CASTLEFINN FLOOD RELIEF SCHEME

Hydraulics Report – Phase 1

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1 INTRODUCTION

1.1 Background

This report provides details of the hydraulic analysis and modelling undertaken as part of the Castlefinn Flood Relief Scheme. The objective of this project is the identification, design and submission (for planning consent) of a Flood Relief Scheme, that is technically, socially, environmentally and economically acceptable, to alleviate the risk of flooding to the town of Castlefinn to a determined Standard of Protection, and to procure, manage and oversee the construction of that Scheme. A Steering Group was established between the Office of Public Works (OPW) and Donegal County Council (DCC) to direct and guide the development of the FRS.

The hydraulic modelling is being undertaken in three distinct phases:

- *Phase 1*: To establish and replicate the existing hydraulic conditions.
- *Phase 2*: To assess the performance of potential options and the preferred Scheme.
- *Phase 3*: To establish and replicate the hydraulic conditions following construction of the Scheme.

This report describes the Phase 1 analysis, with details of the Phase 2 and Phase 3 analyses to follow in subsequent reporting.

1.2 Study Area and Catchment Overview

Castlefinn lies on the northern bank of the River Finn, a large sub-catchment of the Foyle catchment. The main source of flood risk to Castlefinn emanates from the River Finn, its tributaries and drainage channels which flow through the study area. The study area and the watercourses to be modelled are shown in Figure 1.1.

Flood levels in the Finn are influenced by the flood conditions at the confluence of the Finn with the River Mourne at Lifford. This is a result of the runoff generated by the Finn and Mourne sub-catchments and to a lesser extent runoff generated by other sub-catchments downstream (such as the River Deele and Burn Dennett) and tidal influence from Lough Foyle. Although the previous Catchment Flood Risk Assessment and Management (CFRAM) Study did not find that there was a risk of coastal flooding to this area, the development of flood relief options will consider the interaction of flows in each of these water bodies and the associated impact on flooding in Castlefinn.

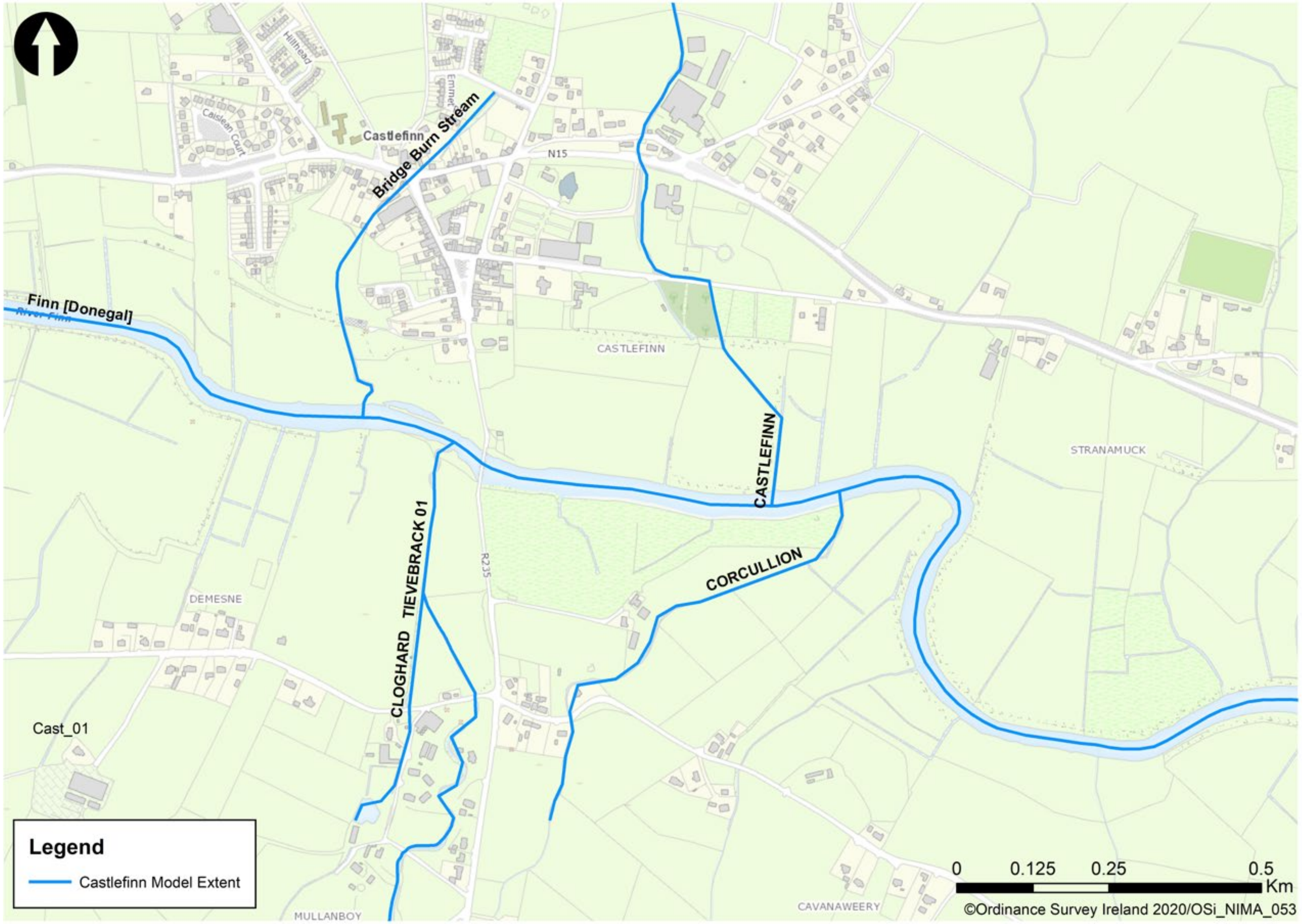

Figure 1.1: Castlefinn FRS Study Area Watercourses

2 DATA COLLECTION

2.1 Flood Event History

Recently, the Study Area has been subject to significant fluvial flooding, most notably in December 2015 (Storm Desmond) and again in August 2017. A summary of the flood history at Castlefinn is presented in the Hydrology Report (Castlefinn FRS Hydrology Report, document no IBE1760_Rp004, RPS, 2022)[1] Section 1.4.

2.2 Existing Hydraulic Models and Reports

2.2.1 NWNB CFRAM Study UoM01 Hydrology Report, OPW, 2013

The NWNB CFRAM Study UoM01 Hydrology Report[2] provides a detailed review of historic floods (up to 2013), analysis of river flow, water level and rainfall data. The report contains analysis of catchments and sub-catchments to derive estimates of event probabilities, peak fluvial flood flows and hydrographs, coastal flood levels and joint probability of occurrence throughout Castlefinn and other areas.

2.2.2 NWNB CFRAM Study UoM01 Hydraulics Report, OPW, 2014

The NWNB CFRAM Study UoM01 Hydraulics Report[3] provides information relating to the modelling that was carried out within Castlefinn and other areas within Unit of Management 01. The report includes detail on hydraulic model build including input data, model schematisation and construction, sensitivity analysis, calibration, verification, model limitations and handover notes for future users.

2.3 Topographical Surveys

2.3.1 Existing Topographical Survey Data

As part of the NWNB CFRAM Study, a topographical survey was undertaken of the River Finn reaches through and downstream of Ballybofey and Stranorlar to Castlefinn and Lifford. Topographical survey was also undertaken on the Castlefinn watercourse, a tributary of the River Finn that flows through Castlefinn. The survey was carried out by Murphy Geospatial in February 2013, with the raw survey data available for use in the Castlefinn FRS.

[1] Castlefinn FRS Hydrology Report

[2] NWNB CFRAM Study UoM01 Hydrology Report

[3] NWNB CFRAM Study UoM01 Hydraulics Report

2.3.2 2021 Survey Data

2.3.2.1 Topographic Survey

Additional survey data was required to produce a more detailed Castlefinn hydraulic model required for flood relief scheme development. The survey specification was prepared based on the project brief, informed by DCC, OPW and RPS' knowledge of the area and procured through the 'OPW Multi Supplier Framework for the provision of Surveying Services'. Full details of the specification are provided in the Supplementary Request for Tenders report (IBE1760Rp001_SRFT_DF01), and can be summarised as:

- **Building Threshold Surveys** – all buildings within the 0.1% AEP flood extent as defined in the NWNB CFRAM Study.
- **Channel and Structure** – Cross-sections and river infrastructure survey were specified along the River Finn and five of its tributaries (including the Bridge Burn and the Castlefinn watercourse) to be surveyed at the same location as previous survey (CFRAM Study) to allow comparison and assessment of the geomorphological changes (see 3.1.3.5). Survey cross sections were also required at new locations in order to provide the required resolution of the survey data for the hydraulic model. An overview of reaches specified for survey is shown in Figure 2.1, structures and flood defences surveys are outlined in Figure 2.2.
- **Flood Embankments and Flood Walls** – The flood defence survey included a 0.35km stretch of embankment along an old railway line south of Chapel Street on the Castlefinn watercourse. The embankment is considered an effective formal defence but was privately constructed in 2016 and not part of a DCC or OPW flood defence scheme.
- **Topographical levels** – The topographic survey was undertaken over an area of 98,612m^2 aiming to identify areas of change in topography since the area was last surveyed during the CFRAM Study. An overview of the topological survey area is shown in Figure 2.3.

Murphy Geospatial were appointed to undertake the survey, works commenced on site on the 27th January 2021 and were completed on the 16th February 2021. Final deliverables were issued to the Steering Group on 17th June 2021.

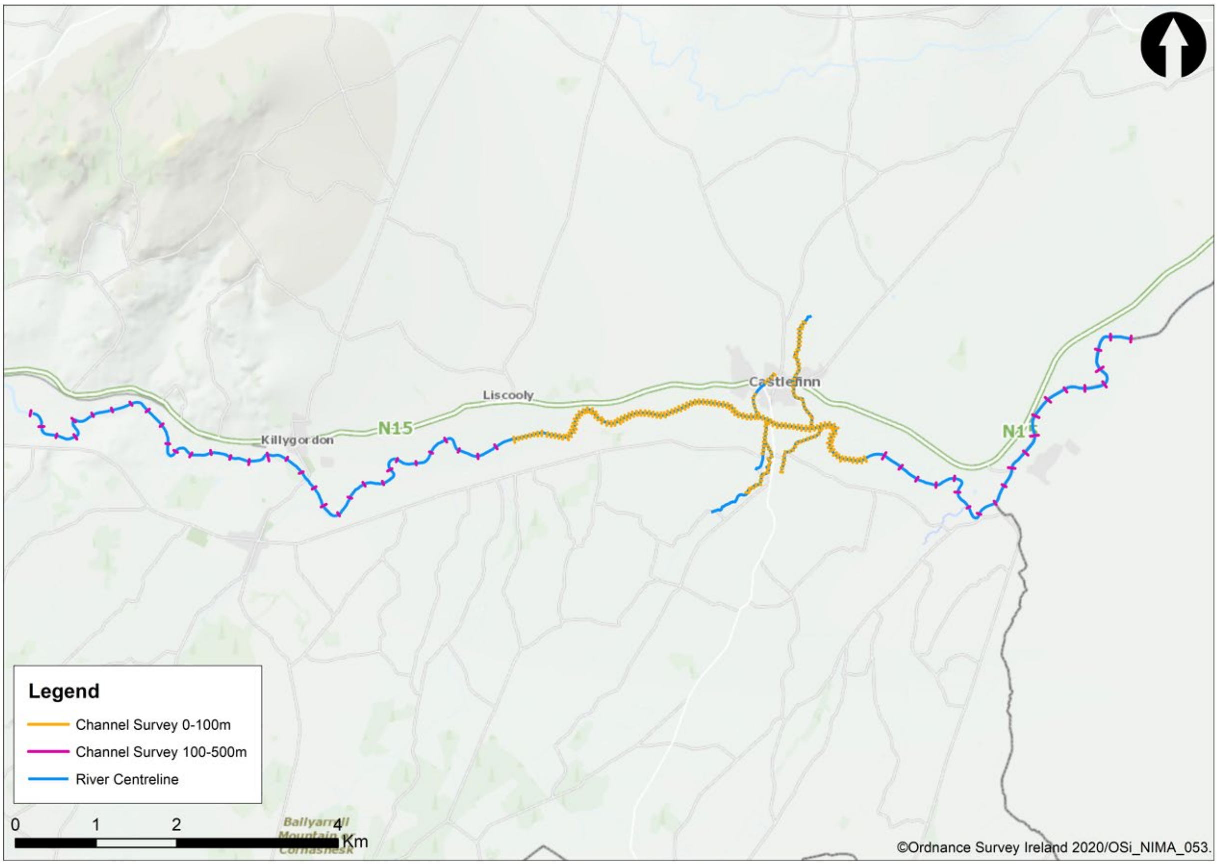

Figure 2.1: River channel survey specification

Figure 2.2: Structure survey specification

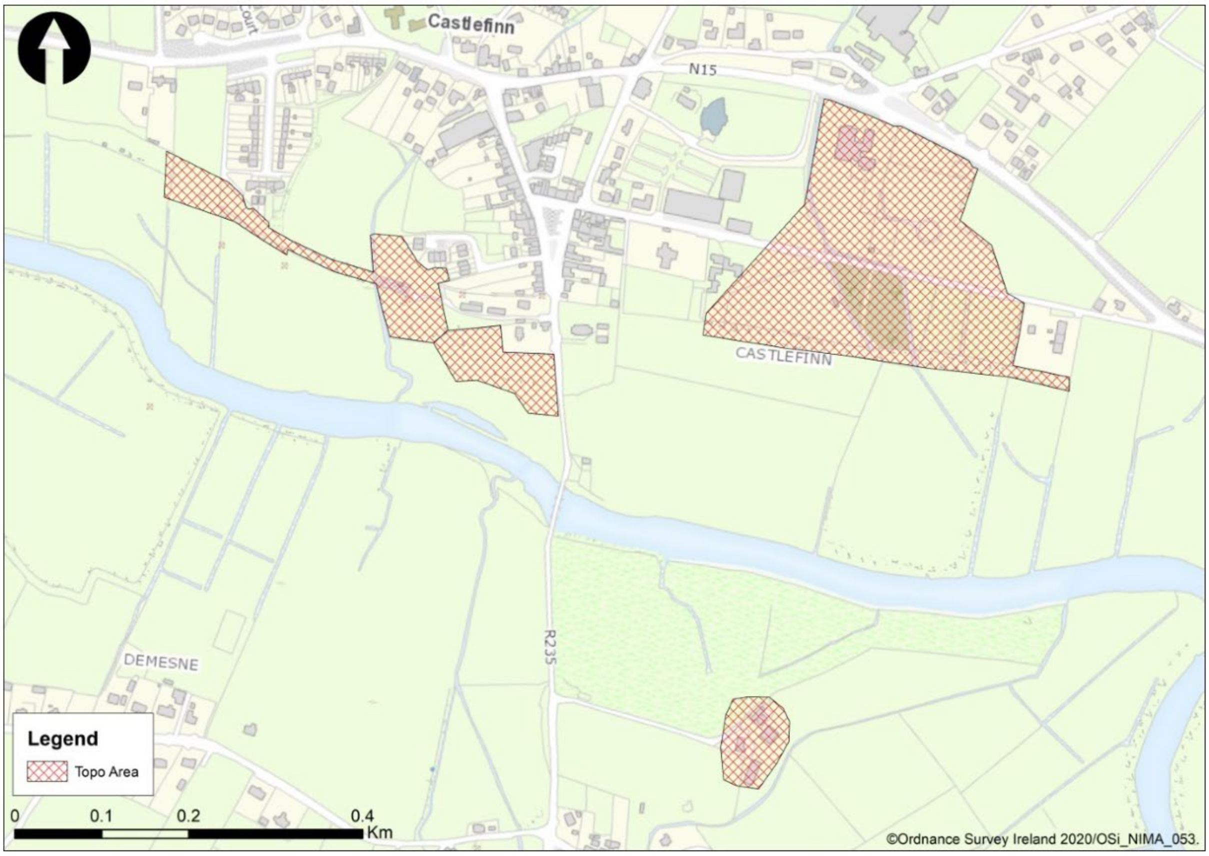

Figure 2.3: Topographical survey specification

2.3.2.2 Culvert Survey

Additional survey data was required for three culverts within Castlefinn to inform the detailed hydraulic model required for FRS development. The locations of the culverts are shown in Figure 2.4, one is located on the Bridge Burn watercourse with the others located on the Castlefinn watercourse. The procured culvert survey information included route tracing of culverts, photographs and video footage to understand internal conditions (any blockages or faults) and sizing of the culverts. The survey specification was prepared based on the project brief, informed by Donegal County Council (DCC), the OPW and RPS' knowledge of the area and procured through the 'OPW Multi Supplier Framework for the provision of Surveying Services'. Full details of the specification are provided in the Supplementary Request for Tenders report (IBE1760Rp001_SRFT_DF01).

The Castlefinn Partnership Initiative (CPI) embankment culvert was highlighted to the surveyor as potentially difficult to survey due to restricted access from downstream extent and the need to remove a trash screen at the upstream extent to gain access. The survey contractor confirmed access issues onsite, noting that the trash screen on the upstream side of the culvert could not be readily removed. The 'as built' drawings combined with data from the CFRAM Study and the topographical survey for the Castlefinn FRS was deemed sufficient information to model the structure accurately. There was no need to procure a separate underwater or confined space survey given the level of information available.

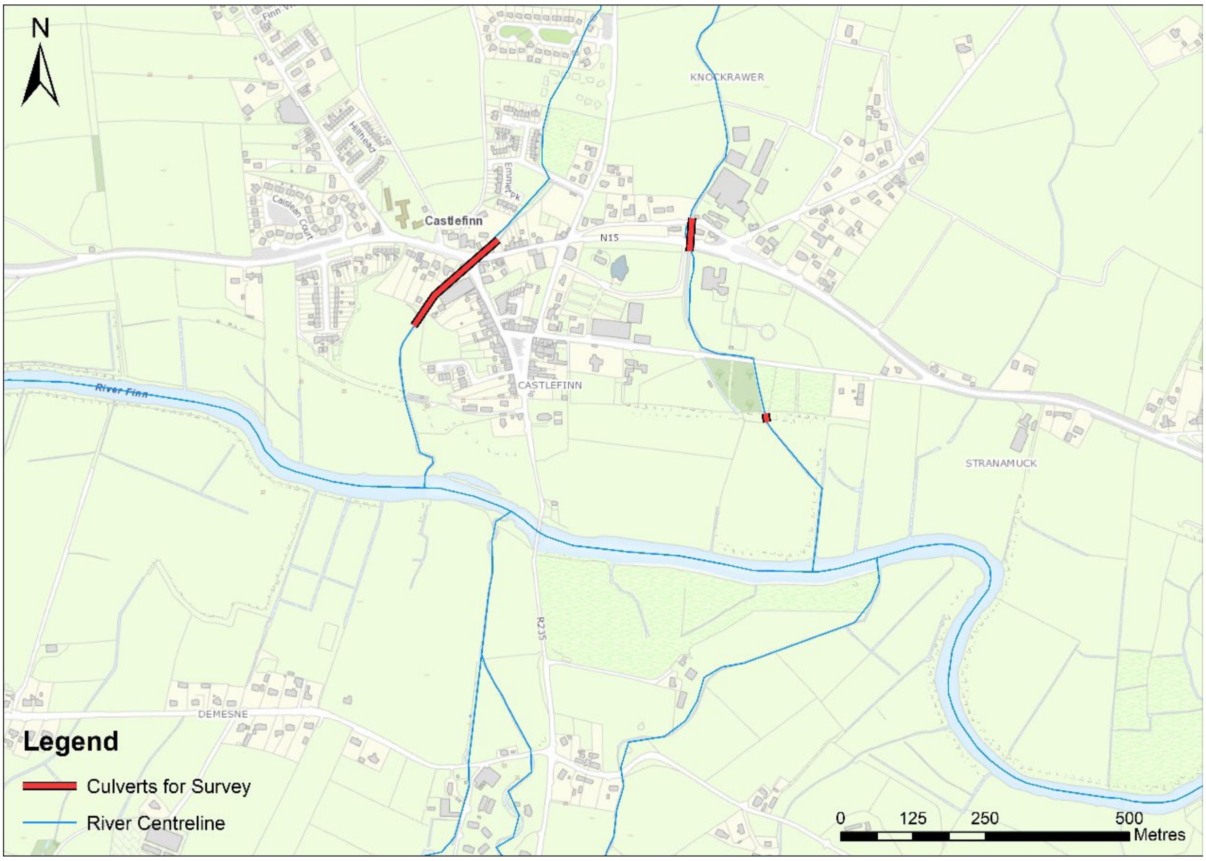

Figure 2.4: Culvert included in CCTV survey

2.4 Surface and Terrain Models

The LiDAR dataset (flown in 2009) used in the CFRAM Study model for the Castlefinn area was confirmed as the most up to date LiDAR dataset available within the study area. The LiDAR dataset covers the Castlefinn study area and was captured at a 2m resolution.

2.5 Walkover Surveys

RPS undertook a number of walkover surveys at Castlefinn including:

12/08/2020 – RPS undertook a general site walkover along with members of the Steering Group. The survey was mainly to investigate areas for potential additional survey and to discuss technical issues on the ground. Areas reviewed included the Bridge Burn culvert including its inlet and the area prone to flooding outside McGlynn's restaurant, the area of raised ground to the north of Castlefinn Bridge and the privately constructed flood defence downstream of the CPI centre.

17/02/2021 – RPS undertook defence asset survey along with members of the Steering Group using principles set out in the Flood Defence Asset Condition Survey OPW Technical Methodology Note[4]. The survey focussed on the defence downstream of the CPI embankment to ascertain its effectiveness and suitability to provide the

[4] Technical Methodology Note - Flood Defence Asset Condition Survey – Management & Specification

design Standard of Protection. At the time of survey there was extensive flooding of the fields upstream and downstream of the embankment.

Figure 2.5: Flooding downstream (left) and upstream (right) of CPI embankment February 2021

22/10/2021 – RPS undertook a site walkover study to sense check the flood mechanisms demonstrated by the model and to familiarise themselves with the at risk properties ahead of optioneering. The walkover focused on the tributary watercourses, namely the Bridge Burn and the Castlefinn watercourse. The walkover looked at the CPI centre and the reaches of the Castlefinn watercourse upstream of the N15.

26/10/2021 – RPS undertook a site walkover to review the upstream extent of the Castlefinn watercourse catchment and to sense check the hydrograph volume.

2.6 Other Information

2.6.1 Opening Public Consultation (OPC)

The OPC was held as an online event through the project website (https://countydonegalfrs.ie/castlefinnfrs) via an online portal from 9th November 2020 until the 21st December 2020. A traditional OPC in person event was not held due to the ongoing COVID-19 public health emergency.

Sixteen responses were provided in the form of returned questionnaires by post and by email. The vast majority of respondents had been affected by previous flooding with most identifying the source as fluvial (river) but with some mention of drains and overland flow as sources also.

Further information and comments made during the OPC are presented in the Castlefinn FRS Opening Public Consultation Summary report (IBE1760_Rp005, F01, 2021) and in the Castlefinn FRS Environmental Constraints Study report[5]

[5] Castlefinn FRS Environmental Constraints Report

3 HYDRAULIC MODELLING

3.1 Fluvial Model Construction

3.1.1 Model Conceptualisation

Model conceptualisation of Castlefinn includes the River Finn and main tributaries modelled from the upstream extent of any potential receptors between Ballybofey and Killygordon to the downstream extent of the model located at Clady Bridge on the River Finn. The model centreline extent presented in Figure 3.1 shows the extent within the Scheme Area. The extent of tributaries assessed was determined based on potential flood risk to receptors in the area.

At the outset the following data preparation and model build approaches were adopted:

- To comply with the brief, data was projected in ITM and converted to OSGM15. Geoid conversions were based off guidance provided within OSGM15 – Geoid Change for Ireland, Society of Chartered Surveyors Ireland.
- LiDAR dataset obtained during CFRAM Study were retained and used for the Digital Terrain Model (DTM) (following re-projection and geoid adjustment) albeit with areas known to have been developed / changed on the ground updated with topographical survey data (Figure 2.3).
- Given the extent of the model area a coarse 2D mesh zone was sufficient to represent the majority of the Finn valley, with a more detailed mesh zone introduced to the study extent.
- Surveyed building finished floor levels (where available) were imprinted onto the DTM with porous polygons representing walls and openings.

The approach to model conceptualisation was discussed at the Hydraulics Technical Workshop (02/09/21) attended by representatives from DCC and OPW. Model conceptualisation was presented to the Steering Group and the model development process further discussed. A summary of the workshop and the presentation slides were circulated to the Steering Group following the workshop.

A detailed hydrological analysis was undertaken to determine the flood flow hydrographs and peak design flows for the Castlefinn study area. The design flow estimation requires a comprehensive understanding of the physical catchment characteristics/descriptors (PCDs) throughout the Castlefinn study area. Hydrological Estimation Points (HEPs) have been specified at the locations where peak design flows have been estimated shown in Figure 3.1.

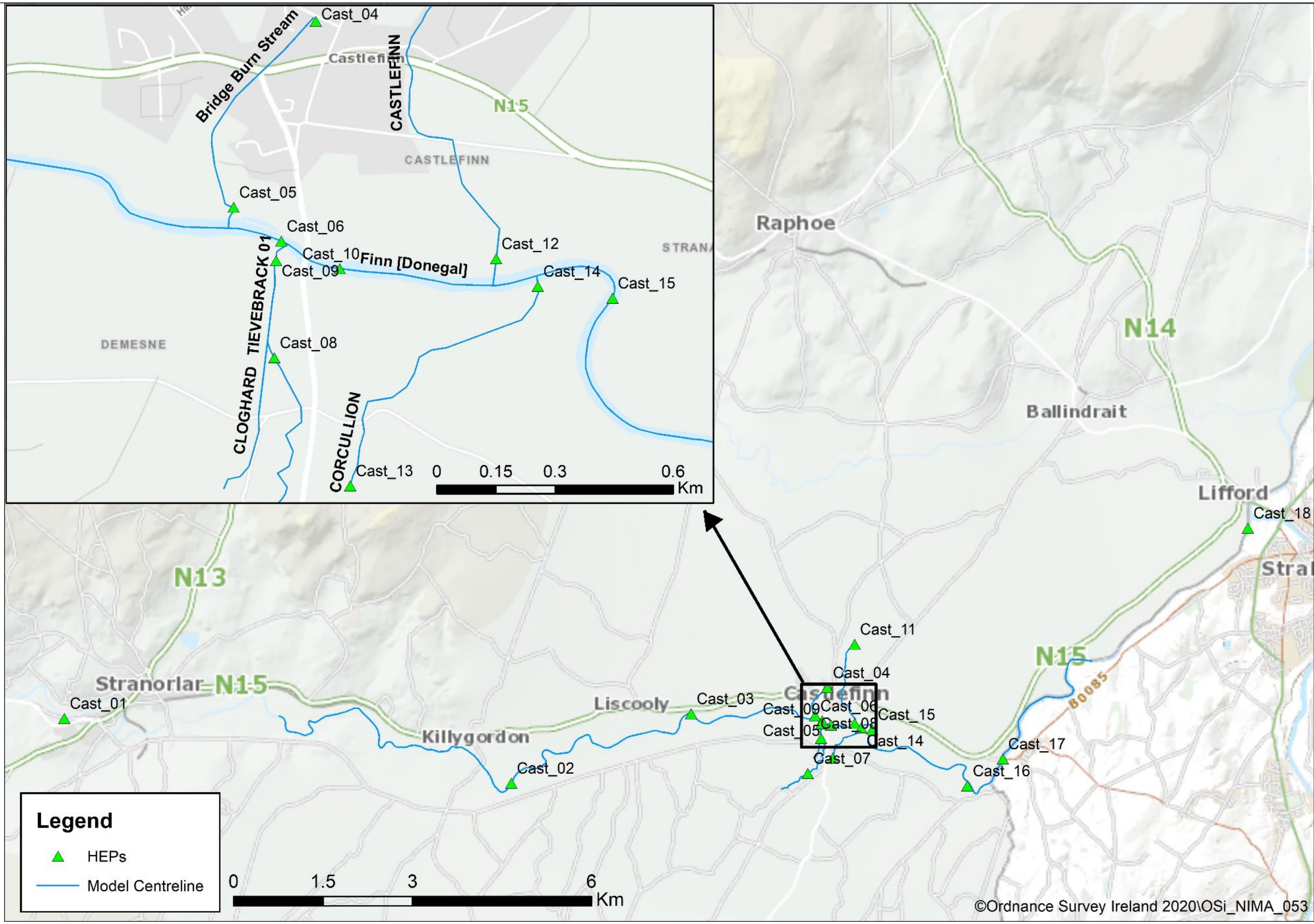

Figure 3.1: Castlefinn FRS Full model extent and Hydrological Estimation Point (HEP) locations

3.1.2 Modelling Software

RPS used InfoWorks ICM (version 2021.5) to undertake the numerical modelling of the watercourses. InfoWorks ICM is an integrated hydrological and hydraulic modelling package developed by Innovyze. InfoWorks ICM includes full solution modelling of open channels, floodplains, embankments and hydraulic structures. Additionally, the 2-dimensional areas within InfoWorks ICM are modelled through a triangular flexible mesh which allows for high levels of detail in specific areas (for example at riverbanks and around buildings) and a broader approach in other areas (for example open floodplains).

3.1.3 1D Model Domain

3.1.3.1 Survey Data

The construction of the 1D model domain incorporated newly surveyed data (2021) for a portion of the River Finn and five of its tributaries. Survey data from the Castlefinn CFRAM Study model was also incorporated to complete the modelled extent of the modelled reaches of the River Finn and the Castlefinn watercourse. These reaches were also surveyed as part of Castlefinn FRS (refer to Section 3.1.3.5). The extent of data used to inform the 1D model build are shown in Figure 3.2.

