASTLETOWN_RIVER	1212.289	5285		Top-up between 06_1084_1_RA & 06_DDalk_D_RARPS
41	Open	Water Level	CASTLETOWN_RIVER	5291.609	0		Model end_Castletown River
42	Open	Inflow	KILCURRY RIVER TRIBUTAR	22.075	0		Kilcurry Riv Trib 1 u/s inflow

To determine joint probability flooding from both fluvial and coastal sources, where relevant, the timings of fluvial peaks were shifted relative to each other. This established the worst case joint coastal and fluvial flooding at each localised area. Details on joint probability are available in Chapter 6.3 of the Hydrology Report and Section 3.6.1 of this report.

Figure 4.7.19 provides an example of the associated upstream hydrograph on the Castletown River at HEP 06_600_4_RA at the 1% AEP fluvial event.

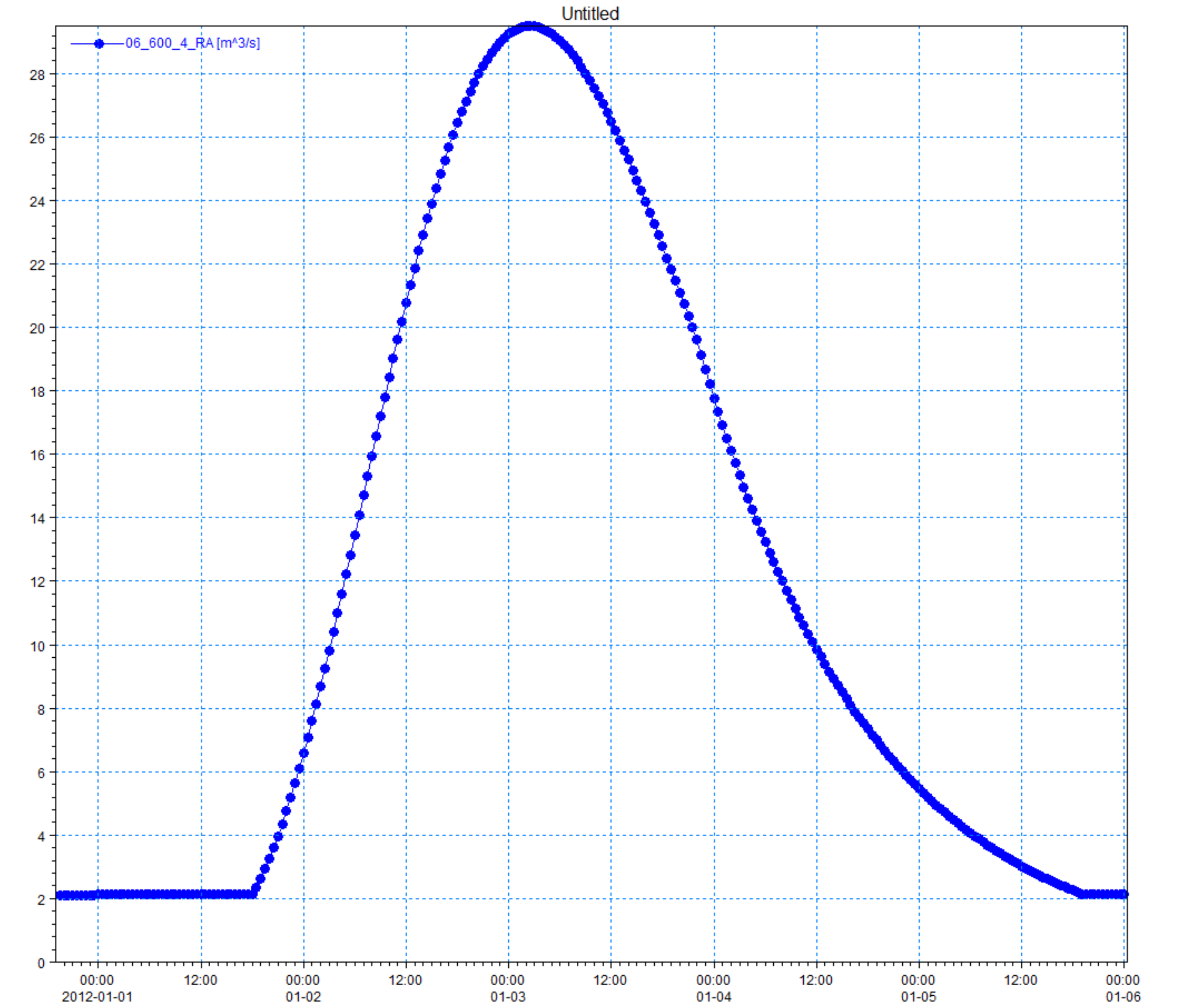


Figure 4.7.19: Upstream hydrograph on the Castletown River at 06_600_4_RA (1% AEP)

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 location are shown in Figure 4.7.20. The associated AEP water levels for the relevant node at Dundalk are contained in Table 4.7.2. Node NE_26 was used to establish total water levels, as this node was situated closest to the model boundary.

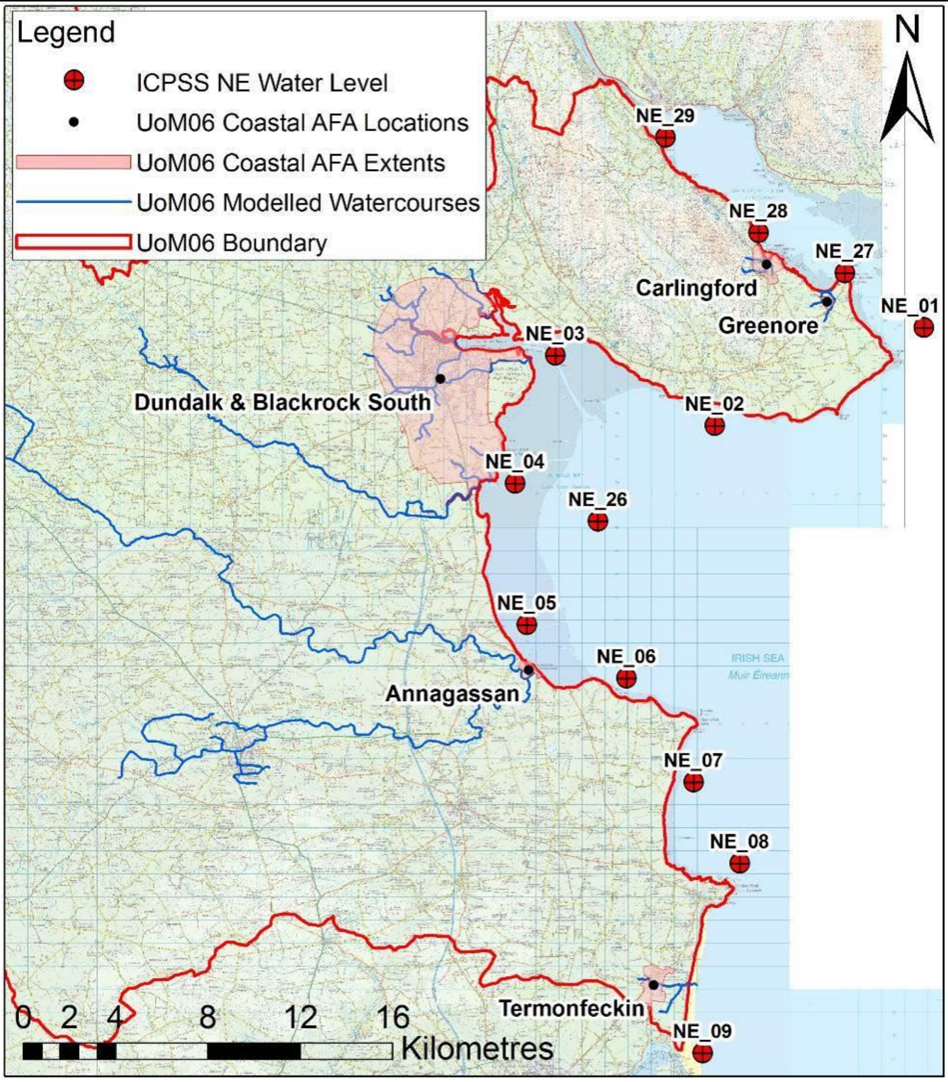


Figure 4.7.20: ICPSS Node Locations (IBE0700Rp0012_UoM06 Hydrology Report)

Table 4.7.2: ICPSS AEP Total Water Levels for Relevant Model Node

ICPSS Node	**Annual Exceedance Probability (AEP) %**							
	2	**5**	**10**	**20**	**50**	**100**	**200**	**1000**
	Highest Tidal Water Level to OD Malin (m)							
NE26	3.04	3.17	3.27	3.37	3.51	3.61	3.71	3.94

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 Ports of Dunany Point and Soldiers Point in the Admiralty Tide Tables, RPS established a tidal water level approaching Mean High Water Springs (MHWS) which was representative for the Dundalk Bay model and from this deduced the resultant magnitude of the surge component required to produce a total water level for the relevant AEP. The astronomic tide level was

calculated to be 1.75m OD Malin and is equivalent to a tide half way between a Mean High Tide (MHT) and a MHWS.

Tidal profiles were extracted from the RPS Irish Seas model and scaled using the established tidal water level. 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. This provided the boundary conditions for 'mechanism 1 tidal' flooding (still water coastal inundation).

Figure 4.7.21 illustrates the tidal profile, storm surge profile and resultant total water level profile for a 50% AEP event on the eastern boundary.

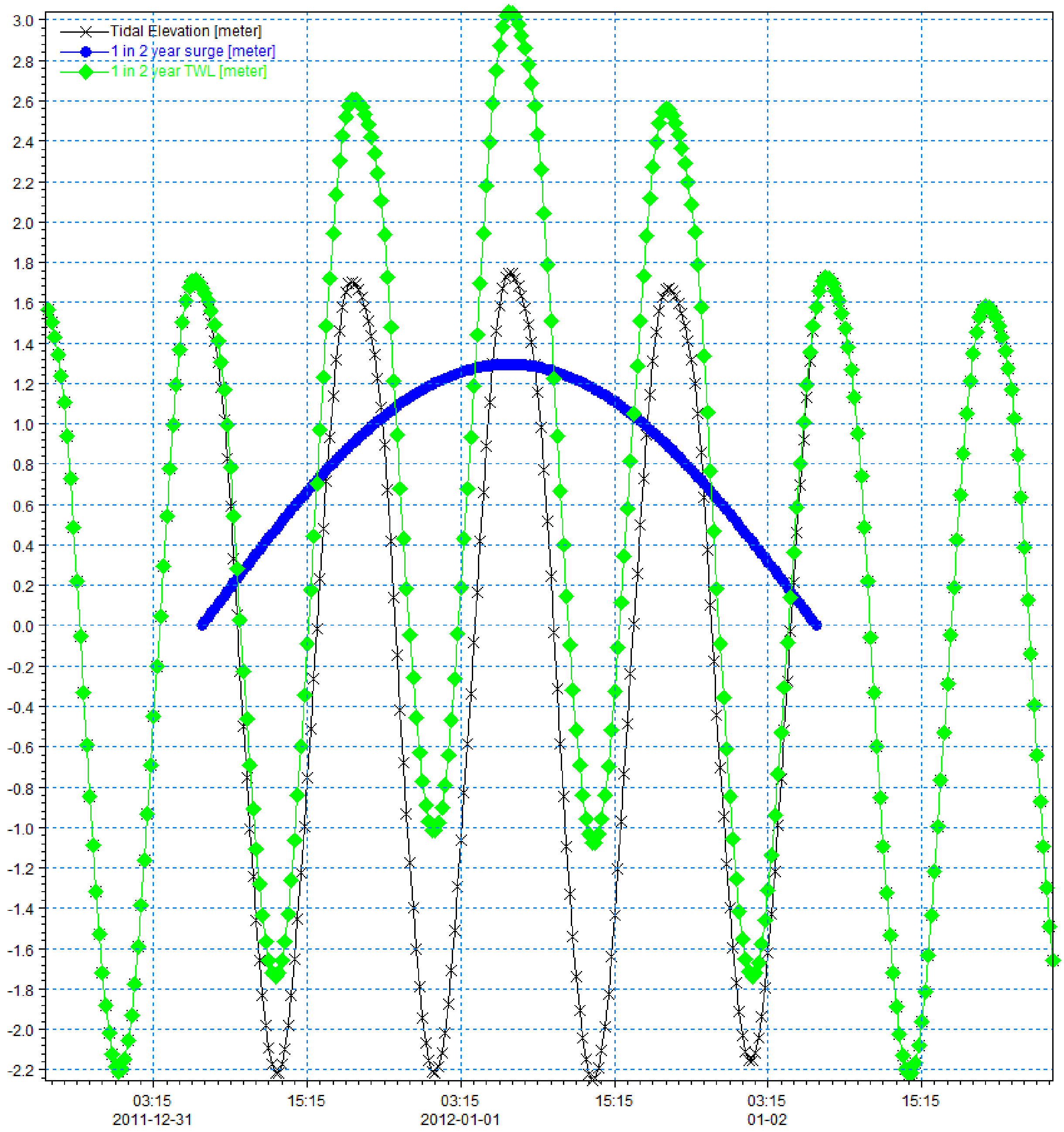


Figure 4.7.21: Tidal, Surge and Total Water Level Profiles for the Dundalk Model Boundary at 50% AEP

To simulate 'mechanism 2 wave overtopping' flooding at the Dundalk/Blackrock AFA, data from the ICWWS was used including peak shoreline water levels and wave heights, periods and directions for each AEP event. An example of this data for the Dundalk/Blackrock AFA is shown below in Figure 4.7.22 and Table 4.7.3. Locations A and B were not taken forward for further analysis as they do not affect the AFA. There is no high point along the small stretch noted as Location F, and therefore a wave overtopping exercise is irrelevant at this location.

Figure 4.7.22: ICWWS CAPO Dundalk/Blackrock Prediction Locations

Table 4.7.3: ICWWS CAPO Dundalk/Blackrock Wave Climate and Water Level Data

Prediction Location Reference: Dundalk_Location E				
Bed Level 0.90m OD Malin				
		Combined Wave Component		
AEP	**WL (OD Malin)**	**Hm0 (m)**	**Tp (s)**	**MWD (°)**
0.1%	2.86	0.88	5.55	117
0.1%	3.06	0.97	5.79	116
0.1%	3.28	1.06	5.95	115
0.1%	3.50	1.15	6.02	115
0.1%	3.59	1.18	5.99	115
0.1%	3.69	1.22	5.97	115

To calculate the overtopping discharge rate for each scenario at various locations along the shoreline from C to E, the empirical method and neural network calculator tools outlined by the EurOtop manual were used in addition to the profiles and levels of the structures to be overtopped. 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.

When the peak discharge rate was less than 0.03l/s/m no further analysis was required. In the case of Location C, this coastline was analysed in terms of a northerly facing C1 and easterly facing stretch C2, with the northerly stretch resulting in discharges below the threshold. Refer to Figure 4.7.23. Location C2 yielded a discharge above the threshold for both the 0.5% and 0.1% AEPs. Modelling tests were undertaken for C2, however due to the relatively low level of wave exposure at this location compared to still water coastal inundation, results showed the worst case scenario joint probability event to be dominated entirely by the still water inundation. For this reason, no additional wave overtopping mapping was required at this location, as the worst case joint probability wave and water level event has already been represented in detail in the mechanism 1 coastal flood maps. Figure 4.7.24 shows the worst case joint probability (Mechanism 1) for Location C2. The same applies to Location D (Figure 4.7.25), where modelling tests revealed that any wave overtopping in the area was dwarfed by the significant coastal inundation occurring from the 10% AEP and above, as shown in Figure 4.7.26 for the 0.1% AEP. Further to this, an extensive area of salt marsh lies between the ICWWS extraction point and the actual defence. The wave climate will therefore be significantly reduced before reaching the embankment, and thus overtopping is not deemed to be of significance in this area.

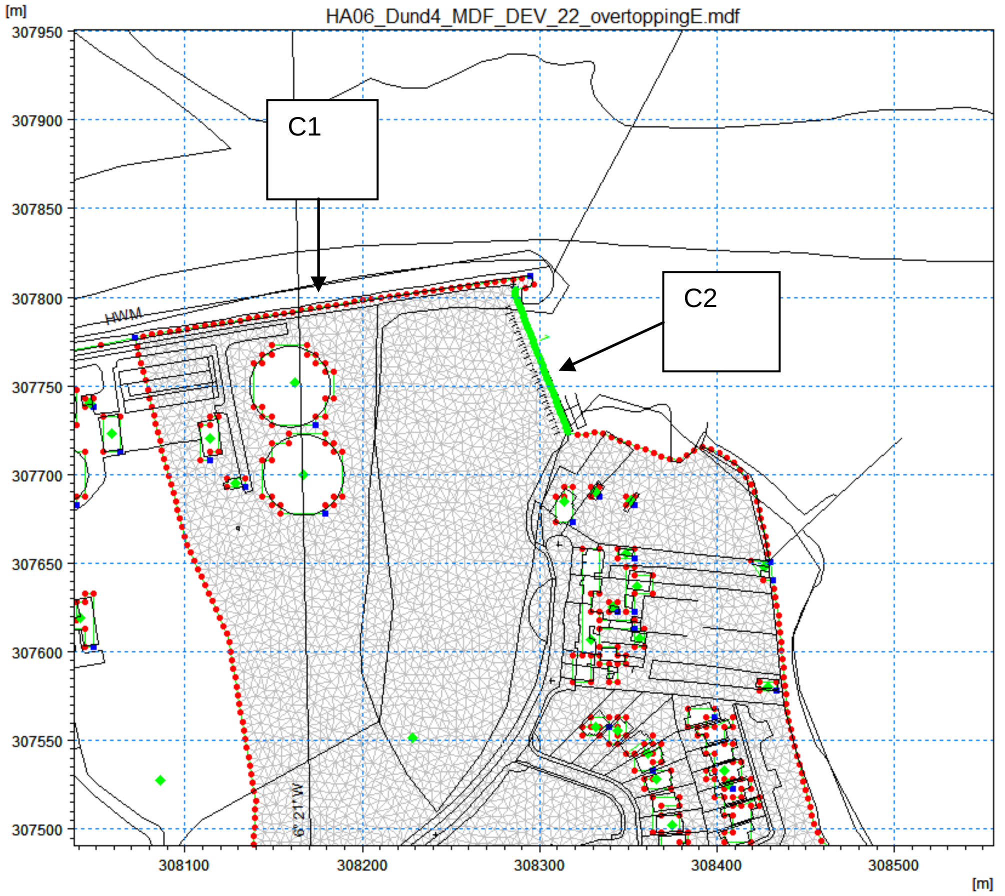


Figure 4.7.23: Dundalk/Blackrock Wave Overtopping Locations C1, C2

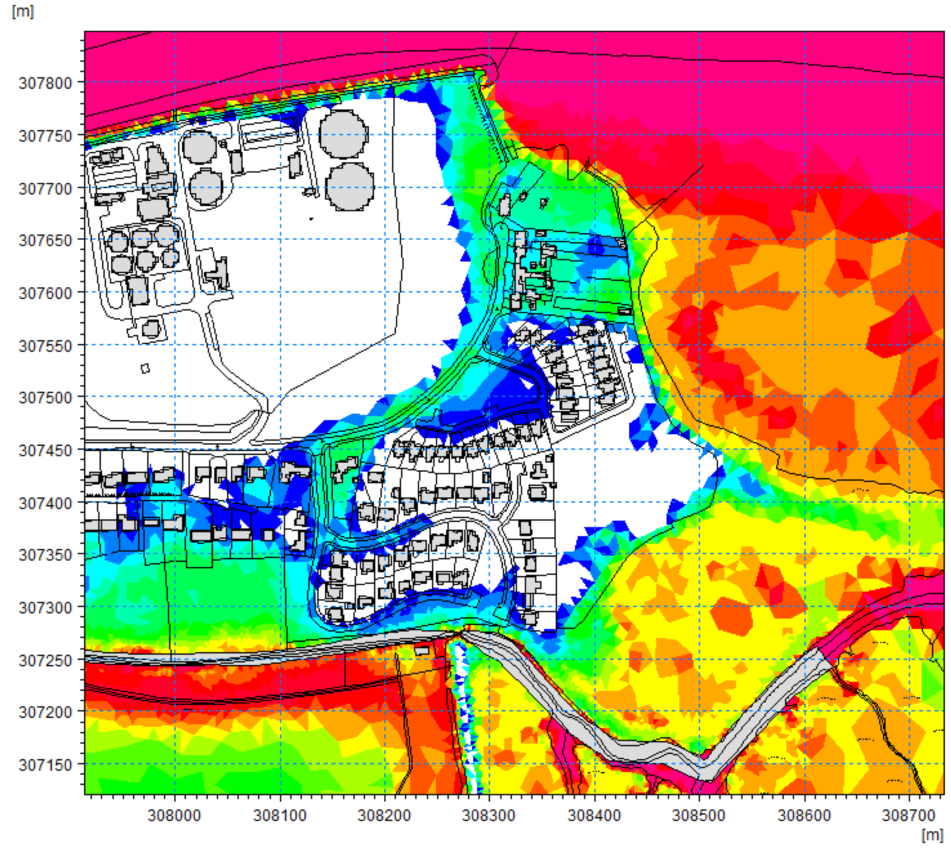


Figure 4.7.24: Mechanism 1 Still Water Coastal Inundation Model Results at C2 at 0.1% Coastal AEP

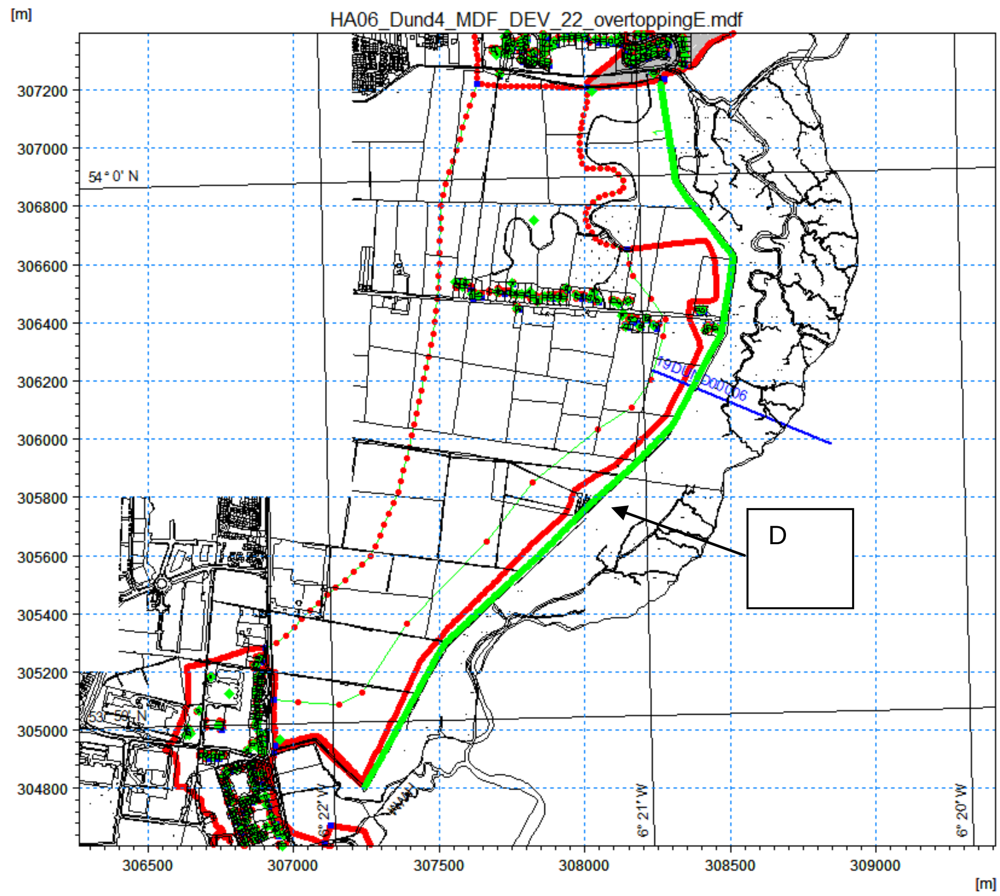


Figure 4.7.25: Dundalk/Blackrock Wave Overtopping Location D

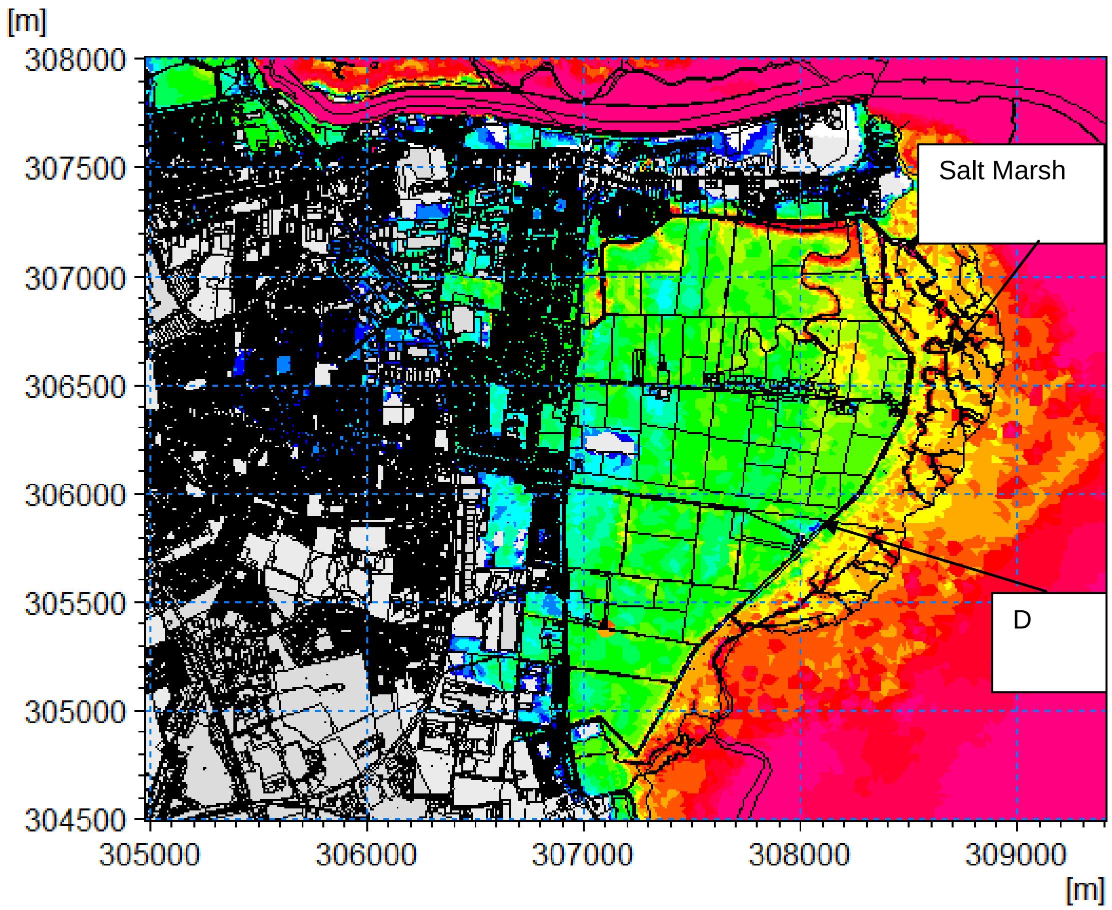


Figure 4.7.26: Mechanism 1 Still Water Coastal Inundation Model Results at D at 0.1% Coastal AEP

Location E affecting the Blackrock area of the AFA was however subject to significant wave overtopping volumes. Due to the variation of the geometry and orientation of the structures, it was necessary to split Location E into a number of sections of different lengths, E1, E2, E3a, E3b, E4 and E5. Refer to Figure 4.7.27 and Figure 4.7.28).

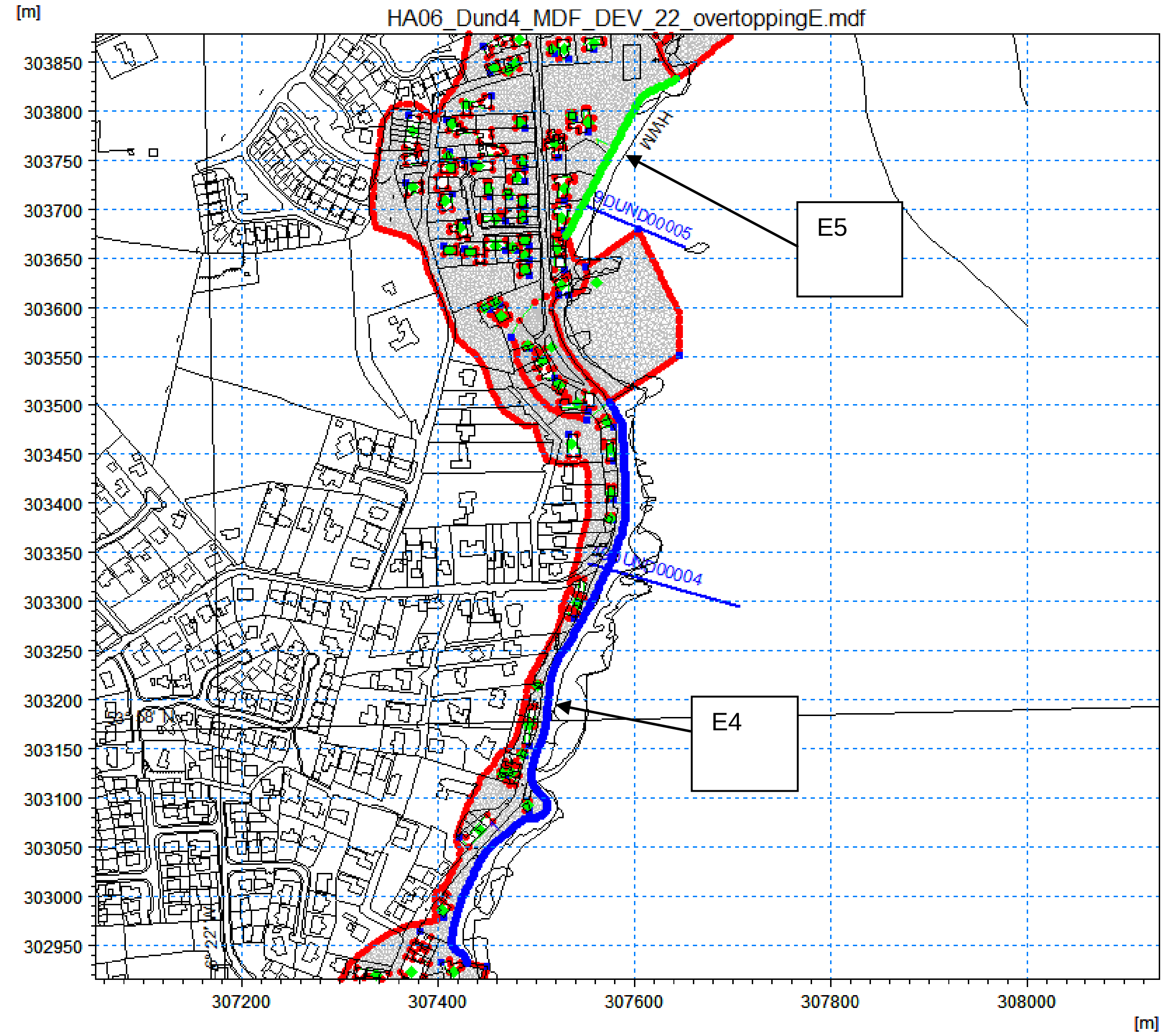


Figure 4.7.27: Dundalk/Blackrock Modelled Wave Overtopping Locations E4, E5

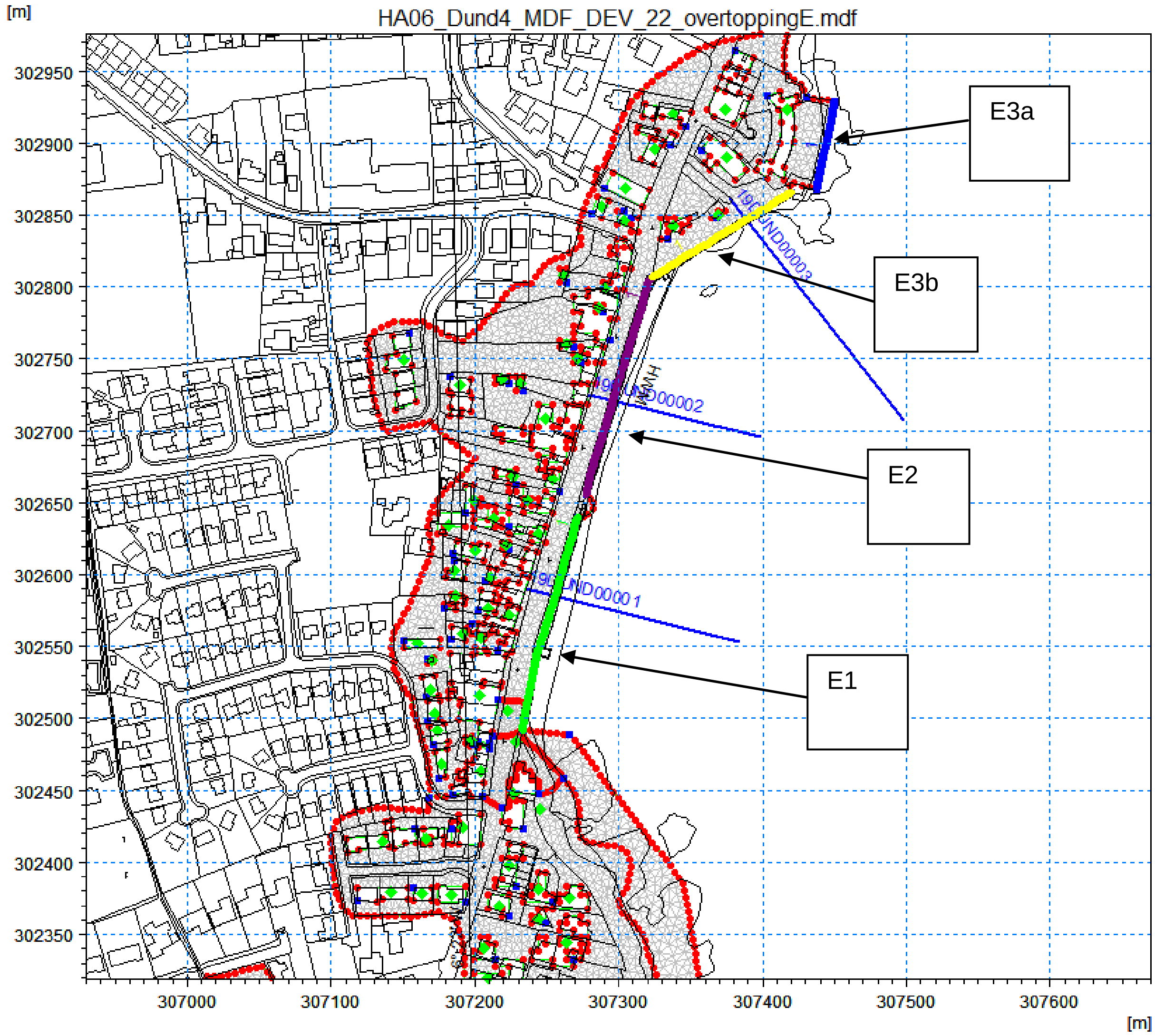


Figure 4.7.28: Dundalk/Blackrock Modelled Wave Overtopping Locations E1, E2, E3a, E3b

Discharge rates were calculated for E1, E2, E3a, E3b, E4 and E5 and model simulations undertaken for the 10%, 0.5% and 0.1% AEP events. Once the discharges for simulation had been ascertained, an idealised water level profile was produced in order to calculate the discharge rate across the tidal cycle, as the rate determined by EurOtop/Neural Network 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, as shown in Table 4.7.4 and Figure 4.7.29. The profile shown in Figure 4.7.29 is for ICWWS prediction locations E1, E2, E3a, E3b, E4 and E5 during design simulations of 0.1% AEP.

