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NORTH WESTERN
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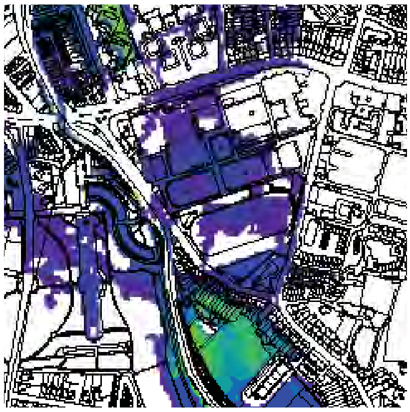
STUDY
CATCHMENT FLOOD RISK
ASSESSMENT AND MANAGEMENT

North Western - Neagh Bann CFRAM Study

UoM 06 Hydraulics Report
4.6 Greenore

IBE0700Rp0012



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Photographs of flooding on cover provided by Rivers Agency

NWNB CFRAM Study

HA06 Hydraulics Report

Greenore Model

DOCUMENT CONTROL SHEET

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

Rev.	Status	Author(s)	Modeller	Reviewed by	Approved By	Office of Origin	Issue Date
D01	Draft	T. Carberry	C. Lewis	S Patterson	G, Glasgow	Limerick/Belfast	04/04/2014
F01	Draft	E. Holland	C. Lewis	L. Arbuckle	G. Glasgow	Belfast	19/11/14
F02	Draft	E. Holland	C. Lewis	L. Arbuckle	G. Glasgow	Belfast	13/08/15
F03	Draft Final	E. Holland	E. Holland	S Patterson	G. Glasgow	Belfast	05/07/2016

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	4.2
North Western Neagh Bann CFRAM Study UoM06 Inception Report	March 2013	IBE0700Rp0003_UoM 06 Inception Report	4.3.2
North Western Neagh Bann CFRAM Study Hydrology Report UoM06	April 2014	IBE0700Rp0008_UoM 06 Hydrology Report	4.2, 4.3
North Western Neagh Bann CFRAM Study Hydraulics Report	May 2014	IBE0700Rp0012_UoM 06_Hydraulics Report	3.1, 3.3.3, 3.6
North Western Neagh Bann CFRAM HA01_06_36 Survey Contract Report	October 2013	IBE0700Rp0007_HA01_06_36 NWNB_CFRAM_Survey Contract Report	1.9, 1.19

4 HYDRAULIC MODEL DETAILS

4.6 GREEENORE MODEL

4.6.1 General Hydraulic Model Information

(1) Introduction:
The NWNB CFRAM Flood Risk Review (2011s5232 NW&NB CFRAM FRR Report_Final_v2.0) highlighted Greenore as an AFA for fluvial and coastal flooding based on a review of historic flooding and the extents of flood risk determined during the PFRA. Greenore AFA is located approximately 3km south west of Carlingford on the shores of Carlingford Lough with Greenore Point situated to the north east. Fluvial flood risk emanates from two small watercourses which drain the surrounding land and flow from south to north through Greenore to discharge to Carlingford Lough. The Greenore 1D model includes the Mullatee watercourse and a small tributary which has a catchment area of 1.7km^2 at its downstream limit. The Greenore 1D model also includes the Millgrange watercourse which has a catchment area of 3km^2 at its downstream limit. There are no gauging station sites within the modelled reaches and as such the model is considered to be ungauged for the purposes of flow estimation. The nearest FSU pivotal site geographically Ballygoly (Station no. 06030). However it is not considered appropriate for adoption as a pivotal site as outlined in Hydrology Report, Section 4.2, (IBE0700Rp0008_UoM 06 Hydrology Report_F01) Full details of derivation of design flows are provided in the UoM 06 Hydrology Report, Chapter 4.2 (IBE0700Rp0008_UoM 06 Hydrology Report_F01). In summary, a review of all hydrologically/geographically similar pivotal site options was undertaken revealing a trend towards upwards adjustment at 8 of the 14 stations. Four of these stations (including Ballygoly, 06030) yielded Q_{med} results above the 95%ile upper limit when the associated adjustment factor was applied to initial Q_{med} estimations within the model. The other four stations yielded results above the 68%ile upper limit. The review therefore suggests that upward adjustment is appropriate. However the adjustment factor should be appropriately capped at the 68%ile upper limit. This has been taken as the factorial standard error of 1.37 at each HEP (the ratio of the initial Q_{med} estimate and its 68%ile upper confidence limit), refer to Hydrology Report, Section 4.3. All watercourses within the Greenore AFA have been identified as HPW and are under tidal influence in their lower reaches. As such, these watercourses have been modelled as 1D-2D using the MIKE suite of software. Channel markers have been located at the right and left banks of all cross-sections. Flow within these markers is calculated by the 1D model component; however when the water level rises sufficiently to meet the bank markers flow can enter the 2D domain which represents the floodplain. These two models are coupled through MIKE FLOOD, refer to Section 3.1 for further details. This approach is considered the most appropriate given the significant potential for tidal inundation. Lower reaches of the watercourses within the tidal transition zone have been modelled in 2D-only to improve representation of the area within the 1D-2D hydraulic models and overall model stability. To further improve representation of the tidal

transition zone under extreme tidal conditions (0.5% and 0.1% AEP), separate fluvial and tidal versions of the models have been setup. – refer to Section 4.6.2 (7) for details on model set-up.		
(2) Model Reference:	HA06_GREE3	
(3) AFAs included in the model:	Greenore	
(4) Primary Watercourses / Water Bodies (including local names):		
Reach ID	**Name**	
0633M	Mullatee	
0633A	Mullatee Tributary 1	
0634M	Millgrange	
0634A	Millgrange Tributary 1	
0634B	MIllgrange Tributary 2	
(5) Software Type (and version):		
(a) 1D Domain: MIKE 11 (2011)	**(b) 2D Domain:** MIKE 21 - Rectangular Mesh (2011)	**(c) Other model elements:** MIKE FLOOD (2011)

4.6.2 Hydraulic Model Schematisation

(1) Map of Model Extents:

Figure 4.6.1 illustrates the extent of the modelled catchment, river centre line, HEP locations and AFA extents as applicable. The Mullatee and Millgrange watercourses are designated HPWs in the Greenore AFA. To the north of the AFA is a transitional waterbody, the Carlingford Lagoons, through which both the Mullatee and Millgrange watercourse flow before discharging to Carlingford Lough.

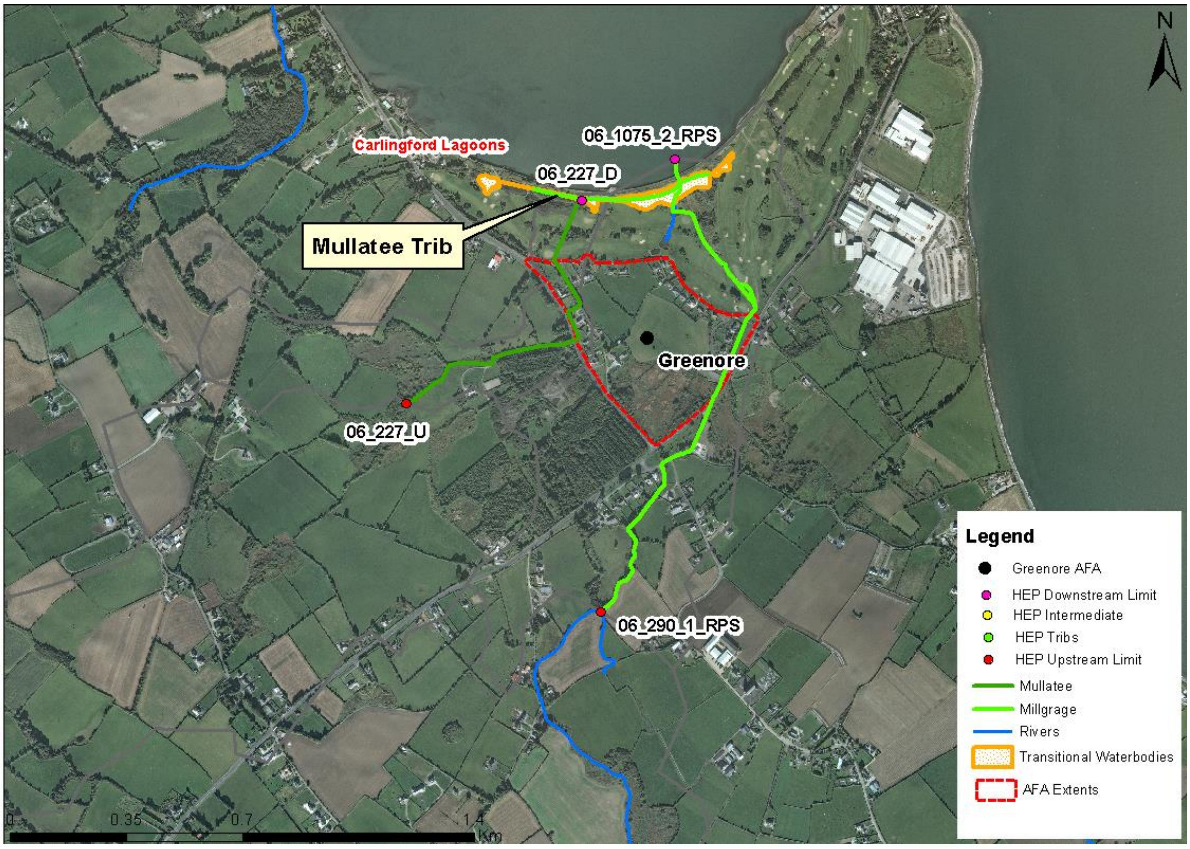


Figure 4.6.1: Map of Model Extents

Millgrange catchment (U0M06 Model 3B) contains 1no. Upstream Limit HEP and 1no. Downstream Limit HEP. The Mullatee catchment (U0M06 Model 3A) contains 1no. Upstream Limit HEP, 1no. Downstream Limit HEP and discharges into the Millgrange catchment at 06_277_D. A separate inflow for the Mullatee Tributary has also been included.

There are no gauging stations or Intermediate HEPs on any of the modelled watercourses.

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

River Name		Easting	Northing
0633M	Mullatee	320903	309599
0633A	Mullatee Trib 1	321284	310252
0634M	Millgrange	321490	308964
0634A	Millgrange Trib 1	321955	309905
0634B	Millgrange Trib 2	321821	310298

Note: Mullatee Trib, Millgrange Trib 1 and Millgrange Trib 2 modelled in 2D only – see Section 4.6.6 for details.

(3) Total Modelled Watercourse Length:		3.3 km	
(4) 1D Domain only Watercourse Length:	0 km	**(5) 1D-2D Domain**	2.0 km

		Watercourse Length:	
(6) 2D Domain Mesh Type / Resolution / Area:		Rectangular / 5 m / 4 km^2	

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

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

(7) 2D Domain Model Extent:

Figure 4.6.2 and Figure 4.6.3 illustrate the modelled extents and the general topography of the catchment for the fluvial dominated and coastal dominated scenarios. The black line depicts the modelled 1D extent of the Mullatee Tributary to the west and the Millgrange Tributary to the east. Figure 4.6.3 illustrates the the lower reaches of the Millgrange Tributary river channel defined by the elevation within the 2D domain.