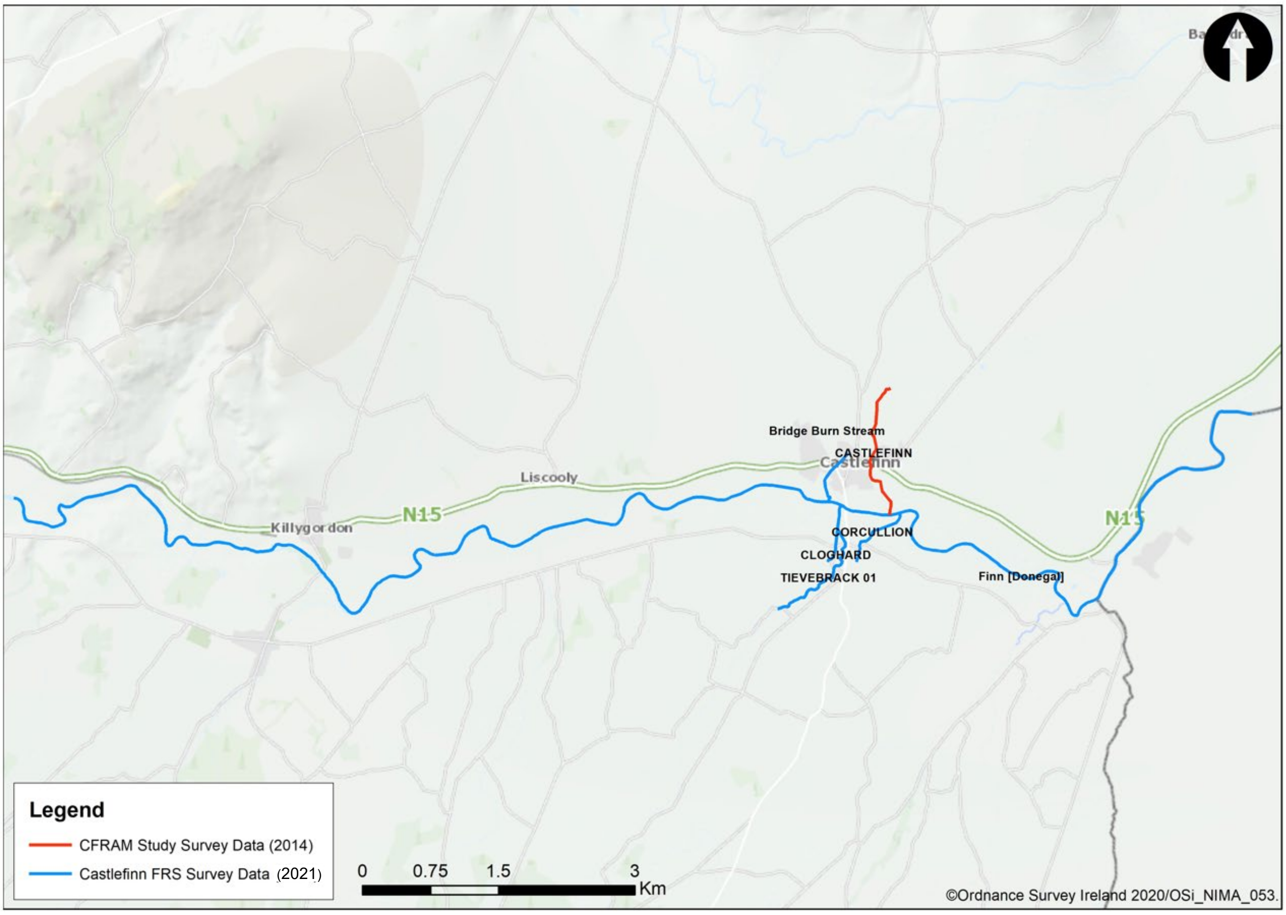

Figure 3.2: River reaches surveyed and previous CFRAM Study data

The downstream extent of the River Finn (2.5km) is modelled as 1D only, this is due to lack of LiDAR data however the representation is deemed appropriate as it is remote from the study extent. An assessment has provided confidence that the 1D representation of the downstream extent of the model would not impact the study area (Figure 3.11). The section of the River Finn modelled in 2D is approximately 6km in length and extends from Clady Bridge to the confluence of the Finn with the River Mourne.

3.1.3.2 Roughness

Manning's coefficient of roughness (*n*) values (Chow, 1959 [6]) were individually assigned to the channel cross sections of the 1D network based on observations from walkover survey supported by surveyors' photographs, with in-channel values ranging from 0.033 to 0.045. These values were adopted as the reaches vary from open and clear watercourses, such as the reaches of the River Finn (Figure 3.3), to more winding sections with the presence of weeds and stones in the lower reaches of the Castlefinn watercourse (Figure 3.4). A value of 0.05 to 0.11 was assigned to the bank and near bank portions of all cross-sections.

Figure 3.3: Open and Clear River Reach on the River Finn (Manning's n value of 0.033)

[6] Chow, V.T., 1959, Open-channel hydraulics: New York, McGraw Hill, 680 p.

Figure 3.4: River reach with weeds and stones on the Castlefinn watercourse (Manning's n value of 0.045)

3.1.3.3 Structures

All in-channel structures were included in the model and defined by the surveyed geometry, an example of a bridge structure is shown in Figure 3.5. There are a total of eight bridges, 12 culverts, three weirs, one flap valve and one trash screen included in the Castlefinn model, with critical structures highlighted in Figure 2.2.

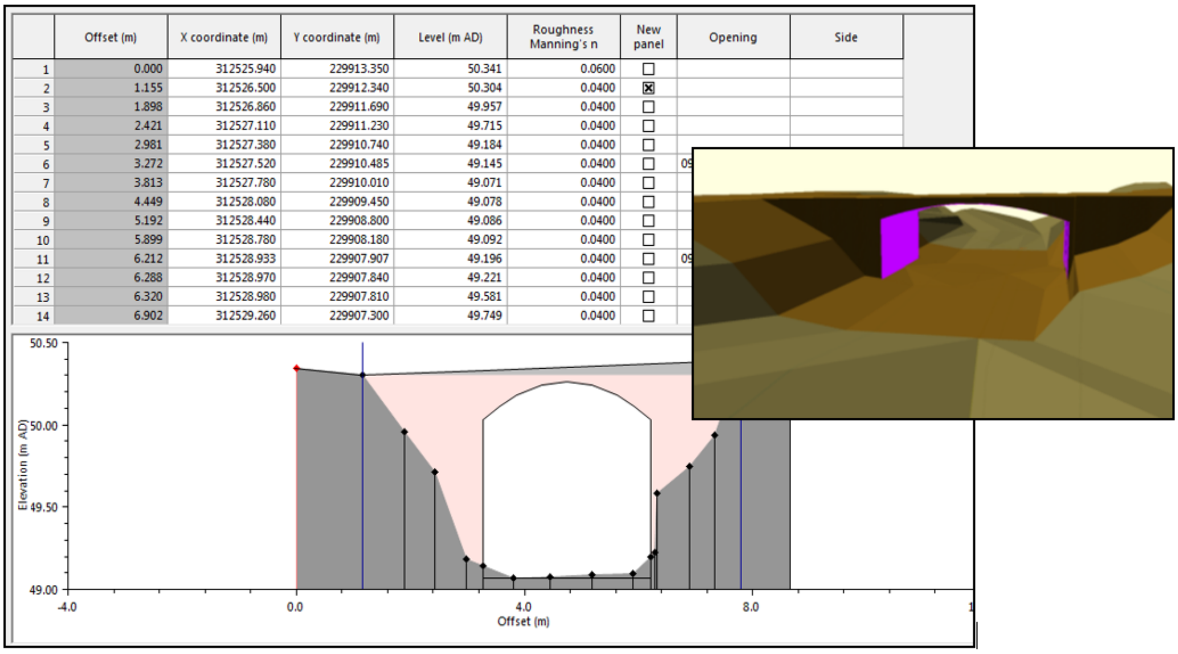

Figure 3.5: Example of ICM Model Input for In-Channel Structures

A trash screen is present on the Castlefinn watercourse at the CPI embankment culvert inlet (Figure 2.2) and was surveyed as part of the topographic survey. There is also a flap valve present on the Castlefinn watercourse at the CPI embankment culvert outlet which was not included in any Castlefinn FRS survey specification. Information on this structure was provided by DCC in 'as built' design drawings.

Six structures were identified as hydrologically significant to flood risk at Castlefinn, these are identified in Figure 3.6. These structures are subject to sensitivity analysis (Section 3.6) and were grouped into three networks:

1. The N15 culvert upstream of the CPI Centre on the Castlefinn watercourse that conveys flow under the N15. The McGlynns culvert on the Bridge Burn that conveys flow under the N15 and the south Finn double-barrelled culvert on the Corcullion watercourse that conveys flow under the L3044.
2. Hollow Road Bridge conveys flow of the Castlefinn watercourse south of the CPI Centre, under Hollow Road, towards the River Finn.
3. The CPI Embankment culvert conveys flow of the Castlefinn watercourse through a privately constructed embankment downstream from the CPI Centre. This culvert is fitted with a flap valve (further information detailed in Section 3.1.4.4).

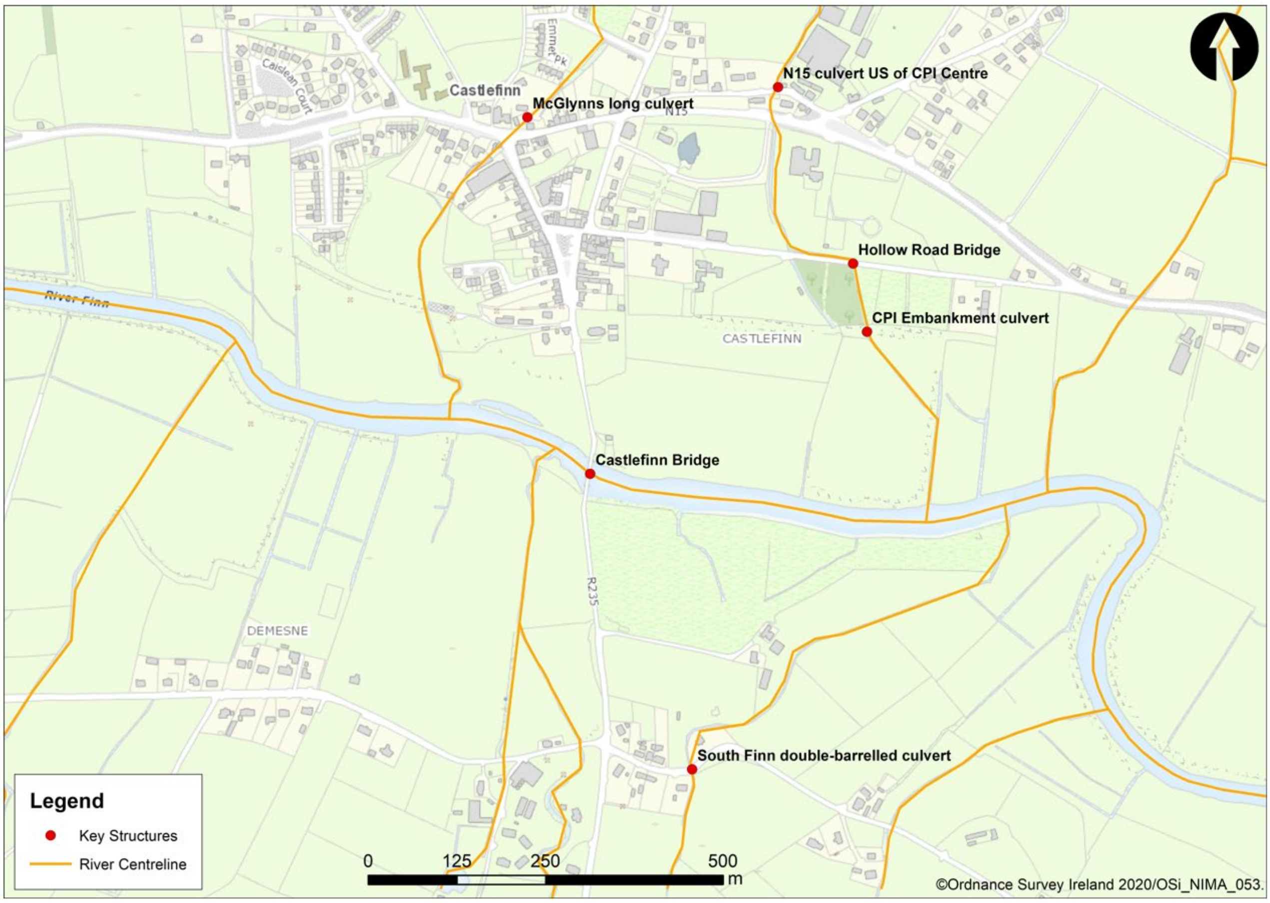

Figure 3.6: Location of Key Structures in Castlefinn

3.1.3.4 Bank Lines

River channels were modelled as 1D and connected to the 2D floodplain using bank lines. Bank lines are created using the surveyed levels at the extremities of the river cross sections and updated using levels from LiDAR.

3.1.3.5 Survey Dataset Comparisons

Newly procured survey was positioned, where possible, at the same location as previously surveyed cross sections (CFRAM Study survey or DfI River Foyle survey). To validate newly surveyed data and to assess geomorphological change between survey periods, comparison between historic survey and updated survey was carried out. Figure 3.7 outlines the location of cross-section comparisons.

The comparisons (Figure 3.8) revealed a small degree of variation potentially attributable to processes of erosion and deposition, but largely the datasets present little change between the survey periods.

Cross-section comparisons between the DfI River Foyle survey data (which were used to inform the Castlefinn CFRAM Study model) and the Castlefinn FRS survey are outlined in Figure 3.9. Similarly, these comparisons displayed a small degree of variation between survey periods. There is no evidence of significant hydro-geomorphological change on the five cross-sections compared along the Finn watercourse. This provides confidence in the 2021 data and demonstrates that the watercourses have not significantly changed over the last 10 years (approximately).

Scheme development and design will consider the potential for hydro-geomorphological change arising from proposed measures.

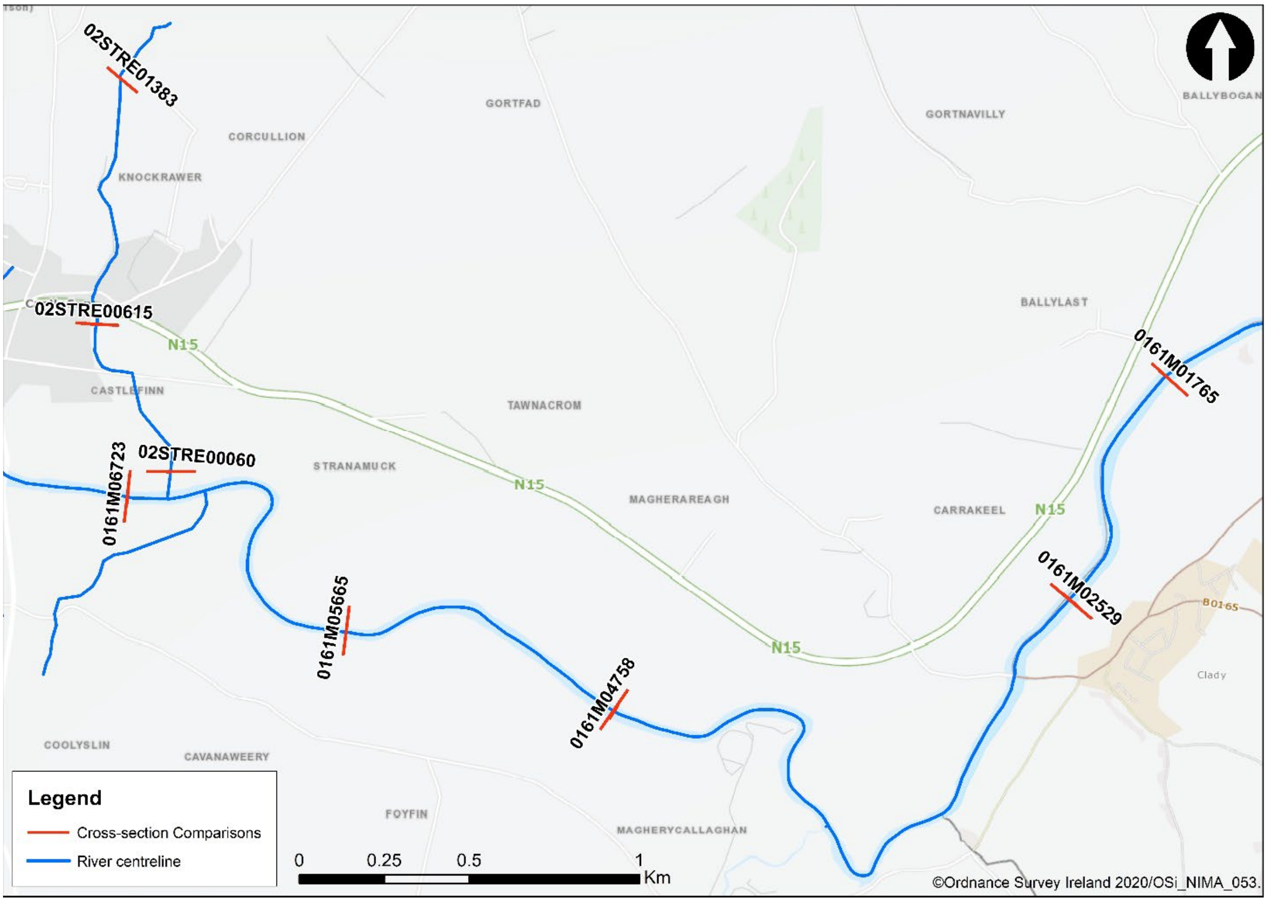

Figure 3.7: Location of cross-section comparisons between Castlefinn FRS survey and historic survey data

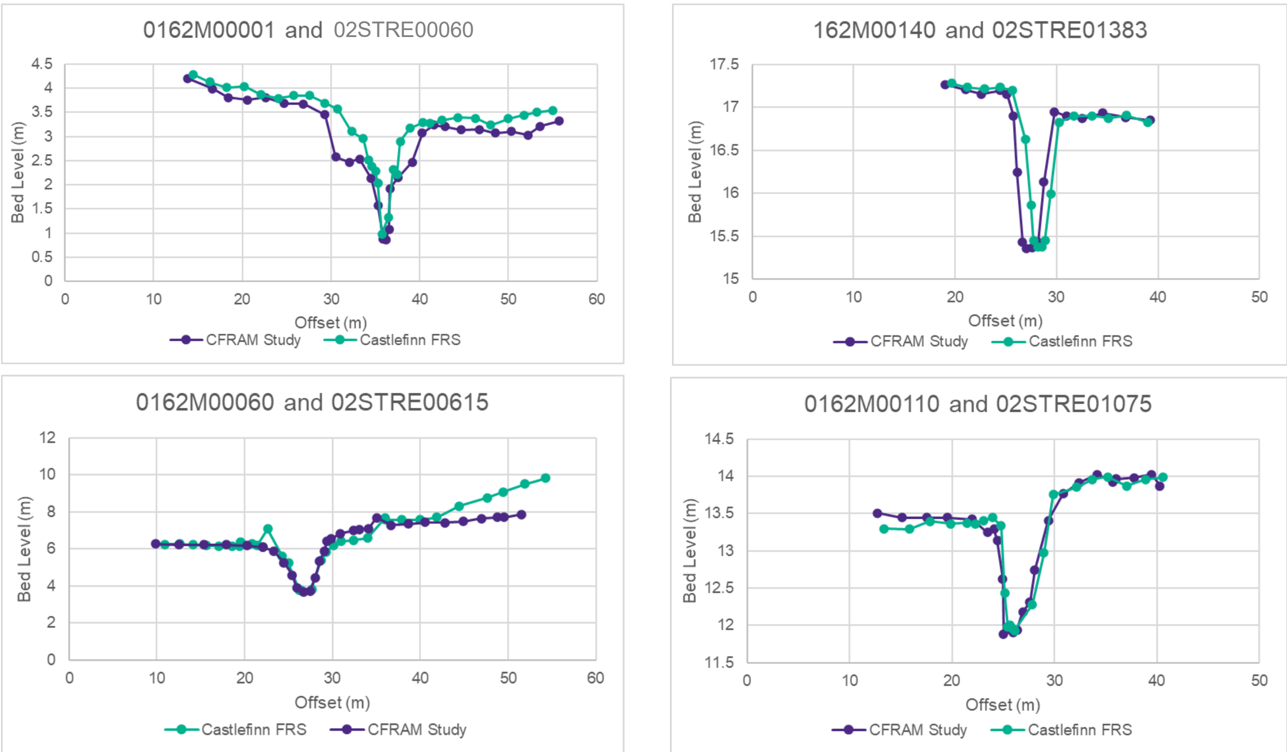

Figure 3.8: Cross-Section Comparisons for Castlefinn watercourse – Castlefinn FRS Survey and CFRAM Study Survey Data

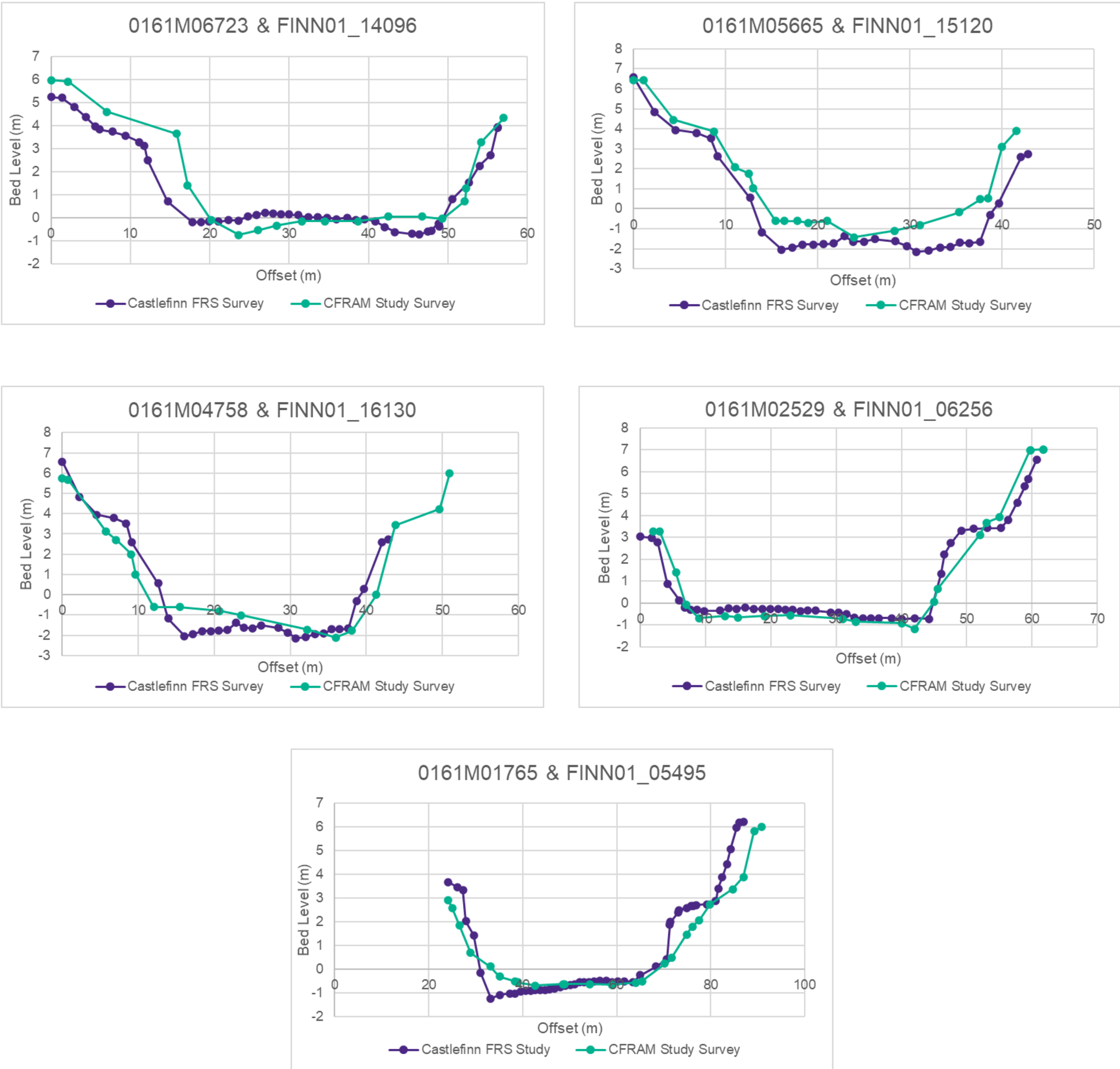

Figure 3.9: Cross-Section Comparisons for River Finn– Castlefinn FRS Survey and DfI River Foyle Survey Data

3.1.4 2D Model Domain

3.1.4.1 Mesh

LiDAR data has been used within the modelling package to generate the computational mesh; this has produced an accurate assessment of 2D flow paths. Details on the LiDAR data are discussed in Section 2.4. The complete LiDAR dataset for the 2D domain was generated in ArcGIS using the CFRAM Study LiDAR which was clipped along the Finn valley from the Ballybofey gauging station to the Clady gauging station (Figure 3.11).

Topographical survey data along with the building floor level data obtained in 2021 (Section 2.3), was merged into the LiDAR dataset for representation within the model (Figure 3.10).

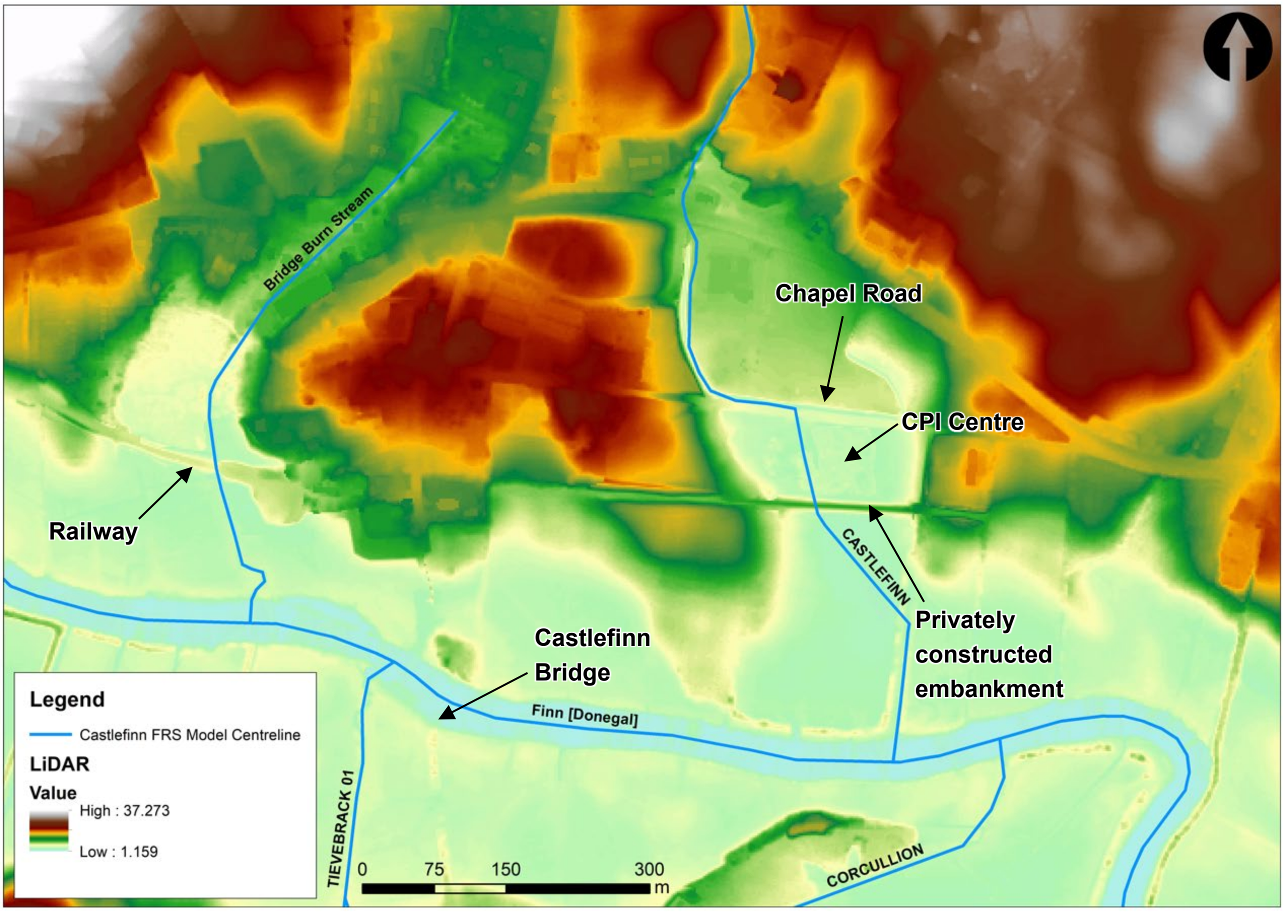

Figure 3.10: Extract from Final DTM used in model with additional topographical survey and building floor levels mosaicked into LiDAR

The mesh in the 2D zone has been augmented to include properties as imprinted floor levels (footprints raised to surveyed finished floor levels (FFL)) with porous polygons above the footprint. A porosity of 0.01 has been applied to all porous polygons, enabling buildings to store/slow water if flood levels surpass the raised finished floor levels providing a more accurate representation of flow paths. This approach is standard in Infoworks ICM models and referred to as “stubby” buildings. All flood receptors were contained within the 2D modelling domain.

The 2D zone of the model is made up of a coarse mesh (max triangle area 100m^2 and minimum triangle area 25m^2) representing more rural areas of the Finn Valley. A more detailed mesh zone was included to represent the study extent where there are receptors at risk (max triangle area 10m^2 and minimum triangle area 5m^2). The finer mesh of the Castlefinn FRS model produces a smoother flood extent when compared with the flood extents produced on the coarser mesh. This is due to triangle mesh size. Figure 3.11 and Figure 3.12 provide an overview of the 2D configuration within the model. This resolution of the coarse mesh is deemed suitably accurate to represent the flow of the Finn floodplain, as is the detailed mesh zone for representing accurate flow paths within the study area.

