



# South Western CFRAM Study

Final Hydraulics and Flood Mapping Report,  
Unit of Management 22  
June 2016

The Office of Public Works







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# Executive Summary

The Office of Public Works (OPW) is undertaking six catchment-based flood risk assessment and management (CFRAM) studies to identify and map areas with existing and potential future flood risk across Ireland. Mott MacDonald Ireland Ltd. has been appointed by the OPW to assess flood risk and develop flood risk management options in the South Western River Basin District. This hydraulics and flood mapping report is one of a series of reports being produced as part of the South West Catchment Flood Risk Assessment and Management Study (SW CFRAM Study). It details the development of the hydraulic models used to map current and future flood risk across Unit of Management 22. The model results and flood maps from this report inform the subsequent strategic environmental assessment and flood risk management plans.

A total of eight hydraulic models have been developed for the six Areas for Further Assessment (AFAs) and Medium Priority Watercourse downstream (MPW) to assess fluvial and coastal flood risk for various flood probabilities.

The majority of models used a 1D/2D ISIS/TUFLOW hydrodynamic ally linked approach such that water can flow between the river and floodplain during the event to simulate the observed flood mechanisms within AFAs. The river channels have been modelled using 1D ISIS software to calculate flows and head loss at hydraulic structures. The 2D TUFLOW software has been used to simulate the multi-directional flows across the complex urban floodplains. However, Portmagee was developed with a 2D TUFLOW only approach to assess coastal flood risk as it was not deemed to be at risk from fluvial flooding.

The Castleisland and Killarney models were calibrated to flood events of 4<sup>th</sup> October 2008, 2<sup>nd</sup> November 1980 and 19<sup>th</sup> November 2009 where sufficient data enabled full calibration of the hydraulic parameters. The Maine model was also calibrated for high flow in-bank events on the 4<sup>th</sup> October 2008 and 12<sup>th</sup> January 2010 events. The Milltown, Glenflesk and Dingle models were validated against reports of recurring flooding to ensure representation for historic flooding. Sensitivity tests were undertaken on flow, downstream level and Manning's 'n' for all models. An additional sensitivity test was undertaken on the culvert coefficient at Milltown following comments from the local area engineers.

The calibrated and tested models were then run for eight flood probabilities under the current design scenario, eight flood probabilities under the mid-range future scenario, and three flood probabilities under the high end future scenario from both fluvial and coastal sources. The flood extent, flood zone, flood depth, flood velocity and flood hazard have all been mapped for the specified scenarios, and are provided in the Appendices to this report.

The findings from the modelling results and flood maps will be used as inputs to the flood risk review. The knowledge of the flood mechanisms, critical structures and impact of flooding established in this report will support the development of sustainable and appropriate flood risk management options in the flood risk areas.

# 1 Introduction

## 1.1 The CFRAM Process

Flooding is a natural process that occurs throughout Ireland as a result of extreme rainfall, river flows, storm surges, waves, and high groundwater. Flooding can become an issue where the flood waters interact with people, property, farmland and protected habitats.

The Office of Public Works (OPW) is the lead agency in implementing flood risk management policy in Ireland. Mott MacDonald Ireland Ltd. has been appointed by the OPW to undertake the Catchment Flood Risk Assessment and Management Study (CFRAM Study) for the South Western River Basin District, henceforth referred to as the SW CFRAM Study. Under the project, Mott MacDonald will produce Flood Risk Management Plans which will set out recommendations for the management of existing flood risk in the Study Area, and also assess the potential for significant increases in this risk due to climate change, on-going development and other pressures that may arise in the future.

The South Western River Basin District is split into five Units of Management (UoM). These Units follow watershed catchment boundaries and do not relate to political boundaries. The Units are as follows;

- The Blackwater catchment (UoM18)
- The Lee / Cork Harbour Catchment (UoM19)
- The Bandon / Skibbereen Catchment (UoM20)
- The Dunmanus / Bantry / Kenmare Bay Catchment (UoM21)
- The Laune / Maine / Dingle Bay Catchment (UoM22)

Map 1.1 displays the extent of UoM22 and the extent of the hydraulic models which are the subject of this report.

The overarching aims of the SW CFRAM Study are as follows:

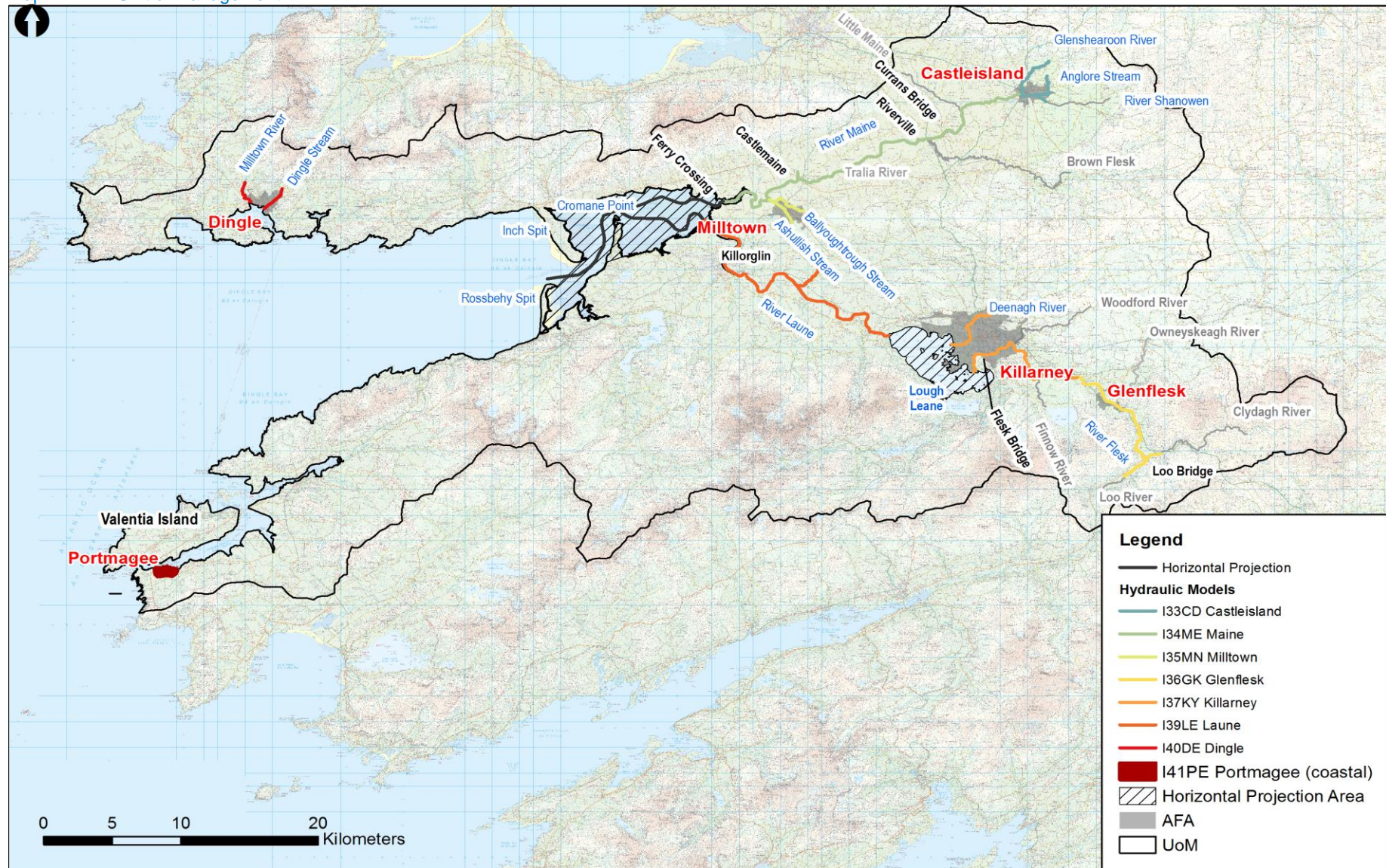
- Identify and map the existing and potential future flood hazard;
- Assess and map the existing and potential future flood risk; and,
- Identify viable structural and non-structural options and measures for the effective and sustainable management of flood risk in the South Western River Basin District.

In order to achieve the overarching aims, the study is being undertaken in the following stages:

- Data collection;
- Hydrological analysis;
- Hydraulic analysis;
- Development of flood maps;
- Strategic Environmental Assessment and a Habitats Directive Appropriate Assessment;
- Flood risk assessment of people, economy and environment;
- Development and assessment of flood risk mitigation options; and,
- Development of the Flood Risk Management Plans (FRMPs).



Map 1.1: Unit of Management 22



## 1.2 Report Structure

The objectives of this report are:

- To document the findings and conclusions of the topographic survey
- To document the analysis and assumptions taken to develop hydraulic models for the AFAs and MPWs
- To map existing and potential flood hazard for the design scenarios
- To use the hydraulic models and maps to assess existing and potential future flood risk and make recommendations for feasible flood risk management options and future modelling.

The main report outlines the generic approach to the hydraulic modelling and mapping. Detailed analysis and discussion of hydraulic modelling and mapping for each Area for Further Assessment (AFA) is provided in the Appendices.

Table 1.1 outlines the report structure and scope of work with a description of the key contents.

Table 1.1: Report Structure

Chapter	Key Contents of Chapter
1. Introduction	<ul style="list-style-type: none"> <li>■ The SW CFRAM process</li> <li>■ Report structure</li> <li>■ Flood probabilities</li> </ul>
2. Data Collection, Survey and Review	<ul style="list-style-type: none"> <li>■ Summary of data sources</li> <li>■ Review of all topographical and land cover data used</li> </ul>
3. Hydrological Approach	<ul style="list-style-type: none"> <li>■ Summary of design inflows and downstream conditions</li> <li>■ Summary of joint probability</li> <li>■ Integration of design hydrology into the hydraulic model</li> </ul>
4. Hydraulic Modelling Approach	<ul style="list-style-type: none"> <li>■ Discussion of general schematisation</li> <li>■ Discussion of overarching methodology for modelling river channels, key structure types and the floodplain</li> <li>■ Model parameters</li> </ul>
5. Calibration and Sensitivity Analysis	<ul style="list-style-type: none"> <li>■ Discussion of calibration events</li> <li>■ Discussion of sensitivity tests on key parameters</li> </ul>
6. Design Runs and Model Performance	<ul style="list-style-type: none"> <li>■ List of design runs</li> <li>■ Discussion of model convergence and performance</li> </ul>
7. Assumptions and Limitations	<ul style="list-style-type: none"> <li>■ The key limitations and assumptions of the models and associated data</li> </ul>
8. Flood Mapping Approach	<ul style="list-style-type: none"> <li>■ Discussion of the flood mapping process</li> <li>■ The types of flood hazard and specific flood risk maps and how these were calculated.</li> </ul>
9. Model and Mapping Results	<ul style="list-style-type: none"> <li>■ Discussion of flood mechanism, frequency of flood issues, risk to life, critical structures, sensitivity to assumptions and guidance on flood risk management options for each AFA.</li> </ul>
10. Summary and Recommendations	<ul style="list-style-type: none"> <li>■ Conclusions and key findings from the hydraulic analysis</li> <li>■ Summary of flood hazard in the Unit of Management</li> <li>■ Recommendations for flood mitigation option development and the FRMP</li> <li>■ Recommendations for future improvements in the hydraulic modelling</li> </ul>



### 1.3 Flood Probabilities

The SW CFRAM Study refers to flood probabilities in terms of annual exceedance probability in preference to the use of “return periods” as used in previous reports. The probability or chance of a flood event occurring in any given year can be a useful tool to better understand the rarity of events of specific magnitude for flood risk management. Due to popular descriptors of floods involving terms like the “1 in 100 year flood” there can be public misunderstanding that a location will be safe from a repeat event of the same magnitude, extent and volume for the duration of the term (100 years in the above example). In reality, flood events of a similar or greater magnitude can occur again at any time.

Annual Exceedance Probability, henceforth referred to as AEP, is a term used throughout this report and the wider CFRAM studies to refer to the rarity of a flood event. The probability of a flood relates to the likelihood of an event of that size or larger occurring within any one year period. For example, a 1 in 100 year flood has a chance of one in a hundred of occurring in any given year; 1:100 odds of occurring in any given year; or a 1% likelihood of occurring. This is described as a 1% annual exceedance probability (AEP) flood event.

Table 1.2 converts the ‘return periods’ to %AEP for key flood events as a reference to previous studies.

Table 1.2: Flood Probabilities

% Annual Exceedance Probability (%AEP)	Odds of a Flood Event in Any Given Year	Chance of a Flood Event in Any Given Year or Previous ‘Return Period’
50%	1:2	1 in 2
20%	1:5	1 in 5
10%	1:10	1 in 10
5%	1:20	1 in 20
2%	1:50	1 in 50
1%	1:100	1 in 100
0.5%	1:200	1 in 200
0.1%	1:1000	1 in 1000

The hydraulic analysis and flood mapping uses a number of other acronyms and technical terminology which are defined in the glossary of this report.

## 2 Data Collection, Survey and Review

### 2.1 Data Collection and Review

A range of different data sources have been used to undertake the hydraulic analysis for the SW CFRAM Study. Table 2.1 lists the data used in Unit of Management 22 and the confidence in each dataset based on the review in the following sections.

Table 2.1: Summary of Data Used

Type	Details	Owner	Date Captured	Confidence Level
Geometric Survey Data	River channel and structure survey and photographs of all HPWs and MPWs in UoM22	OPW	As part of this study 2012-2013	+/- 0.1
Detailed Digital Terrain Models	Filtered LiDAR data for AFAs	OPW	2012	+/- 0.1
National Height Model	IFSAR coarse elevation data with national coverage	OPW	2010	+/- 0.5 to 1.0
OSI Mapping	Building footprints and vector data of land cover	OSI	2010	No elevation data included. Not Applicable

The specific details of the data used for each model are included in the model Appendices.

### 2.2 Geometric Survey Data

As part of this study, extensive river channel survey was undertaken of all the High Priority Watercourses (HPWs) and Medium Priority Watercourses (MPWs) in UoM22 between November 2012 and July 2013 by Murphy Surveys Ltd (Map 2.1). The survey captured topographic information about the elevations, dimensions and hydraulic conditions of the river channel and hydraulic structures. The detailed location of each cross-section is displayed in the model geoschematics provided at the end of the model build proformas in the Appendices. The detailed South West CFRAM Contract 5 Survey is available in a separate survey report (August 2013).

All of the geometric survey data captured by the surveyor was reviewed with checks carried out on 10% of the cross sections. Using GPS survey equipment spot levels checks were carried out on structures and cross sections captured by the surveyor. The levels were reviewed and differences compared at bank crest. The average difference between the levels of the survey and the spot checks was found to be 113 mm. This is considered to be a good correlation when considering that the comparison points were; mostly on rough ground; the exact location of the bank crest could vary from the original survey due to access and vegetation; and, the crest could be subject to footpath erosion where the river bank is unsupported earth.

The following quality assurance of the survey data was also undertaken as part of the hydraulic analysis:

- Sections were surveyed from left bank to right bank facing downstream;
- Sections at the structure face were surveyed parallel to the structure and the skew angle recorded;
- Identification of any gaps and anomalies in the survey drawings or hydraulic model-formatted files;
- Analysis of changes and consistency with any other recent survey data.

The river channel survey was found to be surveyed from left to right bank and in parallel with structures, in accordance with the survey specification. Therefore, bed levels and low flow channel shape were linearly interpolated from the upstream and downstream sections. This assumption ensures that:

- The bed is not artificially elevated due to missing data; and,
- These sections do not act as hydraulic weir controls when the flow through is sub-critical in reality.

Modifications made to individual structures and river channel sections have been justified in the model build proforma for each AFA which can be found in the Appendices.

### 2.3 Digital Terrain Model Data

As part of this study, an aerial LiDAR (Light Detection And Ranging) survey of each AFA was captured in September 2012 as a point cloud with an average of 2 points per square metre (Map 2.2). Subsequently, the raw LiDAR was collated to produce a digital surface model, and post-processed to produce a bare-earth or Digital Terrain Model (DTM) by removing artificial structures, including buildings walls and bridges, and vegetation such as trees and hedges. The DTMs were processed for grid resolutions of 2m, 5m and 10m based on the same raw data.

The LiDAR DTM was compared with the validated survey for large flat surfaces such as roads and hard-standing or flat pasture where hard-standing was limited and deemed to be appropriate for use without further adjustment. The vertical accuracy was found to be 0.05m on average within urban areas, such as Castleisland, increasing to 0.2m in more rural areas such as upstream of Glenflesk and Killorglin.

LiDAR was not available on the Upper Laune, Flesk and Maine downstream of Castleisland to Currans Bridge. Therefore, IFSAR data from OSI's national height model has been used to create the DTM for hydraulic modelling and flood mapping in these reaches. IFSAR has a lower vertical accuracy than LiDAR of  $\pm 0.5$ m on average. When the IFSAR data was compared with river channel survey on the floodplain and discrepancies between -0.2 and +1.30m were found in some locations on the Laune. Therefore, the IFSAR data was adjusted to meet the river channel survey points and then joined with the LiDAR data to create a complete DTM. Every effort has been made to ensure a consistent transition from LiDAR to IFSAR but some uncertainty remains in the areas which use IFSAR due to the poorer data quality.

### 2.4 Land Cover Data

The various types of surfaces in the AFAs were assessed from the following data sources to inform the hydraulic roughness parameters for modelling:

- Building footprints derived from OSI mapping
- 1:1000, 1:2500 and 1:5000 vector OSI Mapping

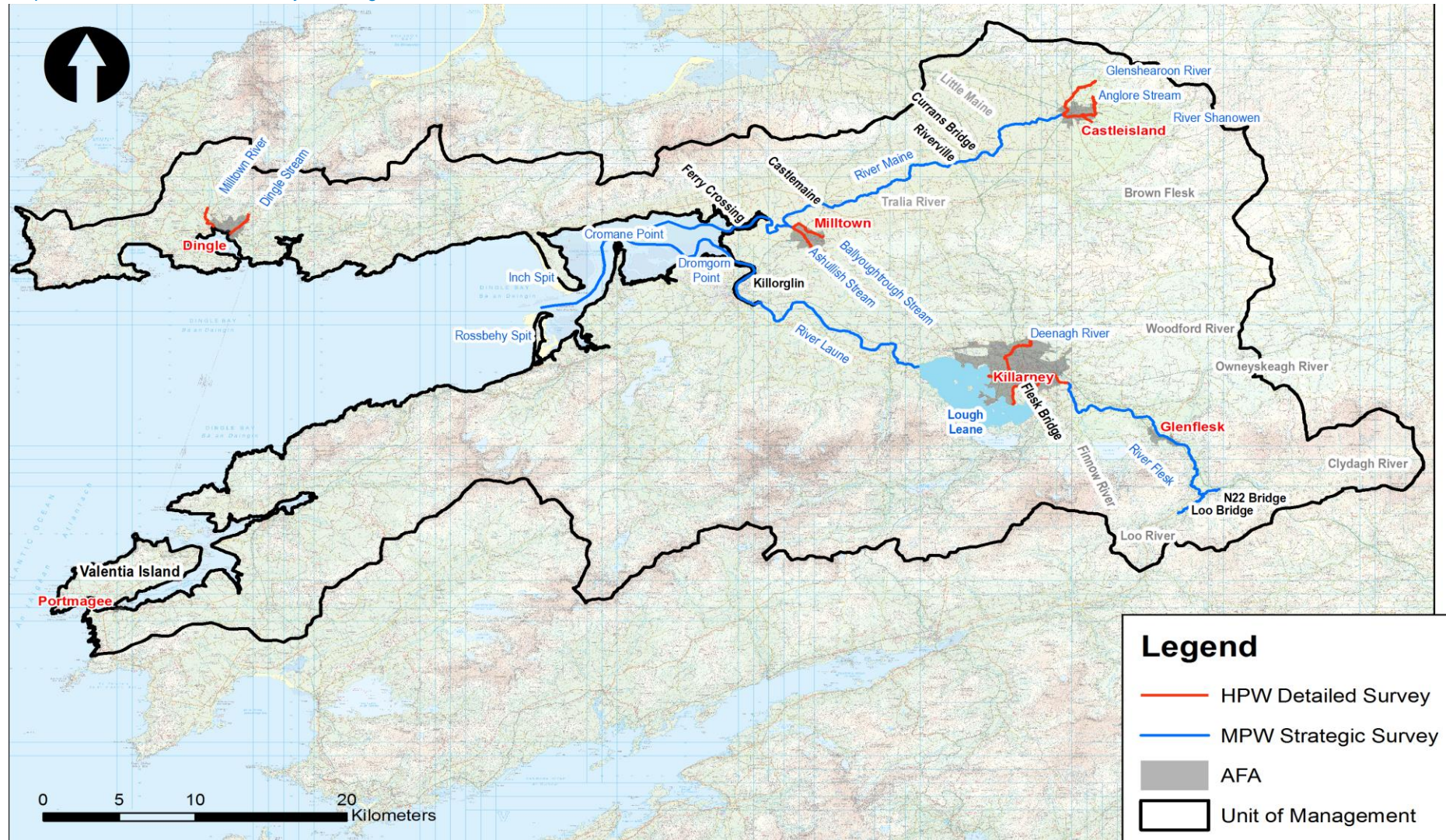
- Surface cover detailed in the geometric survey and survey photographs
- Site visits

The mapping datasets were used in the first instance to classify land cover within each AFA into broad surface types of river bed and standing water; river banks; dense vegetation; pasture, parkland and arable; buildings; and, hard-standing urban areas. The land cover was subsequently refined during the model build process using the survey and site observations. The resultant detailed land cover for each AFA is provided in the Appendices.