Table 4.7.4: Peak Wave Climate and associated Discharges for Modelled Sections

Section	AEP	WL (OD Malin)	Hm0 (m)	Tp (s)	MWD (°)	Discharge Rate (l/s/m)	Discharge (m^3/s)
E1	**10%**	3.28	0.97	4.48	117	8.786	1.344
E1	**0.50%**	3.69	1.18	5.07	116	71.410	10.926
E1	**0.10%**	3.69	1.22	5.43	115	88.630	13.560

E2	**10%**	3.28	0.97	4.48	117	10.970	1.733
E2	**0.50%**	3.69	1.18	5.07	116	86.560	13.676
E2	**0.10%**	3.69	1.22	5.43	115	105.200	16.622
E3a	**10%**	3.28	0.97	4.48	117	17.710	1.080
E3a	**0.50%**	3.69	1.18	5.07	116	110.100	6.716
E3a	**0.10%**	3.69	1.22	5.43	115	128.500	7.839
E3b	**10%**	3.28	0.97	4.48	117	17.710	2.001
E3b	**0.50%**	3.69	1.18	5.07	116	110.100	12.441
E3b	**0.10%**	3.69	1.22	5.43	115	128.500	14.521
E4	**10%**	3.28	0.97	4.93	117	1.800	1.170
E4	**0.50%**	3.69	1.18	5.58	116	6.487	4.217
E4	**0.10%**	3.69	1.22	5.97	115	8.469	5.505
E5	**10%**	3.28	0.97	4.93	117	1.308	0.263
E5	**0.50%**	3.69	1.18	5.58	116	5.912	1.188
E5	**0.10%**	3.69	1.22	5.97	115	7.357	1.479

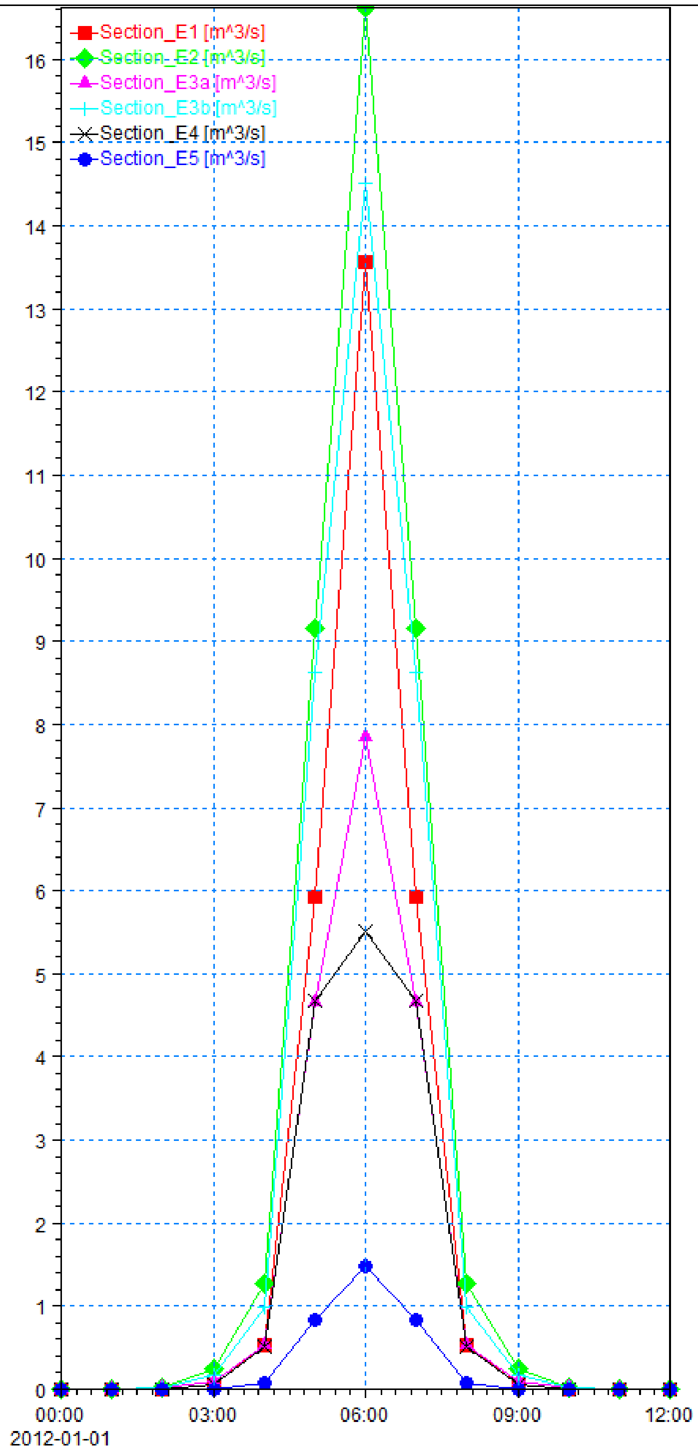


Figure 4.7.29: Discharge Profiles for Sections E1-E5 at 0.1% AEP

(6) Model Boundaries – Downstream Conditions:	1D water level boundaries at the downstream extents of Marshes Lower (Chainage 2211), Dundalk Blackwater (Chainage 7688), Aghaboys (Chainage 1384), Ballynahattin (Chainage 4124), Blackrock (Chainage 1970), Greengates (Chainage 2081) and the Castletown River (Chainage 5292), where they discharge to Dundalk Bay. Water level boundaries allow transfer of flow between 1D and 2D elements. An initial nominal constant water level was provided for each of these 1D downstream boundaries,

	which was superseded by the coastal flow from the 2D domain. Initial constant water levels were ensured to be less than the maximum water level achieved at each location and were determined based on cross section topography.	
(7) Model Roughness: (see Chapter 3.6.1 'Roughness Coefficients')		
(a) In-Bank (1D Domain)	Minimum 'n' value: 0.030	Maximum 'n' value: 0.100
(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: 0.011 (Inverse of Manning's 'M')	Maximum 'n' value: 0.071 (Inverse of Manning's 'M')

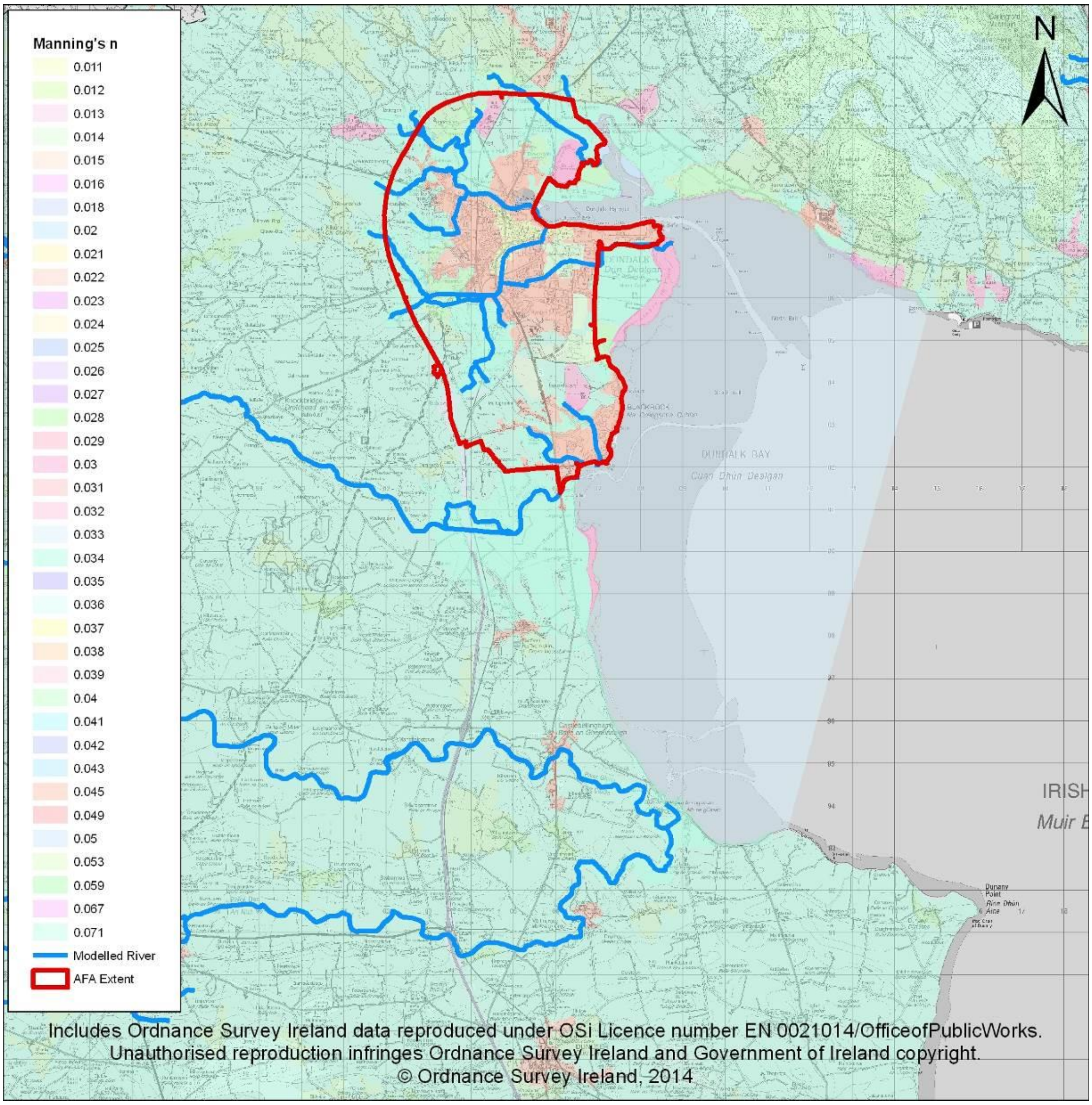


Figure 4.7.30: Map of 2D Roughness (Manning's n)

Figure 4.7.30 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. Any values seaward of the high water mark were also taken as 0.033 unless otherwise specified. Manning's M values were adjusted to 29 (Manning's n of 0.034) along a stretch of major road (M1 ad N52) which were designated as having null roughness. Values were taken from adjacent land in order to be consistent with the general approach.

(d) Examples of In-Bank Roughness Coefficients

Refer to Section 3.5.1 for details on application of Manning's n values. Extreme examples for the Dundalk model are provided in Figure 4.7.31 and Figure 4.7.32.

<table>
<tr>
<td>
Figure 4.7.31: Cross Section 0623M0054 on Castletown River - Manning's n = 0.030 (CFRAM topographic survey)

Natural stream - clean, straight, full stage, no rifts or deep pools</td>
<td>
Figure 4.7.32: Cross Section 0624M0250 on Acarreagh River Manning's n = 0.100 (CFRAM topographic survey)

Natural stream - very weedy reaches, deep pools or floodways with heavy stand timber and underbrush</td>
</tr>
</table>

4.7.4 Sensitivity Analysis

To be completed for final report

4.7.5 Hydraulic Model Calibration and Verification

<table>
<tr><td colspan="2">(1) Key Historical Floods (From IBE07000Rp0003_UoM 06 Inception Report) unless otherwise specified):</td></tr>
<tr><td>(a) OCT 2011.</td><td>Dundalk suffered some flooding although it escaped severe flooding. The heavy rain led to flooding at the Castletown Road and also flooding on the Ardee Road. As the heavy rains coincided with high tides, the council also had 500 sandbags on standby for distribution if necessary. Tidal records from Dublin indicated a maximum coastal water level during October 2011 of 2.13m OD Malin, which using information from the ICPSS equates to an event of less than 0.5% AEP.

Modelling shows that the Castletown Road is mainly affected by coastal flooding from the 1% AEP and above. Flooding also occurs at the 0.5% and 0.1% fluvial dominated event as shown in Figure 4.7.33. The Ardee Road (Figure 4.7.34 on the other hand is mainly affected by fluvial flooding, which occurs from as low as the 20% AEP, in line with historic evidence.</td></tr>
</table>

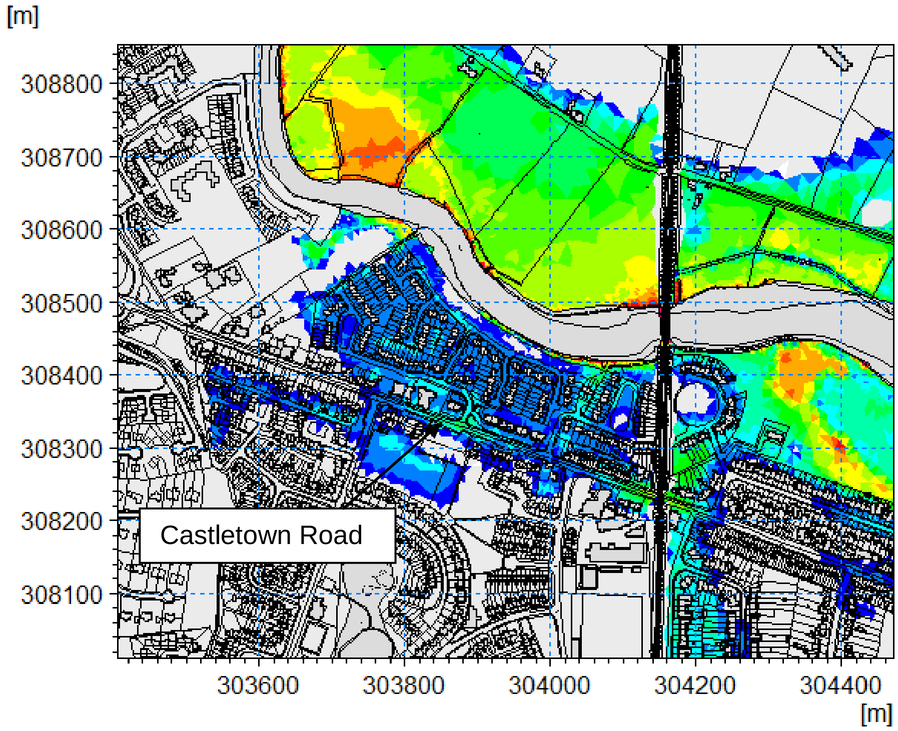


Figure 4.7.33: Modelled flooding at Castletown Road at the Coastal 0.1%AEP Event

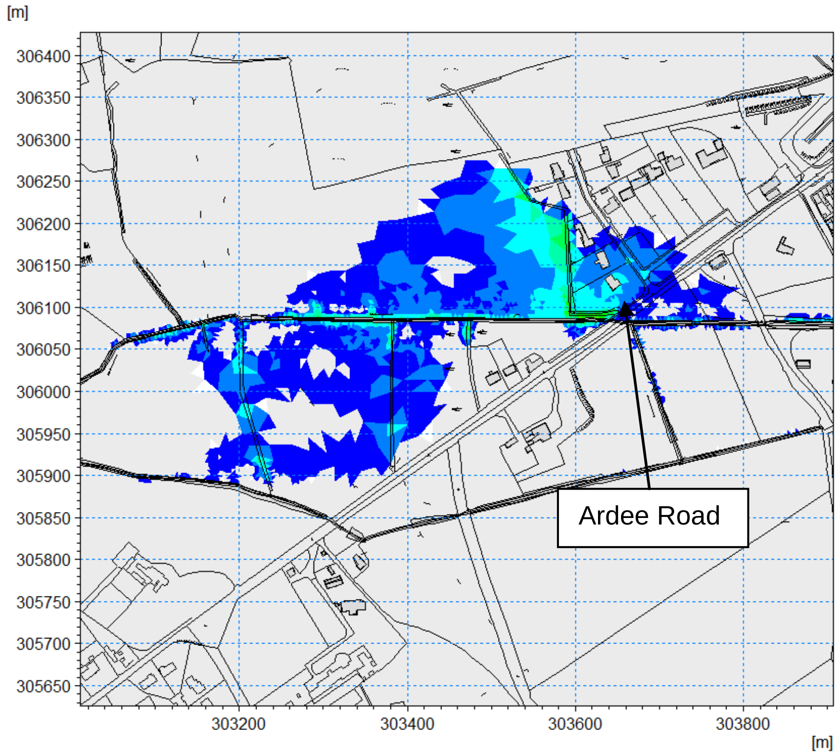


Figure 4.7.34: Modelled flooding at Ardee Road at the Fluvial 20% AEP Event

(b) **SEP 2010.**

On 6th September 2010, flooding occurred due to heavy rainfall, high tides and strong easterly winds. Anecdotal information reported in the Dundalk Democrat estimated this

<table>
<tr><td></td><td>

event to have an AEP of 2%. St Alphonsus Road was reported to be one of the areas worst affected.

Model results show the St. Alphonsus Road to be flooded from the 0.1% AEP event, with flooding occurring from a fluvial source, as shown in Figure 4.7.35.

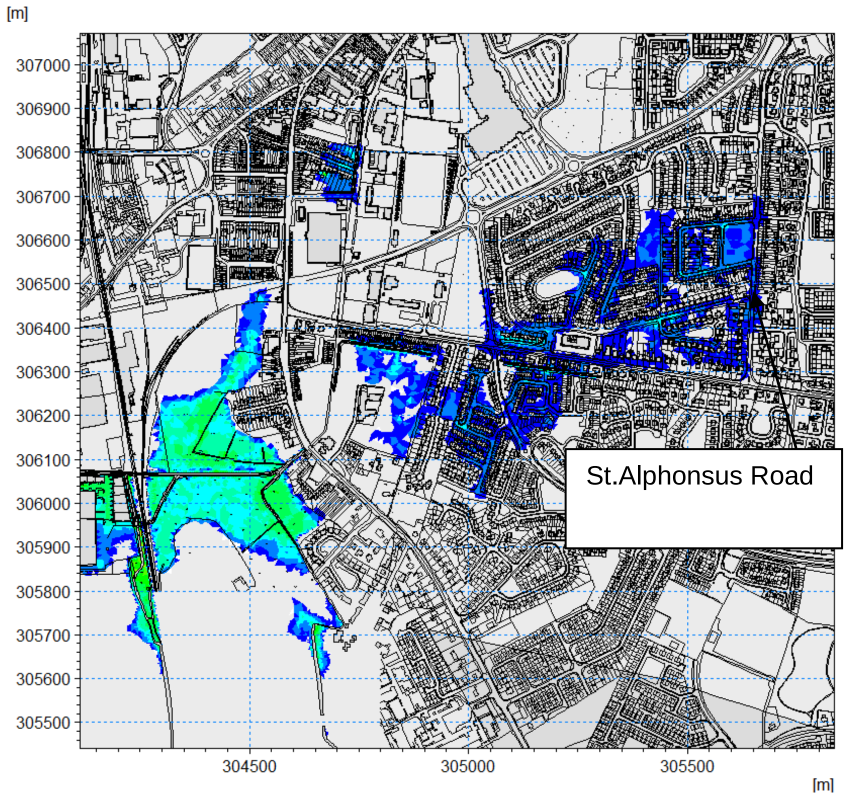


Figure 4.7.35: Modelled flooding at St Alphonsus Road at the Fluvial 0.1%AEP Event

</td></tr>
<tr><td>(c) OCT 2004.</td><td>

Details were found on www.floodmaps.ie which indicated that flooding occurred in Annagassan and Dundalk in October 2004. In Annagassan, high tides and wave action caused coastal flooding.

Dublin Port tide gauge, which is approximately 75km South of Dundalk indicates a 1%-0.5% AEP for this event at Dublin. However, no further information was available for Dundalk or Blackrock and thus this event is not suitable for model calibration.

</td></tr>
<tr><td>(d) FEB 2002.</td><td>

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.

In Dundalk, an unprecedented high tide was recorded (3.65mOD) along with gale force easterly winds, equating to a 1%-0.5% AEP event. This is in line with measured data from the Dublin gauge, which implies an event approaching 1% AEP.

Using data from the Annaskeagh daily rain gauge at Dundalk, it was established that

</td></tr>
</table>

14.3mm of rainfall fell in 24 hours on 2nd February 2002. This yielded a return period of less than 1 year, using the FSU DDF model (FSU WP 1.2 'Estimation of Point Rainfall Frequencies'), thus it was concluded that this was a coastal dominated event.

Correspondence from the Dundalk Area Senior Executive Engineer described a flood event in Blackrock, caused by a high tide and easterly gales. The sea wall was undermined, an old lifeboat house was flooded and houses along Main Street were damaged. Also Village Green/new Golf Links Road and the Wallis Road/Rock Road junction were badly affected. An AEP of 20% was estimated in the minutes of the OPW Flood Hazard Mapping Programme held in October 2005.

As can be seen by the modelling results in Figure 4.7.36, the Blackrock Promenade (Main Street) floods at all mechanism 1 modelled coastal AEP events, with flooding also caused by 'mechanism 2 wave overtopping' (Figure 4.7.37) . However the model shows no flooding at Village Green, New Golf Links Road or the Rock Road (Figure 4.7.38). When assessing the LiDAR of the area, it is not possible for 'mechanism 1' still water coastal flooding to occur in these areas, as the 0.1% AEP coastal water level is situated lower than the LiDAR elevations. However wave overtopping occurs at all modelled AEPs on the Rock Road (Figure 4.7.39), and surface runoff is likely to be the cause for further flooding in the area. It is anticipated that the HEFS results will show flooding from coastal still water elevations at Village Green and part of the New Golf Links Road.

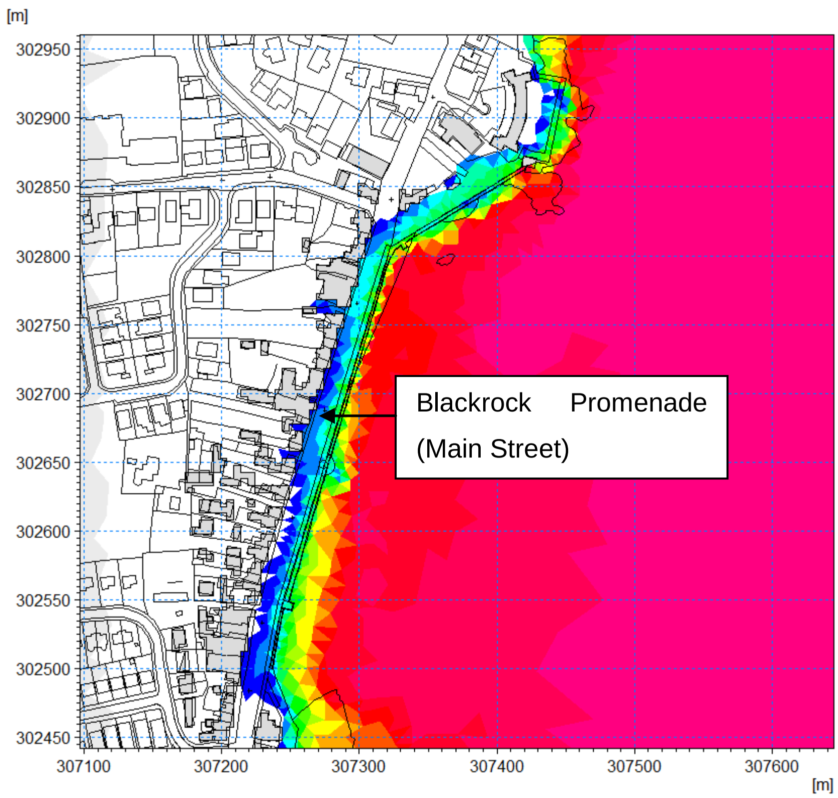


Figure 4.7.36: Modelled flooding at Blackrock Promenade at the Coastal 'mechanism 1' - 0.5%AEP Event

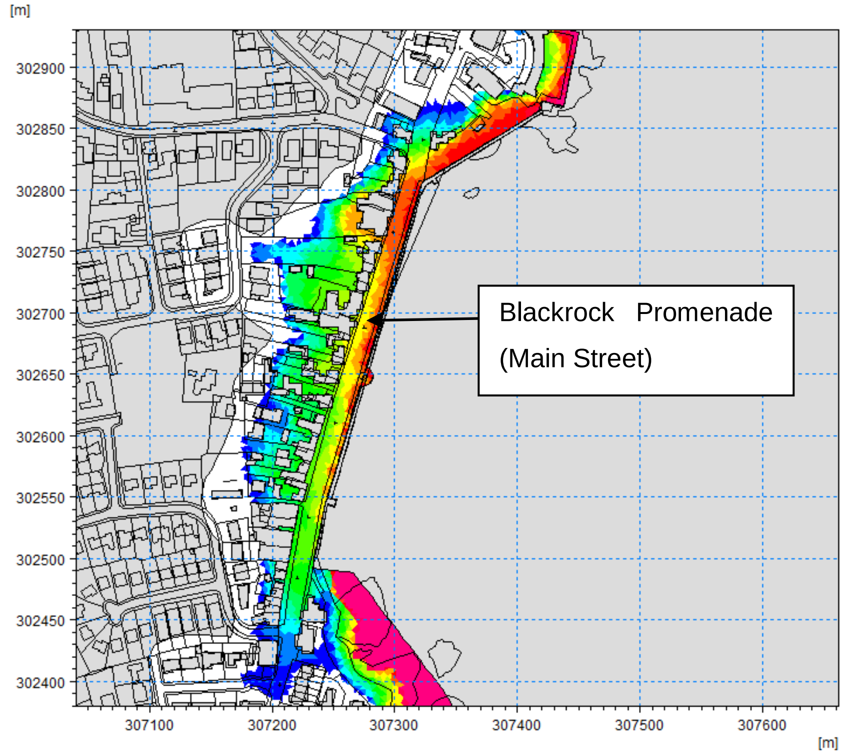


Figure 4.7.37: Modelled flooding at Blackrock Promenade at the Coastal mechanism 2 0.5%AEP Event

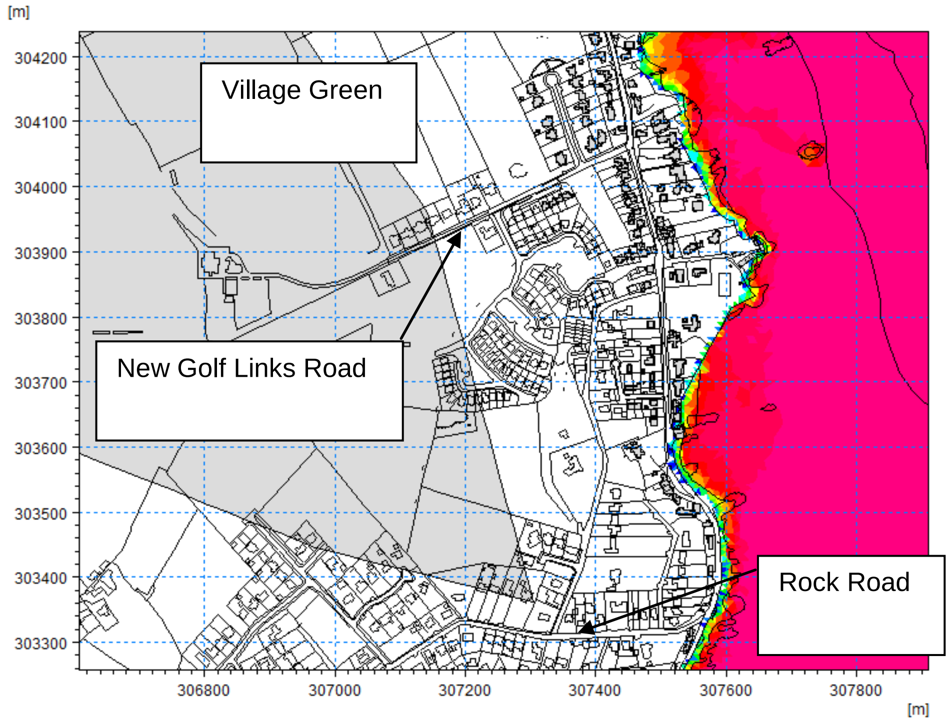


Figure 4.7.38: Modelled flooding at North Blackrock at the Coastal mechanism 1 0.1% AEP Event

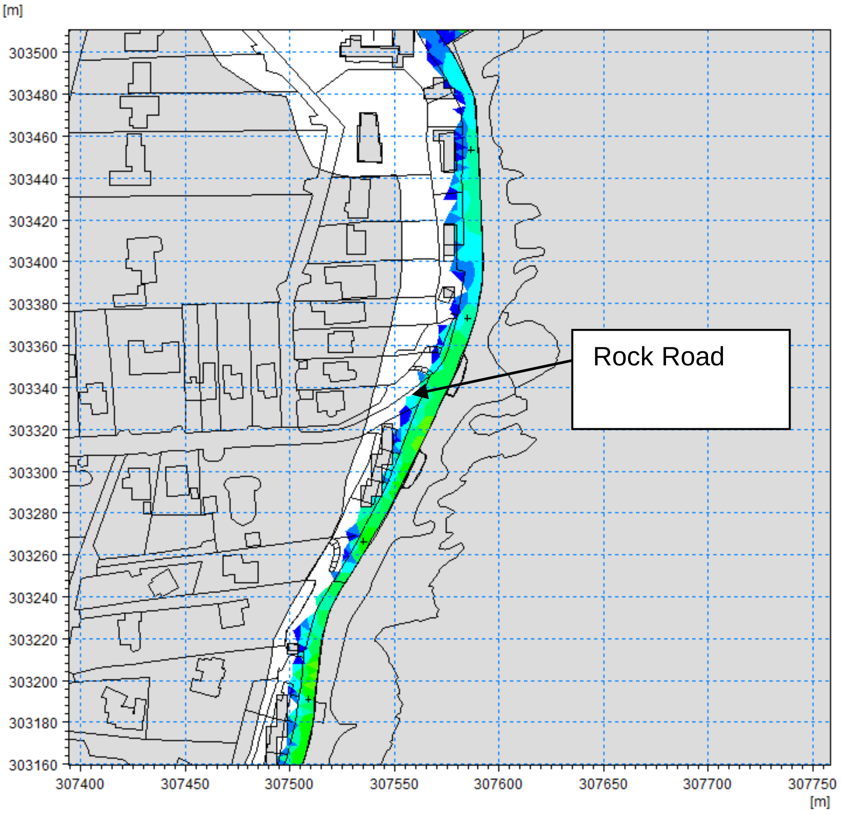


Figure 4.7.39: Modelled flooding at Rock Road at the Coastal mechanism 2 0.5%AEP Event

Flooding occurred at Racecourse Road in February 2002, which is shown to significantly flood in the model from the coastal 20% AEP, with still quite notable flooding at the 50% AEP. Historic evidence suggests that the flooding of the low lying land along Racecourse Road would make the road impassable. This is clearly shown by the model results.

