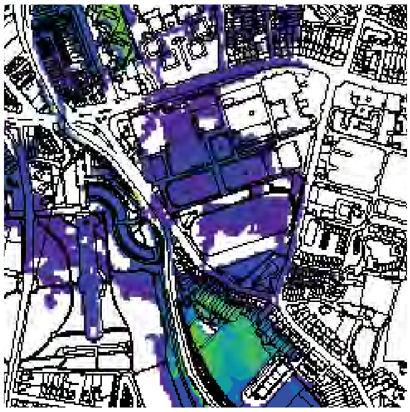
RPS

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

North Western - Neagh Bann CFRAM Study

UoM 01 Hydraulics Report
4.7 Carndonagh

IBE0700Rp0011



OPW
The Office of Public Works
Oifig na nOibreacha Poiblí

Photographs of flooding on cover provided by Rivers Agency

NWNB CFRAM Study

HA01 Hydraulics Report

Carndonagh Model

DOCUMENT CONTROL SHEET

Client	OPW
Project Title	NWNB CFRAM Study
Document Title	IBE0700Rp0011_HA01 Hydraulics Report
Model Name	Carndonagh

Rev.	Status	Author(s)	Modeller	Reviewed by	Approved By	Office of Origin	Issue Date
D01	Draft	Various	I. Bentley	S. Patterson	G. Glasgow	Limerick/Belfast	18/06/2014
F01	Draft Final	Various	I. Bentley	L. Arbuckle	G. Glasgow	Belfast	24/11/2014
F02	Draft Final	Various	I. Bentley	L. Arbuckle	G. Glasgow	Belfast	13/08/2015
F03	Draft Final	Various	J. Deery	S. Patterson	G. Glasgow	Belfast	08/07/2016

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 UoM01 Inception Report	**February 2013**	IBE0700Rp0002_UoM 01 Inception Report	**4.3.2**
North Western Neagh Bann CFRAM Study Hydrology Report UoM01	**July 2013**	IBE0700Rp0006_UoM 01 Hydrology Report	**4.2**
North Western Neagh Bann CFRAM HA01_06_36 Survey Contract Report	**October 2013**	IBE0700Rp0007_HA01_06_36 NWNB_CFRAM_Survey Contract Report	**1.6**

4 HYDRAULIC MODEL DETAILS

4.7 CARNDONAGH MODEL

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 Carndonagh as an AFA for fluvial flooding based on a review of historic flooding and the extents of flood risk determined during the PFRA. The area was not deemed to be at risk from coastal flooding under the NTCG GN20 Joint Probability Guidance (IBE0601TN0002_Joint Probability Guidance_F01) as presented in the North-West and Neagh-Bann Flood Risk Review. Carndonagh is located just upstream of two of the main river sources of Trawbreaga Bay, a tidal estuary at the north of Inishowen in Donegal. The Donagh and Glennagannon Rivers are the main sources of fluvial flood risk to Carndonagh. Both catchments emanate from hilly bog land to the south of the town and their catchments are similar in size at 35km^2 and 25km^2 respectively. The proportion of predominantly peat soils in the Donagh and Glennagannon catchments is high at approximately 40% and 70% respectively. There are three gauging station sites within the modelled reaches but all are inactive, staff gauge sites with no data available. As such the model is totally ungauged for the purposes of flow estimation. The nearest gauging station with flow data available is located near Clonmany on Lough Fad to the west of the catchment. The data at this station was not given a rating classification under FSU due to low confidence in flows at Q_{med}. Stations with available data that are closest geographically or the most hydrologically similar stations to the Carndonagh catchment were not used to adjust initial Q_{med} estimations in the model (based on FSU catchment descriptors). This is because a review of these stations did not indicate a clear trend towards over or under-estimation and as such the initial estimations were unadjusted. Refer to Hydrology Report (Rp0006_F01), Chapter 4.2 for further details. The majority of watercourses that form part of the Carndonagh model are classified as HPW and have therefore been modelled as 1D/2D using ISIS 2D. The downstream sections of the Donagh (0147M) and Glennagannon (0150M) rivers are classified as MPW and were also modelled as 1D/2D using ISIS 2D to simulate floodplain flow. Both these reaches discharge into Trawbreaga Bay, to the north of the Carndonagh AFA. In channel flow has been modelled in ISIS 1D, refer to Chapter 3 and Section 4.7.2 for further details.	
(2) Model Reference:	HA01_CARN2
(3) AFAs included in the model:	Carndonagh
(4) Primary Watercourses / Water Bodies (including local names):	

Reach ID	**Name**	
0147M	DONAGH RIVER	
0147A	DONAGH RIVER TRIB 1	
0148M	CARNDONAGH	
0149M	BALLYWILLY BROOK	
0150M	GLENNAGANNON RIVER	
0150A	MALIN BAY	
Any reaches not named or included within the model have been regarded as minor and hydraulically insignificant. The topography of any minor watercourses is likely to be included within the 2D floodplain DTM.		
(5) Software Type (and version):		
(a) 1D Domain: ISIS v3.7.1	**(b) 2D Domain:** ISIS 2D v3.7.1	**(c) Other model elements:** N/A

4.7.2 Hydraulic Model Schematisation

(1) Map of Model Extents:
Figures 4.7.1 and 4.7.2 illustrate the extent of the modelled catchment, river centre line, HEP locations and AFA extent.

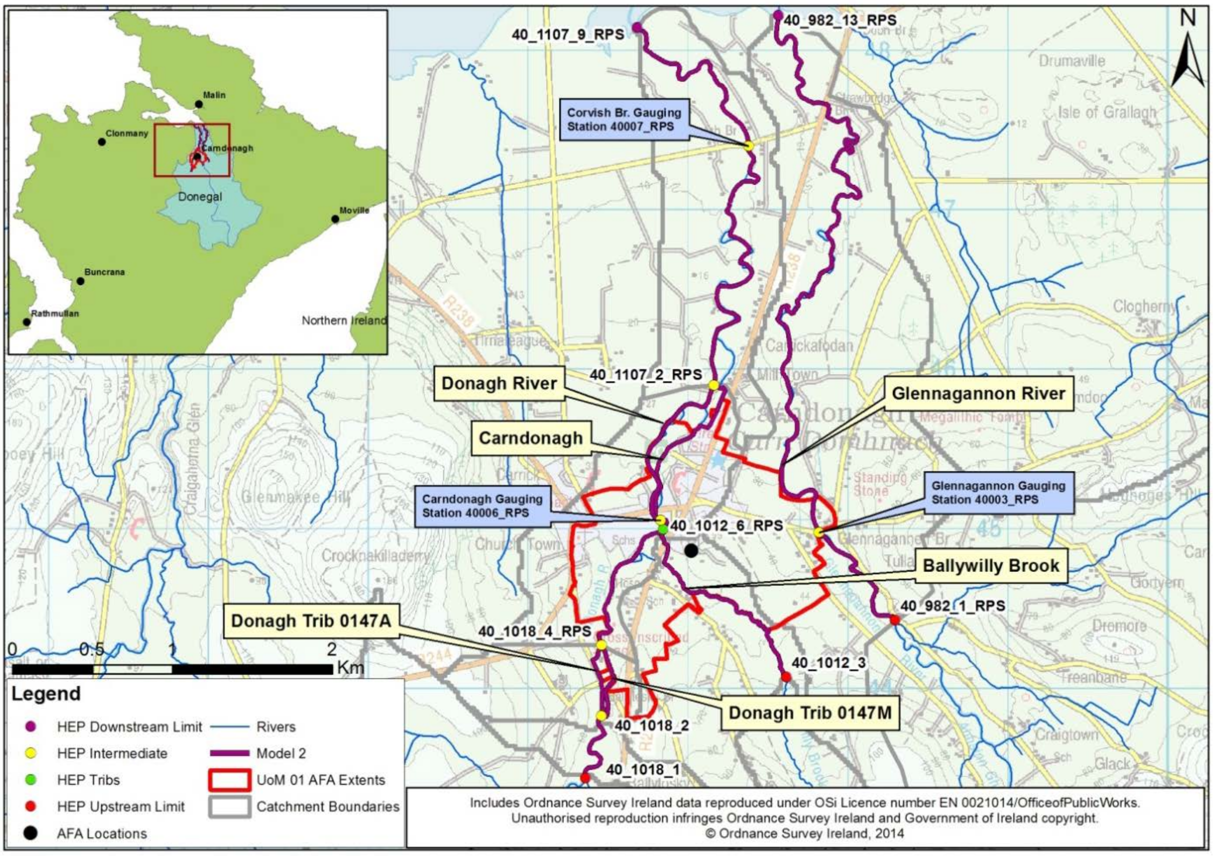


Figure 4.7.1: Map of Model Extents –Carndonagh *** note the gauging stations shown have no data available**

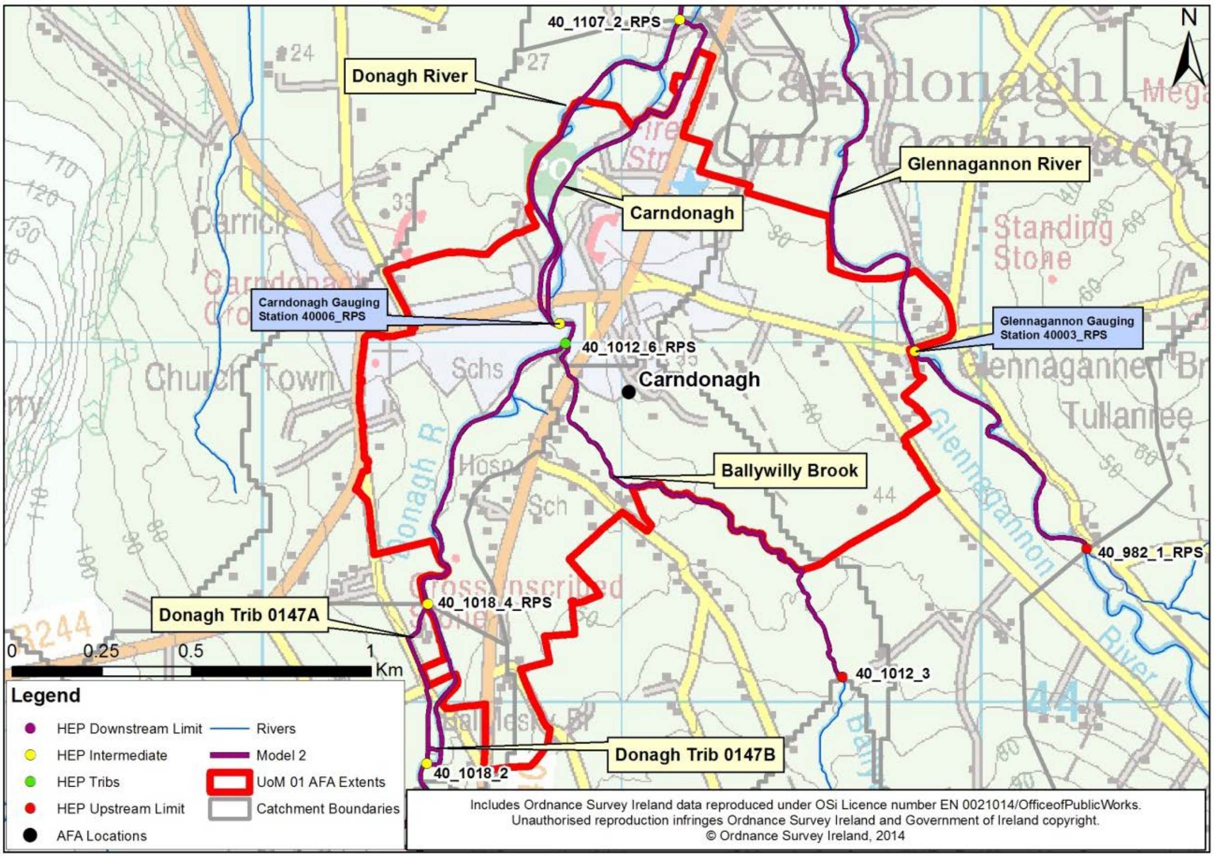


Figure 4.7.2 Map of Model Extents – Carndonagh *** note the gauging stations shown have no data available**

The Carndonagh model contains 3no. Upstream Limit HEPs which are all located to the south and south-east of the AFA boundary, These are HEP 40_1018_1, 40_4012_3 and 40_982_1. There is 1no. HEP Tributary (40_1012_6) where the Ballywilly Brook joins the Carndonagh River. There are three gauging stations (Stn nos. 40003, 40004 and 40006) as shown on Figures 4.7.1 and 4.7.2. These stations have no data available and therefore been redefined as intermediate HEPs. There are 9no. HEP intermediate/ check flow points in total as included in Appendix A.3.