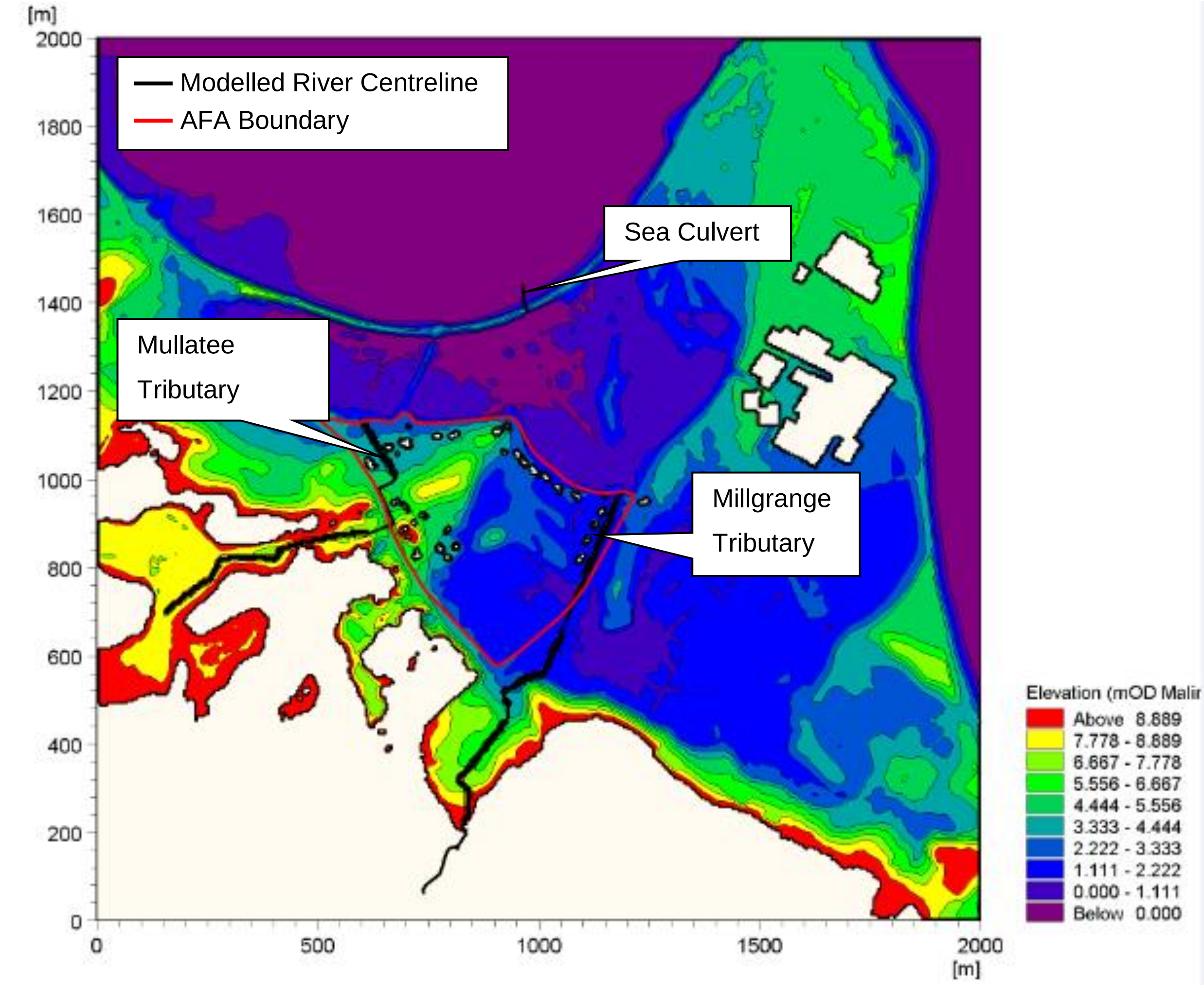


Figure 4.6.2: 2D Model Extent, Fluvial Dominated Scenarios

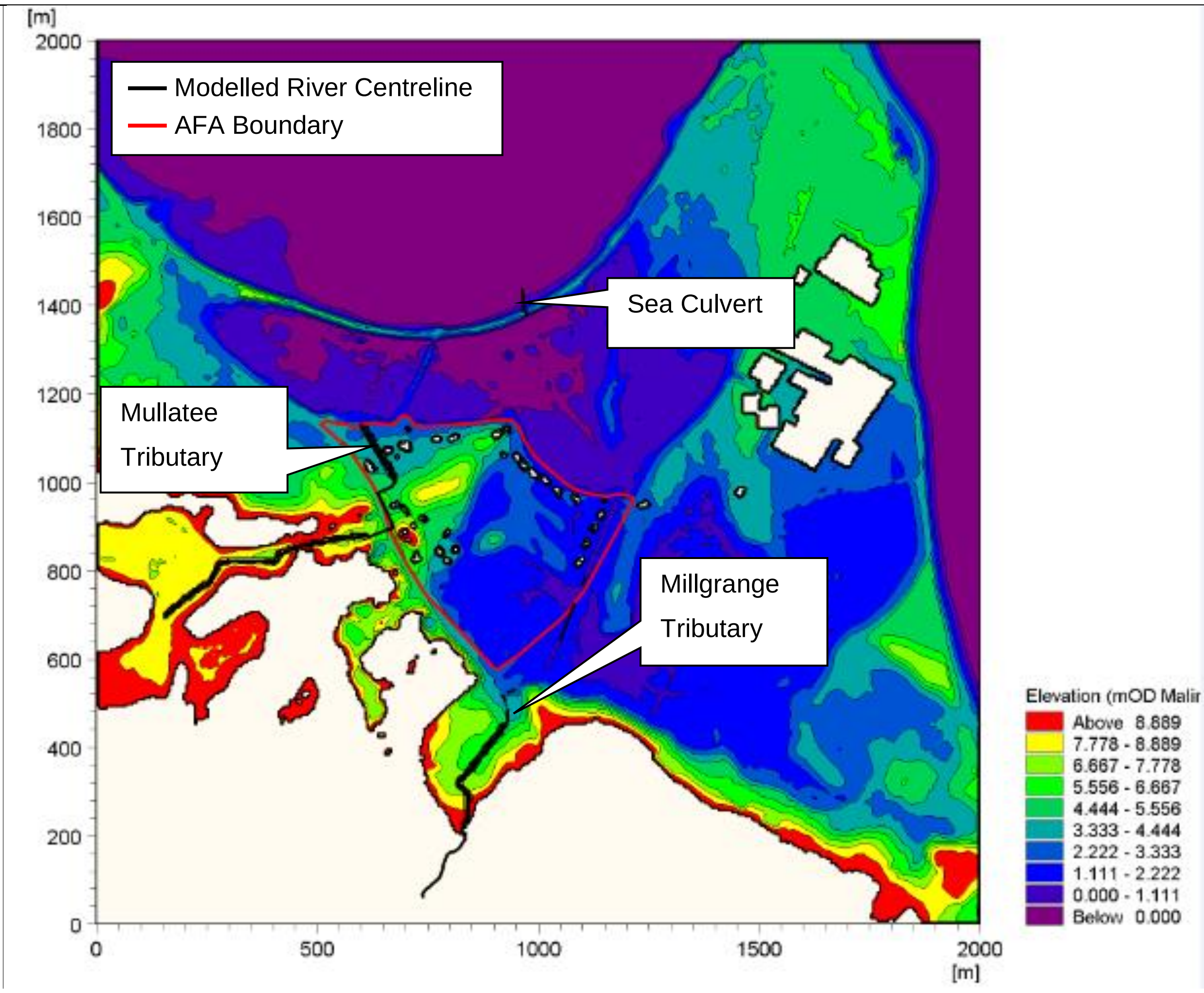


Figure 4.6.3: 2D Model Extent, Coastal Dominated Scenarios

Figure 4.6.4 and Figure 4.6.6 show an overview drawing of the model schematisation for the fluvial dominated scenarios and the coastal dominated scenarios respectively. Figure 4.6.5 and Figure 4.6.7 show a more detailed view. The overview diagrams cover the model extents, showing the surveyed cross-section locations, AFA boundary and river centre line. They also show the area covered by the 2D model domain. Figure 4.6.5 and Figure 4.6.7 show the detailed area where there is the most significant risk of flooding. These diagrams include the surveyed cross-section locations, AFA boundary and river centre. Figure 4.6.5 and Figure 4.6.7 also show the location of the critical structures as discussed in Section 4.1.3 (1), along with the location and extent of the links between the 1D and 2D models.

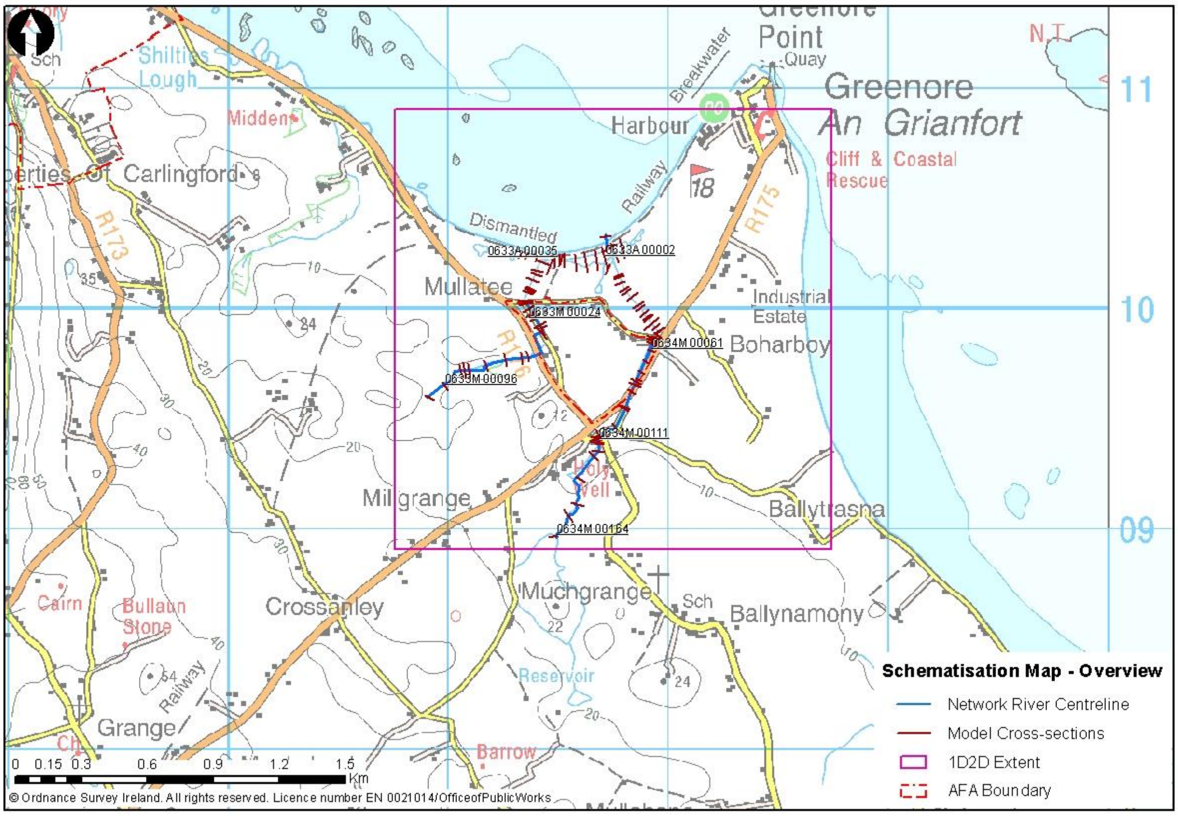


Figure 4.6.4: Overview Drawing of Model Schematisation, Fluvial Dominated Scenarios

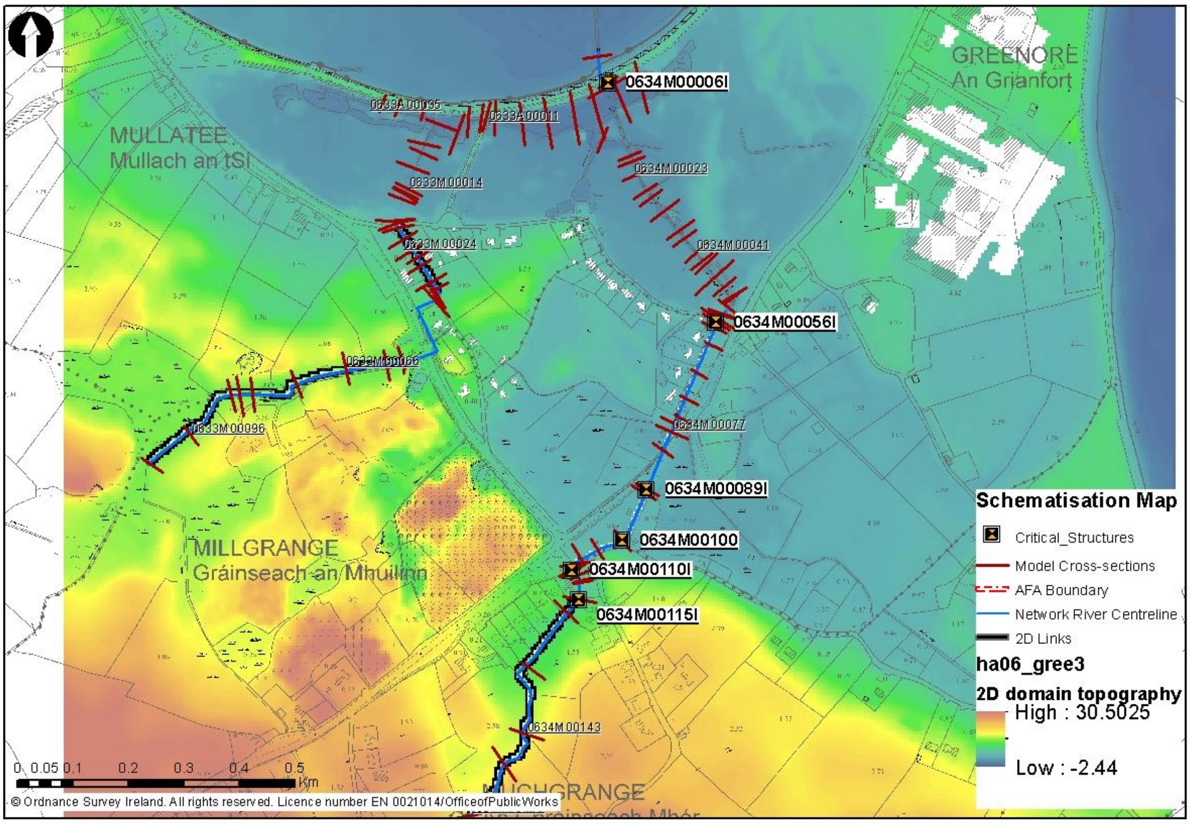


Figure 4.6.5: Detailed Area of Model Schematisation showing Critical Structures, Fluvial Dominated Scenarios