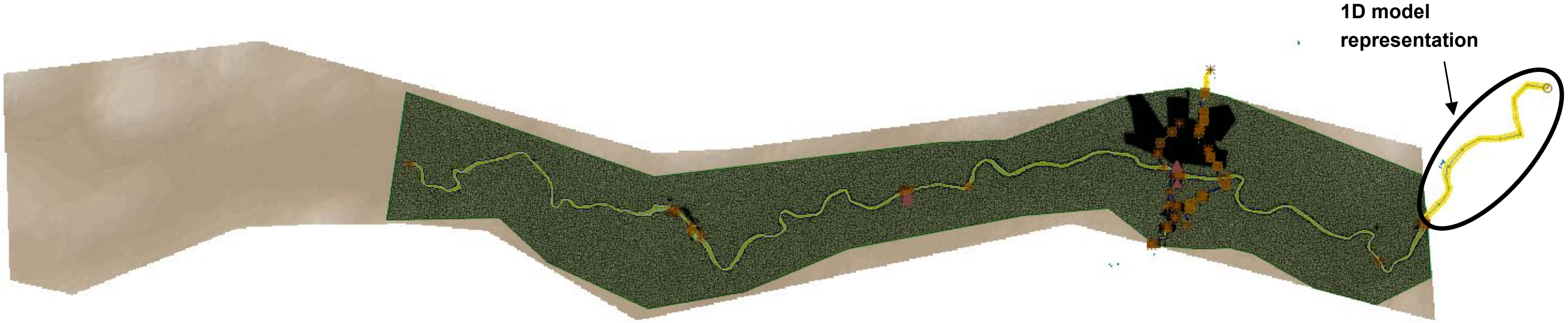

Figure 3.11: Modelled 2D Extent

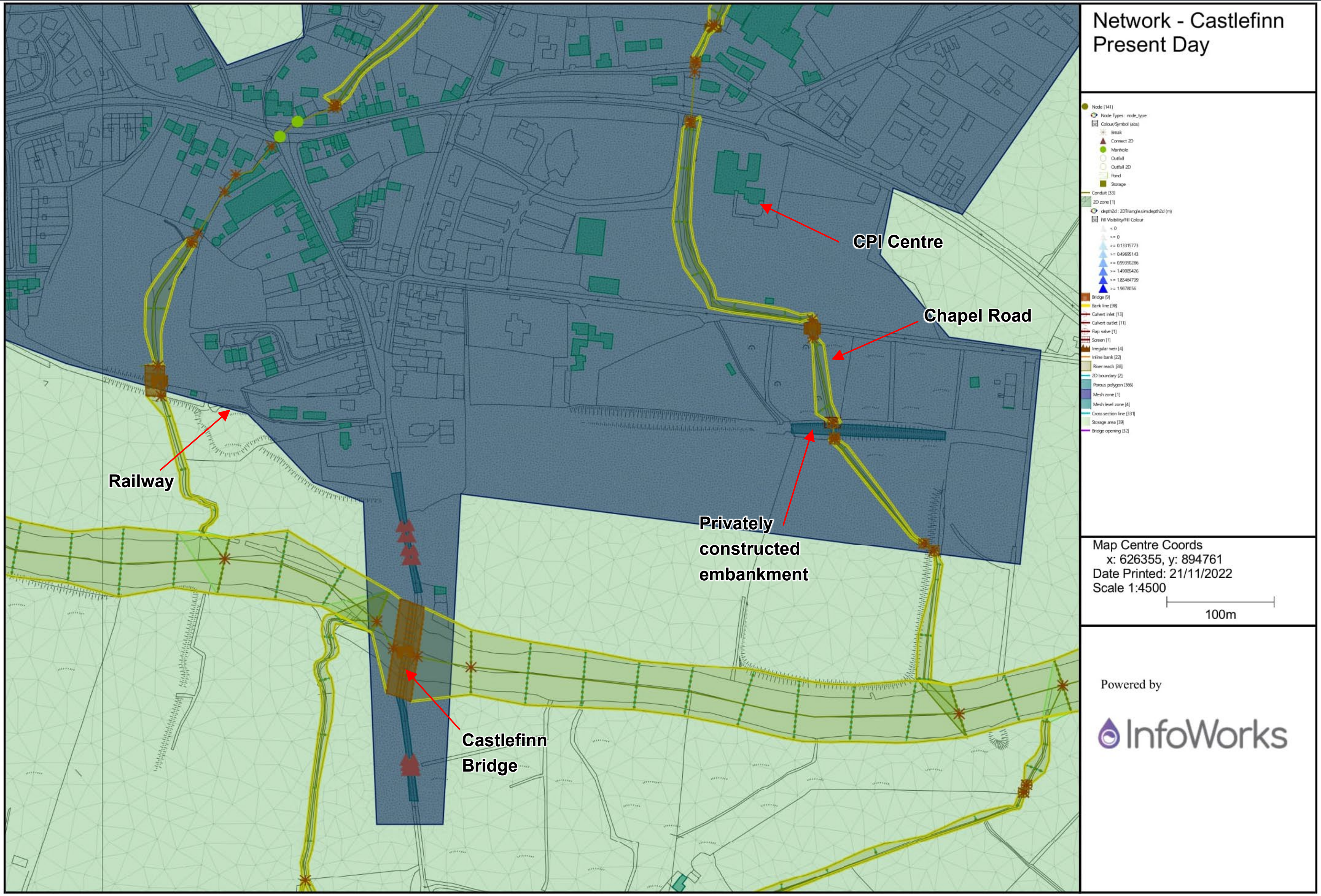

Figure 3.12: Zoomed in Modelled 2D Extent (showing mesh zone differences)

3.1.4.2 Structures

3.1.4.2.1 Floodplain Culverts

Castlefinn Bridge/R235 and Liscooley Bridge/L2534 (outside the Scheme Area) on the River Finn both have floodplain culverts through the road embankment. Although the Liscooley Bridge is outwith the scheme area it has been included in the model to ensure downstream conditions are accurately replicated. These culverts have been represented in the model using 2D connect nodes and Conduit 2D links. These units enable the software to maintain the momentum of the flow in the floodplain whilst reducing the potential for model instabilities when transferring flow between the 1D and 2D computational engines.

3.1.4.3 Roughness

The selection of roughness values used for the 2D domains was based on the land zones defined within the OSi PRIME2 dataset supplemented with Corine data[7]. Figure 3.13 outlines the extents of the OSi PRIME2 dataset. GIS processing removed areas of intersection between the two datasets and assigned the appropriate Manning's n value from Chow (1959) to land zones, prior to importing into the model to define roughness areas within the 2D model domain.

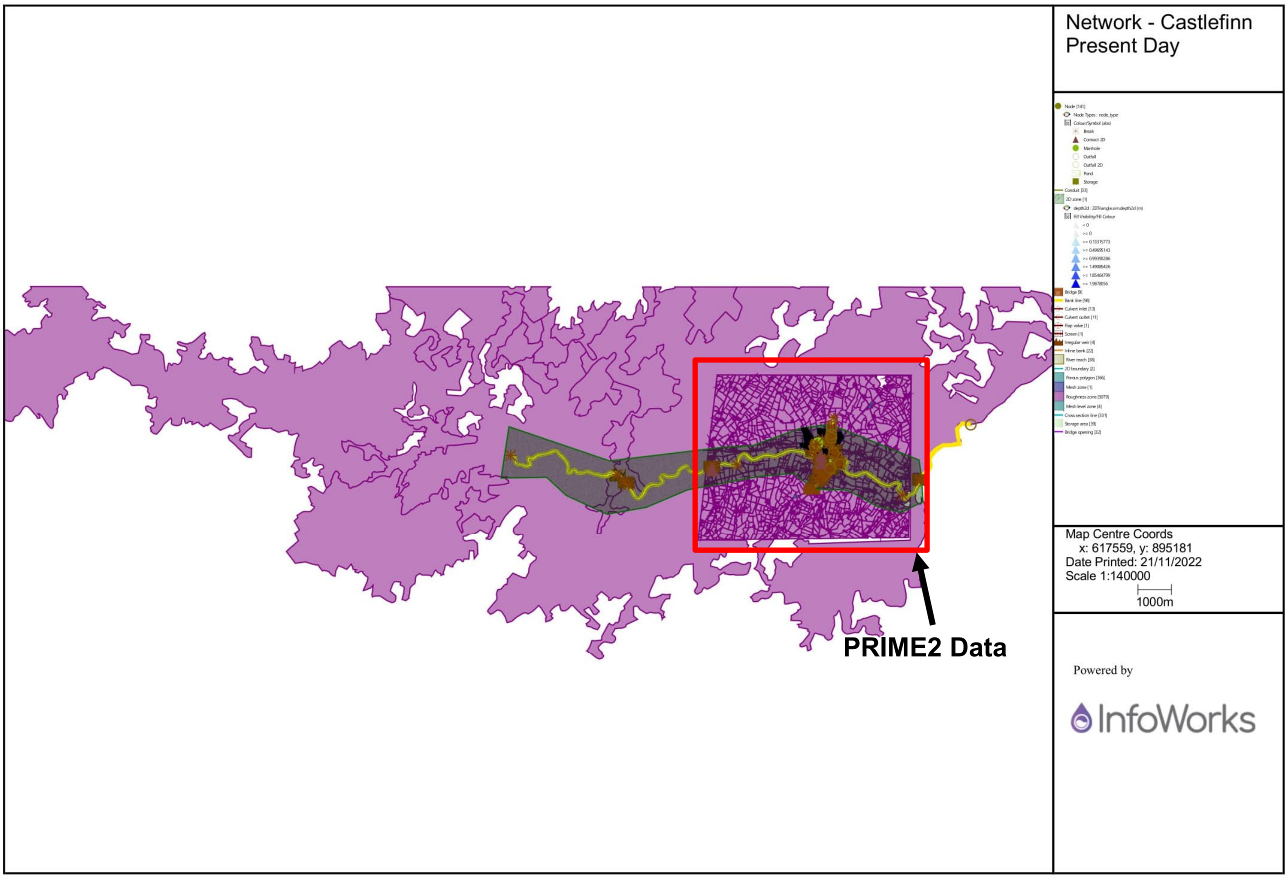

Figure 3.13: Extent of roughness zones in Castlefinn model

[7] (CLC, 2018)

3.1.4.4 Flood Defence

The CPI embankment, a formal effective flood defence provides protection from the River Finn (Figure 3.14). The defence consists of a raised earthen embankment along the old railway line along Chapel Road and a HESCO Flood Wall[8]. This was represented in the model by a “base linear structure (2D)” which is a function of the mesh generation and is used to represent walls and embankments with a specified porosity and level (Figure 3.15). A base linear structure was included in the model set to the level of the embankment with a porosity of zero. A second base linear structure was included in the same location ‘on top’ of the embankment structure to represent the wall to a level of 8.32m OD Malin and a porosity of 0.1.

The old non-return valve (flap valve) on the culvert headwall was replaced by a 1000mm circular flap valve that is fitted to the back of the headwall at the culvert outlet. A 1250mm penstock was fitted to the end of the culvert headwall, which created a confined box between the penstock and the flap valve approximately 1m in length. There is a trash screen present at the upstream extent of the flood defence culvert, which was in place before the old non-return valve was replaced. This trash screen was retained as part of the scheme and is therefore included in the model. This has been captured in the topographic survey and is mentioned in Section 3.1.3.3. Additional survey was not required for these aspects of the culvert arrangement as this information was already available (as noted in Section 2.3).

Figure 3.14: CPI Flood Defence Embankment with HESCO flood wall system lining the crest.

[8] (HESCO®, 2021)

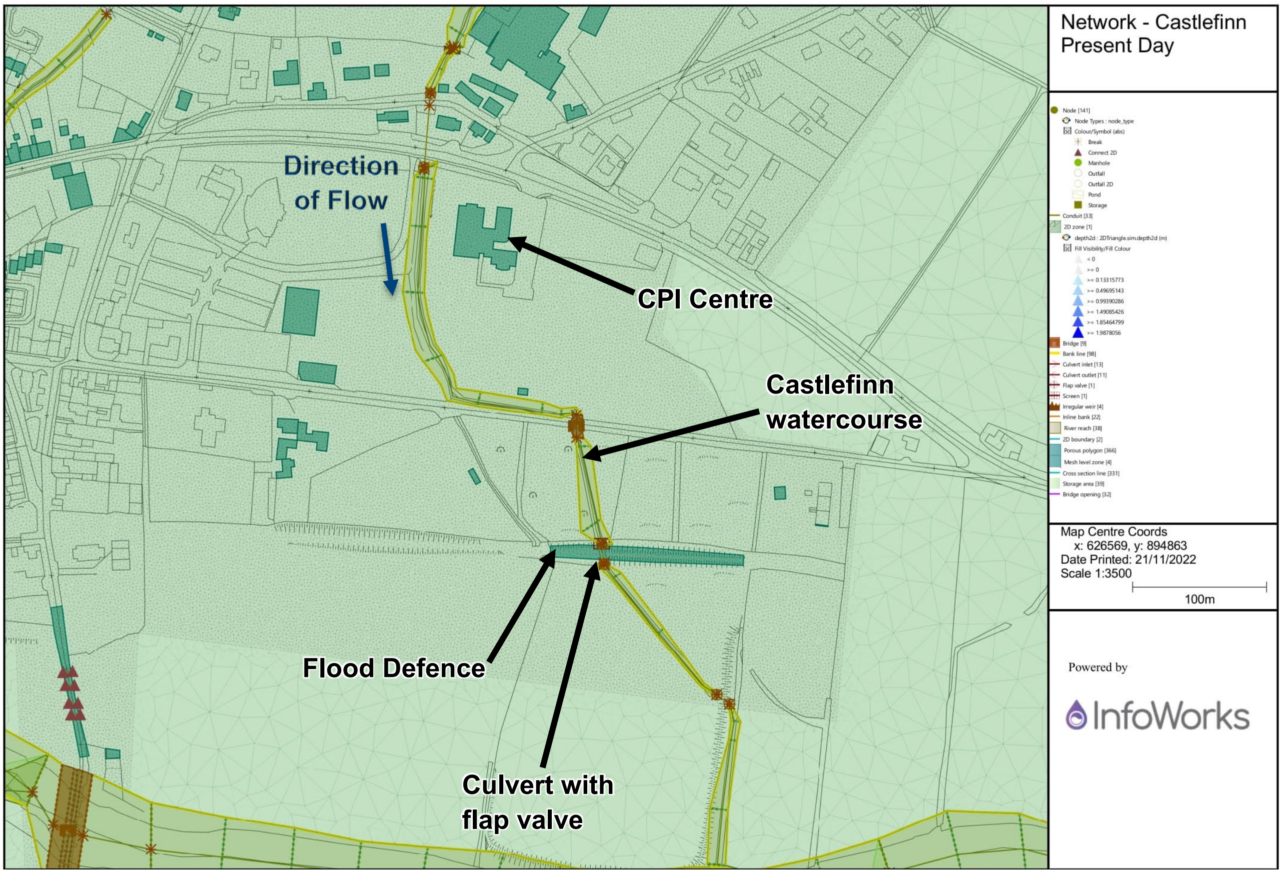

Figure 3.15: Castlefinn model representation of Flood Defence

3.1.5 Boundary Conditions

3.1.5.1 Upstream Boundary

Upstream boundary conditions and input hydrographs for the model (Hydrology Report Chapter 3) as determined at upstream Hydrological Estimation Point (HEPs) have been introduced as point inflows to the 1D model domain. The hydrological assessment determined lateral flows between HEPs, based on the downstream HEP total flow scaled to the area of the lateral catchment, which were disaggregated for the appropriate river reaches between HEPs, based on length. Figure 3.16 illustrates the 1% AEP upstream point inflow hydrograph for the River Finn.

The Hydrology Report Sections 3.4 and 4.1 details the assessment carried out for timings to ensure the model captured fluvial-fluvial joint probability consideration and accounted for the varying sub-catchment hydrograph response times.

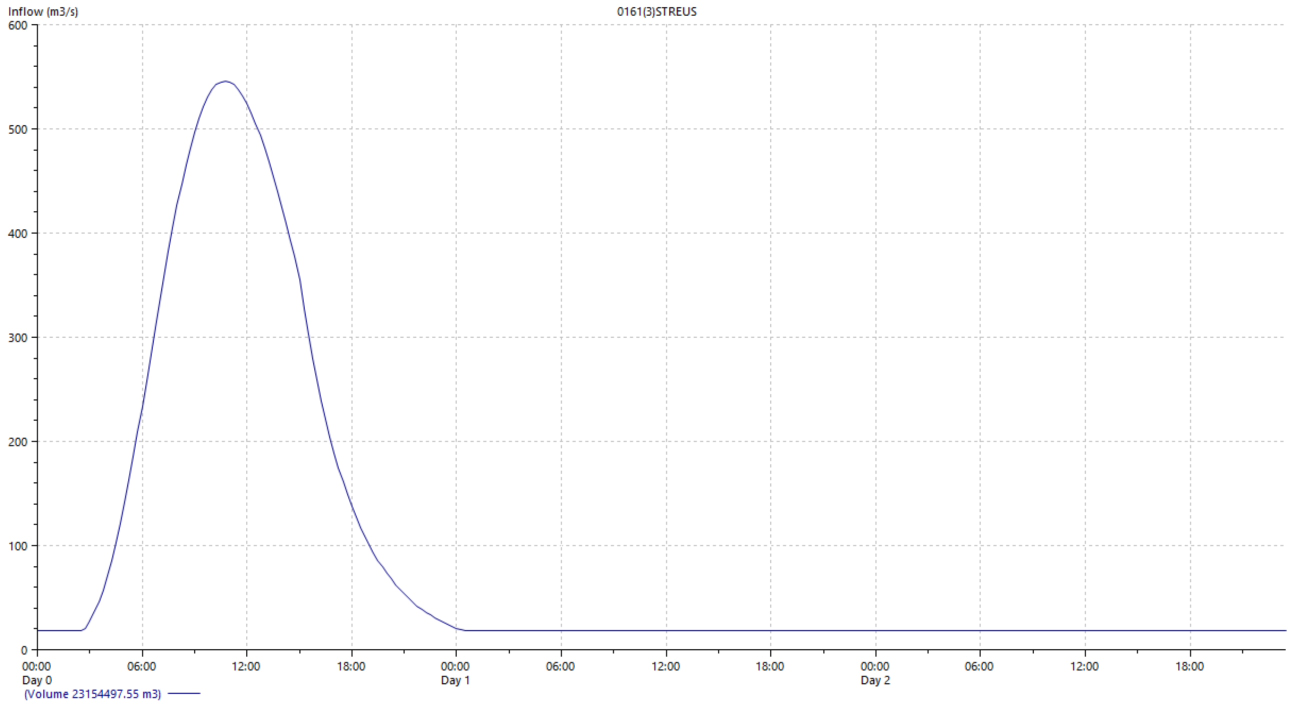

Figure 3.16: 1% AEP Upstream Inflow Hydrograph for the River Finn

3.1.5.2 Downstream Boundary

The downstream boundary condition was extracted from the Lifford FRS hydraulic model so as to capture the complex mechanisms that drive water levels at the top of the River Foyle / Lower Finn Valley. The Lifford FRS hydraulic model was developed by RPS as part of the Lifford Flood Relief Scheme in 2021 ahead of the Castlefinn FRS hydraulic model. It is a larger model covering the extent of the Finn reaches within which the Castlefinn FRS hydraulic model sits but also includes River Mourne, Deele and Foyle reaches affecting Lifford. It is anchored to reliable flood flow data at each of its four main boundaries; the upstream extent of the Finn, Mourne and Deele and at its downstream extent at Lisahally. Further information on the Lifford FRS and the hydraulic modelling can be found at http://liffordfrs.ie/.

The Lifford FRS hydraulic model captures the combination of fluvial flows from the Mourne, Finn and Deele river's as well as the coastal backwater effects from Lough Foyle. By extracting the water level condition from the Lifford FRS hydraulic model at the location of the Castlefinn downstream boundary (i.e. Clady) these effects are projected back into the Castlefinn FRS model. The timing of the boundary condition is discussed in Section 4.2 of the Castlefinn FRS Hydrology Report. The peak of the downstream boundary was set to peak seven hours after the fluvial peak of the upstream inflow to match what has been observed. The 1% AEP downstream boundary is shown in Figure 3.17.

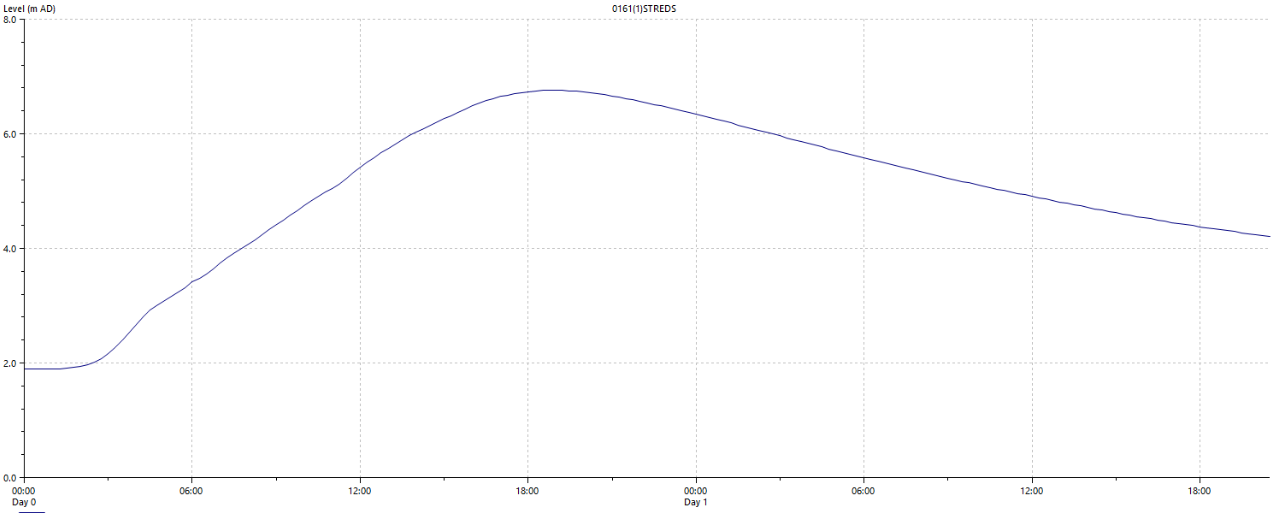

Figure 3.17: 1% AEP Downstream Water Level Boundary

3.1.6 Simulation Parameters

Table 3.1 presents the key simulation parameters used during all modelled simulations.

Table 3.1 – Simulation Parameters

1D Domain	
Timestep (seconds)	1
Min / Max space step	0.1m / 100m
Max Timestep Halvings	30
2D Domain	
Timestep (seconds)	Dynamic
Timestep Stability Control	0.95
Maximum Velocity	10
Theta	0.9
Inundation Mapping Depth Threshold	0.001m

3.2 Model Calibration and Verification

3.2.1 Model Stability

RPS have reviewed model stability through various checks such as flow plots, water level checks, bank line flow and mass balance to ensure the model outputs are reliable. Based on these checks there are no residual issues with the model that may impact on the overall accuracy of outputs for Castlefinn FRS.

3.2.2 Hydrological Anchoring

Internal validation checks using modelled flows against hydrological estimations have ensured that the model is anchored to the hydrological estimates of flow (Table 3.2). Based upon these reviews, there is confidence the model is replicating the expected hydrological flow regime as set out in the Hydrological Analysis, within tolerance. The location of the HEPs is outlined in the Hydrology Report Section 3.1.

Table 3.2 – HEP Flow Comparison

HEP	Peak Flows			
	AEP (%)	Check Flow (m^3/s)	Model Flow (m^3/s)	Difference (%)
CAST_02 (Finn)	50.0	257.5	278.2	8.1
	10.0	387.6	428.7	10.6
	1.0	543.4	605.4	11.4
	0.1	690.5	784.4	13.6
CAST_03 (Finn)	50.0	258.6	288.0	11.4
	10.0	389.3	438.9	12.7
	1.0	545.7	633.4	16.1
	0.1	693.4	812.1	17.1
CAST_05 (Bridge Burn)	50.0	0.4	0.3	-28.6
	10.0	0.7	0.6	-14.3
	1.0	1.2	1.0	-13.0
	0.1	1.8	1.5	-15.7
CAST_06 (Finn)	50.0	256.0	277.3	8.3
	10.0	385.4	417.6	8.3
	1.0	540.3	587.3	8.7
	0.1	686.6	732.2	6.6
CAST_09 (Tievebrack)	50.0	4.3	4.6	6.2
	10.0	7.2	7.5	4.6
	1.0	11.7	11.9	1.4
	0.1	18.2	17.6	-3.2
CAST_10 (Finn)	50.0	260.3	271.8	4.4
	10.0	391.9	395.0	0.8
	1.0	549.4	560.0	1.9
	0.1	698.1	698.6	0.1
Cast_12 (Castlefinn)	50.0	0.9	0.9	0.0
	10.0	1.5	1.4	-6.0
	1.0	2.4	2.0	-18.0
	0.1	3.8	3.1	-18.2
Cast_14 (Corcullion)	50.0	0.5	0.5	2.0
	10.0	0.8	0.8	-2.4
	1.0	1.3	1.2	-10.4
	0.1	2.1	1.9	-8.2
CAST_15 (Finn)	50.0	259.4	260.4	0.4
	10.0	390.5	384.9	-1.4
	1.0	547.4	541.0	-1.2
	0.1	695.6	676.6	-2.7
CAST_17 (Finn)	50.0	254.4	211.6	-16.8
	10.0	383.0	341.7	-10.8
	1.0	536.9	480.6	-10.5
	0.1	682.3	614.8	-9.9

To demonstrate anchoring of the hydraulic model to the design flow estimation it is important that modelled flows at check points are either within tolerances or where there is a hydraulic reason for the discrepancy, this is explained. Where the hydraulic model flow and hydrological estimation are within 10% of each other it is considered that modelled flows are anchored within tolerances, unless the check point HEP represents a flood flow gauging station where much lower (tighter) tolerances are required. The most important return period for anchoring of the hydrology, especially at gauging stations, is the 50% AEP. This is an event that occurs often and is therefore well-documented when compared with lower probability events. The overall results are discussed below for each HEP.

- HEP CAST_02 (River Finn upstream reaches) shows good correlation with the hydrological estimation for the 50% AEP event, with a difference between modelled and estimated flow of 8%. The 10%, 1% and 0.1% AEP events were above the normal 10% bound for demonstration of anchoring. There is high uncertainty in the progression of flood flows within the Finn Valley moving downstream of Ballybofey. In the design flow estimation this was evidenced by the decreasing Q_{med} (50% AEP) values moving down through the Finn Valley. In reality, and as evidenced in the model simulation, peak flood flows when entered into the model are drastically altered by the effects of extensive floodplain attenuation in the active Finn floodplain. The model experiences significant out of bank flow and there is considerable interaction with 2D flow spilling out of the Finn 1D channel resulting in active floodplain flow in all scenarios. Moving to the downstream extents of the model in the Lower Finn Valley the effect of backwatering from the Foyle further attenuates peak flows. In light of the attenuation the sum of the inflows to the model are generally well in excess of the check flows, e.g. from 122% at CAST_02. The model is effectively attenuating the 122% down to 107-109% at CAST_02. Ultimately the model is considered to better represent the effect of this hydraulic attenuation moving down through the Finn Valley and is therefore the better representation of peak flows. In other words the model would not necessarily be expected to be closely anchored to the hydrological estimates along the Finn Valley.
- HEP CAST_03 (River Finn upstream of Castlefinn) shows anchoring checks above the normal bounds, with a difference between modelled and estimated flow of 11% and 17%. This HEP is located on the River Finn near Liscooley. The reason for the difference in hydrological estimates is the same as discussed for CAST_02. Effectively the floodplain attenuation is shown in the model to be a bit less than anticipated in the design flow estimation (HEP check flow at CAST_02). The model is considered to be a better representation given its ability to capture the Finn floodplain attenuation effects.
- HEP CAST_05 (Bridge Burn D.S. Extent) shows anchoring checks well below the normal bounds, with a difference between modelled and estimated flow of -13% and -29%. This HEP is located in the lower reaches of the Bridge Burn, which lies on the floodplain of the Finn to the west of Castlefinn. This watercourse experiences out of bank flow due to an 80% blockage of a long culvert resulting in flow spilling out on to the floodplain. There is also a significant interaction with a backwater effect from the Finn floodplain and during times of flood, water inundates back up through the watercourse. In light of this, the flow had to be extracted upstream of the Finn floodplain and upstream of the blocked culvert to allow for an accurate flow reading. As a result, a reduction in modelled flows when compared against the hydrological estimates is to be expected with the difference decreasing with larger return periods.

The model is essentially demonstrating realistic hydraulic mechanisms which are not captured in the design flow estimates for the lower extent of the Bridge Burn.

- HEP CAST_06 (Finn at Castlefinn) shows good anchoring of the model to the design flow estimation for all reviewed return periods, with a difference between modelled and estimated flow of 6% and 9%. Note that this HEP as well as HEPs 09, 10, 12, 14, 15 and 17 are all within reaches affected by backwater effect from the River Foyle. This makes the anchoring checks less certain on these HEPs. However, a check has also been undertaken on the model inflows to ensure that the sum of all inflows at all HEPs is sufficient to generate the required check flow. At all locations the sum of inflows ranges between 100 – 110% of the check flow.
- HEP CAST_09 (Tievebrack watercourse) shows good anchoring of the model to the design flow estimation for all reviewed return periods, with a difference between modelled and estimated flow of -4% and 6%.
- HEP CAST_10 (Finn at Castlefinn Bridge) shows good anchoring of the model to the design flow estimation for the 50%, 10% and 1% AEP events, with a difference between modelled and estimated flow of -6% and 4%. The 0.1% AEP event was above the 10% limit for good correlation. This HEP is located on the River Finn at the Castlefinn Bridge and downstream of the confluence of the Tievebrack watercourse. The reason for the difference in hydrological estimates is discussed for CAST_02 and CAST_03.
- HEP CAST_12 (Castlefinn watercourse DS extent) shows good anchoring of the model to the design flow estimation for the 50% and 10% AEP events, with a difference between modelled and estimated flow of -6% and 0%. The 1% and 0.1% AEP events are well below (approximately 18%) the normal -10% lower bound for anchoring checks. This HEP is located in the lower reaches of the Castlefinn watercourse, which lies on the floodplain of the Finn to the east of Castlefinn. A flood defence was constructed on this watercourse outlined in Section 3.1.5 which includes a flap valve to prevent water from the Finn backing up through the watercourse. The hydraulic constriction of the flap valve and backwatering from the Finn are considered realistic mechanisms which would reduce the peak flow in the model, particularly in the larger events as capacity of the system is reached. These mechanisms would not be captured within the hydrological estimates.
- HEP CAST_14 shows good anchoring of the model to the design flow estimation for all reviewed return periods, with a difference between modelled and estimated flow of -9% and 10%.
- HEP CAST_15 shows good anchoring of the model to the design flow estimation for all reviewed return periods, with a difference between modelled and estimated flow of -3% and 1%.
- HEP CAST_17 (River Finn downstream of Castlefinn) shows good correlation with the hydrological estimation for the 0.1% AEP event, with a difference between modelled and estimated flow of 10%. The 50%, 10% and 1% AEP events were outside the normal 10% bound for demonstration of anchoring. The reason for the difference in hydrological estimates is the same as discussed for CAST_02. Effectively the floodplain attenuation is larger than anticipated in this location.