In channel flow has been modelled in ISIS 1D, (refer to Chapter 3). The 1D model has been linked with ISIS 2D, with any overtopping flow passing into ISIS 2D to simulate the floodplain flow. In defining the left and right channel banks in ISIS 1D an assessment was made of the surveyed channel data to estimate where out of bank flow would occur. The 1D reaches and the 2D domain have been linked by means of 1D/2D links which are defined as polyline shapefiles. These shapefiles contain attribute fields that define the ISIS 1D model nodes that the 2D model links with. All HPW and MPW have been modelled as 1D in bank with the floodplain element in 2D.

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

River Name		x	y
0147M	DONAGH RIVER	246208.917	443351.914
0147A	DONAGH RIVER TRIB 1	246455.245	443831.869
0147B	DONAGH RIVER TRIB 2	246494.234	443866.208
0148M	CARNDONAGH	246802.709	445059.803
0149M	BALLYWILLY BROOK	247613.670	444060.822
0150M	GLENNAGANNON RIVER	248293.586	444429.601

(3) Total Modelled Watercourse Length:		15.8 km (approx)	
(4) 1D Domain only Watercourse Length:	N/A	**(5) 1D-2D Domain Watercourse Length:**	15.8 km (approx)
(6) 2D Domain Mesh Type / Resolution / Area:		(ISIS 2D) 0147M / 0148M / 0149M: 2m ISIS 2D grid 0150M: 3m ISIS 2D grid 15 km^2 (approx)	

(7) 2D Domain Model Extent:

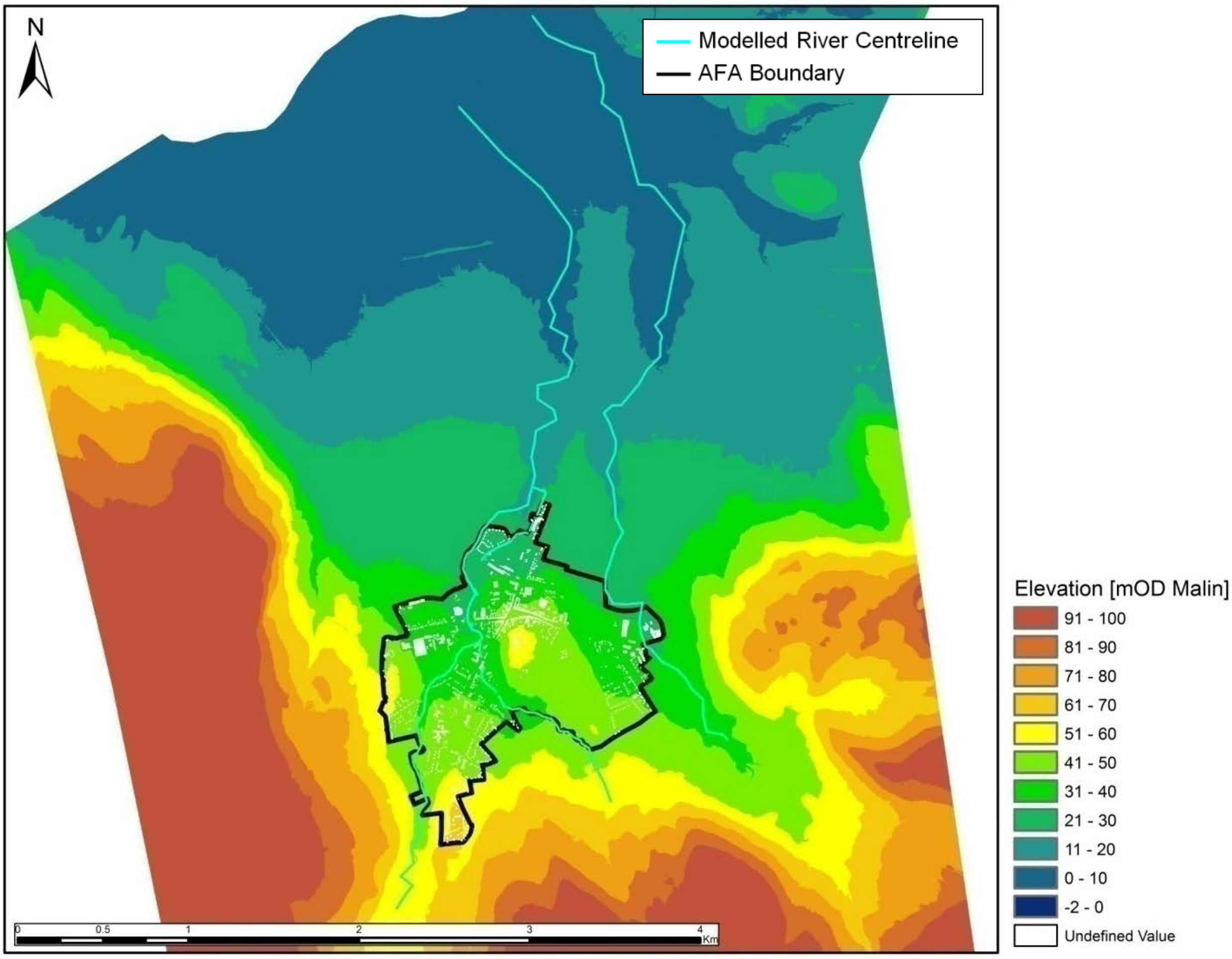


Figure 4.7.3: 2D Model Domain- Carndonagh

Figure 4.7.3 illustrates the modelled extents and general topography. The spatial extent of the AFA boundary is outlined in black. The reach centre-lines are presented in light-blue which also represents the 1D modelled extent that is within the 2D area. Buildings are represented in black, refer to Chapter 3.3.2 for details on representation of buildings in the model.

Figure 4.7.4 shows an overview drawing of the model schematisation. Figure 4.7.5 shows a detailed view. The overview diagram covers the model extents, showing the surveyed cross-section locations, AFA boundary and river centreline. It also shows the area covered by the 2D model domain. The detailed view (Figure 4.7.5) is provided where there is the most significant risk of flooding. This diagram includes the surveyed cross-section locations, AFA boundary and river centreline. It also shows the location of the critical structures as discussed in section 4.7.3(1), along with the location and extent of the links between the 1D and 2D models.

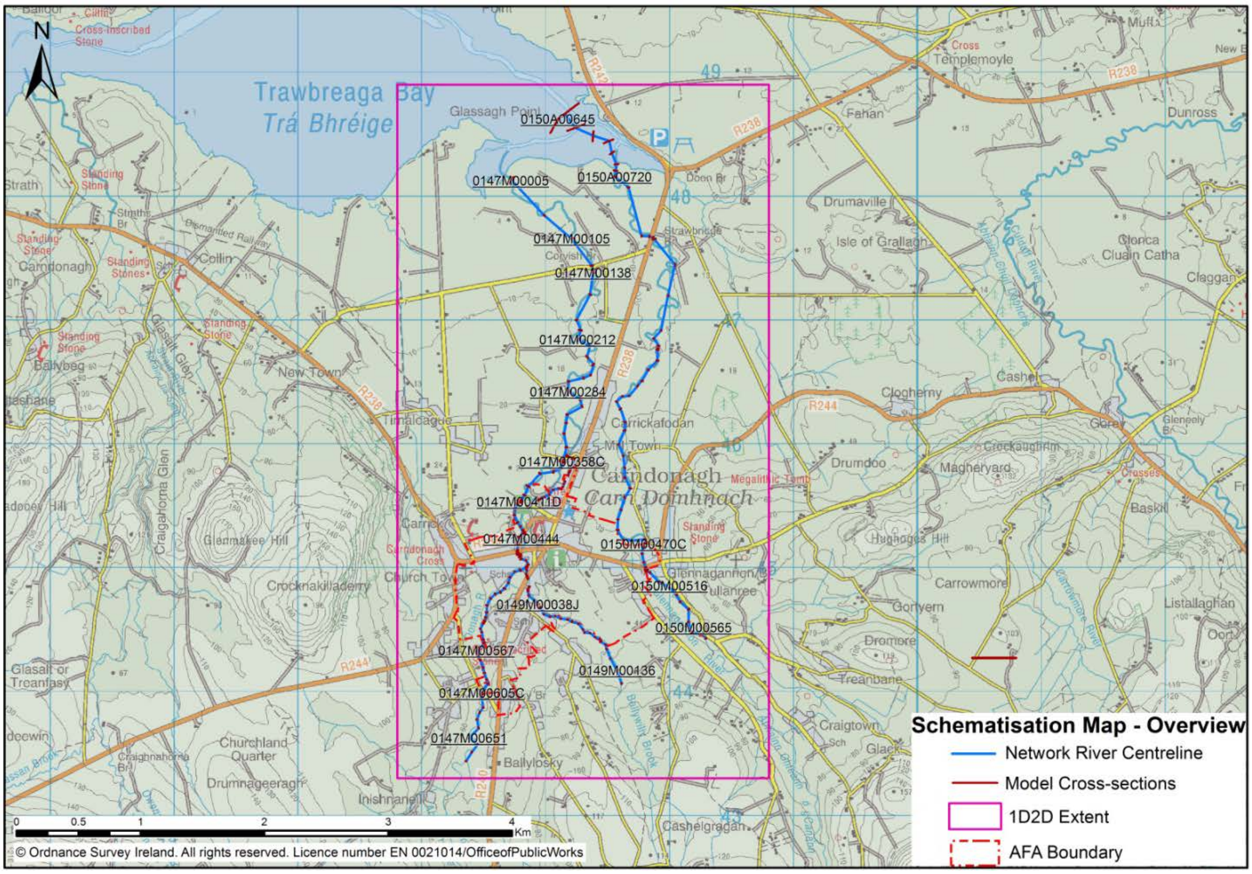


Figure 4.7.4: Model Schematisation Overview Map (Carndonagh)