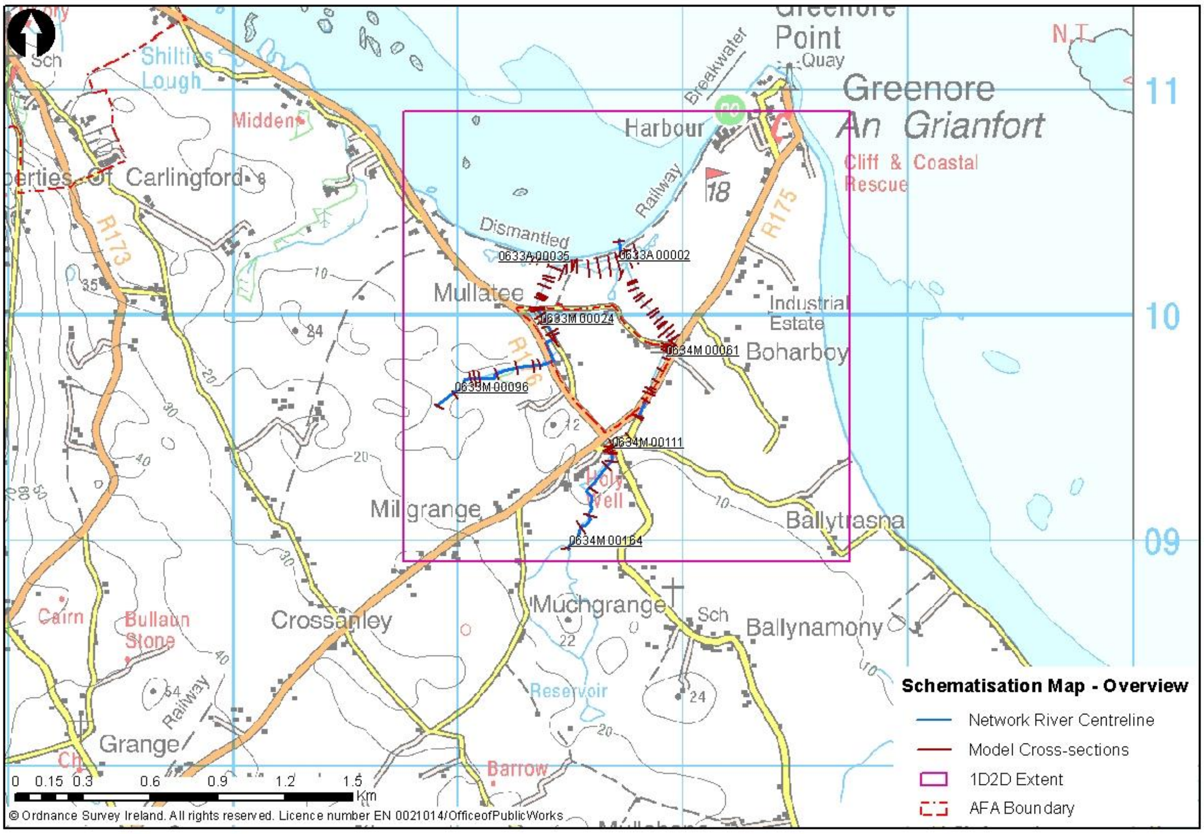


Figure 4.6.6: Overview Drawing of Model Schematisation, Coastal Dominated Scenarios

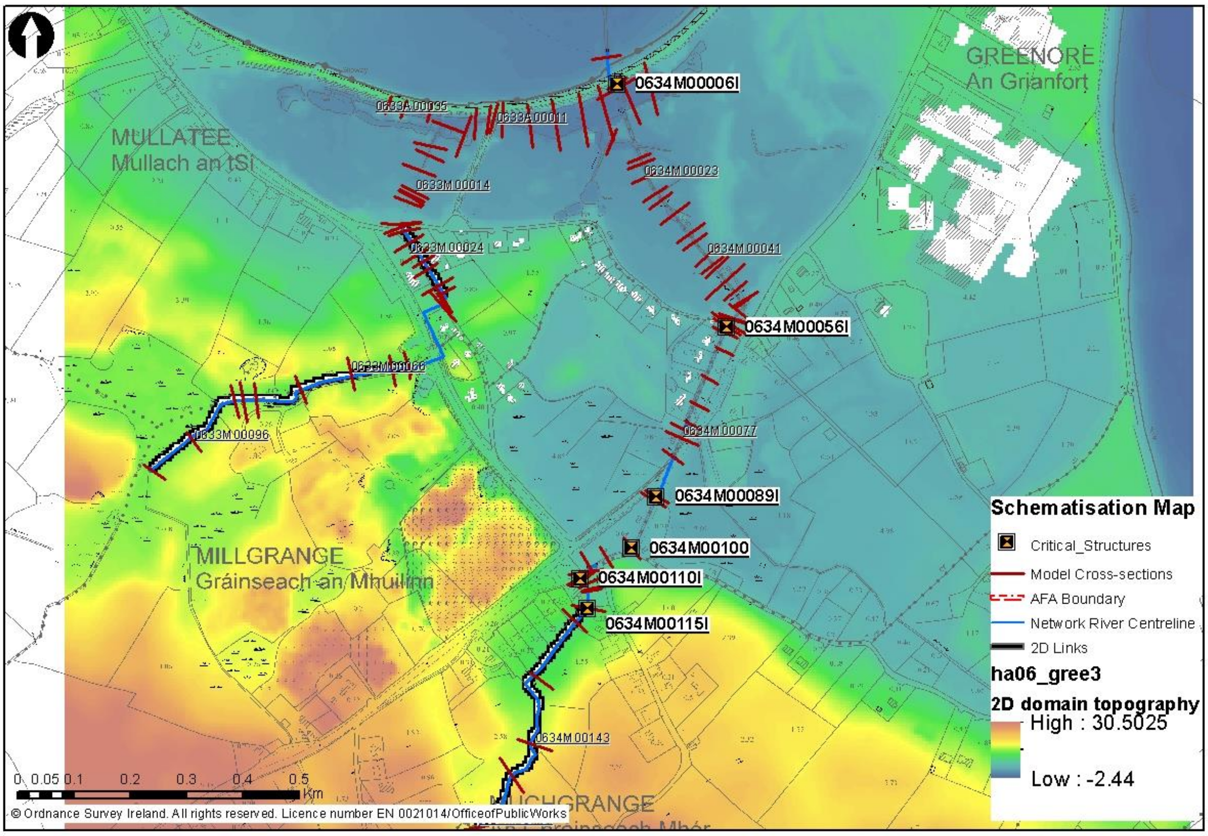


Figure 4.6.7: Detailed Area of Model Schematisation showing Critical Structures, Coastal Dominated Scenarios

(8) Survey Information

(a) Survey Folder Structure:

First Level Folder	Second Level Folder	Third Level Folder
Murphy_NW6_M03_WP6A2_0633A_V1_130215 Greenore Murphy: Surveyor Name NW6: NWNB CFRAM Study Area, Hydrometric Area 10 M03: Model Number 3 0633A: River Reference WP6A2 : Work Package 6A2 V1: Version *130215*– Date Issued (15th Feb 2013)	V0_20130215_Ascii	
	V0_20130215_GIS	Flood_Plane_Photos_and_Shapefile
		Structure_Register
		Surveyed_Cross_Section_Lines
		Watercourse_Register
	V0_20130215_Other	FP_PHOTOS
	Photos *(Naming convention is in the format of Cross-Section ID and orientation - upstream, downstream, left bank or right bank)*	

(b) Survey Folder References:

Reach ID	**Name**	**File Ref.**
0633M	Mullatee	Murphy_NW6_M03_WP6A2_0633M_V1_130215
0633A	Mullatee Trib 1	*Murphy_NW6_M03_WP6A2_0633A_V1_130215*
0634M	Millgrange	Murphy_NW6_M03_WP6A2_0634M__V1_130215
0634A	Millgrange Trib 1	Murphy_NW6_M06_WP6A2_0634A_130215
0634B	MIllgrange Trib 2	Murphy_NW6_M03_WP6A2_0634B_V1_130215

The bathymetry of the 2D model used depth information extracted from CMAP, LiDAR and the topographic surveys carried out for this Study. CMAP data provided depth information for the Carlingford Lough area of the domain. LiDAR data provided depth information for intertidal areas while the topographic survey data, Greenore (Murphy_NW6_M03_WP6A2_0634M__V1_130215), was used to resolve the lower reaches of river channel in the 2D model using Global Mapper. Further details on the bathymetry data sources are presented in Chapter 2.2.3.

(9) Survey Issues:

No survey queries

4.6.3 Hydraulic Model Construction

(1) 1D Structures (in-channel along modelled watercourses):	See Appendix A.1 Number of Bridges and Culverts: 14 Number of Weirs: 1

Details on the inclusion of structures into the MIKE11 model are presented in Chapter 3.3.3. The geometry of structures were taken from the surveyed cross-sections. Roughness coefficients were determined from reviewing survey photographs and selecting an appropriate value associated with that structure from CIRIA (1997) Culvert design guide, see Chapter 3.6. The locations of structures included in the model are presented in Appendix A.2.

On the Millgrange Tributary 0634M, culvert 0634M00115I at Chainage 504.5m (Figure 4.6.8) is a structure contributing to fluvial flooding during the 0.1% AEP fluvial event due to the back up of flow and low lying bank levels on both sides.

Figure 4.6.8: Millgrange Culvert 0634M00115I

On the Millgrange Tributary 0634M, culvert 0634M00110I at Chainage 550.191m (Figure 4.6.9) is considered to be critical to the fluvial flooding in the area during each AEP event. Flooding upstream of the culvert can be attributed to its insufficient capacity, which causes the flow to back up and flood out at mainly the right bank.

Figure 4.6.9: Millgrange Culvert 0634M00110I

On the Millgrange watercourse 0634M, culvert 0634M00100 at chainage 653.443m (Figure 4.6.10) is considered to be critical in terms of fluvial flooding in the area. Flooding upstream of this culvert can be attributed to its insufficient capacity, which causes the flow to back up and flood out at mainly the right bank. Flooding is more predominant during the 1% and 0.1% AEP fluvial events. As can be seen by the photograph, an abundance of vegetation may make the opening prone to blockage.

Figure 4.6.10: Millgrange Culvert 0634M00100I

Another critical structure to the fluvial flooding in Greenore is the culvert 0634M00089I (Figure 4.6.11) on the Millgrange watercourse at Chainage 793.52m. Flooding occurs due to insufficient capacity of this culvert from frequencies as high as the 50% AEP. Flooding here can also be attributed to low lying banks levels on both sides.

Figure 4.6.11: Millgrange Culvert 0634M00089I

Also on the Millgrange watercourse 0634M, culvert 0634M00056I at Chainage 1085.021 m (Figure 4.6.12) is considered to be critical to the flooding in the area. Flooding upstream of this culvert can be attributed to its insufficient capacity , which causes the flow to back up and flood out at mainly the left bank. Flooding at this location occurs during fluvial events as high as 50% AEP.

Figure 4.6.12: Millgrange Culvert 0634M00056I

Figure 4.6.13: Sea Culvert 0634M00006I Downstream Face

Figure 4.6.14: Sea Culvert 0634M00006I Upstream Face (submerged)

The culvert (Figure 4.6.13) through the Railway embankment (Structure ref: 0634M00006I_CUL; Branch: Sea_Cul) is seen to contribute to both fluvial and coastal flooding. Low bank levels are also a factor.

(2) 1D Structures in the 2D domain (beyond the modelled watercourses):	Fluvial Model – Culverts: 1 (see Section 4.6.6 and Appendix A1 for detail) Tidal Model – Culverts: 5 (see Section 4.6.6 and Appendix A1 for detail)
(3) 2D Model structures:	None

(4) Defences:

Type	**Watercourse**	**Bank**	**Model Start Chainage (approx.)**	**Model End Chainage (approx.)**
None				

(5) Model Boundaries - Inflows:

Full details of the flow estimates are provided in the Hydrology Report (IBE0700Rp0008_HA06 Hydrology Report_F01-Section 4.3 and Appendix D. The boundary conditions implemented in the fluvial and tidal dominated scenarios are shown in Table 4.6.1and Table 4.6.2

Fluvial Dominated Scenario

Table 4.6.1: Fluvial Dominated Model Boundary Conditions

	Boundary Description	Boundary Type	Branch Name	Chainage	Chainage	Gate ID	Boundary ID
1	Open	Inflow	Mullatee	0	0		06_227_U
2	Distributed Source	Inflow	Mullatee	0	863.19		Top-up flow between 06_227_U & 06_227_D
3	Open	Inflow	Millgrange	0	0		06_290_1_RPS
4	Distributed Source	Inflow	Millgrange	0	1092.876		Top-up flow between 06_290_1_RPS & 06_1075_2_RPS
5	Open	Water Level	Sea_Cul	0	0		
6	Open	Water Level	Sea_Cul	62.44	0		
7	Open	Water Level	Millgrange	1106.63	0		
8	Open	Water Level	Mullatee	880	0		

Tidal Dominated Scenario

Table 4.6.2: Coastal Dominated Model Boundary Conditions

	Boundary Description	Boundary Type	Branch Name	Chainage	Chainage	Gate ID	Boundary ID
1	Open	Inflow	Mullatee	0	0		06_227_U
2	Distributed Source	Inflow	Mullatee	0	863.19		Top-up flow between 06_227_U & 06_227_D
3	Open	Inflow	Millgrange	0	0		06_290_1_RPS
4	Distributed Source	Inflow	Millgrange	0	488		Top-up flow between 06_290_1_RPS & 06_1075_2_RPS
5	Open	Water Level	Sea_Cul	0	0		
6	Open	Water Level	Sea_Cul	62.44	0		
7	Open	Water Level	Millgrange	519.15	0		
8	Open	Water Level	Mullatee	880	0		
9	Open	Water Level	0634M0011	0	0		
10	Open	Water Level	0634M0011	11.1	0		
11	Open	Water Level	0634M0010	0	0		
12	Open	Water Level	0634M0010	13.16	0		
13	Open	Water Level	0634M0008	0	0		
14	Open	Water Level	0634M0008	84.62	0		
15	Open	Water Level	0634M0007	0	0		
16	Open	Water Level	0634M0007	15.15	0		

The upstream boundary of the Mullatee catchment is located at HEP 06_227_U (refer to Figure 4.6.1); the model node ID at this location is 0633M00106. A point inflow hydrograph was therefore applied at this node to account for flow entering the Mullatee watercourse upstream of this location. A distributed source has been applied evenly to all nodes downstream of this point to account for flow entering the Mullatee watercourse downstream of the Upper Limit HEP.