The European Environment Agency CORINE land cover dataset was not used because the data is based on satellite imagery which is relatively coarse and does not differentiate buildings from surrounding roads and gardens within urban areas. Therefore, the more detailed OSI mapping was used in urban areas in conjunction with site observations.

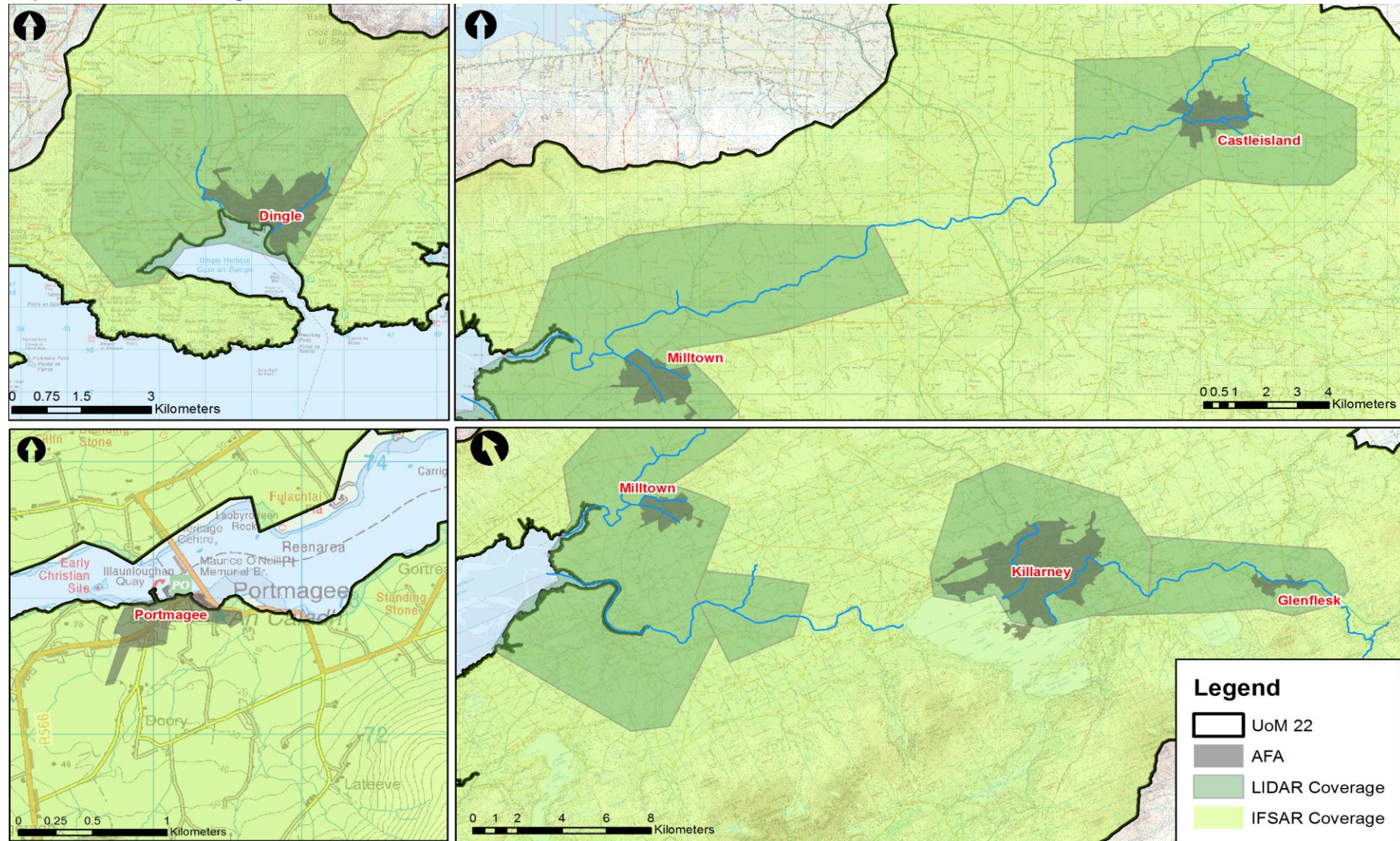


Map 2.1: River Channel Survey Coverage in UoM22





Map 2.2: LiDAR Coverage in UoM22





## 3 Hydrological Approach

### 3.1 Summary of Design Hydrology

As part of the previous UoM22 Hydrology Report, design peak flows and hydrographs were derived at hydrological estimation points for the 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1% AEP fluvial flood events.

The hydrological estimation points were located in every AFA and along the MPWs downstream. The HEP were located at the inflows to the hydraulic models, upstream and downstream of confluences with significant tributaries, and at the downstream limit of the hydraulic models. Catchment descriptors were extracted from the FSU database and checked against the National Height Model, OSi contours and site observations. For smaller catchments not available in the FSU database, the catchment descriptors were derived from the difference between the upstream and downstream points and checked against the available data.

The design peak flows were derived using the recommended statistical method outlined in FSU Work Packages 2.2 and 2.3, and adjusted using the gauge within the AFA where available or the hydrological similar pivotal sites of 22022, 22003, 22006, 22014, 22035 and 22039 as well as 36021, 19014 and 25044. The White Gauge of 22009 was also used to derive QMED along the River Deenagh. However the gauge was not deemed suitable to estimate extreme flows above QMED. Table 3.1 summarises the design peak flows for each catchment in the AFAs for ease of reference.

Table 3.1: UoM22 Design Peak Flood Flows at Key Locations

HEP	Gauge	Flow (m³/s)							
		50%AEP	20%AEP	10%AEP	5%AEP	2%AEP	1%AEP	0.5%AEP	0.1%AEP
River Laune catchment									
22_3712_1	22039 (Clydagh Bridge Gauge)	57.9	72.0	82.1	92.8	108.8	122.6	138.2	182.9
22_3372_6	22006 (Flesk Bridge Gauge)	172.6	205.2	224.4	251.9	295.1	334.8	379.3	494.6
22_510_2	22035 (Laune Bridge Gauge)	114.2	132.1	148.9	168.4	201.8	225.5	252.4	329.4
22_4001_4+	Laune downstream	186.0	215.2	242.4	274.2	328.6	367.3	411.0	536.4
22_4003_14	22009 (White Bridge Gauge)	12.0	13.6	15.4	17.4	21.1	24.3	28.0	36.9
River Maine Catchment									
22_1587_3	22014 (Castleisland Gauge)	29.7	38.0	43.6	48.9	55.5	61.9	69.6	91.9
22_3101_1	22003 (Riverville Gauge)	144.0	181.8	210.5	242.6	292.7	338.2	392.0	558.5
22_3958_1+	Maine Downstream	203.6	257.1	297.8	343.2	414.0	478.4	554.4	790.0
Milltown Catchment									

HEP	Gauge	Flow (m <sup>3</sup> /s)							
		50%AEP	20%AEP	10%AEP	5%AEP	2%AEP	1%AEP	0.5%AEP	0.1%AEP
22_3116_4	Ashullish – Ballyoughtragh U/s Confluence	3.8	4.8	5.4	6.1	7.2	8.1	9.1	12.0
22_3958_2	Ashullish Stream Downstream	6.7	8.3	9.5	10.7	12.6	14.1	15.9	21.1
22_3425_9	Ballyoughtragh Stream Downstream	7.3	9.0	10.3	11.6	13.6	15.3	17.2	22.8
Dingle Catchment									
22_1712_2	Milltown Gauge (22022)	23.0	32.0	40.9	49.0	61.0	70.8	81.4	109.9
22_3437_1	Dingle Stream Downstream	5.1	6.5	7.4	8.4	9.9	11.2	12.7	16.9

The annual maximum flood hydrographs were standardised and compared to derive the width exceedance for specific percentage flows at gauges on the River Maine, Flesk, Deenagh, Laune and Milltown (Dingle) Rivers. The design median flood hydrograph was derived from the width exceedance analysis. The FSU WP 3.1 UPO-ERR-gamma curve was fitted to the design median flood hydrographs and the parameters applied to derive the design hydrograph shape for the ungauged HEPs.

The tidal conditions used in combination with the fluvial flows are discussed in Section 3.3.

### 3.2 Summary of Design Coastal Conditions

As part of the previous UoM22 Hydrology Report, design total tide plus surge levels and tidal hydrographs were derived at each AFA for the 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1%AEP coastal flood events. The total tide plus surge levels were extracted directly from the nearest ICPSS offshore point. The outfall of the Laune and Maine is at the upstream end of Castlemaine Harbour which is over 13km from the nearest prediction point. Furthermore, complex estuarine features such as Cromane Point modify the normal tidal levels and progression up the estuary. Therefore, the design total tide plus surge levels and tidal hydrographs were transformed from the open coast up the estuary based on the ICPSS analysis, Admiralty prediction points and observed water level at Castlemaine gauge. The resultant design levels are provided in Table 3.2.

Table 3.2: UoM22 Design Total Tide Plus Surge Levels

Location	Source	Total Tide Plus Surge Level (mODM)							
		50%AEP	20%AEP	10%AEP	5%AEP	2%AEP	1%AEP	0.5%AEP	0.1%AEP
Portmagee Harbour	ICPSS point SW16	2.15	2.25	2.32	2.38	2.46	2.52	2.59	2.73
Dingle Harbour	ICPSS point SW22	2.20	2.30	2.38	2.45	2.54	2.61	2.68	2.85
Dingle Bay at Inch Point	ICPSS point SW20	2.37	2.48	2.56	2.63	2.73	2.81	2.88	3.06
Cromane Point Castlemaine Harbour	Transformed	2.70	2.80	2.88	2.95	3.04	3.11	3.18	3.35
River Maine	Transformed to meet frequency at Castlemaine Gauge	3.00	3.11	3.19	3.26	3.35	3.42	3.49	3.66

The design astronomic tidal curve was transferred from the primary port of Cobh based on the United Kingdom Hydrographic Office Admiralty Tide Tables. The design surge profile was derived from analysis of typical surge durations along the South West coast, and scaled on top of the astronomic tide to meet the design total tide plus surge level above.

The fluvial flows used in combination with the extreme tide plus surge conditions are discussed in Section 3.4.

### 3.3 Lough Leane Analysis

The assessment for Lough Leane uses extreme value flood frequency analysis to determine design lake levels for the 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1% AEP events rather than hydraulic modelling of the lake which has a flat water level profile. Statistical flood frequency analysis was undertaken on Tomies Pier (22071) and BVM Park (22082) level gauges located on the Lough and water level profiles for extreme events assessed. The water level estimates at Tomies Pier were used as the design lough levels for the corresponding design %AEP event in Killarney (Table 3.3).

Table 3.3: UoM22 Design Lough Leane Levels

Location	Source	Design Water Level (mODM)							
		50%AEP	20%AEP	10%AEP	5%AEP	2%AEP	1%AEP	0.5%AEP	0.1%AEP
Lough Leane	Tomies Pier (22071)	19.23	19.52	19.71	19.88	20.11	20.28	20.46	20.85

### 3.4 Joint Probability

The design flows on each river reach and total tide plus surge levels provided above have been derived independently of each other. In reality, there can be various combinations to achieve a design %AEP event which can be described by the joint probability. The CFRAM study considers the following joint probabilities:

- Fluvial-fluvial – Where a range of combinations of flow on a main river combines with flow on a tributary to generate a specific %AEP flood downstream.
- Fluvial-coastal – Where an approaching depression generates a storm surge which combines with a river flood to generate a specific %AEP flood at the coast.
- Tidal- Wave – Where an approaching depression generates a storm surge which combines with extreme wave to generate a specific %AEP flood at the coast.

#### Fluvial Dominant Events

The fluvial-fluvial dependence was guided by the methodology set out in Flood Studies Update Work Package 3.4. In UoM22, the joint probability of tributaries tended to be the more frequent smaller events in order to achieve the design flow on the main watercourse. In order to simplify the modelling process, the closest design AEP to the joint probability estimate was selected. The flow was interpolated where the joint probability was half way between two design AEPs (Table 3.4).

Table 3.4: Summary of Joint Probabilities Applied for Fluvial Dominant Events

Applicable Models	Overall %AEP (Fluvially dominated event)	Design Flood Event Occurs on	Main River Inflow %AEP	Typical Tributary River Inflows %AEP	Coastal %AEP (where the downstream limit is the open coast)
Castleisland Maine Glenflesk Killarney Laune	50%AEP	Main River	50%	50%	MHWS
		Tributary River	50%	50%	MHWS
	20%AEP	Main River	20%	50%	MHWS
		Tributary River	50%	20%	MHWS
	10%AEP	Main River	10%	20%	MHWS
		Tributary River	20%	10%	MHWS
	5%AEP	Main River	5%	20%	MHWS
		Tributary River	20%	5%	MHWS
	2%AEP	Main River	2%	10%	MHWS
		Tributary River	10%	2%	MHWS
	1%AEP	Main River	1%	5%	MHWS
		Tributary River	5%	1%	MHWS
	0.5%AEP	Main River	0.50%	2%	MHWS
		Tributary River	2%	0.50%	MHWS
	0.1%AEP	Main River	0.10%	1%	MHWS
		Tributary River	1%	0.10%	MHWS

Milltown	50%	Main River and Tributary Rivers ( as tributary provides equal contribution to flow downstream)	50%	50%	MHWS
Dingle	20%		20%	20%	MHWS
	10%		10%	10%	MHWS
	5%		5%	5%	MHWS
	2%		2%	2%	MHWS
	1.00%		1.00%	1.00%	MHWS
	0.50%		0.50%	0.50%	MHWS
	0.10%		0.10%	0.10%	MHWS
Portmagee			Not at fluvial risk. Therefore not assessed.		

### Coastal Dominant Events

The extreme fluvial flow estimates at the outfall of the Maine; outfall of the Laune; and, Milltown River were assessed with the ICPSS total tide plus surge levels to derive the joint probability combinations between fluvial and coastal events based on the DEFRA FD2308\_TR1 desk-based assessment tool in accordance with GN20<sup>1</sup>. The dependence of river flow and storm surge in these estuaries tended to be “well” to “strongly” correlated due to the orientation of the bays and catchments. This resulted in ten different combinations of fluvial flows and tide plus surge levels for each design %AEP and the two critical scenarios for flood risk selected.

Previous studies (Lee CFRAM Study, River Clyde Flood Management Strategy, River Thames T2100 studies) have undertaken extensive sensitivity testing on a range of different combinations of fluvial flows and tidal levels to generate the 0.5%AEP design event, and found the following two scenarios to be critical to the flood extent at the target 0.5%AEP event:

- 1%AEP fluvial flow combined with the MHWS tide; and
- 50%AEP fluvial flow combined with 0.5%AEP tide plus surge level.

Therefore, the SW CFRAM Study has taken a similarly pragmatic approach and limited the joint probability analysis to one fluvial dominate scenario and one tidally dominant scenario for models affected by both fluvial and coastal flooding:

- Design %AEP fluvial flow combined with MHWS tide
- Design %AEP tide plus surge combined with 50% to 70%AEP fluvial flow

The joint probability between total tide plus surge levels and extreme waves has been considered separately under the ICWWS study. The resultant combinations have been assessed using wave overtopping equations and found that the highest still water level combined with smallest wave height was the critical scenario for wave overtopping at Dingle.

In order to simplify the modelling process, the closest design AEP to the joint probability estimate was selected. The flow was interpolated where the joint probability was half way between two design AEPs. The resultant joint probabilities are provided in Table 3.4 and 3.5.

<sup>1</sup> RPS(2012) CFRAM Guidance Note 20, Joint Probability Guidance.

Table 3.5: Summary of Joint Probabilities Applied for Coastal Dominant Events

Applicable Models	Overall %AEP (Coastal dominated event)	Design Flood Event Occurs on	Main River Inflow %AEP	Tributary River Inflows %AEP	Coastal %AEP (where applicable)
Maine	50%	Coast	50%	50%	50%
Laune	20%		50%	50%	20%
Dingle	10%		50%	50%	10%
	5%		50%	50%	5%
	2%		50%	50%	2%
	1.00%		50%	50%	1.00%
	0.50%		50%	50%	0.50%
	0.10%		50%	50%	0.10%
Portmagee	50%	Coast	No fluvial inflows	No fluvial inflows	50%
	20%				20%
	10%				10%
	5%				5%
	2%				2%
	1.00%				1.00%
	0.50%				0.50%
	0.10%				0.10%
Milltown	Coastal risk from the Maine assessed as part of the Maine Model. AFA itself not at coastal risk.				
Castleisland	Not at coastal risk. Therefore not assessed,				
Glenflesk					
Killarney					

### 3.5 Integration of Hydrology and Hydraulic Modelling

The design hydrological inflows summarised in Section 3.1 have been integrated with the hydraulic models as follows:

- Point inflows at the upstream model extents;
- Point inflows at key tributary inflows;
- Lateral inflows representing the inflow from the intervening areas between target HEPs.

The lateral inflows have been calculated from the difference between the design flow hydrographs from the upstream and downstream HEPs for a reach. The resultant hydrographs have been distributed evenly across those locations where the contributing area increases linearly downstream or area-weighted where the contributing area increases disproportionately downstream.

The point inflows representing the upstream model extents and tributary inflows were applied to the upper most cross-sections in the hydraulic model. The inflow for the entire catchment was simplified and lumped at the upstream ends of the models for the Dingle, Milltown, Deenagh (Killarney) and Woodford (Killarney) catchments because the intermediate catchments were relatively small.