3.2.3 Calibration and Verification

Two historic flood events were used to calibrate the Castlefinn model. Modelled flood extents are considered to be representative of the December 2015 and August 2017 calibration events. This provides confidence in the model parameters, timing and magnitude of hydrographs and data included in the model.

3.2.3.1 Observed December 2015 Event

The hydrometric gauging station located on the Mourne at Drumnabuoy House (201010) was reviewed in relation to the December 2015 event in the Lifford FRS Hydrology Report[9] Section 2.1. A flow of 925m^3/s was recorded on the 5th of December 2015 correlating to an estimated AEP of approximately 1.5%. The Finn at Ballybofey (01043) was also reviewed in relation to the December 2015 flood event as detailed in the Castlefinn FRS Hydrology Report section 2.1. A flow of 450m^3/s was recorded on the 5th of December 2015 correlating to an estimated AEP of approximately 1 - 2%. Rating equations were produced to determine the upstream inflows for the model to replicate the 05/12/2015 event and assess how the Castlefinn FRS model performs when compared to observed data. Lateral inflows were applied as scaled hydrological inputs equating to the estimated return periods for each river. The 05/12/2015 event was taken as an approximate 1.5% AEP fluvial flood event based on the estimate of the event frequency at the Ballybofey gauging station.

Model calibration data was obtained from the OPW, DCC, landowner information, OPC submissions, drone video footage, internet searches and flood event response (FER) data collection. FER Reports collect information post-flood event to understand accurate extent of the flooding, including measuring water levels of the observed flood event. An FER Report, completed for Castlefinn for the December 2015 event was provided by OPW.

Figure 3.18 shows the recorded flood extent and modelled flood extent in Castlefinn for the December 2015 flood event, it also displays locations where flood depths were recorded.

Table 3.3 compares the recorded flood depths to the modelled flood depths at these locations and details the data used for model calibration alongside comments on model performance. A threshold of +/-0.2m is accepted for vertical differences in model depth and recorded depth.

[9] Lifford Flood Relief Scheme Hydrology Report document no.IBE1674_Rp02, RPS, 2021 available at:

http://liffordfrs.ie/wp-content/uploads/2021/12/IBE1674_Rp_03_Lifford-FRS-Stage-1-Hydrology_F01-211110.pdf

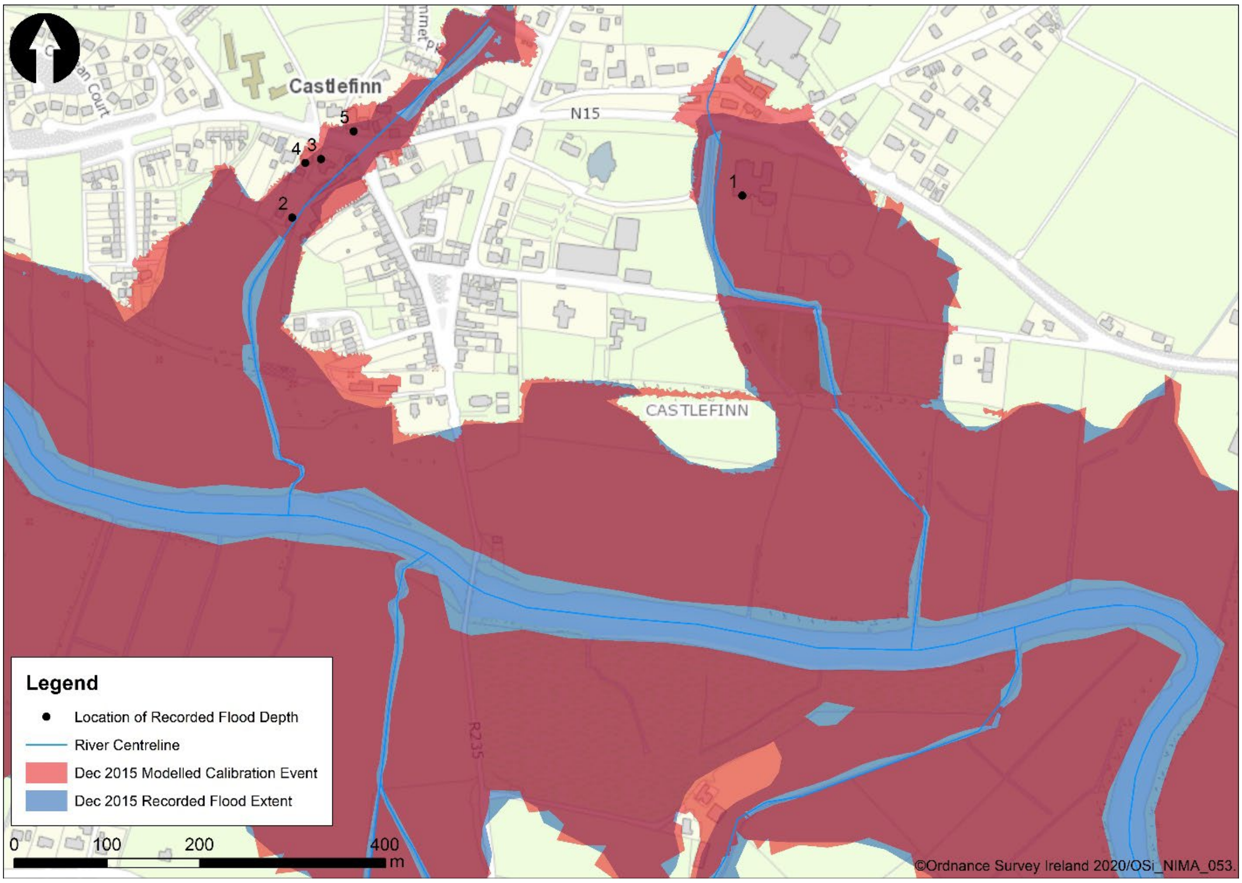

Figure 3.18: Comparison of Recorded and Modelled Flood Extents during Dec 2015 Event

Table 3.3 – Summary of 2015 Calibration Data and Model Verification

Event Data - Depth of Flooding	Location	Source of data	Summary of Model Performance
1.06m	1. Hall of CPI Building	FER	Model depth = 1.04m Vertical difference = +0.02m
1.19m	2. Mechanic's garage at rear of 333 Lifford Road	FER	Model depth = 1.21m Vertical difference = -0.02m
0.68m	3. Gable wall of house on Lifford Road	FER	Model depth = 0.675m Vertical difference = -0.005m
0.55m	4. Rear wall of house at 333 Lifford Road	FER	Model depth = 0.536m Vertical difference = -0.014m
0.47m	5. Front of McGlynn's restaurant	FER	Model depth = 0.509m Vertical difference = 0.039m
0.75m	OPC respondent noted flooding to property in Coolyslin	OPC	Model depth = 0.77m Vertical difference = 0.02m
1.00m	OPC respondent noted 1m of water to the rear of the property in Grahamsland	OPC	Model depth = 1.27m Vertical difference = 0.27m Vertical difference is larger than 0.2m bound. The flood depth given was not measured as part of the flood event response but was estimated by the property owner. RPS cannot confirm exactly where it was measured but a greater depth to the rear of the property is shown in the model. Given the uncertainty in the measurement, level of agreement is considered acceptable.

3.2.3.2 Observed August 2017 Event

As stated in Section 3.2.3.1 rating equations were produced to determine the upstream inflows for the model to replicate the 23/08/2017 event and assess how the Castlefinn FRS model performs when compared to observed data. The August 2017 event is estimated to correlate to an approximate 12.5% AEP fluvial flood event.

Table 3.4 compares flood event data to modelled flood depths and details the data used for model calibration alongside comments on model performance.

Table 3.4 – Summary of 2017 Calibration Data and Model Verification

Event Data	Location	Source of data	Summary of Model Performance
McGlynns was flooded with the water coming up to the step of the restaurant.	McGlynn's restaurant, Castlefinn	FER	Model depth = 0.1m at the front step of restaurant
A total length of 230m of the N15 was recorded as flooded.	N15 at Castlefinn	FER	Model has replicated an area of flooding on the N15, approximately a length of 200m (near McGlynns restaurant) in Castlefinn.

3.2.3.3 Summary of Model Calibration

The principal model parameters reviewed and amended during calibration to the Dec 2015 and Aug 2017 flood event were:

- Bed and floodplain roughness coefficients,
- Timing of hydrographs,
- Magnitude of hydrographs.

The chosen parameter adjusted to calibrate the model to better represent reported historical flooding depended on the desired output i.e. whether there was too much or too little flooding in a particular area of the model. Depending on the model, the chosen parameter required adjustments locally, at a particular structure or reach of watercourse, or globally, affecting the entire model.

As outlined in Section 3.2.3 there are two main flood events for which calibration and verification of the Castlefinn model was undertaken. The model set up was reviewed alongside parameters resulting in the following changes:

1. Following the receipt of CCTV culvert survey deliverables (Section 2.3.2.2) appropriate blockages could be applied to structures in the model and represented in calibration events. The following blockages were applied to culverts in the Castlefinn model, the location of each is displayed in Figure 3.6.

    - A blockage of 80% was applied to the Bridge Burn culvert at McGlynns Restaurant.
    - A blockage of 60% was applied to the CPI Centre Embankment culvert.
    - A blockage of 30% was applied to the culvert on the Castlefinn watercourse upstream of the CPI Centre.

    Blockage percentages were selected to represent the current condition of the culverts as observed from the CCTV survey. The nature of the blockages are considered permanent features of the culverts in their current state caused by:

    - major deformations,
    - heavy siltation, rocks and debris, and;

- tree roots.

The blockages are validated through the modelled flood frequency demonstrated in the calibration event simulations.

2. A review of the duration of flooding in the initial model simulations found that the volume of water which was impounded behind the CPI embankment during the simulations was possibly unrealistic. Initially the hydrology team reviewed the choice of hydrograph pivotal sites on all of the tributaries, but a large flood volume was still apparent on the Castlefinn watercourse. A site walkover was conducted by the project hydrologist and hydraulic modeller to investigate the correct flow path of the Castlefinn and Stranamuck watercourses. The site walkover identified a discrepancy between the actual route on the ground and the route shown in the OSi network. The watercourse route and catchment boundaries were modified as a result, Figure 3.19 outlines the old OSi river network and the updated river network for the Castlefinn FRS.

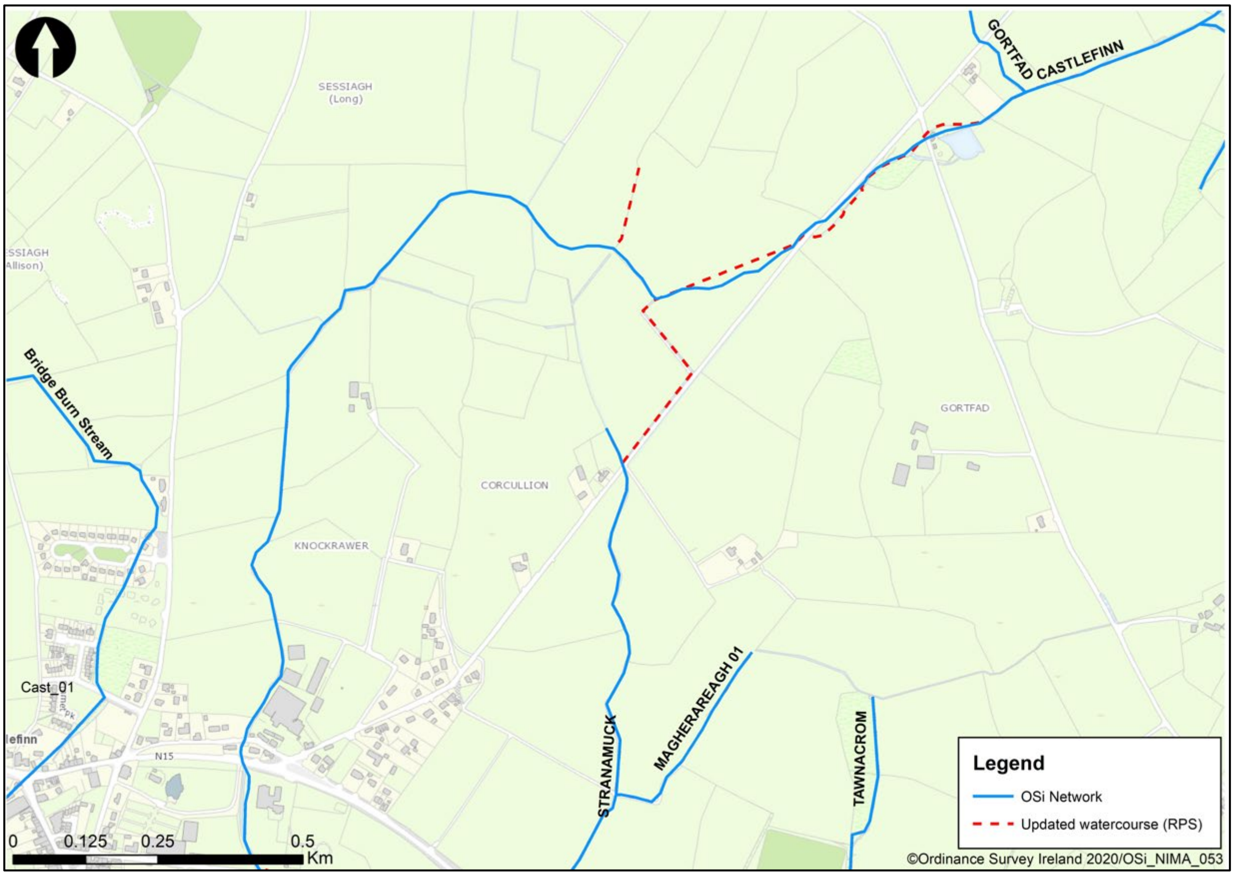

Figure 3.19: Site walkover updated watercourse flow paths

3. It is understood the works that took place at the CPI Embankment after the 2015 events involved the improvement of the flap valve, raising an earthen embankment using the old railway line and the addition of the HESCO flood defence along the crest of the embankment. As these works were not completed at the time of the 2015 event the topographical defence survey data was excluded from the model and the embankment levels based on the LiDAR data only, which was captured in 2009.

3.3 Modelling of Existing Flood Risk for Scheme Development

The core design scenarios (50%, 10%, 1% and 0.1% AEP) were simulated for Castlefinn and are shown in Figure 3.20. Locations at risk of flooding in Castlefinn in the 1% fluvial AEP include Grahamsland, Coolyslin, Emmett Park and properties located on the N15 near the CPI Centre and McGlynns restaurant.

On review of the draft core flood extent maps the Steering Group queried the frequency of flooding on the Bridge Burn watercourse on the N15 outside of McGlynns. The 50% AEP event is simulated to flood this busy road junction. This frequency of flooding is consistent with the observed flood frequency in recent years with flooding having been observed in 2015, 2017 and 2019. The simulated flood frequency is also consistent with comments provided by the proprietor of McGlynns restaurant through the Opening Public Consultation. The proprietor stated that the business is threatened with flood water multiple times a year.

The flood maps will form the basis for the flood risk management option phase, the economic assessment of flood risk and the benefits of such flood risk management options.

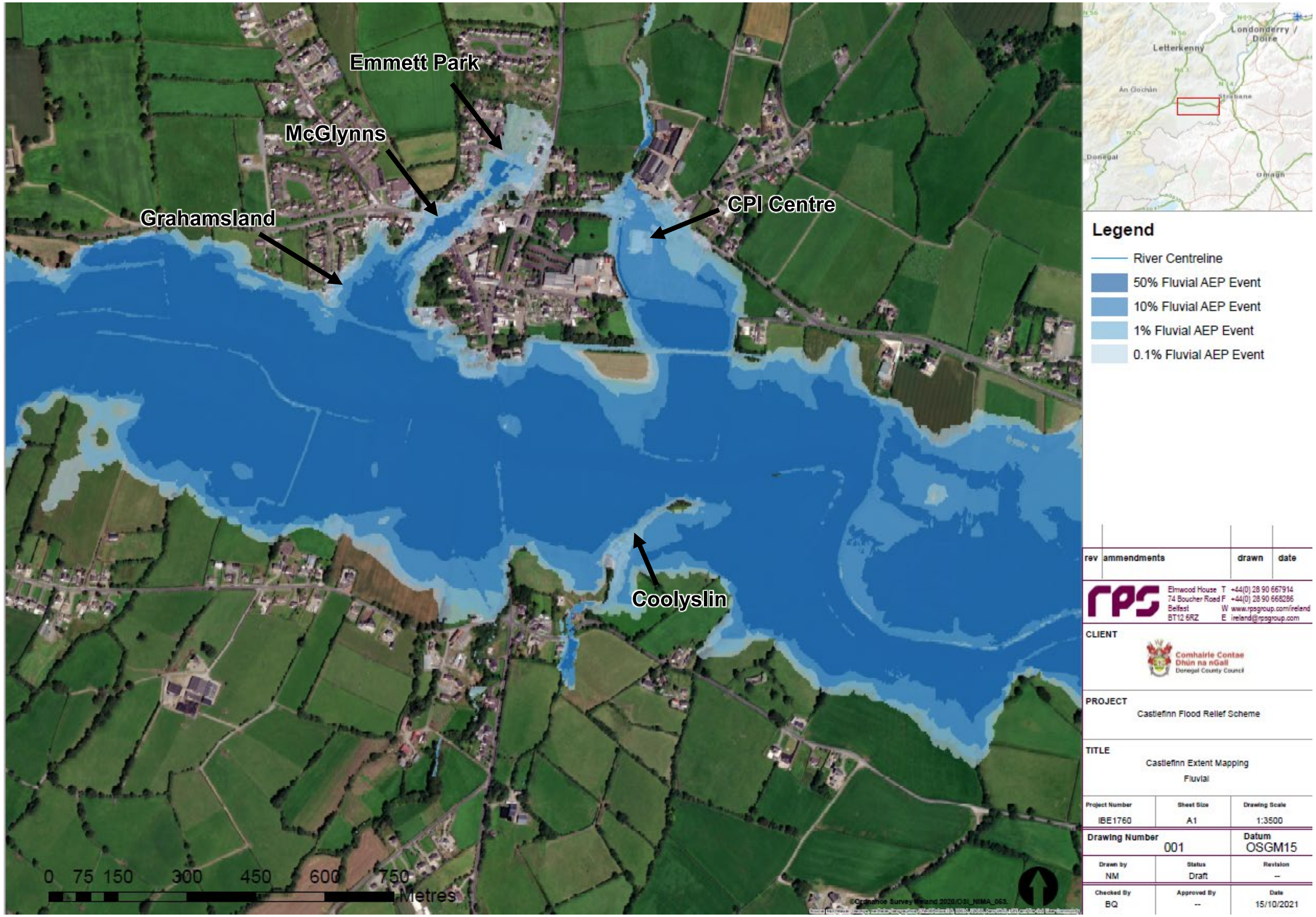

Figure 3.20: Draft Core Flood Extents – Study Area

3.4 Model Limitations and Assumptions

There are inherent assumptions, limitations and uncertainty associated with hydraulic modelling including:

- schematisation decisions regarding out-of-bank flow routes,
- culvert/bridge schematisation,
- data sources,
- changes to parameters from default.

A drainage network model is not part of the project requirements, the model does not include drainage network data and as such out of sewer or drainage flooding has not been modelled. The impacts of high river levels on the ability of the drainage network to discharge during a storm event have not been assessed. This will be assessed as part of option development to ensure scheme design does not cause flooding via this mechanism. It should also be noted that the impact of groundwater or pluvial flooding events have not been assessed. Again, pluvial assessment will be undertaken in Phase 2 to inform options development. This assessment will identify and mitigate any increased pluvial flood risk as a consequence of the FRS. As demonstrated in Table 3.2 the model is well anchored to the design flow estimation however there are a number of limitations and assumptions associated with the Castlefinn model, which include:

- Embankments were represented within the bank lines rather than the 2D domain. This was to improve stability and prevent significant oscillation between 1D and 2D domains.
- Sub-floor levels of buildings are represented in the 2D domain by extruding the building footprint within the DTM to match the finish floor level recorded during the threshold survey. The threshold level of the buildings are represented by incorporating porous polygons, with a porosity of 0.01, into the 2D mesh. These “stubby” buildings enable low depth flow paths to be more accurately defined within the model while maintaining the ability to incorporate the storage of flood water within the building once the threshold level is reached.
- A vertical wall boundary was applied at the upstream extent of the Finn, along the outer boundary of the 2D zone to ensure no flow was lost from the model.
- The downstream water level boundary was extracted from the Lifford FRS hydraulic model and applied to the Castlefinn model downstream of Clady Bridge.
- Modelled timestep is set at 1s. This is based off current Innovyze guidance and provides that the 1D part of the model is forced to run at a timestep closer to that of the 2D so there is a smoother interaction between the two domains, reducing the probability of stability and mass balance issues.
- Assumptions made on the condition of culverts that were informed by culvert CCTV survey were critical to the flood risk in Castlefinn as mentioned in Section 3.2.3.3, with the addition of the Hollow Road/Chapel Street Bridge. Survey photos (2021 survey and CFRAM Study) indicate this bridge has a wooden trash screen present. It has been assumed that the bridge opening is blocked by approximately 50%.

- Simulation parameters are summarised in Section 3.1.6. Default software parameters were applied except for the drowned bank linearisation threshold. This was increased from a default value of 0.01m to 0.1m to improve stability at bank lines where flow is moving between the 1D river channel and 2D floodplain. This is a recommended approach by Innovyze where there are oscillating flows at the 1D-2D interface.

- The CPI embankment was constructed following the 2015 flood event by private developers. It has been assumed that the flood defence would not be fully effective. Following a review of model simulations testing the wall with different porosity settings (0%, 10% and 30%) during the 1% AEP event, the 10% porosity setting was deemed most conservative with regards to flood depths observed at the CPI centre. This assumption has been applied to the baseline model setup.

3.5 Breach Analysis

Breach analysis was undertaken on the CPI Centre embankment (Figure 3.6), the assessment demonstrates flood risk in the event of failure of a structure which would otherwise provide defence against flood waters. GN24 Breach Analysis[10] document provides guidance for simulating the failure of a flood defence. The simulation represents the CPI embankment defence failing over a 40m length. Overtopping was the mode of failure, and the breach height was taken to be the defence crest to the floodplain level as this provides the largest head through the breach. The breach initiated when the water level reaches its peak at 7.3m AD, below the defence crest level (Figure 3.21).

The breach analysis model run resulted in an increase in the flood extent when compared to the 1% AEP design run (Figure 3.22). This resulted in an increased risk of flooding to receptors, including properties located along the N15 and the CPI Centre. These changes have an increasing impact on receptors as approximately four more buildings are affected, accounting for an 18% increase when compared to the 1% AEP design results.

[10] (Mott MacDonald, 2013)

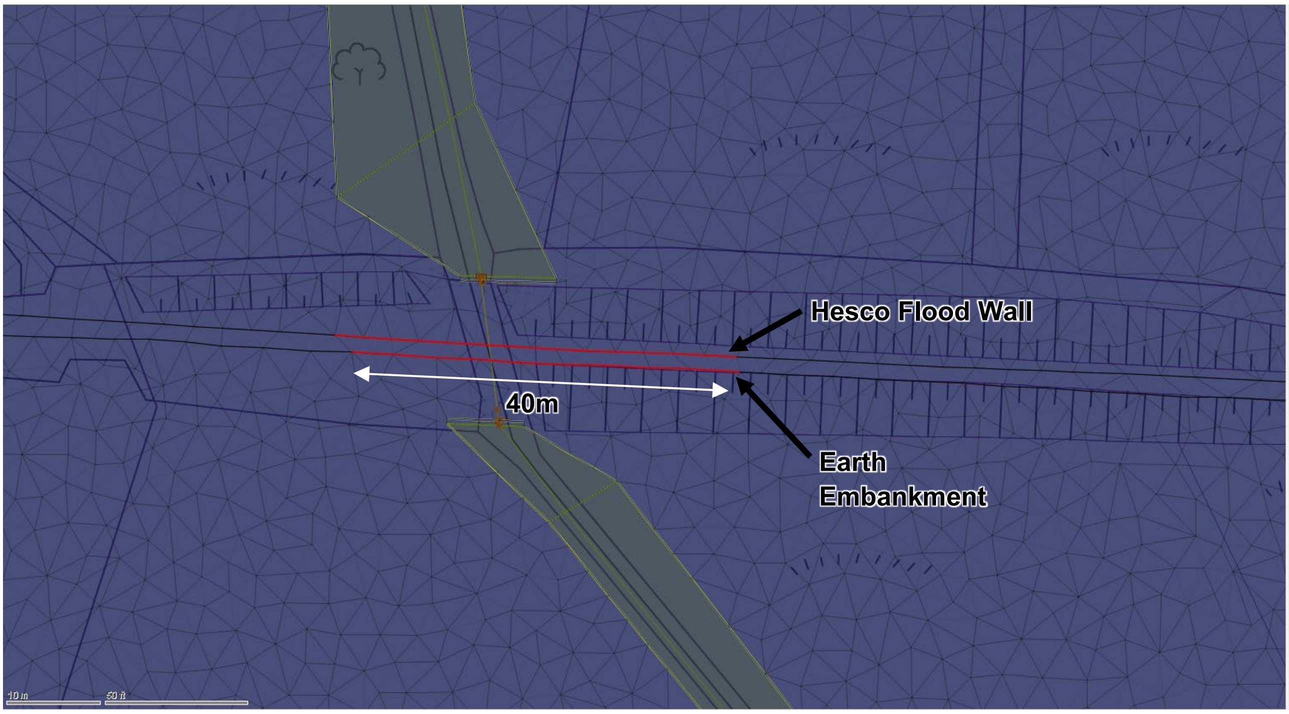

Figure 3.21: Section of CPI Flood Defences breached as part of sensitivity analysis

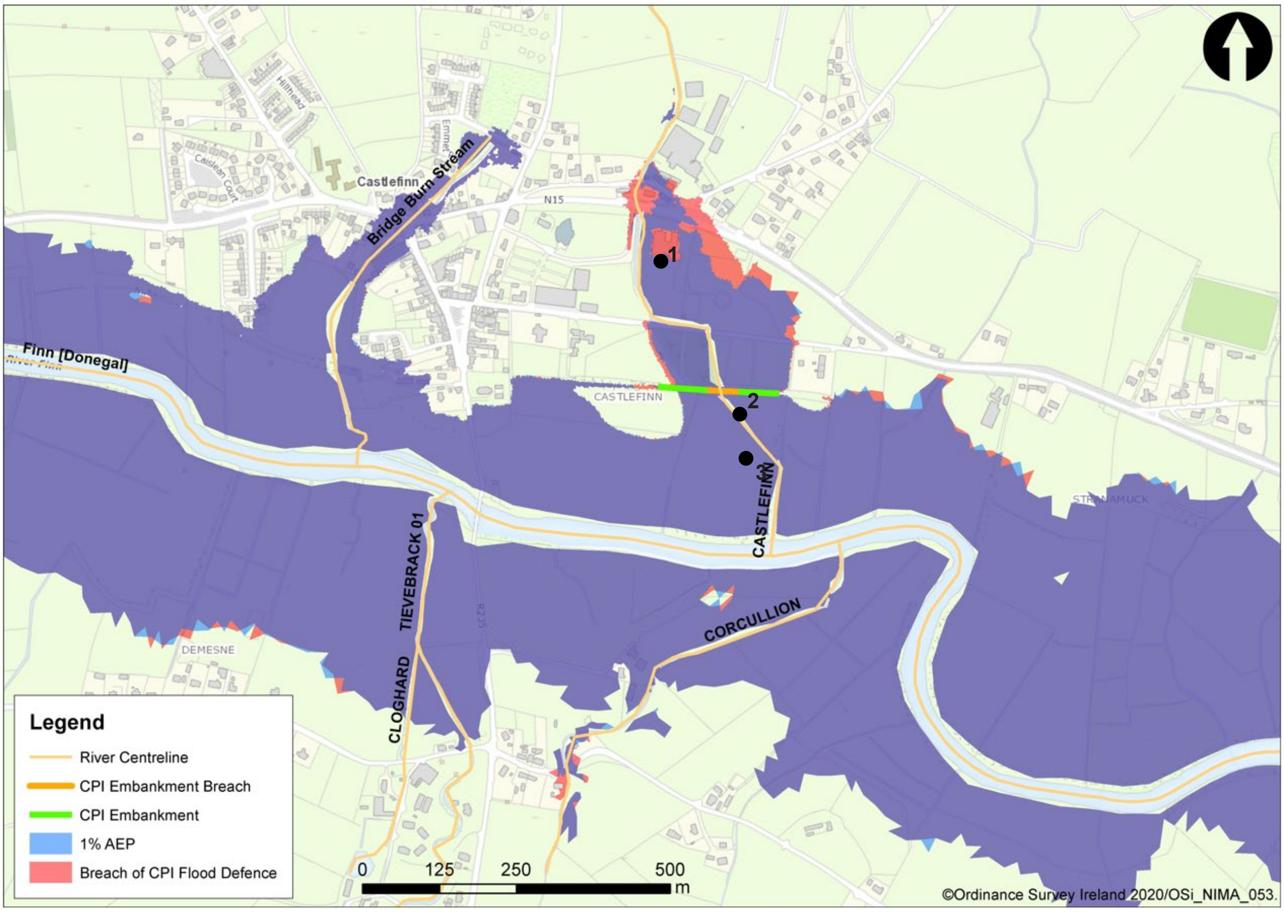

Figure 3.22: CPI Embankment Flood Defence Breach

The water levels in the 1% AEP flood event and the CPI Embankment breach analysis event are compared in Table 3.5.

Table 3.5: Comparison of water levels between 1% AEP flood event and breach analysis simulation

Figure 3.22 Label	Location	1% AEP Breach Simulation (m)	1% AEP Water Level (m)
1	Castlefinn Watercourse upstream of the CPI Centre	7.12	6.49
2	Castlefinn Watercourse upstream of the CPI Embankment	7.14	6.45
3	Castlefinn Watercourse downstream of the CPI Embankment	7.43	7.43

3.6 Blockage Analysis

Blockage model simulations will be used to inform the damage assessment and scheme analysis design for the Castlefinn FRS. In conjunction with the Steering Group, five culverts were identified as being hydraulically significant to the flood risk in Castlefinn (as outlined in Figure 3.6). An assessment to determine blockage ratios of these structures was undertaken as part of the sensitivity analysis. The likelihood of a blockage was assessed using guidance outlined in CIRIA C786 'Culvert, screen and outfall manual'[11] which recommends a blockage between 80% - 100% is used to assess the consequences during an extreme event. Likelihood of blockage was also informed by internal culvert conditions as per the Culvert and CCTV survey. A scoring matrix has been used to assess the likelihood of blockage for each culvert deemed hydraulically significant, outlined in Table 3.6. The higher the score for each category the higher the likelihood of blockage. The total score has been used to determine whether the culvert should be included in the sensitivity test. The 1% AEP design scenario event is then simulated in the model to determine the envelope of potential flooding arising from a blockage.