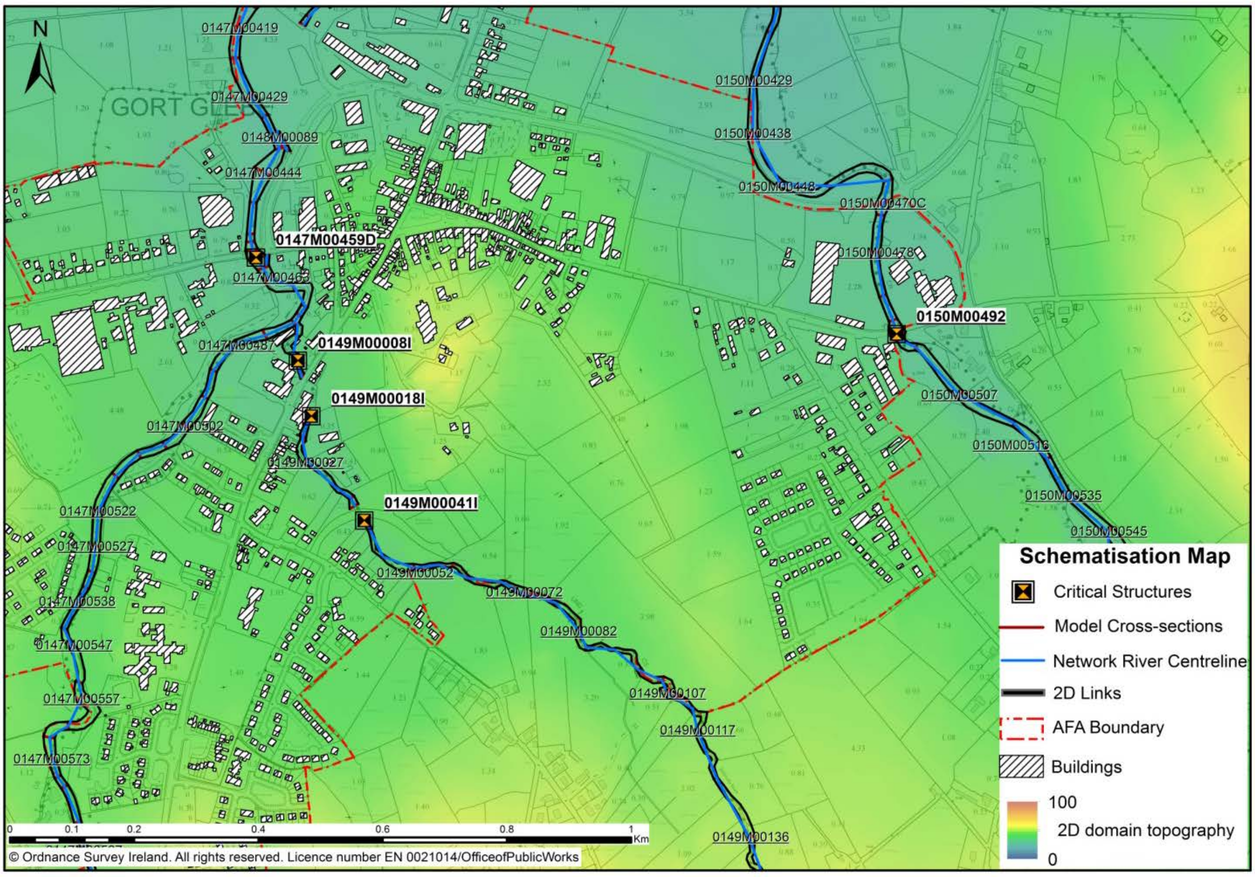


Figure 4.7.5: Detailed Area of Model Schematisation showing Critical Structures

(8) Survey Information

(a) Survey Folder Structure:

<table>
<tr><th>First Level Folder</th><th>Second Level Folder</th><th>Third Level Folder</th></tr>
<tr><td rowspan="4">Murphy_NW1_M02_WP3_0147A_V1_130308
Carndonagh
Murphy: Surveyor Name
NW1: North Western CFRAM Study Area, Hydrometric Area 1
M02: Model Number 2
0147A: River Reference
WP3: Work Package 3
Version: V1
130308: Date Issued (08th MAR 2013)</td><td>V0_20130301_ASCII</td><td></td></tr>
<tr><td>V0_20130301_Other</td><td>Floodplain Photos</td></tr>
<tr><td>V1_20130308_Dwg</td><td>5921_0147A_Donagh River Tributary 1_V1</td></tr>
<tr><td>Photos (Naming convention is in the format of Cross-Section ID and orientation - upstream, downstream, left bank or right bank)</td><td></td></tr>
</table>

(b) Survey Folder References:

Reach ID	Name	File Reference
0147M	DONAGH RIVER	Murphy_NW1_M02_WP3_0147M_V1_130308
0147A	DONAGH RIVER TRIB 1	Murphy_NW1_M02_WP3_0147A_V1_130308
0147B	DONAGH RIVER TRIB 2	Murphy_NW1_M02_WP3_0147B_V1_130308
0148M	CARNDONAGH	Murphy_NW1_M02_WP3_0148M_V1_130308
0149M	BALLYWILLY BROOK	Murphy_NW1_M02_WP3_0149M_V1_130308
0150M	GLENNAGANNON RIVER	Murphy_NW1_M02_WP3_0150M_V1_130308

(9) Survey Issues:

None

4.7.3 Hydraulic Model Construction

(1) 1D Structures (in-channel along modelled watercourses):	14 bridges 10 culverts 3 weirs Note: Detailed information on the chainage of these structures and how they have been represented within the hydraulic model is presented in Appendix A.2.

Figure 4.7.5 (Section 4.7.2 (7)) shows the location of the critical structures which are described as follows.

Structure 0147M00459D is a road bridge on the Donagh River, refer to Figure 4.7.6. Model results indicate that significant out of bank flow occurs at this road bridge, where water levels upstream are increased due to restricted flow for all fluvial events.

Figure 4.7.6: Road Bridge 0147M00459D

Structure 0149M00008I is a culvert on the Ballywilly Brook (refer to Figure 4.7.7) that restricts the flow of flood water during all modelled scenarios, increasing water levels by around 0.5m and contributing to extensive flooding on the left bank.

Figure 4.7.7: Culvert 0149M00008I

Structure 0149M00018I is a culvert on the Ballywilly Brook (refer to Figure 4.7.8) that becomes surcharged during all modelled scenarios and contributes to flooding on the left bank in this area.

Figure 4.7.8: Culvert 0149M00018I

Structure 0149M00022D is a bridge on the Ballywilly Brook (refer to Figure 4.7.9) that becomes surcharged during all modelled scenarios and contributes to flooding on the left bank.

Figure 4.7.9: Culvert 0149M00022D

Structure 0149M00041I is a culvert on the Ballywilly Brook (refer to Figure 4.7.10) that restricts the flow of flood waters during higher fluvial events (≥1%AEP), causing significant additional flooding from the Ballywilly Brook (0149M).

Figure 4.7.10: Culvert 0149M00041I

Structure 0150M00090D. Is a road bridge on the R238 over the Glennagannon River (refer to Figure 4.7.11). It causes an increase in upstream water levels for all modelled scenarios, contributing to extensive flooding in this area.

Figure 4.7.11: Road Bridge 0150M00090D (R238)

Section 3.4.3 describes how structures have been modelled in ISIS.

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

Inflow hydrographs have been derived using the methodology detailed in Section 2.3.3 of the Hydrology Report (IBE0700Rp0006_UoM 01 Hydrology Report_F01). Full details of the flow estimates for Carndonagh are detailed in Section 4.2 and Appendix D of the hydrology report. The boundary conditions implemented in the model are shown in Table 4.7.1 below.

Table 4.7.1: Model Boundary Conditions

	Boundary Type	Branch Name	Boundary HEP
1	Upstream	Donagh River	40_1018_1
2	Upstream	Ballywilly Brook	40_1012_3
3	Upstream	Glennagannon River	40_982_1_RPS
4	Lateral	Donagh River	40_1018_1 & 40006_RPS
5	Lateral	Donagh River	40006_RPS & 40_1107_2_RPS
6	Lateral	Donagh River	40_1107_2 & 40007_RPS
7	Lateral	Ballywilly Brook	40_1012_3 & 40_1012_6_RPS
8	Lateral	Glennagannon River	40_982_1_RPS and 40_982_13

Figure 4.7.12 provides an example of the associated upstream inflow hydrographs on the Donagh, Ballywilly Brook and Glennagannon watercourses at HEPs 40_1018_1, 40_1012_3 and 40_982_1_RPS respectively for a 1% AEP event. The model flow at checkpoints was examined during initial development runs and adjustment of timing of inflow hydrographs was not required for anchoring of the model to estimated flows. Appendix 3 contains further details of comparison of estimated flows with simulated flows in the model.

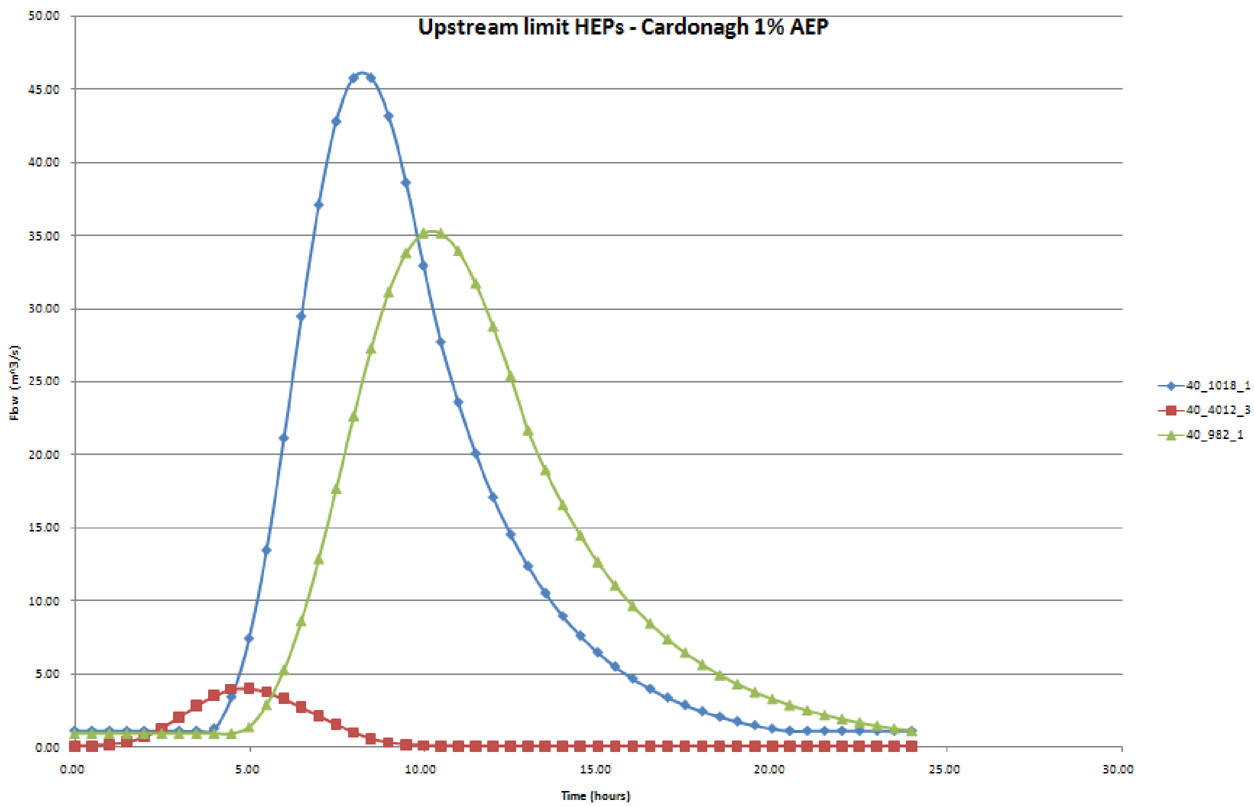


Figure 4.7.12: Upstream Inputs

(5) Model Boundaries – Downstream Conditions:

Both 1D-2D models include head-time (HTBDY) boundaries at their downstream ends to represent coastal water levels. This downstream model boundary is reflective of a Total Water Level (TWL). This was applied to reflect the influence of coastal water levels upon fluvial flooding scenarios. This TWL has been calculated using predicted tidal levels combined with the surge residual. Outputs from the Irish Coastal Protection Strategy Study (ICPSS) have produced extreme tidal and storm surge water levels at nodes around the Irish Coast for a range of AEPs. ICPSS node NW46 (Irish Grid ref. 241921_452568) was used to generate extreme water levels for Trawbreaga Bay, as listed in Table 4.7.2. This ICPSS node is positioned approximately 6.5 km NNW from downstream extent of river 0147M (Donagh).

The Donagh River 1D model was extended by 2km at its downstream end using a copy of cross-section 0147M00005, with the x values increased (to minimise frictional effects in the dummy reach) and y values reduced, to allow the full tidal curve to be included (low water levels are below the bed level in the original surveyed downstream cross-section). A 50% AEP coastal boundary as taken from the ICPSS has been used for the Donagh and Glennagannon, specifically at node NW46.