The lateral inflows have been integrated with the relevant cross-sections at locations which fit the following criteria:

- Natural inflows from minor watercourses which are not considered explicitly within the hydrology;
- Overland flow paths identified from surveyed low points in the river bank and site walkover;
- Reconciliation adjustments of hydrological flow estimates and hydraulic models.

The model proformas provided in the Appendices detail the location of each lateral inflow.

In order to enhance the modelling outputs and ensure hydrological continuity along the larger catchments, the hydraulic models were compared to the design peak flows derived at the target HEPs to assess performance. The hydrological inflows were iteratively phased such that the modelled flows were within 10% of the design peak flows along the reach as part of the hydraulic modelling process. However, it should be noted that the design fluvial flows do not consider the following hydraulic processes:

- Backwater effect at confluences;
- Exchange of flows between tributaries at confluences; and,
- Significant modification to the hydrograph shape due to floodplain attenuation and /or hydraulic structures.

Therefore, it was not appropriate to compare modelled flows upstream of confluences to the design HEPs where there are significant out-of-bank flows. Table 3.6 details the timing adjustments made to the inflow hydrographs to achieve the design peak flows at the target HEPs for each reach.

Section 6.2 discussed the performance of the modelled flows against the design flows.

Table 3.6: Phasing of Inflows

Model	Sub-catchment	Time Shift Applied to the Tributary Inflows to Achieve the Design Peak Flows at the target HEPS (Hours)
Castleisland AFA	Maine	0.00
	Glenshearoon	0.00
Maine MPW	Tributaries to Brown Flesk	2.00
	Tributaries from Inchiveema to Groin	6.00
Milltown AFA	Ashullish	0.00
	Ballyoughtragh	0.00
Glenflesk AFA	Flesk, Loo and tributaries to Oweneskagh	0.00
Killarney AFA	Finnow	-7.00
	Flesk, Woodford and Deenagh	0.00
Laune MPW	Loe and upper tributaries	30
	Gweestin	17.5
Dingle AFA	Dingle Stream	0.00
	Milltown Stream	0.00
Portmagee AFA		Not Applicable

The tributaries to the Laune were delayed because Lough Leane significantly attenuates flows resulting in a much later peak. The Finn timer was phased 7 hours before the Flesk because the Dromickbane gauge on the Finn timer statistically peaks earlier than the River Flesk due to the storm track movement from northwest to southeast.

The design tide plus surge hydrographs discussed in Section 3.2 were used to form the downstream boundary conditions for the hydraulic models. An iterative approach was used to phase the design tide plus surge hydrographs so that the peak tide coincides with the peak flow in the AFA. This phasing is a conservative assumption of combined flood risk in line with the joint-probability analysis discussed in Section 3.3 above. Table 3.7 outlines the downstream conditions applied and time by which the tidal hydrograph was adjusted in order to meet the peak river flow.

Table 3.7: Downstream Boundary Conditions

Model	Downstream Condition	Time Adjustment to Coincide Peak Tide with Peak Flow (Hours)
Castleisland AFA	Fluvial downstream boundary set by Flow-Stage boundary	Not Applicable
Maine MPW	Full tidal boundary at the outfall in Castlemaine Harbour.	3.0
Milltown AFA	Tidal boundary set by the Maine model.	Extracted from the Maine model.
Glenflesk AFA	Fluvial downstream boundary set by Flow-Stage boundary	Not Applicable
Killarney AFA	Fluvial downstream boundary set by Lough Leane	Not Applicable



Model	Downstream Condition	Time Adjustment to Coincide Peak Tide with Peak Flow (Hours)
Laune MPW	Full tidal boundary at the outfall in Castlemaine Harbour.	22.5
Dingle AFA	Full tidal boundary along the coast.	2.5
Portmagee AFA	Full tidal boundary along the coast.	Not applicable as there is no fluvial inflows

### 3.6 Critical Storm Duration

In UoM22, the median width hydrographs have been derived at the gauged locations to establish the design storm duration at target HEPs across each catchment. The duration of the tributary inflows were based on the gauged duration. The intermediate inflows account for the difference in duration between the target HEPs within the same hydrological catchment. Table 3.8 outlines design storm durations for UoM22.

Table 3.8: Critical Storm Durations

Gauge ID	Name	Watercourse	Applicable Reach/AFA	Design Duration (Hours)
22014	Castleisland	Maine	Castleisland	13
22003	Riverville	Maine	Maine Milltown	24
22022	Milltown	Milltown (Dingle)	Dingle	11
22039	Clydagh Bridge	Clydagh	Flesk (upstream of Oweneskagh) Glenflesk	15
22006	Flesk Bridge	Flesk	Flesk (downstream of Oweneskagh) Killarney ( tributaries to the Laune)	29
22009	White Bridge	Deenagh	Killarney	23
22035	Laune Bridge	Laune	Laune	237*

\*Significantly affected by attenuation of Lough Leane. Therefore the duration at Flesk Bridge (29hrs) used to inform tributary inflows

## 4 Hydraulic Modelling Approach

### 4.1 Schematisation

Table 4.1 outlines the approach for each of the eight models which cover the six AFAs and MPW reaches downstream. Maps 4.1 to 4.3 present the areas and reaches modelled.

Table 4.1: UoM22 Model Approach

Model ID	AFA/MPW	Modelled Rivers	Approach	Length Modelled (km)	Upstream Limit(s) (Irish NGR)	Downstream Limit(s) (Irish NGR)
I33CD	Castleisland AFA	River Maine River Shanowen Glenshearoon River Anglore Stream	1D/2D ISIS/TUFLOW	10.1	101333,109073 101418,111041 101320,111975	098629,109333
I34ME	Maine MPW	River Maine Annagh Stream	1D ISIS to Currans Bridge 1D/2D ISIS/TUFLOW Currans Bridge to Castlemaine Harbour	29.5	098629,109333	077744,101293
I35MN	Milltown AFA	Ballyoughtrough Stream Ashullish Stream	1D/2D ISIS/TUFLOW	4.3	083165,100740 082695,100032	081259,101423
I36GK	Glenflesk AFA	River Flesk Clydagh River Loo River Owneyskeagh River	1D ISIS leading to 1D/2D ISIS/TUFLOW	16.7	109709,081837 106976,080040 106980,086634	103586,087657
I37KY	Killarney AFA	River Flesk River Deenagh Woodford River	1D ISIS from Old Flesk Bridge to White Bridge Killarney 1D/2D ISIS/TUFLOW from White Bridge Killarney to Lough Leane	18.1	103586,087657 099400,090607 097240,092782	096084,088014 094466,090214
I39LE	Laune MPW	River Flesk Gweestin River	1D ISIS	22.2	089869,090909	077220,099220
	Lough Leane MPW	N/A	Horizontal projection Combined with the mapping for I39LE	N/A	096084,088014 094466,090214	089869,090909
	Castlemaine Harbour MPW	N/A	Horizontal projection Combined with the mapping for I39LE	N/A	077220,099220 077744,101293	065210,095750
I40DE	Dingle AFA	Dingle Stream Milltown Stream	1D/2D ISIS/TUFLOW	4.3	045666,102210 042976,102772	044455,100745 043415,101309
I41PE	Portmagee AFA	None (Coastal)	2D TUFLOW	N/A	N/A	037275,073046

## Modelling of AFAs

A hydrodynamically linked one-dimensional (1D) and two-dimensional (2D) approach has been taken for Castleisland, Milltown, Glenflesk, Killarney and Dingle. The HPWs have been modelled in ISIS 1D modelling software (version 3.6.0) to simulate in-bank flows as it is capable of accurately calculating conveyance, attenuation and head loss at structures in narrow rivers. TUFLOW 2D modelling software version 2013-AC has been hydrodynamically linked to the ISIS model and used to simulate out-of-bank and river-floodplain interactions.

TUFLOW two-dimensional modelling software (version 2013-AC) has been used to model the floodplains in all the AFAs in order to simulate complex flow paths and variable velocities across the urban floodplains. The 2D approach is also the most appropriate to simulate coastal flooding, such as found in Portmagee, as it is able to simulate the multi-directional flow paths as the sea overtops the quayside, coastal roads and sea walls.

## Modelling of MPWs

The MPW reaches have typically been modelled using ISIS to simulate both in-bank and out-of-bank flows by extending the river sections across the floodplain. In order to improve hydrological routing and simplify modelling, the Flesk MPW upstream of Glenflesk has been modelled with Glenflesk AFA (I36GK), and the Flesk MPW downstream of Glenflesk has been modelled with Killarney AFA (I37KY).

However, extended sections are inappropriate for the Maine MPW downstream of Currans Bridge because this approach would overestimate flow across the floodplain which is disconnected from the river by the raised embankment. Therefore, the lower Maine MPW model takes a 1D/2D approach to more accurately simulate the raised channel above the floodplain, flow over the raised embankments and complex flows across the low-lying floodplain.

The assessment for Lough Leane is a special case where horizontal projection of the design lough levels have been mapped rather than full hydraulic modelling. This approach is appropriate for Lough Leane as the water level determines the extent of flooding rather than volume overtopping the banks. This approach has two key benefits over detailed hydraulic modelling:

- It provides an accurate estimate of design water levels without the need for extensive bathymetric survey of the Lough itself.
- It is based on observed gauge data rather than taking assumptions that simplify lake storage and complex lake currents.

Castlemaine Harbour downstream of the Laune and Maine outfalls is tidally-dominated. Therefore, the design water level profile for the extreme coastal events has been horizontally projected across the estuary. This approach is sufficient to generate reliable flood extents and depths required for this MPW reach.

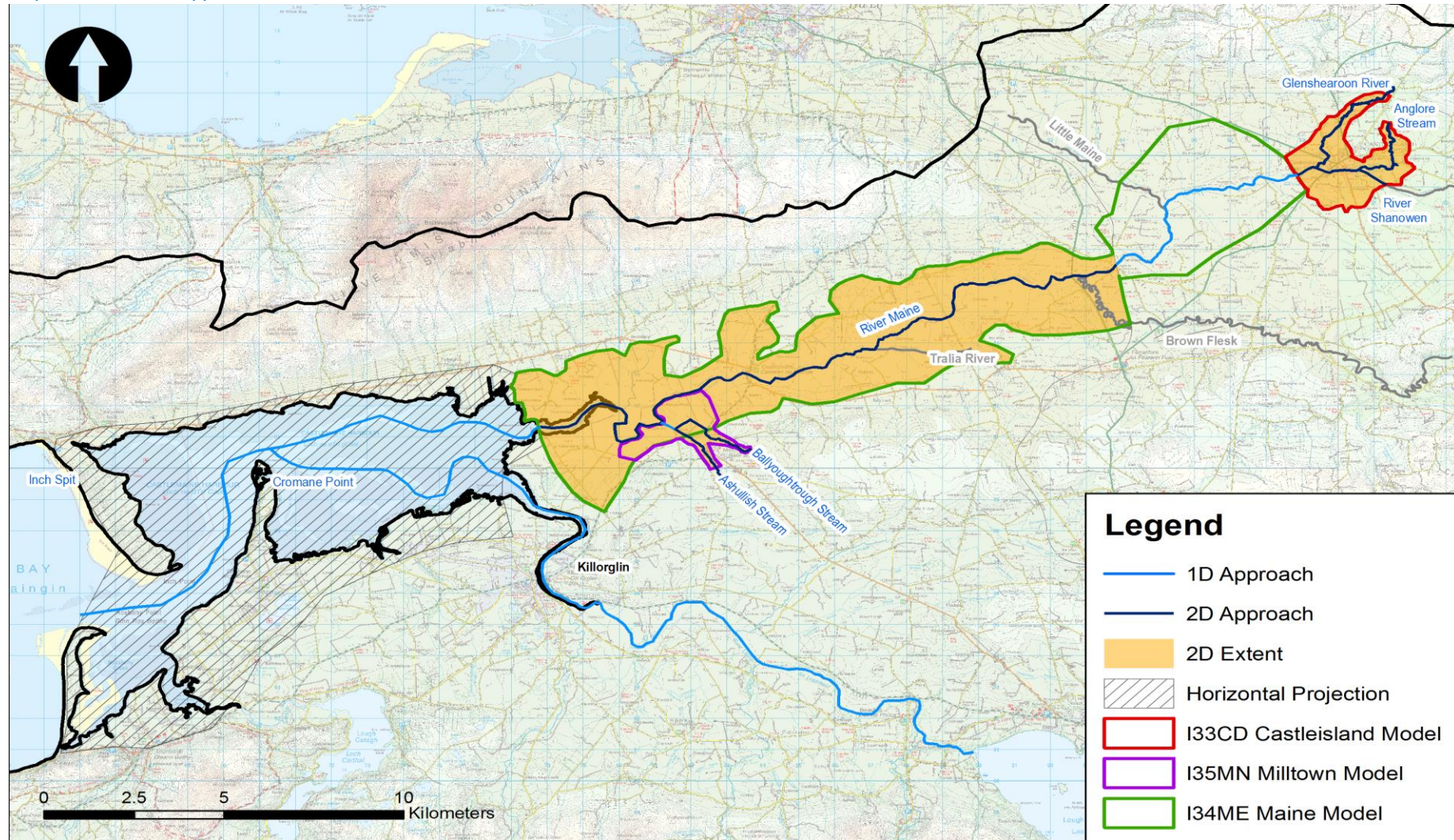
Therefore, there is no hydraulic model for Lough Leane and Castlemaine Harbour. The flood maps for these MPW reaches are included as part of the Laune flood maps (I39LE).

The River Flesk and River Maine catchments were split into several model reaches to more accurately model the upstream AFAs. The model reaches tended to be split at weirs or steep slope sections which form a hydraulic control and defined by the modelled stage-discharge relationship. This ensures that the water levels from the upstream model reach are consistent with the downstream model results

A full geoschematic of each model is provided in the appendices of this report, along with proformas detailing the model build assumptions, run parameters, model performance and flood maps.

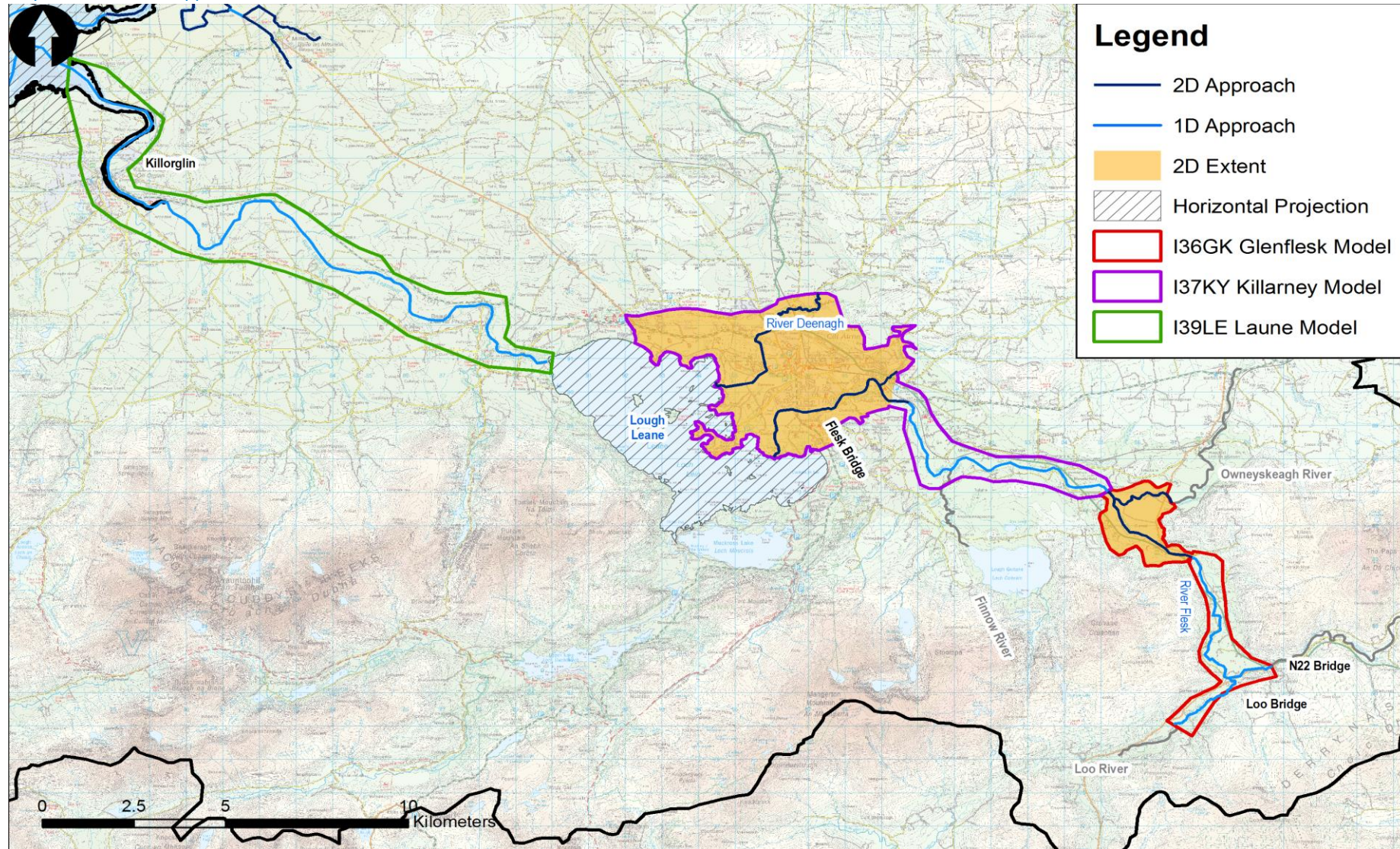


Map 4.1: Model Approach in the Maine Catchment



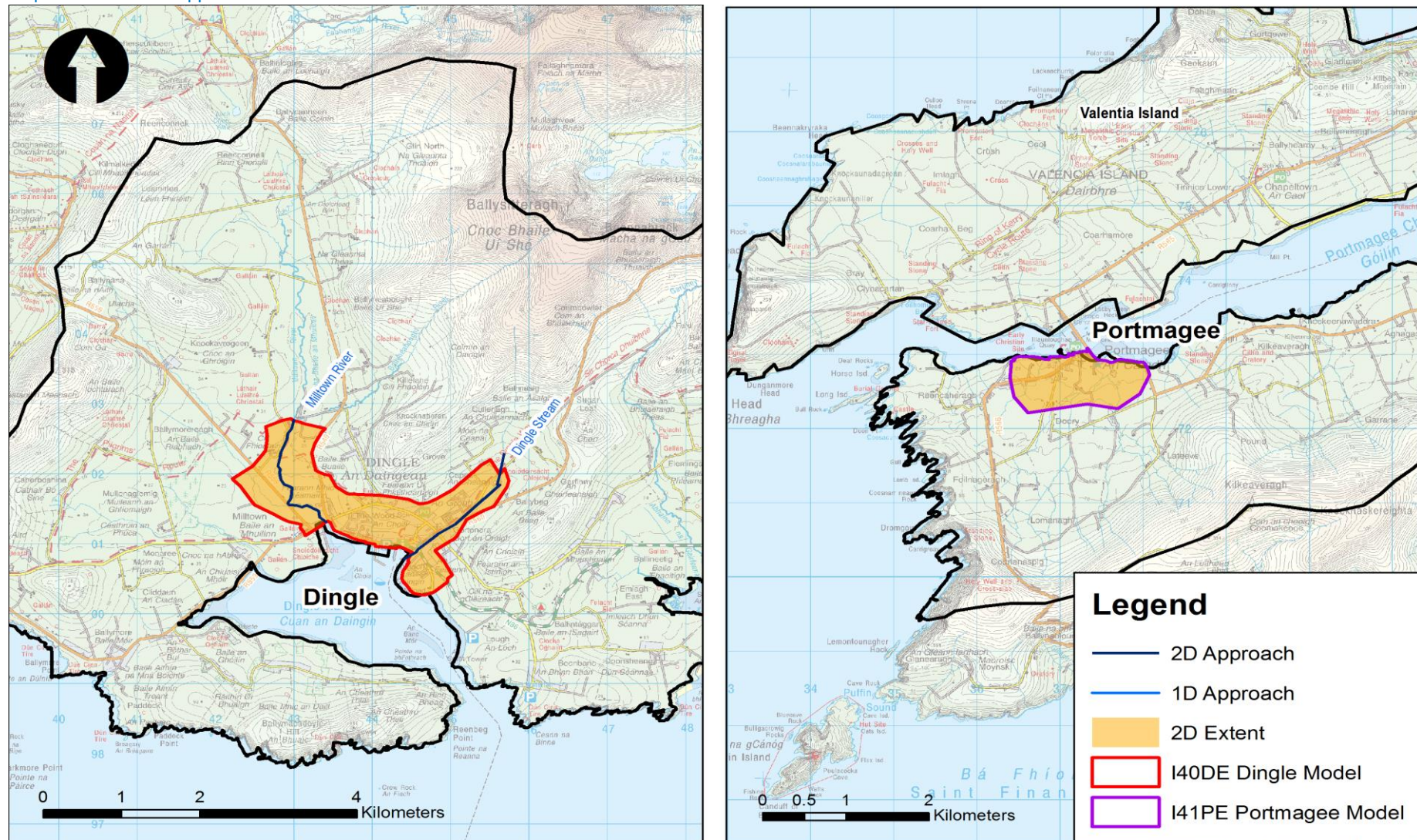


Map 4.2: Model Approach in the Laune Catchment





Map 4.3: Model Approach for Remote AFAs in UoM22



## 4.2 River Channels

The 1D model components were developed to simulate in-bank flows between the left and right river banks. The river channel survey data was used to inform the river cross-sections in ISIS and ESTRY. The raw survey data did not require correction for the majority of sections in UoM22 with the exceptions of the following:

- Correction for skew angle surveyed at Herbert's Bridge on the River Maine in Castleisland.
- Correction for skew angle surveyed at the N22 (Brewsterfield) bridge on the River Flesk.
- Open channel sections were interpolated at the rapid section upstream of the N22 road bridge on the River Flesk to maintain stability.
- Interpolate sections were added and bank levels modified along Milltown River in Dingle to stabilise the exchange of flows between the channel and floodplain round the meander bend on the Commons.