Table 3.6 - Blockage analysis scoring matrix

Scoring Criteria	Scoring	Description
Historical Evidence	10	Any historical evidence of flooding as a resulting of blockage of a structure would indicate a high likelihood of future blockage.
Existing Maintenance Regime	10	Lack of maintenance of culverts can result in increased blockage and therefore increase flood risk. Introducing a maintenance regime will reduce the likelihood of blockage.
Screen	10	If a well-designed screen is present the likelihood of blockage is reduced, as is the associated flood risk. A poorly designed screen and no screen being present may increase the likelihood of blockage.
Cross-Sectional Area (m^2)	5	The likelihood of blockage is increased if a culvert has small cross-sectional area conveying a larger flow.
Culvert Capacity (m^3/s)	5	Refers to the free-flowing capacity i.e. maximum amount of flow the structure can convey before surcharging. Any structures with current blockage (identified in Culvert CCTV Survey) will have a reduced capacity and therefore a high likelihood of further blockage and increased risk of flooding.
Catchment Type	10	Rural catchments pose an increased likelihood of blockage from sedimentation and natural debris and urbanised catchments pose an increased likelihood of blockage from manmade debris.

There is no known active maintenance regime for any culverts in the Castlefinn FRS Scheme Area, however there is a reactive maintenance regime, i.e. removal/clearing of culverts in response to flood events.

For the Castlefinn FRS only culverts with a high likelihood of blockage (scoring 30+) were considered for further analysis. Table 3.7 outlines the how the scoring and likelihood of blockage are linked and the percentage of blockage applied for each. A 90% blockage is modelled to determine the maximum potential blockage for a culvert where the structure has a high likelihood.

[11] (Benn, 2019)

Table 3.7: Likelihood of blockage and percentage of blockage applied

Scoring	Likelihood of blockage	Blockage sensitivity required (%)
0 – 10	Low	0
10 – 30	Moderate	60
30+	High	90

3.6.1 McGlynns Culvert

The McGlynns culvert is located on the Bridge Burn and conveys flow under the N15 in the east of Castlefinn (Figure 3.23).

Figure 3.23: McGlynns culvert inlet

Prior to project commencement, DCC indicated that there was evidence of blockage in McGlynns culvert and this was confirmed in survey deliverables from the culvert CCTV survey, which identified a severely blocked section of the culvert (70%-90% blockage) outlined in Figure 3.24. With the remainder of the culvert exhibiting approximately 10%-40% blockage throughout.

Figure 3.24: (L) Heavily blocked section of McGlynns culverts (90% blockage). (R) View of culvert from manhole chamber.

There is no debris screen present on the McGlynns culvert. The culvert is approximately 180m in length and the cross-sectional area varies over its length ranging from 0.28m^2 – 2.54m^2, with a capacity of approximately 2.5m^3/s. The capacity is calculated with the appropriate levels of blockage applied to the model as per the baseline scenario conditions agreed with the Steering Group. As such, the culvert scored highly due to surcharging in the most frequent events (50% AEP and above).

The Bridge Burn sub-catchment is an urbanised catchment as per Hydrology Report Section 3.2.3, which increases the risk of potential blockage from manmade materials for this culvert. The upper catchment is characterised as largely agricultural land with the watercourse flanked by hedgerows. This results in an increased risk of blockage from debris (e.g. cuttings, brash).

Table 3.8 details the scoring of the McGlynns culvert to assess the requirement for blockage analysis.

Table 3.8: McGlynns culvert scoring

Structure	Historical Evidence	Existing Maintenance Regime	Screen	Cross-Sectional Area (m^2)	Culvert Capacity (m^3)	Catchment Type	Overall Scoring
McGlynns Culvert	10	8	8	5	5	6	42

Overall the recommendation is to include this culvert in the blockage assessment, assuming a 90% blockage. The CCTV survey has outlined the culvert is already up to 90% blocked in sections and has greatly diminished capacity and as such an increased flood risk. The rural upper catchment, combined with a lack of existing maintenance regime for the culvert and no debris screen present suggests a high likelihood of further blockage in the structure, therefore it is prudent that this culvert is assessed in the blockage analysis, with a 90% blockage of the entire culvert length.

3.6.2 N15 Culvert U/S of CPI Centre

The N15 culvert upstream of the CPI Centre is located on the Castlefinn watercourse and conveys flow under the N15 in the west of Castlefinn (Figure 3.25).

Figure 3.25: Inlet of N15 culvert upstream of CPI Centre

Blockage in the N15 culvert on the Castlefinn watercourse was confirmed in culvert CCTV survey deliverables. The culvert was identified as being blocked by approximately 30% throughout its length Figure 3.26

Figure 3.26: (L) Blocked outlet of culvert submerged in water (40% blockage). (R) Internal blockage of culvert

There is no debris screen present on the N15 culvert. The culvert is approximately 55m in length and the cross-sectional area varies as the dimensions of this culvert change over its length and range from 1.14m^2 – 2.54m^2, with a culvert capacity of approximately 1.35m^3/s. The capacity is calculated with the appropriate levels of blockage applied to the model as per the baseline scenario conditions agreed with the Steering Group and as such has resulted in a lower scoring due to this culvert not surcharging even in less frequent events (0.1% AEP).

The Castlefinn watercourse sub-catchment is a relatively urbanised catchment as per Hydrology Report Section 3.2.3, which increases the risk of potential blockage from manmade materials for this culvert. The upper catchment is characterised as a rural landscape, which also comes with an increased risk of blockage from debris.

Table 3.9 details the scoring of the N15 culvert upstream of the CPI Centre to assess its requirement for blockage analysis

Table 3.9: N15 culvert scoring

Structure	Historical Evidence	Existing Maintenance Regime	Screen	Cross-Sectional Area (m^2)	Culvert Capacity (m^3)	Catchment Type	Overall Scoring
N15 Culvert U/S of CPI Centre	**6**	**8**	**8**	**2**	**1**	**6**	**31**

Overall the recommendation is to include this culvert in the blockage assessment, assuming a 90% blockage. The CCTV survey has outlined the culvert already has a 30%-40% blockage and as such the culvert has already incurred diminished culvert capacity and as such an increased flood risk. Similar to the McGlynns culvert, the rural upper catchment, combined with a lack of existing maintenance regime for the culvert and no debris screen present suggests a high likelihood of further blockage in the structure, therefore it is prudent that this culvert is assessed in the blockage analysis, with a 90% blockage of the entire culvert length.

3.6.3 Hollow Road Bridge

The Hollow Road Bridge is located on the Castlefinn watercourse and conveys flow under the Hollow Road/Chapel Road in Castlefinn town (Figure 3.27).

Figure 3.27: Hollow Road Bridge opening (downstream)

This structure was not surveyed in culvert CCTV survey due to its short length relative to the large opening. The structure is not considered to have a high impact on flood risk as it sits within a flat, sluggish reach with the CPI culvert downstream considered to be the restricting structure on this reach presently. The upstream opening was identified as being obstructed in surveyor photographs from the topographic survey deliverables (Figure 3.28). The CFRAM Study survey noted the obstruction to be 'temporary trash screen in the form of timber pallets across entire culvert opening'. A blockage of 50% is applied in the baseline scenario for the Castlefinn FRS hydraulic model.

Figure 3.28: Wooden screen at downstream extent of Hollow Road Bridge

The bridge is approximately 7m in length and the cross-sectional area of this bridge is consistent throughout its length at 4.5m^2, with a capacity of approximately 1.1m^3/s. The capacity of this structure is calculated with ad-hoc debris screen as there is no evidence of sedimentation of the bridge itself. The capacity is calculated with the appropriate levels of blockage applied to the model as per the baseline scenario conditions agreed with DCC and as such is scored highly due to surcharging in the most frequent events (50% AEP and above).

The Castlefinn watercourse sub-catchment is a relatively urbanised catchment as per Hydrology Report Section 3.2.3, which increases the risk of potential blockage from manmade materials for this culvert. The upper catchment is characterised as a rural landscape, which also comes with an increased risk of blockage from debris (e.g. cuttings, brash).

Table 3.10 details the scoring of the Hollow Road Bridge to assess its requirement for blockage analysis

Table 3.10: Hollow Road bridge scoring

Structure	Historical Evidence	Existing Maintenance Regime	Screen	Cross-Sectional Area (m^2)	Culvert Capacity (m^3)	Catchment Type	Overall Scoring
N15 Culvert U/S of CPI Centre	9	8	10	3	5	6	41

Overall the recommendation is to include this bridge in the blockage assessment, assuming a 90% blockage. The topographic survey has already identified some blockage and as such a high risk is assumed. Similar to the McGlynns culvert, the rural upper catchment, combined with a lack of existing maintenance regime suggests a high likelihood of further blockage in the structure. The poorly designed debris screen structure on the bridge is a greater concern for risk of blockage, therefore it is prudent that this bridge is assessed in the blockage analysis, with a 90% blockage.

3.6.4 CPI Centre Embankment Culvert

The CPI Centre embankment culvert is located on the Castlefinn watercourse just downstream of the CPI Centre and conveys flow through the privately constructed flood defence (Figure 3.29), discussed in Section 3.1.4.4.

Figure 3.29: (L) CPI Embankment culvert inlet with debris screen (submerged at time of survey). (R) Sluice gate non-return and valve at downstream extent of culvert

Prior to project commencement, the Steering Group were aware of blockages in culverts located on the Castlefinn watercourse and this was confirmed in culvert CCTV survey deliverables. The culvert was identified as being blocked by approximately 30% throughout its length, with additional blockage at the upstream extent due to the trash screen Figure 3.30.

Figure 3.30: Blocked internal conditions of culvert and blockage of debris screen at upstream extent.

A debris screen is present on the CPI Centre embankment culvert. The purpose of a well-designed screen is to collect any large objects that may obstruct the culvert and allow small debris to pass through without causing blockage and effectively reducing the flood risk associated with the structure. The case for the screen on the CPI Centre embankment culvert is poorly designed and is not maintained adequately which in turn has increased the flood risk associated to this structure. As per culvert CCTV survey Figure 3.30 identifies the blockage caused by the trash screen. It was previously noted by DCC that the screen had an approximate headloss of 1m between the upstream and downstream faces during a site visit.

The culvert is approximately 11m in length and the cross-sectional area varies as the dimensions of this culvert change over its length and range from 0.56m^2 – 5.22m^2, with a culvert capacity of approximately 0.6m^3/s. The capacity is calculated with the appropriate levels of blockage applied to the model as per the baseline scenario conditions agreed with the DCC and as such is scored highly due to surcharging in the most frequent events (50% AEP and above).

As noted in Section 3.6.2, the Castlefinn watercourse sub-catchment is at increased risk of blockage due its partially urbanised catchment.

Table 3.11 details the scoring of the CPI Centre embankment culvert to assess its requirement for blockage analysis.

Table 3.11: CPI Embankment culvert scoring

Structure	Historical Evidence	Existing Maintenance Regime	Screen	Cross-Sectional Area (m^2)	Culvert Capacity (m^3)	Catchment Type	Overall Scoring
N15 Culvert U/S of CPI Centre	10	10	10	3	5	6	44

Overall the recommendation is to include this culvert in the blockage assessment, assuming a 90% blockage. The CCTV survey has outlined the culvert already has a 30%-40% loss of cross-sectional area and as such the culvert has already incurred diminished flow capacity and as such an increased flood risk. The presence of a debris screen that does not have an active maintenance regime and is already showing blockage is further reasoning for a high likelihood of further blockage in the structure. Therefore, it is prudent that this culvert is assessed in the blockage analysis, with a 90% blockage of the entire culvert length.

3.6.5 South Finn Double-Barrelled Culvert (Corcullion)

The South Finn double-barrelled culvert is located on the Corcullion watercourse and conveys flow under a local road (L3044) to the south of Castlefinn (Figure 3.31).

Figure 3.31: (L) South Finn double-barrelled culvert inlet. (R) Culvert outlet.

When simulating the design run scenarios for Castlefinn FRS hydraulic model this culvert was causing out of bank flooding the area south of the Finn. Investigating this culvert in the model identified the culvert was surcharging as it was undersized to convey flow of a 1% AEP flood event.

These culverts were not included in the culvert CCTV survey as this was procured prior to the design run stage and as such the internal conditions of the culvert are unknown. Referring to Figure 3.31 there appears to be some sedimentation in the larger of the two culverts, however for the purposes of the baseline scenario this culvert has been modelled as clear. There is no debris screen present on the Corcullion double-barrelled culvert.

The culvert is approximately 11m in length and the cross-sectional area varies as the dimensions of this culvert change over its length. The inlet diameters of the barrels of the circular culverts are 225mm and 450mm, which leads into a 750mm x 500mm box culvert opening at the outlet. The culvert cross-sectional area ranges between 0.16m^2 and 0.64m^2, with an overall culvert capacity of approximately 0.56m^3/s. The culvert has scored highly due to surcharging in the most frequent events (20% AEP and above).

The Corcullion watercourse sub-catchment as per Hydrology Report Section 3.2.3 is a rural catchment, characterised by agricultural lands with the watercourse flanked by hedgerows. This increases the risk of potential blockage from debris (e.g. cuttings, brash).

Table 3.12 details the scoring of the Corcullion double-barrelled culvert to assess its requirement for blockage analysis.

Table 3.12: South Finn double-barrelled culvert scoring

Structure	Historical Evidence	Existing Maintenance Regime	Screen	Cross-Sectional Area (m^2)	Culvert Capacity (m^3)	Catchment Type	Overall Scoring
N15 Culvert U/S of CPI Centre	2	8	8	5	5	4	32

Overall, the recommendation is to include this culvert in the blockage assessment, assuming a 90% blockage. The unknown internal conditions of the culvert make it difficult to assess if the culvert has already become susceptible to blockage. Due to the small cross-sectional area of the culvert there is an increased chance of blockage, particularly in an entirely rural catchment with the chances of debris and silt building up within either of the structures. Similar to other culverts mentioned, the combined lack of existing maintenance regime for the culvert and no presence of a debris screen suggests there is a high likelihood of blockage in the structure, therefore it is prudent that this culvert is assessed in the blockage analysis, with a 90% blockage.

3.7 Sensitivity Analysis

Sensitivity simulations have been completed. The purpose is to test the models sensitivity to various parameter changes, outputs of the analysis will inform the development of the options and detailed design of the Castlefinn FRS, particularly in making recommendations regarding adjustments to freeboard or other design considerations to ensure a 'no-regrets' approach. A summary of the sensitivity simulations are outlined in Table 3.13. Sensitivity simulations which present the greatest impact are in discussed detail whereas simulations resulting in less impact are presented in Appendix A.

To assess model sensitivity 2D zones representing flooding have been extracted from the model for each scenario tested and compared to the baseline results. The 1% AEP design simulation and 1% AEP sensitivity outputs have been extracted the same way and therefore comparisons are like for like on a georeferenced basis.

Table 3.13: Summary of Sensitivity Analysis

Sensitivity Test		Change in Buildings affected (%)	Model Sensitivity	Comment
Roughness	1D roughness upper bounds, 2D roughness lower bounds	23	Moderate	Refer to Section 3.7.1
	1D roughness lower bounds, 2D roughness upper bounds	-5	Low	There is a decrease in flood extents particularly affecting properties near McGlynns restaurant on the Bridge Burn. It is estimated one less building was impacted on the Bridge Burn. (Apx Figure 1).
Structures **(Refer to Figure 3.6 in Section 3.1.3.3)**	Increased headloss structures Run 1	0	Low	A decreased flood extent was observed with no impact on receptors in the Scheme Area. (Apx Figure 2). The structures altered in this sensitivity run include: McGlynns long culvert (Bridge Burn), N15 culvert U/S of CPI Centre (Castlefinn) and South Finn double-barrelled culvert (Corcullion).
	Increased headloss structure Run 3	13	Low	Increasing hydraulic parameters of this structure showed an increased flood extent on the Castlefinn watercourse when compared with the 1% AEP. It is estimated an additional 3 buildings were impacted (Apx Figure 3). The structures altered in this sensitivity run includes the CPI flood defence culvert.
	Decreased headloss structure Run 1	0	Low	Decreasing hydraulic parameters of these structures showed low impact on flood extents when compared with the 1% AEP. (Apx Figure 4). The structures altered in this sensitivity run include: McGlynns long culvert (Bridge Burn), N15 culvert U/S of CPI Centre (Castlefinn) and South Finn double-barrelled culvert (Corcullion).
	Decreased headloss structure Run 3	0	Low	Decreasing hydraulic parameters of this structure showed low impact on flood extents when compared with the 1% AEP. (Apx Figure 5). The structures altered in this sensitivity run includes the CPI flood defence culvert.

Sensitivity Test		Change in Buildings affected (%)	Model Sensitivity	Comment
	Change structure type structure Run 2	0	Low	Changing the Hollow Road Bridge to a culvert had a low impact on flood extents, showing a decrease when compared with the 1% AEP. (Apx Figure 6).
	Change structure type C'Finn Bridge	9	Low	Changing the Castlefinn Bridge to a series of culverts had a low impact on flood extents, showing an increase when compared with the 1% AEP. It is estimated two additional buildings were impacted. (Apx Figure 7).
Ineffective Flow (Refer to Figure 3.6 in Section 3.1.3.3)	Increased contraction and expansion structure Run 2	9	Low	The Castlefinn model demonstrated increased modelled flood extents when compared with the 1% AEP. It is estimated two additional buildings are impacted. (Apx Figure 8).
	Decreased contraction and expansion structure Run 2	0	Low	The Castlefinn model demonstrated no change in the modelled flood extents when compared with the 1% AEP. It is estimated no additional building was impacted. (Apx Figure 9).
	Increased contraction and expansion C'Finn Bridge	0	Low	The Castlefinn model demonstrated a decreased modelled flood extents when compared with the 1% AEP. (Apx Figure 10).
	Decreased contraction and expansion C'Finn Bridge	5	Low	The Castlefinn model demonstrated an increase of modelled flood extents when compared with the 1% AEP. It is estimated one additional building was impacted. (Apx Figure 11).
2D Cell Size	Increased 2D cell size	0	Low	Modelled flood extents changed when larger mesh triangles were used. This produced a slightly altered flood extent outline but overall the extent remains comparable to the 1% AEP (Apx Figure 12).

Sensitivity Test		Change in Buildings affected (%)	Model Sensitivity	Comment
	Decreased 2D cell size	9	Low	The Castlefinn model demonstrated an increase of modelled flood extents when compared with the 1% AEP. It is estimated two additional building was impacted. (Apx Figure 13).
	Terrain sensitive meshing turned on	35	Moderate	Refer to Section 3.7.2
Sensitivity Flows	10% Present Day Sensitivity Flow	63	High	Refer to Section 3.7.3
	1% Present Day Sensitivity Flow	59	High	Refer to Section 3.7.3
	1% MRFS	68	High	Refer to Section 3.7.4
	1% HEFS	182	High	Refer to Section 3.7.4
Joint Probability	Downstream boundary in an open condition	-36	Moderate	Refer to Section 3.7.5.1
	Finn hydrographs to be 10 hrs after trib peaks	23	Moderate	Refer to Section 3.7.5.2
	Coinciding peak flows	41	High	Refer to Section 3.7.5.3

Sensitivity Test		Change in Buildings affected (%)	Model Sensitivity	Comment
DS Boundary	Increase DS WL by 300 mm	32	Moderate	Refer to Section 3.7.5.4
Blockage (Refer to Section 3.6)	Blockage Run 1	9	Low	A Blockage of 90% was applied to the following structures: McGlynns long culvert (Bridge Burn), N15 culvert U/S of CPI Centre (Castlefinn) and South Finn double-barrelled culvert (Corcullion). This resulted in an increased flood extent for properties located along the N15 and the CPI Centre, accounting for two additional buildings affected when compared to the 1% AEP. (Apx Figure 14).
	Blockage Run 2	0	Low	A Blockage of 90% was applied to the following structures: Hollow Road Bridge (Castlefinn), with no additional buildings affected when compared to the 1% AEP. (Apx Figure 15).
	Blockage Run 3	0	Low	A Blockage of 90% was applied to the following structures: N15 culvert US of CPI Centre (Castlefinn), with no additional buildings affected when compared to the 1% AEP. (Apx Figure 16).

3.7.1 Roughness

River reach in-channel (1D) roughness was increased to upper bound values and flood plain (2D) roughness was decreased to lower bound values. The change in channel and floodplain roughness values resulted in a moderate impact on flood extents, when compared to the 1% AEP flood extent as shown in Figure 3.32. The increase in flood extents has an impact upon properties located within the Castlefinn FRS Scheme Area including the CPI Centre and properties located close to the N15. It is estimated five additional buildings are impacted accounting for a 23% increase compared to the 1% AEP.

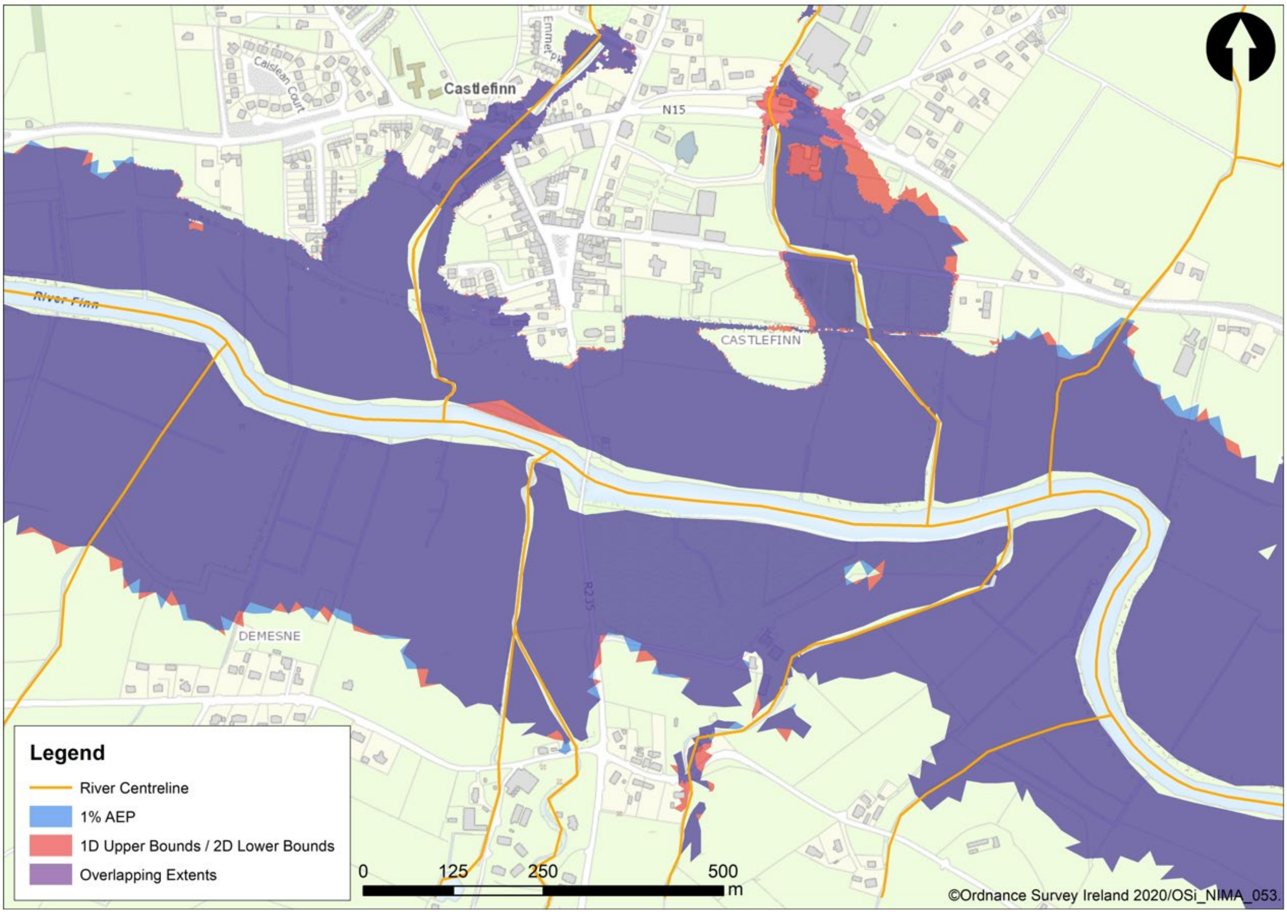

Figure 3.32: 1D upper / 2D lower Bounds Roughness Sensitivity Event (GIS file ref: rough2)

3.7.2 Mesh

Terrain-sensitive meshing is used to increase the resolution of the 2D mesh that have a large variation in height, without increasing the number of elements in relatively flat areas. This process samples the LiDAR in each candidate triangle and if the height within the triangle exceeds the maximum height variation specified for the 2D Zone, the triangle is split, increasing the resolution of the mesh in areas where terrain height varies rapidly.

Terrain-sensitive meshing was turned off during baseline scenarios due to the size of the Castlefinn model, so this analysis is concerned with terrain-sensitive meshing activated. Comparing the terrain sensitive mesh with the 1% AEP for Castlefinn there is a moderate impact on flood extent, when compared with 1% AEP, observed

Figure 3.33. It is estimated seven more buildings are impacted accounting for a 35% increase compared to the 1% AEP.

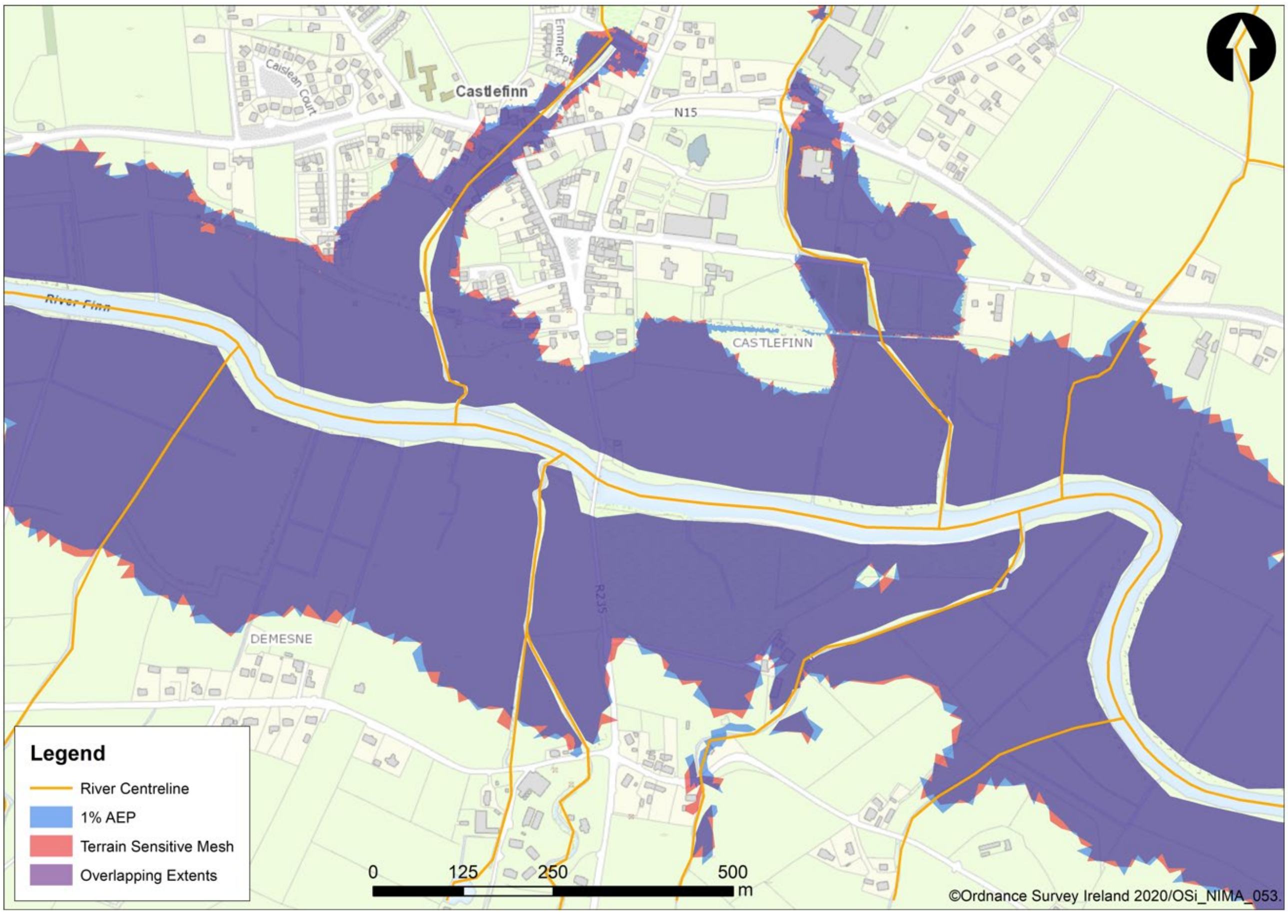

Figure 3.33: Terrain Sensitive Meshing Sensitivity Event (GIS file ref: mesh3)

Baseline adopted minimum and maximum cell size was also increased and decreased by 50% (Table 3.14) to determine the impact of variation with impacts previously summarised in Table 3.13.

Table 3.14 2D Cell size variations

	Original Triangle Min / Max (m^2)	Decreased Cell Size Sensitivity Run Min / Max (m^2)	Increased Cell Size Sensitivity Run Min / Max (m^2)
2D Zone Mesh	**25 / 100**	12 / 50	50 / 200
Detailed mesh zone	**10 / 5**	5 / 2.5	20 / 10

3.7.3 Flow

The 1% AEP and 10% AEP sensitivity flows were used to assess the sensitivity of the model to inflows. The hydrological analysis for sensitivity flows are discussed in Castlefinn FRS Hydrology Report Section 5. The results of introducing these flows to the model are shown in Figure 3.34 and Figure 3.35. The Castlefinn design flow estimation was assessed as having low to moderate uncertainty in the River Finn flows due to the presence of gauged data along the Finn. On the tributaries, the level of uncertainty in the design flow estimation is higher considering the ungauged, small nature of the watercourse catchments.