Table 4.7.2: ICPSS extreme water levels – Node NW46

AEP (%)	**50**	**20**	**10**	**5**	**2**	**1**	**0.5**	**0.1**
NW46 (m AOD Malin)	2.699	2.847	2.953	3.056	3.191	3.293	3.394	3.629

The ICPSS water levels are Total Water Levels (TWL), comprising tidal and surge components which together yield a joint probability event of a particular AEP.

Using information from the Secondary Port of Bulbinbeg in the Admiralty Tide Tables, a tidal water level was established. A tidal curve was generated by fitting this tide level to a sinusoidal curve. A normalised surge profile of 48 hour duration was scaled based on the difference between the peak water level of the generated tidal profile and the target total water level from Table 4.7.2. The scaled residual surge profile was then appended to the tidal profile to obtain the total combined water level time series as required for the relevant AEPs.

Figure 4.7.14 illustrates the tidal profile, storm surge profile and resultant combined total water level profile for a 50% AEP design event. The total water level profile was applied as a level boundary to the Northern edge of the 2D domain, representing the entrance to Trawbreaga Bay.

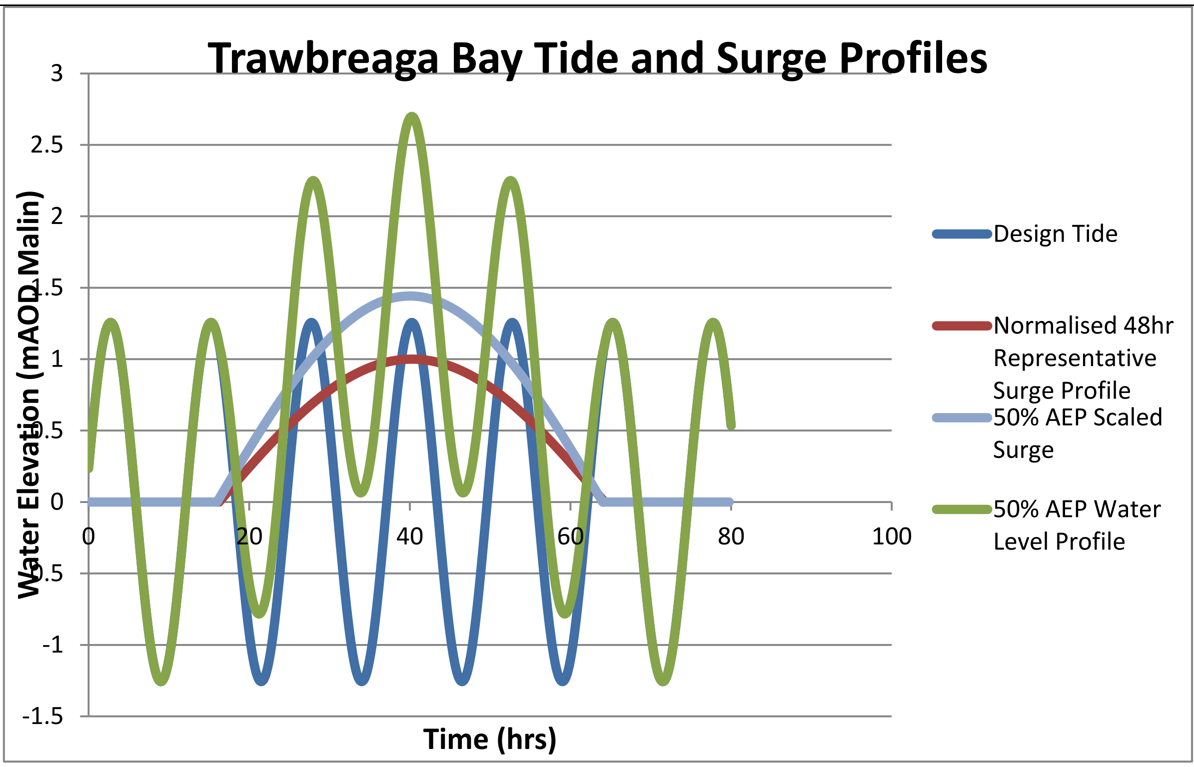


Figure 4.7.13: Trawbreaga Bay Tide and Surge Profiles

NOTE: This AFA has not been identified as potentially vulnerable to a coastal flooding mechanism as detailed in the ongoing Irish Coastal Wave and Water level Study. Therefore no coastal dominated runs have been undertaken.

(6) Model Roughness	In bank roughness values have been derived using Table 3.2 in Chapter 3.6.1.	
(a) In-Bank (1D Domain)	Minimum 'n' value: 0.040	Maximum 'n' value: 0.040
(b) MPW Out-of-Bank (1D)	Minimum 'n' value: 0.034	Maximum 'n' value: 0.059
(c) MPW/HPW Out-of-Bank (2D)	Minimum 'n' value: 0.034 (Inverse of Manning's 'M')	Maximum 'n' value: 0.059 (Inverse of Manning's 'M')

Map of 2D Roughness (Manning's n)

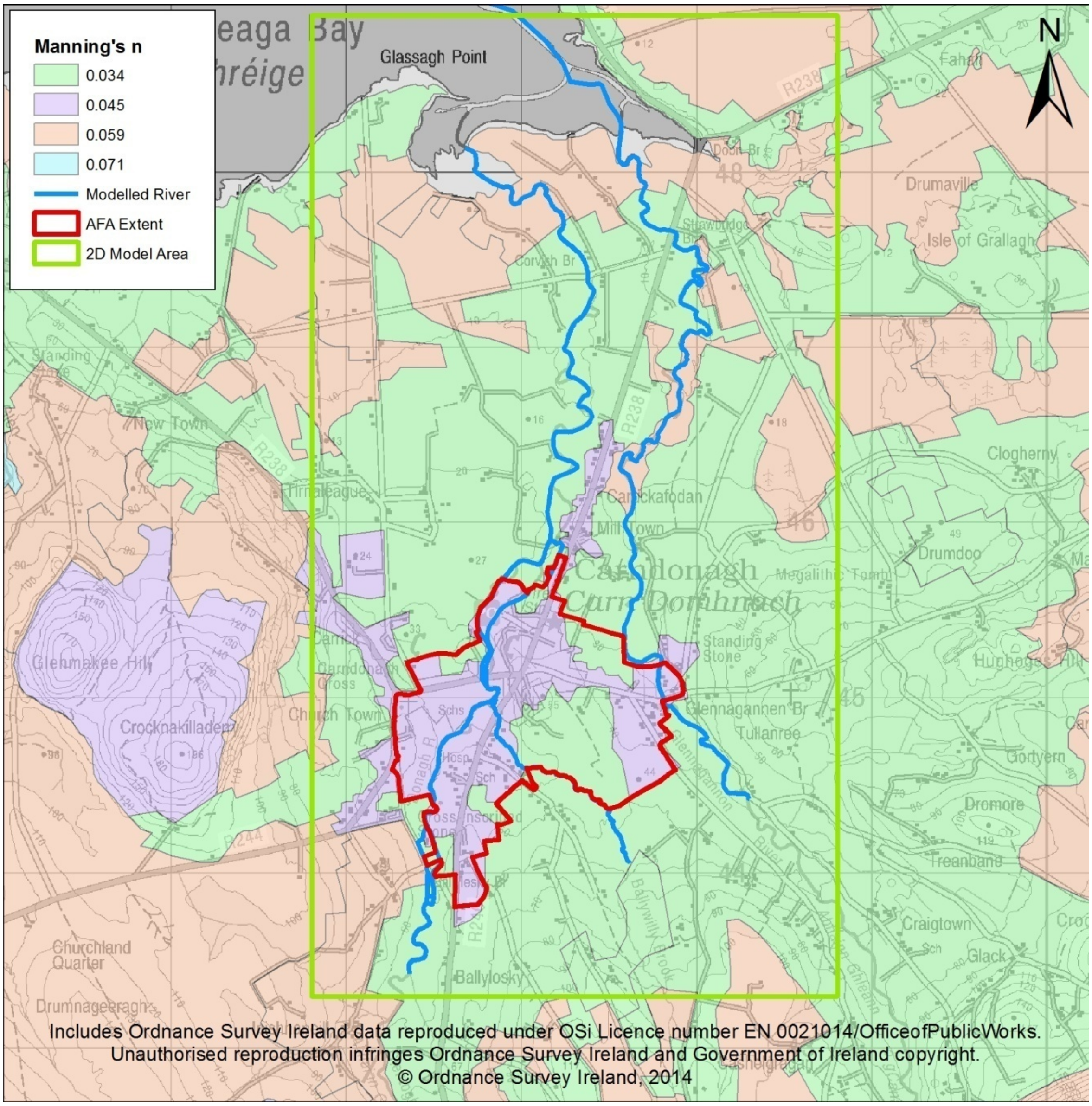


Figure 4.7.14: Map of 2D Roughness (Manning's n)

Figure 4.7.12 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 were taken as 0.033 unless otherwise specified.

(d) Examples of In-Bank Roughness Coefficients

0150M00577_UP

Clean, straight, some stones and bank vegetation

Figure 4.7.15: Manning's n = 0.040

0149M00107_UP

Clean, straight with vegetation on left bank

Figure 4.7.16: Manning's n = 0.040

0150M00031_UP

Clean, winding, irregular banks

Figure 4.7.17: Manning's n = 0.040

0149M00002_UP

Clean, straight with vegetation on left bank

Figure 4.7.18: Manning's n = 0.040

0148M00113_UP

Clean straight, some stones and vegetation on banks.

Figure 4.7.21: Manning's n =0.040

0148M00002_DN

Clean, winding, some weeds and vegetation on banks

Figure 4.7.19: Manning's n = 0.040

0147M00682_UP

Clean straight with some vegetation on banks

Figure 4.7.22: Manning's n = 0.040.

014700005_DN

Clean, straight, some vegetation on banks.

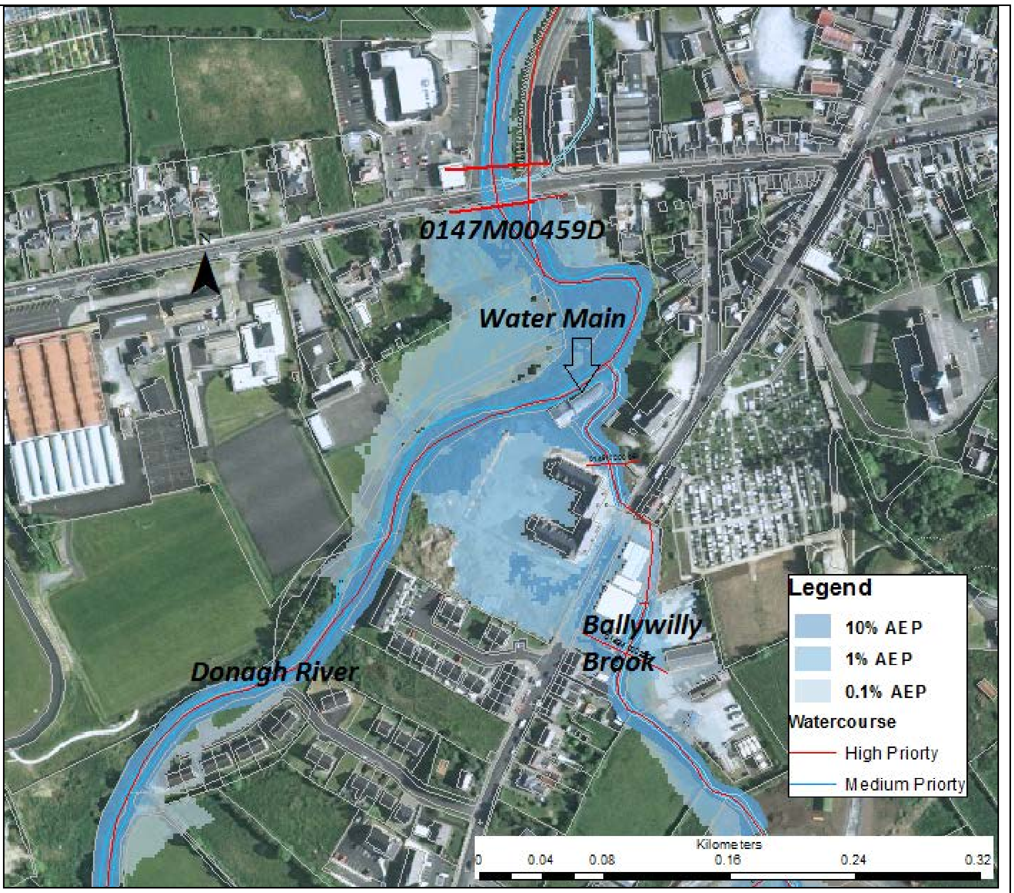
Figure 4.7.20: Manning's n = 0.040

4.7.4 Sensitivity Analysis

To be completed in final version of report.