The river channel gradient, width and shape can vary rapidly on the approach and exit of bridges which is not necessarily representative of the broader open channel reach. Therefore, the surveyed sections observed 20m upstream and downstream of bridges tended to be used to inform the open channel modelled upstream and downstream of bridges because these survey sections tended to be more representative of the broader reach.

The exception are the bridges in Dingle where the survey section immediately upstream of the bridges through the town centre was deemed to be representative of the upstream gradient and channel shape due to the short distance between some of the bridge structures.

Resistance to flow from varying surface roughness across the river channel was represented by various Manning's 'n' values based on the material type and vegetation density (Table 4.2). The material types were assigned based on the survey data, photographs and site observations. The selection of the Manning's 'n' value was guided by the industry standard value ranges (Chow 1959) and subsequently adjusted during the calibration process where data was available. The selected Manning's 'n' values for each model are summarised in the model build proformas and in the model section data.



Table 4.2: Summary of Channel Manning's 'n' Values

Material Type	Selected Manning's 'n'	Applicable Reaches
Active river bed with gravel to boulders	0.045 to 0.050	River Flesk Anglore Stream
Active river bed with silts	0.040 to 0.045	River Maine
Light brush and/or grass during winter	0.060 to 0.075	Shanowen River Glenshearoon River Ashullish and Ballyoughtrough Streams Milltown and Dingle Streams White River River Flesk and Oweneskagh River Laune
Dense vegetation year round	0.080	Anglore Stream River Maine in some reaches

Source: Chow 1959

### 4.3 Structures

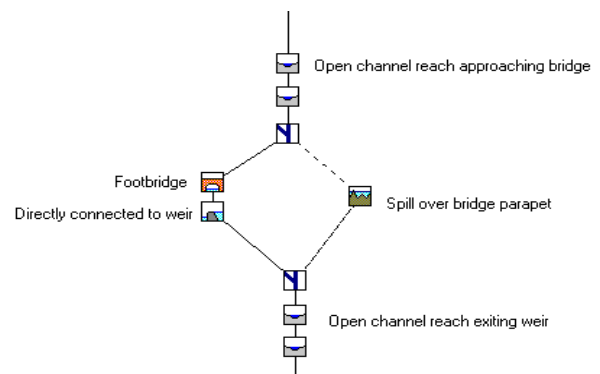
The surveyed structure dimensions were used to conceptualise bridges, culverts and weirs to simulate the hydraulic controls and flow paths that modify flood risk in the AFA. The conceptualisation sought to reduce complex structures to the simplest schematisation that accurately represented the hydraulic mechanisms at the target flows whilst maintaining model stability and robustness.

For example, many bridges in the South West Region have a plinth extending a short distance from the downstream face which causes a hydraulic jump similar to a weir at low flows (Figure 4.1a). The short open channel reach between the bridge and the weir is likely to cause instability at high flows as the reach is so much shorter than the other reaches in the 1D model and connection to the 2D model may cause recirculation of water. Therefore, the model is simplified to the configuration in Figure 4.1b which maintains the weir as the level control at low flows but avoids instabilities at high flow.

Figure 4.1: Simplification of Kanturk Footbridge and Weir



A: Kanturk Footbridge with Weir 2m downstream



B: Simplified Model Configuration

The simplification of structures in UoM22 is discussed in the following sections. There were no operable structures within the UoM22 AFAs. Full details of the hydraulic parameters and justification of structure specific assumptions can be found in Schedule 2 of the Model Build Proformas in the relevant appendices.

## Bridges

Bridges were modelled in three ways in UoM22:

- Using the USBPR approach where the bridge was a flat soffit highways bridge and the afflux was largely controlled by the flow around the piers and a spill over the deck to consider high flow routes.
- Using the HR Wallingford arched bridge approach where the bridge was arched and the afflux was largely controlled by the flow under the arch above springing point and a spill over the deck to consider high flow routes.
- Using a Bernoulli head loss unit based on the calculated head loss with the effects of piers, skew, eccentricity and other hydraulic losses. The loss coefficients (K values) were derived using the industry standard Hydraulics of Bridge Waterways<sup>2</sup>.

The first two approaches were applied most widely in UoM22. However, the Bernoulli Loss approach was applied to several bridges through Dingle to improve stability when transitioning between open channel flow, bridge flow and orifice flow in this steep catchment. Orifice units were used to represent other bridges in Dingle where the opening was relatively small compared with the channel area and the bridge was in orifice flow in the 50%AEP event.

Photo 4.1: Barrack Lane Bridge, Castleisland



Captured: 14 Sept 2012

In UoM22, there are a number of bridges with utilities crossing immediately upstream or under the bridge structure, obstructing the bridge flow and increasing head loss before the soffit was reached (Photo 4.1). The modelled soffit elevation was lowered to the pipe soffit level where the pipe was deemed to be a significant obstruction and bridge coefficient adjusted to 1.5, assuming inefficient turbulent flow above this level. This is a conservative estimate of head loss for flood mapping purposes.

## Culverts

Culverts were modelled in ISIS using; i) a culvert inlet to simulate losses associated with the constriction of flow at the entrance ii) an appropriate sized and shaped conduit unit and iii) a culvert outlet to simulate losses associated with the expansion of flow at the exit, or a weir unit to simulate the bed drop for culverts out-falling above the downstream river water level.

<sup>2</sup> US ACE (1978) Hydraulics of Bridge Waterways

Losses associated with trash screens have been considered as part of the inlet coefficients for both ISIS and ESTRY models. The trash screens have been assumed to be clear in accordance with the design scenario defined by OPW. However there are no trash screens in the modelled reaches for UoM22. Blockage of such structures will be considered separately as part of the option development process.

### Weirs

Formal weir structures, such as those found at Flesk Bridge in Killarney at Castleisland gauge, have been modelled using formal round-nosed weir equations. Other informal weirs/natural bed drops over steep gradients, such as the rapid sections on the Flesk and Dingle Stream, have been modelled using online spill approaches. In both cases, the river sections have been extracted 20m upstream and downstream of the weir structure based on the surveyed weir long profile to adjust the bed levels and better represent the upstream and downstream open channel reaches. The surveyed weir crest was then used to inform the width and elevation in the formal round-nose weir structures and the spill elevations for informal structures. This approach ensures the weir or spill crest forms the hydraulic control and the localised scour pool effects are removed. Where the defined weir crest is narrower than the river channel width, online spills have been used to represent flow over the banks with calibrated coefficients to simulate the effects of bank vegetation.

## 4.4 Floodplain

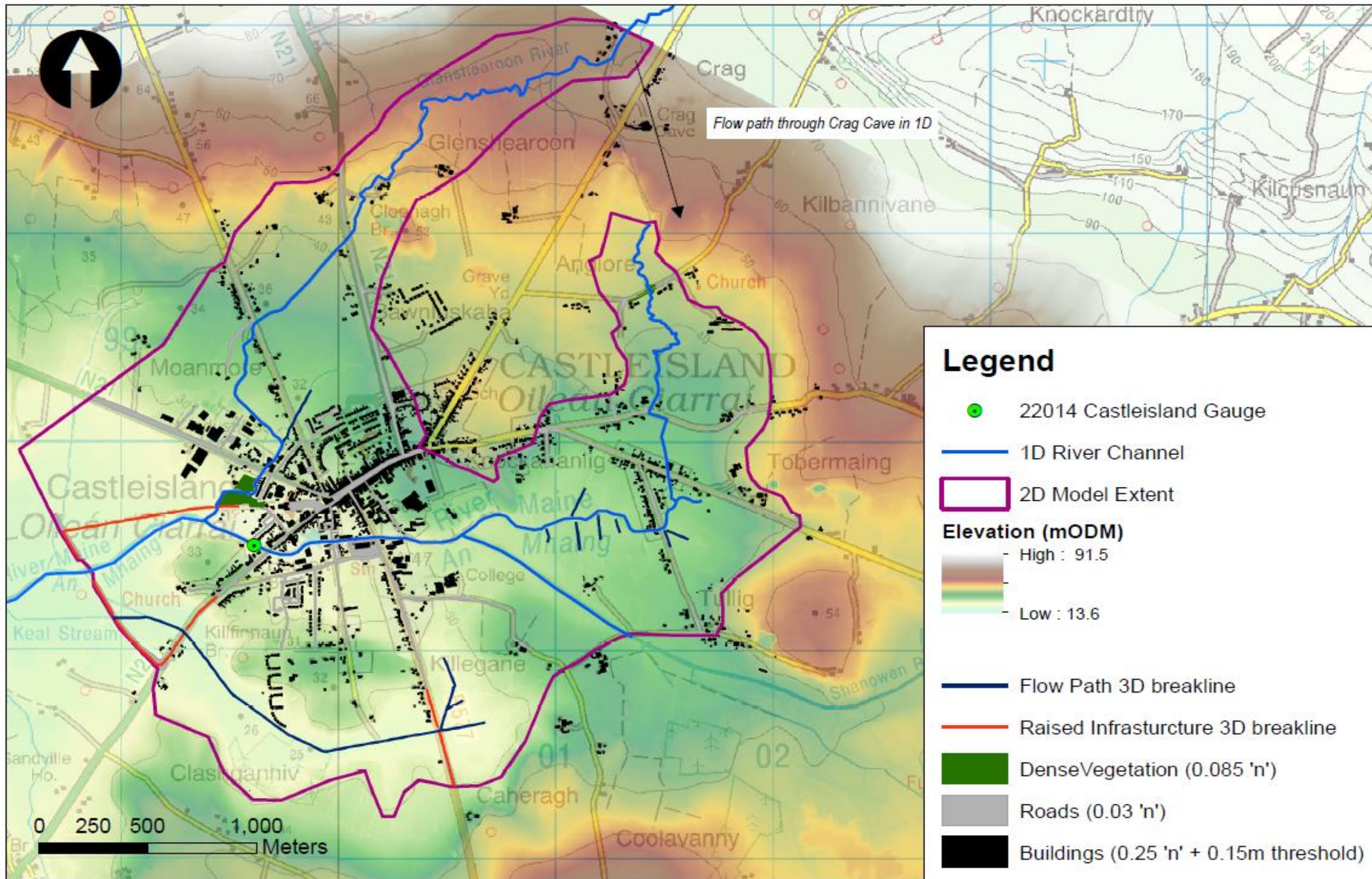
The floodplain in all the AFAs was represented by a regular 5m grid orientated to be perpendicular to the dominant flow path. A 5m grid cell size was selected to optimise the run time whilst adequately representing the complex urban nature of these AFAs. Map 4.4 presents an example for Castleisland.

### Floodplain Topography

The 2D topography was extracted from the LiDAR DTMs. The 5m grid resolution limits the representation of small and thin urban features. Therefore, key floodplain features that would modify flow paths have been explicitly represented in the 2D domain. This includes raised barriers to flow, such as road and rail embankments, as well as flow routes such as drainage ditches and archways through buildings. The elevations for these features have been extracted from the LiDAR data and enforced in the 2D domain using the “Z-line” option. Thin features, such as fences and garden walls, have not been considered, as they cannot be guaranteed to retain water during a flood event where they are not designed as flood defences.



Map 4.4: Example Geoschematic of the Castleisland Hydraulic Model





## Urban Features

Buildings within the floodplain were represented as footprints with a threshold level of 150mm above ground level extracted from the DTM. The threshold of 150mm was selected as typical from threshold surveys and survey photographs. The buildings were assigned a Manning's 'n' value of 0.20 to simulate the storage and reduction in velocity through the buildings once water was above the threshold value of 0.15m. A value of 0.2 has been selected as the upper limit of industry standard values for floodplains.

Syme (2008)<sup>3</sup> tested different methodologies of representing buildings including blocking out, Manning's 'n' and cell blockage approaches. Syme found the increase in water levels due to the different representation of buildings were all within 0.04m of each other with a standard deviation of 0.03m (Table 3.2 Syme 2008).

The blocked out methodology presents a more "visually correct" representation of flow paths around the building but does not simulate the effects of storage within the building and does not produce a representative flood level. Therefore, the Manning's 'n' approach combined with the building threshold approach has been selected to represent the impact of building whilst providing a representative flood level for subsequent damage calculations. This approach assumes water is able to flow through the buildings which might otherwise be diverted if the building was made watertight, such as from the use of sandbags or individual property protection measures. The use of individual protection property measures, such as sandbags, has been considered when comparing model results with historic flood extents.

The roads in UoM22 are typically 6 to 16 m wide, and are neither significantly raised above nor sunken below the floodplain. Therefore, the model grid topography was deemed to represent the flow paths of the roads without further modification to the model topography. Instead, a lower Manning's 'n' of 0.03 was used to represent the relatively lower resistance to flow of the tarmac. This approach enforces the roads as flow paths across the floodplain to better model flood progression. Where the road is raised above the floodplain such as the N71 at Castleisland and N22 at Glenflesk, the road crest has been enforced in the 2D model domain based on LIDAR elevations and a lower Manning's 'n' applied as above.

## Land Cover

The floodplain was classified into broad land use types from the survey information, photographs of the river banks, site observations and OSi mapping. The European Environment Agency CORINE land cover dataset was not used because the data is based on satellite imagery which is relatively coarse and does not differentiate buildings from surrounding roads and gardens within urban areas.

Each land classification from the OSI mapping was then assigned an appropriate Manning's 'n' roughness value based on the type and density of the vegetation, guided by industry standard value ranges (Chow 1959). Small urban features, such as fences and walls, have not been considered explicitly as they are not designed to retain water during a flood event. However, the overall impact of these features has been

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<sup>3</sup> Syme (2008) Flooding in Urban Areas - 2D Modelling Approaches for Buildings and Fences. Engineers Australia, 9th National Conference on Hydraulics in Water Engineering. Darwin Convention Centre, Australia 23-26 September 2008

incorporated into the selection of the upper range of recommended floodplain Manning's 'n'. Table 4.3 summarises the design values selected. Sensitivity tests on Manning's 'n' values are discussed in Section 5.2.3.

**Table 4.3: Floodplain Roughness Values**

Surface	Manning's 'n' Roughness Value
Standing water	0.040
River Banks - Dense Vegetation	0.080 to 0.100
Buildings	0.200
Roads and Hard Standing	0.030
Pasture, Parklands and Gardens	0.060

#### 4.5 Model Run Parameters

The design models were run for the full inflow hydrograph duration to consider attenuation and the recession of any flooding in each AFA.

Initial river flow and level conditions were derived at every river section along the entire modelled reach for the 1D model components to match the start of the hydrograph for the current scenario, as well as the mid-range and high-end future scenarios. The minimum flows used to derive the initial conditions and lower limit of model stability are stated for each model reach in the model proformas included in the Appendices.

The initial coastal conditions were set to start at low water and below the floodplain level in both 1D Laune model, the 1D/2D Maine and Dingle models and the 2D only Portmagee model to dry conditions on the floodplain and stability of the models.

A 1D timestep interval of one second was applied to all the UoM22 models to ensure stability along the steep tributaries and to be divisible into the 2D timestep. A 2D timestep of two seconds was applied to all models to be divisible by the 1D timestep and within the recommended a half to a quarter of the 2D cell size.

All other run parameters were set to default both in ISIS and TUFLOW. The river sections were extended in the 1D only reaches to avoid "glass-walling" of water above the limit of the cross-section. Hence the height added to the maximum section elevation (Dflood) was set to the default value of 3m.

## 5 Calibration and Sensitivity Analysis

### 5.1 Calibration

Table 5.1 outlines the historic flood events selected for the calibration of the hydraulic models during the hydrological analysis. The selection of historic events was based on scoring the flow estimates, observed data and reliable flood history as set out in Guidance Note 23<sup>4</sup>.

Table 5.1: Selection of Calibration Events

Event	Model	Source of Flooding	Likely Accuracy of Flow Estimate <sup>1</sup>	Likely Accuracy of Gauged Level Estimate	Known Hydraulic Conditions <sup>2</sup>	Likely Accuracy of Spot Levels <sup>3</sup>	Reliable Flood History <sup>4</sup>	Indicative Calibration Score	Calibration Approach
02/11/1980	Killarney	Fluvial	3	3	2	0	1	9	Largest flood on record at Flesk Bridge. Calibrate main channel to large event data. Smaller tributaries such as Woodford River should take note of uncertainties due to blockage.
04/10/2008	Castle-island	Fluvial	3	3	2	0	2	10	Calibrate main channel to large event data. Flows along Anglore stream should take note of uncertainties with % of Glanshearoon flow through the Crag Cave complex.
19/11/2009	Killarney	Fluvial	3	3	2	0	2	10	Calibrate main channel to large event data. Smaller tributaries such as Woodford River should take note of uncertainties due to blockage.

Note 1: 3 = gauged flows are available in the catchment, 2 = gauged flows used from pivotal gauges nearby, 1 = rainfall data used to estimate flows using rainfall-runoff methodology and 0 = no flow estimate available

Note 2: Hydraulic conditions relate to controls on water levels during a flood e.g. level of blockage, wall collapse etc.