The upstream boundary of the Millgrange catchment is located at HEP 06_290_1_RPS; the model node ID at this location is 0634M00164. A point inflow hydrograph was therefore applied at this node to account for flow entering the Millgrange watercourse upstream of this location. A distributed source has been applied evenly to all nodes downstream of this point to account for flow entering the Millgrange watercourse downstream of the Upper Limit HEP.

Inflows from Mullatee Tributary, represented in 2D model, have been applied using an Isolated Source in

conjunction with the associated inflow hydrograph for this watercourse – see Section 4.6.6 (1)(d) for detail.

Figure 4.6.15 provides an example of the associated upstream hydrograph generated and used as the inflow boundary for the fluvial dominated 1% AEP scenario.

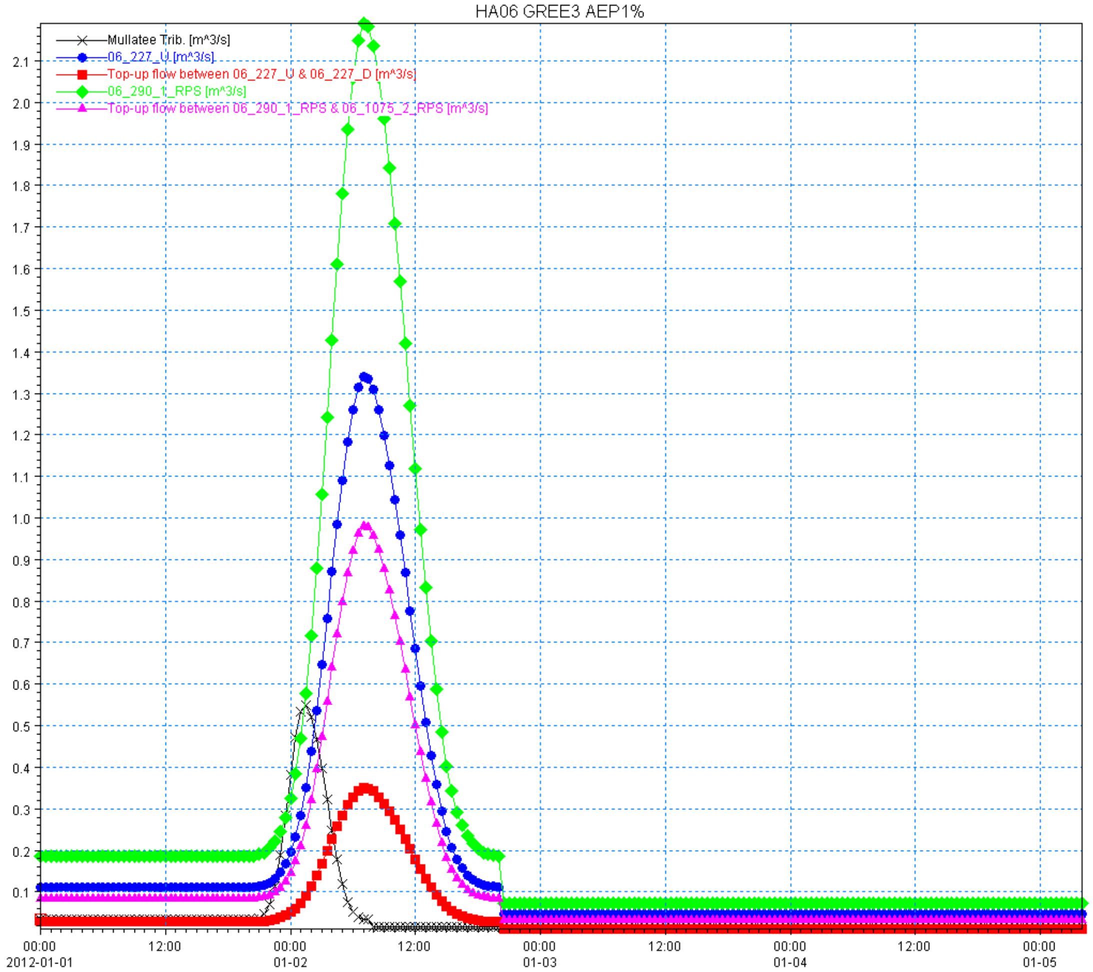


Figure 4.6.15: 1% AEP Inflow Hydrograph for the Millgrange and Mullatee watercourses

The flows provided in the Hydrology Report have not been changed during the development of the model. The fluvial hydrographs have been shifted temporally to ensure peaks fluvial flows align with the given peak tide water levels provided. This approach was adopted to ensure the AFA was subjected to the highest volumes of water from both sources of flooding at the same time for each scenario.

Boundary conditions for the MIKE21 open boundaries were generated by combining storm surge and tidal elevation data. Outputs from the Irish Coastal Protection Strategy Study (ICPSS) have resulted in extreme tidal and storm surge water levels being made available around the Irish Coast for a range of AEPs. The locations of the ICPSS nodes along with the relevant AFA locations are shown in Figure 4.6.18. The associated AEP water levels for node NE27, those used for the Greenore AFA, are contained Table 4.6.3. It should be noted that the water levels listed below are 'still' water levels, as this model does not account for wave run-up or overtopping.

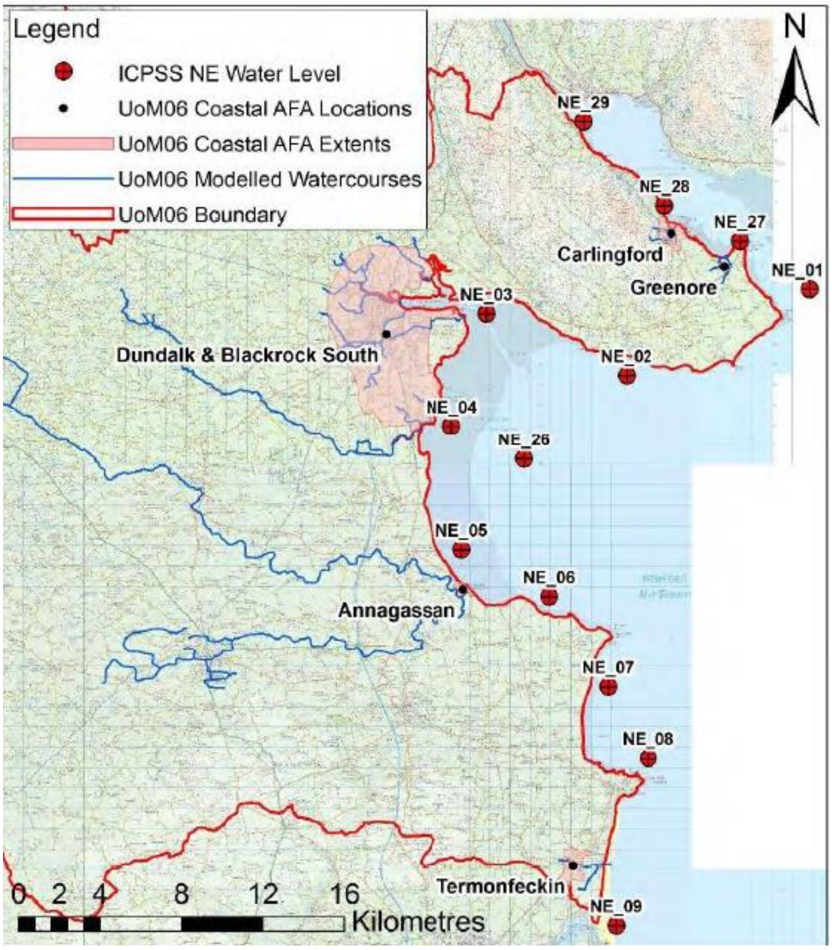


Figure 4.6.16: ICPSS Node Locations (IBE0700Rp0008_UoM06 Hydrology Report_F01)

Table 4.6.3: ICPSS AEP Total Water Levels for Relevant Model Nodes

ICPSS Node	AFA/HPW	Annual Exceedance Probability (AEP) %							
		2	5	10	20	50	100	200	1000
		Highest Tidal Water Level to OD Malin (m)							
NE27	Greenore	3.1	3.23	3.33	3.42	3.55	3.65	3.75	3.97

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

Using information from the Secondary Port of Cranfield Port in the Admiralty Tide Tables, RPS established a tidal water level which was based on MHWS. Using this water level a tidal curve was generated by fitting it to a sinusoidal curve. Also the resultant magnitude of the surge component required to produce a total water level for the relevant AEP was deduced, see Chapter 3.9.1. The tidal curve was combined with the appropriate scaled residual surge profile of 48 hours duration to obtain the total combined water level time series as required for the relevant AEPs.

Figure 4.6.17 illustrates the tidal profile, storm surge profile and resultant total water level profile for a

0.5% AEP design event. The total water profile was applied as a level boundary to the northern and eastern boundaries of the 2D domain.

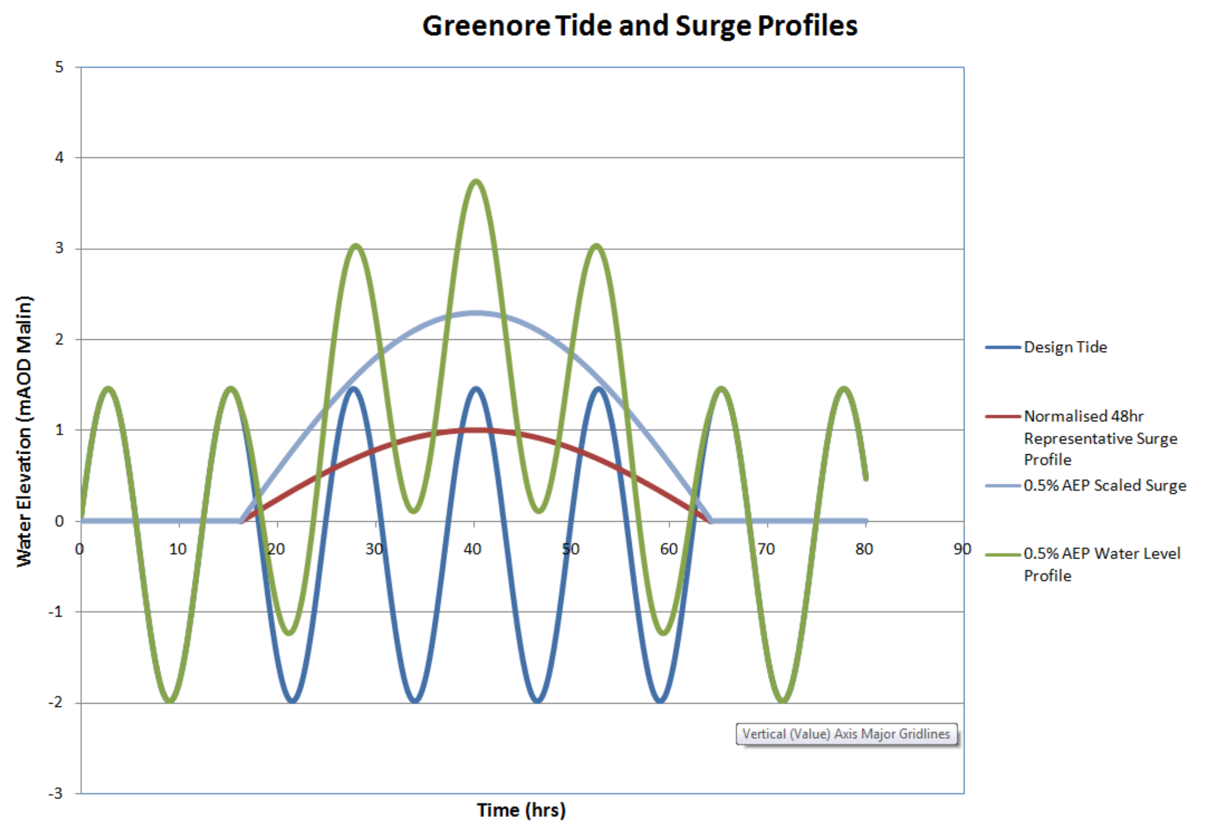


Figure 4.6.17: Greenore Coastal Boundary

(6) Model Boundaries – Downstream Conditions:	1D model (Fluvial Dominated Scenarios) Water level boundaries were applied at the downstream extent of the Mullatee and the Millgrange watercourses where it discharges to the 2D model domain (chainage 880 and 1106.63 respectively). The water level boundary allows transfer of flow between 1D and 2D elements. This enables the transfer of flow between the 1D and 2D domain. It should be noted that this boundary is given an initial 'dummy' water level value of 0 mOD Malin (slightly greater than the bed level at this location), however this value is ignored once the simulation commences and the level of this boundary varies in time based on dynamic calculations driven by the water levels in Mullatee, Millgrange and Carlingford Lough. 1D model (Tidal Dominated Scenarios) Water level boundaries were applied at the downstream extent of the Mullatee and the Millgrange watercourses where it discharges to the 2D model domain (chainage 880m and 519.15m respectively).