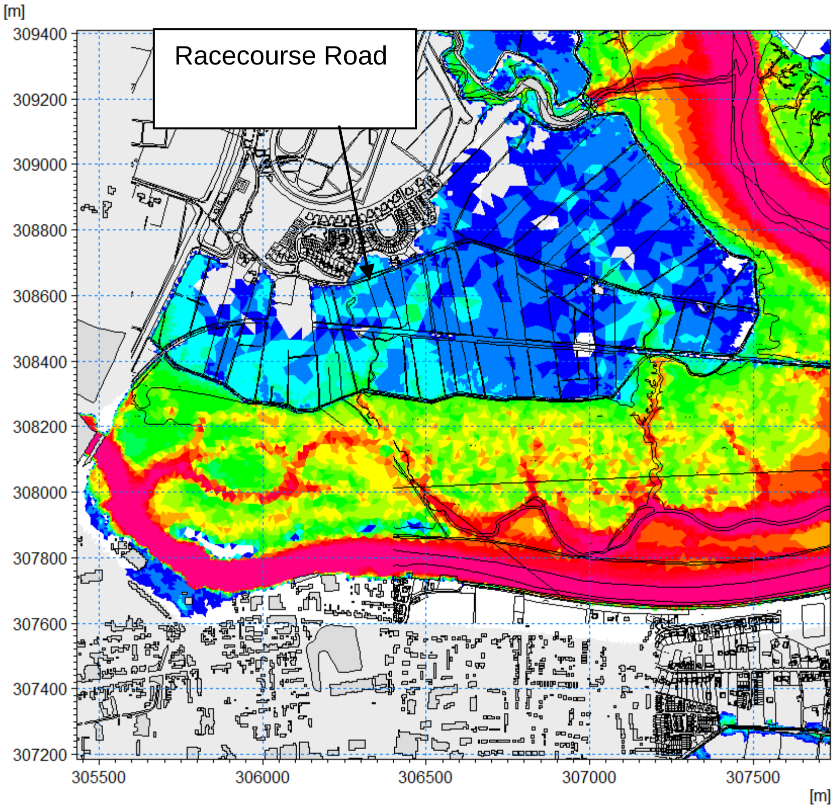


Figure 4.7.40: Modelled flooding at Racecourse Road at the Coastal 10% AEP Event

An embankment runs along the Castletown River, upstream of the N1 bridge. This embankment has not been identified as a formal defence as part of the CFRAM study and thus has not been included in the model. In February 2002, the tide backed up beyond the embankment and flooded the Moorland Road. Model results, as shown in Figure 4.7.41, indicate that flooding of the Moorland Road is predominantly from a coastal dominated event on the Castletown River, with flooding occurring at all modelled AEPs.

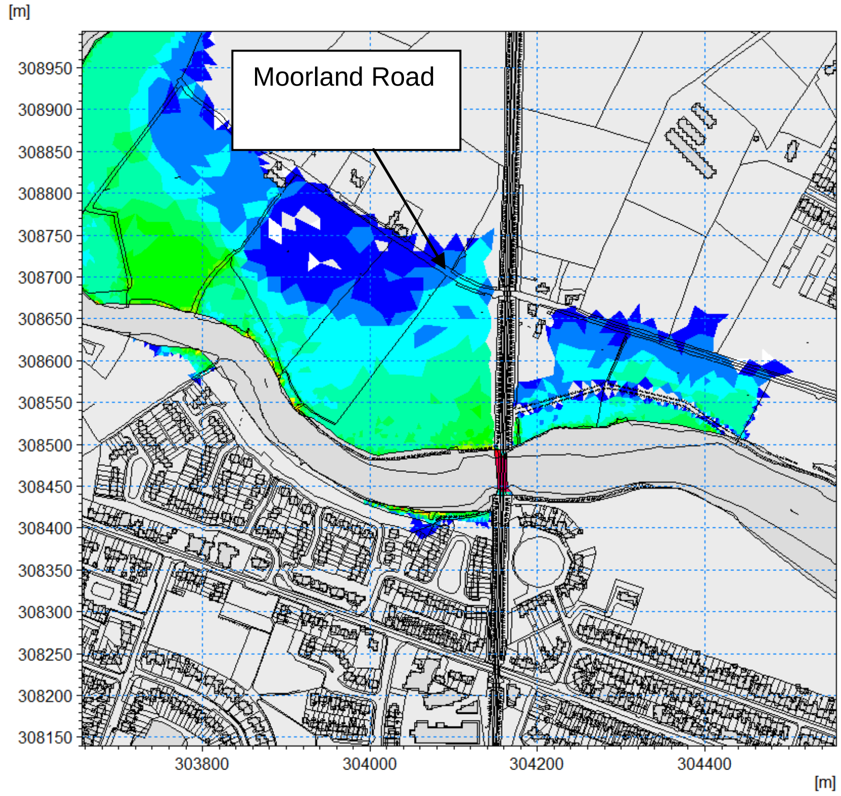


Figure 4.7.41: Modelled flooding at Moorland Road at the Coastal 50%AEP Event

Quay Street was subject to coastal flooding during this extreme event, which is in line with model results, as shown in Figure 4.7.42. Flooding occurs in the model at the 5% AEP and above. Quay Street has been noted to flood during many of the extreme events discussed in the following pages.

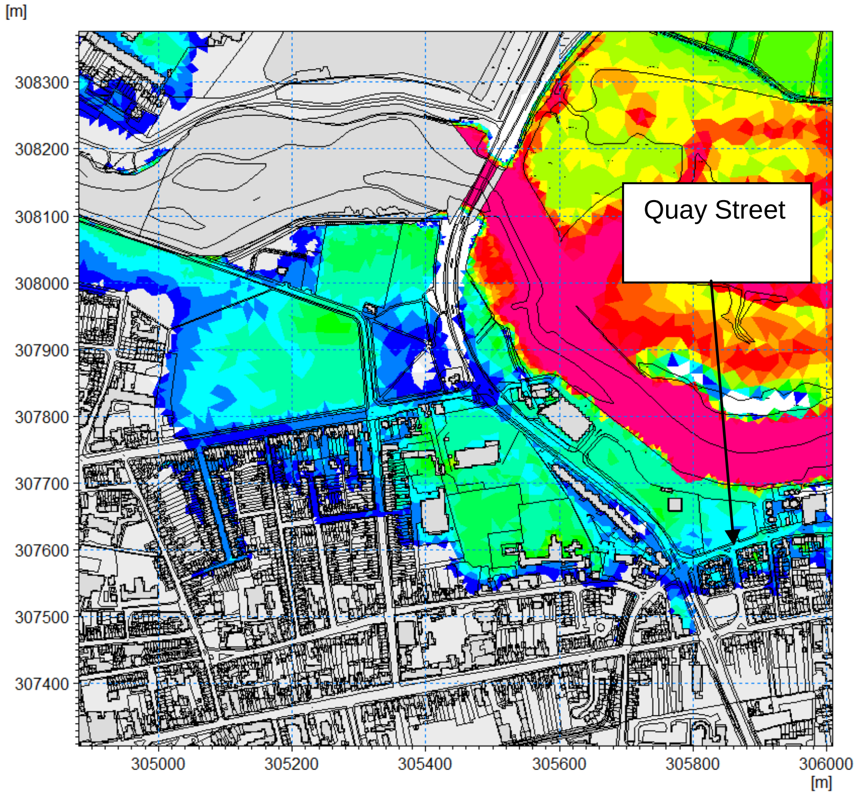


Figure 4.7.42: Modelled flooding at Quay Street at the Coastal 0.5%AEP Event

Lismore was also flooded due to insufficient culvert capacity causing flooding upstream. Gardens were flooded and the road was impassable. It is expected that the fluvial flooding was heightened by coastal mechanisms, which prevented fluvial sources from being discharged to the sea, as the 2002 event was predominantly of a coastal nature. However remedial works have since been carried out and thus Lismore is no longer expected to flood during extreme fluvial events. This is in agreement with the modelling results, with only some minor flooding occurring in the surrounding areas at all coastal and fluvial modelled AEPs, as shown in Figure 4.7.43 and Figure 4.7.44.

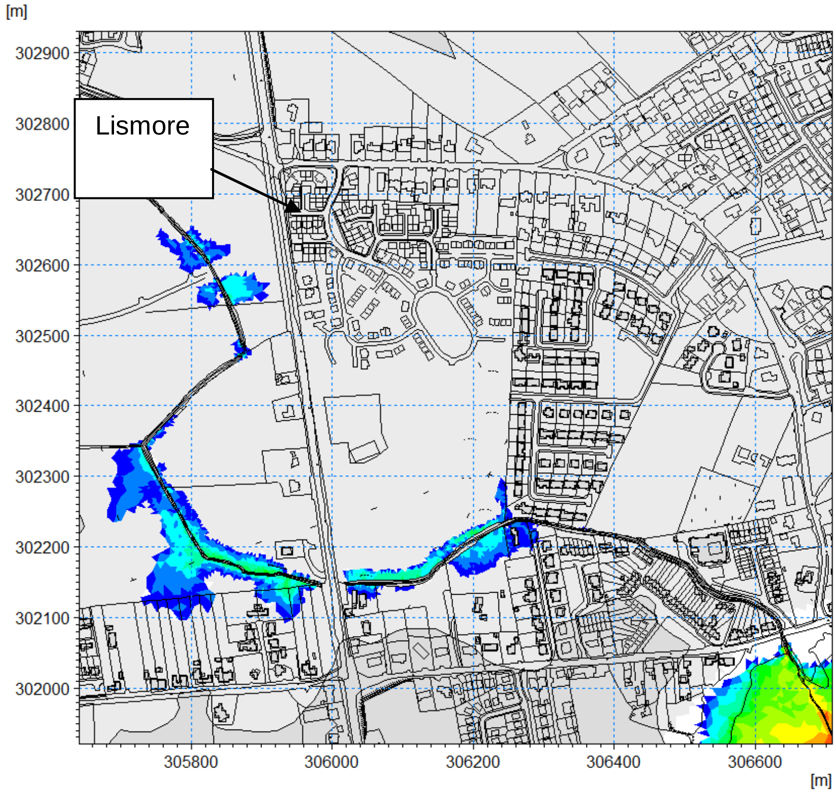


Figure 4.7.43: Modelled flooding at Lismore at the Fluvial 0.1%AEP Event

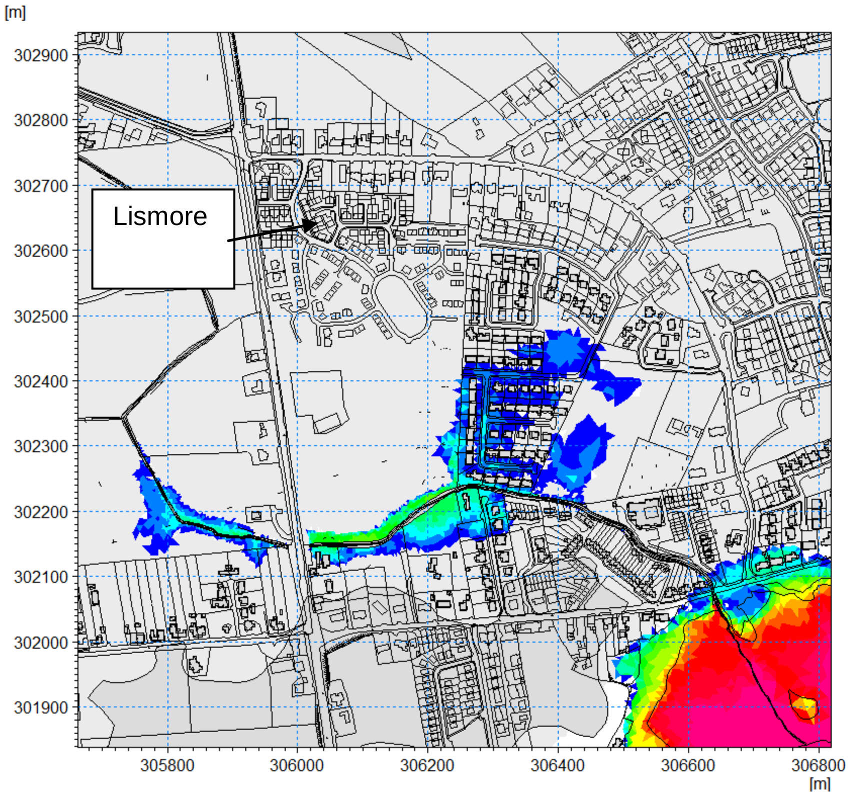
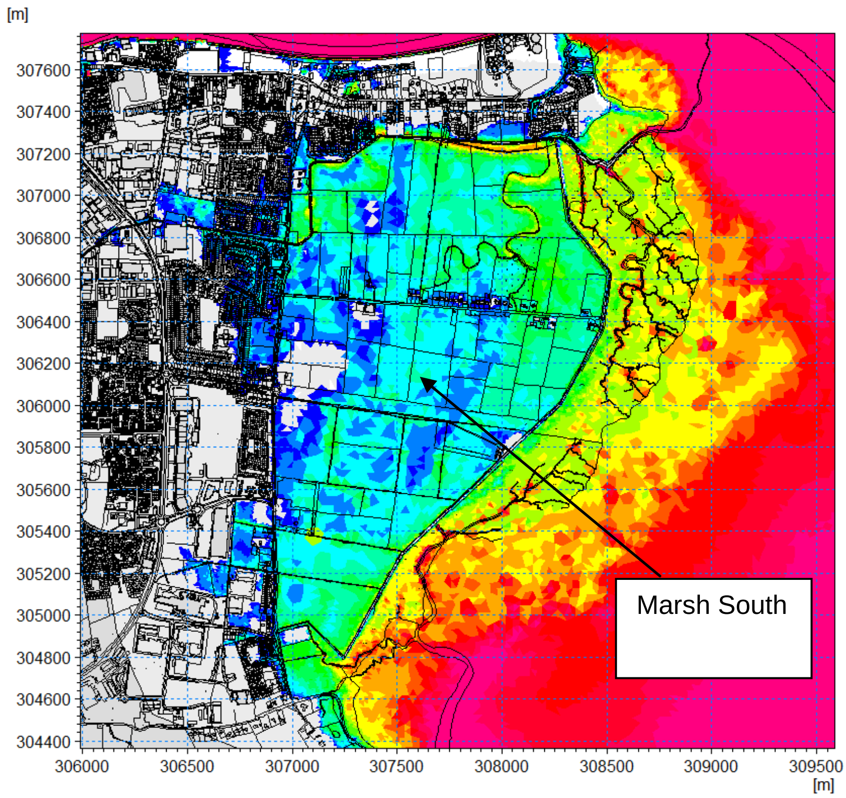


Figure 4.7.44: Modelled flooding at Lismore at the Coastal 0.1%AEP Event

Marsh South (Figure 4.7.45) was also flooded in 2002, due to the breach of an old sand

	embankment in four places. This resulted in up to 0.5m of water in some gardens and the flooding of one residential property. A construction site on the R172 was also flooded. Model results have shown Marsh South to be subject to both fluvial and coastal flooding. Excessive flooding occurs here at many modelled coastal AEP events and at the more extreme fluvial events. This area is protected by a designated defence within the model, as listed in Section 4.7.3; however flow enters the area behind the embankment at the southern end and also from the Castletown River to the North. Lower points in the embankment will breach at more extreme coastal events however.  **Figure 4.7.45: Modelled flooding at Marsh South at the Coastal 0.5%AEP Event**
(e) **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. Within the Dundalk UDC area, repairs to damaged roads, upgrading of culverts and drains was estimated to cost an additional IR£100,000. The information from the review does not indicate any details on return periods, nor any specific location within the Dundalk model that was affected by this event. Thus this

	information is not useful to facilitate calibration.
(f) **DEC 1981.**	Flooding occurred in Annagassan, Carlingford and Dundalk & Blackrock South on 3rd December 1981 due to heavy rainfall, high tides and strong winds. In Blackrock flood water entered most houses and business premises along the exposed length of village for several hundred yards. Damage was caused to the sea wall fronting the village. Walls to the swimming pool were also damaged. As discussed under the February 2002 event, Blackrock promenade floods at all modelled AEP events, and is also susceptible to wave overtopping. Evidence in 1981 further indicates a strong wave climate in the area, as it is likely the damage caused to the sea wall was the result of wave action. Articles in the Dundalk Democrat were downloaded from www.floodmaps.ie, which indicated a flood event in Dundalk on the same date when the tide rose above the quay wall. The Town Engineer reported that the tide was 450mm higher than any previously recorded tide. Evidence dictates that the December 1981 event was a coastal dominated event. No tidal gauge data was available for this event so it was not possible to estimate the AEP of the coastal water level. The worst affected areas were at Seatown and Quay Street, where basements of houses were "flooded to depths of several feet and in some cases, almost to their ceilings". Flooding is not uncommon at Quay Street and occurred also in February 2002 as well as other occasions. Flooding occurs in the model at the 5% AEP and above. Seatown however is not shown to flood within the model results, although as this event occurred over 30 years ago, it is possible that ground elevations have changed in that time. The 0.1% AEP coastal boundary provides a water level of 3.94m OD Malin. LiDAR indicates elevations of between 3.85-5.24m OD Malin along the Seatown Road, with any coastal flow paths to the road reaching at least 4m OD Malin. It is not physically possible therefore for the model to flood at Seatown from still water coastal inundation. Refer to Figure 4.7.46. Flooding also occurred at Fair Green, as shown by the model results. In the minutes of a meeting held on 25th October 2005 as part of the OPW Flood Hazard Mapping Programme, the Fairgreen Road was noted to be subject to recurring flooding. Heavy rain in conjunction with high tides was stated to flood low lying land at the Fairgreen Road/177 junction. This is due to runoff being unable to discharge via tidal sluice valves. As this is recurring flooding, it would be anticipated that more flooding would be evident in the less extreme coastal AEP model results; however surface water runoff is not simulated in the modelling process.

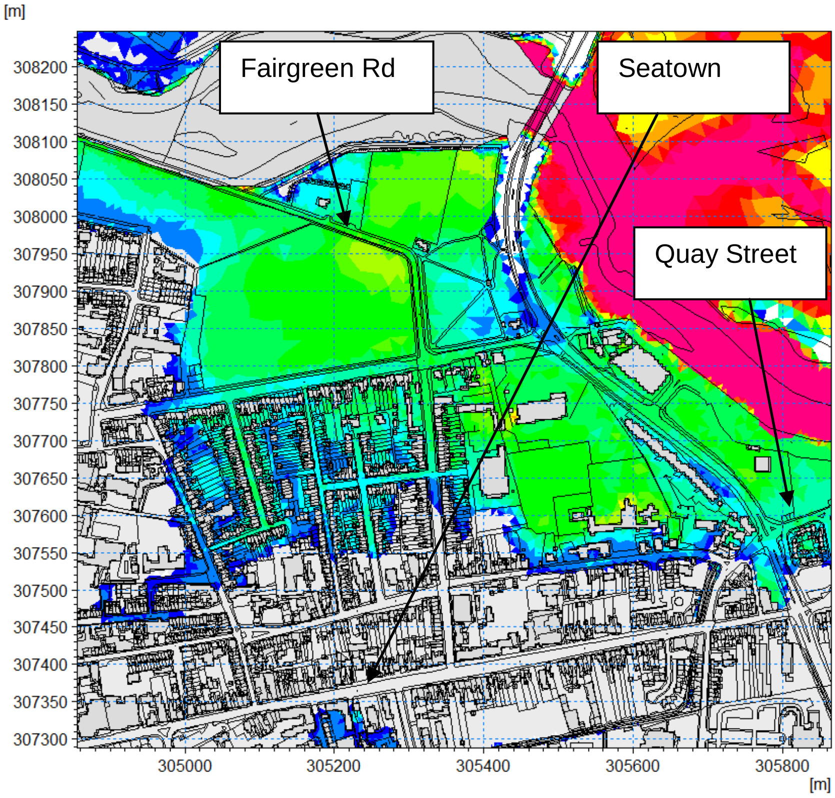


Figure 4.7.46: Modelled flooding at Seatown at the Coastal 0.1%AEP Event

Flooding also occurred at St. Marys Road, Broughton Street, Castle Road, St. Patrick's Terrace and St. Brigid's Terrace, as shown in Figure 4.7.47. Offices of C.C.O. coal firm, a local shop, PMPA offices, the Harbour Offices and a number of houses were flooded. Model results confirm that these locations are subject to coastal flood risk from at least the 0.5% AEP and above.

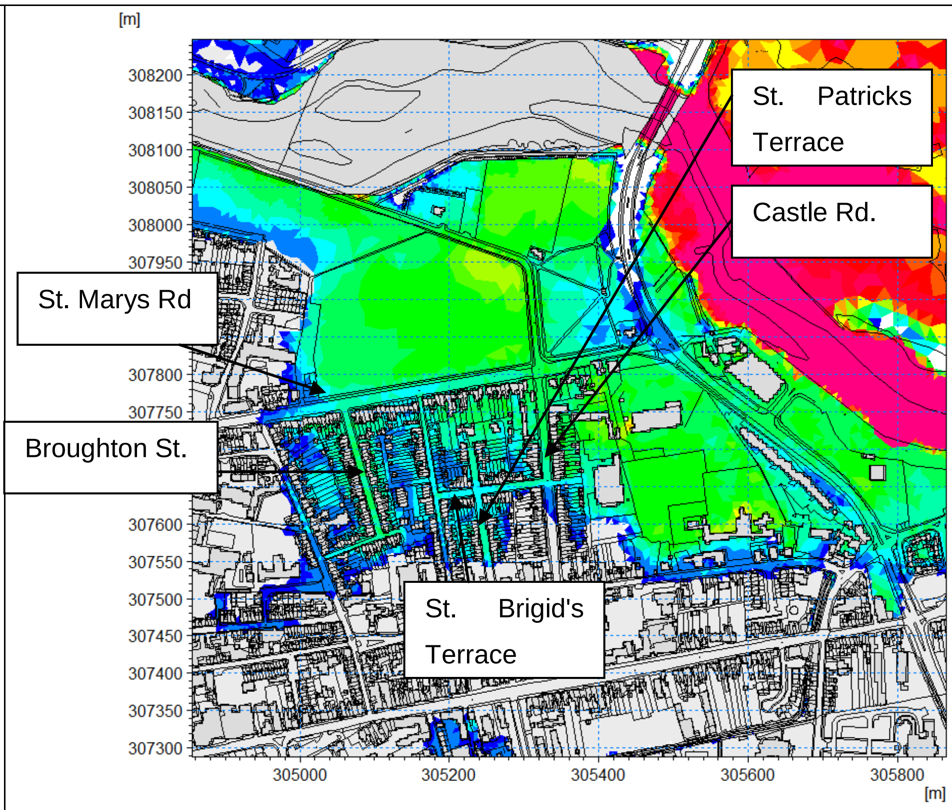


Figure 4.7.47: Modelled flooding at St. Marys Road, Broughton St, St. Patricks Terrace, St. Brigid's Terrace and Castle Rd at the Coastal 0.1% AEP Event

The Newry Road, from Lisdoo corner to the Racecourse Road, was also flooded when floodwater entered over the sloblands. Some houses at Lisdoo corner flooded. The Dundalk Democrat reported one fatality from the floods when a man drowned at Race Course Road. Gardaí suspect he was caught unexpectedly by a tidal surge, which is reported “to have reached a height of several feet after it crossed the sea banks along the estuary of the Ballymascanlon River”. Other people had to be evacuated from their homes in this area also and sheep, pigs and domestic animals were drowned. Both the Newry Road and Racecourse Road (Figure 4.7.48) are shown to flood within the model results at the coastal 2% and 50% AEP events respectively.

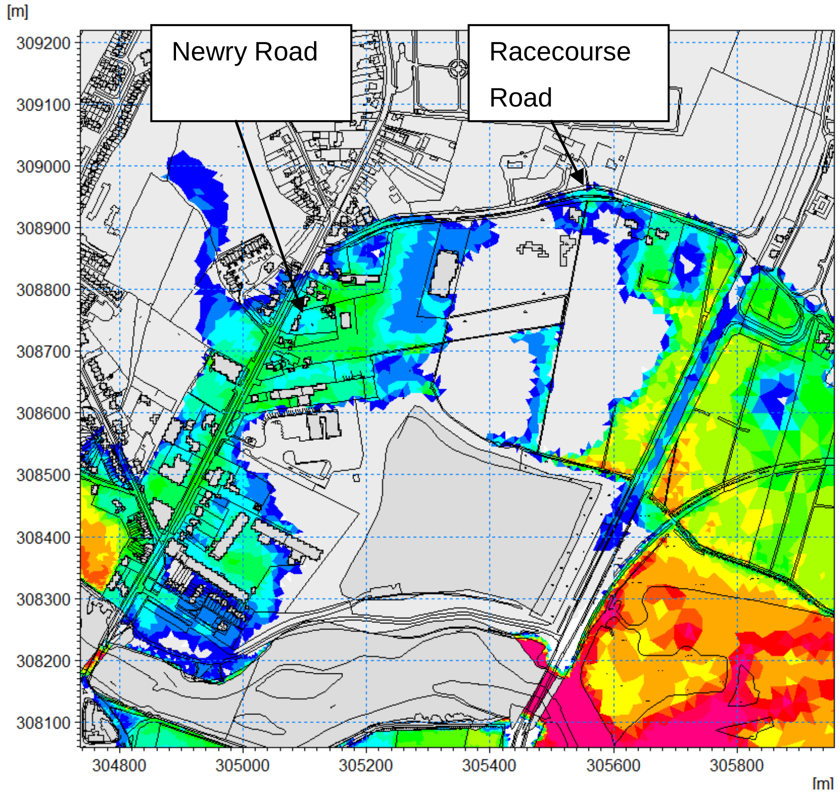
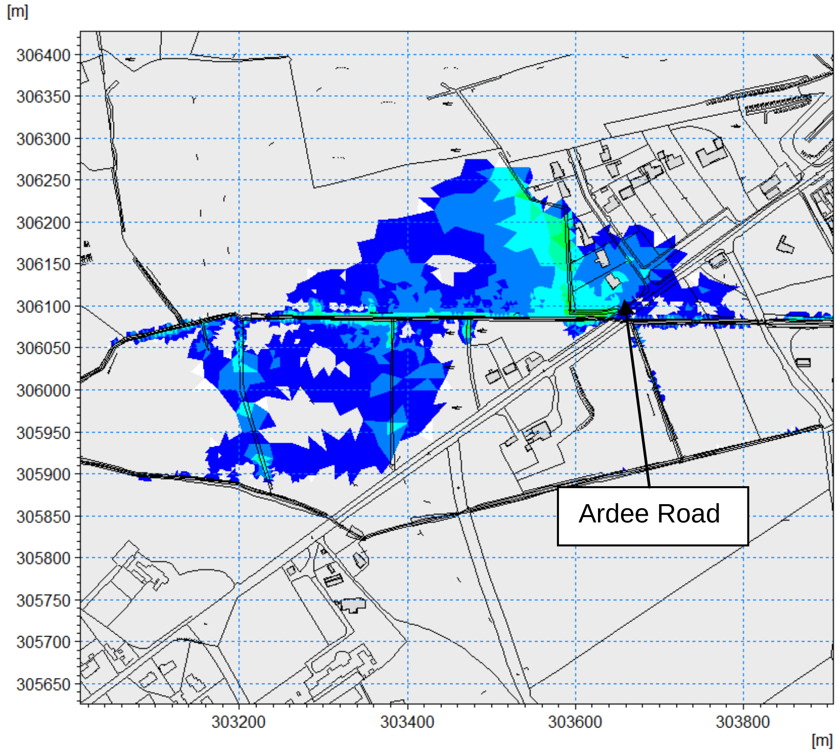
<table>
<tr>
<td></td>
<td>


Figure 4.7.48: Modelled flooding at Newry Road at the Coastal 0.5%AEP Event
</td>
</tr>
<tr>
<td>(g) **FEB 1977.**</td>
<td>
Information contained in a Consultant's report entitled 'Rampart River Flooding Relief - A Feasibility Study' indicates that in early February 1977, prolonged rainfall caused the Rampart River to burst its banks inundating considerable areas of land in the Dundalk urban district. The flooding caused extensive disruption to traffic flow and to business in the low lying areas adjacent to the Ardee Road, as well as causing damage to stocks and domestic dwellings in the area.

This report also notes that flood relief works were carried out within two years of this event.

Using data from the Castletown daily rain gauge at Dundalk, it was established that 58mm of rainfall fell in 96 hours between 8-11 February 1977. This yielded an AEP of circa 29%, using the FSU Depth Duration Frequency model (FSU WP 1.2 'Estimation of Point Rainfall Frequencies')

This evidence adds to the information discussed under the October 2011 event. Model results indicate that fluvial flooding occurs from the Rampart (Dundalk) River from as low as the 50% AEP, affecting low lying areas adjacent to the Ardee Road. Figure 4.7.49 shows flooding at the Ardee Road at the fluvially dominated 20% AEP event.
</td>
</tr>
</table>

	 **Figure 4.7.49: Modelled flooding at Ardee Road at the Fluvial 20%AEP Event**
(h) **DEC 1954.**	Archive articles from the Dundalk Democrat indicate that flooding occurred on 8th December 1954 in Dundalk. Flooding was caused by prolonged rainfall, high tides and strong easterly winds. This was exacerbated when stream flow was impeded by debris in a culvert near the Fatima housing estate. Some speculated that an open sluice valve was to blame for some of the flooding. Houses were flooded to a depth of over 200mm on Quay Street with houses also flooded in Ladywell Terrace. Gardens were flooded at Thomastown while “there was up to three feet of water at the Castletown Bridge”. There was also flooding at O’Hanlon Park, Castleblaney Road, Ardee Road, Fatima Park and Mill Road. Using data from the Annaskeagh daily rain gauge near Dundalk, it was established that 84mm of rainfall fell in 72 hours between 6th and 8th December 1954. This yielded an AEP of circa 9%, using the FSU DDF model. Model results show flooding in the Fatima estate area from the 10% AEP and above, revealing that the general area is at risk from both coastal and fluvial flooding. However in 1954, flooding may have been increased due to the open sluice valve, as mentioned.

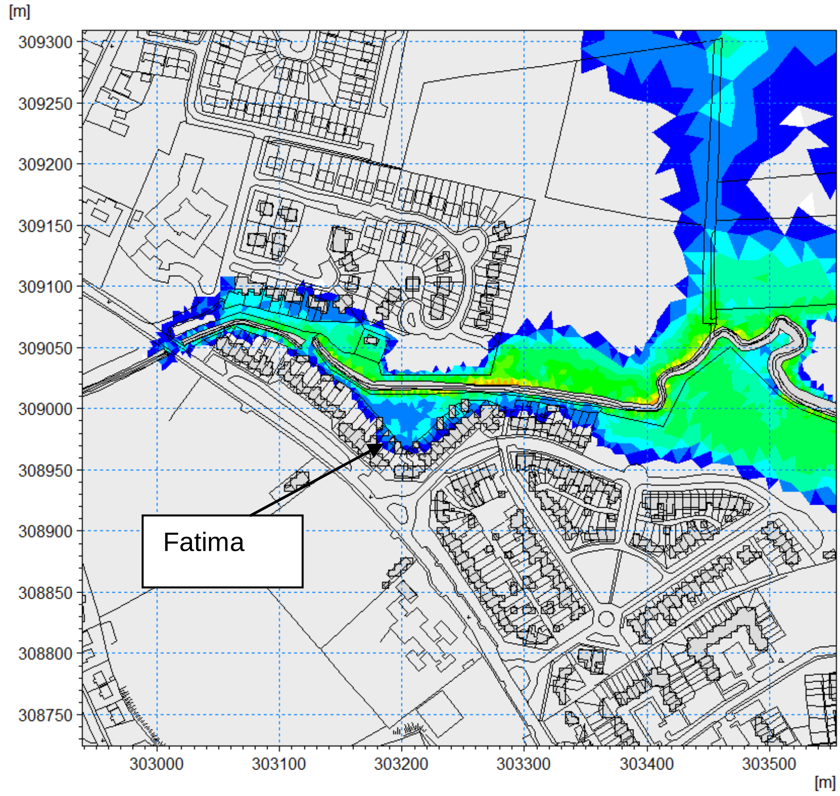


Figure 4.7.50: Modelled flooding at Fatima at the Coastal 0.1%AEP Event

Once again, Quay Street was mentioned as having been subject to flooding, in line with model results, as discussed previously. Ladywell Terrace is shown to flood in the model from the 0.1% AEP fluvial dominated event, as shown in Figure 4.7.51.