4.7.5 Hydraulic Model Calibration and Validation

(1) Key Historical Floods (From IBE0700Rp0002_UoM 01 Inception Report unless otherwise specified):	
(a) JUN 2012.	This report has not been included in the Inception Report, but was published in the 'Derry Journal'. This press report described how Carndonagh was hit by the worst flooding in 40 years on 22nd June 2012. There are no local rainfall records are available for this event in Carndonagh town. The available record at the closest daily rainfall gauge (Rockmount 248400_445900 ING) does not cover this date. The closest hourly rainfall gauge at Malin Head, which is approximately 14km north-north-west from Carndonagh, indicates that 41.4mm of rain fell over 14 hours. This rainfall depth and duration was used to estimate rainfall frequency using the FSU DDF model (FSU WP 1.2 'Estimation of Point Rainfall Frequencies'); which indicates that it was a 7.9% AEP event. It therefore assumed that the rainfall experienced in Carndonagh on the same date was of a similar frequency. However this assumption is treated with caution since the rainfall data is not local to the AFA. The report described how the heaviest rain in living memory flooded an area that extended from the 'planting' (Glentogher, upstream 0147M); to the town of Carndonagh and mentioned that 'it didn't stop raining all day'. It also described how a water main located behind a convent in the town (Chapel Street) was washed away. No other information was made available. Figure 4.7.23 illustrates how the flood extent compares well with the flooding description provided by the press report. The model illustrates that this area is affected by flooding during the 10%, 1% and 0.1% AEP fluvial event, including the aforementioned water main on Chapel Street. It is likely that that the presence of several structures including the bridge at cross-section 0147M00459D (refer to Figure 4.7.6) and the confluence with Ballywilly Brook contribute to the flooding in this area.

	 **Figure 4.7.23: Modelled Flood Extents**
(b) OCT 2005.	Several photographs were found on www.floodmaps.ie during the review process, indicating that flooding occurred in Carndonagh on 24th October 2005. The photographs provided evidence of localised flooding of low lying lands and roads. The source of flooding or flooding extent was not reported. On 23rd of October 2005 the daily rain gauge at Rocksmount recorded 29mm of rainfall, which based on the FSU DDF model (using a 24 hour duration since it is a daily gauge and higher temporal resolution is not available) relates to a high frequency low magnitude rainfall event of approximately 83% AEP. Based on photographs of the event (Figure 4.7.24 and 4.7.25) it is unlikely that the flooding that occurred was of such a low magnitude. Furthermore this area does not flood in the 10% AEP modelled event as indicated on the flood extent maps. Therefore it was considered possible that the event was pluvial in nature as a result of intense rainfall over a short duration. To get an impression of the intensity of the rainfall in Carndonagh the hourly rain gauge at Malin Head, 14km north-north-west of Carndonagh, was reviewed. Rainfall depth of 21.1mm over a 10 hour period was recorded at Malin which again, is estimated as a very high frequency event (90-100% AEP) using the FSU DDF model. This is not considered significant in terms of rainfall intensity that would cause pluvial flooding. As the rainfall event is estimated to have been of high frequency and low magnitude and this area is not known to

flood on a regular basis, it is considered that another factor may have had an influence on the affected areas, such as a blockage. Due to the lack of information about this event it is not possible to speculate what caused the localised flooding.

Figure 4.7.24 is a photograph that was taken along the Moville Road at Tulnaree, which is located to the east of Carndonagh. Tulnaree is within close proximity to the Glennagannon River (0150M) and contains several commercial properties.

Figure 4.7.24: Photograph of flooding on Moville Road at Tulnaree, 24th October 2005

Figure 4.7.25 is a photograph taken during construction of the Newpark Road looking back towards the Carndonagh town. The partially constructed bridge abutments and Glengannon River is in the foreground. It is not known if the works contributed to the flood event.

Figure 4.7.25: Photograph taken during construction of the Newpark Road looking back towards the Carndonagh town

	Given the lack of quantitative data and the significant uncertainty surrounding the cause of this flood event, it cannot be used for model calibration or validation. As part of the sensitivity analysis a blockage on the bridge structure on the Newpark Road (150M00470BRU, Glennagannon) will be modelled to identify if this condition provides similar outputs for a representative rainfall event.
(c) OCT 1954.	Several press reports including the Irish Times and Irish Independent, described how flooding occurred in and around Carndonagh town on 18th October 1954 following 12 hours of incessant rain. Although no actual rainfall levels were given for Carndonagh town, the closest daily rainfall gauge (Rocksmount) recorded 25.9mm of daily rainfall. This rainfall depth and duration was used to estimate rainfall frequency using the FSU DDF model; which indicates that it was at least a 91% AEP event. The lack of specific geographical references renders this evidence inadequate for model calibration or validation purposes.

Summary of Calibration

Due to the lack of quantitative data on previous flood events it has not been possible to calibrate the model with historical reports. With the limited information available it has been possible is to compare certain areas that have been identified to have been affected in the past and determine that the model is producing similar results. As such, there has not been any information presented in previous flood events that suggest that any of the model parameters should be changed.

There are total of 9 HEP check flow points, these have been included in Appendix A.3. Model flows were checked against the estimated flows at HEP check points, where possible to ensure they were within an acceptable range. For example at HEP 40006_RPS, the estimated flow during the 0.1% AEP event was 71.5 m^3/s and the modelled flow was 72.5 m^3/s. Full flow tables can be found in Appendix A.4.

Checks have been carried out on the ISIS mass balance model outputs for the 1% AEP events on the Donagh and Glennagannon reaches which may give an indication as to the robustness and stability of the model. These methods are discussed in Section 3.12.

Comparing 1D-2D link flow with flow in and out of the 2D domain indicated a difference of 0.11% for the Donagh watercourse, and 9% for the Glennagannon. The 9% difference for the Glennagannon is within the acceptable range according to ISIS and not likely to adversely affect model predictions. Minor instabilities in this reach have been discussed later in Section 4.7.6(2).

The maximum Qe (mass balance error) at any time step was recorded to be 5.04% for the Donagh and 9.6% for the Glennagannon watercourses. The average was -0.52% and 1.37% respectively, which are within guideline tolerances.

Overall the model results imply both models are robust. To illustrate this, a screenshots of a 'discharge long-section plot' relating to the Donagh and Glennagannon rivers at peak flow are presented in Appendix A.2. No significant model instabilities have been identified.
(2) Post Public Consultation Updates:
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) Gauging Stations:
There are three gauging stations located within the modelled reaches of the Carndonagh model. These staff gauges are inactive with no data available therefore the model is considered to be totally ungauged.
(4) Other Information:
A report extracted from www.floodmap.ie has described how a combination of high tide and heavy rain would result in the downstream areas (0150M) Glennagannon and (0147M) Donagh Rivers to frequently flood. It was described how these rivers would overflow their banks once or twice a year. Specific reference was made of the Corvish Bridge and Strawbridges, located on the Rivers Glennagannon and Donagh, respectively. These reports also mentioned that the road at these locations were liable to flooding. Figure 4.7.26 shows modelled flood extents at this location, and indicates that this area is susceptible to flooding. However, caution should be employed since these modelled results represent extreme flooding extents as the result of a 10, 1 and 0.1% AEP fluvial event. Also, the description provided by the report has described higher frequency, lower magnitude events that have been influenced by high spring tides, combined with fluvial flooding mechanism.

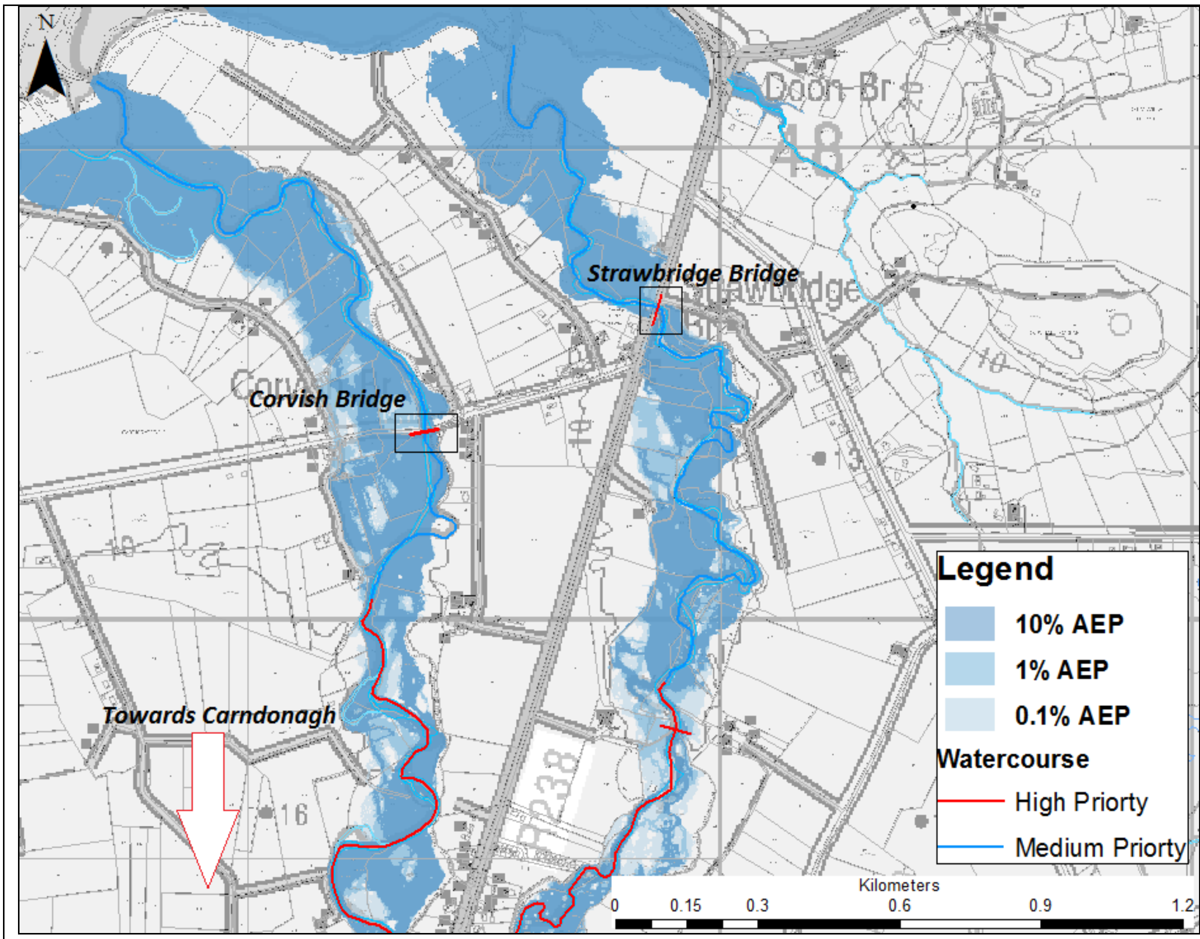


Figure 4.7.26: Modelled Extents at Corvish Bridge and Strawbridge – 10%, 1% and 0.1% AEPs