(7) Model Roughness: see Chapter 3.6.1 'Roughness Coefficients'		
(a) In-Bank (1D Domain)	Minimum 'n' value: 0.04	Maximum 'n' value: 0.06
(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: 0.015 (Inverse of Manning's 'M')	Maximum 'n' value: 0.04 (Inverse of Manning's 'M')

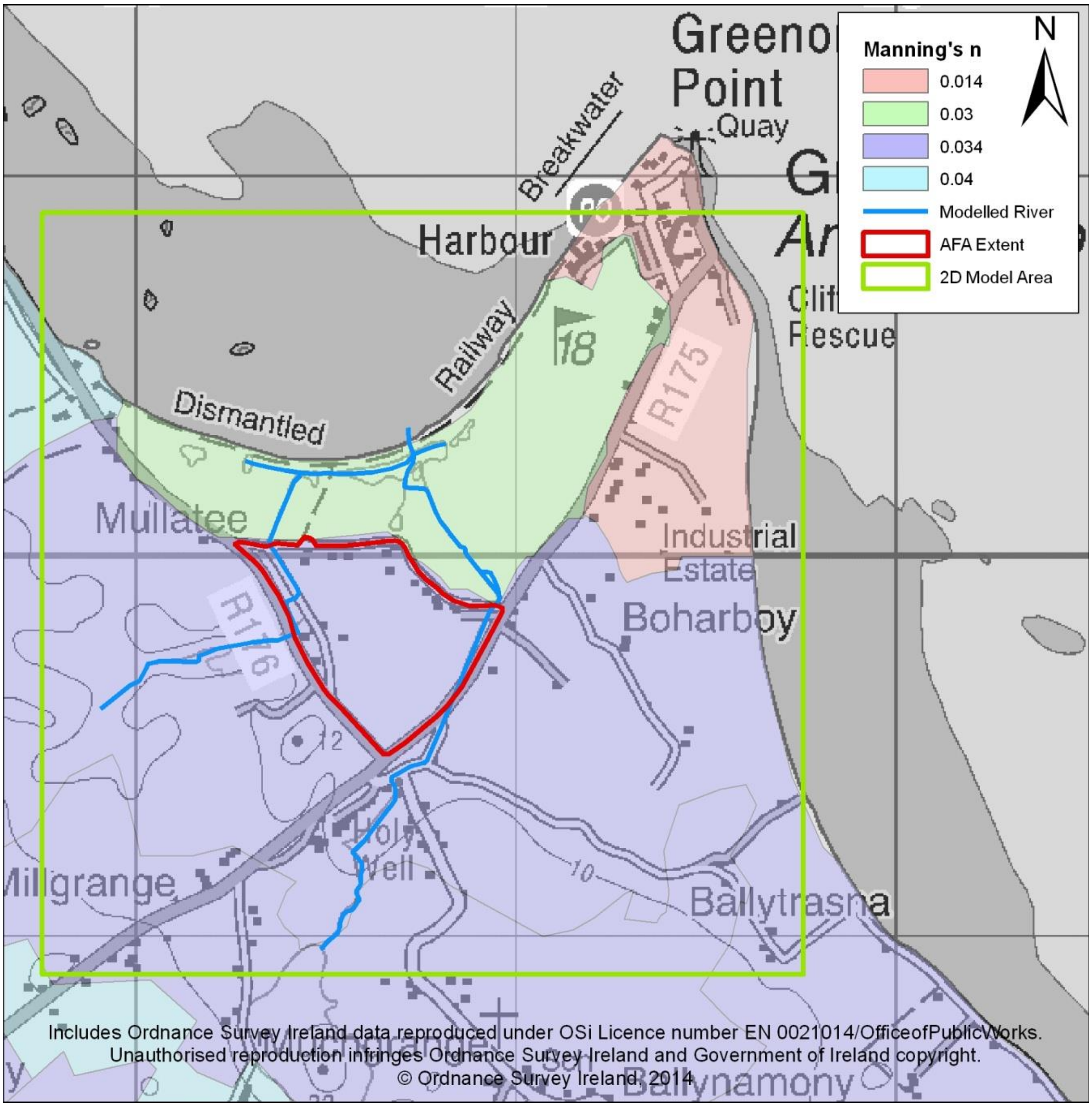


Figure 4.6.18: Map of 2D Roughness (Manning's n)

Figure 4.6.18 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. See Chapter 2.4 for more details. Any values seaward of the high water were also taken as 0.033 unless otherwise specified.

(d) Examples of In-Bank Roughness Coefficients

Figure 4.6.19: Mullatee – 0633M00027_UP

Manning's n = 0.04

Modified channel in stable condition; some cobbles on bed

Figure 4.6.20: Millgrange – 0634M00130_DN

Manning's n = 0.04

Modified channel in stable condition; some cobbles on bed

4.6.4 Sensitivity Analysis

To be completed for final version of report.

4.6.5 Hydraulic Model Calibration and Verification

(1) Key Historical Floods (No recorded flood events were documented in BE0700Rp0003_HA06 Inception Report_F02 for Greenore. Flood records provided after the Inception Report publication have been used).

(a) **FEB 2014.**	Flood Event Reports provided by Hanlon Transport Ltd and S McParland (Farm Owner) describe coastal flooding along a 160m (approx.) stretch of coast line to the east of the Greenore industrial estate. The cause of this flooding was identified as a combination of high tide and failure / erosion of the defences leading to tidal inundation of the immediate area. Two properties, 20m of public highway and an industrial facility were affected (all outside the designated AFA). No evidence of flooding within the Greenore AFA was provided. The AEP of the tidal event was also not provided. Maximum water depth plots extracted from the 0.5% AEP tide model (see below) show the mechanism described above to be reasonable with shallow depth flooding shown to occur along in the area outside the AFA to be affected. However, significant areas to the west of the affected area are also shown to be inundated during this

event indicating the frequency of the Feb 2014 event was less than 0.5% AEP.

The evidence provided also indicates that there was a breach in the defences in this area. No details of these defences have been provided for the model study. Therefore there was no information available on the geometry of the defence structure during model development. There was also no information on whether this breach was already present at the time of the event or breached at the time. Such a scenario has therefore has not considered to date but will be investigated future scenarios.

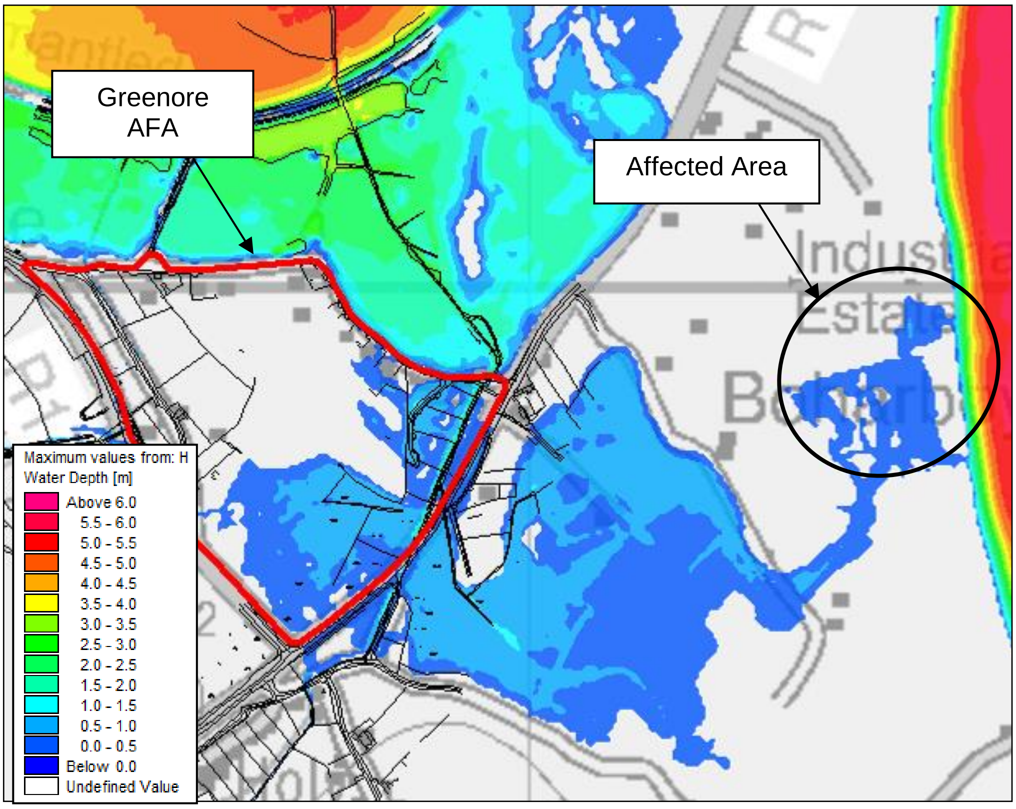


Figure 4.6.21: Water Depth Plots extracted from the 0.5% AEP tide model

No further information on source, flow levels, tide levels or return period is available so this event is not suitable to facilitate model calibration.

Summary of Calibration

No data could be found relating to specific historical flood events at Greenore, so it was not possible to use data from nearby rainfall, flow or tidal gauges to verify the model.

Model flows were checked against the estimated flows at HEP check points where possible to ensure the model is well anchored to the hydrological estimates. For example at HEP 06_1075_2_RPS, the estimated flow during the 1% AEP event is 3.12m^3/s (IBE0700Rp0006_UoM 01 Hydrology Report_D01, Appendix D) and the modelled flow is 1.35m^3/s. It should be noted that the downstream HEP 06_1075_2_RPS is subject to tidal processes from Carlingford Lough, so the model simulated flow at this

point is subject to both fluvial and coastal influences which is not accounted for in the hydrological estimates. Full flow tables and discussion of comparison results are in Appendix A.3

There are a limited number of historic flood events to and therefore very little detail is available relating to affected areas, flood extents and estimated fluvial and tidal AEPs. The model outputs from the fluvial and tidal events considered can be considered a worst case with the fluvial peak flows coinciding with peak tide levels. More detail on previous flood event conditions would be required to achieve calibration.

The mass error in the model simulations is very small, showing good conservation of mass and momentum throughout; refer to Chapter 3.11 for details on mass balance acceptable limits. The mass balance was calculated for the fluvial dominated 1% AEP to ensure the model schematisation is robust. The mass balance of the fluvial dominated 1% AEP scenario is -1.44% and as such the model is considered robust and reasonable stability has been achieved.

(2) Post Public Consultation Updates

During consultation with the Local Authorities regarding the draft flood extent maps for Greenore AFA the following points were noted:

- The flooding near the south eastern boundary of the AFA near the R175 was identified as being representative. Comments suggested that the flooding in this area is more likely to be fluvial. This area flooded in February 2014.
- It was suggested that the flood extent around the industrial estate should be more extensive, however flooding at this location may be pluvial.
- Tidal flooding occurred north of the industrial estate in February 2014 and the tidal maps indicate flooding within this area.
- It was commented that during the event in February 2014 a 2-3m land slip occurred to the east of the industrial estate.
- It was stated that there was no memory of the houses flooding within the AFA, however it was stated that it still may have happened in the past.
- The flooding to the north of the AFA boundary is representative, the golf course closes quite often during winter as a result.

All recorded comments were investigated following informal public consultation and formal S.I. public consultation periods in 2015. General model updates were applied to refine model resolution and improve model stability, mapping issued as Final reflects these changes.

(3) Standard of Protection of Existing Formal Defences:

Defence Reference	Type	Watercourse	Bank	Modelled Standard of Protection (AEP)
None				

(4) Gauging Stations:

None

(5) Other Information:
None

4.6.6 Hydraulic Model Assumptions, Limitations and Handover Notes

(1) Hydraulic Model Assumptions:

(a) On the northern edge of the AFA the watercourses discharge into a tidal transition zone prior to discharging into Carlingford Lough through a culvert beneath the dismantled railway (Structure ref: 0634M00006I_CUL). During the events considered, this transitional zone is shown to regularly inundate with tidal flows, submerging the small watercourses and numerous minor structures in this area (associated with the golf course) by 1-2m causing significant model instabilities. To improve the overall representation of this low lying area and model stability, this area has been modelled in 2D-only with the relevant watercourses discharging into the area via standard links in the MIKE FLOOD model.

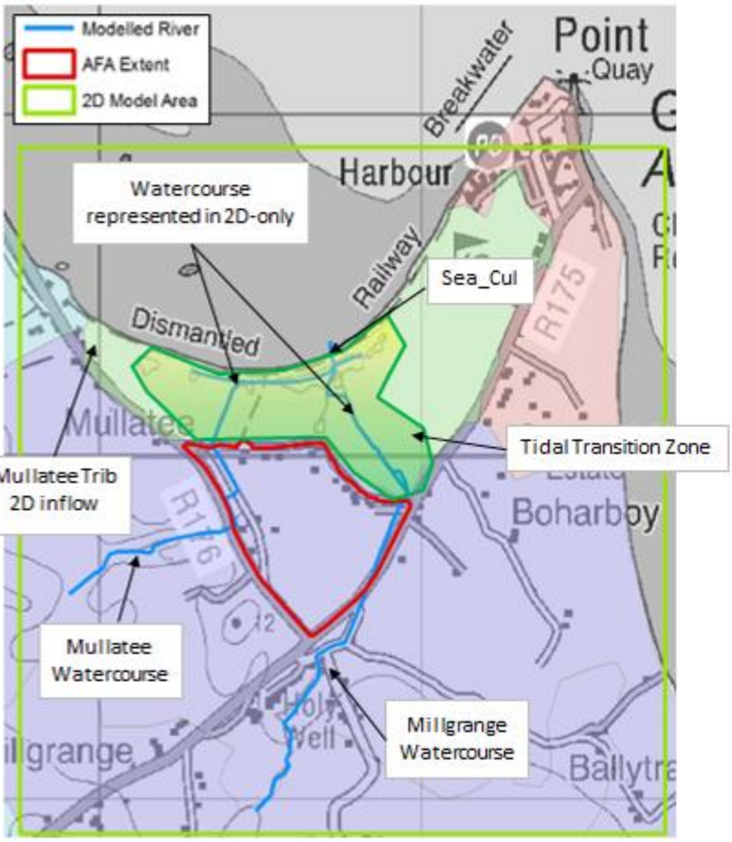


Figure 4.6.22: Watercourse reaches that were represented in the 2D domain only

(c) Minor structures in the tidal transition zone have not been included as they are considered to have limited effect on local flood risk but are a source of significant instabilities. The excluded structures are detailed below (Figure 4.6.23- Figure 4.6.29).