Translated through the model, the Castlefinn mapped flooding is moderately sensitive to increased 10% AEP inflows, reflected by the increased flood extent, particularly in Grahamsland, near McGlynns and on the N15 near the CPI Centre. These changes have an impact on receptors as approximately five additional buildings are affected, which is a 63% increase when compared to the 10% AEP design results.

The 1% sensitivity flows demonstrated an increased impact on receptors as approximately 13 additional buildings are affected, which is a 59% increase when compared to the 1% AEP design results. Overall, the Castlefinn model displayed a moderate sensitivity to changes to flow when compared with the 1% AEP event.

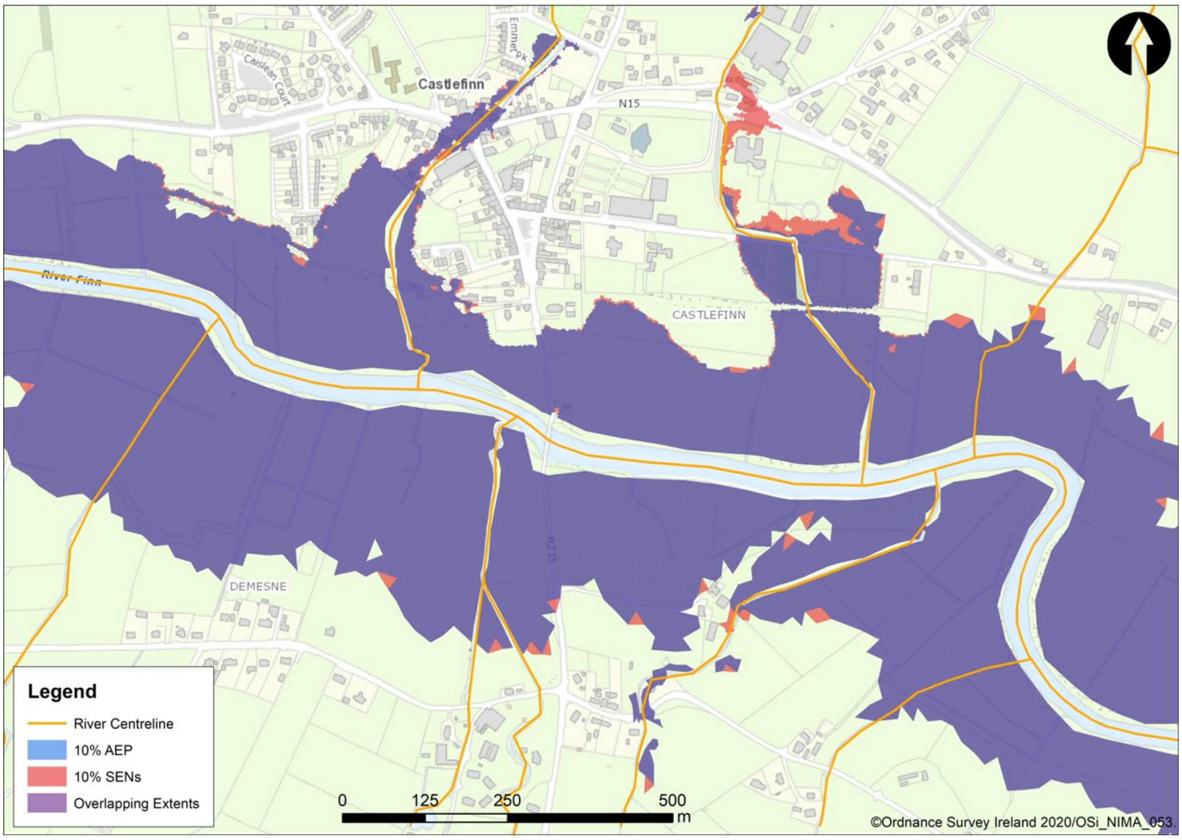

Figure 3.34: 10% AEP Model Inflow Sensitivity Event (GIS file ref: flow2)

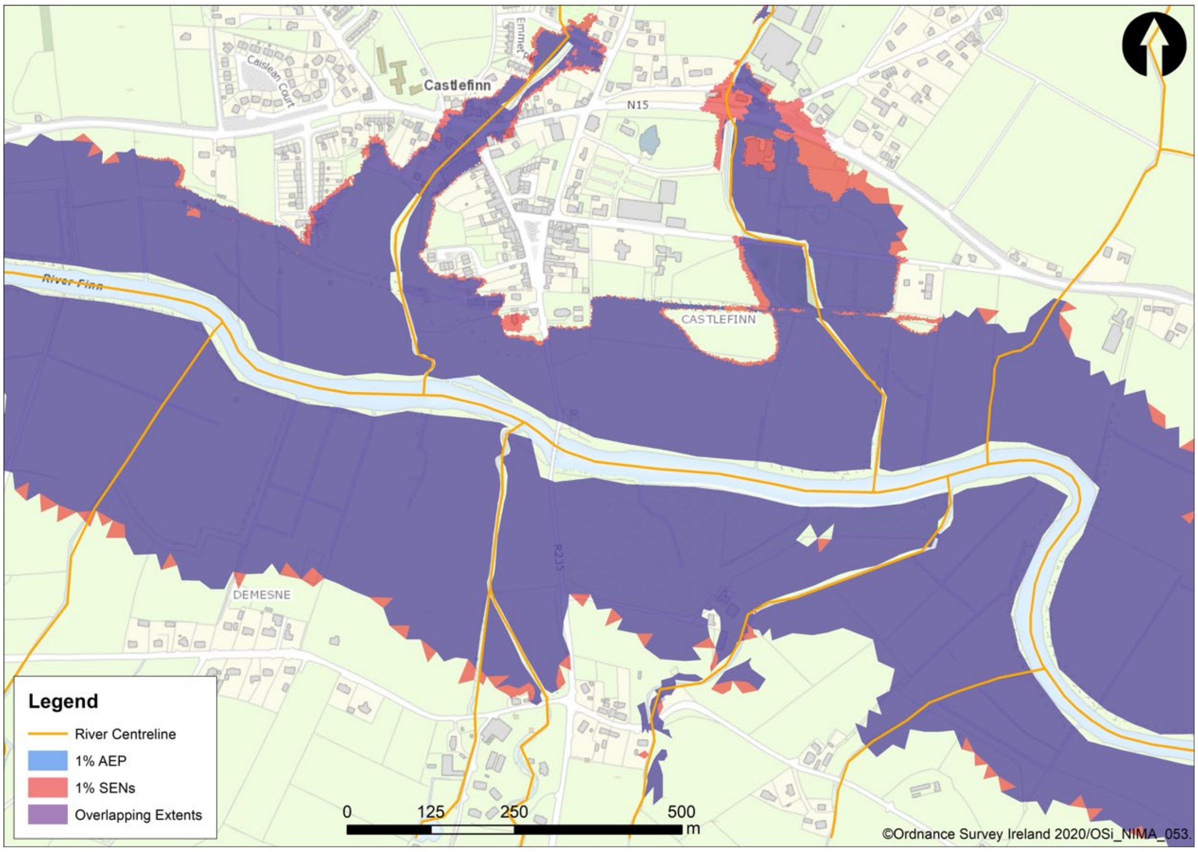

Figure 3.35: 1% AEP Model Inflow Sensitivity Event (GIS file ref: flow1)

3.7.4 Climate Change Flow

The 1% Mid-Range Future Scenario (MRFS) and 1% High End Future Scenario (HEFS) were modelled to assess the impacts of climate change flows in Castlefinn outlined in Figure 3.36 and Figure 3.37 respectively. The Castlefinn model was assessed as having moderate to high sensitivity to the effects of climate change flows.

Figure 3.36 shows that the Castlefinn model has an increased flood extent when comparing the 1% MRFS with the 1% AEP. The increase in flood extents has an impact upon properties located in Grahamsland, Emmett Park and properties along the N15 near the CPI Centre. These changes have an increasing impact on receptors as approximately 15 additional buildings are affected, accounting as a 68% increase when compared to the 1% AEP design results.

Figure 3.37 shows that the Castlefinn model has an increased flood extent when comparing the 1% HEFS with the 1% AEP. The increase in flood extents has an impact upon properties located in Grahamsland, Emmett Park, properties along the N15 near the CPI Centre and additional risk to Mullanboy. These changes have an impact on receptors as approximately 40 additional buildings are affected, accounting as a 181% increase when compared to the 1% AEP design results.

Overall, the Castlefinn model displayed a moderate sensitivity to the effects of Mid-Range Future Scenario flows when compared with the current 1% AEP scenario. High sensitivity was predicted in response to the High End Future Scenario flows. The impact in both scenarios, is greater along the tributaries where the effects of future urbanisation are likely to be more pronounced. Long section flow profiles of the climate change flow sensitivity runs are presented in Appendix B.

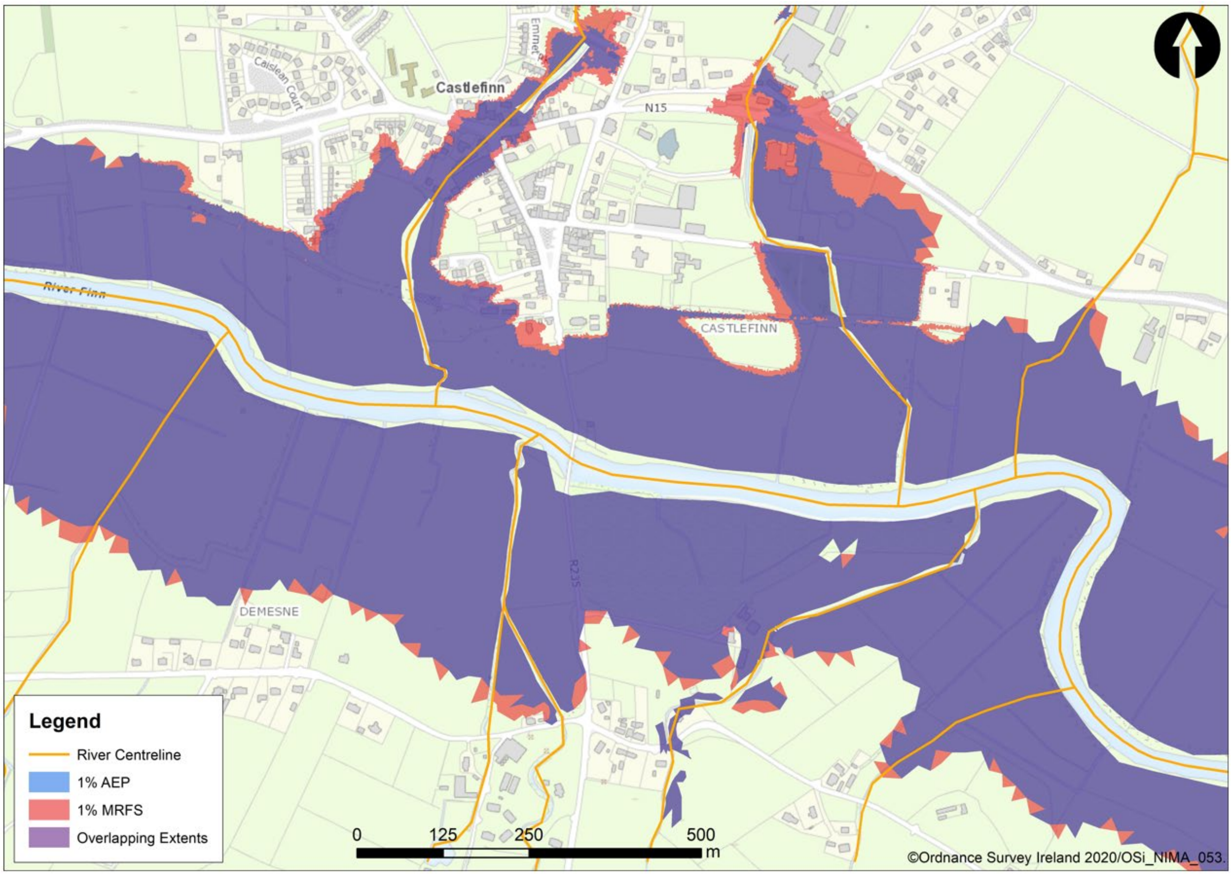

Figure 3.36: 1% AEP MRFS Sensitivity Event

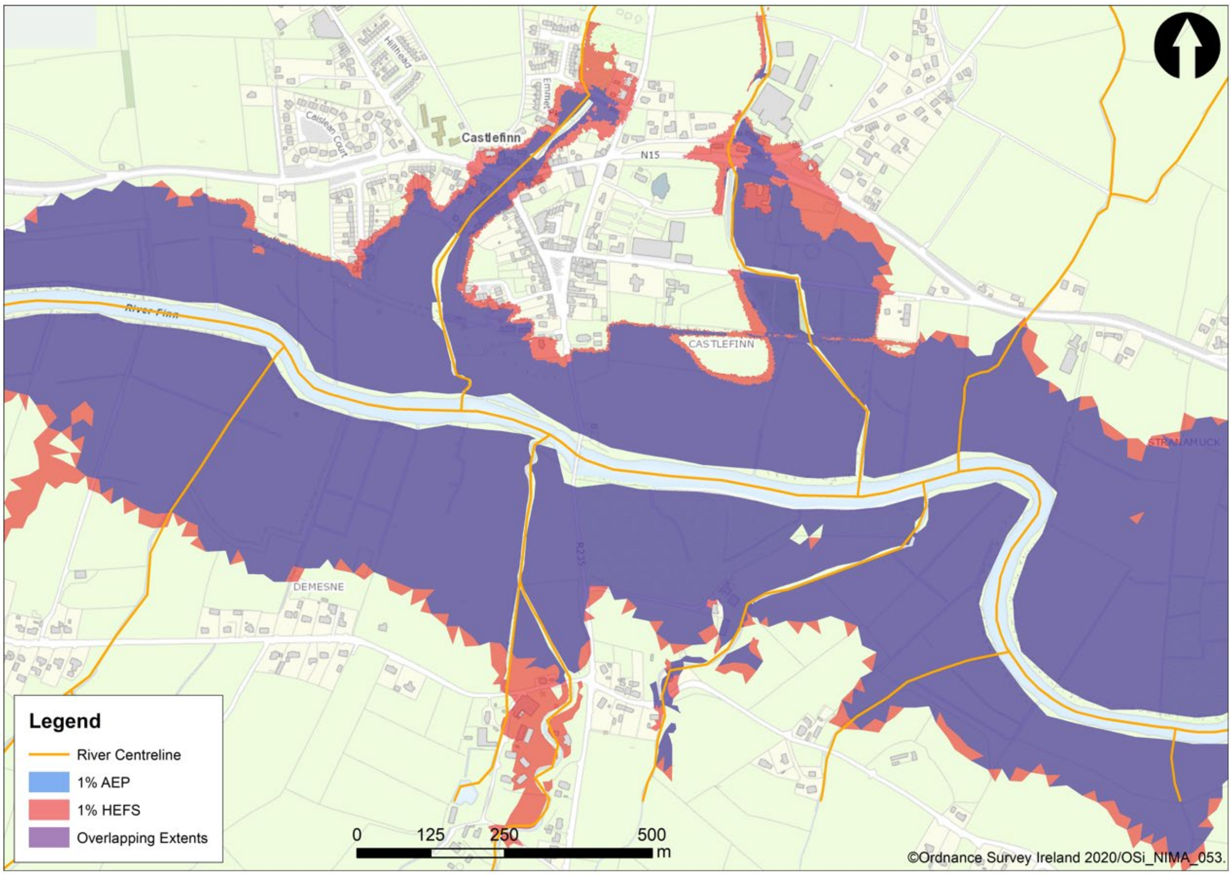

Figure 3.37: 1% AEP HEFS Sensitivity Event

3.7.5 Joint Probability

The Castlefinn model was assessed as having moderate/high sensitivity to Joint probability. Various scenarios were modelled to understand the impact of joint probability,

- Downstream boundary modelled as open,
- River Finn hydrograph peak moved to 10hrs after tributary peaks and
- River Finn hydrograph peak coinciding with tributary peaks.

3.7.5.1 Downstream Boundary Modelled as Open

This scenario demonstrated a decreased flood extent when compared with the original 1% AEP flood extent shown in Figure 3.38. A decreased flood extent was observed for properties located near McGlynns restaurant, Grahamsland, Coolyslin and properties along the N15 near the CPI Centre. Approximately eight less buildings are affected, accounting as a 36% decrease when compared to the 1% AEP design results.

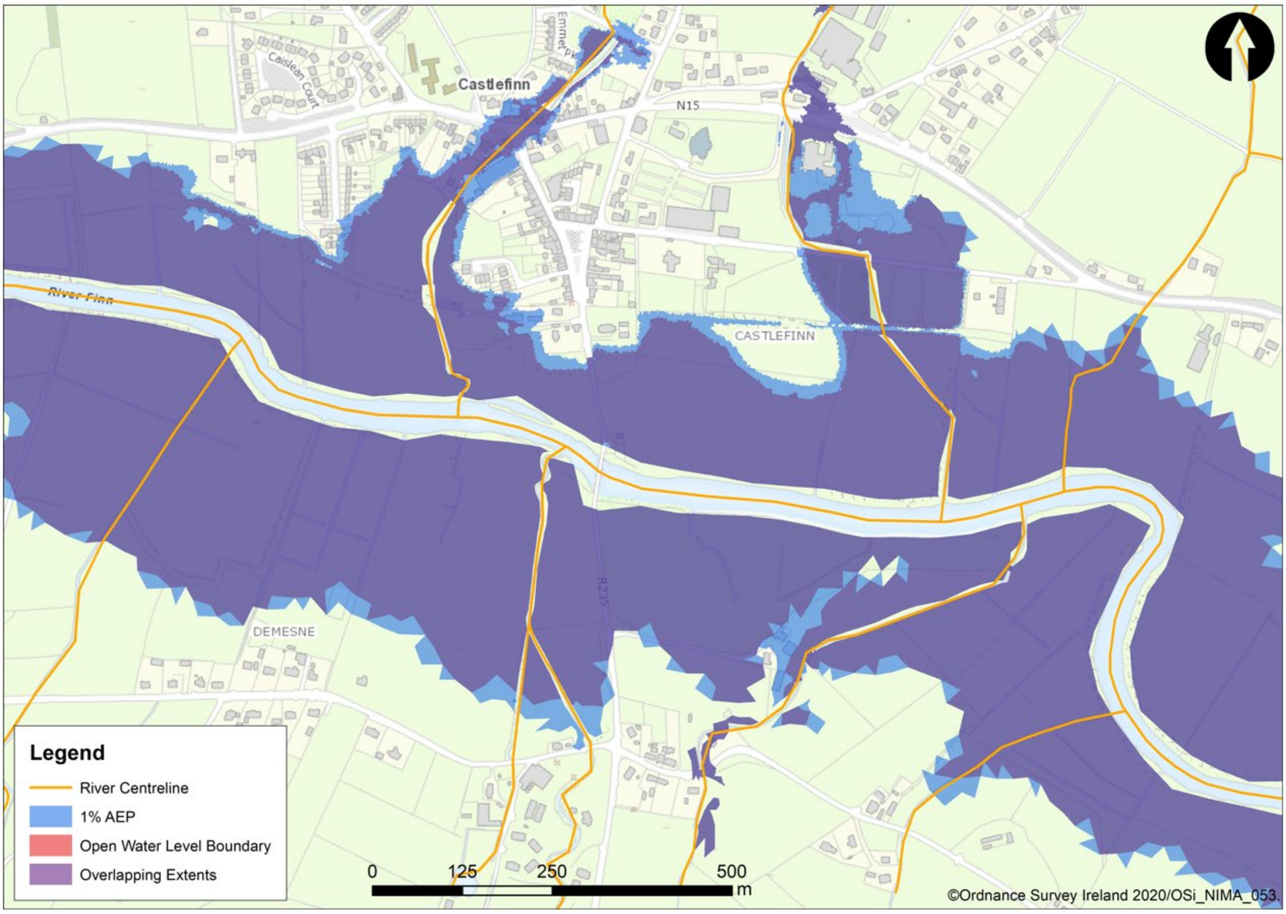

Figure 3.38: Open Water Level Boundary Sensitivity Event (GIS file ref: wlbnd2)

3.7.5.2 River Finn Hydrographs Moved to 10hrs after Tributary Peaks

This scenario involved altering the hydrographs of the River Finn to peak 10 hours after the peak of the last tributary peak to test the sensitivity flow from the Finn has on the Castlefinn model. This resulted in a larger flood extent when compared with the original 1% AEP flood extent, shown in Figure 3.39. An increase in flood extent increases risk to properties located near McGlynns restaurant whereas a reduced flood extent was identified at the CPI Centre. These changes have an impact on receptors as approximately five additional buildings are affected, accounting as a 23% increase when compared to the 1% AEP design results.

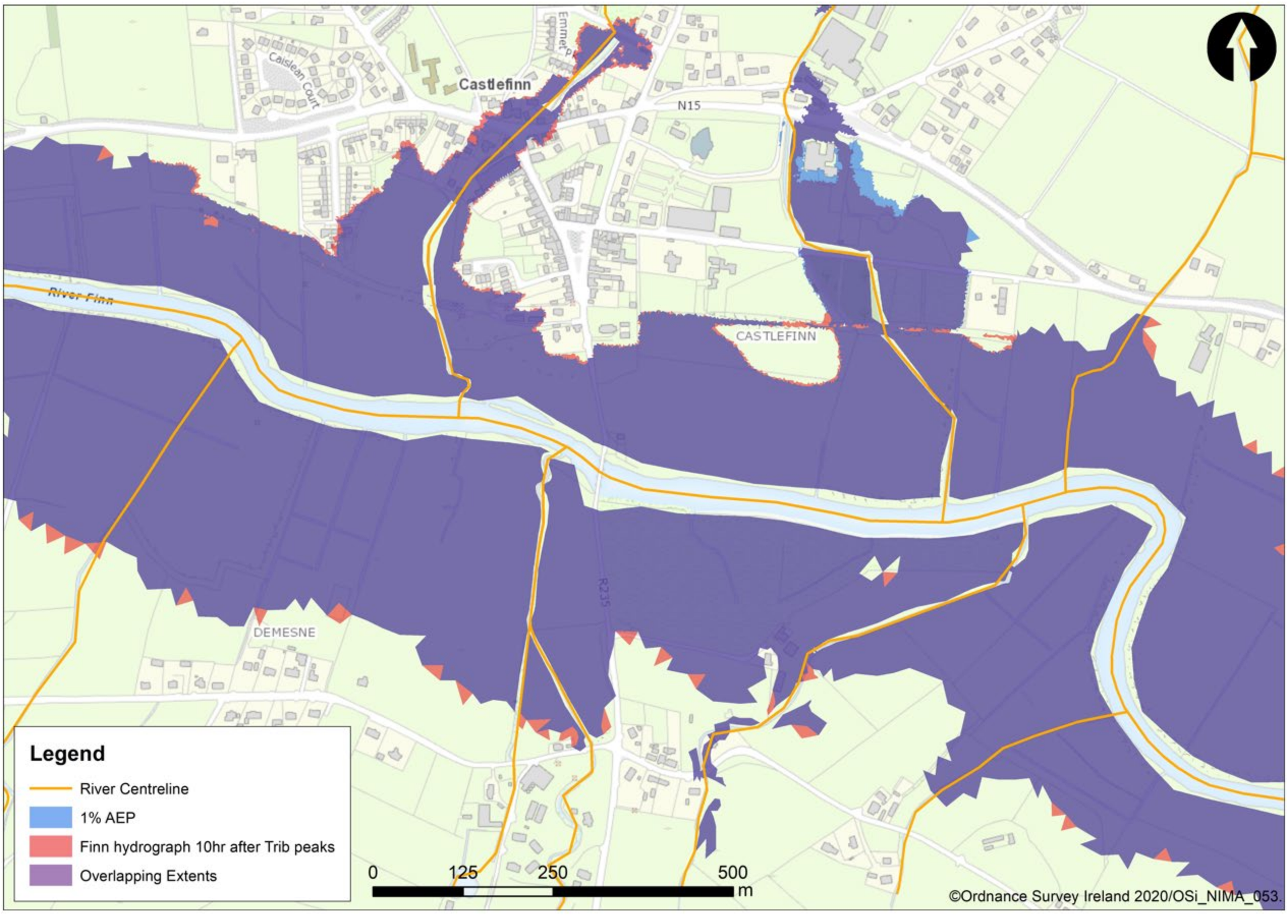

Figure 3.39: Finn hydrograph peak 10hr after tributaries peak Sensitivity Event (GIS file ref: time1)

3.7.5.3 River Finn Hydrograph Peak Coinciding with Tributary Peaks

This scenario resulted in a larger flood extent when compared with the original 1% AEP flood extent shown in Figure 3.40. The increase in flood extents impacted properties located near McGlynns restaurant, Grahamsland and properties along the N15 near the CPI Centre. Approximately nine additional buildings are affected, accounting as a 41% increase when compared to the 1% AEP design results.

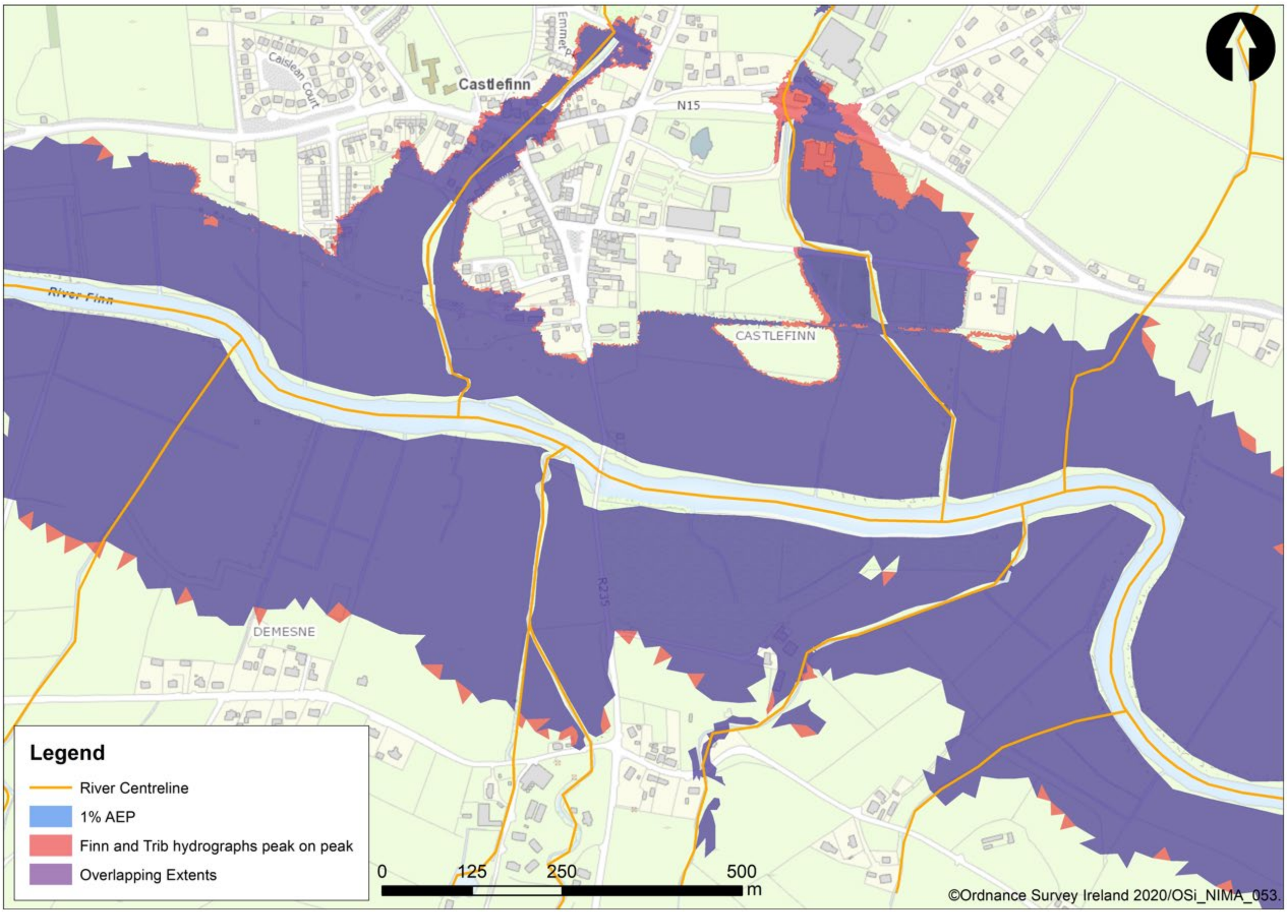

Figure 3.40: Coincidental Inflow Peak Sensitivity Event (GIS file ref: time2)

3.7.5.4 Increase Downstream Water Level Boundary by 300mm

The water level boundary with an additional 300mm scenario involved running the 1% AEP fluvial inflows with the increased water level to test impact in Castlefinn. The increased water level boundary simulation demonstrated a larger flood extent when compared with the original 1% AEP flood extent shown in Figure 3.41. An increase in flood extent was observed for properties located near McGlynns restaurant and properties along the N15 near the CPI Centre. These changes have an increasing impact on receptors as approximately seven additional buildings are affected, accounting as a 32% increase when compared to the 1% AEP design results.