Note 3: Levels during a known flood event NOT at a gauged location that represents a true flood level rather than a localised issue.

Note 4: Any information that includes date/time, precise location and mechanism of flooding

In the absence of detailed historic flood evidence, there are a number of in-bank events which can be calibrated along the Maine and Laune catchments based on the gauged data only. These include:

- 12<sup>th</sup> January 2010 – River Maine Catchment
- 1<sup>st</sup> February 2002 – River Maine Catchment
- 4<sup>th</sup> January 2008 – River Maine Catchment
- 26<sup>th</sup> October 2008 – River Laune Catchment

<sup>4</sup> Jacobs, (January 2013) Guidance Note 23 Model Calibration. Version 1.

Reports of recurring flooding and information from local engineers were also used to verify the modelled outlines such that there is “reasonable” representation of the historical flood frequency in Milltown, Glenflesk, Laune and Dingle models.

It was not practical to calibrate the Laune model as there was no flood extent or level for specific events beyond the gauge at the upstream limit to calibrate the hydraulic parameters. Additionally, there were no reports of flooding in Portmagee or gauge data to enable model calibration for this AFA.

Sensitivity analysis has been used to further assess hydraulic parameters where there was insufficient data to fully calibrate the hydraulic model, discussed in Section 5.2.



### 5.1.1 2<sup>nd</sup> November 1980 Killarney

The November 1980 event was the largest flow on record at Flesk Bridge. The River Flesk levels spilled out-of-bank to flood Killarney National Park as well as fields and recreational grounds adjacent to the river in Killarney. The River Deenagh was also reported as flooding but no precise locations were provided.

The quality of the historic flood data has been reviewed based on the local engineers' comment for the 3<sup>rd</sup> November 1980 event:

- Photographs
  - Photographs were available however it was difficult to reconcile the recorded location with the view shown in the photograph due to development since 1980 along Kenmare Road.
  - Therefore the description from the local engineer has been used to validate the flood extent.
- Levels and flows
  - Peak water levels were recorded at the Flesk Bridge gauge and are deemed to be reliable. However the floodplain flows may be underestimated based as the rating is based on in-bank gaugings.
  - Gauge records at White Bridge were not available from this period.
- Extent
  - No flood outline was produced as part of the report.
  - Areas flooded are based on the description contained within the local engineer's report.

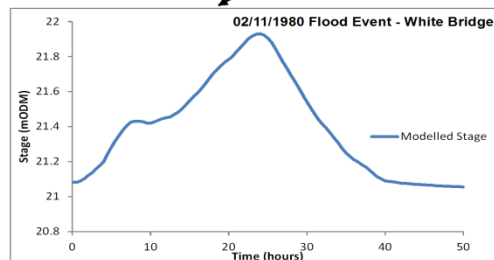
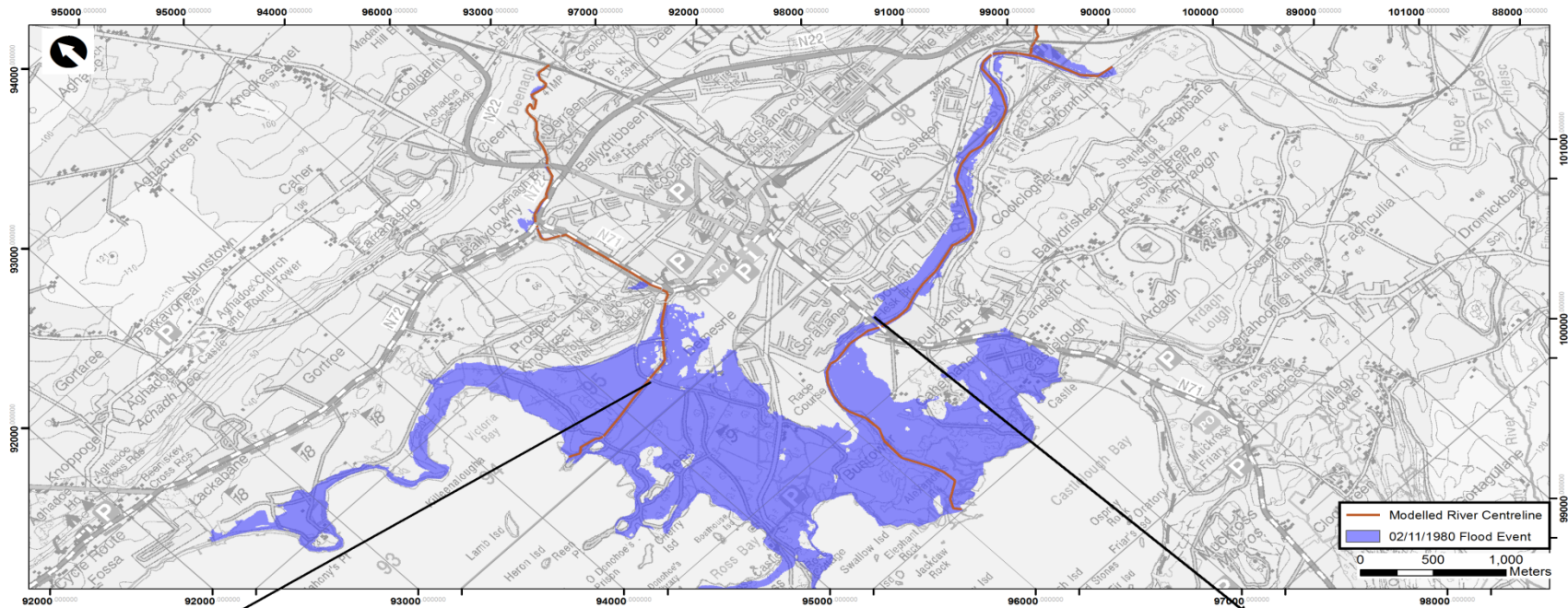
The design hydraulic model was modified as follows to represent the hydrological and hydraulic conditions of this event:

- The rainfall profile was transferred from Valentia Observatory, and hydrographs produced using the FSSR16 rainfall-runoff approach with percentage runoff increased to over 90% to meet the observed flows at Flesk Bridge.
- This corresponds with saturated conditions in the Met Eireann records.
- The downstream water level in Lough Leane was set based on the design gradient, because level records on the Lough were not available for this event.
- No other topographic conditions were changed to reflect the 1980 event.

The Manning's 'n' values were adjusted from 0.040 to 0.045 in order to best match the flood levels and extents in Killarney. The weir coefficients, spill coefficients and Bernoulli Loss at White Bridge were also iteratively adjusted to the values quoted in the appendices in order to replicate the mechanisms of flooding reported.

Map 5.1 compares the resultant model flood extent and levels with the recorded information at the gauges. White Bridge was not operational in 1980, therefore the Deenagh was not calibrated for this event. The FSSR hydrograph was calibrated by adjusting the percentage runoff and phasing as part of the previous hydrology report. This achieved a flow hydrograph within +7% of the peak flow at Flesk Bridge gauge. The flood level is 0.17m lower than observed principally because the rating curve at Flesk Bridge is based on in-bank gaugings. Extrapolation of this rating curve can lead to underestimation of floodplain flows and therefore the discrepancy in level. However, the flood level is still within the required accuracy of 0.2m for HPWs.

Map 5.1: Calibration of Killarney Model to 2<sup>nd</sup> November 1980 Event

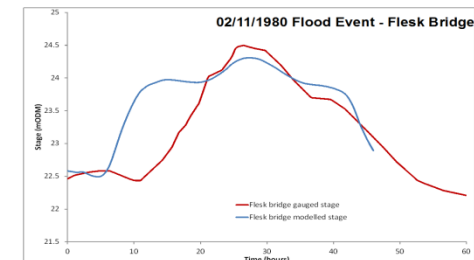


	Gauged Peak Flow	Modelled Peak Flow	Gauged Peak Stage	Modelled Peak Stage
02/11/1980 event	no gauge data	15.89	no gauge data	21.93

White Bridge 22006



Unidentified location - 1980 Flood Extent



	Gauged Peak Flow	Modelled Peak Flow	Gauged Peak Stage	Modelled Peak Stage
02/11/1980 event	255.8	275.15	24.49	24.31

Flesk Bridge 22006

### 5.1.2 4<sup>th</sup> October 2008 Castleisland

Initially, river levels in the Glenshearoon River overtopped the left bank on 4<sup>th</sup> October 2008 whereupon the flood water entered the Crag Cave complex to flood areas downstream on the Anglore Stream. Several properties were flooded along Anglore Stream at Cordal Road. An additional commercial property was also affected by the flooding.

The quality of the historic flood data from the post flood report <sup>5</sup> has been reviewed:

- Photographs
  - The photographs were taken of the Glenshearoon spilling out of bank, but were not available at flooded property locations.
- Flood Levels
  - Water levels were recorded at the Castleisland gauge on the River Maine in the AFA and are deemed to be reliable.
  - Depth of flooding at the affected properties was not recorded at the time, so levels on the floodplain could not be calibrated.
- Extent
  - No flood outline was produced as part of the report.
  - Areas flooded are based on the annotated points on the flood report map and description contained within.

The design hydraulic model was modified as follows to represent the hydrological and hydraulic conditions of this event:

- The rainfall profile was transferred from Valentia Observatory and hydrographs produced using the FSSR16 rainfall-runoff approach with percentage runoff increased to 60% to meet the observed flows at Castleisland gauge. These calibrated rainfall-runoff parameters were then transferred to the model inflows.
- The design downstream QH relationship was retained for this event.
- No other hydraulic modifications were made.

Map 5.2 compares the resultant model extent and levels with the recorded information. The model was calibrated by adjusting Manning's 'n' to 0.048 and the spill coefficient of the spill at the swallow hole to 1.0 in order to reproduce the recorded flow route through Crag Cave and extent of flooding on the Anglore Stream. The resultant flood extent matches well with the reported flooding at Glebe House Road and the property flooding at Tullig as the excess flows cause the Anglore to exceed the capacity of Glebe House Bridge and the Tullig culvert.

The modelled water level at the gauge was 0.05m higher than recorded however it is within the CFRAM framework calibration tolerance of +/- 0.1m and reproduces the duration reasonably, given that the hydrological calibration underestimated duration on the falling limb.

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<sup>5</sup> Kerry County Council (2008) Flooding at Tullig, Castleisland Co. Kerry on 04<sup>th</sup> October 2008.



Map 5.2: Calibration of the Castleisland Model for 04 October 2008 Event

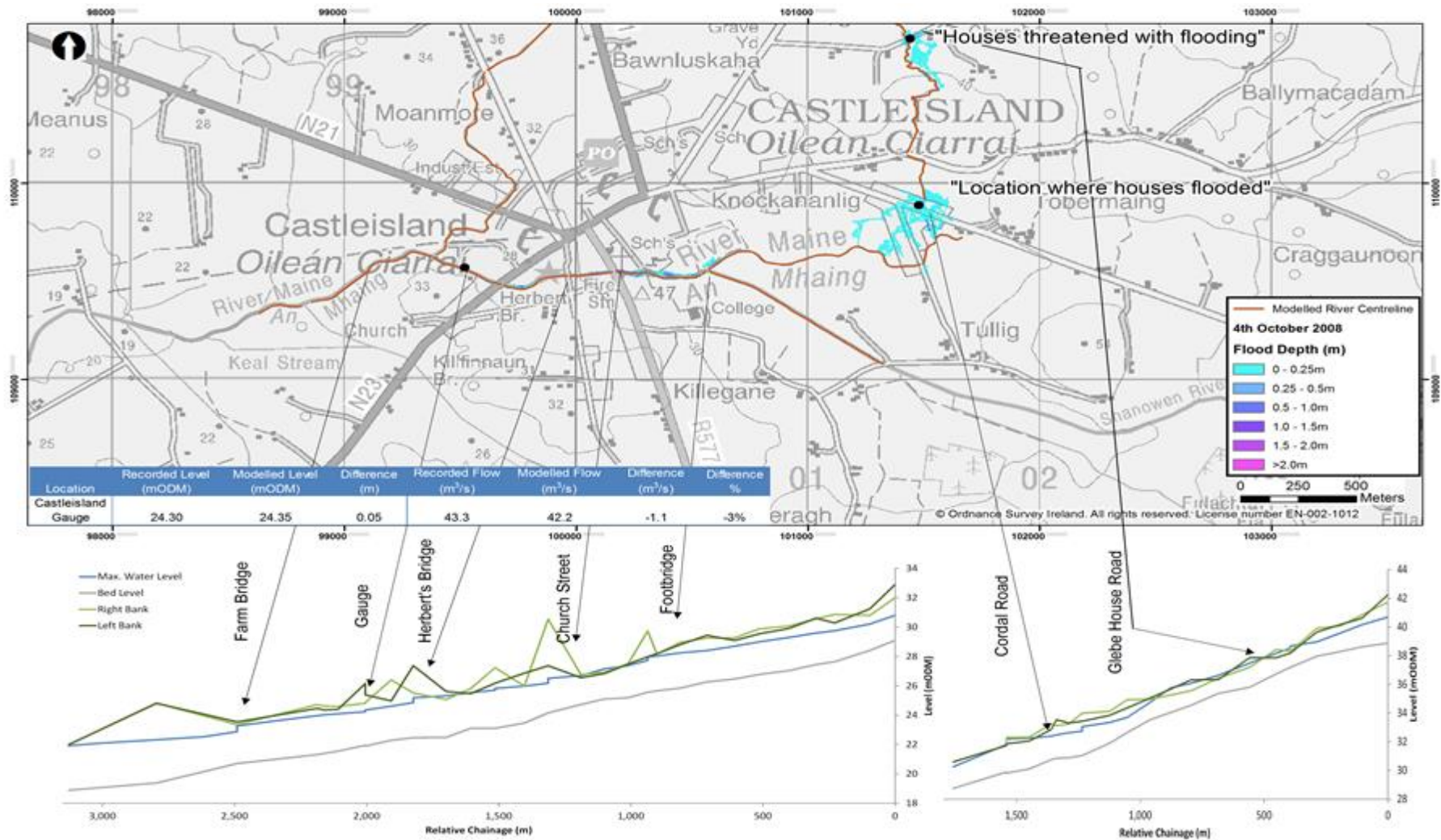




Figure 5.1: Performance of Flow at Castleisland Gauge

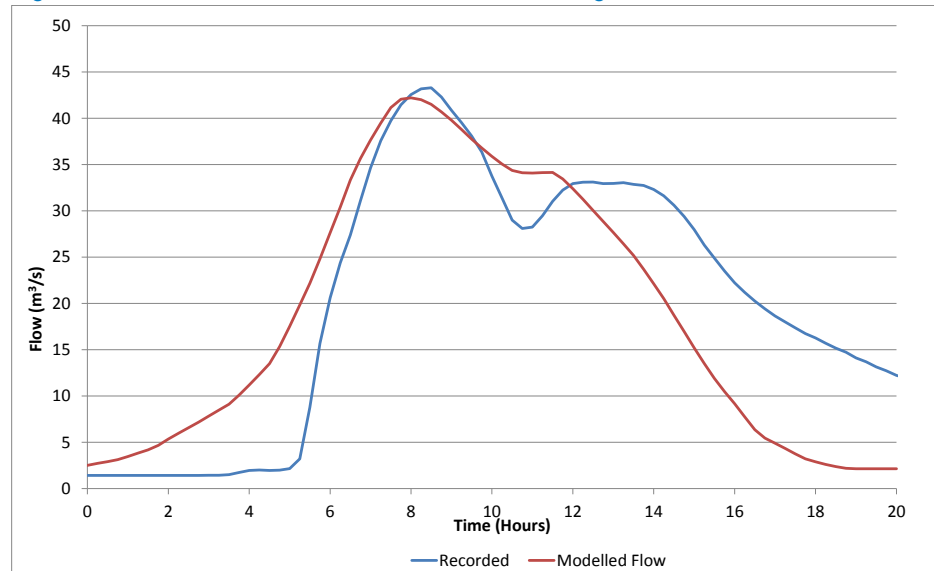
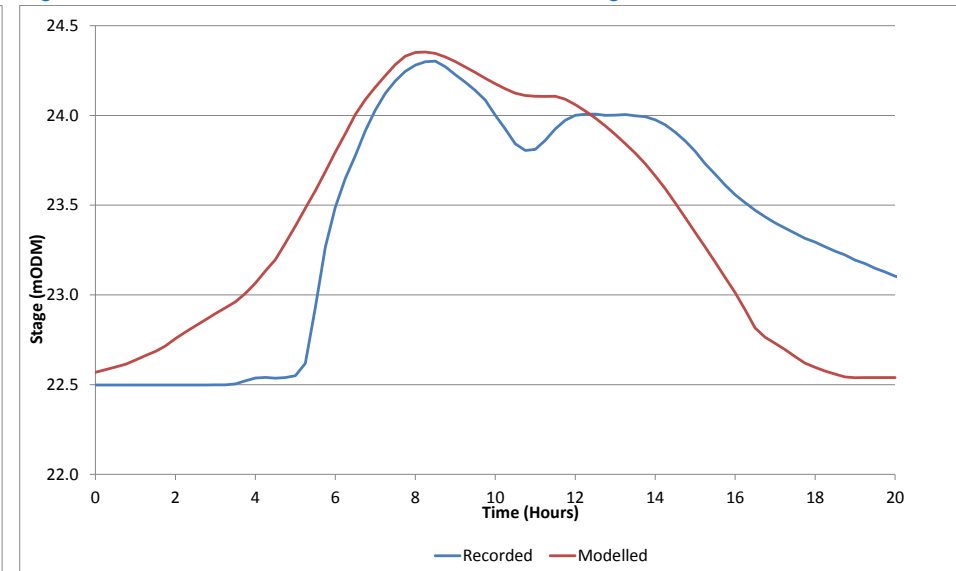


Figure 5.2: Performance of Level at Castleisland Gauge



### 5.1.3 19<sup>th</sup> November 2009, Killarney

Lough Leane levels were already high prior to the event due to prolonged rainfall over the preceding month and saturated catchment conditions. The intense rainfall on the 19th November 2011 further raised levels which caused significant flooding to the Killarney National Park area, parts of the N70 and the local road network. The tourist area around Muckross and the Lake Hotel were extensively flooded. This was the first recorded flooding of the Lake Hotel in the past 190 years.