Structures not included (considered to have limited effect on local flood risk):

Millgrange Watercourse:

0634M00021D,0634M00027D, 0634M00038D,0634M00043D, 0634M00046D, 0634M00053D

Mullatee Watercourse:

0633M00005D, 0633A00025D

Figure 4.6.23: Structure 0634M00021D – Golf Course Access

Figure 4.6.24: Structure 0634M00027D – Golf Course Access

Figure 4.6.25: Structure 0634M00038D – Golf Course Access

Figure 4.6.26: Structure 0634M00043D – Golf Course Access

Figure 4.6.27: Structure 0634M00046D – Golf Course Access

Figure 4.6.28: Structure 0634M00053D – Golf Course Access

Figure 4.6.29: Structure 0634M00038D – Golf Course Access

(c) To ensure the watercourse channels are adequately represented within the 2D domain, the M11 Map tool has been used to 'stamp' the surveyed river x-sections and bed profile into the 2D domain. Limitations of this approach are discussed in Section 4.6.6(2) below. Having removed the lower reaches of the Mullatee and Millgrange watercourses from the tidal transition zone, the culvert beneath the dismantled railway has been represented using a 1D culvert structurs defined by the survey data provided (Structure ref: 0634M00006I_CUL; Branch Sea_Cul).

(d) To ensure all fluvial inflows are considered within the 1D/2D model domain, a single 2D inflow has been applied to represent the flow contribution from the Mullatee Tributary - i.e. hydrograph applied directly to given MIKE 21 cell.

(e) Separate fluvial and tidal versions of the models have been set up each with a separate network and cross-section file. This was done to further improve model stability through the lateral links in the lower reaches (880m for Mullatee and 1100m for Millgrange) which become significantly drowned under extreme tidal conditions (0.5% and 0.1% AEP). For the tidal dominated scenarios the length of Millgrange reach,

0634M was further reduced in the 1D model to chainage 519m. Hydraulically significant culverts downstream of chainage 519m on the 0634M reach have been included within the 2D domain using 1D structures; namely 0634M00110I, 0634M00107I, 0634M00089I and 0634M00076I. (f) The in-channel roughness coefficients were selected based on normal bounds using photos received from the channel and structure survey. It is assumed that the final selected values are representative using CIRIA's (1997) Manning's n values for culverts as a reference, see Chapter 3.6.1. (g) Input hydrographs were delayed so that fluvial peak flows corresponds with the tidal surge peak. This is to ensure the AFA was subjected to the highest volumes of water from both sources of flooding at the same time for each scenario. (h) For all simulations it has been assumed that all culverts and screens are free of debris and sediment. (i) Sections of the 1D model represented by long culverts (>20m) have not been 'blocked out' or linked to the 2-D model (via lateral links) to improve representation of possible cross-flow over the structure in the 2-D modal during high flow events. (j) The 2-D model has two open boundaries as the estimated high tide levels could overtop adjacent land.
(2) Hydraulic Model Limitations and Parameters:
Limitations (a) The model is poorly calibrated due to a lack of historical and hydrometric data. (b) The model is effectively ungauged for the purposes of flow estimation, as detailed in IBE0700Rp0008_UoM06 Hydrology Report_F01. (c) Coastal still water levels are modelled, as such flooding caused by wave run-up and overtopping is not taken account of. (d) The lateral links on the Mullatee and Millgrange watercourses require an exponential smoothing factor of 0.8 for improved stability. All standard links have been given an exponential smoothing factor of 0.2 for improved stability. (e) The lateral length depth tolerance was increased to 0.2m to improve model stability through the lateral links. (f) A 5m grid Digital Terrain Model was used with buildings excluded from the floodplain. When blocking out the watercourse channels in preparation for joining the 1-D and 2-D models, the 'minimum of one grid cell' has been applied. This approach may give some mass balance issues where the channel width is less than then grid size (<5m). (g) Courant numbers have been reviewed for both the fluvial and tidal versions of the models and are shown to be <1. (f) A detailed review of discharge curves and hydrographs throughout the fluvial and tidal versions of the models has been completed. The models (including structures) are shown to be stable throughout the simulations completed. Discharge curves through the 1D structures within the 2D domain of the tidal dominated scenario show some instabilities during the 0.1% AEP event only. However surrounding water levels are shown to be stable. None of these instabilities cause out of bank flooding therefore the instabilities were considered acceptable.

Hydraulic Model Parameters:	
MIKE 11	
Timestep (seconds)	0.5
Wave Approximation	Fully Dynamic
Delta	0.7
Inter1Max	100
MIKE 21	
Timestep (seconds)	0.5
Drying / Flooding / (metres)	0.01 / 0.02
Eddy Viscosity (and type)	1/Constant/Flux based
MIKE FLOOD	
Link Exponential Smoothing Factor (where non-default value used)	Standard Links: 0.2 Lateral Links: 0.8
Lateral Length Depth Tolerance (m) (where non-default value used)	0.2
(3) Design Event Runs & Hydraulic Model Handover Notes:	

(a) The coastal boundary total water level is based on tide levels at Cranfield Point and ICPSS point NE27.

(b) The cross-section and network files differ for the fluvial dominated and tidal dominated design run simulations, see Appendix A.4 for file references. The parameters within the HD parameter file are identical for all design run scenarios.

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

(d) Global surface elevation initial conditions of -1.87mOD Malin in the 2D domain have been used during all design runs.

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

Fluvial Domainted Scenarios

During the fluvial events (coinciding with the 50% AEP tidal event) shallow depth flooding of the southern

portion of the Greenore AFA is shown. No properties are shown to experience flooding during the 10% AEP event. However, during both the 1% and 0.1% AEP fluvial events 2no. and 6no. properties respectively are shown to flood (≈150mm), see Figure 4.6.30 and Figure 4.6.31.

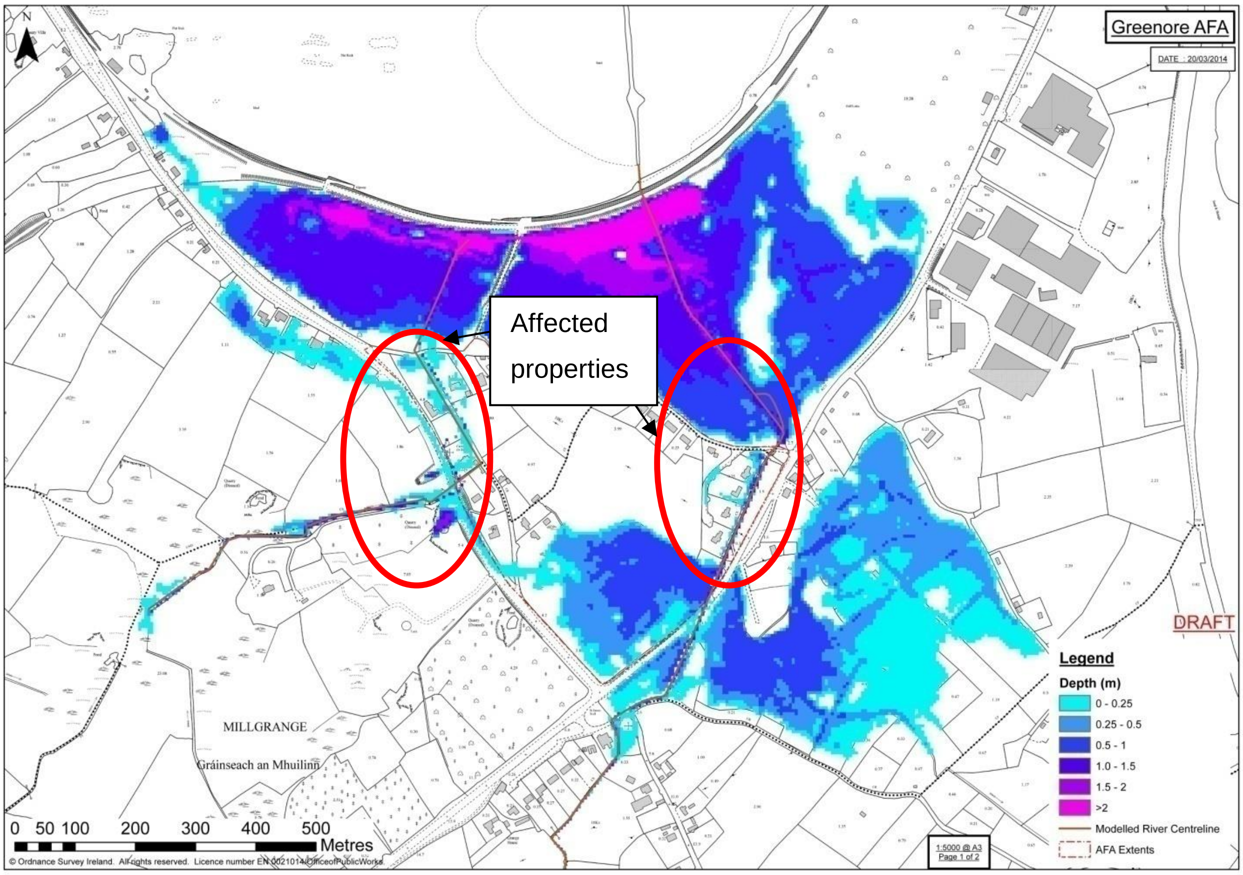


Figure 4.6.30: Modelled flooding at Greenore AFA at the Fluvial Dominated 1%AEP

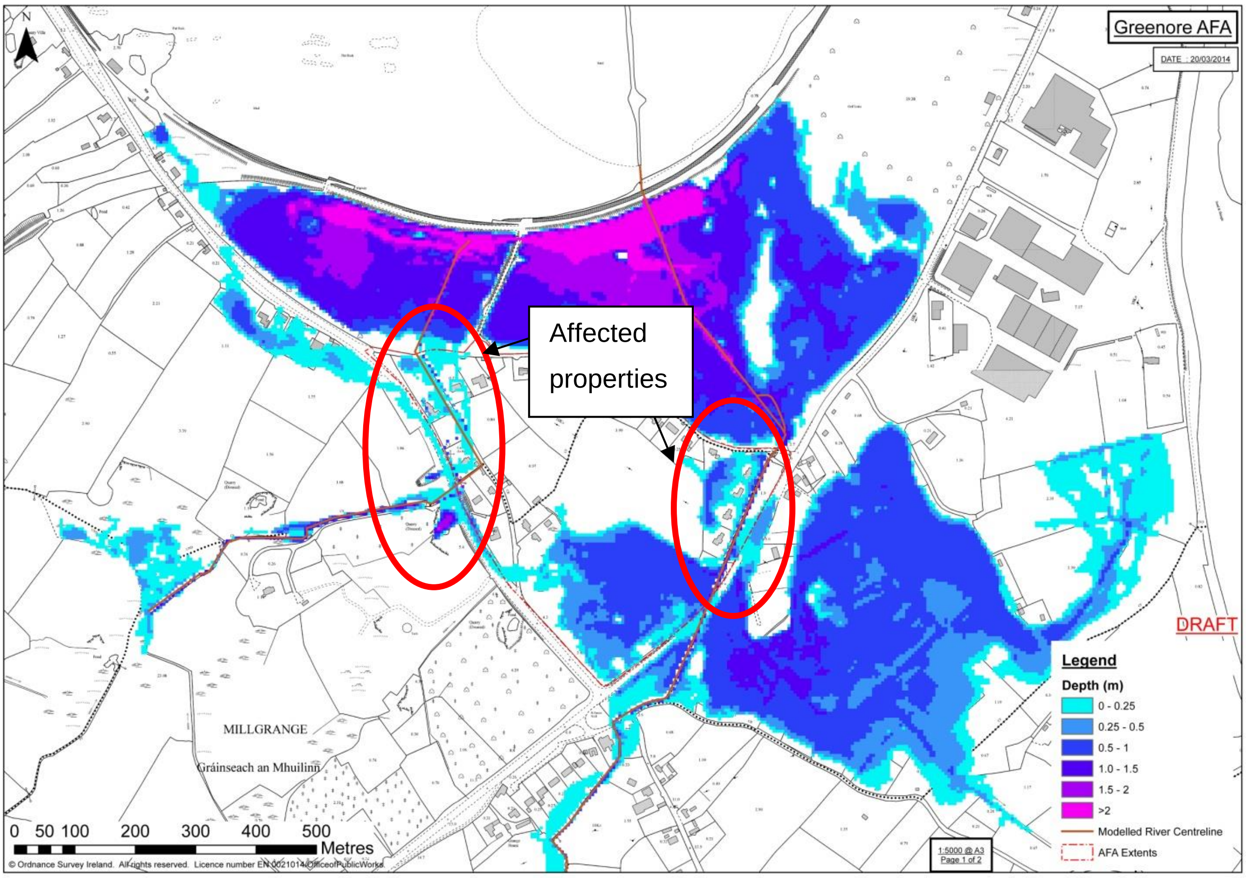


Figure 4.6.31: Modelled flooding at Greenore AFA at the Fluvial Dominated 0.1%AEP

Outside of the Greenore AFA, the Carlingford Lagoons are shown to be completely inundated with depths in excess of 2.5m near the culvert beneath the dismantled railway embankment during the 0.1% AEP event. The embankment itself is not shown to overtop. The golf course in this area is shown to experience significant flooding. To the south-east of the AFA, low lying agricultural land is shown to flood to depths of up to 1m during the 0.1% AEP event with a small number of agricultural buildings being affected.