4.7.6 Hydraulic Model Assumptions, Limitations and Handover Notes

(1) Hydraulic Model Assumptions:

a) Reaches 0147A & B were excluded from the 1D model since their channels were shown to be dry. Additionally, several culvert openings were not located by the surveyors and were assumed to be blocked off. The area occupied by these channels was included within the 2D model domain, however.

b) At cross-section 0147M00411D a Bernoulli Loss unit was used to model the head loss due to a partly demolished bridge. Areas were based on the channel section with bridge area removed and head loss coefficients calculated from the reduction in area, from the unrestricted channel, using coefficients of contraction and expansion of 0.3 and 0.75 respectively. The river channel downstream of this structure is split into two separate channels; however, since during flood conditions the central island will be fully submerged, this section is modelled as a single channel.

c) At cross-section 0148M00108I, an orifice unit was used to represent the restricted opening to the culvert, caused by a partly closed sluiced gate. The sluice appears old and rusted on the survey photos and it is assumed that it will remain in its current position. The culvert dimensions at the

downstream end of the culvert also differ from those surveyed at the upstream end and the contraction from 1.2m diameter to 0.9m diameter is assumed to occur midway along the culvert. This contraction is represented by a Bernoulli loss unit.

d) At cross-section 0149M00023 a pipe bridge is represented using an orifice unit (to model flow under the pipe) and a spill unit (to model flow over the pipe).

e) Culvert at cross-section 0149M00018I. The downstream end of the culvert is rectangular concrete and this was assumed to be a bridge under Chapel Street, with the circular upstream section being a later addition. The width of Chapel Street was scaled from the OS data on the survey drawing. The transition from circular to rectangular profiles is an expansion and an ISIS junction unit was therefore used to connect the two culvert sections.

f) Post-processing of draft final maps was carried out regarding bridge inundation - flood extents were edited at the location of the bridge to remove it from the flood extent where it has been identified that inundation of the bridge does not occur.

(2) Hydraulic Model Limitations and Parameters:

a) The MaxItr parameter was increased to 17 for the Donagh River model, to improve model convergence.

b) All model runs used 1D time-steps of 1s and 2D time-steps of 0.5s.

c) A 2D model grid size of 2m was used for the urban area surrounding the Carndonagh River, its two tributaries and the Ballywilly Brook to allow flow paths to exist between narrow buildings in the urban area, whilst not resulting in unreasonable model run times. A grid size of 3m was used for the hydraulically separate Glennagannon River to represent narrow channels appropriately.

d) The ADI (Alternating Direction Implicit) Solver was used in ISIS 2D, as is to be used for most coastal, fluvial and surface water models. Small isolated pockets with Froude number greater than one were identified from the model outputs, although a map showing maximum Froude for the full duration of the model suggests there are not any areas deemed as significant in proximity to receptors. The ADI solver is considered to 'produce acceptable solutions as it includes methods to reduce the effects of instabilities around supercritical flows', and therefore is considered to be appropriate for this AFA. This information was taken from Section 1.2 of the ISIS 2D User Manual.

e) Some instability was identified at interpolated sections between 0147M000055 and 0147M00005C along the Donagh River, which is over 2km downstream of the AFA boundary. This caused a fluctuation of around 5mm in stage, which had negligible effect on the upstream AFA. Similar instability was identified on a long section of interpolates in proximity to 0150A0700 at the downstream end of the Glennagannon River. This area is a sandbank which is affected by natural tidal effects. Similarly to the Donagh River, the differences in stage are not likely to have any effect on Carndonagh AFA due to the distance downstream where it occurs.

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

a) The fluvial flood mechanisms in the AFA are influenced by a number of critical structures as detailed in Section 1.1.3.1 with properties at risk of flooding in the three AEP design event simulated. The culvert

0149M0018I becomes surcharged contributing to out of bank flooding on the left side between the Ballywilly Brook and the Donagh River, in proximity to commercial properties on Chapel Street leading to significant flooding in this area. This is the first out of bank flow occurring along the Donagh and Ballywilly watercourses. More out of bank flooding occurs upstream of this point on the Ballywilly Brook to the rear of residential properties on the Ballyloskey Road. Another area identified as inundated is downstream of the junction where the Ballywilly Brook and the Donagh River merges, although does not appear to affect any properties.

b) Out of bank flooding is also identified with the AFA and downstream of the AFA on the Donagh River. One such area affected is the Clos Phadraig residential area, where out of bank flow is related to the cross-section 0148M00060. This appears to be the only section showing out of bank flow in this area.

c) The Carndonagh watercourse (reach 0148M) appears to be an old mill run. Although the inlet to this watercourse is restricted by a sluice gate, flood water can enter via the right bank of the Donagh River (reach 0147M) around cross-section 0147M00439. Flooding is shown to occur due to overtopping on the left bank of the Carndonagh watercourse, upstream of the culvert at cross-section 0148M00058I. This result is likely to be sensitive to the model parameters for this culvert and also the culvert at cross-section 0148M00088I, which controls the inflow of flood water to the watercourse.

d) The model was reviewed to resolve instabilities. Some instabilities exist in areas downstream of the AFA, along both the Donagh and Glennagannon rivers. In the Donagh River this occurs between cross-section 0147M000055 and 0147M00005C which is one of the furthest downstream points. Fluctuations in discharge were apparent at this location, although this relates to oscillations in stage of around 5mm. This is not considered to be a significant issue that will have any bearing on the AFA upstream. On the Glennagannon River at cross-section 0150A0700 similar oscillations were identified that again had a negligible effect on stage, occurring at a downstream location 3km from the AFA.

(4) Hydraulic Model Deliverables:

Refer to Appendix A.4 for a list of all model files provided with this report.

(5) Quality Assurance:

Model Constructed by:	Ian Bentley
Model Reviewed by:	Stephen Patterson
Model Approved by:	Malcolm Brian

APPENDIX A.1

Structure details – bridges & culverts								
River branch	**Chainage**	**Id****	**Length (m)**	**Opening shape**	**Height (m)**	**Width (m)**	**Spring height from invert (m)**	**Mannings n (or colebrook white k)**
Bridges								
Donagh river	776	0147M00605D	6.6	Arch	2.70, 2.91, 2.67	5.48, 6.04, 5.38	1.64, 1.54, 1.43	0.04
Donagh river	1456	0147M00537D	2.5	Rectangular	2.42	7.62	2.415	0.04
Donagh river	2238	0147M00459D	12.83	Rectangular	2.66	11.58	30.12	0.04
Donagh river	2709	0147M00411D	5.12	Arch	3.06	9.78	1.785	0.04
Donagh river	3249	0147M00358D	5	Rectangular	1.86, 2.48, 2.93	6.07 / 6.07 / 5.96	1.86, 2.48, 2.93	0.06
Donagh river	5357	0147M00136D	6.5	Arch	3.09, 2.93, 2.35	6.06 / 6.29 / 6.11	1.42, 1.56, 0.94	0.06
Ballywilly brook	1285	0149M00022D	4.2	Arch	1.1	2.75	1.1	0.05
Carndonagh	944	0148M00019D	1.4	Arch	1.2	3.05	1.2	0.04
Carndonagh	974	0148M00016D	5	Arch	1.39	1.32	1.39	0.04
Glennagannon river	907	0150M00492D	6.139	Arch	3.79, 2.39	6.13, 5.95	2.56, 0.7	0.04
Glennagannon river	1126	0150M00470D	17.496	Rectangular	2.23	14.03	2.23	0.04
Glennagannon river	3344	0150M00248D	5.294	Arch	2.28	9.14	2.11	0.04
Glennagannon river	4933	0150M00090D	6.59	Arch	2.07, 3.19	6.32, 6.26	0.63, 1.81	0.04
CULVERTS								
Ballywilly brook	1104	0149M00041I	27.8	Circular	2	2	N/a	0.015
Ballywilly brook	1320	0149M00018I	72	Circular	1.8	1.8	N/a	0.02
Ballywilly brook	1419	0149M00008I	4	Circular (double barrel)	1.2 and 0.3	1.2/0.3	N/a	0.02
Carndonagh	49	0148M00108I	172	Circular	1.2	1.2	N/a	0.02
Carndonagh	259	0148M00088I	190	Circular	0.9	0.9	N/a	0.02
Carndonagh	558	0148M00058I	14	Rectangular	0.9	0.75	N/a	0.2

Carndonagh	784	0148M00035I	20	Rectangular	0.67	1.12	N/a	0.2
Carndonagh	855	0148M00029I	54.3	Circular	0.9	0.9	N/a	0.02
Carndonagh	1059	0148M00008I	1.4	Arch	1.11	1	1.11	0.04
Carndonagh	1062	0148M00007I	5.5	Rectangular	0.63	1.02	0.63	0.2
Carndonagh	1094	0148M00004I	7.7	Rectangular	0.73	2.46	0.73	0.035

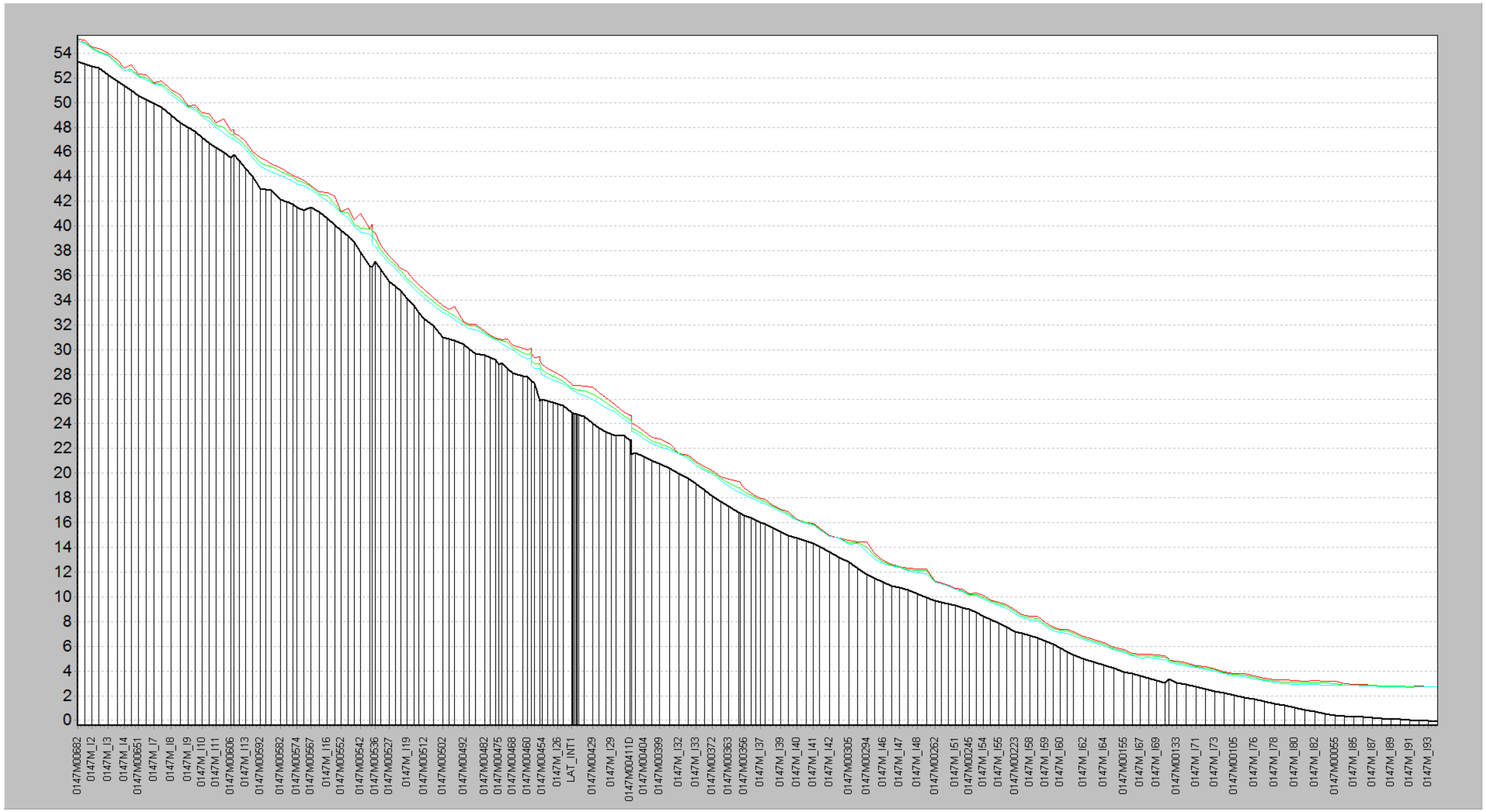
Structure Details - Weirs			
RIVER BRANCH	**CHAINAGE**	**ID**	**Type**
DONAGH RIVER	2268	0147M00457W	IRREGULAR PROFILE
DONAGH RIVER	2707	0147M00410X	IRREGULAR PROFILE
GLENNAGANNON RIVER	57	0150M00576W	IRREGULAR PROFILE

All bridges and culverts listed in this table were represented in the model based on surveying and photographic information. The Manning's n number was considered to reflect the resistance that a series of cross channels might produce during a flooding event.