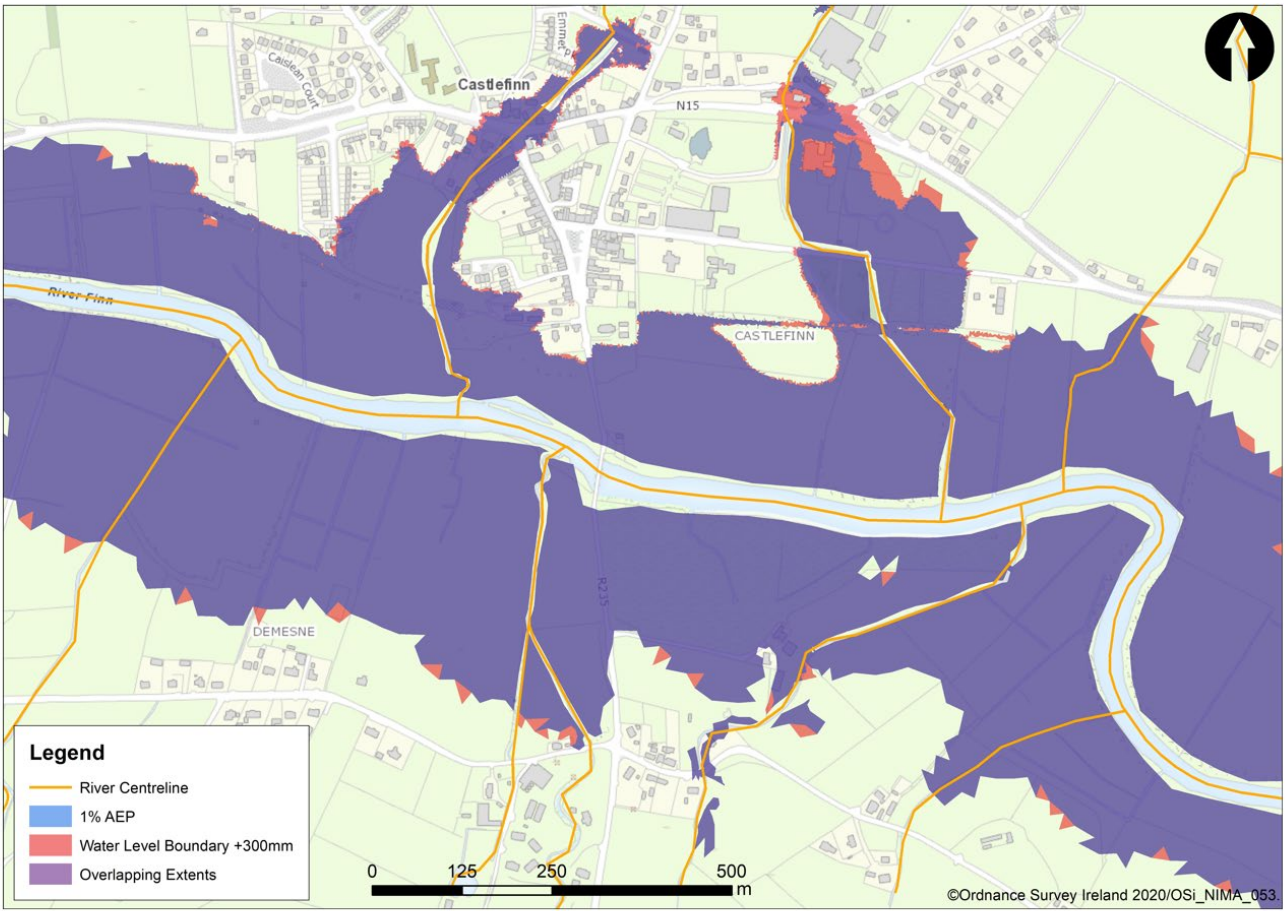

Figure 3.41: Downstream Water Level Boundary +300mm Sensitivity Event (GIS file ref: wlbnd1)

3.7.6 Sensitivity Analysis Conclusions

The purpose of sensitivity analysis is to test the model's sensitivity to various parameter changes. The outcomes are flagged to inform the development of the options, robustness of business case and detailed design of the Castlefinn FRS. It may be used to make recommendations regarding adjustments to freeboard or other design considerations to ensure a 'no-regrets' approach.

The Castlefinn model was shown to be most sensitive to changes in present day sensitivity flows, climate change flow scenarios and the joint probability scenarios. Areas in the model that were most sensitive to changes in flood risk were properties located near the CPI Centre on the Castlefinn watercourse and properties near McGlynns Restaurant on the Bridge Burn. Changes in flood risk were due to review of extent only. However, as stubby buildings with threshold levels are represented within the model, any additional properties flooded due to increased depths would have been considered in economic damage assessment.

Some moderate sensitivity was shown to reduced grid size and terrain sensitivity meshing. The 2D extent of the Castlefinn Model is extensive and a using reduced cell size and terrain sensitive meshing would significantly increase run times. Given the iterative testing of options required adopting both these conditions as the base case would have a detrimental impact on programme while offering limited increase in accuracy. The small number of additional properties are unlikely to significantly change the baseline damages given the areas impacted are not predicted to be affected until a 20yr event and beyond. If flood risk were predicted here in a 2yr or 5yr event the impact on baseline damages would be more significant based on accrual of damages over the appraisal period which would make the more detailed grid associated longer run times more worthwhile. In order to provide a “no regrets approach” a sensitivity check on these outputs for the baseline economic damage appraisal will be carried out to determine potential increase in baseline damages and if this is sufficient to justify increased run times.

3.8 Model Performance

RPS have undertaken a mass balance check on the 1% AEP model to ensure that the total volume of water entering and leaving the model at the upstream and downstream boundaries balances the quantity of water remaining in the model domain at the end of a simulation. This will be a further indication of how the model is performing. Generally mass errors should be less than 2%. If the mass error is greater than 2%, the cause and location of the mass error within the model schematisation should be identified and the consequence of this error assessed with improvements to the model considered. If the mass error is greater than 5%, then it suggests that the model schematisation is not robust and needs to be reviewed (Environment Agency[12]).

The mass error of the Castlefinn FRS model during the 1% AEP simulation was calculated as -0.0441% therefore the model is deemed to be robust.

[12] (Environment Agency, 2021)

4 QUALITY ASSURANCE

RPS have carried out internal reviews of the model. The hydraulic model lead has reviewed model set up at 1D and 2D development and reviewed calibration and design simulation outputs to ensure the model meets expectations. Quality assurance sheets are in the form of RPS' internal model log which will accompany the hydraulic model.

5 CONCLUSIONS

RPS have undertaken a comprehensive review of existing information including historical flood event data, reports and models from previous studies and survey information. Additional topographical and culvert survey information has been procured for the purposes of the Castlefinn FRS.

An Infoworks ICM model was developed to undertake the numerical modelling of watercourses affecting the study area. The 1D domain of the model incorporates all hydraulic structures and connects with the 2D domain to provide an accurate assessment of both the in-channel flow regime and floodplain flow paths.

Following the Castlefinn CFRAM Study, updates were made to the hydrological analysis, as discussed in the Castlefinn FRS Hydrology Report. The updates resulted in a hydrological conclusion that the methodologies for understanding the flood frequency and deriving the design flows presented in this report are considered the most robust possible utilising all available data.

Castlefinn has suffered extensive flooding in 2015 and 2017 and these flood events served as calibration events. Both flood events were calibrated to a high degree of accuracy in the Castlefinn FRS hydraulic model.

The model is moderately well anchored to hydrological estimates and where there are significant discrepancies this is explained by the hydraulic mechanisms captured within the model. The model is well calibrated to two recent flood events and has a mass balance error of -0.0441%. The model is deemed robust and reliable.

Breach, sensitivity and blockage assessments have also been undertaken as part of the Castlefinn FRS model assessment. The breach analysis (conducted in line with OPW GN24 Breach Analysis) focused on the CPI Centre embankment and demonstrated additional flood risk in the event of failure. Sensitivity simulations were conducted to test the models sensitivity to various parameter changes. The model is particularly sensitive to flows, climate change flow scenarios and the joint probability scenarios. Outputs of the analysis will inform the development of the options and detailed design of the Castlefinn FRS, particularly in making recommendations regarding adjustments to freeboard or other design considerations to ensure a ‘no-regrets’ approach.

The model does not include drainage network data as this was not a project requirement and as such out of sewer flooding has not been modelled. The model does not currently represent pluvial modelling, with this aspect of modelling to be undertaken in Phase Two of the Castlefinn Hydraulics Report. The impacts of high river levels on the ability of the drainage network to discharge during a storm event have not been assessed.

The hydraulic model and its spatial data outputs are considered robust and suitable for the progression of the Scheme Analysis and Development phase of the project.

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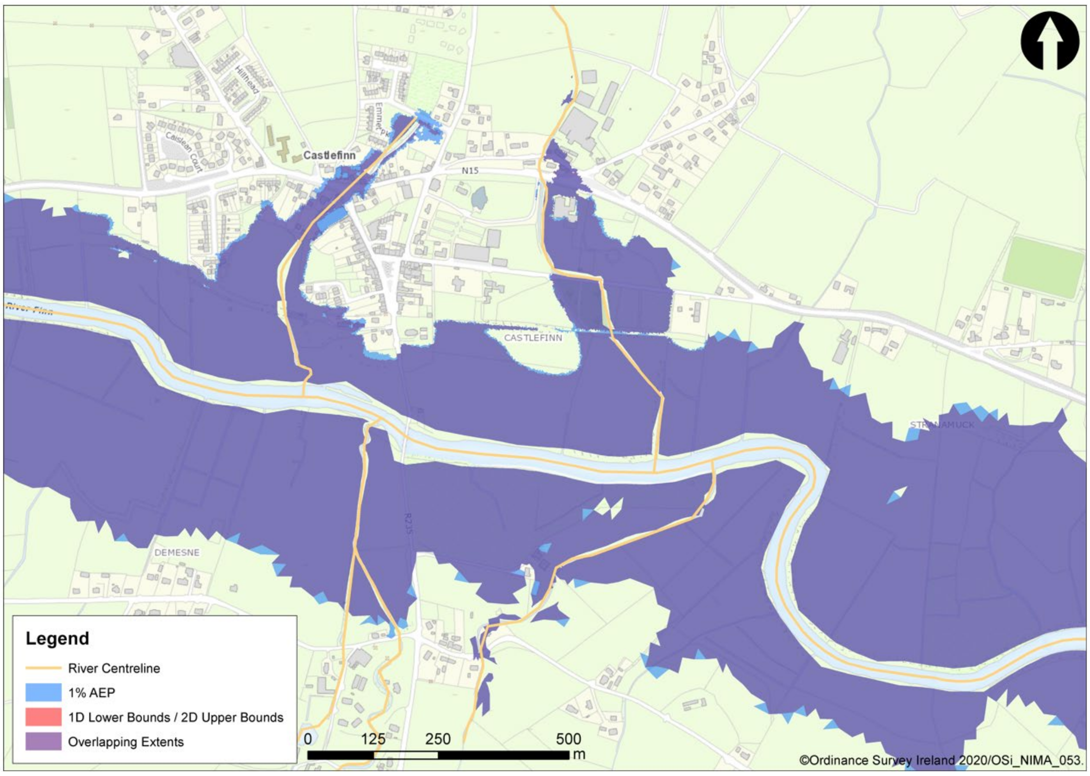
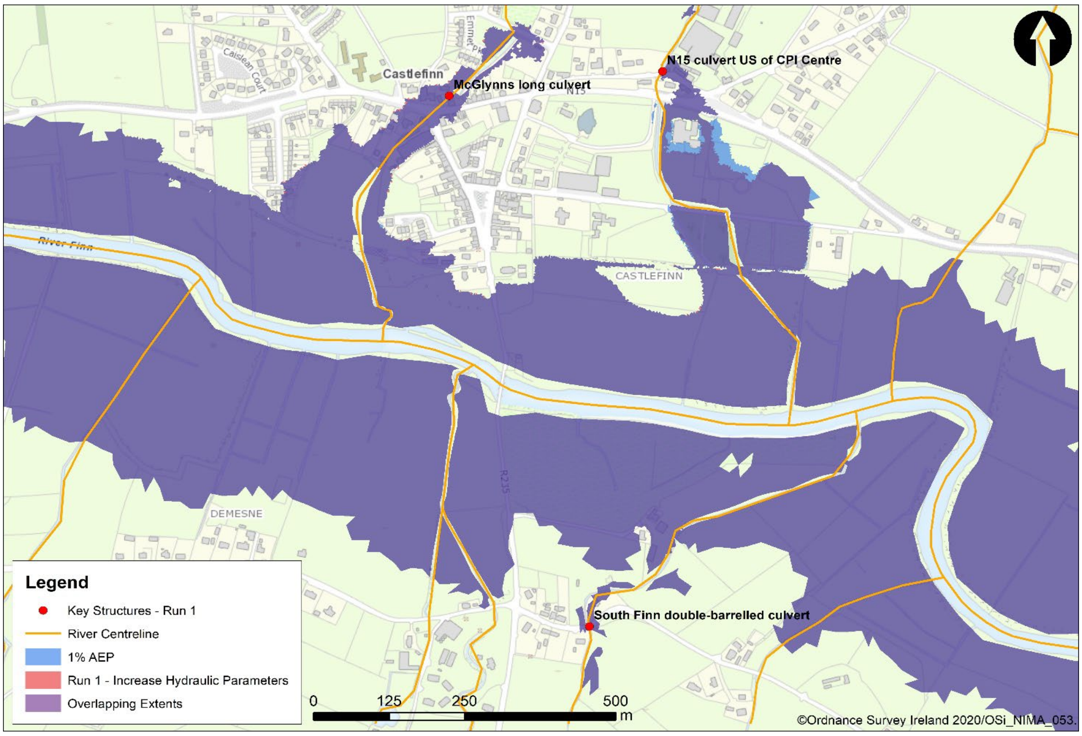
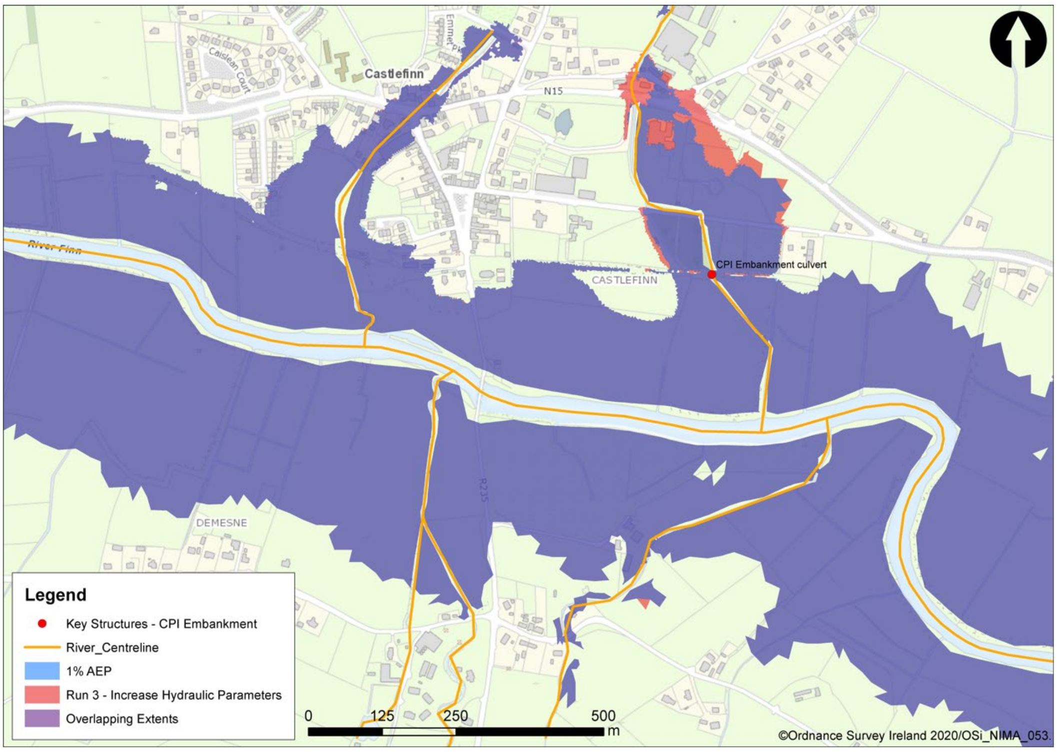
Appendix A– Sensitivity Analysis Figures



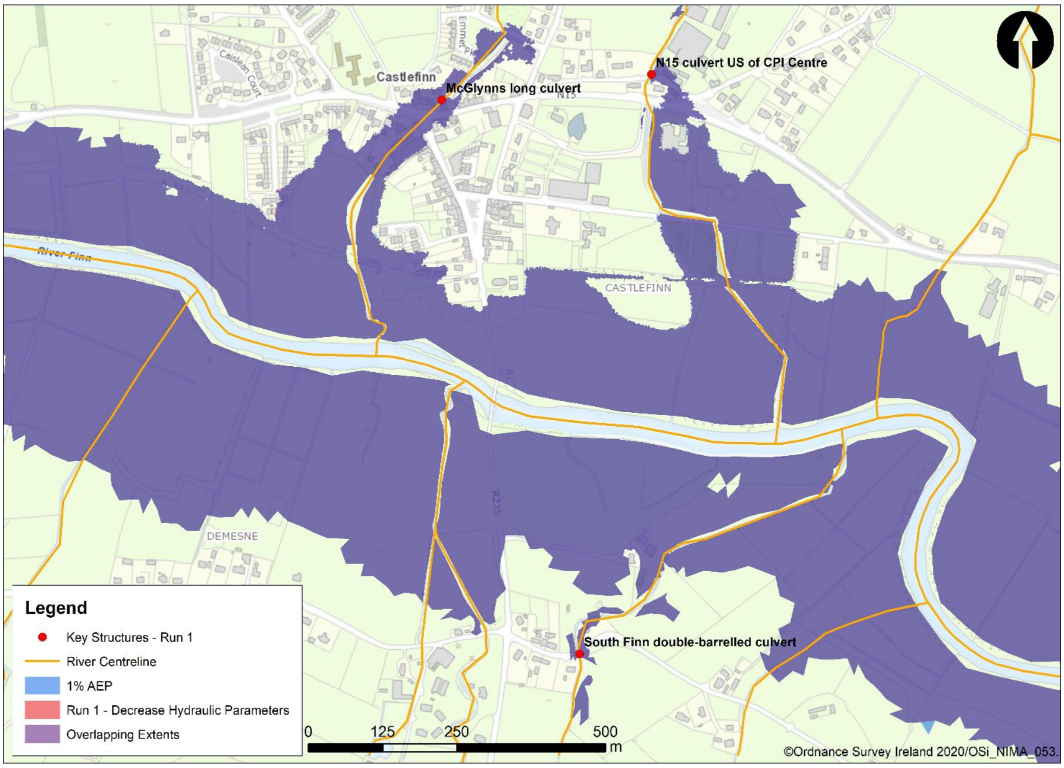
Apx Figure 1: 1D Lower / 2D Upper Bounds Roughness Sensitivity Event (GIS file ref: rough1)



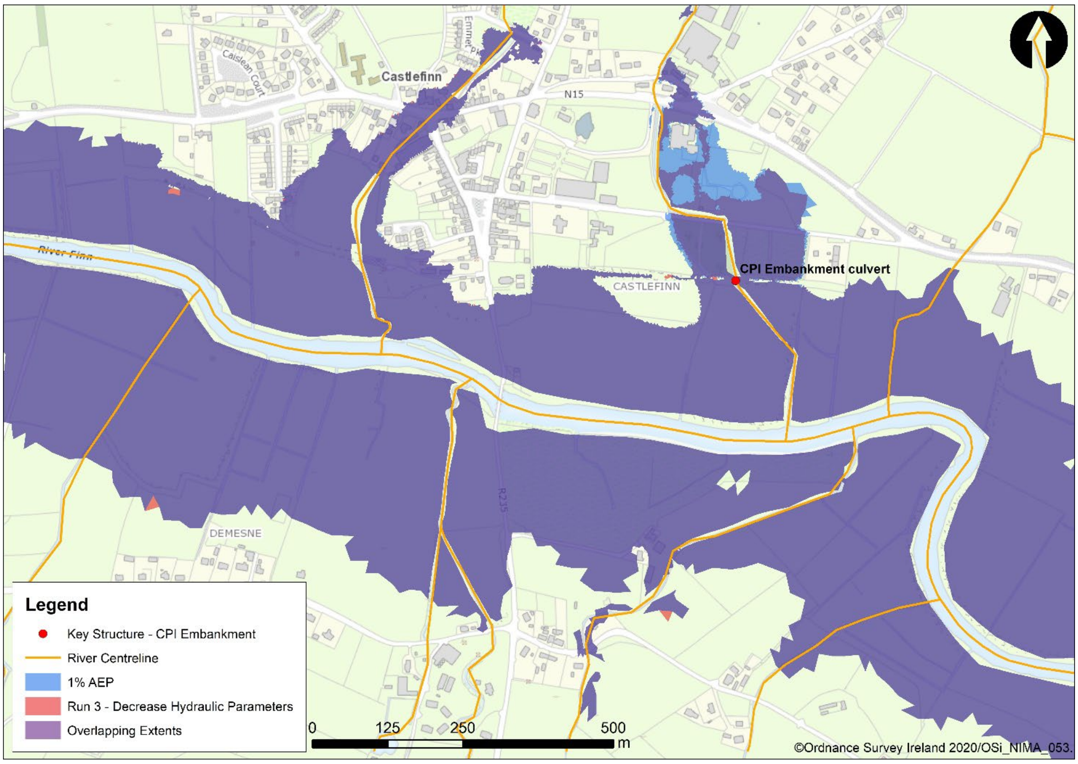
Apx Figure 2: Structures Run 1 Increased Headloss Parameters Sensitivity Event (GIS file ref: hp3)



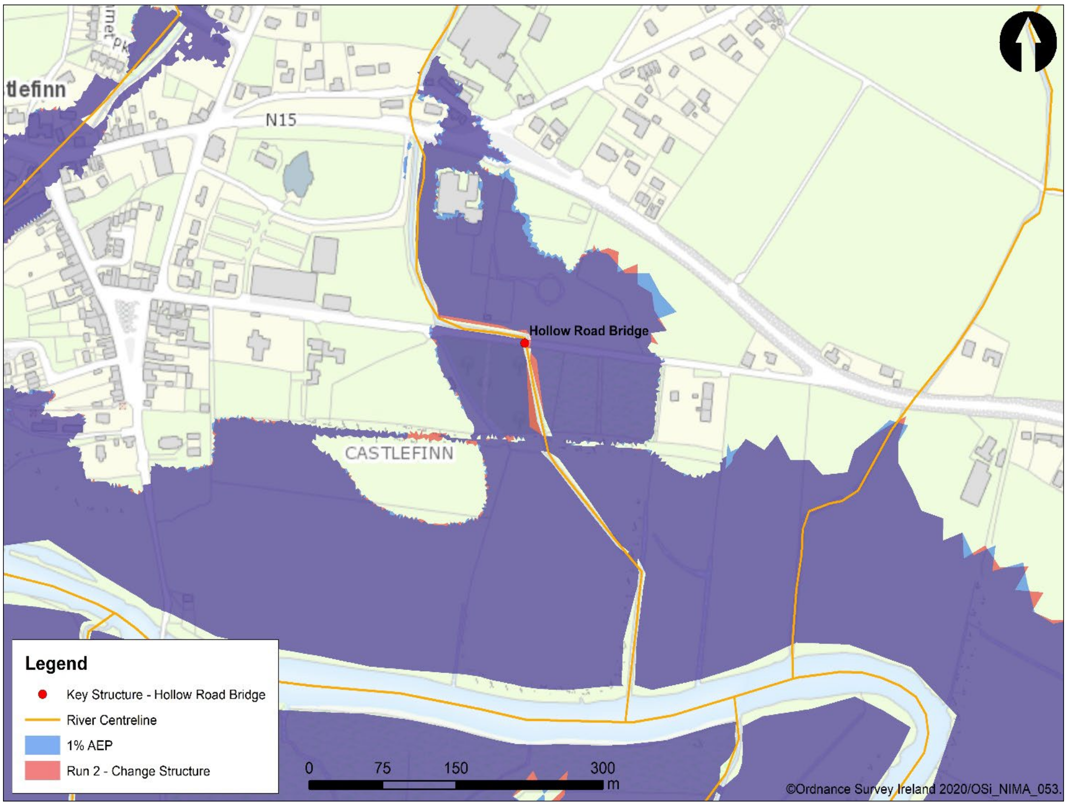
Apx Figure 3: Structures Run 3 Increased Headloss Parameters Sensitivity Event (GIS file ref: hp4)



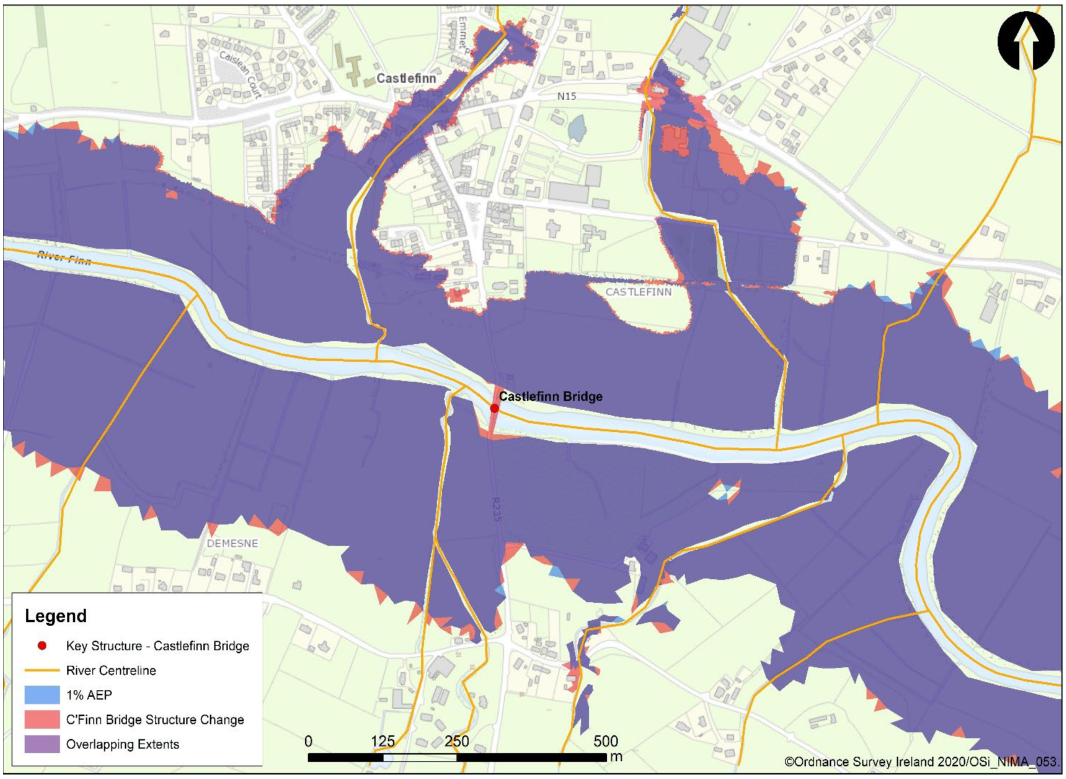
Apx Figure 4: Structures Run 1 Decreased Headloss Parameters Sensitivity Event (GIS file ref: hp2)



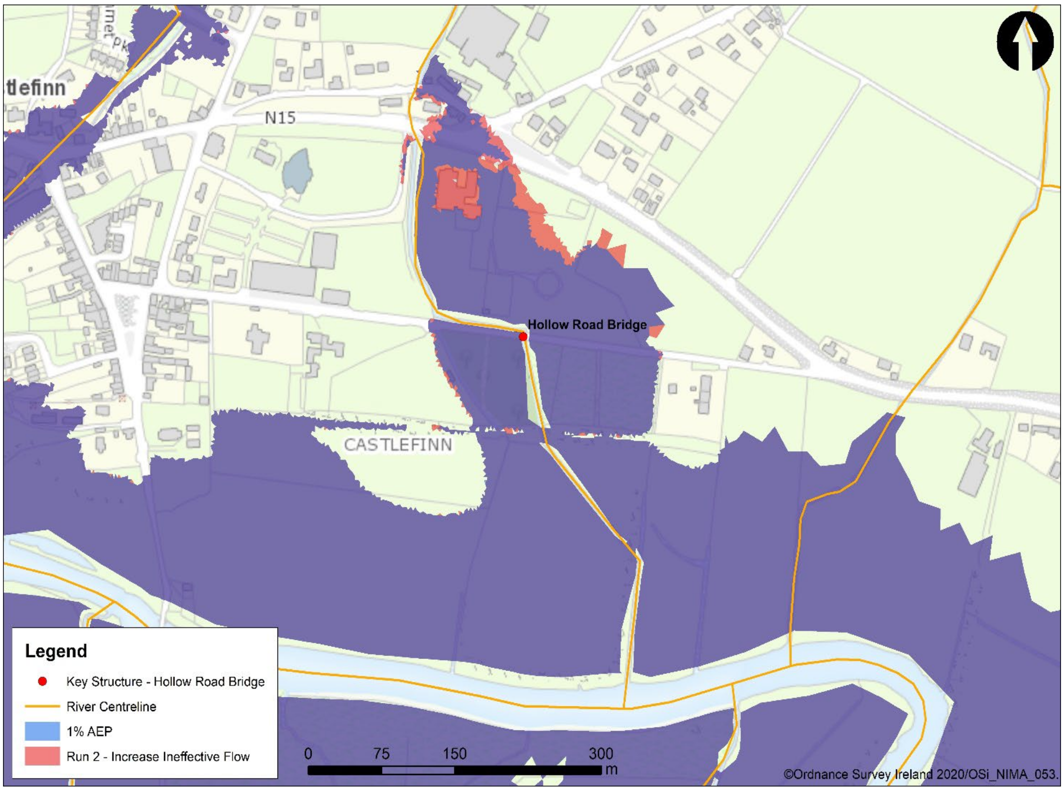
Apx Figure 5: Structures Run 3 Decreased Headloss Parameters Sensitivity Event (GIS file ref: hp1)