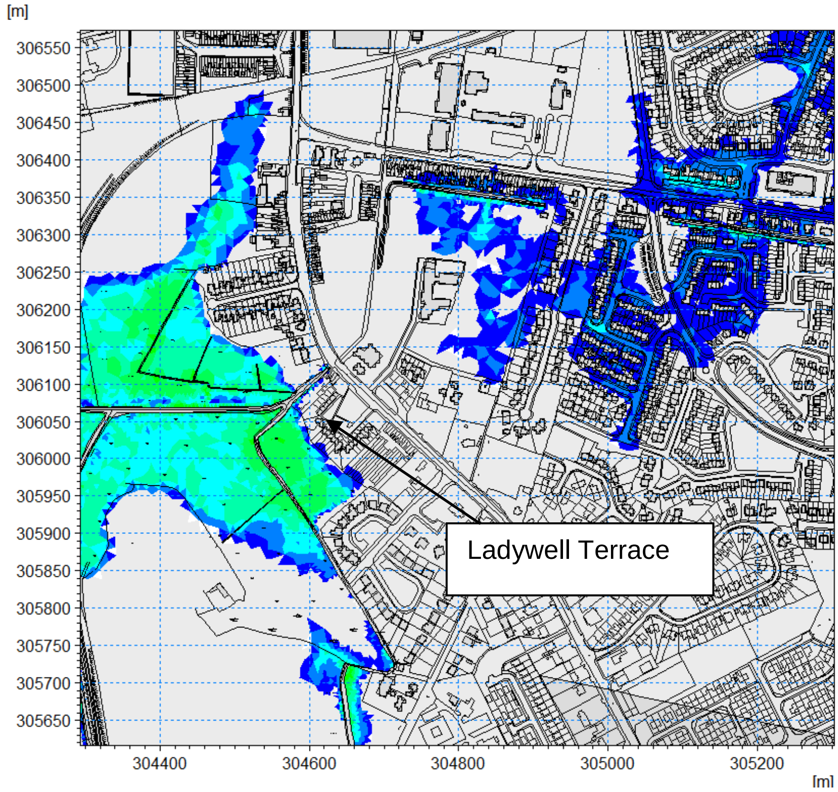
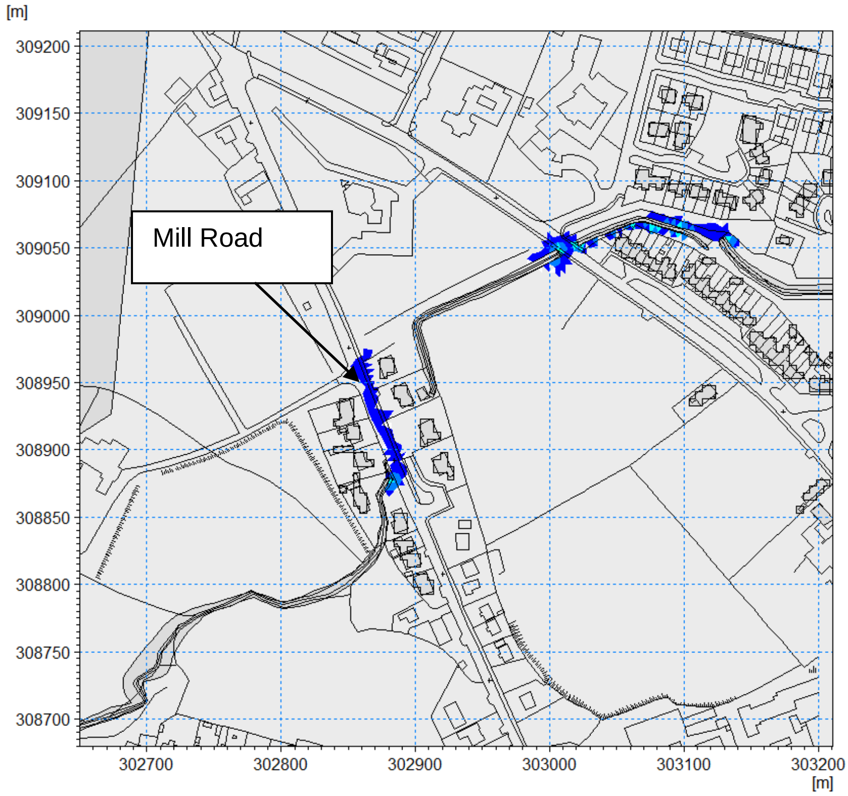


	Figure 4.7.51: Modelled flooding at Ladywell Terrace at the Fluvial 0.1%AEP Event Thomastown lies outside of the AFA and thus is not useful for calibration. Model results do not show any flooding at O'Hanlon Park, however it is expected that this flooding was as a result of surface water runoff. It is assumed that the Castleblaney Road is the same as the Castletown Road, which is mainly affected by coastal flooding from the 1% AEP and above, as discussed previously. The Ardee Road on the other hand is mainly affected by fluvial flooding, which occurs from as low as the 20% AEP. The Mill Road (Figure 4.7.52) is shown to be subject to fluvial flooding from the 10% AEP.  **Figure 4.7.52: Modelled flooding at Mill Road at the Fluvial 1%AEP Event**
(i) **NOV 1954.**	The historical data from www.floodmaps.ie indicated that flooding occurred in Dundalk on 8th November 1954 due to high tides, strong winds and heavy rainfall. It was reported that the worst flood spot around the town was at Castletown, under the railway bridge, where there was "over 5 feet of water lying under the bridge". In addition flooding occurred at Long Avenue up to the doorsteps of houses at the pork factory, at Fair Green and the basement and playground of the Convent New Schools. It was also reported that three warehouses on Quay Street were flooded with water "at least 12 inches high". Fluvial flooding occurs in the model from as low as the 10% AEP at Long Avenue, with coastal flooding affecting the Castletown Road from the 1% AEP and above. Flooding occurs in the model at Quay Street from the 5% AEP and above, as discussed

previously. Long Avenue is represented in Figure 4.7.53, which shows flooding in the area at the 1% AEP event.

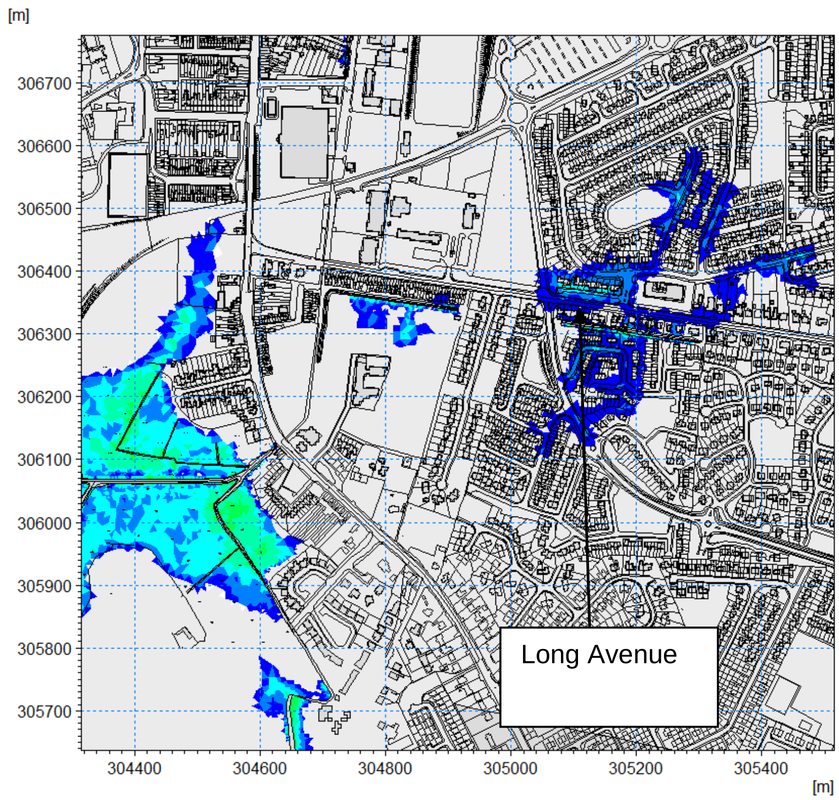


Figure 4.7.53: Modelled flooding at Long Avenue at the Fluvial 1%AEP Event

Summary of Calibration

Where historical reports suggest that coastal mechanisms may have contributed to a flood event, efforts were made to quantify the AEP of the coastal event. This applies particularly to the events of October 2004 and February 2002, where the Dublin gauge was used to estimate a coastal AEP. It should be noted that assigning an AEP in this manner is an estimate only and should be treated with caution, due to the distance and variation in location between these gauges and Dundalk.

Model flows were validated against the estimated fluvial flows at HEP check points where possible to ensure they were within an acceptable range, where flows were not tidally influenced. For example at HEP 06032_RA on the Castletown River, the estimated flow during the 10% AEP event was 38.13m^3/s and the modelled flow was 38.66m^3/s, a difference of 1.39%. There were some HEPs with larger differences, for example on the Fairhill Tributary, the estimated flow during the 10% AEP event was 0.75m^3/s and the modelled flow was 2.04m^3/s, a difference of +172.13%. This is due to out of bank flooding from adjacent rivers contributing to the flows in the Fairhill Tributary. The large percentage difference is also reflective of the small magnitude of the flows. Refer to Appendix A3 for flow tables and further details.

There are no gauging stations with available flow data located on the watercourses within the Dundalk model.

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. The mass error in the 1D and 2D components of the model was calculated for each scenario. Table 4.7.5 summarises the mass errors of each model run:

Table 4.7.5: Mass Error of Model

Model	1D Mass Error	2D Mass Error
10% AEP Fluvial	0.78%	0.02%
1% AEP Fluvial	1.04%	0.02%
0.1% AEP Fluvial	0.68%	0.02%
10% AEP Coastal	1.52%	0.00%
0.5% AEP Coastal	1.47%	0.38%
0.1% AEP Coastal	0.92%	0.59%

There is extensive historical flood information available (including photographs and flood outlines) for a verification exercise of the Dundalk and Blackrock model, with the model comparing well with the vast majority of evidence, as discussed throughout Section 4.7.5. However it should be noted that as there are no active gauging stations with available flow data within the model extent, full fluvial model calibration was not possible. However, the 2D coastal domain of the model has been calibrated well using Admiralty tidal information. Those areas considered subject to frequent flooding, for example Quay Street in Dundalk and Main Street in Blackrock are simulated well by the model, and are shown to flood regularly, as expected.

A model instability occurs at the upstream end of the Marshes Lower River, as shown in Figure 4.7.54. This only occurs at the 1% AEP fluvial event and is situated within a culverted reach, therefore the mapping is not affected by the momentary spiking.

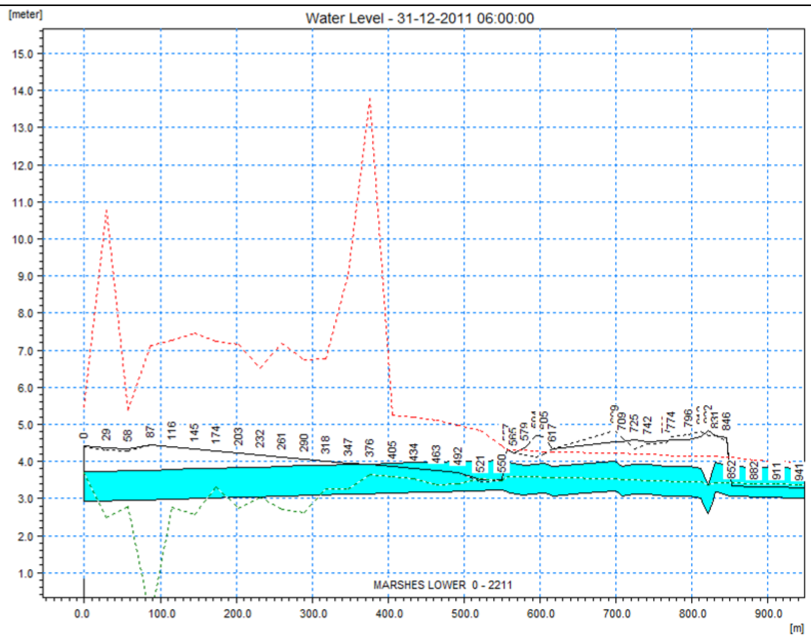


Figure 4.7.54: Marshes Lower Instability at Fluvial 1% AEP

A very minor instability occurs at the upstream end of the Dundalk Blackwater River, as shown in Figure 4.7.55. This only occurs at the 0.1% AEP fluvial event. Efforts were made to stabilise the model, however due to the complex and extensive nature of flooding in this area, the instability could not be entirely removed. However, due to the amount of 2D flooding in the area, this instability in 1D flow becomes insignificant.

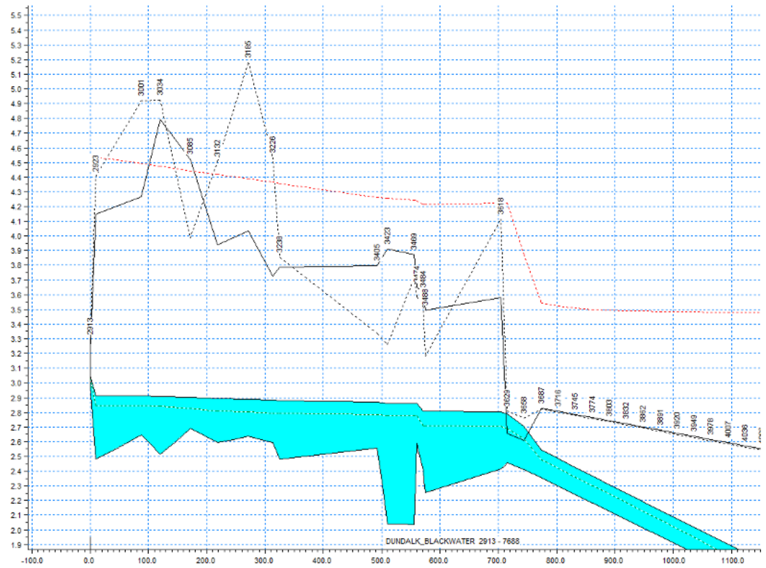


Figure 4.7.55: Dundalk Blackwater Instability at Fluvial 0.1% AEP

A very minor instability occurs at Chainage 977 on the Castletown River, as shown in Figure 4.7.56. This occurs at the 10%, 1% and 0.1% AEP fluvial events. Efforts were made to stabilise the model, however due to the complex and extensive nature of flooding in this area, the instability could not be entirely removed. This is a very minor instability which does not have a significant effect on the mapping.

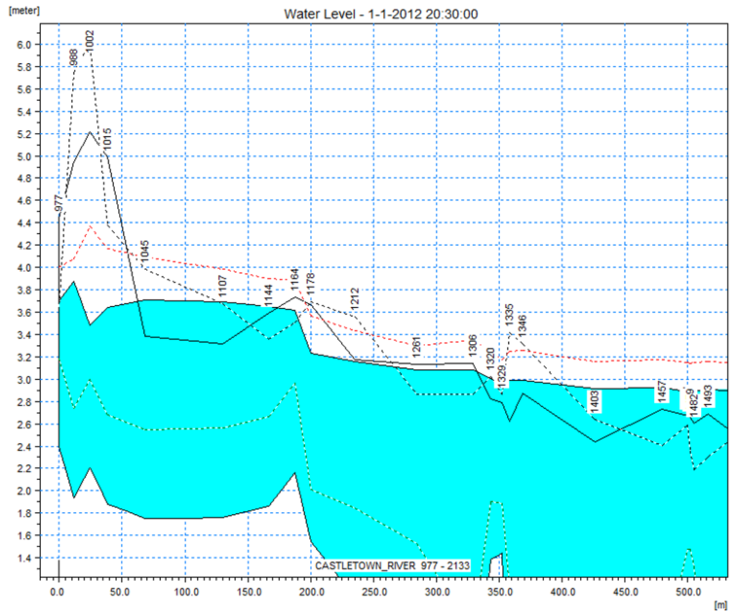


Figure 4.7.56: Castletown River Instability at Fluvial 0.1% AEP

The model is considered to be performing satisfactorily for design event simulation, with any instabilities less than the required tolerance.

(2) Post Public Consultation Updates

Following consultation with the local authorities on the draft flood extent maps for the Dundalk AFA, the following points were noted:

- Generally the coastal flood extents look acceptable.
- The coastal 10% AEP was queried in a small number of places close to the Castletown River in the Townparks area. Following investigation of LiDAR and defence levels, these issues were attributed to pluvial flooding, or potential seepage of coastal waters through a defence/ tidal ingress via gullies along the road behind the defence.
- Coastal flooding occurred behind the Bay Estate Defence in 2002. As discussed in this report, the likely AEP for this event was 1-0.5%. This correlated well with the flood outlines which show flooding at the 0.5% AEP event.
- Coastal extents were also queried for the 10% AEP on the Blackrock Road in The Loakers. Following investigation of the LiDAR, elevations dictate that this road could not flood under the 10% AEP via coastal still water inundation and flooding may be the result of a pluvial issue.
- It was suggested that fluvial flooding may occur more frequently in some areas, (Castletown and Haggardstown), however following analysis of the model and LiDAR in these areas, it was deemed that the likely cause of flooding was due to structure blockage, as suggested by the local authorities for the Castletown area.
- The main issue arising from the review of the draft flood maps was the excessive fluvial flooding in the Marshes Lower area. The model has since been revised, with significantly less fluvial flooding now occurring.

Following informal public consultation on 5th March 2015, a number of points were noted on the draft final flood extent maps of the Dundalk AFA. These are as follows:

- Fluvial flooding in the Cambrickville area, as shown in Figure 4.7.57 was noted to be correct, with regard to businesses affected. This area was noted to flood once every 5-10 years. On 15th November 2014, houses and businesses were flooded, as represented by the flood extents. It was considered to be due to drains and culverts not being maintained.

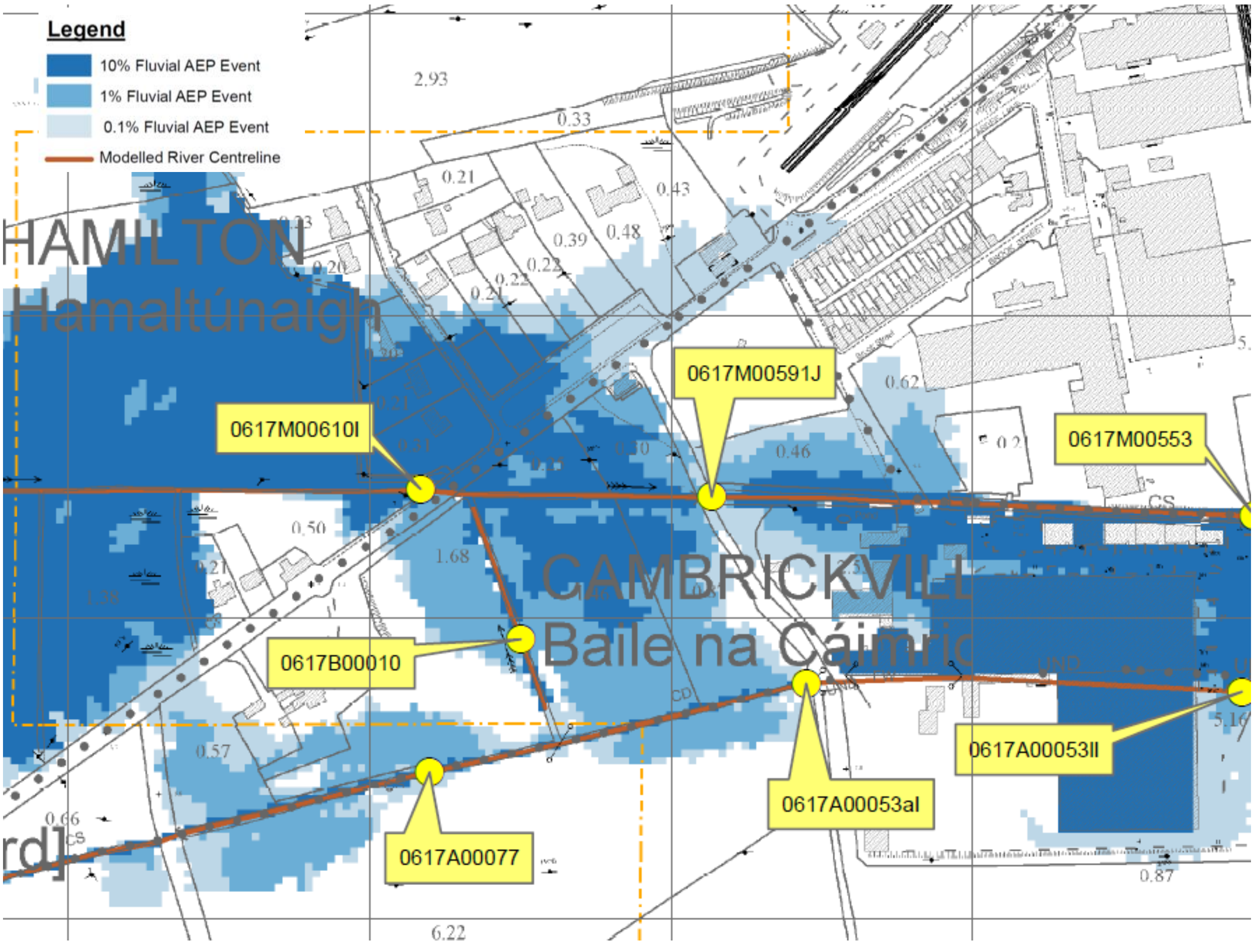


Figure 4.7.57: Fluvial Flooding in the Cambrickville area

- Fluvial flooding in the vicinity of Rock Court (Figure 4.7.58) was considered accurate. This area flooded in 2013 and 2014, affecting houses and roads.

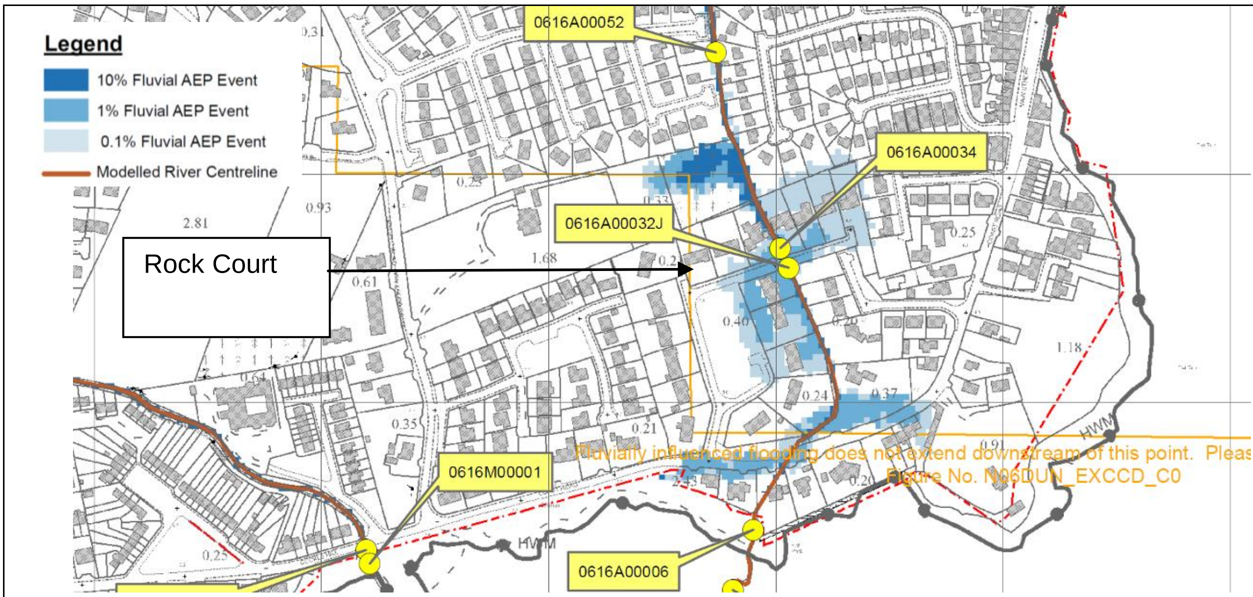


Figure 4.7.58: Fluvial Flooding at Rock Court

- The Clan na Gael / Ecco Road area was noted by one member of the public as being over-estimated in the flood outlines. The only coastal flooding in this area is from the 1% AEP and above and occurs at the junction of Ecco Road and Castletown Road. Fluvial flooding from the Acarreagh River does occur in the model from the 10% AEP and above, as shown in Figure 4.7.59. This occurs mainly between Chainages 484-1289 due to low banks and insufficient culvert capacity at Chainage 683. A comparison of model flows at Chainage 875 and hydrological estimated flows at HEP 06_1089_4_RA, show a small under-prediction of flows by the model at the three core AEPs, therefore altering the hydrology would not have the desired effect. No model instabilities were noted in the Acarreagh River at the 10% AEP, with out of bank flooding occurring at a number of locations. It is however clear from aerial photography that this is an urban area with numerous garden walls, which may prevent fluvial flooding from reaching the Ecco Road in practice. However, as these cannot be considered as defences, it is necessary for the omission of these features within the model.

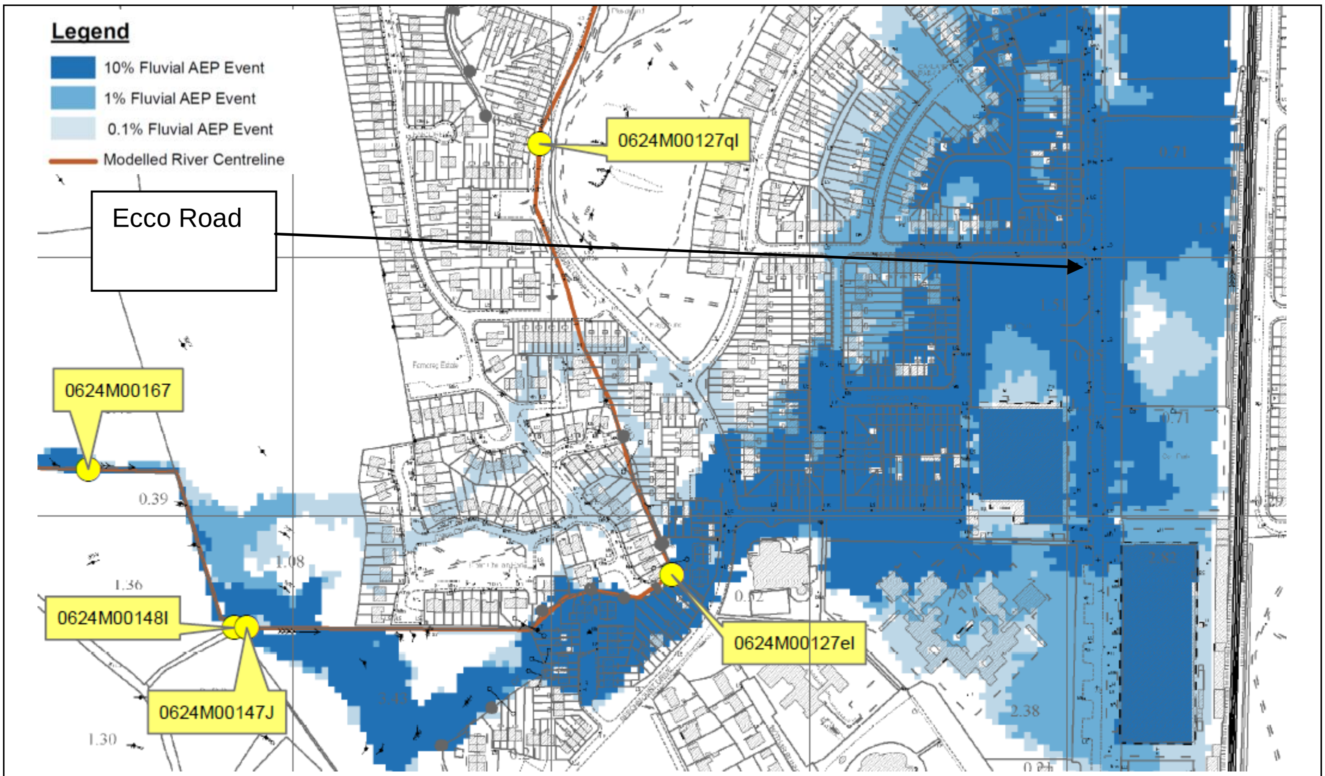


Figure 4.7.59: Fluvial Flooding at Ecco Road

- The Loakers was noted to flood once every 5-10 years. In January 2014, the road and houses were flooded. This event was considered to be represented by the flood outlines, as shown in Figure 4.7.60, which shows coastal flooding in The Loakers from the 10% AEP and above. It was considered that coastal flooding was accentuated by drainage ditches not being maintained.

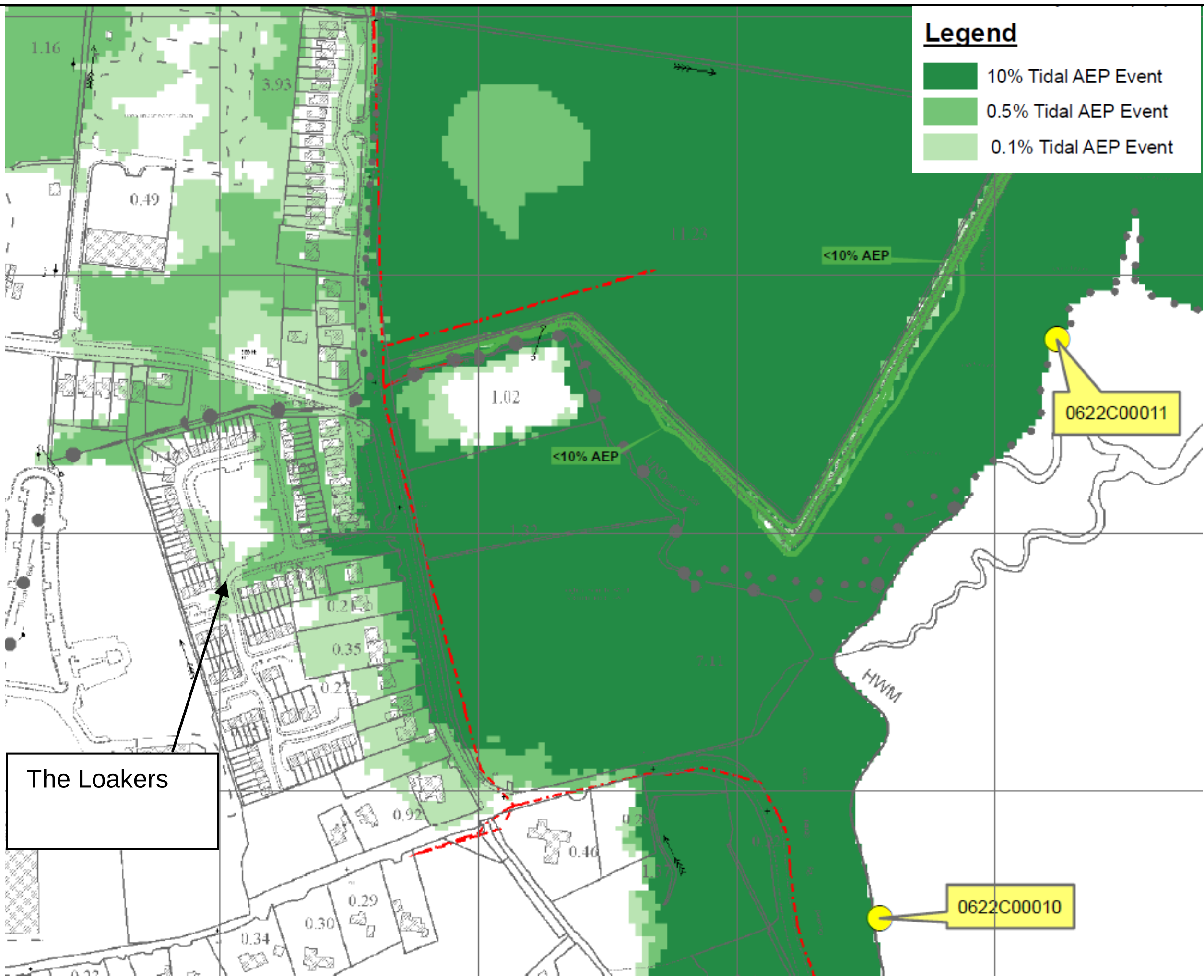


Figure 4.7.60: Coastal Flooding at the Loakers

- Video footage acquired as part of the public consultation process shows the flooding of the Blackrock Promenade on 1st February 2002, affecting a significant number of properties, in line with modelled results. Wave overtopping is also evident. This event is in the order of a 1%-0.5% AEP as discussed in Section 4.7.5. Figure 4.7.61 to Figure 4.7.63 show still images extracted from the footage, revealing the extent of the flooding by both high water levels and wave overtopping. Figure 4.7.64 and Figure 4.7.65 show the model results for coastal flooding and wave overtopping respectively.

Figure 4.7.61: Video Footage showing high water levels at Blackrock Promenade in 2002

Figure 4.7.62: Video Footage showing wave overtopping at Blackrock Promenade in 2002

Figure 4.7.63: Video Footage showing sample affected properties at Blackrock Promenade in 2002

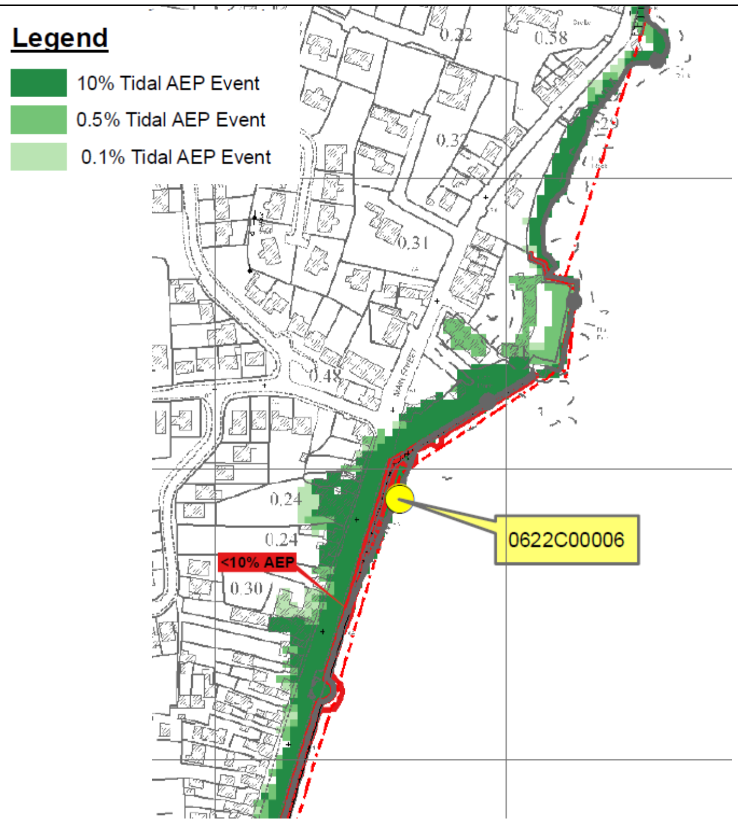


Figure 4.7.64: Coastal Flooding at Blackrock Promenade

Figure 4.7.65: Wave Overtopping at Blackrock Promenade

- The acquired video footage also focuses on 'The Boat House' located off the coast Road to the South of the Blackrock Promenade. The small grey building which is located closest to the coastline

is completely flooded in the video footage, in line with the 10% AEP for both the still water coastal inundation and the wave overtopping events. Flooding is also seen to occur both north and south of the boathouse, in line with modelled extents, and reaches close to the Boat House itself at the 0.5% AEP still water event. As previously mentioned, this event is considered to be in the order of a 1%-0.5% AEP event, and thus these outlines tie in well with this historic evidence. Figure 4.7.66 to Figure 4.7.69 show examples from the video footage at the Boat House during the 2002 event, whilst Figure 4.7.70 and Figure 4.7.71 show the comparative coastal flooding and wave overtopping in the vicinity.