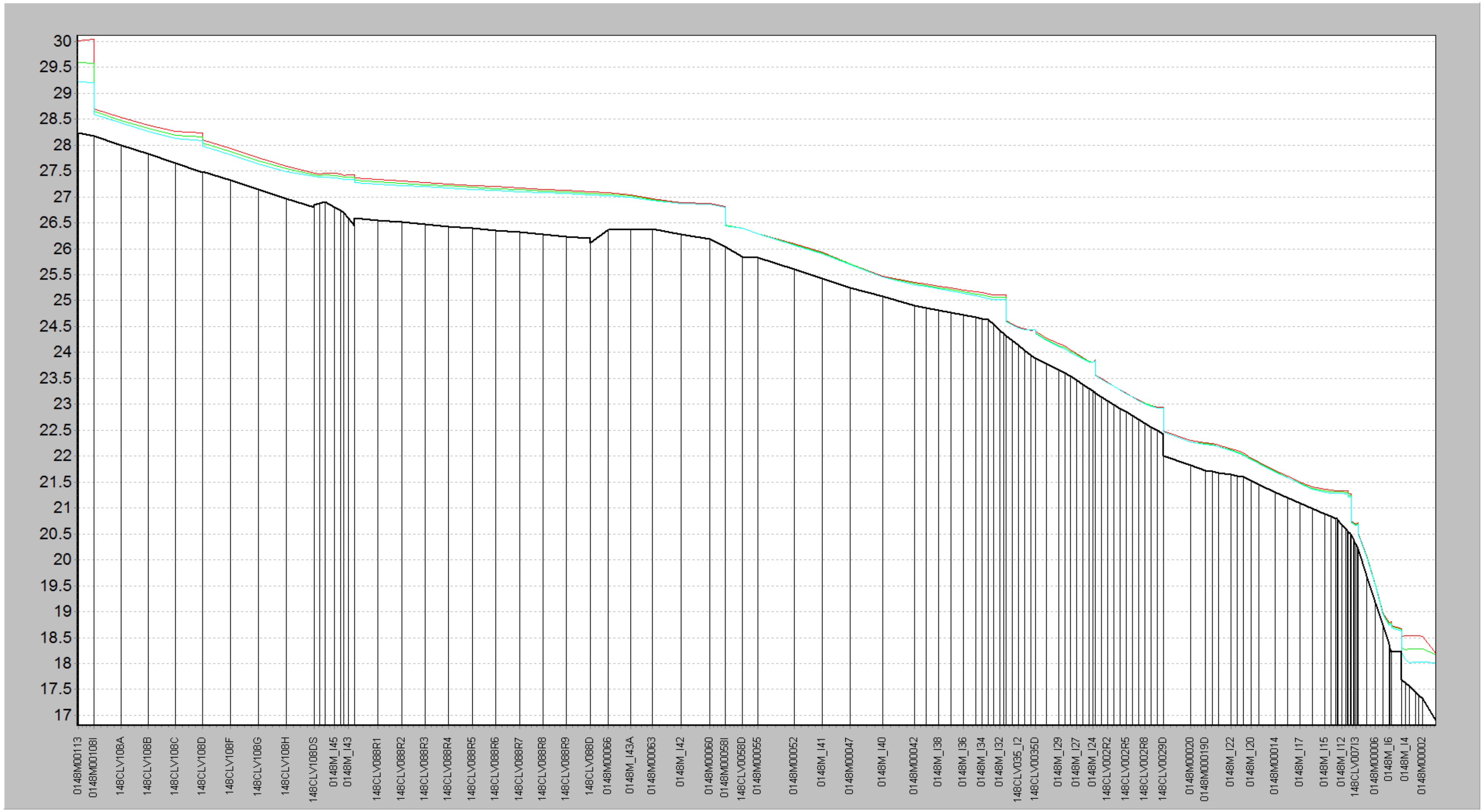
** Structure ID Key:
D – Bridge Upstream Face; **E** – Bridge Downstream Face; **I** – Culvert Upstream Face; **J** – Culvert Downstream Face

APPENDIX A.2

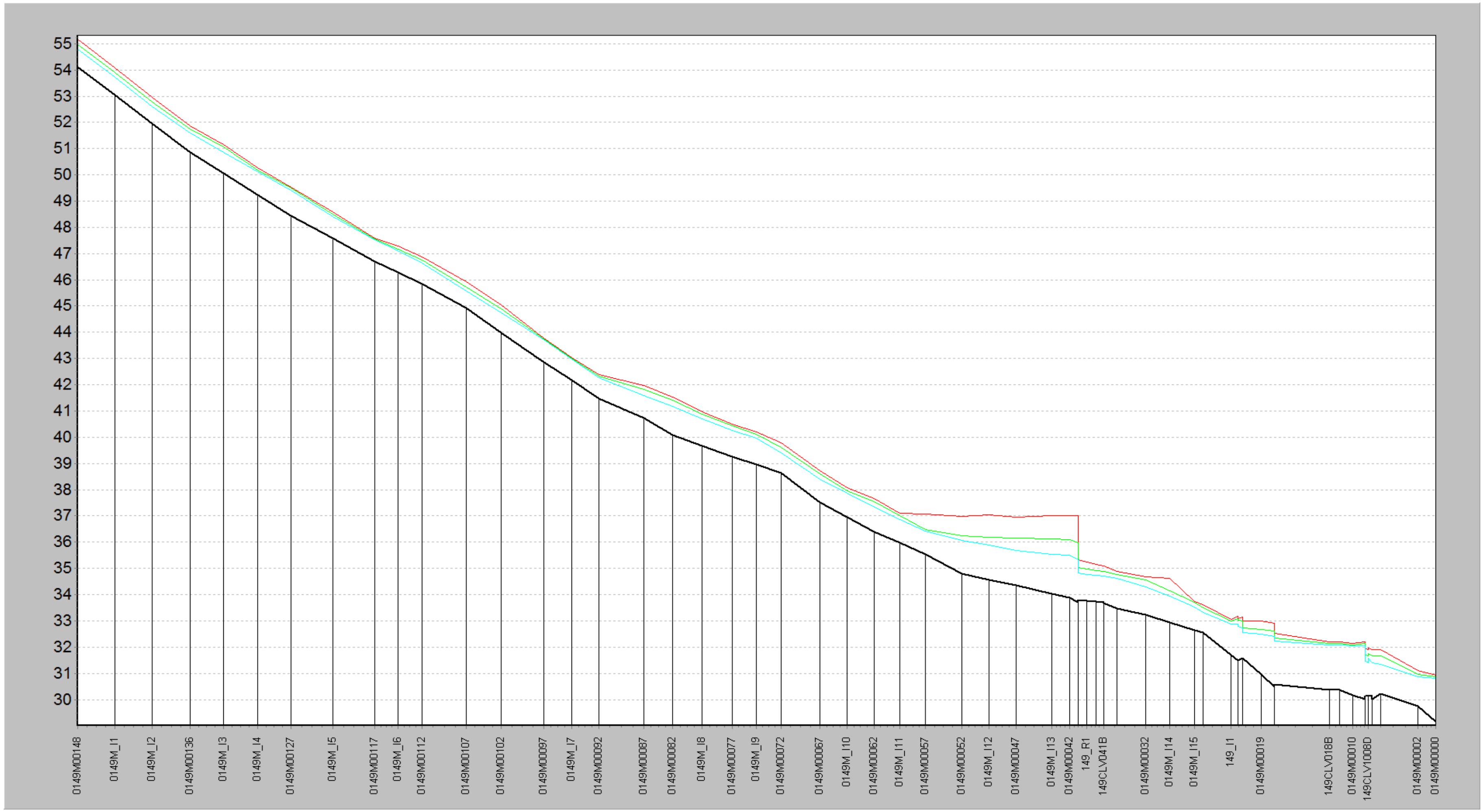
Long section plots



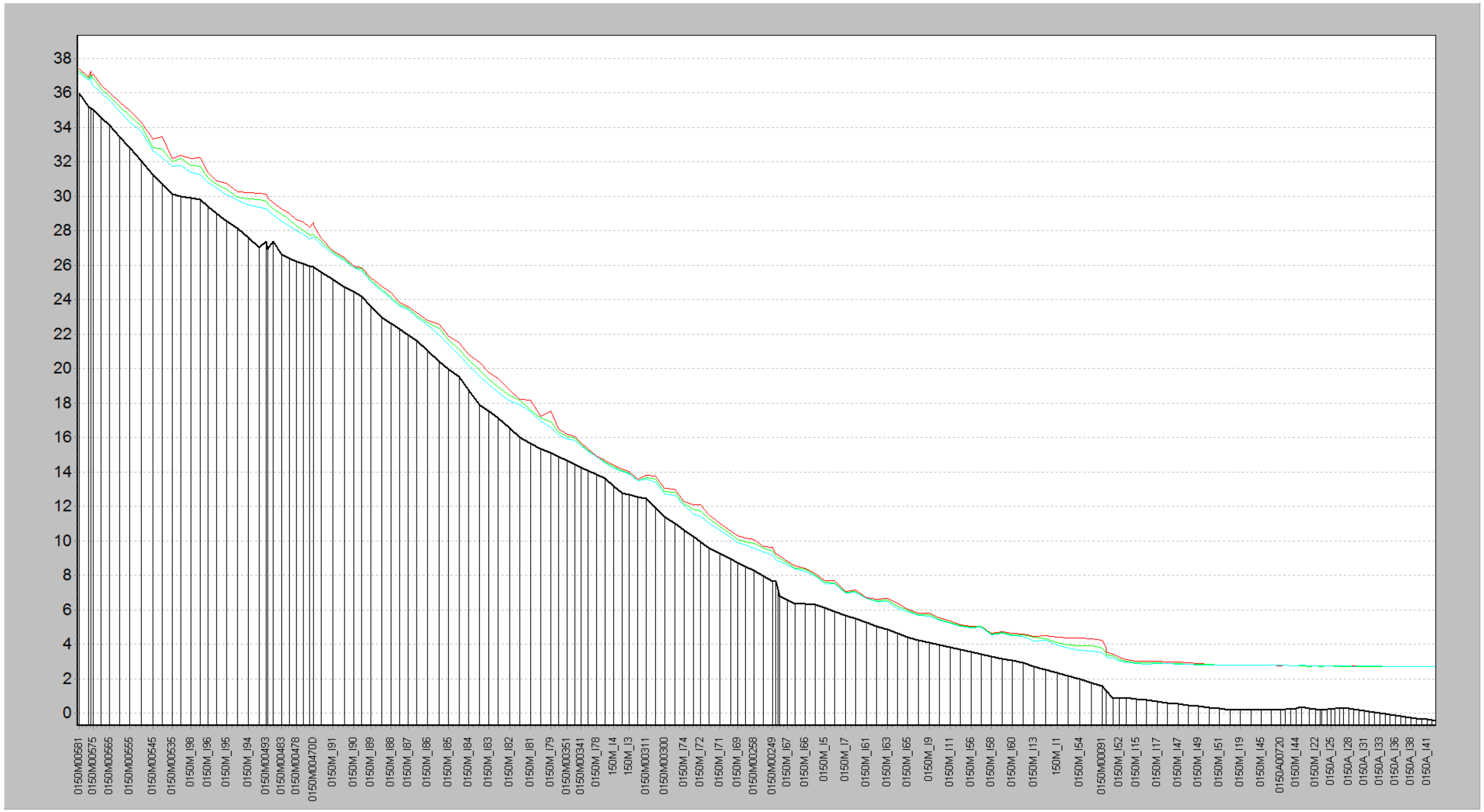
Reach 0147M: Donagh River. Peak water levels for the 10% (blue), 1% (green) and 0.1% (red) AEP events