The quality of the historic flood data has been reviewed from Kerry County Council and correspondence with the Lake Hotel staff:

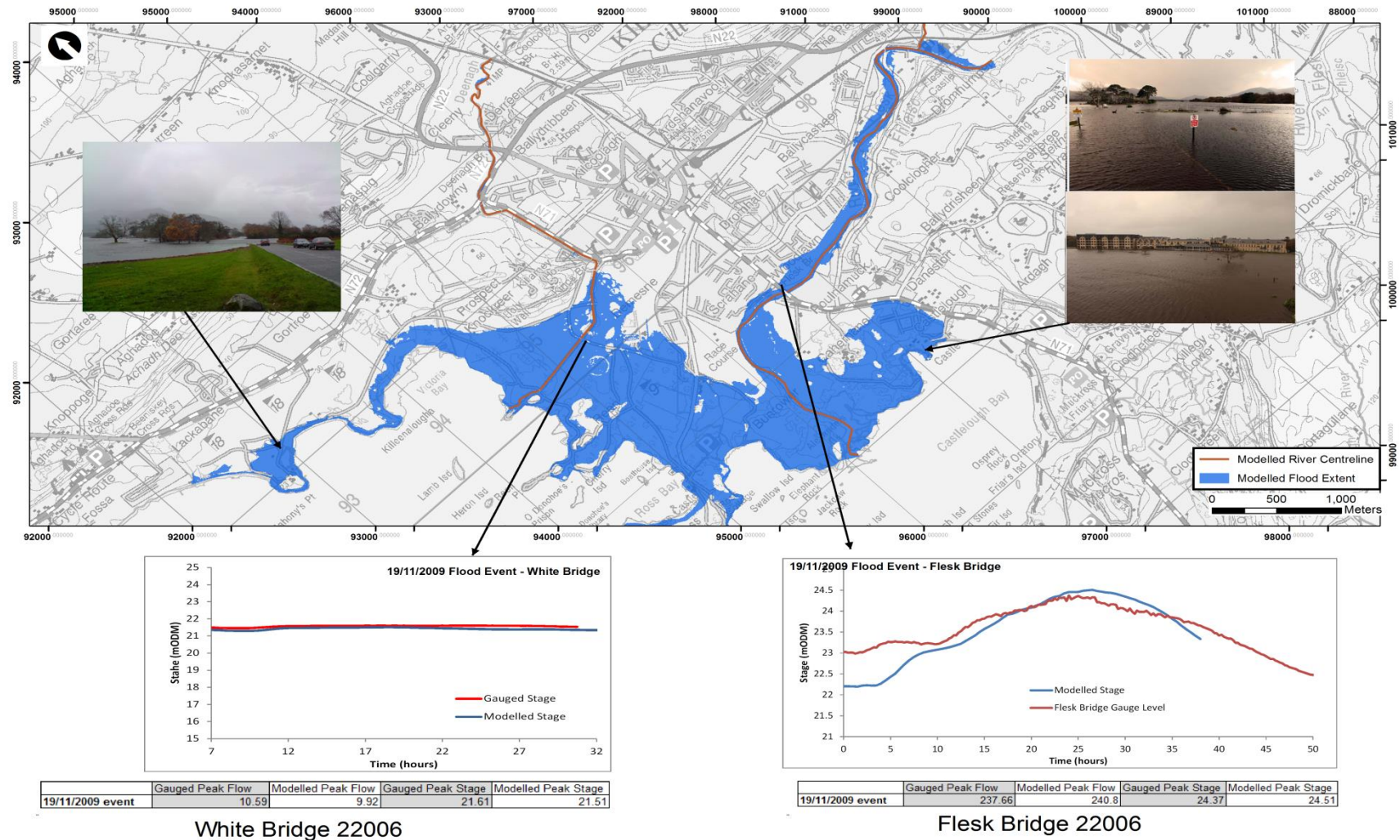
- Photographs
  - The photographs have been collected from Kerry County Council and the Lake Hotel staff.
  - The photographs are taken on 19<sup>th</sup> November 2009 during the flood, but the time is not known.
  - Therefore these photographs are deemed representative of locations flooded but do not necessarily represent the peak.
- Flood Levels and Depths
  - Flood level was recorded at Flesk Bridge and White Bridge gauges.
  - Depth of flooding was not recorded, however anecdotal reports during the flood risk review suggest flooding at the Lake Hotel was over 0.5m deep.
- Extent
  - No recorded extent was available,
  - The areas flooded have been verified by the photos and correspondence with the Lake Hotel (annotations provided on the following map).

The design hydraulic model for Killarney was modified as follows to represent the hydrological and hydraulic conditions of this event:

- The rainfall profile was transferred from Valentia Observatory and hydrographs produced using the FSSR16 rainfall-runoff approach with percentage runoff increased to 58% to meet the observed flows at Flesk Bridge.
- The downstream water level in Lough Leane was set based on level gauge records at Tomies Pier.
- No other topographic conditions were changed to reflect the 2009 event.

The hydraulic parameters were adjusted to best match the flood levels and extents in Killarney including Manning's 'n' values as discussed in Section 5.1.1. Map 5.2 compares the resultant model extent and levels with the recorded information. The calibrated model results match well with the recorded flooding at the lakeside hotels and extensive flooding of Killarney National Park. The gauge flow was within 1% of the peak flow and 0.1m of the peak level at Flesk Bridge. The peak flow at White Bridge was 7% greater because the rating does not account for bypass flow once out of bank. However the level was within 0.1m. Therefore the model is deemed to provide a reasonable representation of the November 2009 event.

Map 5.3: Calibration of the Killarney Model for 19<sup>th</sup> November 2009





#### 5.1.4 In Bank Calibration

In-bank calibration was undertaken on the River Maine for two additional fluvial events where there was data available at multiple gauges:

- 4<sup>th</sup> January 2008: Data available at Castleisland gauge and Riverville gauge
- 12<sup>th</sup> January 2010: Data available at Riverville gauge and Castlemaine (tidal) gauge

For the 4<sup>th</sup> January 2008 event the Castleisland gauged hydrograph formed the inflow to the Maine and the hydraulic model calibrated to achieve the gauged hydrograph at the Riverville gauge.

For the 12<sup>th</sup> January 2010 event, the observed rainfall at Valentia was transferred to Riverville gauge to form the input to the rainfall-runoff hydrograph. The rainfall-runoff hydrograph was calibrated to the gauged flow by adjusting percentage runoff to 30%. The observed rainfall at Valentia was then transferred to the various HEPs based on the daily rainfall gauge totals and the flood hydrograph derived using the FSSR rainfall runoff approach with the calibrated 30% runoff.

The astronomic predicted tide was derived for Castlemaine Harbour and applied directly to the downstream of the Maine model for all scenarios. The surge residual at Castletown Bearhaven was less than 0.1m in all events therefore surge was not considered.

The model was calibrated by adjusting the Manning's 'n' in-bank and the weir coefficients at Riverville gauge to reproduce the water level and flow at Riverville gauge and the level at the tidally influenced Castlemaine gauge. Figures 5.3 and 5.4 summarise the performance at the Riverville gauge for this event. The hydrological routing of flow was within 1% and the hydraulic model was within 0.02m of the peak at Riverville. The 15 minute level record for Castlemaine was not readily available for this event.

In-bank calibration was also undertaken on the River Maine catchment for the 4<sup>th</sup> October 2008 where there was concurrent gauge information available at Castleisland, Riverville and Castlemaine. The astronomic predicted tide was derived for Castlemaine Harbour and applied directly to the downstream of the Laune model. The surge residual at the nearby Castletown Bearhaven tidal gauge was less than 0.1m in all events therefore surge was not considered.

The model was calibrated by adjusting the Manning's 'n' in-bank and the weir coefficients at the rapid sections to reproduce the water level gauge and the level at the tidally influence Castlemaine gauge. Figures 5.5 to 5.7 summarise the performance at the gauge locations for the 4<sup>th</sup> October 2008 event. The hydrological routing of flow was within 1% at Riverville and the hydraulic model was within 0.01m of the peak level at Riverville and 0.03m of peak level at Castlemaine.

Therefore, the in-bank model of the Maine is deemed representative of the gauge data for fluvial flood events.

Figure 5.3: Calibration of Flow at Riverville – 4<sup>th</sup> October 2008

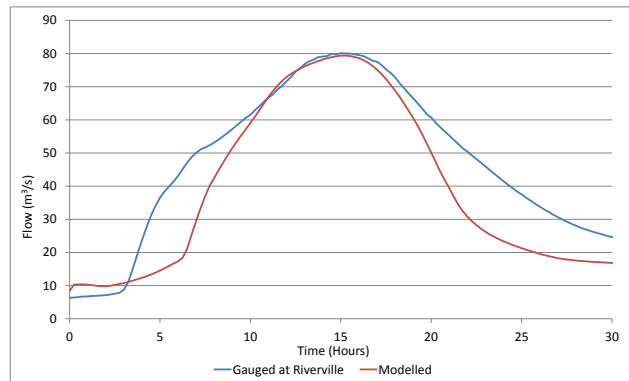


Figure 5.4: Calibration of Level at Riverville – 4<sup>th</sup> October 2008

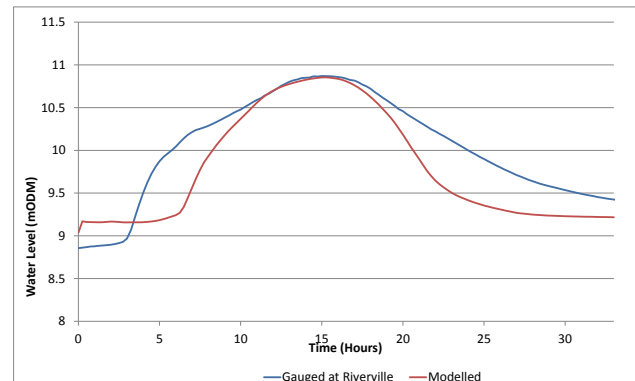


Figure 5.5: Calibration of Flow at Riverville – 12<sup>th</sup> January 2010

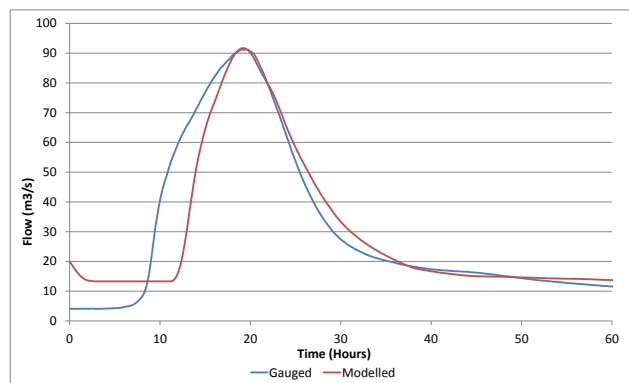


Figure 5.6: Calibration of Level at Riverville – 12<sup>th</sup> January 2010

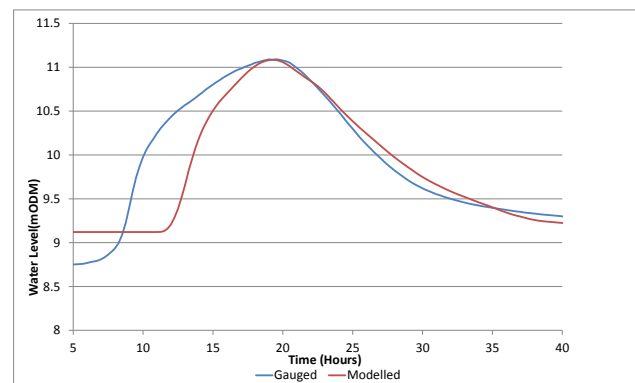
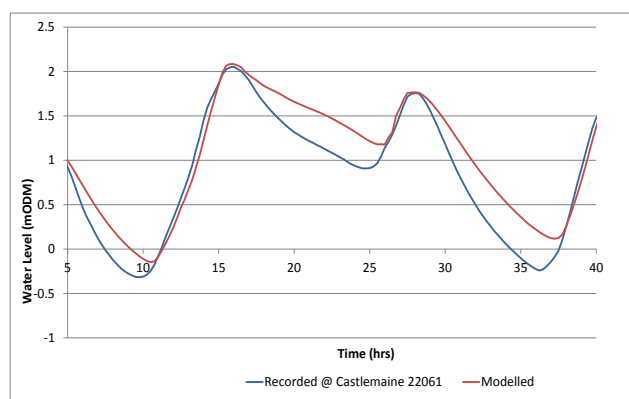


Figure 5.7: Calibration of Level at Castlemaine – 12<sup>th</sup> January 2010



### 5.1.5 Validation to Historic Flood Information

There was insufficient historic flood evidence and/or gauge data to fully calibrate flood levels and extents in Milltown, Glenflesk and Dingle AFA. Therefore, reports of recurring flooding and information from local engineers were compared with the modelled outlines to ensure that there is “reasonable” representation of the historical flood frequency.

In Milltown, the overtopping along Old Station Road in the 10%AEP and larger events matched well with previous reports of flooding in 2008 and recurring flooding from local residents during the Flood Risk Review (Map 5.4). In Glenflesk, the 50%AEP reaches the road level of the N22 upstream of Glenflesk which corresponds with the photographs and reports of annual flooding provided by Kerry County Council (Map 5.5). In Dingle, the recurring flooding on the road near The Woods corresponds well with the 20%AEP and larger coastal events (Map 5.6). The 10%AEP fluvial flood extent and larger magnitude events also correspond with recurring flooding along the Mall and overtopping at Herbert’s Bridge.

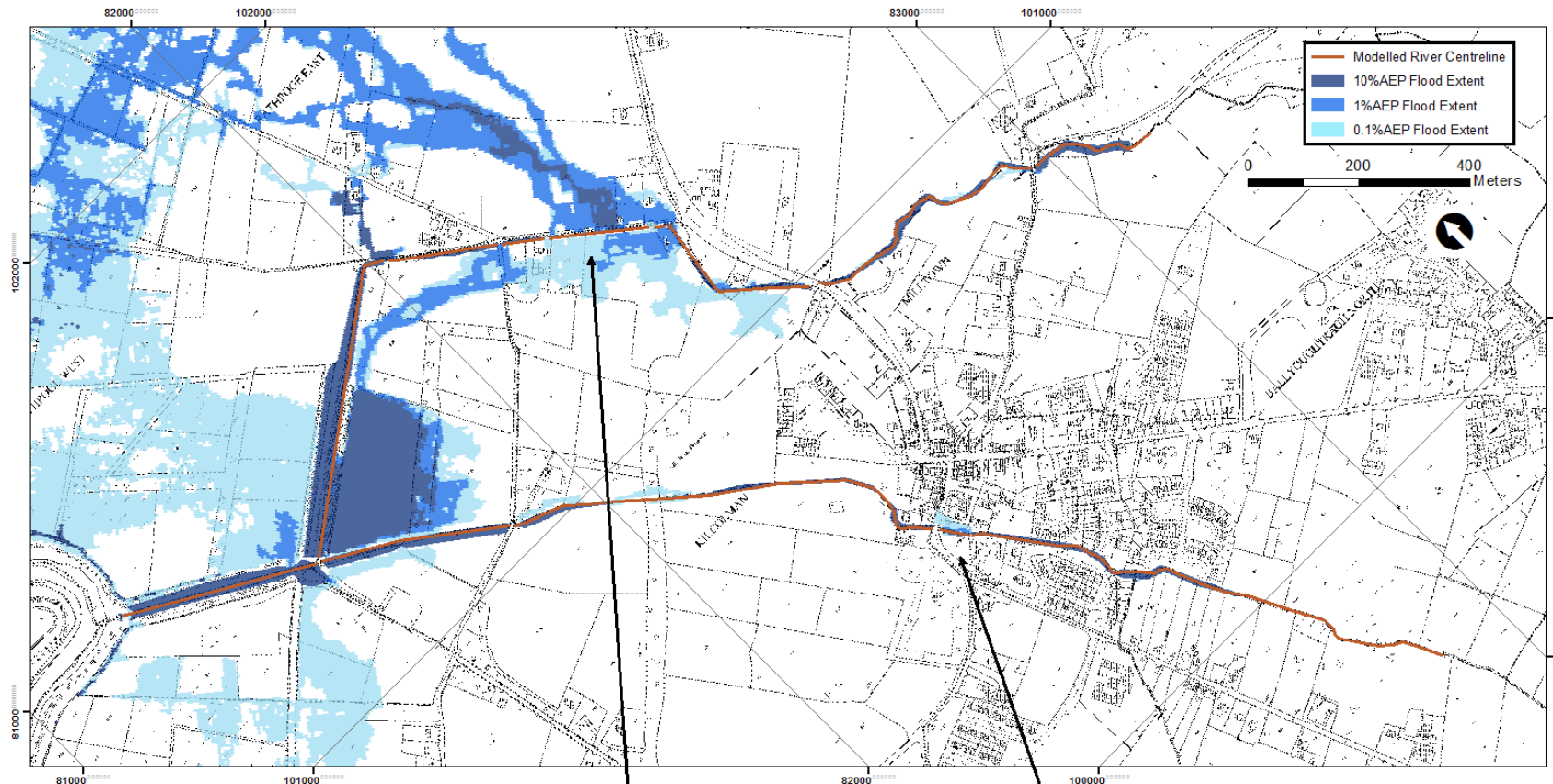
Flooding has been observed in Castleisland on 24th January 2014, since the completion of the hydrological analysis and agreement of the calibration events. Photographs have been used to validate the areas that are vulnerable to flooding as a common sense check (Map 5.7). The 5%AEP to 2%AEP modelled flood extent correspond well with photographs of overtopping along the Glenshearoon into the Crag Cave, flooding at Glebe House Bridge, Tullig and around Church Street.

The prolonged period of rainfall also resulted in surface water flooding/ponding of agricultural lands/public roads in the townlands of Meanus/Camp, situated to the northwest of the town centre. However, the CFRAMS model does not consider surface water flooding therefore the modelled outlines do not indicate flooding at this location.

Unfortunately the gauge data was not available in the AFA at the Castleisland gauge due to a malfunction. Local engineers observed a similar flooding at Glenshearoon 5 years ago in the October 2008 event. However the flooding of Church Street and Tuillig Road (off Cordal Road) was observed to be the first flooding in 20 years by residents. Therefore the modelled flood frequency is deemed to be broadly representative of the historical flood frequency at Tullig and Church Street.

There were no reports of flooding in Portmagee or gauge data to enable validation to historic flooding for this AFA.

Map 5.4: Validation of Modelled Outlines to Historic Flood Evidence in Milltown AFA

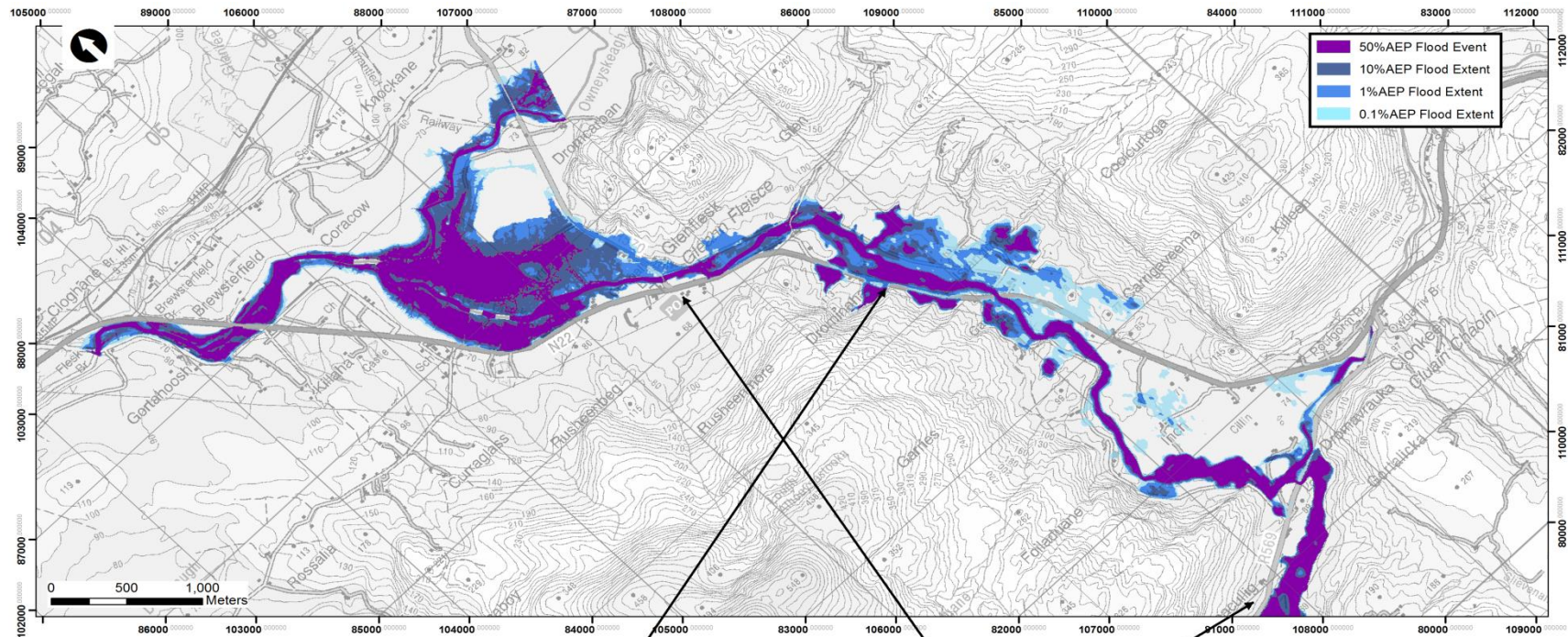


Flooding reported at these properties between 1998-2000

Flooding reported both in JBA report (2011) and anecdotally along this road in January 2008.