Figure 4.7.66: Video Footage showing flooding at the Boat House in 2002

Figure 4.7.67: Video Footage showing flooding at the Boat House in 2002

Figure 4.7.68: Video Footage showing flooding at the Boat House in 2002

Figure 4.7.69: Video Footage showing flooding at the Boat House in 2002

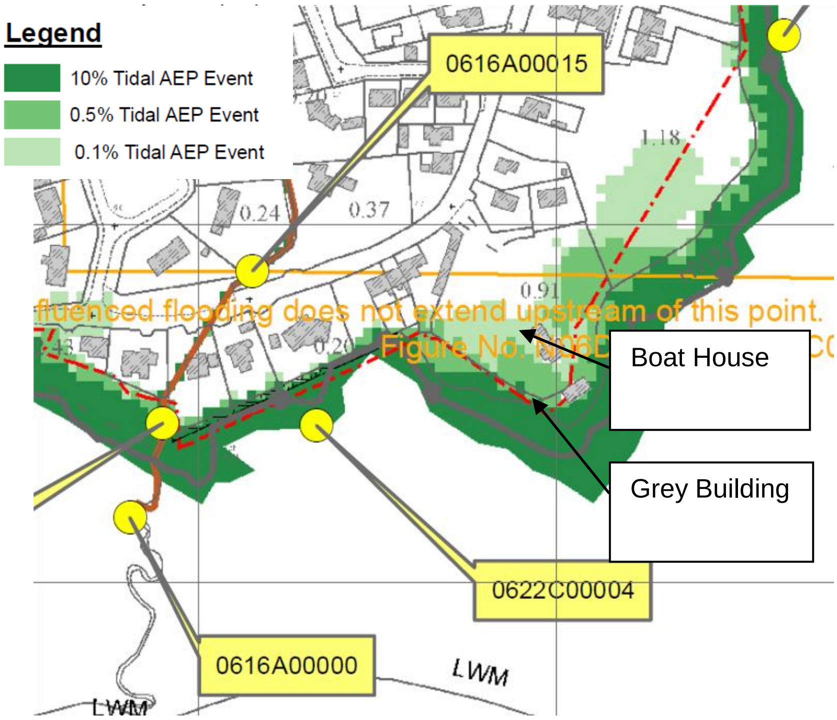


Figure 4.7.70: Coastal Flooding at The Boat House

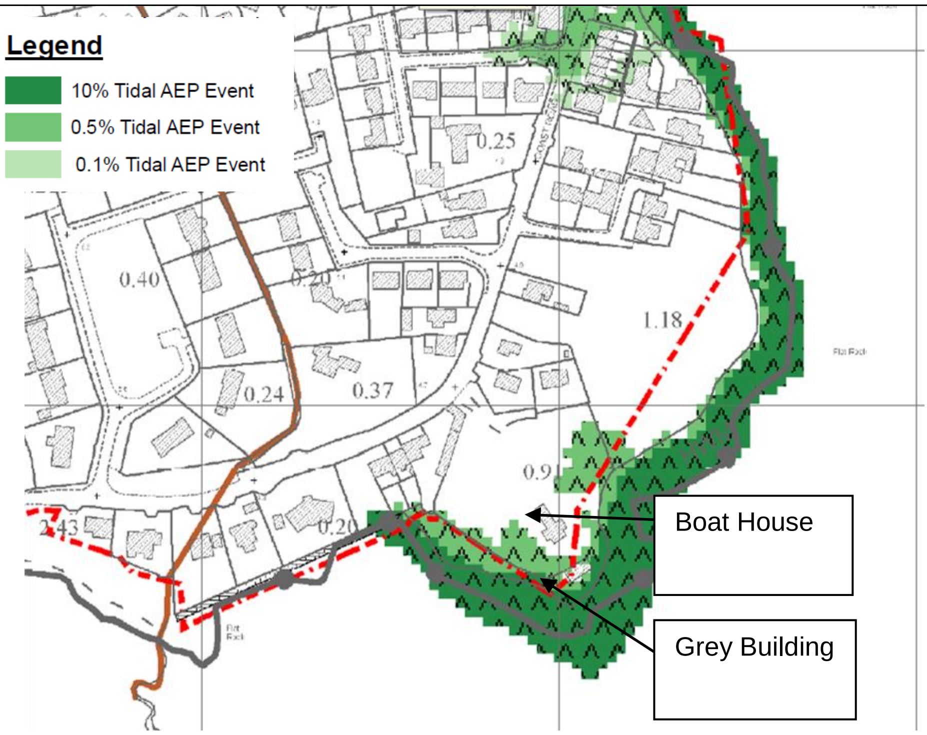


Figure 4.7.71: Wave Overtopping at The Boat House

(3) Standard of Protection of Existing Formal Defences:				
Defence Reference	**Type**	**Watercourse**	**Bank**	**Modelled Standard of Protection (AEP)**
1	EMBANKMENT	Dundalk Harbour (307300,310328 - 305532,308202)	N/A	<10% AEP
2	EMBANKMENT	Dundalk Bay (306955,304932 - 308273,307253)	N/A	<10% AEP
3	WALL	Dundalk Bay (307430,302932 - 307235,302484)	N/A	<10% AEP
4	WALL	Castletown River (304819,308123 - 305080-308034)	RB	5% AEP
5	WALL	Dundalk Harbour (306615,307721 - 307898,307736)	N/A	2% AEP

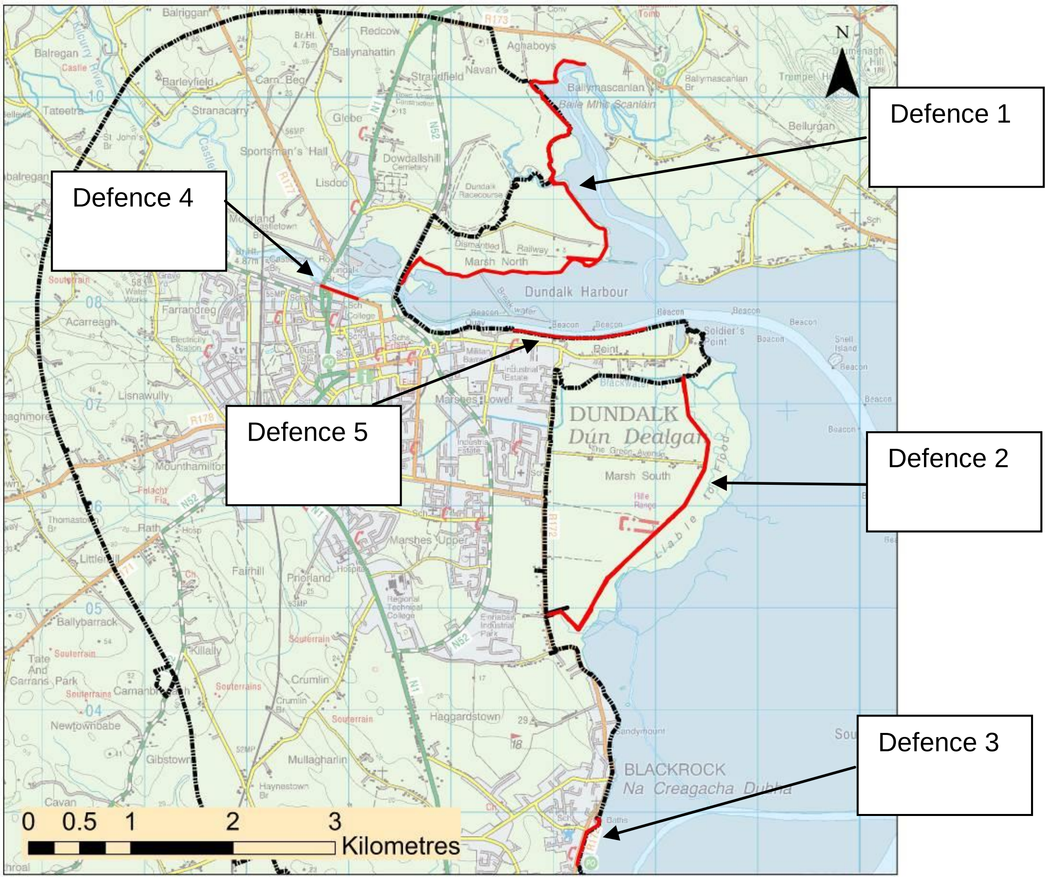


Figure 4.7.72: Formal Defences Dundalk

There are five formal defences in Dundalk, as shown in Figure 4.7.72. These embankments and walls are critical in the protection of the Dundalk and Blackrock areas from coastal inundation. Defence 1 features an embankment over 5.6km long, with a crest level of between 2.3-4.4m OD Malin, whilst Defence 2 is circa 3.4km long, with a crest level of 2.7-4.4m OD Malin. Defence 3 is shorter, just under 50m in length and with a crest level of 3.6-5.4m OD Malin. Defence 4 is a 375m long wall situated on the Castletown River, ranging in height between 3.717m-3.971m OD Malin. Defence 5 is a longer wall structure of 3km, with an elevation of 4.3m OD Malin. The height of this wall was determined following a site visit of the area, where a level was taken at a small number of places along the wall. This level was assumed to be constant. The site visit also determined a number of small gaps in the wall, which were included in the model.

In order to simulate an undefended scenario, defences were removed from the 2D element of the model. As most structures were represented by dike structures in the 2D model, these could be easily removed from the modelling process. However, as the structures were also partially depicted by the LiDAR data, this had to be refined in order to fully remove the embankments from the model. Defence 4 was represented in the Mike 11 element, and thus bank levels were adjusted for the undefended scenario, in order to remove this defence from the modelling process.

Figure 4.7.73 shows that flood defence 4 would reduce the risk of an area from flooding during a flood event. The grey hatching identifies the area that would flood during a 10% AEP event if the defences were removed.

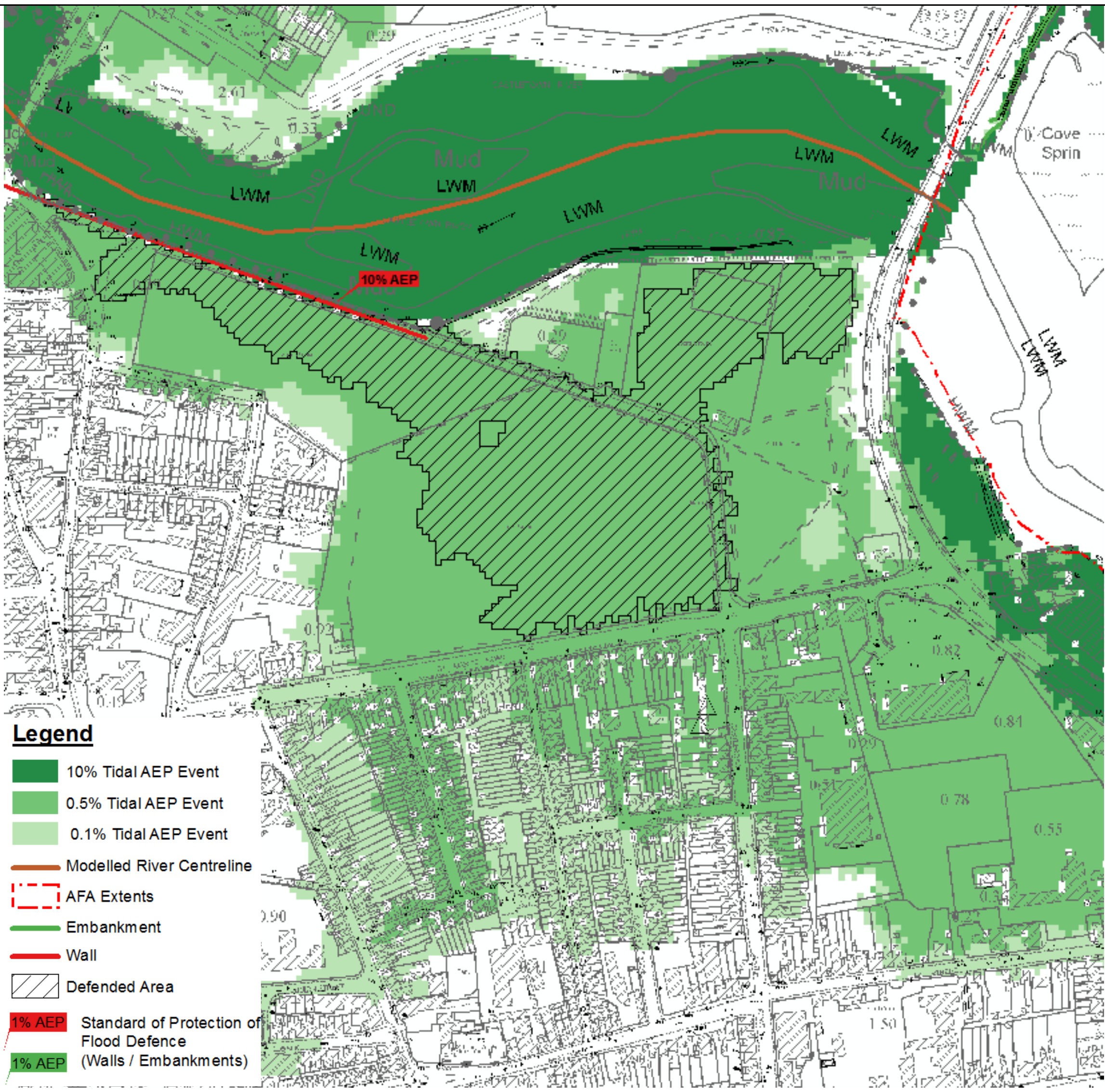


Figure 4.7.73: Defence 4 - Defended Areas

(4) Gauging Stations:

The Dundalk (Ramparts) River has one gauging station located at Ladyswell, Station 06036, with only water level available from September 1979 to the present. The Castletown River has a staff gauge (06032) at St. John's Bridge. As gauges are tidally influenced and have limited data available, they were not used any further in model calibration.

(5) Other Information:

In the minutes of a meeting held on 25th October 2005 as part of the OPW Flood Hazard Mapping Programme, St. Nicholas Avenue was noted to have been subject to flooding from the Castletown River due to embankment failure. St. Nicholas Avenue is shown to flood in the model results from the 0.5% AEP and above and is subject to predominantly coastal flood risk (Figure 4.7.74). The open area to the north of the avenue floods from the 20% AEP and above. It should be noted that the rough grass embankment along this stretch of the Castletown River is not included in the modelling.

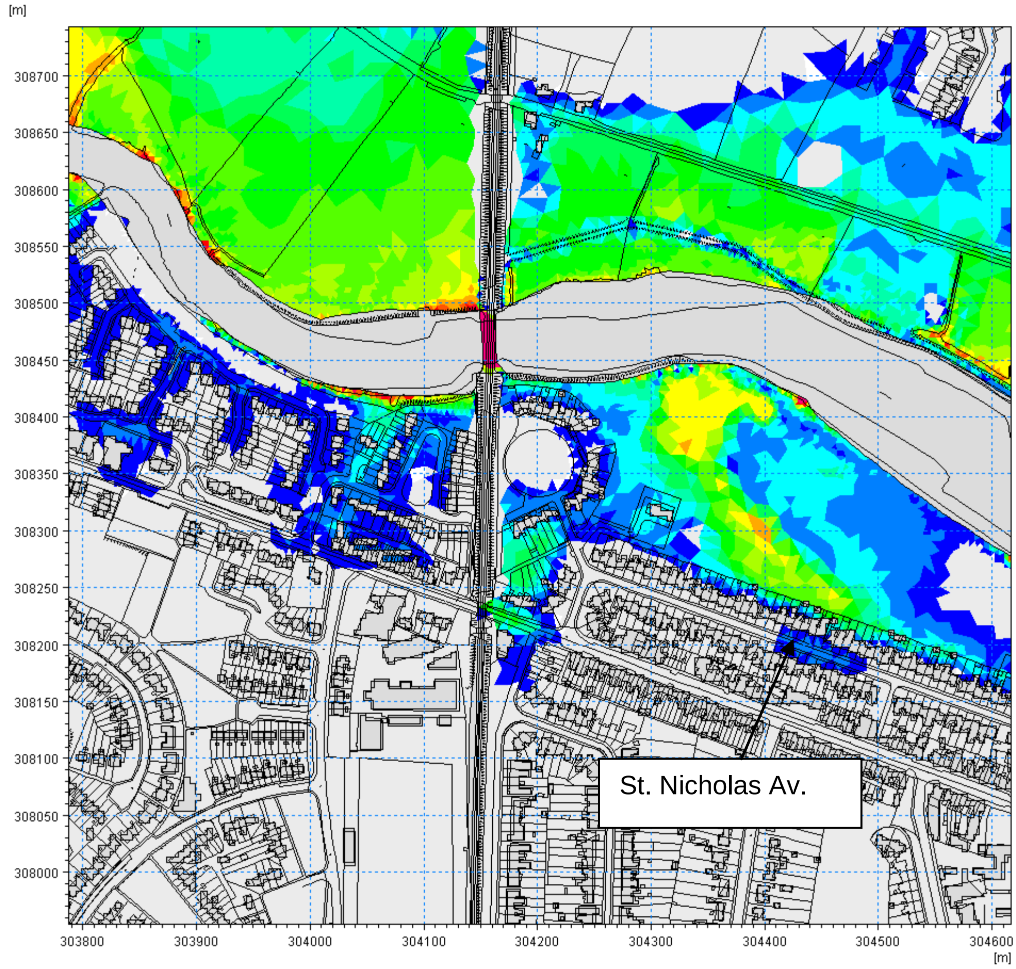


Figure 4.7.74: Modelled flooding at St. Nicholas Avenue at the Coastal 0.5% AEP Event

The minutes also suggest that Balmer's Bog, near Cambrickville is subject to recurring flooding (Figure 4.7.75). A culvert acts as a constriction to flow, with land upstream flooding regularly, and sometimes backing up to the R171 (Armagh Road). Model results show Balmer's Bog to flood, including the back up of flow onto the R171 at all modelled AEP events. Culverts 0617M00651I and 0617M00610I at chainages 1346 and 1750 respectively on the Dundalk river are critical to the flooding in the Cambrickville area and are detailed in Section 4.7.3.

Figure 4.7.75: Modelled flooding at Balmer's Bog at the Fluvial 10% AEP Event

Further to this the Thomas Street and Rampart Road junction, along with Long Avenue were stated to be subject to recuring flooding. Again, this is in line with model results, which show fluvial flooding from the 10% AEP and above at Long Avenue and from the 2% AEP and above at the Thomas Street and Ramart road junction (Figure 4.7.76). There is also evidence of high coastal levels impacting on the fluvial flooding in this area, due to water being slower to discharge to the sea.

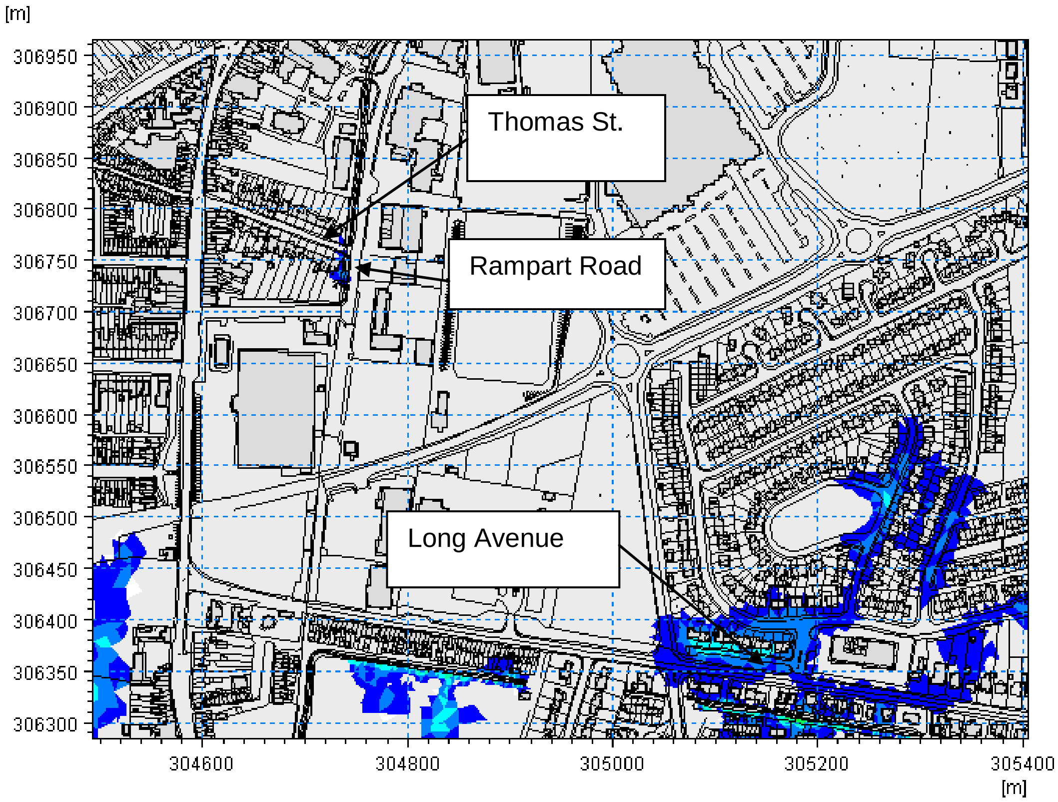


Figure 4.7.76: Modelled flooding at Thomas Street/Rampart Road and Long Avenue at the Fluvial 1% AEP Event

A series of letters (available on Floodmaps.ie) between a member of the public and Dundalk County Council have highlighted recurring flooding on the Mullaharlin Road, close to its junction with the N1 in Marshes Upper. However the County Council have clarified that flood issues in the area are due to surface water drainage issues. Thus this information is not relevant to the calibration of the Dundalk model.

Minutes of a meeting held on 14th October 2005, as part of the OPW Flood Hazard Mapping Programme indicate further areas at risk from flooding. The Haynestown Road is flooded by the Fane River during high tides, although the Fane River was not included in the modelling process for the Dundalk AFA. It is assumed that the Haynestown Road refers to the coast road (Cocklehill Road) towards Haynestown (Figure 4.7.77), which does flood in the model during coastal dominated events from the 2% AEP.

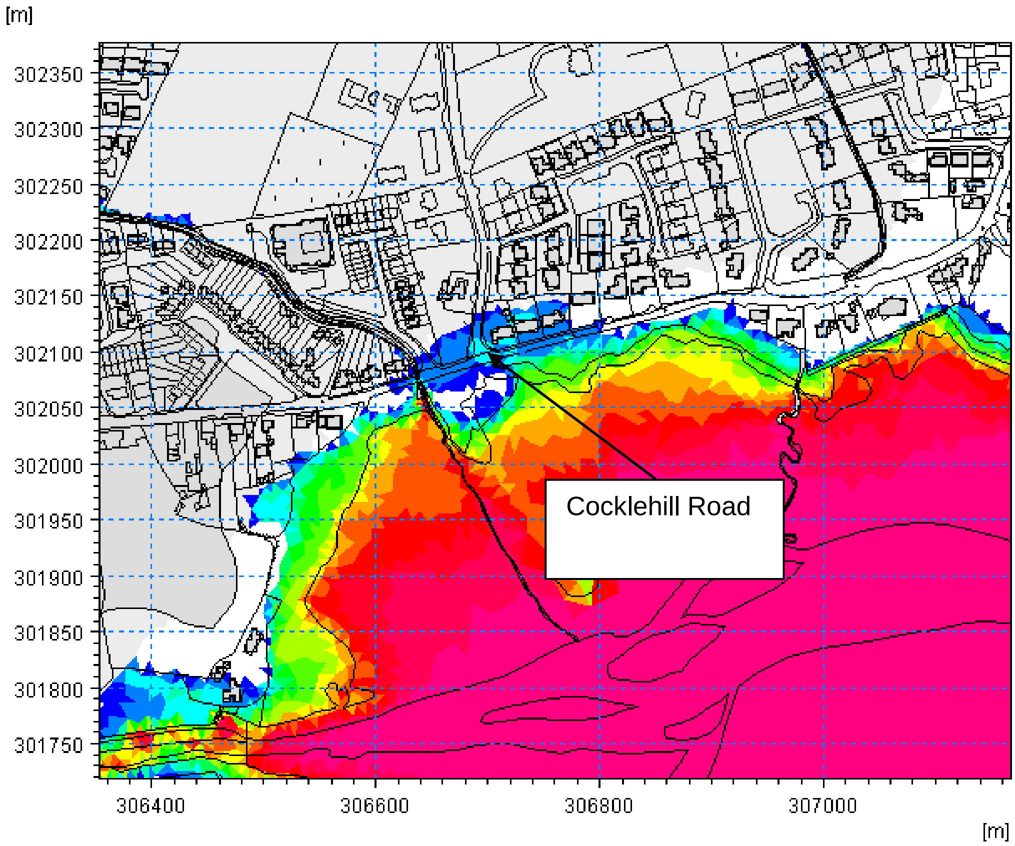


Figure 4.7.77: Modelled flooding at Cocklehill Road at the Coastal 0.5% AEP Event

The minutes also state that a road in Barleyfield (Figure 4.7.78) is subject to regular winter flooding due to a combination of high tides and river flooding, with the road occasionally becoming impassable. It also states however that remedial works have been carried out. Nonetheless, model results are in agreement, showing both coastal and fluvial flooding of this area at all modelled AEP events.

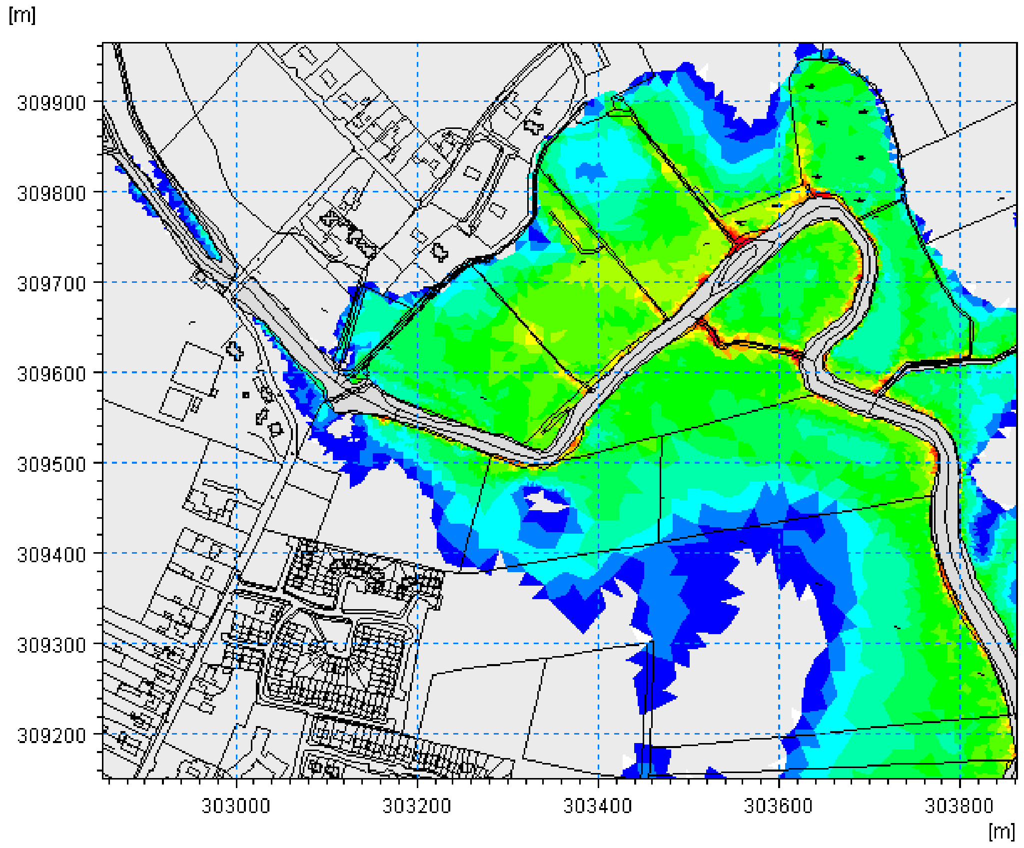


Figure 4.7.78: Modelled flooding at Barleyfield at the Coastal 0.5% AEP Event

The Donaghmore Road is also noted in the minutes as being impassable most winters, although remedial works have also been carried out here. The model results show fluvial flooding from as low as the 20% AEP (Figure 4.7.79).

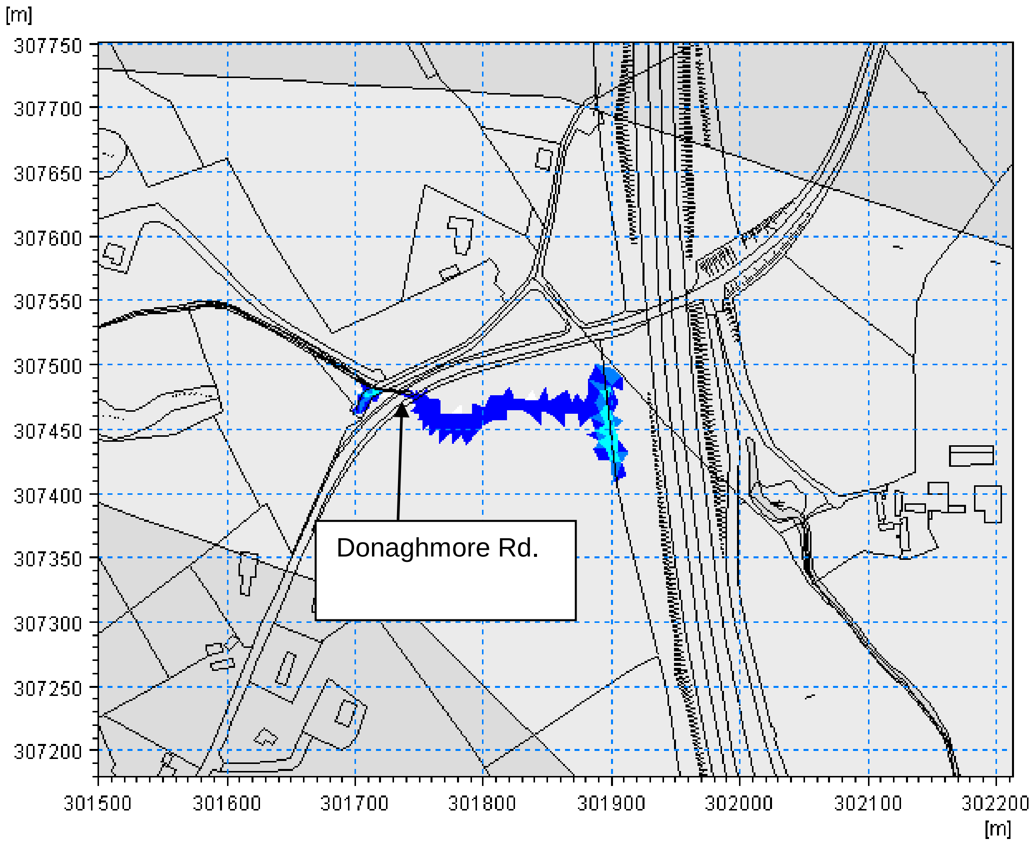


Figure 4.7.79: Modelled flooding at Donaghmore Road at the Fluvial 20% AEP Event

An article on www.floodmaps.ie also refers to the recurring flooding from the Blackrock Stream, due to inadequate channel cross section, culvert capacity and poor channel condition exacerbated by development. This has resulted in the flooding of roads, gardens and land adjacent to housing. Some houses have been flooded and the sewerage collection system inundated. This is in line with model results, which shows flooding from the Blackrock River at all modelled fluvial dominated AEP events (Figure 4.7.80). The article also mentions the Mullagharlin Stream, although this has not been included in the model.