Reach 0148M: Carndonagh Watercourse. Peak water levels for the 10% (blue), 1% (green) and 0.1% (red) AEP events



Reach 0149M: Ballywilly Brook. Peak water levels for the 10% (blue), 1% (green) and 0.1% (red) AEP events



Reach 0150M: Glennagannon River. Peak water levels for the 10% (blue), 1% (green) and 0.1% (red) AEP events

APPENDIX A.3

Flow Comparison at HEP Check Points

Watercourse	HEP Point	AEP	Check Flow (m^3/s)	Model Flow (m3/s)	Difference (%)
Donagh	**40_1018_2**	10%	32.2	32.51	+0.98
		1%	46.2	46.59	+0.94
		0.1%	66.1	66.63	+0.76
Donagh	**40_1018_4_RPS**	10%	32.2	33.67	+4.59
		1%	46.2	47.65	+3.25
		0.1%	66.1	68.86	+4.13
Donagh	**40006_RPS**	10%	34.6	35.10	+1.39
		1%	49.9	49.82	-0.16
		0.1%	71.5	72.14	+0.88
Donagh	**40_1107_2_RPS**	10%	34.8	35.93	+3.36
		1%	50.1	51.65	+3.07
		0.1%	71.8	74.35	+3.53
Donagh	**40007_RPS**	10%	35.1	36.70	+4.52
		1%	50.6	54.43	+7.53
		0.1%	72.5	75.92	+4.67
Donagh	**40_1107_9_RPS***	10%	35.1	19.47	-44.54
		1%	50.6	26.11	-48.42
		0.1%	72.5	25.94	-64.23
Ballywilly Brook	**40_1012_6_RPS**	10%	4.1	3.93	-5.19
		1%	6.7	6.50	-3.41
		0.1%	11.0	8.88	-19.03
Glennagannon	**40003_RPS**	10%	25.1	25.01	-0.21
		1%	36.2	36.23	+0.22
		0.1%	52.1	52.82	+1.35
Glennagannon	**40_982_13_RPS***	10%	26.1	22.35	-14.37
		1%	37.7	36.88	-2.03
		0.1%	54.3	56.62	+4.33

**Subject to tidal influence*

The downstream checkpoints 40_1107_9_RPS on the Donagh River and 40_982_13_RPS on the Glennagannon River is subject to tidal influences from Trawbreaga Bay. The discharge at this HEP point in the model is 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 hydrology only considers the fluvial component of flow at this location.

At HEP 40_1012_6_RPS at the downstream end of Ballywilly Brook during the 0.1% AEP event, flood flow crosses to the Donagh River upstream of the HEP point, which explains the underestimation of peak flow at this location for this event.

In general the model is well anchored to hydrological estimates as all other modelled flows are within 10% of check flows.

APPENDIX A.4

Model Files provided with this report

ISIS 2D .xml Files	ISIS 1D .ief Files	Sub-Folders
UOM01_CARN2A_2D_DES_Q10F.xml UOM01_CARN2A_2D_DES_Q100F.xml UOM01_CARN2A_2D_DES_Q1000F.xml UOM01_CARN2B_2D_DES_Q10F.xml UOM01_CARN2B_2D_DES_Q100F.xml UOM01_CARN2B_2D_DES_Q1000F.xml	UOM01_CARN2A_1D_DES_Q10F.ief UOM01_CARN2A_1D_DES_Q100F.ief UOM01_CARN2A_1D_DES_Q1000F.ief UOM01_CARN2B_1D_DES_Q10F.ief UOM01_CARN2B_1D_DES_Q100F.ief UOM01_CARN2B_1D_DES_Q1000F.ief	ISIS 1D ISIS 2D Results

1st Level Sub-Folder	2nd Level Sub-Folder	Files
ISIS 1D	Donagh_0147M	UOM01_CARN2A_1D_DES.dat UOM01_CARN2A_1D_DES.zzs UOM01_CARN2A_1D_DES_Q10F.IED UOM01_CARN2A_1D_DES_Q100F.IED UOM01_CARN2A_1D_DES_Q1000F.IED
	Glennagannon _0150M	UOM01_CARN2B_1D_DES.dat UOM01_CARN2B_1D_DES.zzs UOM01_CARN2B_1D_DES_Q10F.IED UOM01_CARN2B_1D_DES_Q100F.IED UOM01_CARN2B_1D_DES_Q1000F.IED

1st Level Sub-Folder	2nd Level Sub-Folder	3rd Level Folder	Files
ISIS 2D	Donagh_0147M	Active Area	UOM01_CARN2A_2D_DES_ACTVA.dbf UOM01_CARN2A_2D_DES_ACTVA.shp UOM01_CARN2A_2D_DES_ACTVA.shx
		Links	UOM01_CARN2A_2D_DES_0147M_LB.shp UOM01_CARN2A_2D_DES_0147M_RB1.shp UOM01_CARN2A_2D_DES_0147M_RB2.shp UOM01_CARN2A_2D_DES_0147M_RB3.shp UOM01_CARN2A_2D_DES_0147M_RB4.shp UOM01_CARN2A_2D_DES_0148M_LB.shp UOM01_CARN2A_2D_DES_0148M_RB.shp UOM01_CARN2A_2D_DES_0149M_LB.shp UOM01_CARN2A_2D_DES_0149M_RB.shp UOM01_CARN2A_2D_DES_DSBDY.shp UOM01_CARN2A_2D_DES_0147M_LB.shx. UOM01_CARN2A_2D_DES_0147M_RB1.shx UOM01_CARN2A_2D_DES_0147M_RB2.shx UOM01_CARN2A_2D_DES_0147M_RB3.shx UOM01_CARN2A_2D_DES_0147M_RB4.shx UOM01_CARN2A_2D_DES_0148M_LB.shx UOM01_CARN2A_2D_DES_0148M_RB.shx UOM01_CARN2A_2D_DES_0149M_LB.shx UOM01_CARN2A_2D_DES_0149M_RB.shx UOM01_CARN2A_2D_DES_DSBDY.shx UOM01_CARN2A_2D_DES_0147M_LB.dbf UOM01_CARN2A_2D_DES_0147M_RB1.dbf UOM01_CARN2A_2D_DES_0147M_RB2.dbf UOM01_CARN2A_2D_DES_0147M_RB3.dbf UOM01_CARN2A_2D_DES_0147M_RB4.dbf UOM01_CARN2A_2D_DES_0148M_LB.dbf UOM01_CARN2A_2D_DES_0148M_RB.dbf UOM01_CARN2A_2D_DES_0149M_LB.dbf UOM01_CARN2A_2D_DES_0149M_RB.dbf UOM01_CARN2A_2D_DES_DSBDY.dbf
	Glennagannon _0150M	Active Area	UOM01_CARN2B_2D_DES_ACTVA.dbf UOM01_CARN2B_2D_DES_ACTVA.shp UOM01_CARN2B_2D_DES_ACTVA.shx
		Links	UOM01_CARN2B_2D_DES_0150M_LB.shp UOM01_CARN2B_2D_DES_0150M_RB.shp UOM01_CARN2B_2D_DES_0150M_LB.shx UOM01_CARN2B_2D_DES_0150M_RB.shx UOM01_CARN2B_2D_DES_0150M_LB.dbf UOM01_CARN2B_2D_DES_0150M_RB.dbf UOM01_CARN2B_2D_DES_DSBDY.shp UOM01_CARN2B_2D_DES_DSBDY.shx UOM01_CARN2B_2D_DES_DSBDY.dbf
	DTM		UOM01_CARN2A_2D_DES_2M_DTM.asc UOM01_CARN2B_2D_DES_2M_DTM.asc UOM01_CARN2_2D_DES_BLD.shp UOM01_CARN2_2D_DES_BLD.shx UOM01_CARN2_2D_DES_BLD.dbf
	2D Roughness		UOM01_CARN2_2D_DES_MANN.asc

1st Level Sub-Folder	2nd Level Sub-Folder	Files
Results	ISIS 1D MIN-MAX	UOM01_CARN2A_1D_DES_Q10F.xls UOM01_CARN2A_1D_DES_Q100F.xls UOM01_CARN2A_1D_DES_Q1000F.xls UOM01_CARN2B_1D_DES_Q10F.xls UOM01_CARN2B_1D_DES_Q100F.xls UOM01_CARN2B_1D_DES_Q1000F.xls
	ISIS 1D UNSTEADY RESULTS	UOM01_CARN2A_1D_DES_Q10F.zzl UOM01_CARN2A_1D_DES_Q10F.zzn UOM01_CARN2A_1D_DES_Q100F.zzl UOM01_CARN2A_1D_DES_Q100F.zzn UOM01_CARN2A_1D_DES_Q1000F.zzl UOM01_CARN2A_1D_DES_Q1000F.zzn UOM01_CARN2B_1D_DES_Q10F.zzl UOM01_CARN2B_1D_DES_Q10F.zzn UOM01_CARN2B_1D_DES_Q100F.zzl UOM01_CARN2B_1D_DES_Q100F.zzn UOM01_CARN2B_1D_DES_Q1000F.zzl UOM01_CARN2B_1D_DES_Q1000F.zzn
	ISIS 2D MAX DEPTH	UOM01_CARN2A_2D_DES_Q10F.asc. UOM01_CARN2A_2D_DES_Q100F.asc UOM01_CARN2A_2D_DES_Q1000F.asc UOM01_CARN2b_2D_DES_Q10F.asc UOM01_CARN2b_2D_DES_Q100F.asc UOM01_CARN2b_2D_DES_Q1000F.asc
	Check Files	UOM01_CARN2A_2D_DES_Q10F_1DMB.csv UOM01_CARN2A_2D_DES_Q10F_2DMB.csv UOM01_CARN2A_2D_DES_Q100F_1DMB.csv UOM01_CARN2A_2D_DES_Q100F_2DMB.csv UOM01_CARN2A_2D_DES_Q1000F_1DMB.csv UOM01_CARN2A_2D_DES_Q1000F_2DMB.csv UOM01_CARN2B_2D_DES_Q10F_1DMB.csv UOM01_CARN2B_2D_DES_Q10F_2DMB.csv UOM01_CARN2B_2D_DES_Q100F_1DMB.csv UOM01_CARN2B_2D_DES_Q100F_2DMB.csv UOM01_CARN2B_2D_DES_Q1000F_1DMB.csv UOM01_CARN2B_2D_DES_Q1000F_2DMB.csv