Map 5.5: Validation of Modelled Outlines to Historic Flood Evidence in Glenflesk AFA

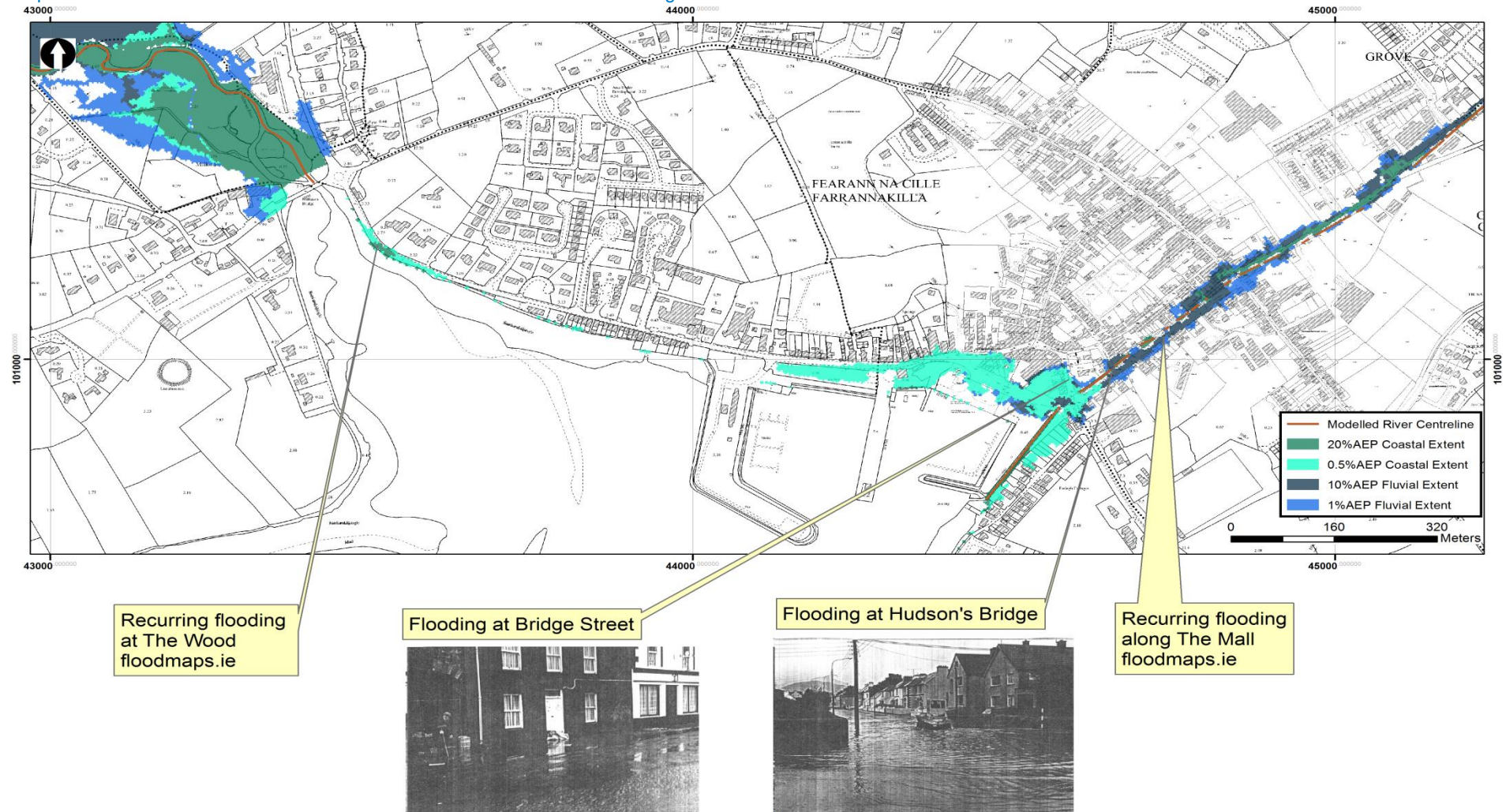


Recurring flooding along the N22 East of Killarney  
(photograph from 1980 event)



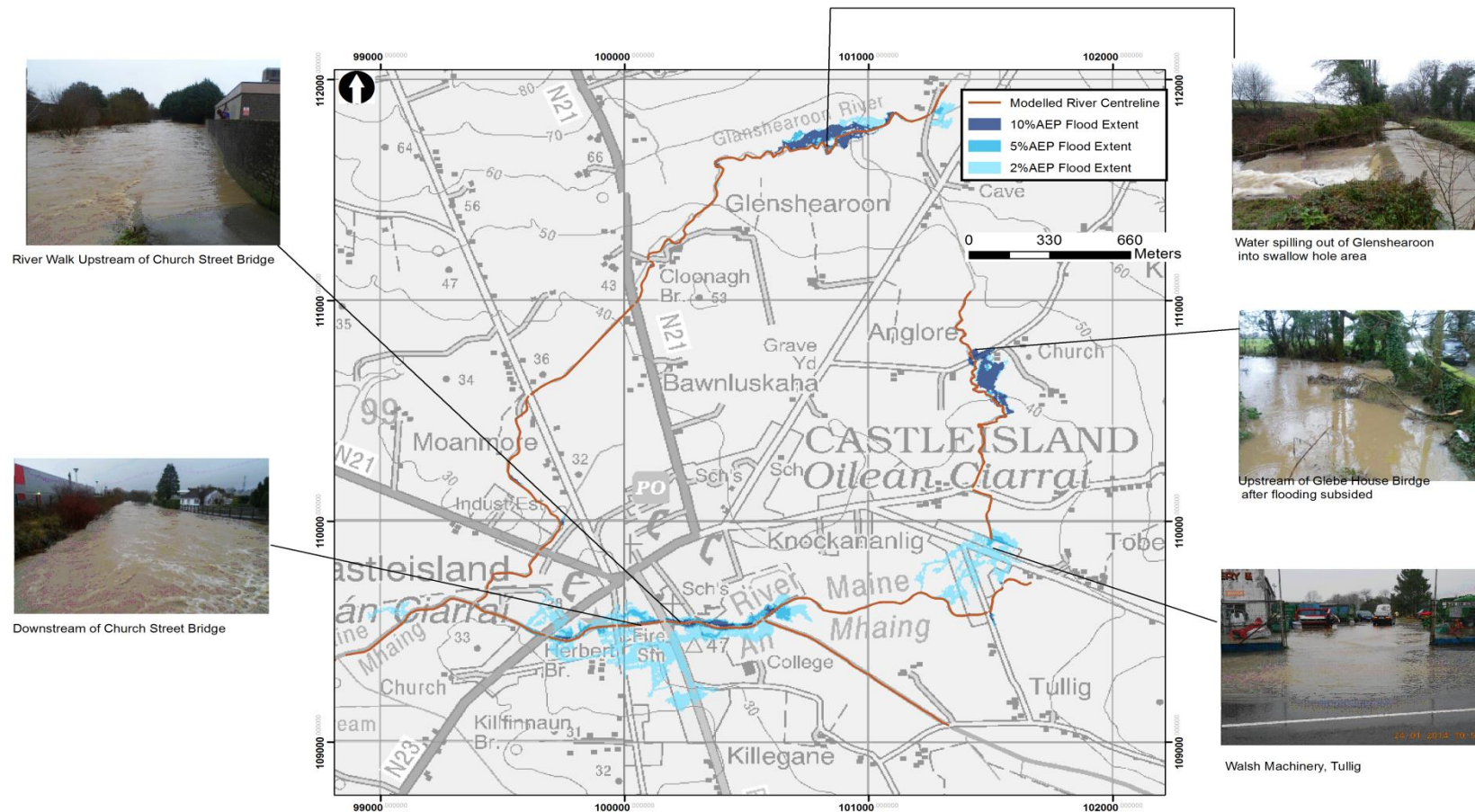
23 houses and 3009 acres flooded between  
Curreal Bridge and Loo Bridge (01/11/1980)

Map 5.6: Validation of Modelled Outlines to Historic Flood Evidence in Dingle AFA





Map 5.7: Validation of Modelled Outlines to January 2014 Flood Evidence in Castleisland AFA



### 5.1.6 Summary

Table 5.3 summarises the calibration run performance, average difference from recorded levels, and tolerance of recorded levels for the three historic events simulated. The average error of the modelled flood levels were within the required  $\pm 0.1\text{m}$  of the recorded levels for the calibration events.

Table 5.2: Summary of Calibration Performance

Event	Reliability of Recorded Level and Extents	Location	Absolute Difference to Recorded Level/Depth (m)	Average Error to Recorded Levels/Depths (m)	Root Mean Square Difference
02/11/1980	$\pm 0.1\text{m}$ (Gauged)	Killarney	0.17	0.17	0.17
04/10/2008	$\pm 0.1\text{m}$ (Gauged)	Castleisland	0.05	0.05	0.05
19/11/2009	$\pm 0.1\text{m}$ (Gauged)	Killarney	0.10	0.10	0.10
In- calibration:					
04/10/2008	$\pm 0.1\text{m}$ (Gauged)	Maine MPW	0.02	0.02	0.02
12/01/2010	$\pm 0.1\text{m}$ (Gauged)	Maine MPW	0.03	0.02	0.02

The Castleisland model matched well with the gauged and flood report information for the 4<sup>th</sup> October 2008 event. The design model outlines were also validated with locations which are known to flood during the recent January 2014 event.

The Killarney model tended to overestimate water level by 0.1 to 0.2m following calibration of the weir coefficient downstream. However the flood extent matched well with recorded flooding in both events.

The in-bank calibration on the Maine indicated good performance of the model at Riverville and Castlemaine. However, concurrent gauge information for flood events was limited to calibrate the model further.

The Milltown, Glenflesk and Dingle models all represent the recorded historical flood frequency based on recurring flood reports and local engineer's comments.

The calibrated hydraulic parameters have been used to simulate the design scenarios discussed in Chapter 6. The calibrated hydrological parameters were not applied to the design scenarios as a rainfall-runoff approach was not used to generate the design inflow hydrographs.



## 5.2 Sensitivity Analysis

### 5.2.1 Flow

In accordance with CFRAM Guidance Note 22, the 1%AEP design peak flow was raised by 30% to assess the sensitivity to uncertainties in the QMEDrural coefficients, the selection of pivotal sites and the flood growth curves derived in the hydrological analysis. This is approximately equivalent to the flow increase applied to simulate climate change in the High End Future Scenario (HEFS), as the increase in flows due to urbanisation is less than 1%.

Flood level and extent in Castleisland, Killarney and the Ashullish Stream in Milltown AFA were sensitive to assumptions in peak flow. The largest increase in flood extent due to the uncertainty in flows was in Milltown whereby large areas of the flat Abbeylands become flooded. However, the increase in flood extent did not significantly increase flood risk to properties within the AFA.

In Castleisland and Killarney, the increased flows exceeded the capacity at key bridges, thereby increasing flood risk to properties nearby. The lower Maine (downstream of Tralea River) was also sensitive to assumptions in peak flow because there is limited capacity between the raised embankments. However, the increase in flood extent did not affect properties.

For the Flesk MPW upstream of Glenflesk, the increase in flows raised flood levels significantly but did not significantly increase flood extent because the narrow floodplain was already inundated in the 1%AEP design. However, the increased flows resulting in more extensive overtopping of the N22. Therefore, the Flesk upstream of Glenflesk is considered sensitive to flow.

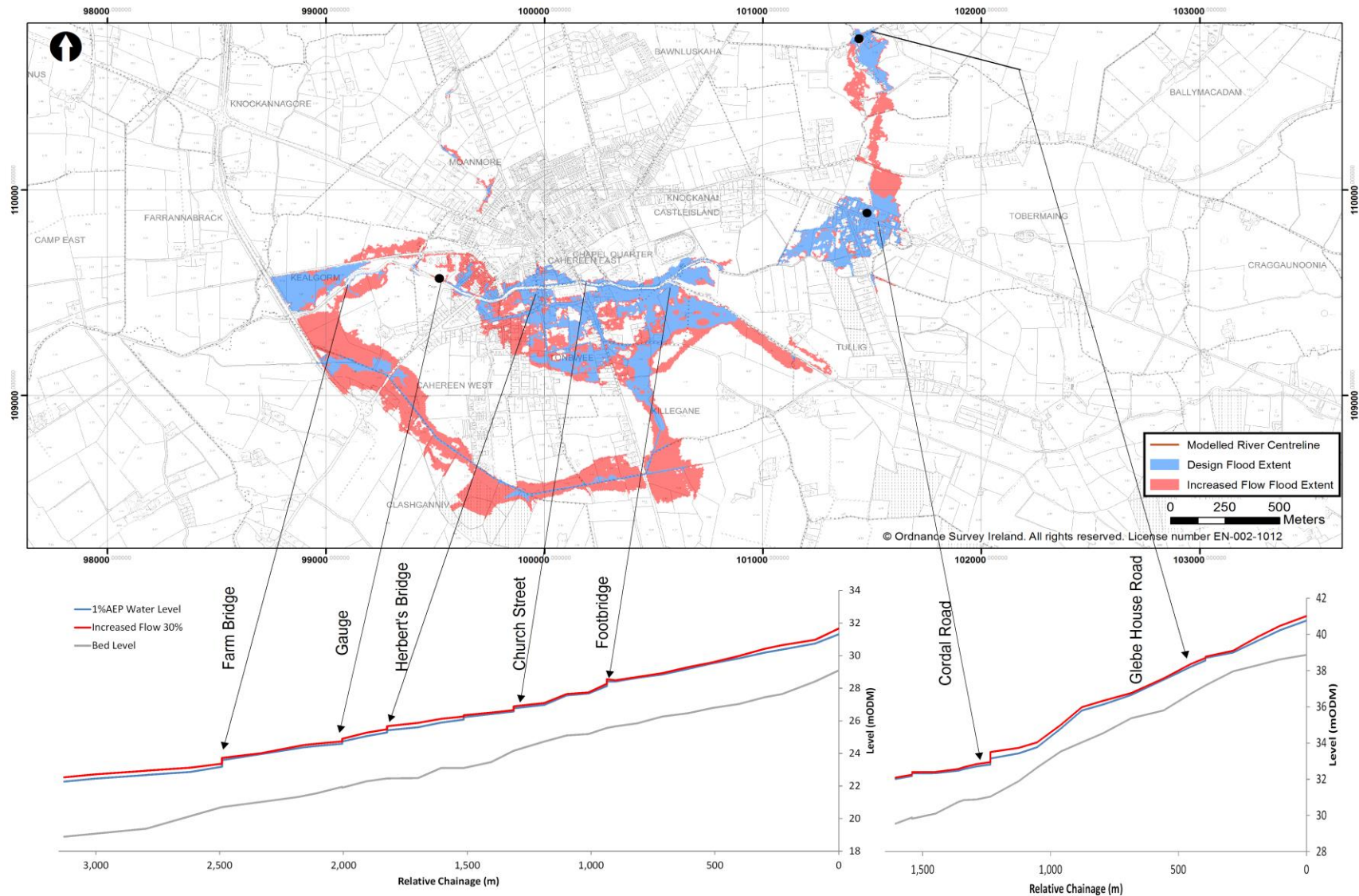
The Killarney and Dingle AFAs and the Flesk and Laune MPWs were less sensitive to the assumptions in peak flow, as their narrow floodplains are already inundated in the design 1%AEP fluvial scenario. Therefore, the increase in flow does not significantly increase areas at flood risk, although depth of flooding and risk to life increases slightly with the more extreme conditions.

While specific sensitivity tests were not carried out in respect of storm duration the impact of the increased volume has been investigated through the analysis of increased peak flow which simulates a similar increase in flood volume. The impacts of increased storm duration would be similar to the increase in peak flow.

Sensitivity to flow was not assessed at Portmagee as the AFA is only deemed to be at coastal risk based on the Flood Risk Review.