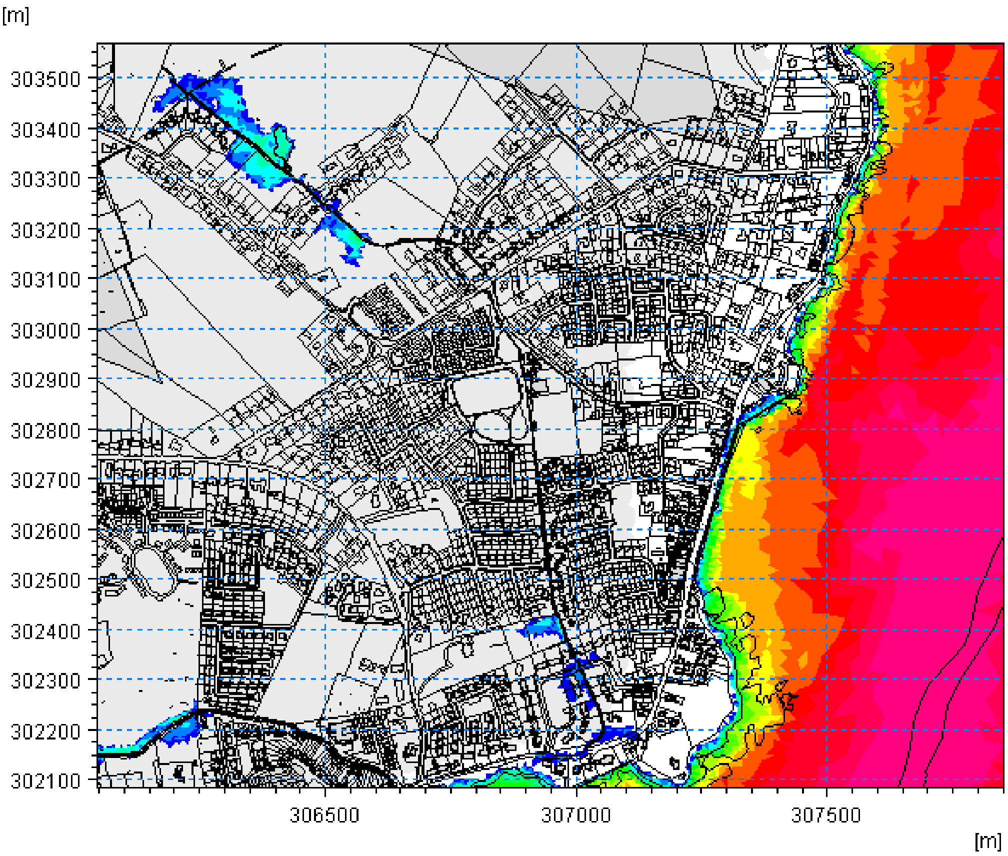


Figure 4.7.80: Modelled flooding of Blackrock River at the Fluvial 1%AEP Event

The Rock Court Residents' Association have expressed concern over the flooding from a small river flowing through part of Rock Court, as sourced from www.floodmaps.ie. Following heavy rain, flooding occurred in a number of residents' gardens adjacent to where the river crosses under the Southend Road en route to the sea. Part of the Southend Road was also flooded. The model does not show any flooding of the Southend Road, although this concern dates back to 2001, so it is considered that remedial action may have been undertaken as requested. The model results do show flooding in the general area from as low as the 50% AEP fluvial event.

During the CFRAM Study, as part of the flood event response, information on a flood event which occurred on 3rd January 2014 was captured. The event resulted in flooding of the Dundalk Port Inner Relief Road (N52) from Helens Road to Quay Street, as shown in Figure 4.7.81.

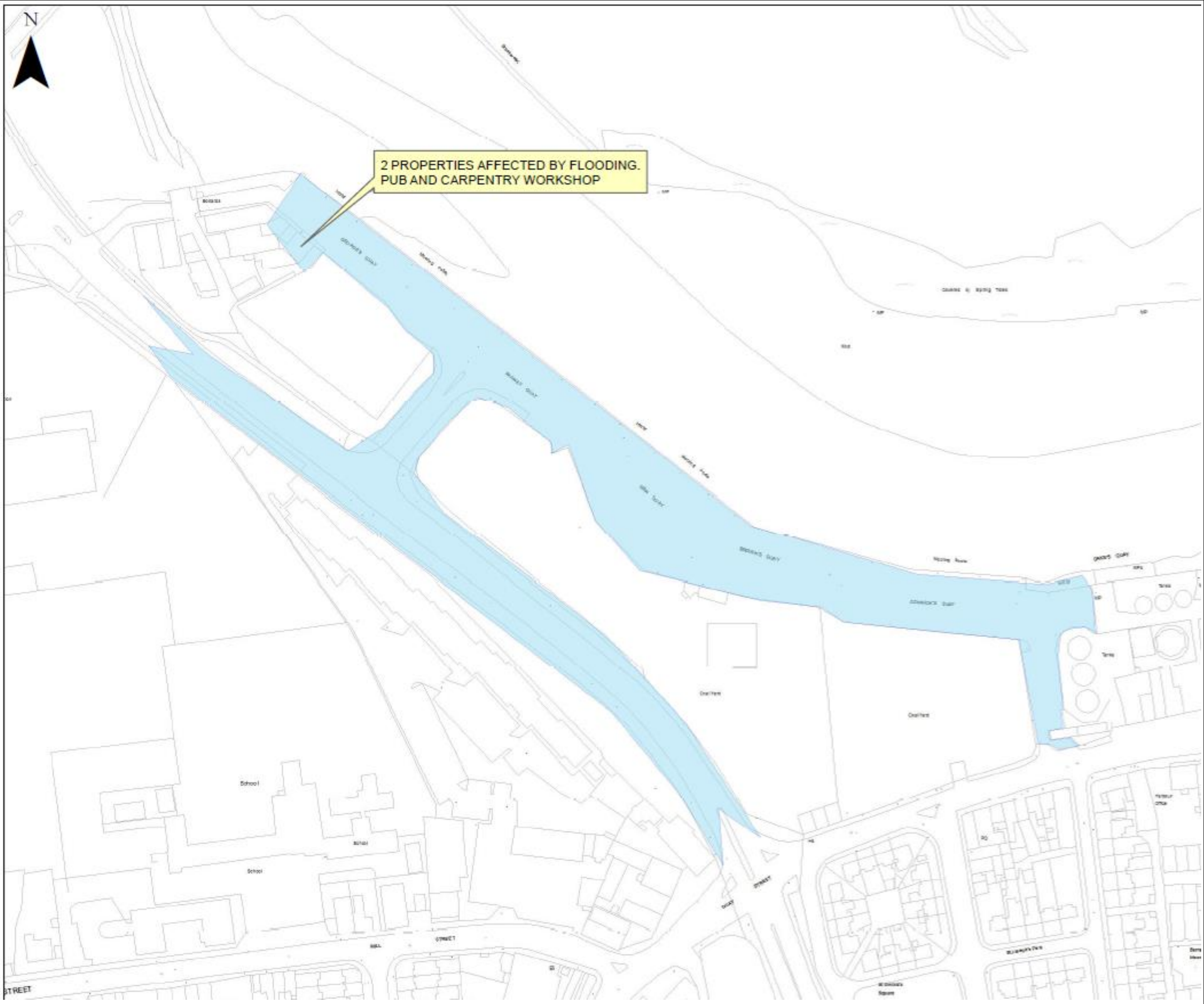


Figure 4.7.81: Flooding at Dundalk Port Inner Relief Road - January 2014

The flooding was noted to be as a result of high tides, overtopping, low air pressue and wind direction and a peak flood level of 3.45m OD Malin was recorded at Georges Quay. This equates to an AEP of circa 5-2%. This is in line with modelled results, which shows flooding of a similar area from the 10% AEP, with more exensive flooding at the more extreme AEPs. Flooding of Dundalk Port occurs at all modelled coastal AEPs. (Refer to Figure 4.7.82 and Figure 4.7.83).

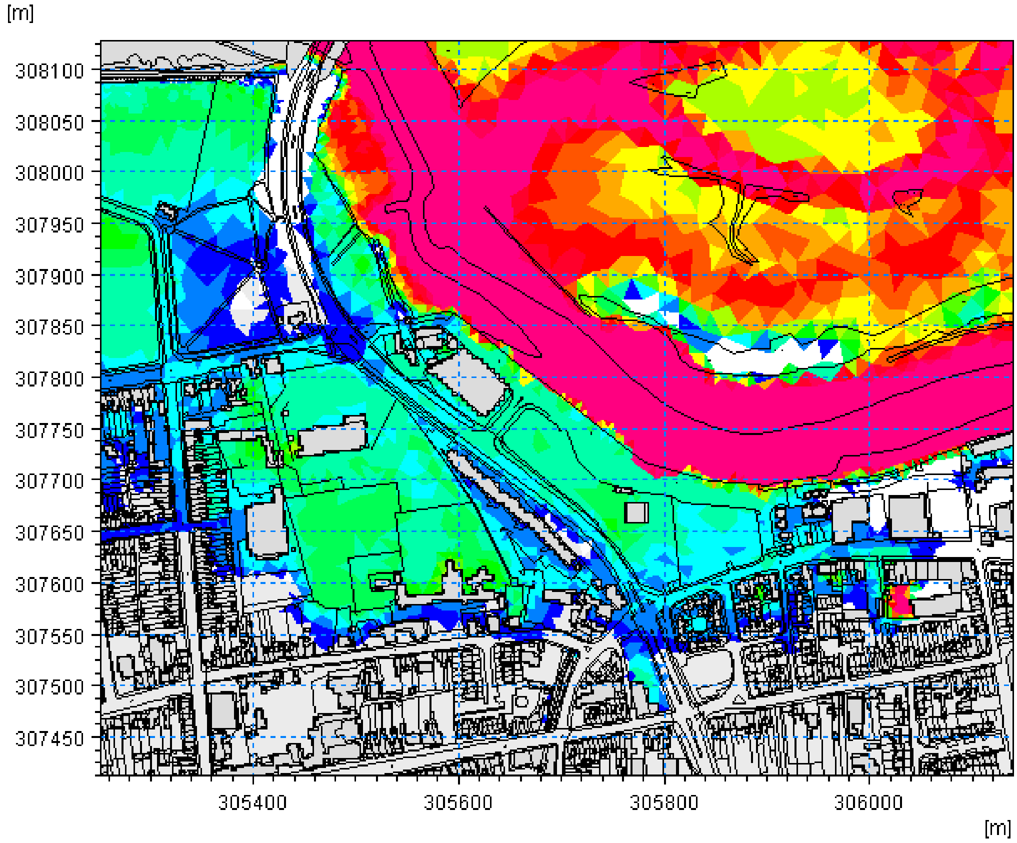


Figure 4.7.82: Modelled flooding of Dundalk Port at the Coastal 0.5% AEP Event

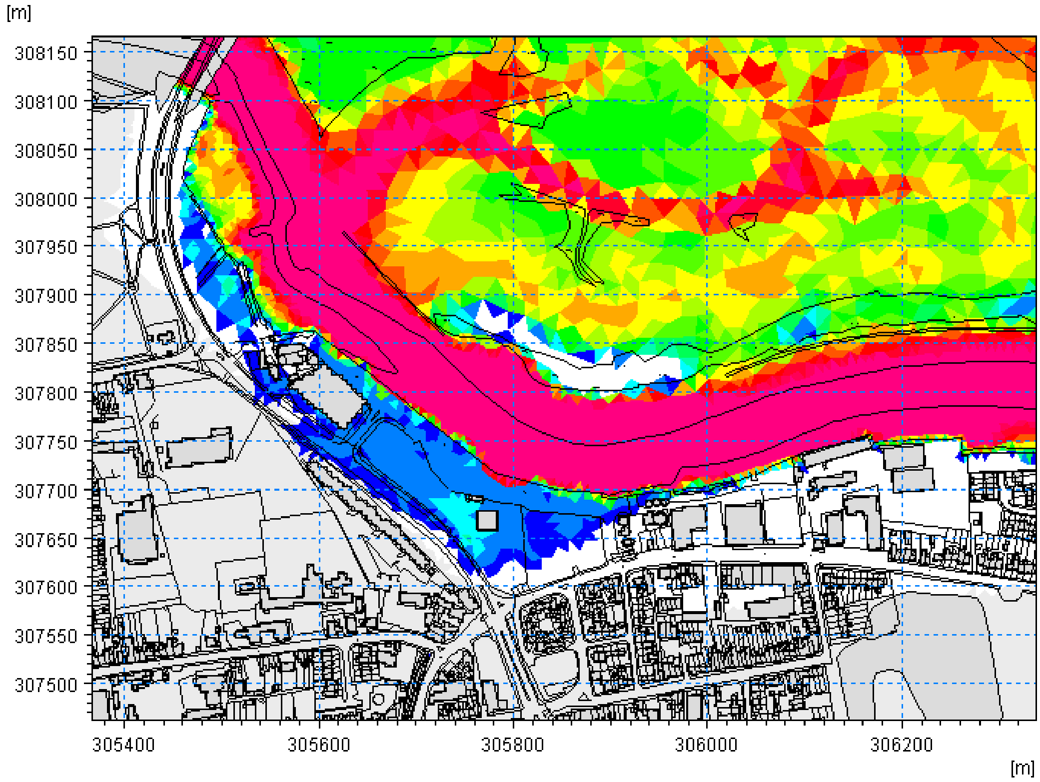


Figure 4.7.83: Modelled flooding of Dundalk Port at the Coastal 10% AEP Event

Flooding was also recorded at Blackrock during the Flood Event Response, as shown in Figure 4.7.84. Main

Street was flooded due to high tides and wave overtopping due to large wave heights. The seawall was overtopped causing flooding of the adjacent street and shops. A maximum flood level of 3.219m OD Malin was recorded. As discussed previously, Main Street in Blackrock floods at all modelled coastal AEP events. (Refer to Figure 4.7.85).

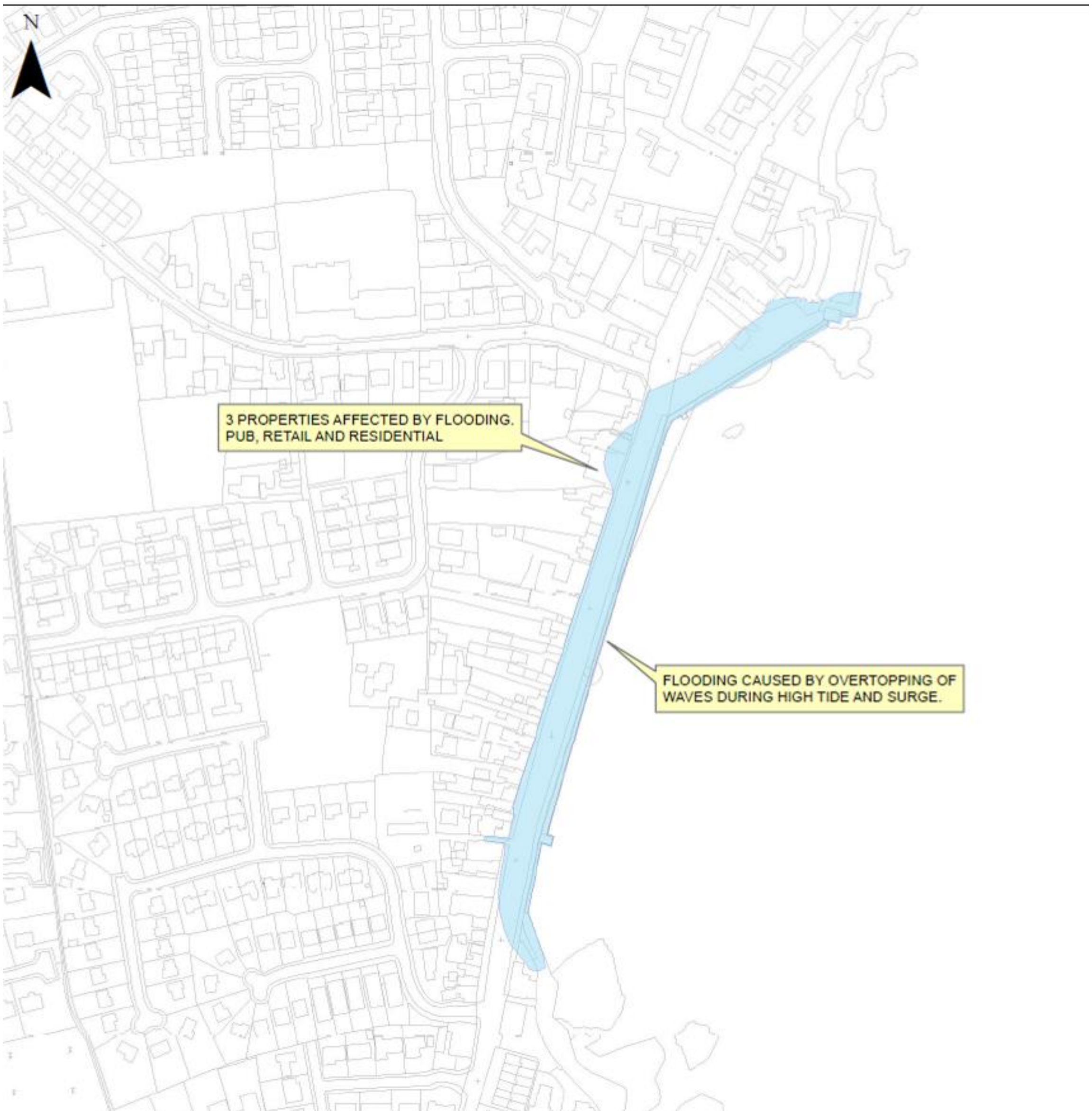


Figure 4.7.84: Flooding at Blackrock- January 2014

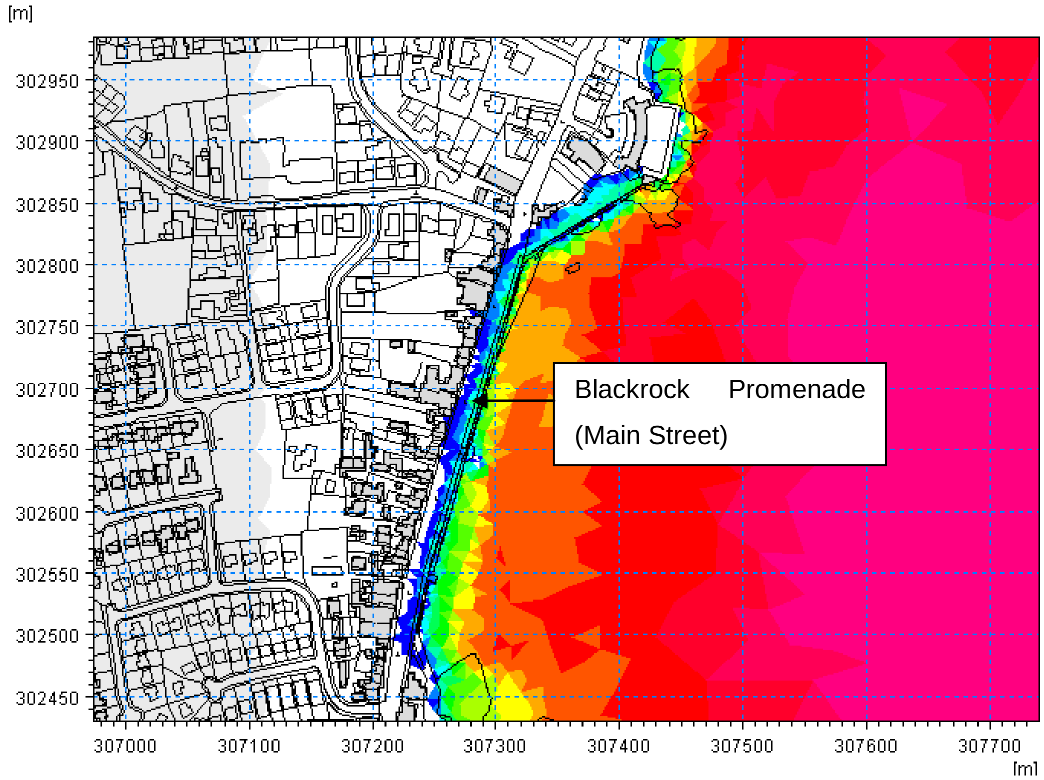


Figure 4.7.85: Modelled flooding at Blackrock Promenade at the Coastal 0.5%AEP Event

In January 2014, photographs were captured of some of the extensive flooding at Dundalk Port and Blackrock Main Street as shown in Figure 4.7.86 and Figure 4.7.87. As discussed previously, this is in line with modelling results.

Figure 4.7.86: Flooding of Blackrock Main Street in January 2014

Figure 4.7.87: Flooding of Dundalk Port in January 2014

4.7.6 Hydraulic Model Assumptions, Limitations and Handover Notes

(1) Hydraulic Model Assumptions:
(a) Delayed input hydrographs so that fluvial peak corresponds roughly with surge peak at worst fluvial flooding location. (b) The in-channel roughness coefficients were selected based on normal bounds and are considered representative of channel roughness in photographs taken during the study survey. (c) Eddy viscosity map produced over the area based on equation $k*x^2/t$, where k=0.02 (d) The coastal boundary total water level is based on tide levels at Dunany Point and Soldiers Point and ICPSS point NE26. (e) The model was simulated using drying, flooding and wetting depths of 0.005m, 0.05m and 0.1m respectively. However, in order to remain consistent with rectangular mesh models, all flooding below 20mm depth was discarded from the mapping. (f) Coastal bathymetry was adjusted as necessary, where data was limited, to ensure representative flows and levels within the model domain. Care was taken to ensure the deep channels within the bay were adequately represented, making use of available Infomar data. (g) On the Kilcurry River Tributary 2, the culvert 0627B00001I was assumed to have a pipe diameter of 0.9m, in line with other culverts on the same reach. Survey data was limited for this structure, with only the length available. Surveyors were unable to gather more information, as the culvert inlet and outlet were flooded, thus they were unable to see the pipe diameter. (h) On the Fairhill, the culverts 0619M00206I and 0619M00144I had assumed levels for the overtopping weirs, due to insufficient survey information. Deck levels could not be measured in both cases, due to the presence of the railway line. Available bank level information provided in AutoCAD was manipulated to determine an appropriate deck level, ensuring consistency with other structures on the same watercourse. (i) On the Fairhill River, culvert 0617A00053I was assumed to be 350m long running through the Brewery Business Park, based on aerial imagery and vector mapping. Information on the downstream face of the culvert was unable to be obtained, as it was inaccessible. The culvert is located in a swamp and surveyors determined it unsafe to survey. (j) On the Kilcurry River, the bridge structure at Chainage 520 was removed from the Network file and modelled as an open section in the cross section file, assuming that the height of the soffit level means it will never be reached by the flow. The bridge abutments are represented in the cross section file, with Manning's values adjusted to represent the smoother finish of the channel sides. There are no additional piers within the channel itself.
(2) Hydraulic Model Limitations and Parameters:
(a) An overall timestep of 2 seconds has been selected for all model scenarios. The MIKE 21 model component is capable of dynamic timesteps in the range of 0.01-2 seconds. (b) The delta factor is set to 0.65. (c) The Inter1Max factor is set to 85.

(d) Due to the scale and complexity of the model, model stability was difficult to achieve. However the exponential smoothing factor of a number of links in MIKE FLOOD was adjusted to 0.8/0.5, or 0.2 in particularly difficult areas. The depth tolerance was also increased to 0.3m in complex areas, achieving model stability. (e) A maximum cell size of $20m^2$ was used for all land adjacent to HPWs. (f) No available survey information was available with details on the chambers located downstream of Ladywell Bridge on the Dundalk (Ramparts) River, which are known to regulate the flow in this area. As such, information was extracted from the report by Tobin Consulting Engineers (Refer to Section 4.7.2), indicating that all the flow from the Dundalk River should be redirected down the Marshes Lower River, with the Dundalk Blackwater being treated as an entirely separate watercourse, with a nominal point inflow. (g) On the Castletown, the culvert 0625M00221I was shortened from 60m to 54m in order to aid model stability, due to the close proximity of two weirs. (h) On the Marshes Lower River, bridge 0622M00081D was removed due to the close proximity to 0622M00082D (less than metres apart). Due to limitations of the software, often two structures cannot be located this close together in a model whilst maintaining stability. Therefore, as a standard approach, the structure which will cause most constriction to the flow was kept in the model, with the lesser impacting structure removed. In theory, as these structures are close together, the resultant flow downstream of the structures should not be greatly affected.	
Hydraulic Model Parameters:	
MIKE 11	
Timestep (seconds)	2
Wave Approximation	High Order Fully Dynamic
Delta	0.65
MIKE 21	
Timestep (seconds)	0.01-2
Drying / Flooding / Wetting depths (metres)	0.005 / 0.02 / 0.1
Eddy Viscosity (and type)	Constant eddy formulation varying in space based on equation $k*x^2/t$, where k=0.02
MIKE FLOOD	
Link Exponential Smoothing Factor (where non-default value used)	0.2-0.8
Lateral Length Depth Tolerance (m) (where non-default value used)	0.3

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

(a) Model files have been provided along with this report. For mechanism 1 coastal and fluvial flooding, M11 cross section and network files, M21 mesh, bed resistance and eddy viscosity files and MIKEFLOOD linkage information are identical for all modelled simulations. Boundary files vary for different AEPs as appropriate. For the undefended simulation, defences have been removed from the M21 steering file, mesh file and the M11 cross section file. Mechanism 2 files have also been provided.

(b) The overall flood extents in Dundalk and Blackrock are extensive and are the result of both fluvial and coastal flooding. The relative timings of the fluvial hydrographs and the coastal boundary were considered and tested in a preliminary sensitivity analysis to ensure peaks coincided at the relevant locations. This is discussed in more detail in Section 3.8.3 of this report.

(c) As discussed in IBE0700Rp0012_UoM06 Hydrology Report, joint probability was considered for Dundalk and appropriate analysis carried out. Correlation between total water levels and fluvial flow within HA06 were considered to be negligible and therefore the following simplified conservative approach was undertaken. The 50% AEP design event was maintained for one mechanism while the whole range of probabilities for the other mechanism were simulated and vice versa. Details on the joint probability procedure can be found in Section 3.8.3 of this report.

(d) As discussed in length during the calibration section of this report, Dundalk and Blackrock are subject to coastal flooding in a number of areas, the most notable of such depicted in Figure 4.7.88 to Figure 4.7.91. Coastal flooding is a recurring issue due to large areas of flat and low lying land adjacent to the sea. Marsh North, the Dundalk Quay area and surrounding streets, including Quay Street, Castle Road, Fair Green Road and George's Quay, Marsh South and the Blackrock Promenade are all subject to extensive coastal inundation.

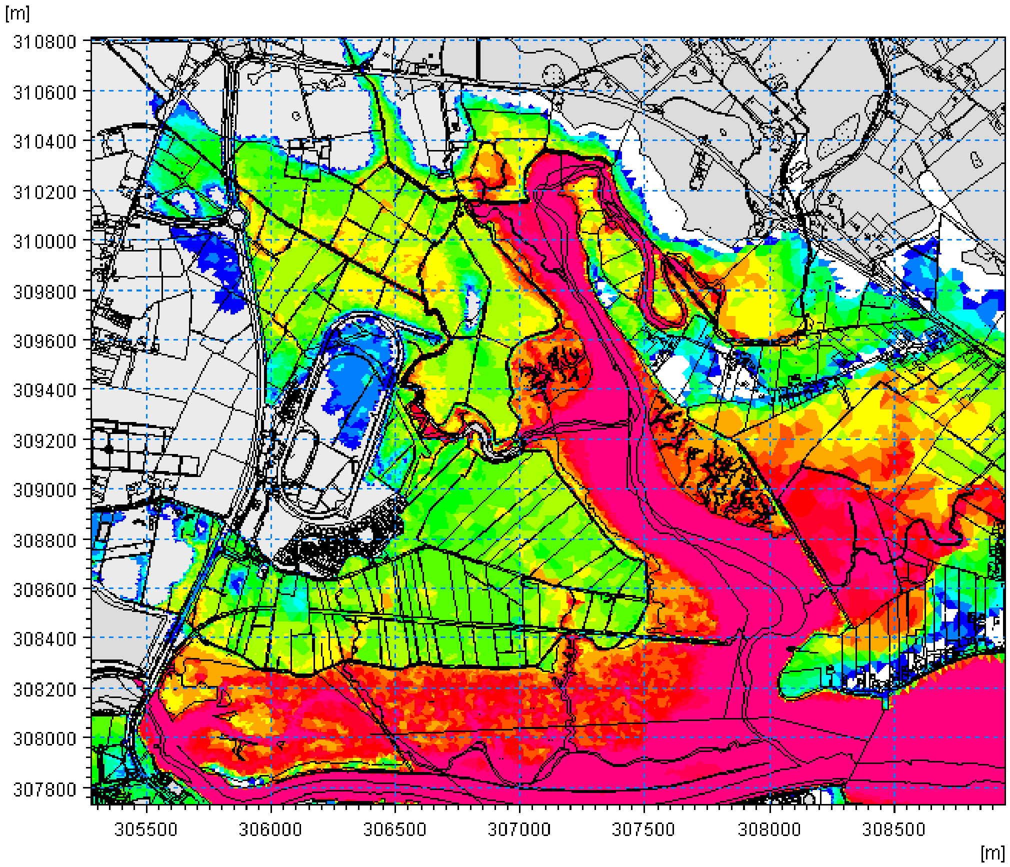


Figure 4.7.88: Modelled flooding of Marsh North at the Coastal 0.1% AEP Event

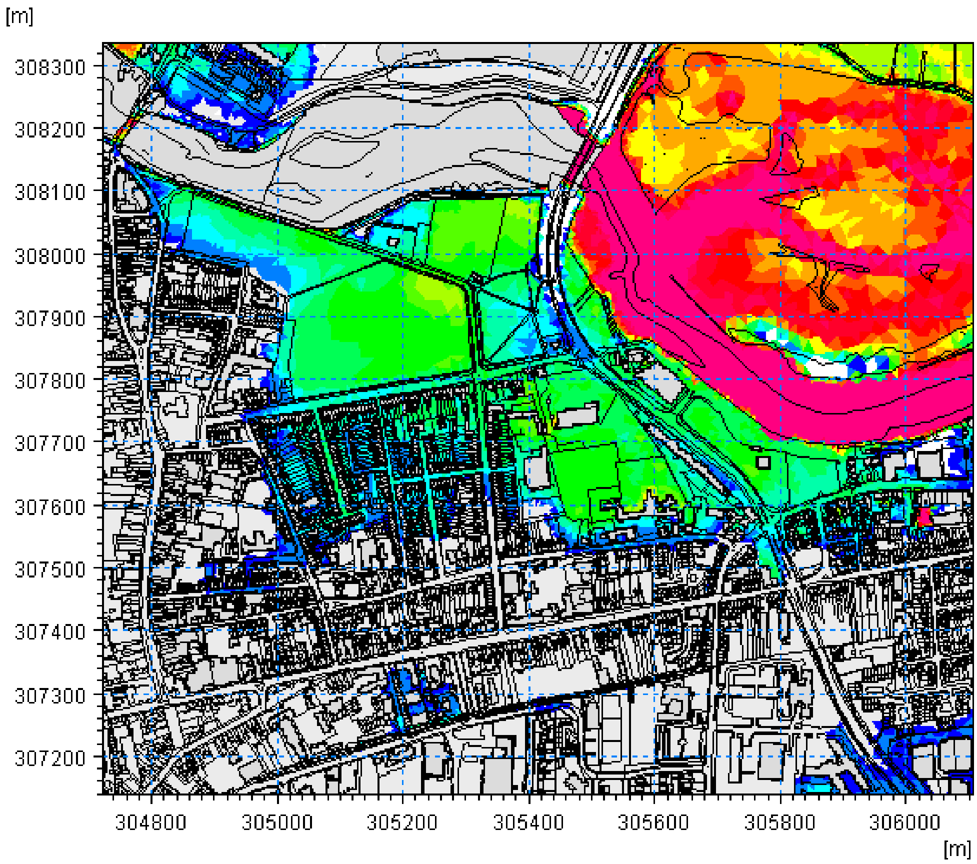


Figure 4.7.89: Modelled flooding at Dundalk Quays Area and adjacent streets at the Coastal 0.1%

AEP Event

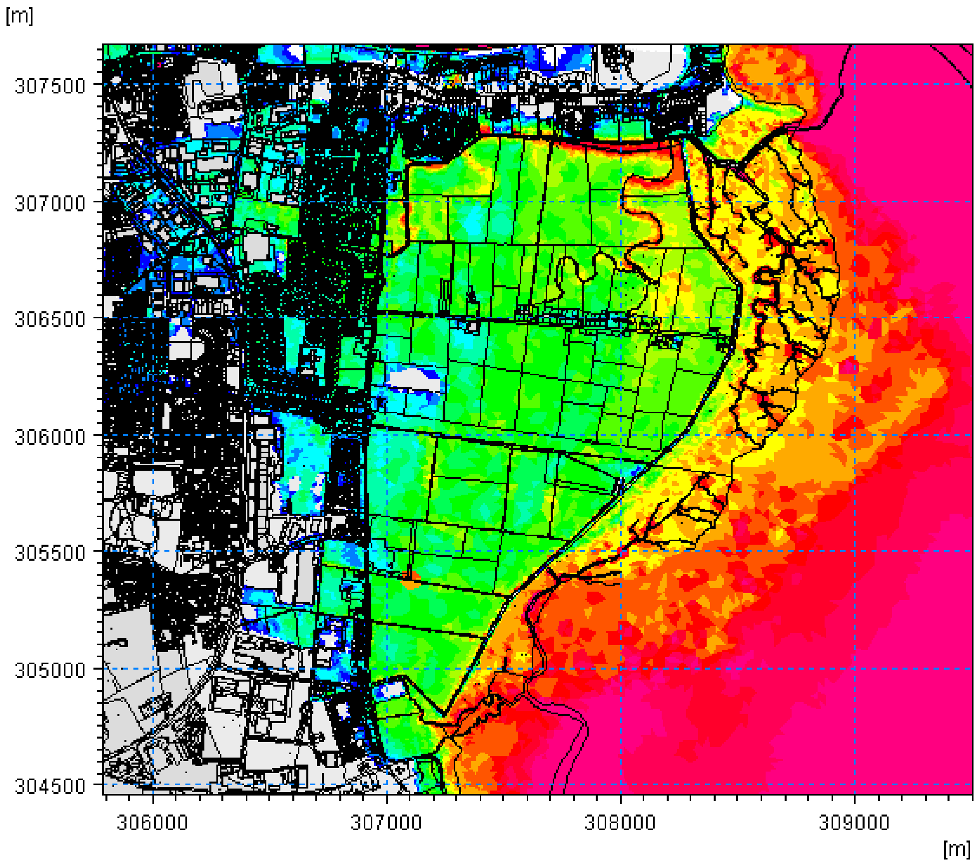


Figure 4.7.90: Modelled flooding of Marsh South at the Coastal 0.1% AEP Event

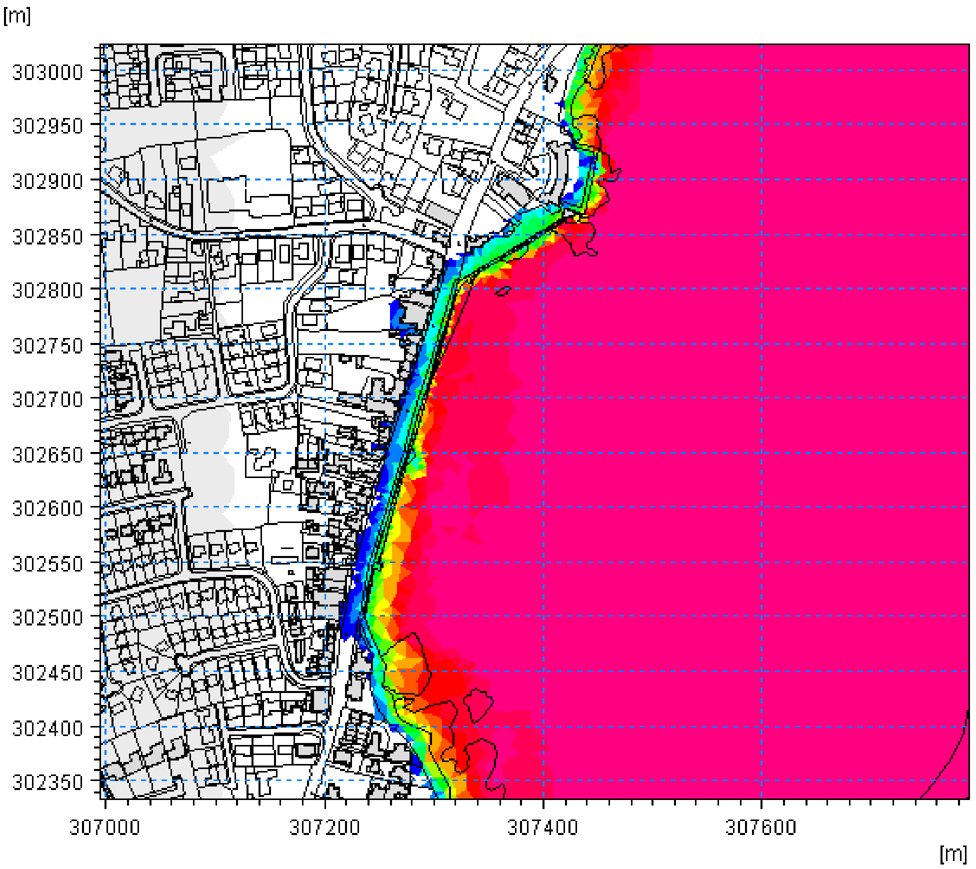


Figure 4.7.91: Modelled flooding at Blackrock Promenade at the Coastal 0.1% AEP Event

(e) The Barleyfield, Stranacarry, Sportsmans Hall and Moorland areas are predominantly subject to coastal flooding at all modelled AEP events, which is exacerbated by fluvial flooding on the Castletown River, as shown in Figure 4.7.92. Note, due to the extensive area of flat land, the small increase in water levels between AEP events and the nature of this hydrodynamic modelling, there were some minor differences in extent and depth in this area, resulting in the manual adjustment of the 0.5% AEP fluvial outputs to ensure consistency.