The primary cause of the flooding throughout the Carlingford Lagoons is the height of the predicted tidal events with the 50% AEP tide levels being higher than the low lying ground throughout this area. Water enters this area from Carlingford Lough via the culvert beneath the dismantled railway embankment (Structure ref: 0634M00006I_CUL). Tidal inundation of the lagoons (which coincides with peak fluvial flows) prevents both the Mullatee and Millgrange watercourses discharging into this area. This subsequently results in water backing up the channels leading to localised spilling around the AFA.

Tidal Dominated Scenarios

During the tidal events (coinciding with the 50% AEP fluvial event) large parts (eastern portion) of the Greenore AFA are shown to flood, particularly during the 0.1% AEP event. Although no properties are shown to experience flooding during the 10% AEP event, properties are shown to flood during both 0.5% and 0.1% AEP fluvial events; 7no. and 13no. properties during the 0.5% and 0.1% respectively, see Figure 4.6.32 and Figure 4.6.33. During the 0.1% AEP event flooding to some of these properties exceed

1.5m.

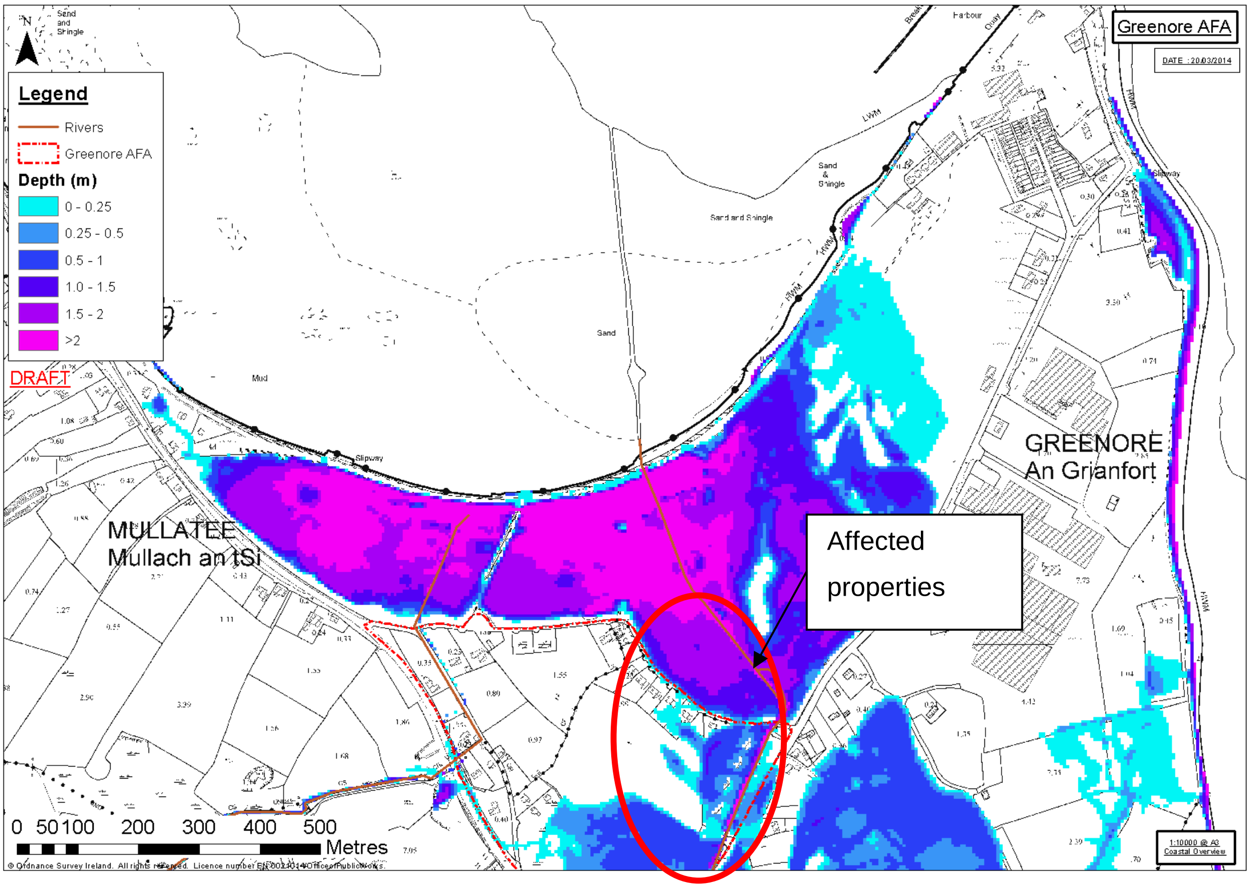


Figure 4.6.32: Modelled flooding at Greenore AFA at the Tidal Dominated 0.5%AEP

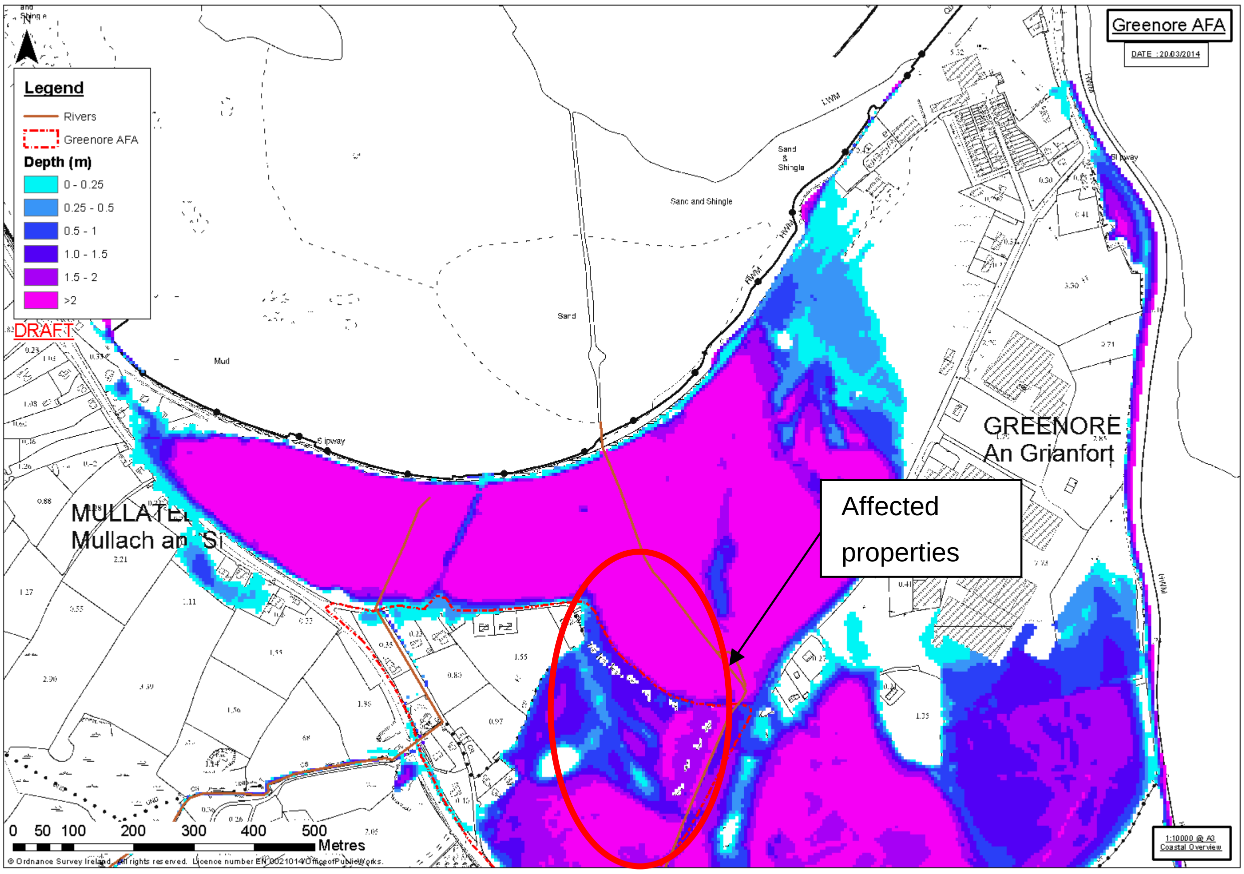


Figure 4.6.33: Modelled flooding at Greenore AFA at the Tidal Dominated 0.1%AEP

Outside of the Greenore AFA, the Carlingford Lagoons are shown to be completely inundated with depths in excess of 4.7m near the culvert beneath the dismantled railway embankment during the 0.1% AEP event. The embankment itself is shown to overtop during the 0.5% and 0.1% AEP events. The golf course in this area is shown to experience significant flooding. To the south-east of the AFA, low lying agricultural land is shown to flood to depths of up to 2.5m during the 0.1% AEP event. This area extends toward the Greenore Industrial estate (outside the AFA) which would also experience flooding of approximately 0.5m. Some tidal inundation from the eastern model boundary into this area is also shown to contribute to flooding during the 0.5% and 0.1% AEP events.

The primary cause of the flooding throughout the area is the height of the predicted tidal levels which inundate the lower lying areas during the event peak.

(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:	Chris Lewis
Model Reviewed by:	Stephen Patterson
Model Approved by:	Malcolm Brian

APPENDIX A.1

MODELLED STRUCTURES

1D Structures modelled in the 1D domain

Structure Details - Bridges and Culverts:

RIVER BRANCH	CHAINAGE	ID**	LENGTH (m)	OPENING SHAPE	HEIGHT (m)	WIDTH (m)	SPRING HEIGHT FROM INVERT (m)	MANNING'S n
Millgrange	1099.872	0634M00055I	4.35	Irregular	1.77	1	N/A	0.013
Millgrange	1085.021	0634M00056I	7.65	Irregular	1.28	1.05	N/A	0.013
Millgrange	890.994	0634M00076I	13.35	3 x Circular	0.6	-	N/A	0.013
Millgrange	793.552	0634M00089I	75.7	2 x Circular	0.8	-	N/A	0.013
Millgrange	653.443	0634M00100	1.1	Irregular	0.2	0.58	N/A	0.013
Millgrange	603.808	0634M00103	1	Irregular	0.36	1.13	N/A	0.013
Millgrange	574.5	0634M00107I	9.6	Irregular	0.29	0.35	N/A	0.013
Millgrange	504.5	0634M00115I	31.6	Irregular	0.67	1.07	N/A	0.013
Mullatee	875.2	0633M00022I	8	Circular	0.6	-	N/A	0.013
Mullatee	725.25	0633M00037I	6.9	Circular	0.7	-	N/A	0.013
Mullatee	624.67	0633M00049I	186	Irregular	0.27	0.51	N/A	0.013
Mullatee	219.35	0633M00083I	3	Irregular	1.17	5.35	N/A	0.013
Sea_Cul	31.22	0634M00006I_CUL	51	2 x Circular	1	-	N/A	0.013
Millgrange	550.191	0634M00110I	9.6	Irregular	0.5	1.08	N/A	0.015

Structure Details - Weirs

RIVER BRANCH	CHAINAGE	ID**	MANNING'S n	TYPE
Millgrange	537.346	0634M00111W	0.06	Broad Crested Weir

1D Structures modelled in the 2D domain
Structure Details - Bridges and Culverts:
See table below
Structure Details - Weirs:
None

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

D – Bridge Upstream Face

E – Bridge Downstream Face

I – Culvert Upstream Face

J – Culvert Downstream Face

NB: All other weirs in the Network file are over topping weirs which form part of a composite structure with the culvert/bridge at the corresponding chainage.