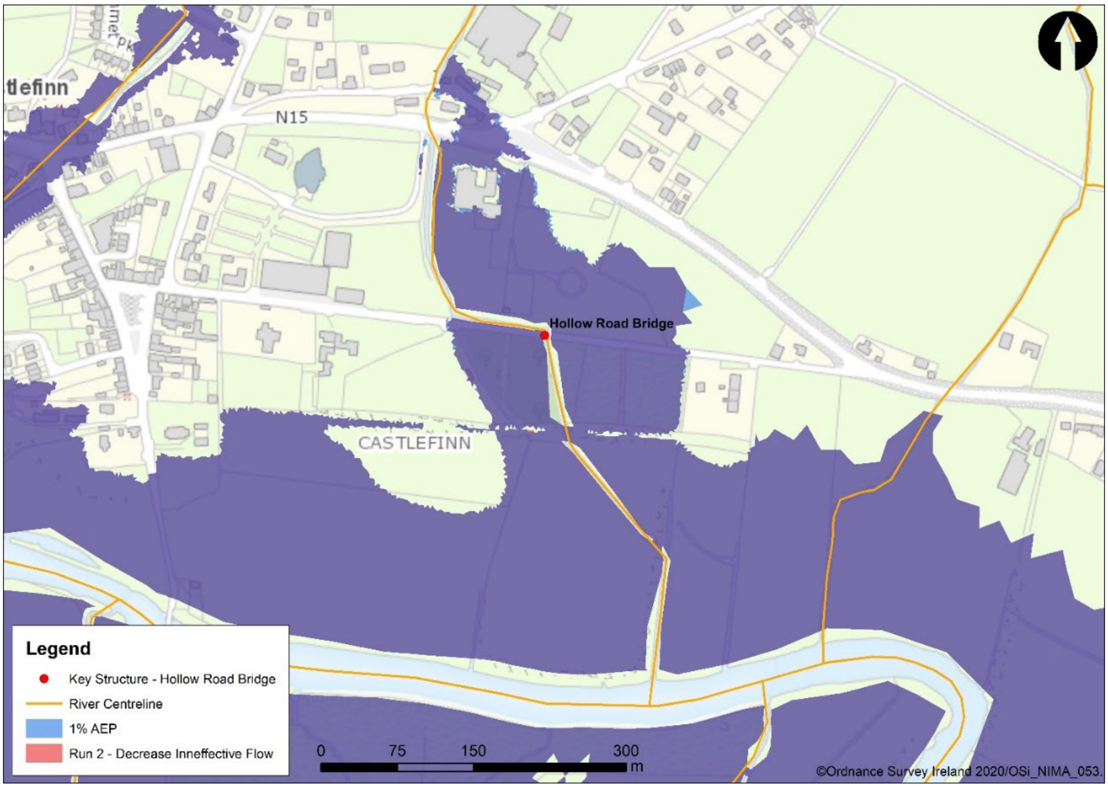
Apx Figure 6: Structures Type Change Run 2 Sensitivity Event (GIS file ref: struct2)



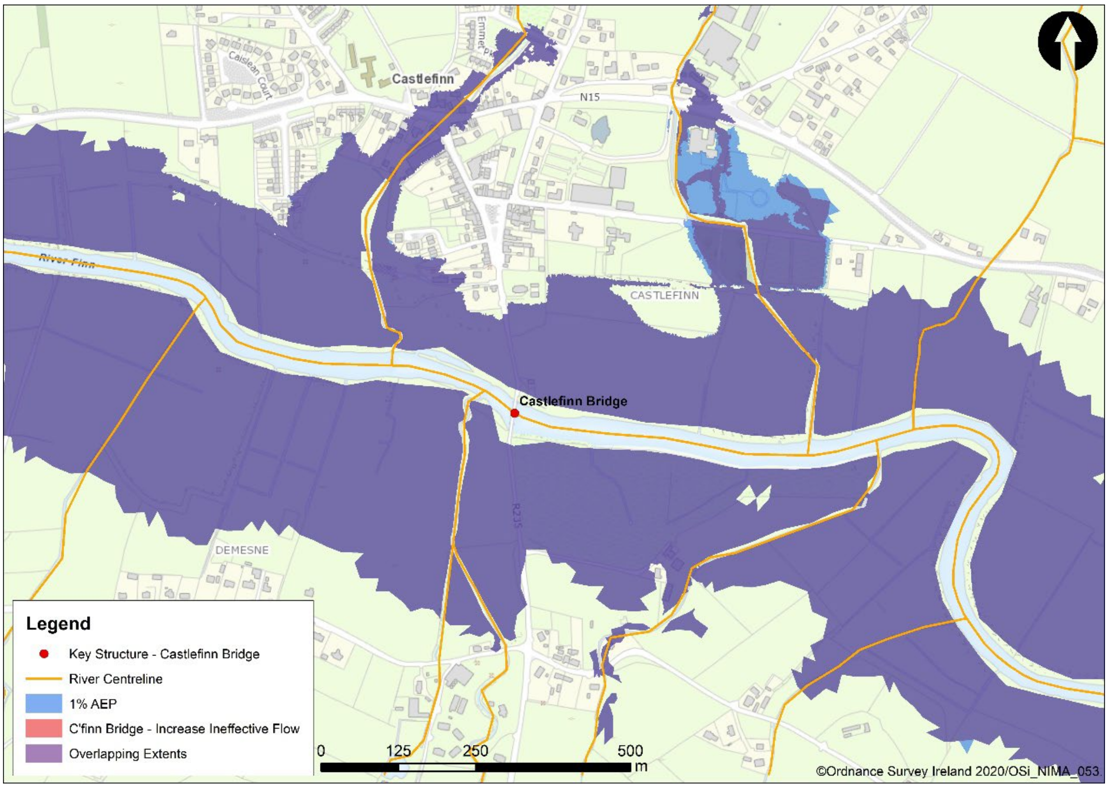
Apx Figure 7: Structures Type Change Castlefinn Bridge Sensitivity Event (GIS file ref: struct2)



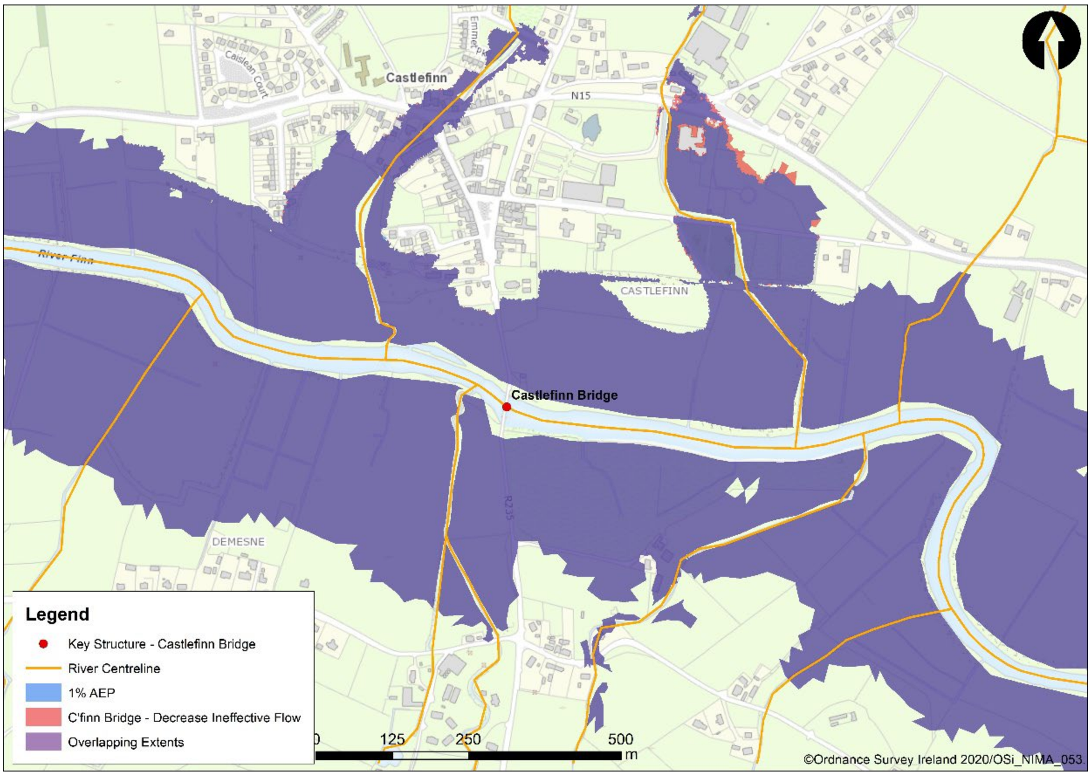
Apx Figure 8: Structures Run 2 Increased Ineffective Flow Sensitivity Event (GIS file ref: if4)



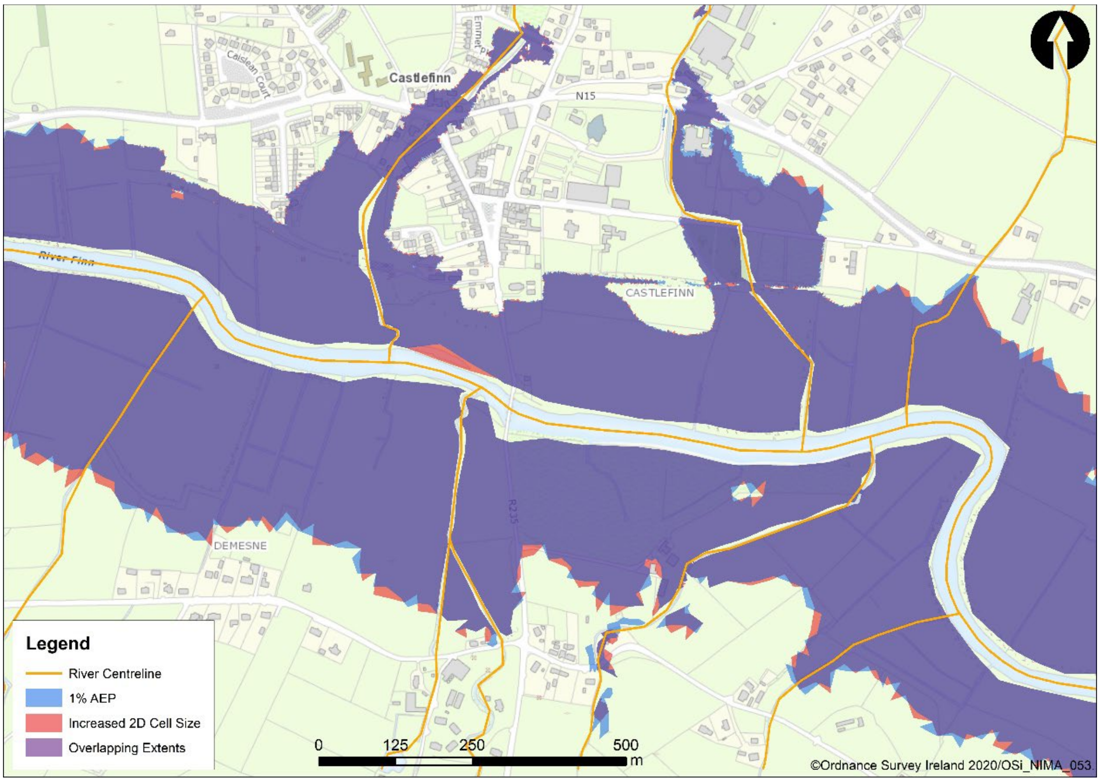
Apx Figure 9: Structures Run 2 Decreased Ineffective Flow Sensitivity Event (GIS file ref: if3)



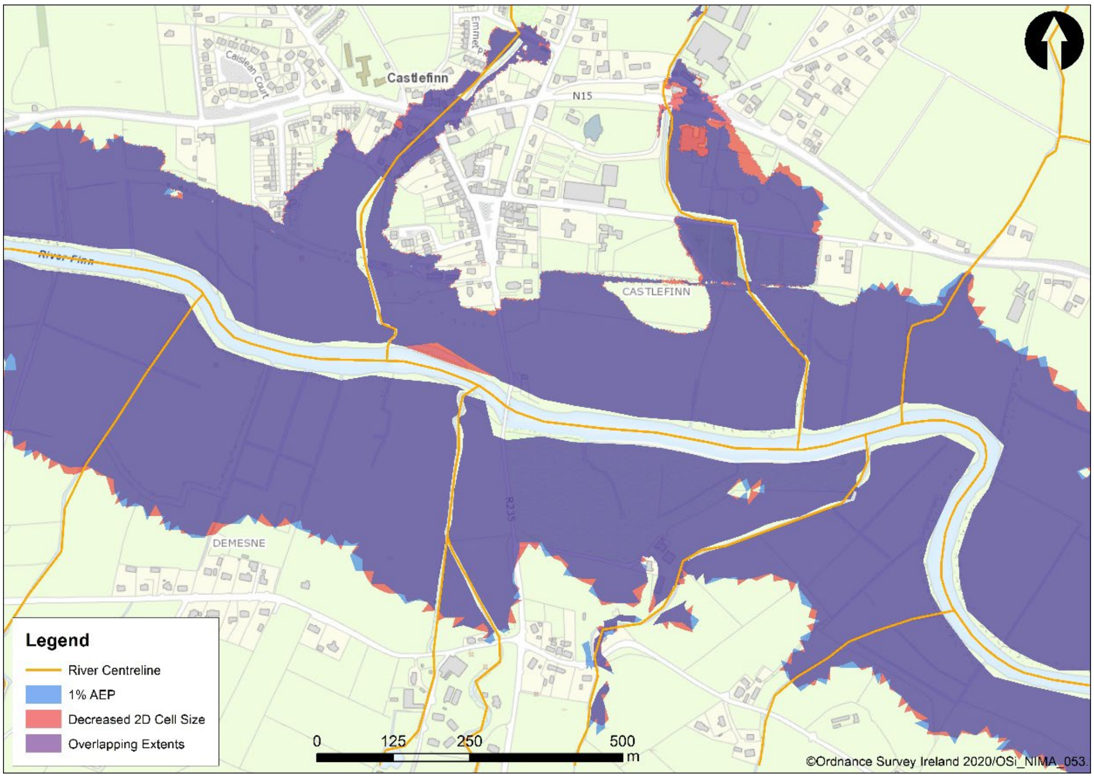
Apx Figure 10: Castlefinn Bridge Increased Ineffective Flow Sensitivity Event (GIS file ref: if2)



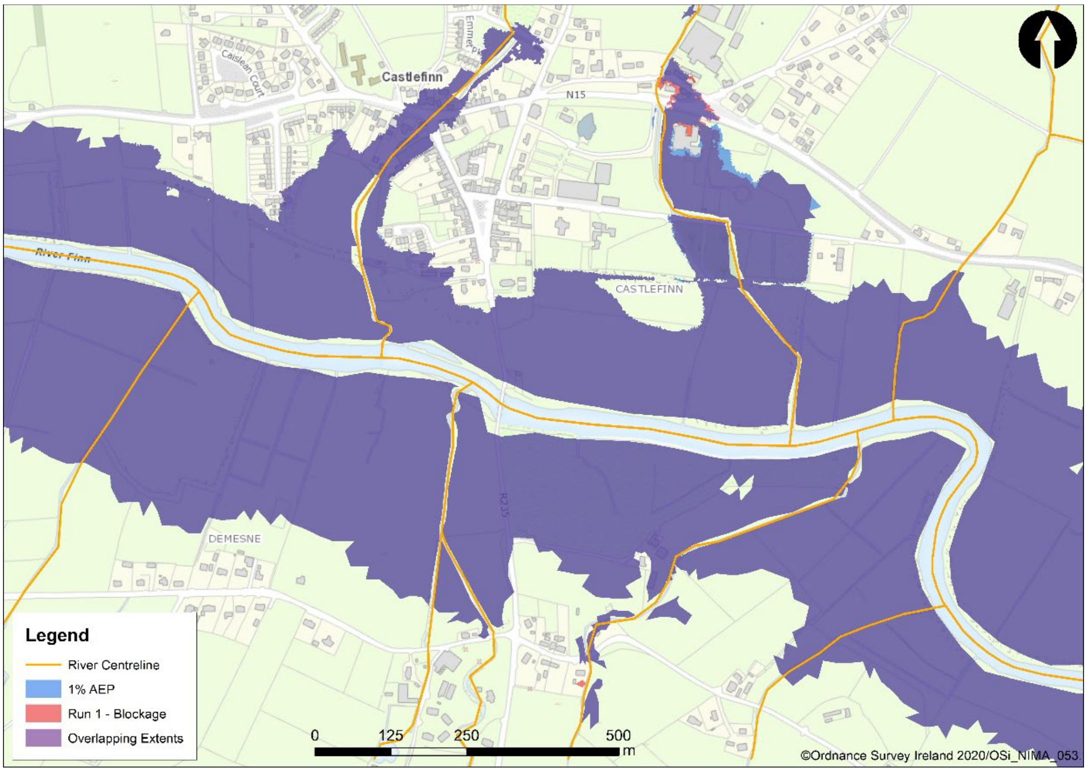
Apx Figure 11: Castlefinn Bridge Decreased Ineffective Flow Sensitivity Event (GIS file ref: if1)



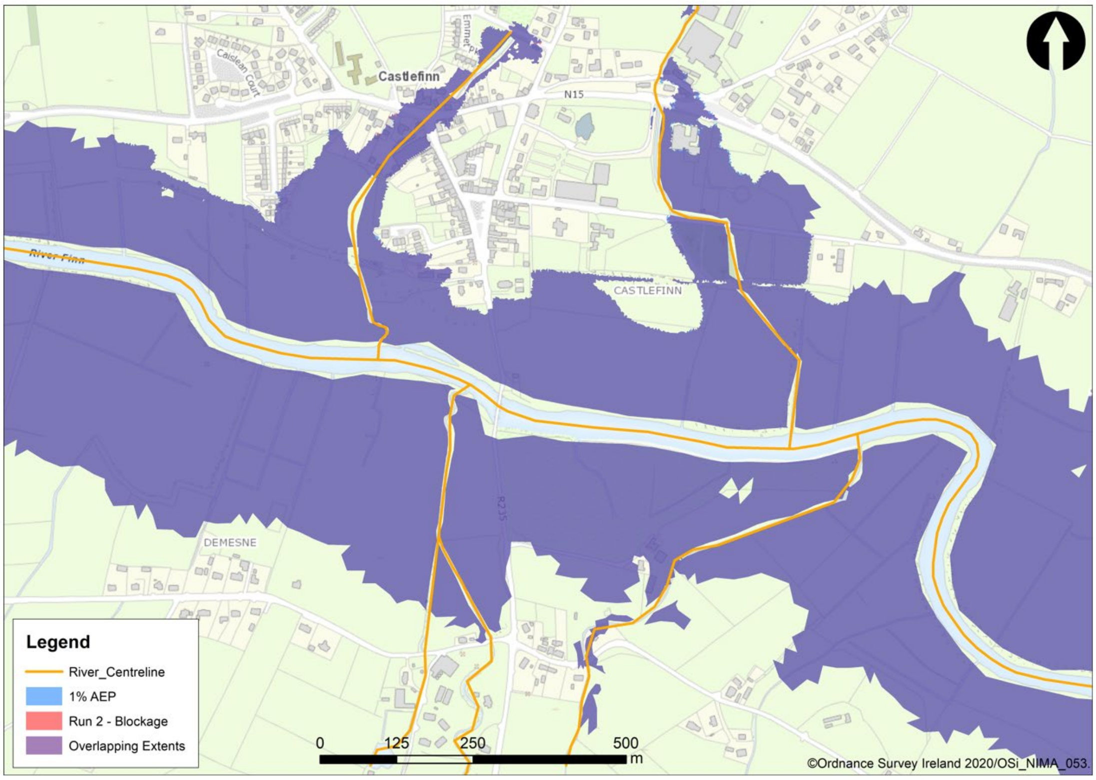
Apx Figure 12: Increased 2D Cell Size Sensitivity Event (GIS file ref: mesh2)



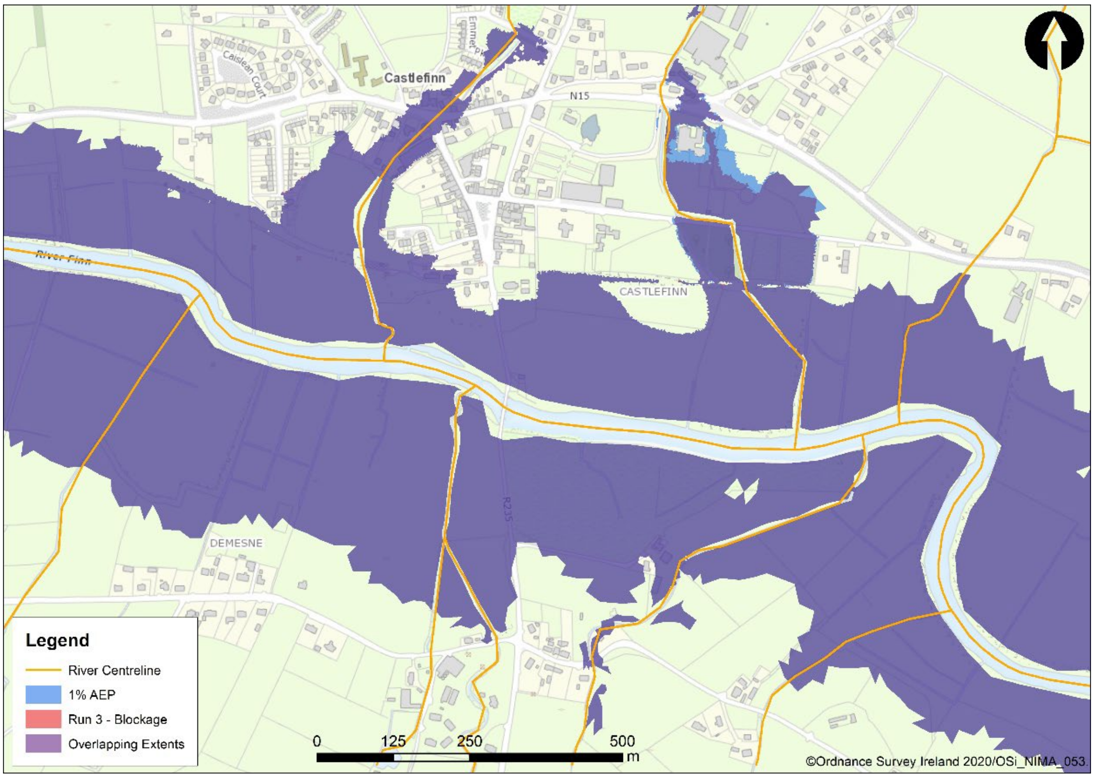
Apx Figure 13: Decreased 2D Cell Size Sensitivity Event (GIS file ref: mesh1)



Apx Figure 14: Structure Run 1 Blockage Sensitivity Event (GIS file ref: block 1)

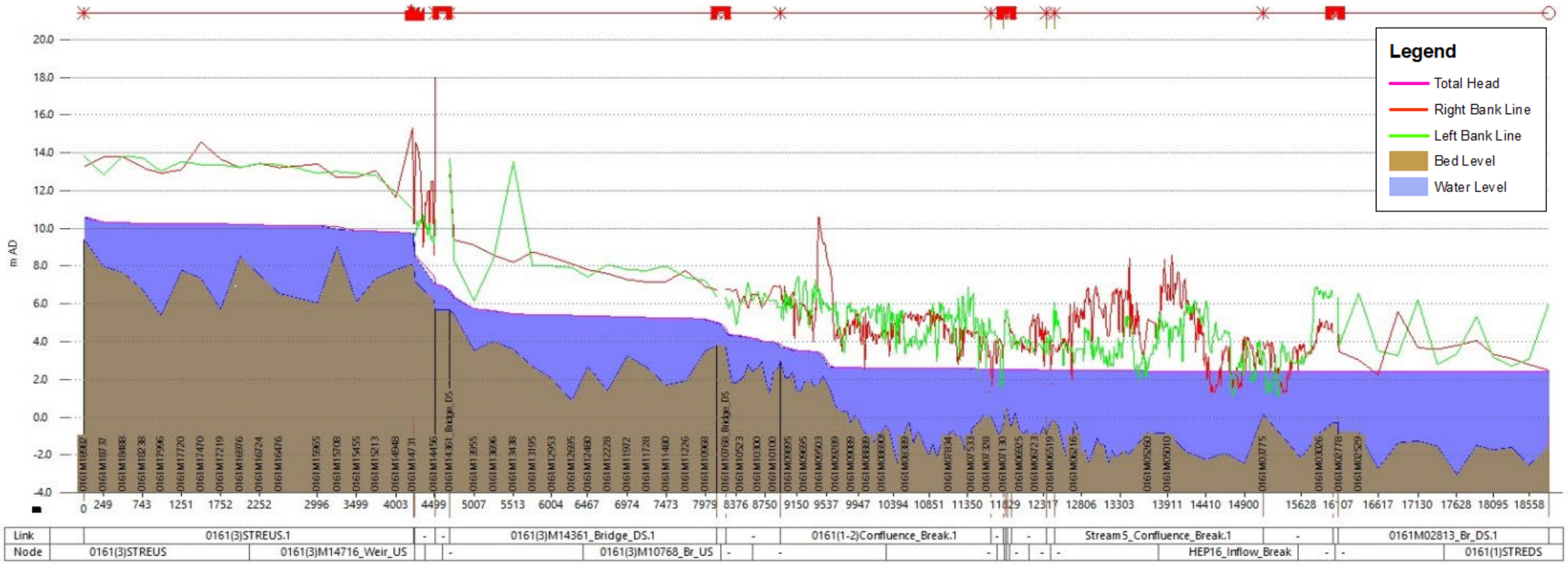


Apx Figure 15: Structure Run 2 Blockage Sensitivity Event (GIS file ref: block2)

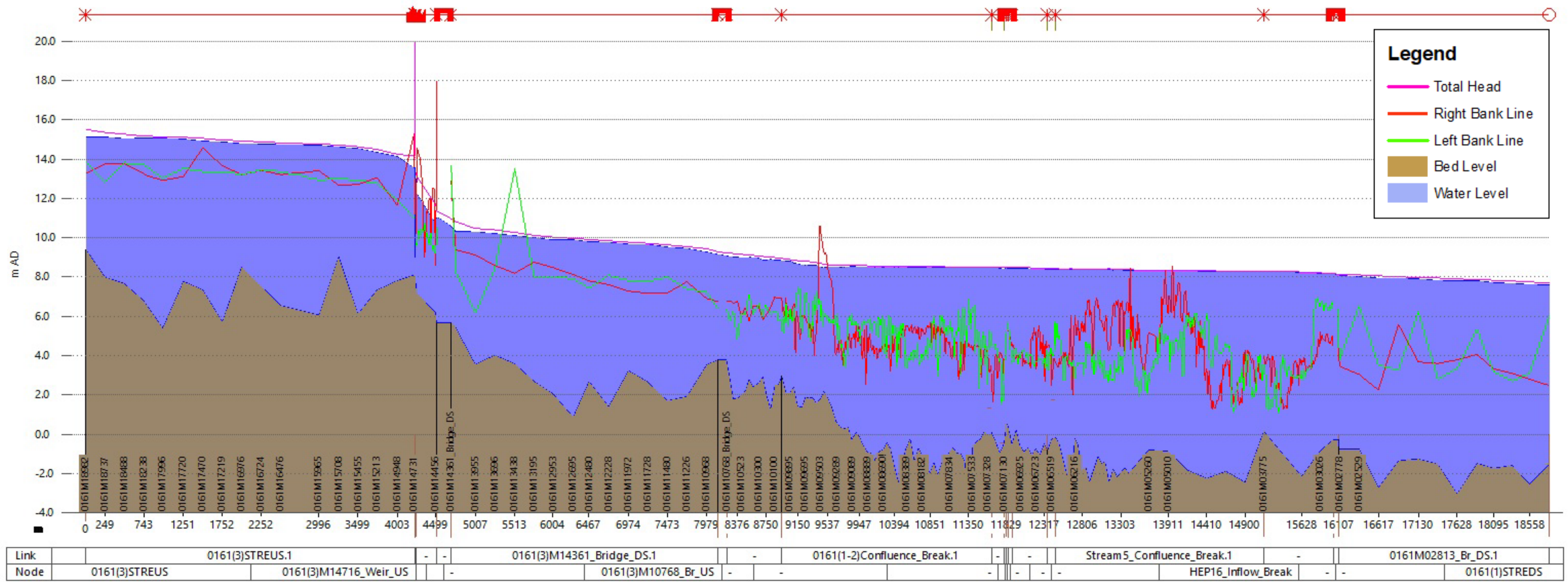


Apx Figure 16: Structure Run 3 Blockage Sensitivity Event (GIS file ref: block3)

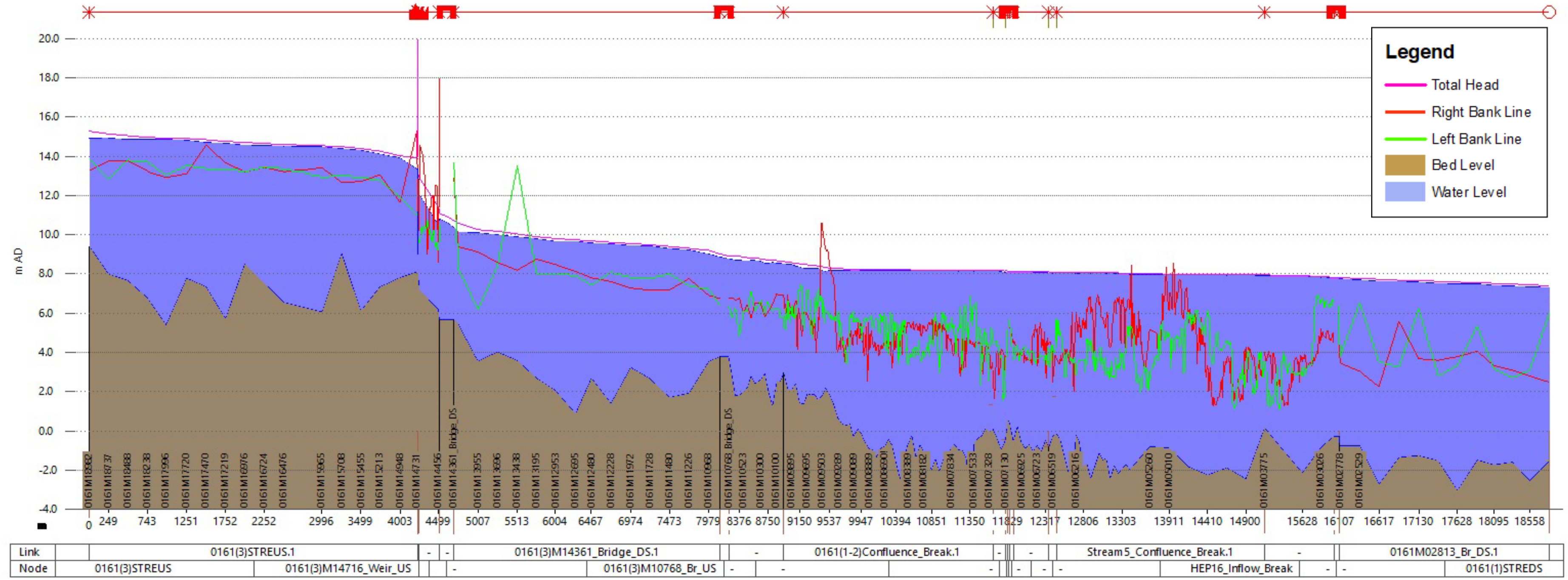
Appendix B – Climate Change Flows Long Section Profiles



Apx Figure 17: Long Section Flow Profile of River Finn showing Baseflow



Apx Figure 18: Long Section Flow Profile of River Finn at Peak Flow during 1% AEP MRFS Event



Apx Figure 19: Long Section Flow Profile of River Finn at Peak Flow during 1% AEP HEFS Event