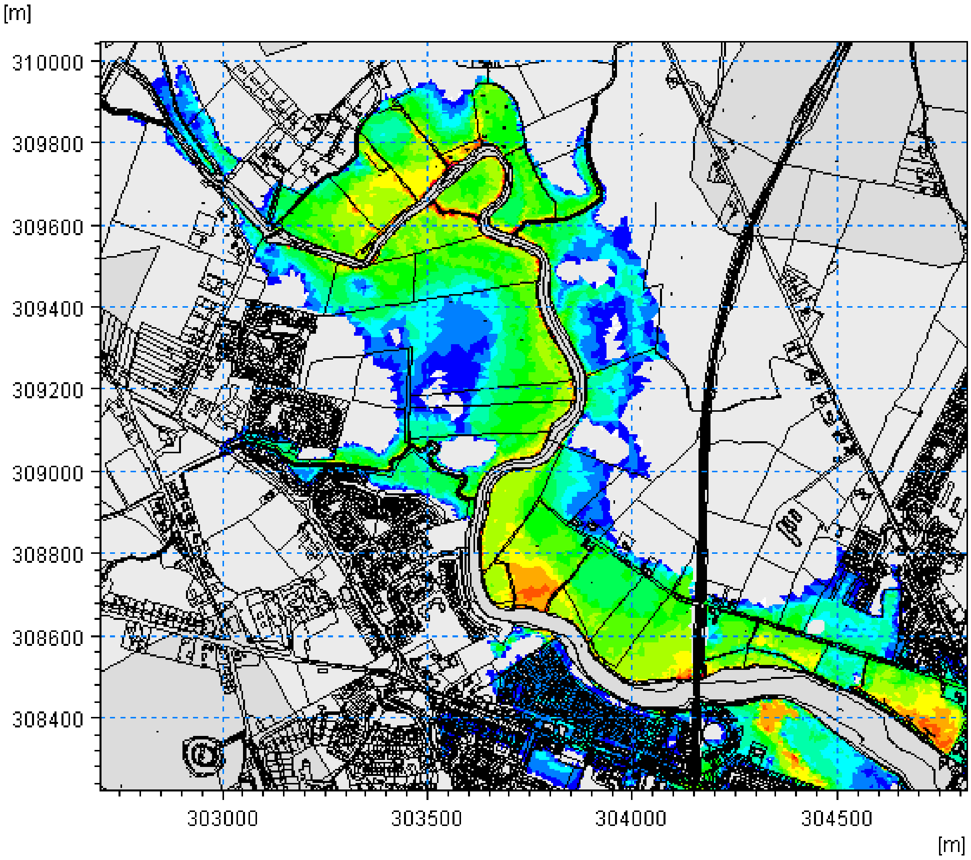


Figure 4.7.92: Modelled flooding of Castletown River at the Coastal 0.1% AEP Event

(f) Extensive fluvial flooding was shown in the model results in the Demesne area and along the Castletown Road from the 1% AEP and above. (Refer to Figure 4.7.93). Flooding occurs from the Acarreagh River mainly from Chainages 484-1289 due to low banks and insufficient culvert capacity at Chainage 683. Refer to Section 4.7.3 for more detail on the culvert, and Appendix A2 for a long section of the Acarreagh River, showing the location of this culvert.

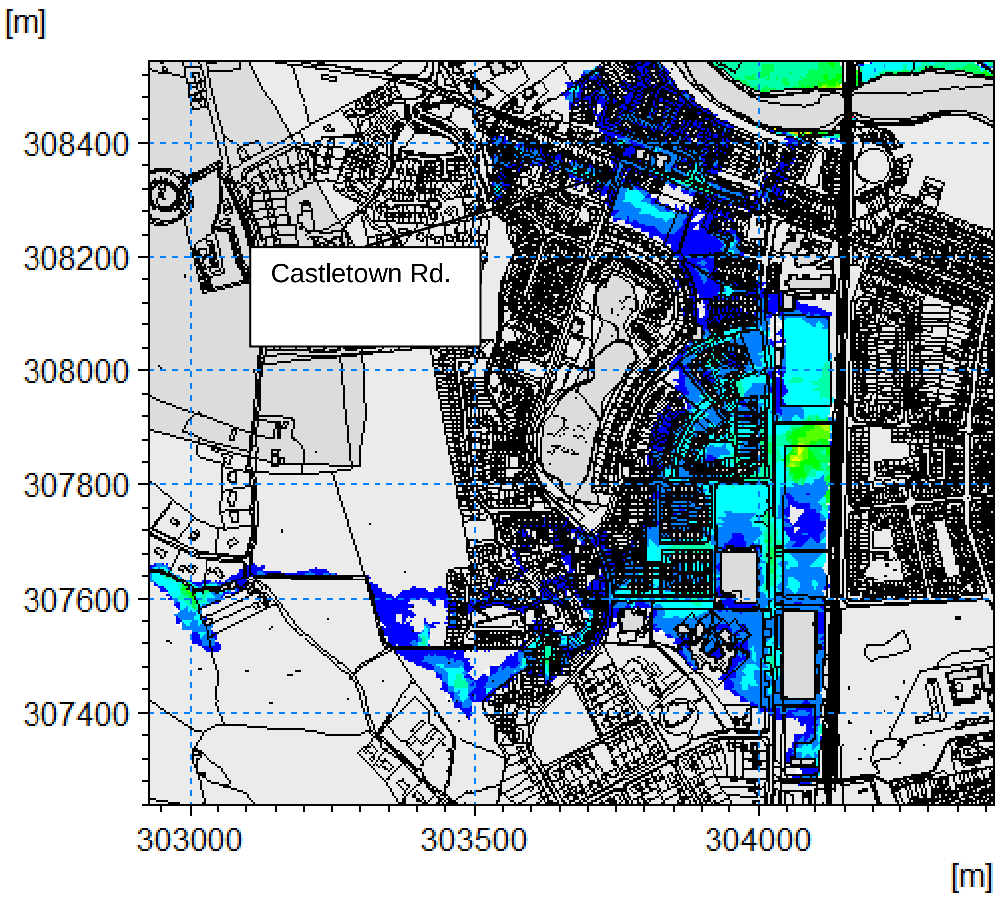


Figure 4.7.93: Modelled flooding of Acarreagh River at the Fluvial 0.1% AEP Event

(g) Extensive fluvial flooding also occurs at modelled higher return periods in the Marshes Lower and Upper areas of Dundalk, which are densely populated. (Refer to Figure 4.7.94). Flooding of this area is complex and occurs as a result of a combination of low banks and flat land on the Dundalk Blackwater River, the Dundalk River and the Marshes Lower River. Of particular note is the upstream reach of the Dundalk Blackwater, with flooding occurring due to the presence of a culvert commencing at Chainage 3629. This culvert causes significant back up of flow, which results in flow exceeding bank limit between Chainages 2923 and 3617. Refer to Section 4.7.3 for more detail on the culvert. Low lying banks between Chainage 5135 and 7208 also contribute to fluvial flooding of the area.

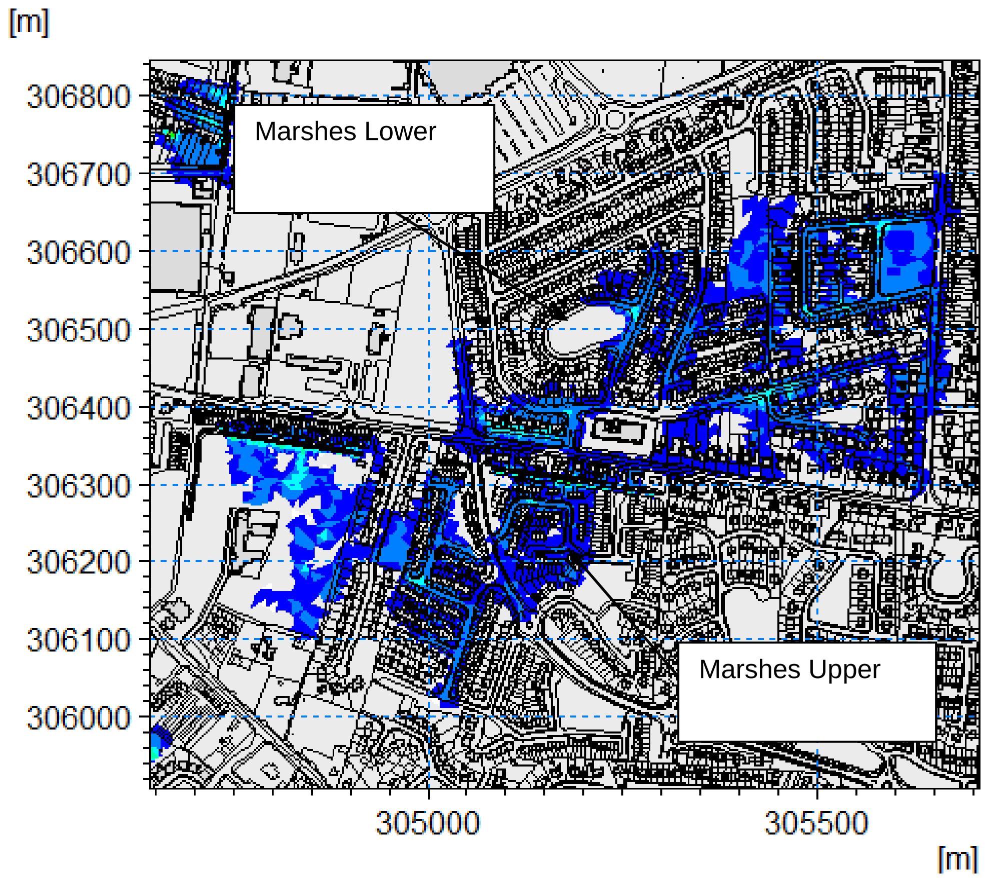


Figure 4.7.94: Modelled flooding of Marshes Upper and Lower at the Fluvial 0.1% AEP Event

(h) Significant fluvial flooding also occurs in the Cambrickville area mainly due to low lying banks on the Dundalk River and the presence of two culvert structures at Chainages 1346 and 1750. (Refer to Figure 4.7.95). However this area is not as densely populated as some of the other areas at risk. Refer to Section 4.7.3 for more detail on the culverts.

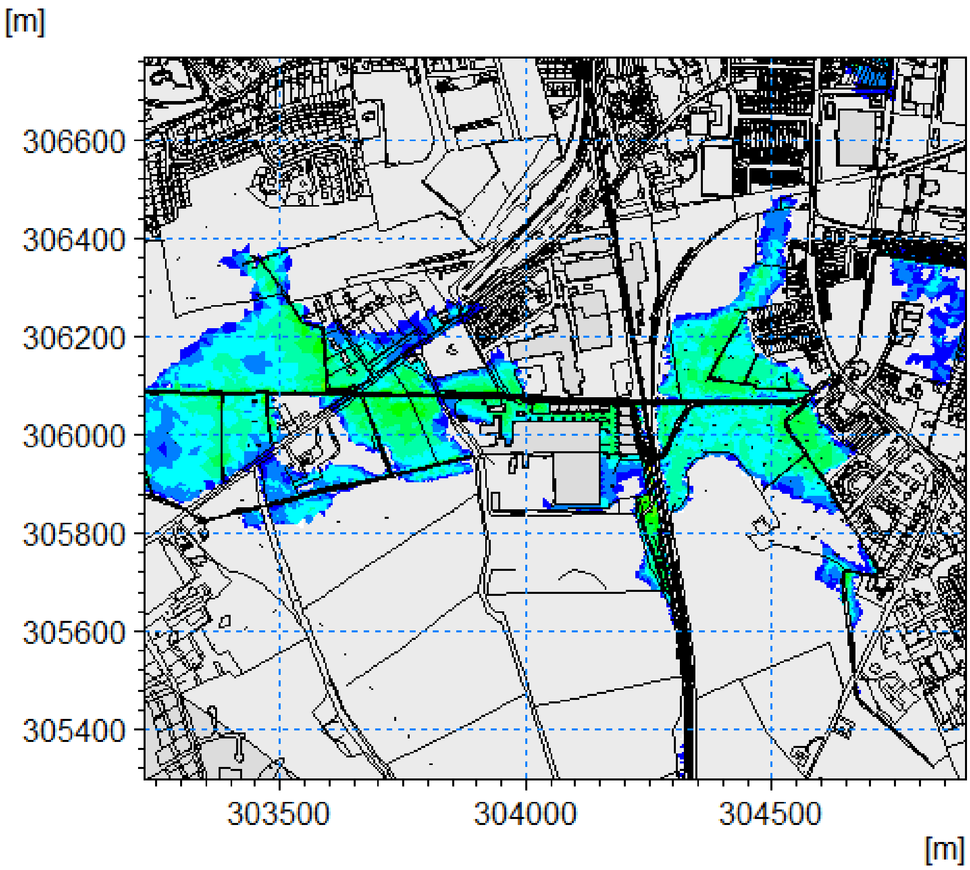


Figure 4.7.95: Modelled flooding of Cambrickville area at the Fluvial 0.1% AEP Event

(i) Further details on notable fluvial flooding within the model have been discussed in the Calibration Section of this report.

(j) Mechanism 2 flooding caused by wave overtopping was also modelled for the Dundalk/Blackrock model where appropriate. Following derivation of input discharges to the model, as discussed in Section 4.7.3, model simulations were undertaken in order to provide outlines for this flooding mechanism. As can be seen in Figure 4.7.96, Figure 4.7.97 and Figure 4.7.98, excessive inundation occurs due to overtopping at E1, E2, E3a and E3b, with a smaller but notable volume occurring at E4 from the 10% AEP and above. Main Street in Blackrock was the worst affected. A small amount of wave overtopping also occurs at E5 at all modelled AEPs.

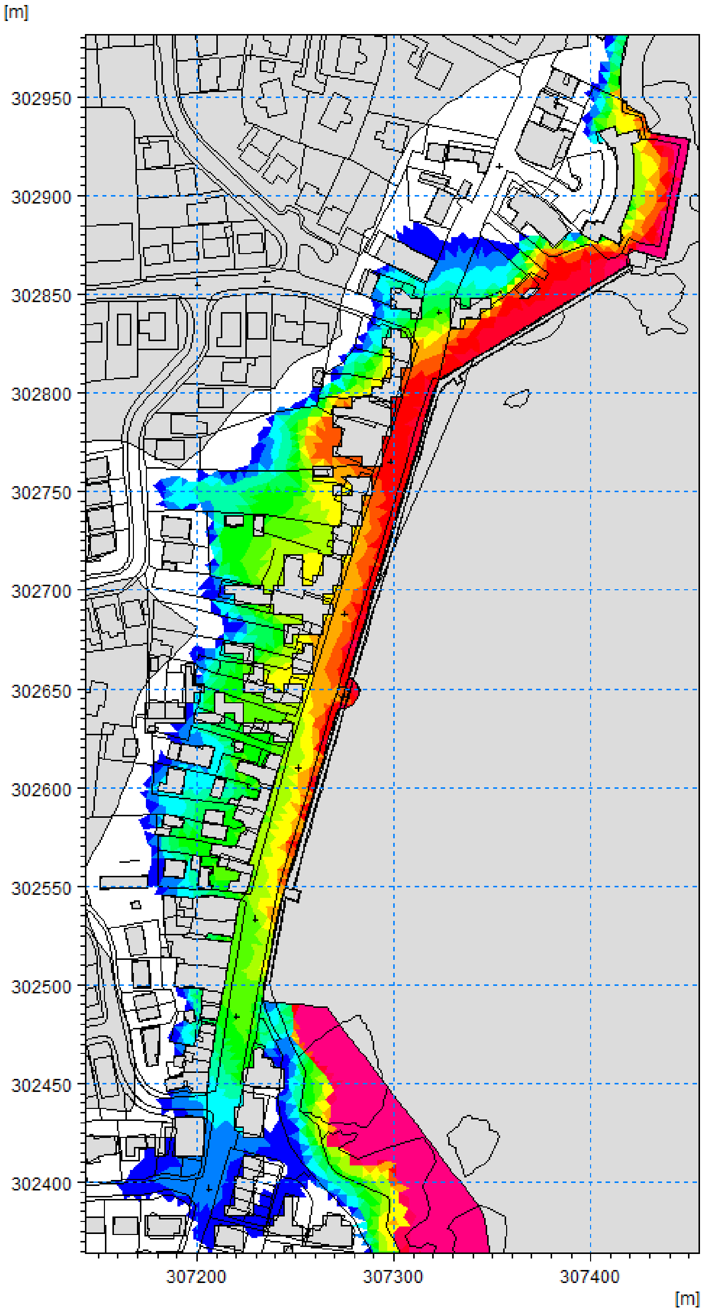


Figure 4.7.96: Mechanism 2 Flooding caused by Wave Overtopping at the 0.1% Joint Probability AEP - E1, E2, E3a, E3b

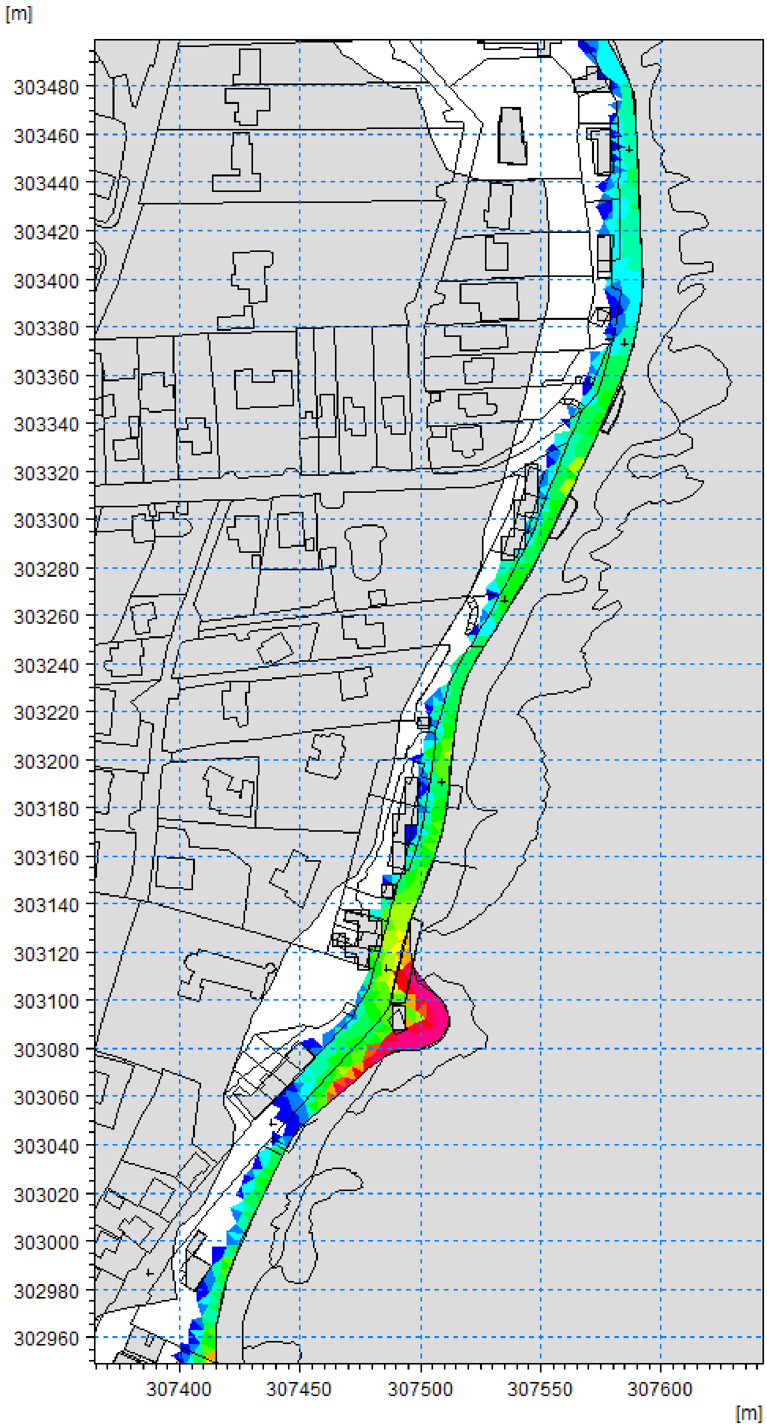


Figure 4.7.97: Mechanism 2 Flooding caused by Wave Overtopping at the 0.1% Joint Probability AEP - E4

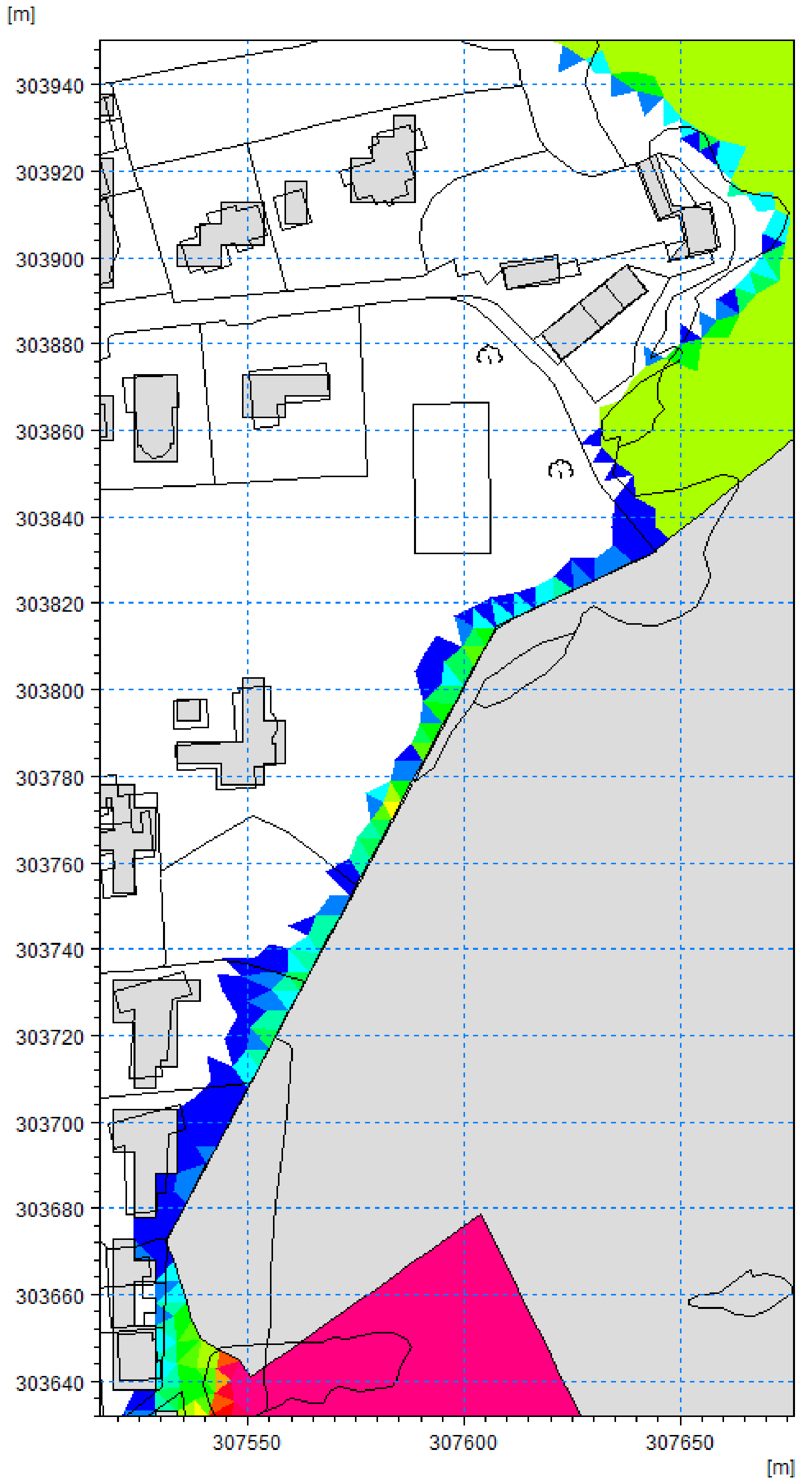


Figure 4.7.98: Mechanism 2 Flooding caused by Wave Overtopping at the 0.1% Joint Probability AEP - E5

(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:	Caroline Neill
Model Reviewed by:	Stephen Patterson
Model Approved by:	Malcolm Brian

APPENDIX A.1

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
ACARREAGH	683.18	0624M00189I	76.53	Circular	0.30	-	N/A	0.02
ACARREAGH	1055.11	0624M00148I	7.153	Circular	0.35	-	N/A	0.013
ACARREAGH	1270.00	0624M00124I	29	Circular	0.45	-	N/A	0.015
AGHABOYS	30.57	0629M00141I	11	Circular	0.90	-	N/A	0.013
AGHABOYS	123.96	0629M00131I	4.4	Rectangular	0.53	0.61	N/A	0.013
AGHABOYS	146.05	0629M00130I	5.2	Circular (x2)	1.20	-	N/A	0.013
AGHABOYS	623.06	0629M00079I	34.554	Rectangular	0.92	0.86	N/A	0.014
AGHABOYS	1378.65	0629M00001J	11.4	Circular	0.80	-	N/A	0.014
BALLYNAHATTIN	79.47	0628M00413I	11.854	Circular	0.75	-	N/A	0.014
BALLYNAHATTIN	251.20	0628M00398I	16.035	Circular	0.60	-	N/A	0.014
BALLYNAHATTIN	277.94	0628M00394I	5.8	Circular	0.45	-	N/A	0.013
BALLYNAHATTIN	316.09	0628M00390I	12.781	Circular	0.60	-	N/A	0.013
BALLYNAHATTIN	381.67	0628M00385I	12.196	Rectangular	0.39	0.84	N/A	0.013
BALLYNAHATTIN	408.62	0628M00383I	10.996	Irregular	0.22	0.39	N/A	0.013
BALLYNAHATTIN	431.66	0628M00380I	16.4	Circular (x2)	0.60	-	N/A	0.013
BALLYNAHATTIN	912.40	0628M00331I	88.969	Arch	1.43	1.67	0.9	0.013
BALLYNAHATTIN	1138.83	0628M00304J	96.2	Rectangular	1.56	2.79	N/A	0.012
BALLYNAHATTIN	1633.95	0628M00257E	16	Arch	1.82	2.02	1.02	0.013
BALLYNAHATTIN	1989.02	0628M00226I	55.921	Circular	2.00	-	N/A	0.013
BALLYNAHATTIN	4094.56	0628M00009I	17.944	Circular (x2)	1.20	-	N/A	0.013

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**
BLACKROCK	400.45	0616A00156I	5.828	Circular	0.45	-	N/A	0.014
BLACKROCK	552.41	0616A00140I	7.48	Circular	0.45	-	N/A	0.014
BLACKROCK	785.02	0616A00119I	33.635	Circular	1.20	-	N/A	0.013
BLACKROCK	859.03	0616A00113I	79.29	Rectangular	0.39	1.14	N/A	0.014
BLACKROCK	923.42	0616A00104I	12.43	Irregular	0.65	1.09	0.53	0.014
BLACKROCK	978.08	0616A00098D	2.59	Rectangular	0.94	1.31	N/A	0.013
BLACKROCK	1072.16	0616A00090D	2.497	Rectangular	0.79	1.36	N/A	0.012
BLACKROCK	1630.38	0616A00033I	10.07	Circular (x2)	0.60	-	N/A	0.014
BLACKROCK	1849.83	0616A00014I	71.128	Circular	0.60	-	N/A	0.014
CAMBRICKVILLE TRIB 1	93.42	0617B00008D	3	Rectangular	0.56	3.00	N/A	0.015
CASTLETOWN	24.56	0625M00252I	6.085	Circular	1.20	-	N/A	0.014
CASTLETOWN	106.24	0625M00243I	5.23	Circular	1.00	-	N/A	0.013
CASTLETOWN	306.78	0625M00228D	4.361	Rectangular	0.57	4.20	N/A	0.02
CASTLETOWN	358.12	0625M00221I	52.766	Rectangular (x2)	1.41, 1.47	2.87, 2.85	N/A	0.017
CASTLETOWN	428.80	0625M00211I	5.683	Circular	1.00	-	N/A	0.014
CASTLETOWN	651.11	0625M00189D	1.968	Rectangular	0.63	1.15	N/A	0.017
CASTLETOWN	671.70	0625M00187D	4.69	Rectangular (x2)	0.61, 0.54	0.41, 0.66	N/A	0.017
CASTLETOWN	714.58	0625M00179J	28.722	Irregular	0.55	1.09	0.54	0.017
CASTLETOWN	758.50	0625M00178I	30.338	Rectangular	0.58	1.35	N/A	0.013
CASTLETOWN	857.84	0625M00169D	8.211	Arch	0.70	0.98	0.51	0.013
CASTLETOWN	1050.11	0625M00150I	13.763	Irregular	1.04	1.31	0.76	0.02
CASTLETOWN	1440.56	0625M00110D	4.631	Rectangular	0.60	2.11	N/A	0.017