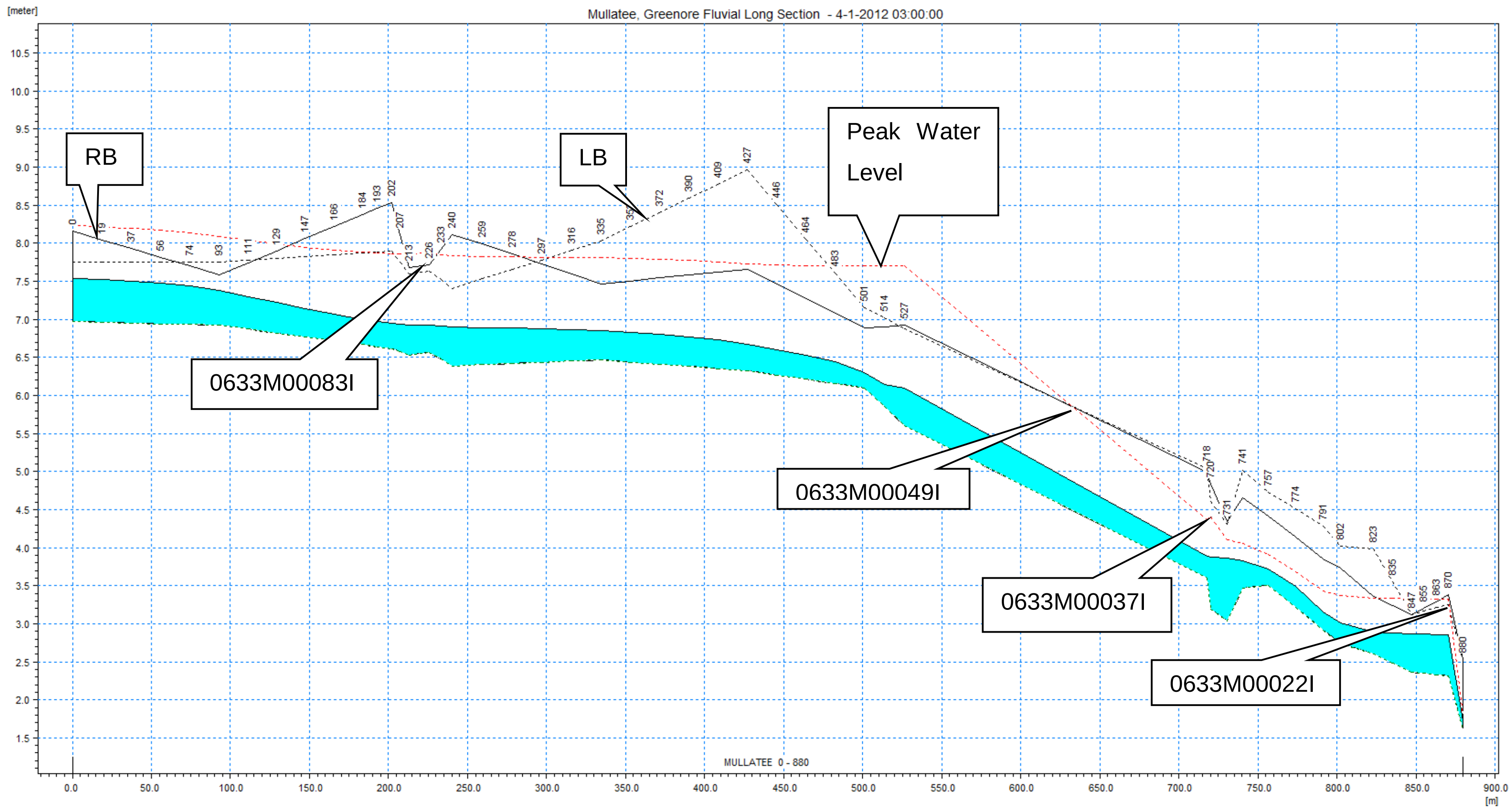
River Branch	Structure ID	Chainage	Fluvial Dominated Events		Tidal Dominated Events	
			1D	2D	1D	2D
Millgrange	0634M00055I	1099.872	□	-	-	-
Millgrange	0634M00056I	1085.021	□	-	-	-
Millgrange	0634M00076I	890.994	□	-	-	□
Millgrange	0634M00089I	793.552	□	-	-	□
Millgrange	0634M00100	653.443	□	-	-	-
Millgrange	0634M00103	603.808	□	-	-	-
Millgrange	0634M00107I	574.5	□	-	-	□
Millgrange	0634M00110I	550.191	□	-	-	□
Millgrange	0634M00115I	504.5	□	-	□	-
Mullatee	0633M00022I	875.2	□	-	□	-
Mullatee	0633M00037I	725.25	□	-	□	-
Mullatee	0633M00049I	624.67	□	-	□	-

Mullatee	0633M00083I	219.35	□	-	□	-
Sea_Cul	0634M00006I_CUL	31.22	□	-	-	-
Millgrange	0634M00111W	537.346	□	-	-	-

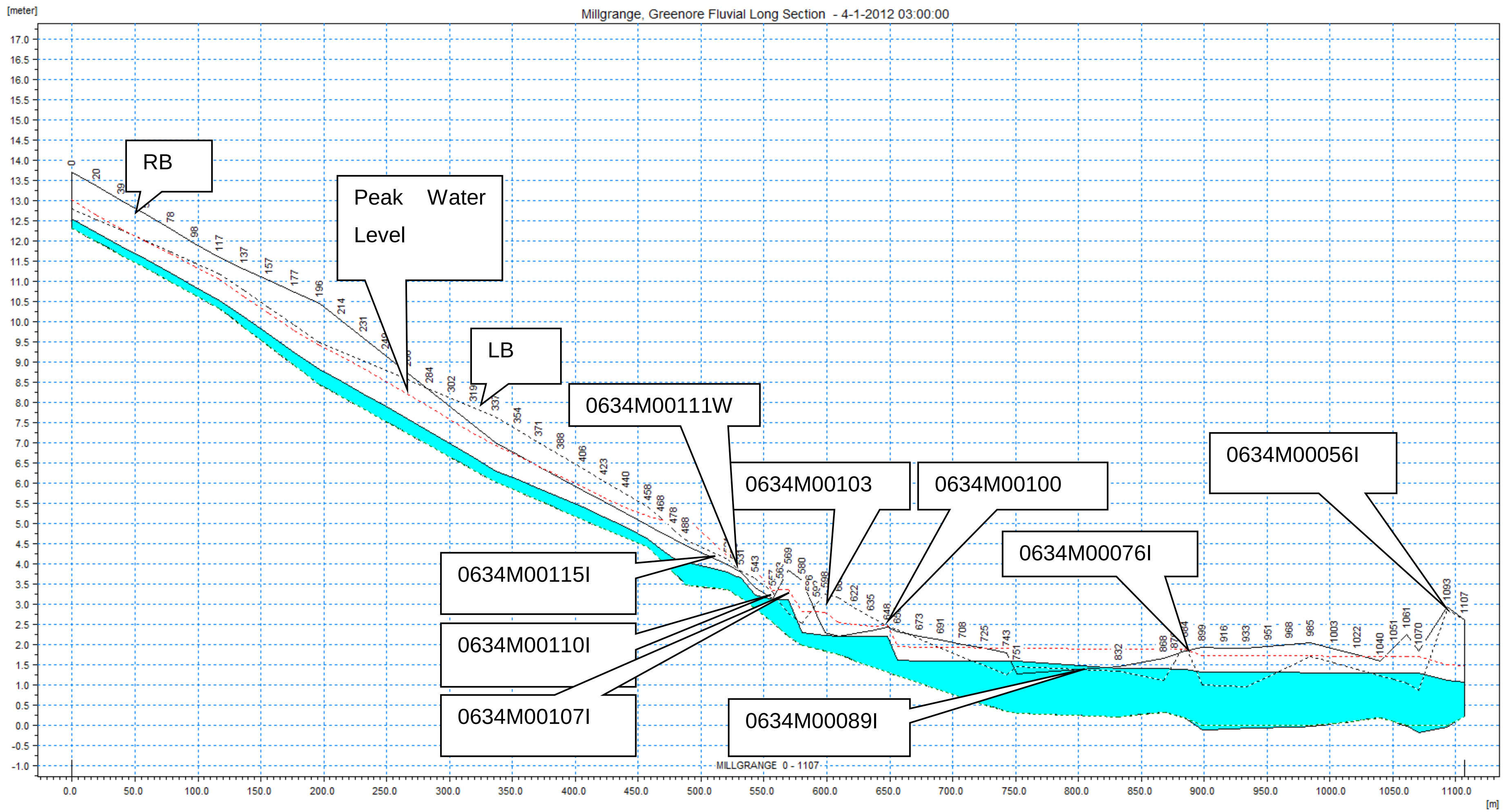
APPENDIX A.2

RIVER LONG SECTION PROFILES

Long Section Profile Plots



Mullatee Watercourse 0.1% Fluvial Dominated Flow



Millgrange Watercourse 0.1% Fluvial Dominated Flow

APPENDIX A.3

ESTIMATED PEAK FLOW AND MODEL FLOW COMPARISON

		Peak Water Flows		
River Name & Chainage	**AEP**	**Check Flow (m^3/s)**	**Model Flow (m^3/s)**	**Diff (%)**
MILLGRANGE 1099.87	10%	1.69	1.12	-33.61
06_1075_2_RPS	1%	3.12	1.35	-56.63
	0.1%	5.53	1.50	-72.95
MULLATEE 875.2	10%	0.89	0.86	-3.37
06_227_D	1%	1.63	1.60	-1.72
	0.1%	2.89	2.39	-17.23

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

The discharge at both Millgrange 1099.87 and Mullatee 875.2 are a combination of fluvial and tidal components. As a result, it is not possible to reliably check the model flow at this point against the hydrological estimation as the estimated flows are based on fluvial inputs only and do not account for this tidal influence, as such there is a large difference shown during all events simulated in the River Mullatee and the River Millgrange.

APPENDIX A.4

DELIVERABLE MODEL AND GIS FILES

MIKE FLOOD	MIKE 21	MIKE 21 RESULTS
HA06_GREE3_MF_DES_1_F_Q10	HA06_GREE3_M21_DES_1_F_Q10	HA06_GREE3_M21_DES_1_F_Q10
HA06_GREE3_MF_DES_1_F_Q100	HA06_GREE3_M21_DES_1_F_Q100	HA06_GREE3_M21_DES_1_F_Q100
HA06_GREE3_MF_DES_1_F_Q1000	HA06_GREE3_M21_DES_1_F_Q1000	HA06_GREE3_M21_DES_1_F_Q1000
HA06_GREE3_MF_DES_1_T_Q10	HA06_GREE3_M21_DES_1_T_Q10	HA06_GREE3_M21_DES_1_T_Q10
HA06_GREE3_MF_DES_1_T_Q200	HA06_GREE3_M21_DES_1_T_Q200	HA06_GREE3_M21_DES_1_T_Q200
HA06_GREE3_MF_DES_1_T_Q1000	HA06_GREE3_M21_DES_1_T_Q1000	HA06_GREE3_M21_DES_1_T_Q1000

MIKE 11 - SIM FILE & RESULTS FILE	MIKE 11 - NETWORK FILE	MIKE 11 - CROSS-SECTION FILE	MIKE 11 - BOUNDARY FILE
HA06_GREE3_M11_DES_1_F_Q10	HA06_GREE3_NWK_DES_1	HA06_GREE3_XNS_DES_1	HA06_GREE3_BND_DES_1_F_Q10
HA06_GREE3_M11_DES_1_F_Q100	HA06_GREE3_NWK_DES_1_Tidal	HA06_GREE3_XNS_DES_1_Tidal	HA06_GREE3_BND_DES_1_F_Q100
HA06_GREE3_M11_DES_1_F_Q1000			HA06_GREE3_BND_DES_1_F_Q1000
HA06_GREE3_M11_DES_1_T_Q10			HA06_GREE3_BND_DES_1_T_Q10
HA06_GREE3_M11_DES_1_T_Q200			HA06_GREE3_BND_DES_1_T_Q200
HA06_GREE3_M11_DES_1_T_Q1000			HA06_GREE3_BND_DES_1_T_Q1000
MIKE 11 - DFS0 FILE		**MIKE 11 - HD FILE & RESULTS FILE***	
GREE3_DFS0_F_Q2		HA06_GREE3_HD_DES_1_F_Q10	HA06_GREE3_MF_DES_1_F_Q10
GREE3_DFS0_F_Q10		HA06_GREE3_HD_DES_1_F_Q100	HA06_GREE3_MF_DES_1_F_Q100
GREE3_DFS0_F_Q100		HA06_GREE3_HD_DES_1_F_Q1000	HA06_GREE3_MF_DES_1_F_Q1000
GREE3_DFS0_F_Q1000		HA06_GREE3_HD_DES_1_T_Q10	HA06_GREE3_MF_DES_1_T_Q10
GREE3_DFS0_T_Cut		HA06_GREE3_HD_DES_1_T_Q200	HA06_GREE3_MF_DES_1_T_Q200
		HA06_GREE3_HD_DES_1_T_Q1000	HA06_GREE3_MF_DES_1_T_Q1000

GIS Deliverables - Hazard		
Flood Extent Files (Shapefiles)	**Flood Depth Files (Raster)**	**Water Level and Flows (Shapefiles)**
Fluvial n24exfcd100f0 n24exfcd010f0 n24exfcd001f0 Coastal n24exccd100f0 n24exccd005f0 n24exccd001f0	Fluvial n24dpfcd100f0 n24dpfcd010f0 n24dpfcd001f0 Coastal n24dpccd100f0 n24dpccd005f0 n24dpccd001f0	Fluvial N16NDFCDF0 Coastal N16NDCCDF0
Flood Zone Files (Shapefiles)	**Flood Velocity Files (Raster)**	**Flood Defence Files (Shapefiles)**
N26ZNA_MCDC1 N26ZNB_MCDC1	Fluvial n24vlfcd100f0 n24vlfcd010f0 n24vlfcd001f0 Coastal n24vlccd100f0 n24vlccd005f0 n24vlccd001f0	N/A
GIS Deliverables - Risk		
Specific Risk - Inhabitants (Raster)	**General Risk - Economic (Shapefiles)**	**General Risk-Environmental (Shapefiles)**
n26riccd001F0 n26riccd005F0 n26rifcd001F0 n26rifcd010F0 n26rifcd100F0		