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
CASTLETOWN	1479.71	0625M00109I	61.115	Circular (x5)	0.45	-	N/A	0.015
CASTLETOWN	1693.20	0625M00085I	15.325	Circular (x2)	0.65	-	N/A	0.015
CASTLETOWN	1811.73	0625M00073I	10.846	Arch	0.84	1.45	0.59	0.015
CASTLETOWN	2517.23	0625M00002D	5.201	Rectangular (x2)	1.15, 0.90	1.15, 0.57	N/A	0.017
CASTLETOWN_RIVER	412.81	0623M00518D	3.65	Arch	2.55	6.23	1.47	0.02
CASTLETOWN_RIVER	579.09	0623M00502D	36.006	Rectangular	8.56	20.17	N/A	0.02
CASTLETOWN_RIVER	997.18	0623M00460D	7.463	Arch (x4)	2.24, 2.70, 2.69, 2.34	5.16, 5.86, 5.85, 4.71	1.28, 1.78, 1.58, 1.52	0.017
CASTLETOWN_RIVER	3812.38	0623M00179D	11.29	Arch (x4)	5.19, 5.16, 5.04, 5.35	9.09, 9.20, 9.11, 9.12	3.24, 3.26, 3.05, 3.27	0.015
CASTLETOWN_RIVER	4505.73	0623M00109D	10.75	Arch (x3)	4.28, 4.90, 4.07	11.46, 12.78, 12.07	2.50, 2.78, 1.83	0.019
CASTLETOWN_RIVER	5269.90	0623M00033D	15.04	Rectangular (x3)	3.69, 5.07, 3.37	26.59, 34.09, 26.82	N/A	0.02
DONAGHMORE	1763.46	0621M00056I	32	Irregular	0.94	1.10	0.59	0.017
DONAGHMORE	1857.59	0621M00047I	7.893	Circular	0.75	-	N/A	0.017
DONAGHMORE	2112.66	0621M00022D	9	Arch	7.34	6.50	4.25	0.017
DUNDALK	78.85	0617M00778I	7.4	Circular (x2)	0.80	-	N/A	0.013
DUNDALK	182.22	0617M00767D	4.2	Circular (x3)	0.50	-	N/A	0.013
DUNDALK	523.55	0617M00729J	72	Rectangular	1.35	2.80	N/A	0.013
DUNDALK	1308.26	0617M00655I	4.6	Circular	1.00	-	N/A	0.013
DUNDALK	1346.14	0617M00651I	4.4	Circular	0.90	-	N/A	0.013
DUNDALK	1750.48	0617M00610I	9.3	Rectangular	0.57	0.63	N/A	0.013
DUNDALK	1852.48	0617M00598D	3.8	Rectangular	1.07	3.17	N/A	0.013

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**
DUNDALK	1934.24	0617M00592I	9.3	Arch	1.46	1.25	1.35	0.013
DUNDALK	2074.24	0617M00578I	21.14	Rectangular	1.15	6.96	N/A	0.013
DUNDALK	2358.33	0617M00550I	24.23	Rectangular	1.25	5.01	N/A	0.013
DUNDALK_BLACKWATER	3321.80	0617M00461I	167.119	Rectangular & Circular	0.66, 0.45	0.88	N/A	0.013
DUNDALK_BLACKWATER	3476.48	0617M00438I_1	10	Circular	0.45	-	N/A	0.013
DUNDALK_BLACKWATER	3476.48	0617M00438I_2	10	Circular	0.45	-	N/A	0.013
DUNDALK_BLACKWATER	3476.48	0617M00438I_3	10	Circular	0.45	-	N/A	0.013
DUNDALK_BLACKWATER	4595.68	0617M00326I_1	12.7	Circular	1.20	-	N/A	0.013
DUNDALK_BLACKWATER	4595.68	0617M00326I_2	12.7	Circular	1.20	-	N/A	0.013
DUNDALK_BLACKWATER	4595.68	0617M00326I_3	12.7	Circular	1.20	-	N/A	0.013
DUNDALK_BLACKWATER	4816.68	0617M00304I_1	29	Circular	1.20	-	N/A	0.012
DUNDALK_BLACKWATER	4816.68	0617M00304I_2	29	Circular	1.20	-	N/A	0.012
DUNDALK_BLACKWATER	4816.68	0617M00304I_3	29	Circular	1.20	-	N/A	0.012
DUNDALK_BLACKWATER	4844.82	0617M00300J	8	Rectangular	1.22	3.53	N/A	0.015
DUNDALK_BLACKWATER	4880.48	0617M00297I	8.3	Rectangular	1.23	3.58	N/A	0.015
DUNDALK_BLACKWATER	4898.01	0617M00296I	12	Circular (x3)	1.20	-	N/A	0.013
DUNDALK_BLACKWATER	5012.87	0617M00290I_1	112.5	Circular	1.20	-	N/A	0.013
DUNDALK_BLACKWATER	5012.87	0617M00290I_2	112.5	Circular	1.20	-	N/A	0.013
DUNDALK_BLACKWATER	5552.59	0617M00231I	17.5	Circular (x3)	0.90	-	N/A	0.013
DUNDALK_BLACKWATER	5893.52	0617M00195E	7.5	Arch	1.55	2.32	1.23	0.013
DUNDALK_BLACKWATER	5997.34	0617M00186I_1	4	Circular	1.20	-	N/A	0.013
DUNDALK_BLACKWATER	5997.34	0617M00186I_2	4	Circular	1.20	-	N/A	0.013

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**
DUNDALK_BLACKWATER	5997.34	0617M00186I_3	4	Circular	1.20	-	N/A	0.013
DUNDALK_BLACKWATER	6622.27	0617M00123D	5.2	Arch	1.85	2.17	1.12	0.015
DUNDALK_BLACKWATER	7248.72	0617M00060I	6	Arch	2.34	2.56	2.09	0.015
FAIRHILL	194.85	0619M00206I	28.5	Rectangular	0.86	0.60	N/A	0.013
FAIRHILL	215.92	0619M00202I	6.5	Circular	0.30	-	N/A	0.013
FAIRHILL	723.21	0619M00152I	5.1	Circular	0.20	-	N/A	0.035
FAIRHILL	813.84	0619M00144I	24.18	Arch	1.22	1.00	0.83	0.017
FAIRHILL	878.59	0619M00137I	12.7	Circular	0.60	-	N/A	0.02
FAIRHILL	1116.47	0619M00113I	8.2	Circular	0.90	-	N/A	0.017
FAIRHILL	1606.47	0619M00065I	12	Circular	0.80	-	N/A	0.017
FAIRHILL	1697.02	0619M00059I	27	Circular	0.60	-	N/A	0.017
FAIRHILL RIVER	423.11	0617A00112D	24	Irregular	0.88	1.31	N/A	0.015
FAIRHILL RIVER	493.93	0617A00098I	59	Circular	1.20	-	N/A	0.015
FAIRHILL RIVER	587.07	0617A00095D	15	Rectangular	0.93	2.26	N/A	0.015
FAIRHILL RIVER	1393.59	0617A00014I	17.92	Irregular	0.87	1.94	N/A	0.015
GREEN GATES	545.36	0616M00151I	7.9	Circular	1.20	-	N/A	0.013
GREEN GATES	653.66	0616M00141I	22.15	Irregular	0.88	1.51	0.79	0.014
GREEN GATES	771.25	0616M00128I	4.2	Circular	0.45	-	N/A	0.015
GREEN GATES	1076.89	0616M00098I	7.85	Circular	0.60	-	N/A	0.013
GREEN GATES	1345.85	0616M00073J	33.25	Circular	1.20	-	N/A	0.017
GREEN GATES	2061.06	0616M00002J	14.76	Arch	1.14	1.52	0.68	0.014
KILALLY	532.30	0620M00038I	10.7	Circular	0.50	-	N/A	0.015

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
KILCURRY RIVER TRIBUTARY 2	141.22	0627B00018I	15	Circular	0.90	-	N/A	0.013
KILCURRY RIVER TRIBUTARY 2	187.65	0627B00016I	56	Circular	0.90	-	N/A	0.013
KILCURRY RIVER TRIBUTARY 2	296.79	0627B00001I	3.2	Rectangular	0.87	1.88	N/A	0.013
KILCURRY_RIVER	25.13	0627M00073D	2.9	Rectangular (x2)	2.57, 2.50	6.01, 6.17	N/A	0.02
MARSHES LOWER	567.01	0622M00164D	3.5	Rectangular	0.85	3.76	N/A	0.013
MARSHES LOWER	599.58	0622M00161D	11	Circular (x5)	0.60	-	N/A	0.013
MARSHES LOWER	716.21	0622M00149I_1	15.3	Circular	0.60	-	N/A	0.013
MARSHES LOWER	716.21	0622M00149I_2	15.3	Circular	0.60	-	N/A	0.013
MARSHES LOWER	716.21	0622M00149I_3	15.3	Circular	0.60	-	N/A	0.013
MARSHES LOWER	716.21	0622M00149I_4	15.3	Circular	0.60	-	N/A	0.013
MARSHES LOWER	716.21	0622M00149I_5	15.3	Circular	0.60	-	N/A	0.013
MARSHES LOWER	769.68	0622M00144I_1	7.79	Circular	0.60	-	N/A	0.013
MARSHES LOWER	769.68	0622M00144I_2	7.79	Circular	0.60	-	N/A	0.013
MARSHES LOWER	769.68	0622M00144I_3	7.79	Circular	0.60	-	N/A	0.013
MARSHES LOWER	769.68	0622M00144I_4	7.79	Circular	0.60	-	N/A	0.013
MARSHES LOWER	769.68	0622M00144I_5	7.79	Circular	0.60	-	N/A	0.013
MARSHES LOWER	813.40	0622M00139D	3.7	Rectangular	0.97	5.77	N/A	0.013
MARSHES LOWER	834.29	0622M00137D	5.9	Rectangular	0.67	5.17	N/A	0.013
MARSHES LOWER	1138.80	0622M00108D	1	Rectangular	1.04	5.35	N/A	0.018
MARSHES LOWER	1149.85	0622M00106D	1	Rectangular	1.02	5.47	N/A	0.018

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**
MARSHES LOWER	1178.64	0622M00103D	4	Irregular	0.99	6.86	0.79	0.018
MARSHES LOWER	1211.61	0622M00101E	1.4	Rectangular	1.30	5.98	N/A	0.018
MARSHES LOWER	1247.85	0622M00096D	9.2	Irregular	0.98	5.04	0.52	0.018
MARSHES LOWER	1332.73	0622M00088D	12.7	Irregular	0.92	4.94	0.8	0.018
MARSHES LOWER	1388.00	0622M00082D	1.2	Rectangular	1.34	5.48	N/A	0.018
MARSHES LOWER	1443.64	0622M00077I	11.188	Circular (x5)	0.60	-	N/A	0.015
MARSHES LOWER	1457.62	0622M00074D	1.5	Rectangular	1.45	4.53	N/A	0.018
MARSHES LOWER	1587.52	0622M00062D	2.7	Rectangular	0.99	3.65	N/A	0.018
MARSHES LOWER	1703.72	0622M00050D	1	Rectangular	0.98	5.29	N/A	0.018
MARSHES LOWER	1903.34	0622M00029E	47.6	Circular (x3)	1.0, 0.3, 1.0	-	N/A	0.015
PRIORLAND	249.17	0618M00073I	26.161	Circular	0.90	-	N/A	0.013
STRANACARRY	489.96	0626M00084I	13.8	Circular	0.35	-	N/A	0.017
STRANACARRY	616.79	0626M00073I	13.527	Circular	1.00	-	N/A	0.013
STRANACARRY	644.21	0626M00070I	8.07	Circular (x2)	0.40	-	N/A	0.013
ACARREAGH*	1318.50	0624M	1122.3	Circular	Range from 0.45 to 0.8	-	N/A	0.015
AGHABOYS*	158.28	0629M00128I	181.54	Circular	Range from 2.00 to 1.22	-	N/A	0.013
DONAGHMORE*	209.15	0621M00209I	88.22	Rectangular	0.26	0.34	N/A	0.013
DONAGHMORE*	297.37	0621M	176.43	Circular	Range from 0.70 to 1.1	-	N/A	0.013
DUNDALK*	2757.66	0617M00509I	80	Arch	1.63	2.94	1.28	0.014

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**
DUNDALK_BLACKWATER*	2913.10	0617M00494J	155.2	Circular (x2)	0.45	-	N/A	0.02
DUNDALK_BLACKWATER*	3628.53	0617M00420I	58.27	Circular (x2)	0.45	-	N/A	0.02
DUNDALK_BLACKWATER*	3686.80	0617M	670	Rectangular	Range from 0.44 to 1.28	Range from 1.11 to 3.53	N/A	0.02
FAIRHILL*	932.22	0619M00132I	77.59	Rectangular	0.21	0.30	N/A	0.035
FAIRHILL*	1009.81	0619M	77.59	Circular	Range from 0.35 to 0.6	-	N/A	0.035
FAIRHILL RIVER*	1023.51	0617A00053I	344.99	Rectangular	0.84	0.96	N/A	0.017
MARSHES LOWER*	0.00	0622M00165I	57.91	Arch	1.86	2.94	1.98	0.014
MARSHES LOWER*	86.86	0622M	434.31	Rectangular	Range from 1.28 to 0.5	Range from 1.96 to 2.56	N/A	0.023
MARSHES LOWER*	521.17	0622M00165I	28.95	Circular (x5)	0.50	-	N/A	0.018
MARSHES LOWER*	851.89	0622M00135I	238.15	Circular (x4)	0.55	-	N/A	0.015
MARSHES LOWER*	2006.19	0622M00020I	212	Arch	1.51	2.01	0.88	0.017

Structure ID Key:

D – Bridge Upstream Face

E – Bridge Downstream Face

I – Culvert Upstream Face

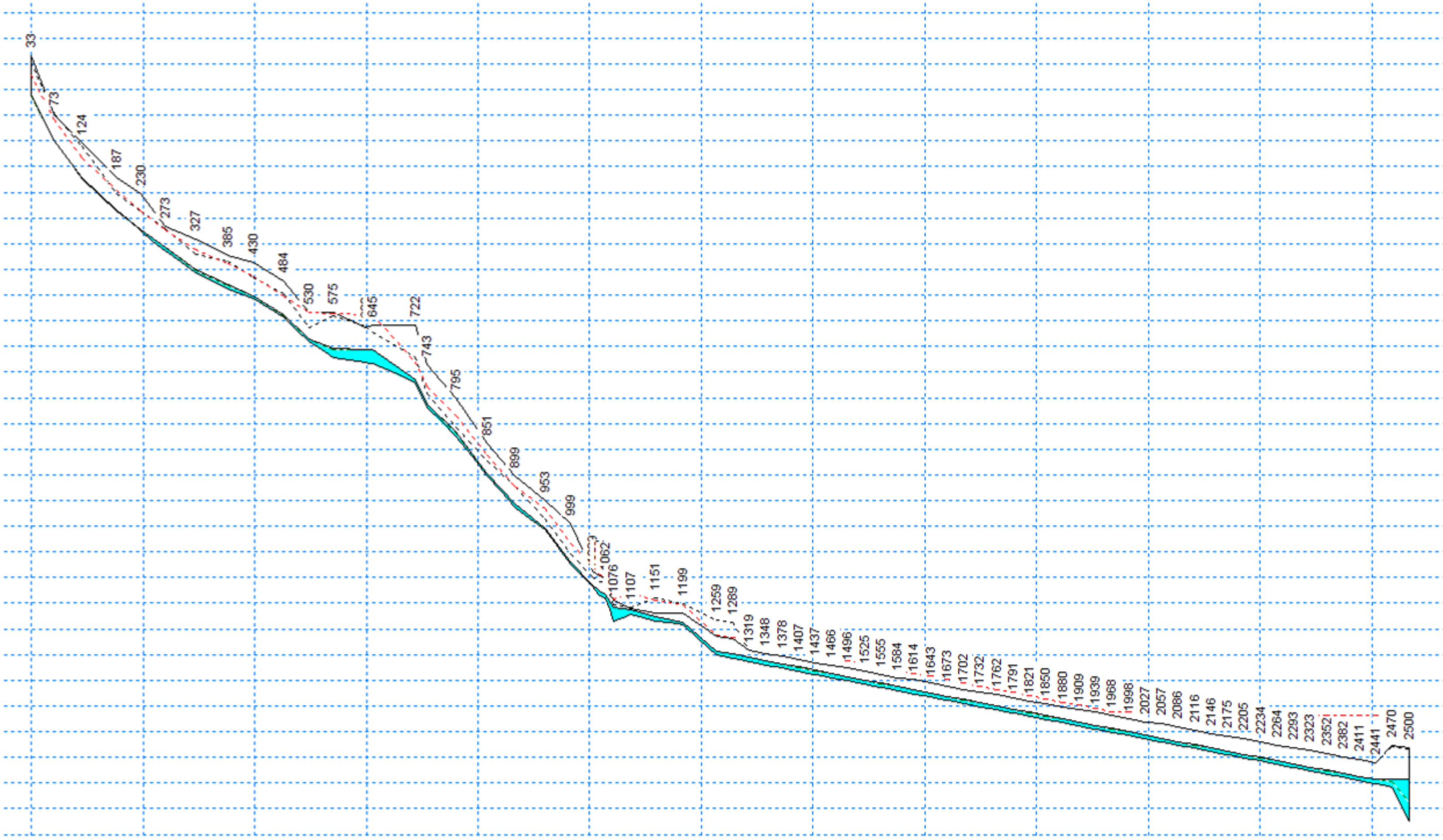
J –Culvert Downstream Face

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

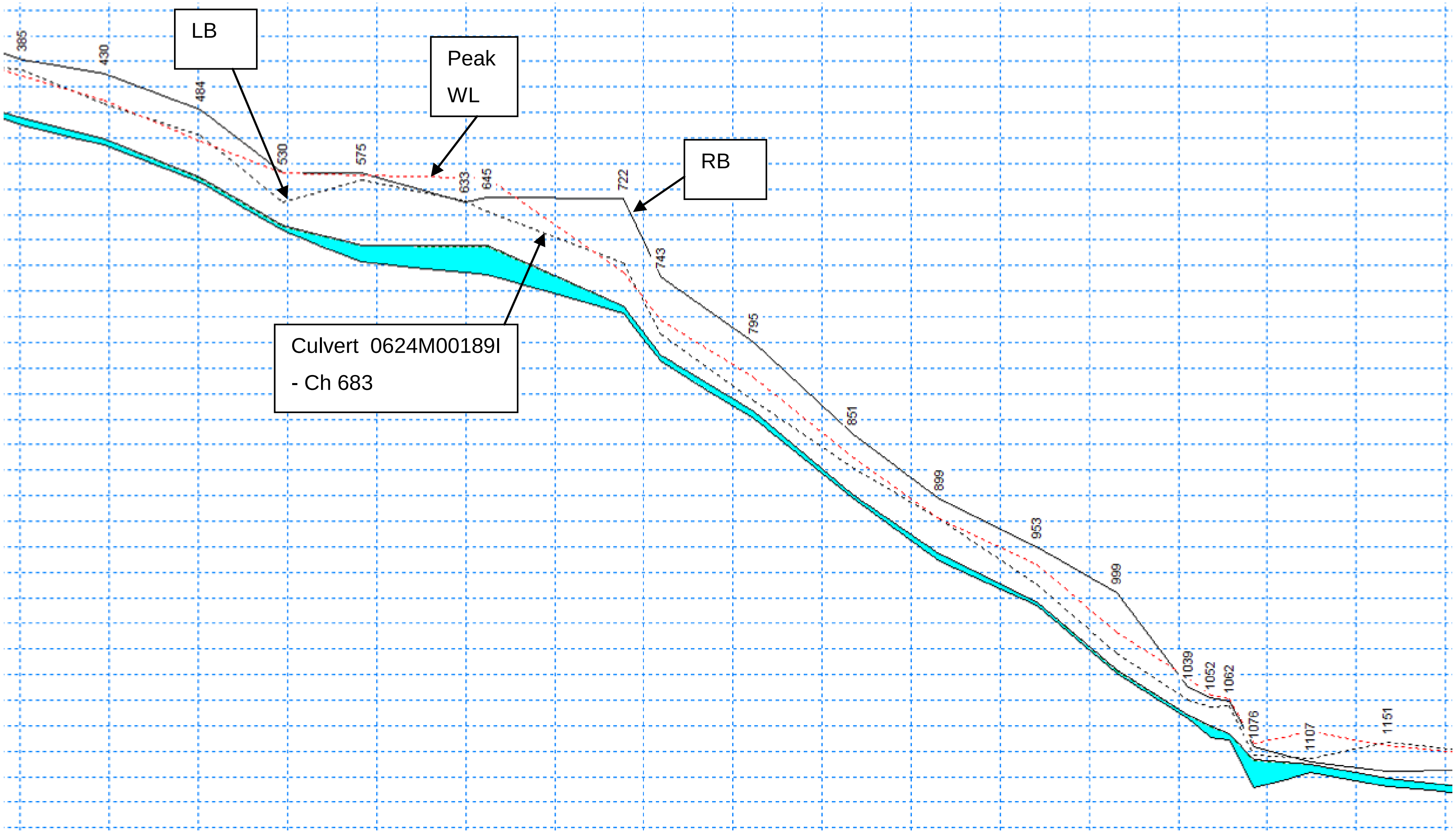
Structure Details - Weirs			
RIVER BRANCH	**CHAINAGE**	**ID**	**TYPE**
DUNDALK	481.632	0617M00737W	Broad Crested Weir
CASTLETOWN_RIVER	965.767	0623M00461W	Broad Crested Weir
CASTLETOWN_RIVER	1169.799	0623M00443W	Broad Crested Weir
CASTLETOWN	325.19	0625M00222W	Broad Crested Weir
CASTLETOWN	390.451	0625M00214W	Broad Crested Weir
CASTLETOWN	698.5	0625M00184W	Broad Crested Weir

APPENDIX A.2

Long section plot



Acarreagh watercourse 1% AEP fluvial flow - extents



Acarreagh watercourse 1% AEP fluvial flow - zoom

See Section 4.7.2(8) for structure details and references to survey data and photographs. Manning's values used vary with structure types and materials. All relevant structures are included within the model, unless otherwise mentioned under the limitations in Section 4.7.6 of this report.

APPENDIX A.3

	Peak Water Flows			
River Name & Chainage	**AEP**	**Check Flow (m^3/s)**	**Model Flow (m^3/s)**	**Diff (%)**
PRIORLAND 851.074	10%	0.21	0.17	-19.05
06_918_1	1%	0.38	0.31	-18.42
	0.1%	0.67	0.96	+43.28
FAIRHILL TRIBUTARY 195.199	10%	0.75	0.70	-6.93
06_147_4_RPS	1%	1.39	1.02	-26.98
	0.1%	2.46	2.45	-0.41
KILALLY 886.497	10%	0.08	0.08	0
06_Trib_Ddalk_1	1%	0.15	0.14	-6.67
	0.1%	0.26	0.25	-3.85
MARSHES LOWER 101.338	10%	5.66	0.99	-82.49
06_318_Inter	1%	10.78	1.03	-90.49
	0.1%	19.89	1.08	-94.57
MARSHES LOWER 2137.85	10%	0.77	1.20	+55.84
06_318_D	1%	1.42	1.63	+14.79
	0.1%	2.51	2.49	-0.80
DONAGHMORE 2112.66	10%	1.30	1.15	-11.62
06_242_4_RPS	1%	2.40	1.86	-22.63
	0.1%	4.24	3.25	-23.35
DUNDALK_BLACKWATER 6065.69	10%	3.75	4.20	+12.00
06_1038_D	1%	6.92	5.33	-22.98
	0.1%	12.25	5.95	-51.43
DUNDALK 947.707	10%	2.70	3.00	+11.22
06_913_4_RPS	1%	4.97	4.73	-4.79
	0.1%	8.80	7.97	-9.41
DUNDALK 2750.28	10%	5.52	1.01	-81.72
06036_RPS	1%	10.53	1.09	-89.64
	0.1%	19.42	1.39	-92.86
BALLYNAHATTIN 3098.12	10%	4.24	8.21	+93.56
06_1081_D_RA	1%	7.89	9.87	+25.08
	0.1%	14.17	10.02	-29.30
AGHABOYS 1289.54	10%	3.54	1.70	-51.98
06_1078_3_RA	1%	6.54	3.13	-52.14
	0.1%	11.57	6.82	-41.08
BLACKROCK 1907.55	10%	1.24	2.33	+87.74
06_0616A_D	1%	2.30	2.59	+12.48
	0.1%	4.07	6.55	+60.93
GREEN GATES 2074.68	10%	0.78	0.59	-24.87
06_315_5_RA	1%	1.44	0.86	-40.42
	0.1%	2.55	1.13	-55.57

	Peak Water Flows			
River Name & Chainage	**AEP**	**Check Flow (m^3/s)**	**Model Flow (m^3/s)**	**Diff (%)**
CASTLETOWN 2045.9	10%	2.72	2.99	-9.96
06_1087_13_RA	1%	5.02	5.17	+2.95
	0.1%	8.89	8.72	-1.90
KILCURRY_RIVER 634.029	10%	19.80	26.16	+32.12
06_600_4_RA	1%	29.50	42.15	+42.89
	0.1%	42.37	64.35	+51.88
CASTLETOWN_RIVER 997.18	10%	38.13	38.00	-0.34
06032_RA	1%	53.22	53.80	+1.09
	0.1%	72.49	78.86	+8.78
CASTLETOWN_RIVER 1194.91	10%	38.18	39.50	+3.46
06_1084_1_RA	1%	53.29	54.00	+1.33
	0.1%	72.59	78.93	+8.73
CASTLETOWN_RIVER 5269.9	10%	39.24	37.90	-3.41
06_DDalk_D_RARPS	1%	54.78	62.00	+13.18
	0.1%	74.61	96.55	+29.41
ACARREAGH 874.661	10%	1.97	0.26	-86.70
06_1089_4_RA	1%	3.64	0.19	-94.81
	0.1%	6.44	1.27	-80.28
STRANACARRY 1170.09	10%	1.00	0.81	-19.00
06_1055_2_RA	1%	1.84	1.57	-14.95
	0.1%	3.26	2.50	-23.31

The table above provides details of the flow in the model at every HEP intermediate check point, modelled tributary and gauging station. These flows have been compared with the hydrology flow estimation and a percentage difference provided. Note that the estimation of flows at HEP check points and their reliability are discussed in the hydrology report IBE0700Rp0012_UoM06 Hydrology Report under Sections 4 and 5.

As can be seen, there is a considerable difference between the modelled flows and the HEP at 06_147_4_RPS on the Fairhill Tributary, with the modelled flows being notably lower, particularly for the 1% AEP. However the actual difference in flow is only $0.37m^3/s$ which is negligible and does not need to be revised. With low flows the percentage difference is amplified.

The large difference in flows at 06_318_Inter on Marshes Lower and again at 06_318_D at the downstream end can be attributed to the hydraulic set up and assumption that all the flow from the Dundalk River should be redirected down the Marshes Lower River, with the Dundalk Blackwater being treated as an entirely separate watercourse, with a nominal point inflow. Due to the arrangement of these watercourses in the model, model flows are likely to be different than the check point flows. A difference in flows could also be due to the long culverts situated on the watercourse. However

sensitivity testing should identify the optimum resistance of these culverts to ensure the most realistic flood mapping. The same applies to HEP 06036_RPS on the Dundalk River.

The difference in flows at Greengates 06_315_5_RA is due to the tidal component included within the modelling, which is not represented by the fluvial HEP node. It should be noted that as many of the reaches are tidally influenced, the modelled results tend to have large percentage differences when compared to the estimated flows.

Overall, there is reasonable correlation between the modelled flows and the check flows at HEPs 06_Trib_Ddalk_1, 06_913_4_RPS, 06_1087_13_RA, 06032_RA and 06_1084_1_RA in the Dundalk and Blackrock model. However due to the inclusion of the tidal component within the model results a number of results cannot be directly compared.

APPENDIX A.4

A list of all model files provided with this report

Fluvial and 'Mechanism 1 Tidal' Model Files			
MIKE FLOOD	**MIKE 21**	**MIKE 21 - DFS0 FILE**	**MIKE 21 RESULTS**
HA06_DUND4_MF_DES_156_C2_F10 HA06_DUND4_MF_DES_156_C2_F100 HA06_DUND4_MF_DES_156_C2_F1000		HA06_DUND4_TWL_15min_Bnd_Malin_REV2_TIMING4	
	HA06_DUND4_M21FM_DES_156_C2_F10 HA06_DUND4_M21FM_DES_156_C2_F100 HA06_DUND4_M21FM_DES_156_C2_F1000		HA06_DUND4_RESULTS_DES_156_C2_F10.dfsu HA06_DUND4_RESULTS_DES_156_C2_F100.dfsu HA06_DUND4_RESULTS_DES_156_C2_F1000.dfsu
HA06_DUND4_MF_DES_164_C10_F2	HA06_DUND4_M21FM_DES_164_C10_F2		HA06_DUND4_RESULTS_DES_164_C10_F2.dfsu
HA06_DUND4_MF_DES_164_C100_F2 HA06_DUND4_MF_DES_164_C1000_F2	HA06_DUND4_M21FM_DES_164_C100_F2 HA06_DUND4_M21FM_DES_164_C1000_F2 HA06_DUND4_MESH_DES_18 HA06_DUND4_EDDYVIS_DES_18 HA06_DUND4_BEDRES_DES_18 HA06_DUND4_RESULTS_DES_35_HOTSTART		HA06_DUND4_RESULTS_DES_164_C100_F2.dfsu HA06_DUND4_RESULTS_DES_164_C1000_F2.dfsu
MIKE 11 - SIM FILE & RESULTS FILE	**MIKE 11 - NETWORK FILE**	**MIKE 11 - CROSS-SECTION FILE**	**MIKE 11 - BOUNDARY FILE**
	HA06_DUND4_NWK_DES_28	HA06_DUND4_XNS_DES_28	
HA06_DUND4_M11_DES_156_C2_F10 HA06_DUND4_M11_DES_156_C2_F10.res11 HA06_DUND4_M11_DES_156_C2_F100 HA06_DUND4_M11_DES_156_C2_F100.res11 HA06_DUND4_M11_DES_156_C2_F1000 HA06_DUND4_M11_DES_156_C2_F1000.res11 HA06_DUND4_M11_DES_164_C10_F2 HA06_DUND4_M11_DES_164_C10_F2.res11			HA06_DUND4_BND_DES_13_F10 HA06_DUND4_BND_DES_13_F100 HA06_DUND4_BND_DES_13_F1000
HA06_DUND4_M11_DES_164_C100_F2 HA06_DUND4_M11_DES_164_C100_F2.res11			
HA06_DUND4_M11_DES_164_C1000_F2 HA06_DUND4_M11_DES_164_C1000_F2.res11			

MIKE 11 - DFS0 FILE		MIKE 11 - HD FILE & RESULTS FILE	
HA06_DUND4_DFS0_10%AEP_v3-TIMING1-part1 HA06_DUND4_DFS0_1%AEP_v3-TIMING1-part1 HA06_DUND4_DFS0_0.1%AEP_v3-TIMING1-part1 HA06_DUND4_DFS0_10%AEP_v3-TIMING1-part2 HA06_DUND4_DFS0_1%AEP_v3-TIMING1-part2 HA06_DUND4_DFS0_0.1%AEP_v3-TIMING1-part2		HA06_DUND4_HD_DES_156_C2_F10 HA06_DUND4_HDMAPS_DES_156_C2_F10.dfs2 HA06_DUND4_HD_DES_156_C2_F100 HA06_DUND4_HDMAPS_DES_156_C2_F100.dfs2 HA06_DUND4_HD_DES_156_C2_F1000 HA06_DUND4_HDMAPS_DES_156_C2_F1000.dfs2 HA06_DUND4_HD_DES_164_C10_F2 HA06_DUND4_HDMAPS_DES_164_C10_F2.dfs2 HA06_DUND4_HD_DES_164_C100_F2 HA06_DUND4_HDMAPS_DES_164_C100_F2.dfs2 HA06_DUND4_HD_DES_164_C1000_F2 HA06_DUND4_HDMAPS_DES_164_C1000_F2.dfs2	

'Mechanism 2 Wave Overtopping' Model Files		
MIKE 21	**MIKE 21 - DFS0 FILE**	**MIKE 21 RESULTS**
HA06_DUND4_M21FM_WAV_22E_Q10 HA06_DUND4_M21FM_WAV_22E_Q100 HA06_DUND4_M21FM_WAV_22E_Q1000 HA06_DUND4_MESH_WAV_22E HA06_DUND4_BR_WAV_22E	HA06_DUND4_WAV_Q10 HA06_DUND4_WAV_Q100 HA06_DUND4_WAV_Q1000 HA06_DUND4_WAV_WL_E	HA06_DUND4_RESULTS_WAV_22E_Q10 HA06_DUND4_RESULTS_WAV_22E_Q100 HA06_DUND4_RESULTS_WAV_22E_Q1000

GIS Deliverables - Hazard

Flood Extent Files (Shapefiles)	**Flood Depth Files (Raster)**	**Water Level and Flows (Shapefiles)**
Fluvial N22EXFCD100F0 N22EXFCD010F0 N22EXFCD001F0 Coastal N22EXCCD100F0 N22EXCCD005F0 N22EXCCD001F0 Wave Overtopping N22EXWCD100F0 N22EXWCD005F0 N22EXWCD001F0	Fluvial N22DPFCD100F0 N22DPFCD010F0 N22DPFCD001F0 Coastal N22DPCCD100F0 N22DPCCD005F0 N22DPCCD001F0 Wave Overtopping N22DPWCD100F0 N22DPWCD005F0 N22DPWCD001F0	Fluvial N22NFCDF0 Coastal N22NCCDF0
Flood Zone Files (Shapefiles)	**Flood Velocity Files (Raster)**	**Flood Defence Files (Shapefiles)**
N22ZNA_CDF0 N22ZNB_CDF0	Fluvial N22vlFCD100F0 N22vlFCD010F0 N22vlFCD001F0 Coastal N22vlCCD100F0 N22vlCCD005F0 N22vlCCD001F0 Wave Overtopping N22vlWCD100F0 N22vlWCD005F0 N22vlWCD001F0	Defended Areas N22DFCCD100F0

GIS Deliverables - Risk

Specific Risk - Inhabitants (Raster)	**General Risk - Economic (Shapefiles)**	**General Risk-Environmental (Shapefiles)**
Fluvial N22RIFCD100F0 N22RIFCD010F0 N22RIFCD001F0 Coastal N22RICCD100F0 N22RICCD005F0 N22RICCD001F0	N/A	N/A