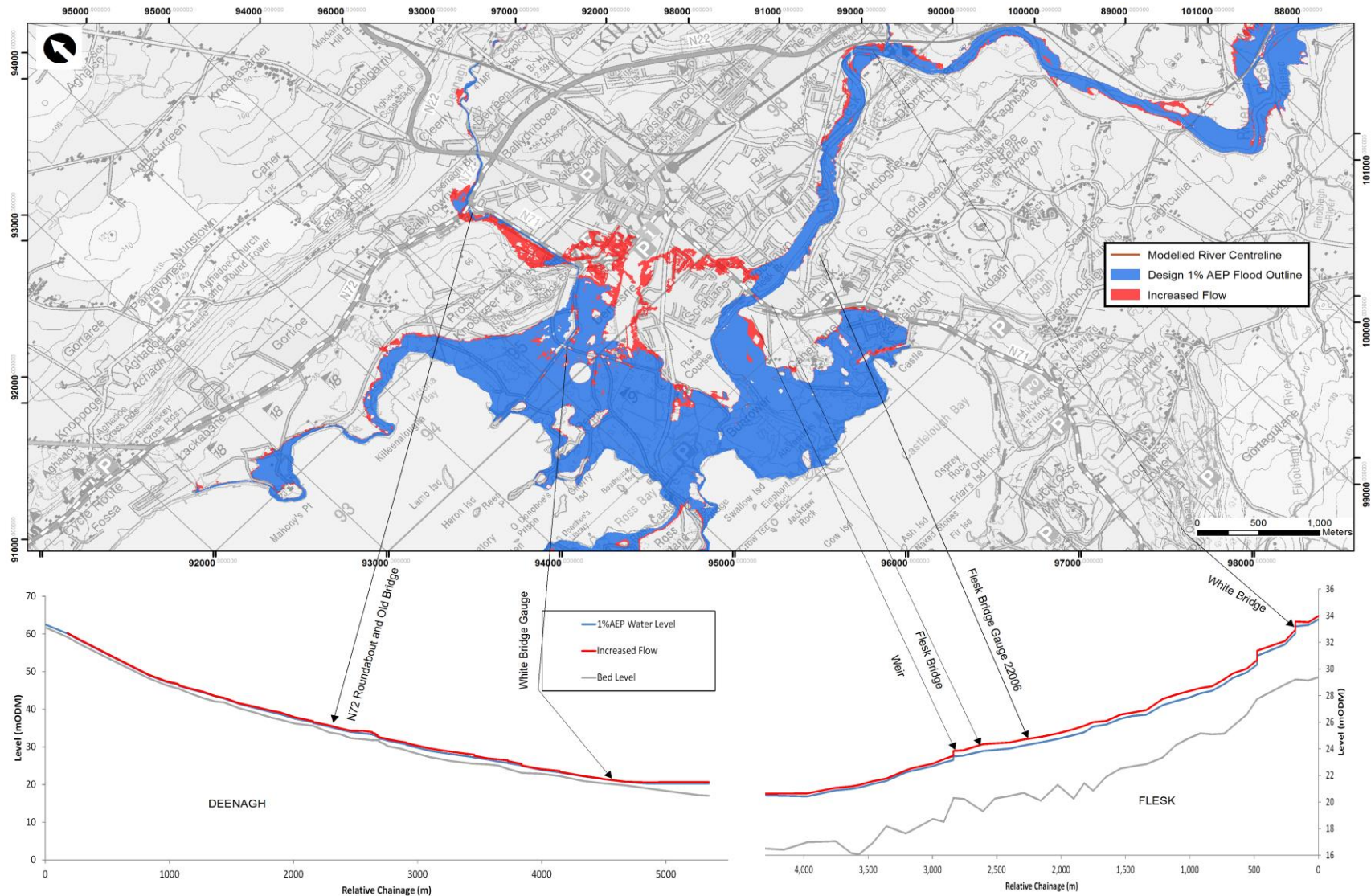
Maps 5.8 to 5.10 show the sensitivity plots for most sensitive reaches. The plots for all flow sensitivity tests can be found in the model performance proformas in the relevant Appendices

Map 5.8: Sensitivity to Peak Flow – Castleisland





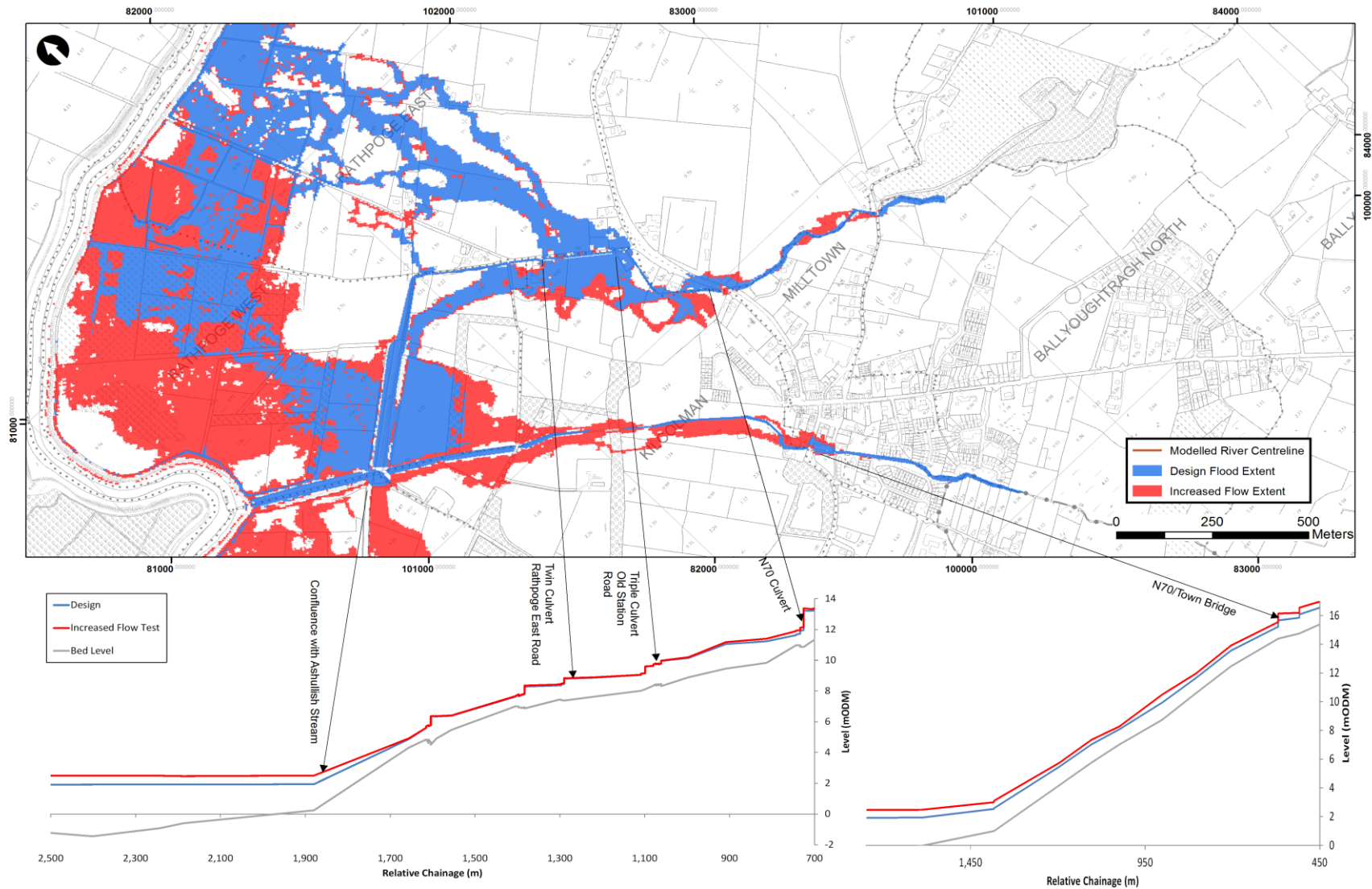
Map 5.9: Sensitivity to Peak Flow-Killarney



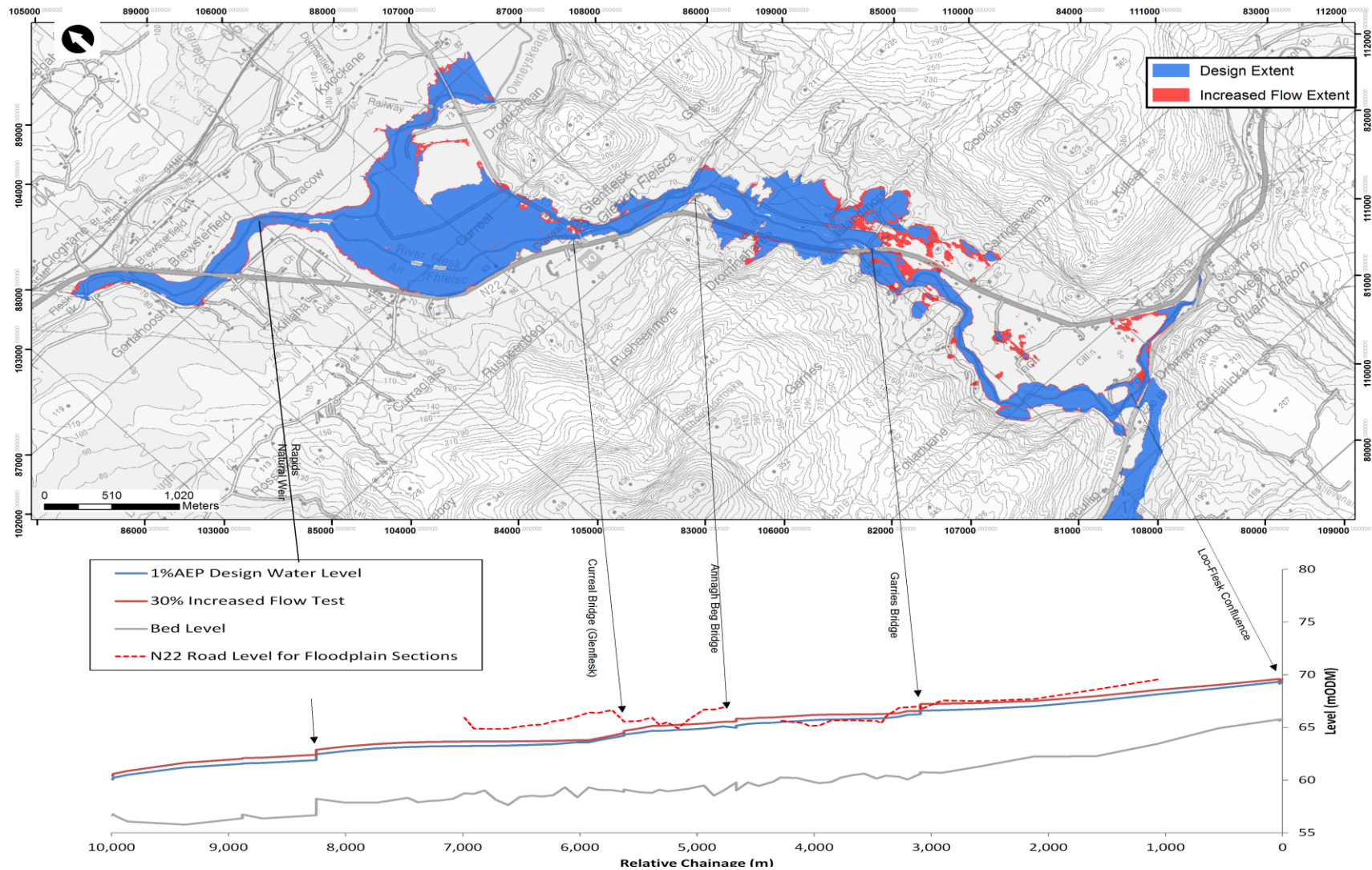




Map 5.10: Sensitivity to Peak Flows - Milltown



Map 5.11: Sensitivity to Peak Flow - Glenflesk



### 5.2.2 Level

A sensitivity test was undertaken on downstream water level for tidally-affected reaches in UoM22 (i.e. Maine MPW, Laune MPW, Dingle AFA and Portmagee AFA). This was done to investigate the uncertainties in the estimation of extreme tide plus surge levels extracted from the ICPSS model, and the uncertainties in the transformation of water levels along the various bays. The downstream water level was increased by 0.5m to account for these uncertainties. This is broadly equivalent to the sea level increase applied to simulate climate change in the Mid Range Future Scenario (MRFS).

In UoM22, flood level and extent was sensitive to the downstream coastal level in Dingle AFA and Maine MPW. The increase in water level results in more extensive coastal flooding along Dingle Quay affecting properties. On the lower Maine, the flooded area increased significantly as the increased level exceeds more of the raised embankment, but it did not significantly increase the number of properties affected.

Portmagee AFA and the Laune MPW were less sensitive to downstream coastal level. In Portmagee the land rises inland, therefore the increase in water level does not significantly increase flood risk within the AFA. Along the Laune, the narrow floodplain was already inundated in the design 1%AEP tidal scenario. Therefore, the increase in downstream water level does not significantly increase areas at flood risk, although depth of flooding and risk to life increases slightly with the more extreme conditions.

Maps 5.12 and 5.13 show the sensitivity plots for the most sensitive reaches. The plots for all level sensitivity tests can be found in the model performance proformas in the relevant Appendices.

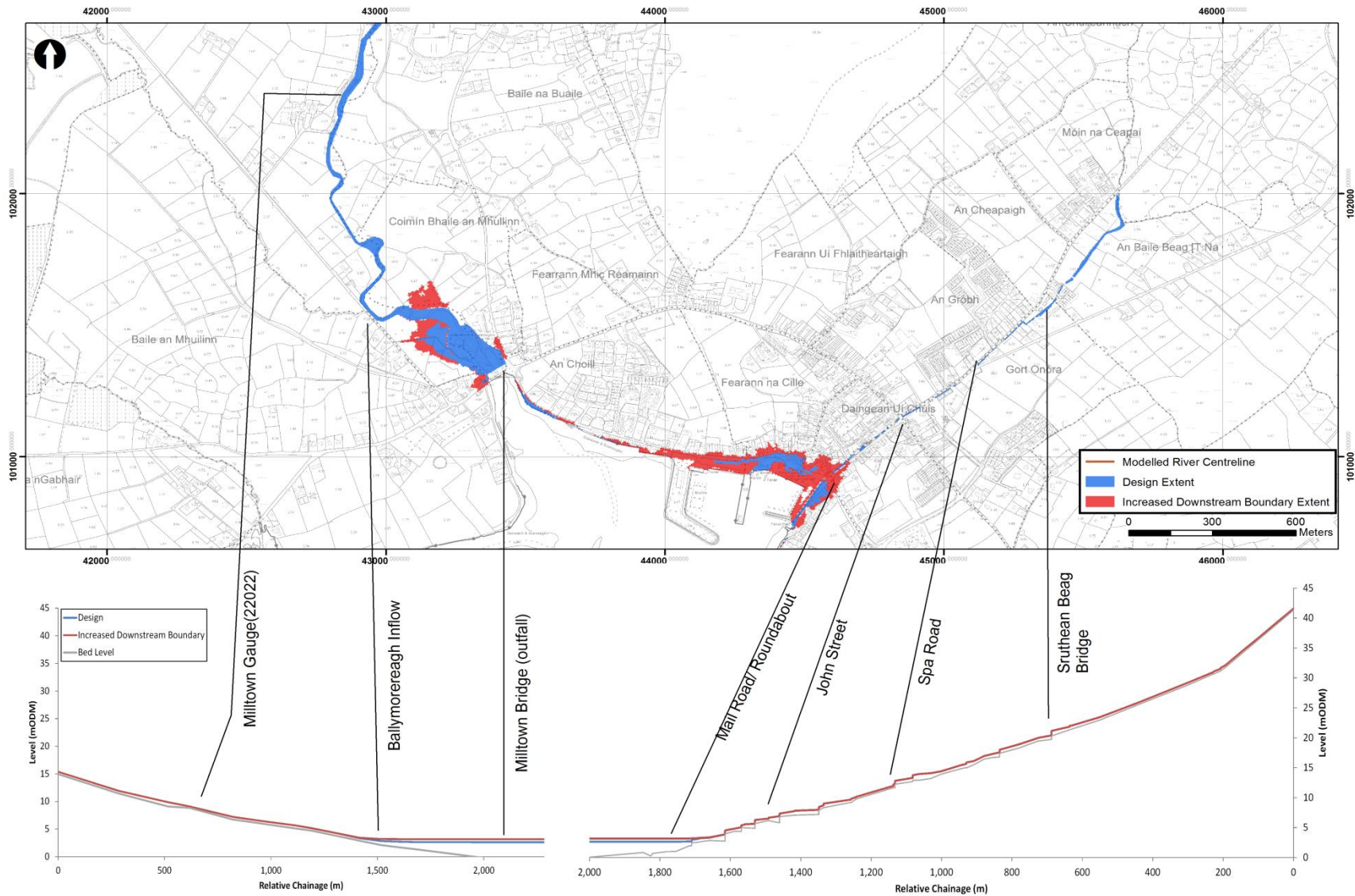
Large catchments such as the Maine and Laune been split up into several separate models to ensure accuracy within the upstream AFAs of Glenflesk, Killarney and Castleisland. Therefore, the downstream boundaries of these fluvial models in the upper catchment are defined by a QH relationship representing the fluvial MPW reach downstream. The gradient in the QH boundary was reduced based on the flattest estimate of the floodplain gradient in the MPW reach downstream to investigate the impact of increased backwater upstream and interaction with the downstream MPW.

Flood risk in Killarney, Castleisland and Glenflesk was found to be less sensitive to the backwater assumptions taken at the downstream boundary, because the AFA was significantly above the downstream boundary and there were weir type structures that reduced the progression of backwater upstream.

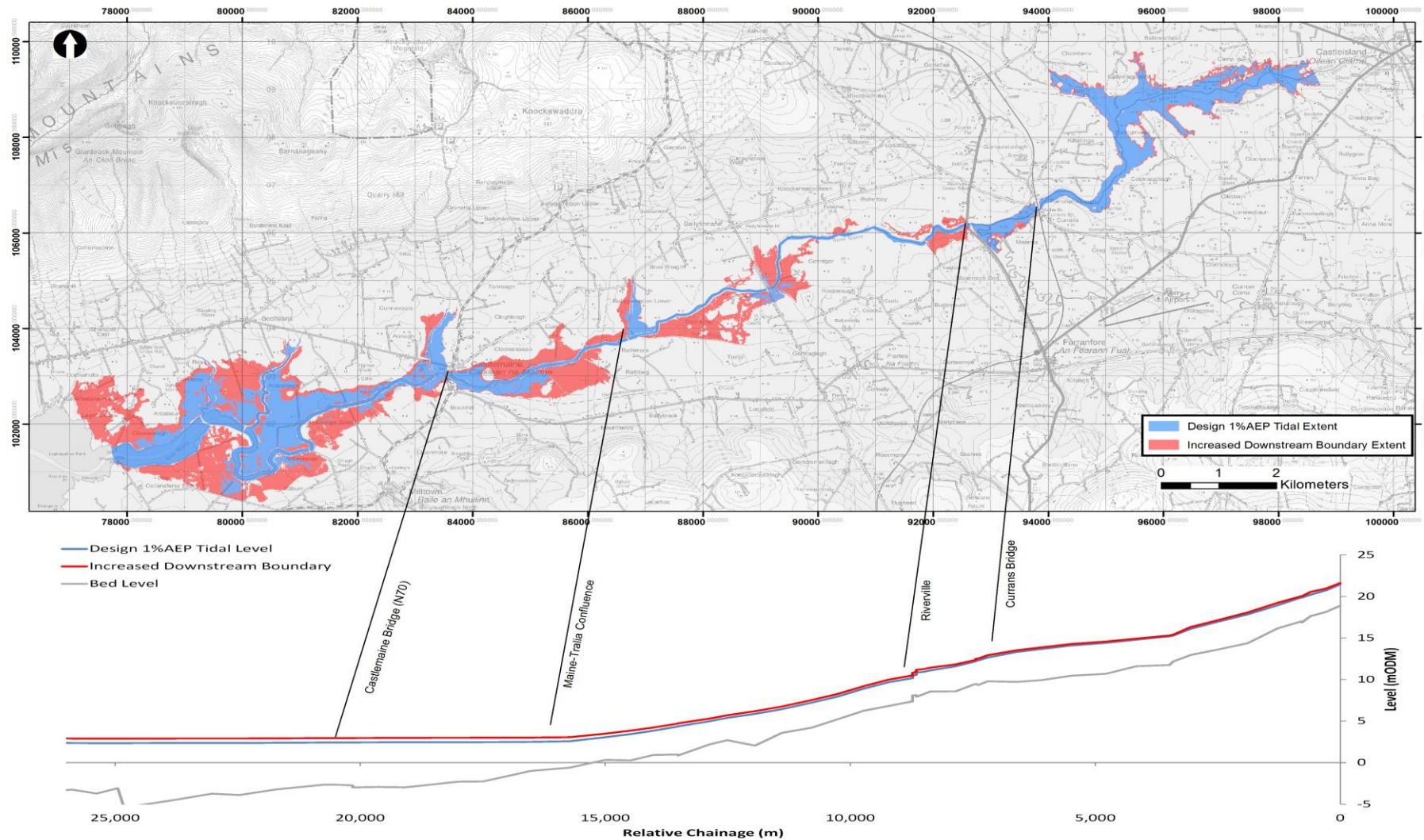
The plots for all flow sensitivity tests can be found in the model performance proformas in the relevant Appendices.



Map 5.12: Sensitivity to Downstream Level – Dingle Model



Map 5.13: Sensitivity to Downstream Level – Maine MPW Model



### 5.2.3 Roughness

In accordance with CFRAM Guidance Note 22, the Manning's 'n' was increased to the next highest value in the recommended ranges for that channel or surface type (Chow 1959) in both the 1D and 2D model components. The Manning's 'n' values were increased in the design model as specified in Table 5.3 and the 1%AEP fluvial event simulated to assess the sensitivity of the predicted flood outline to assumptions in roughness.

Table 5.3: Sensitivity Manning's 'n' Values

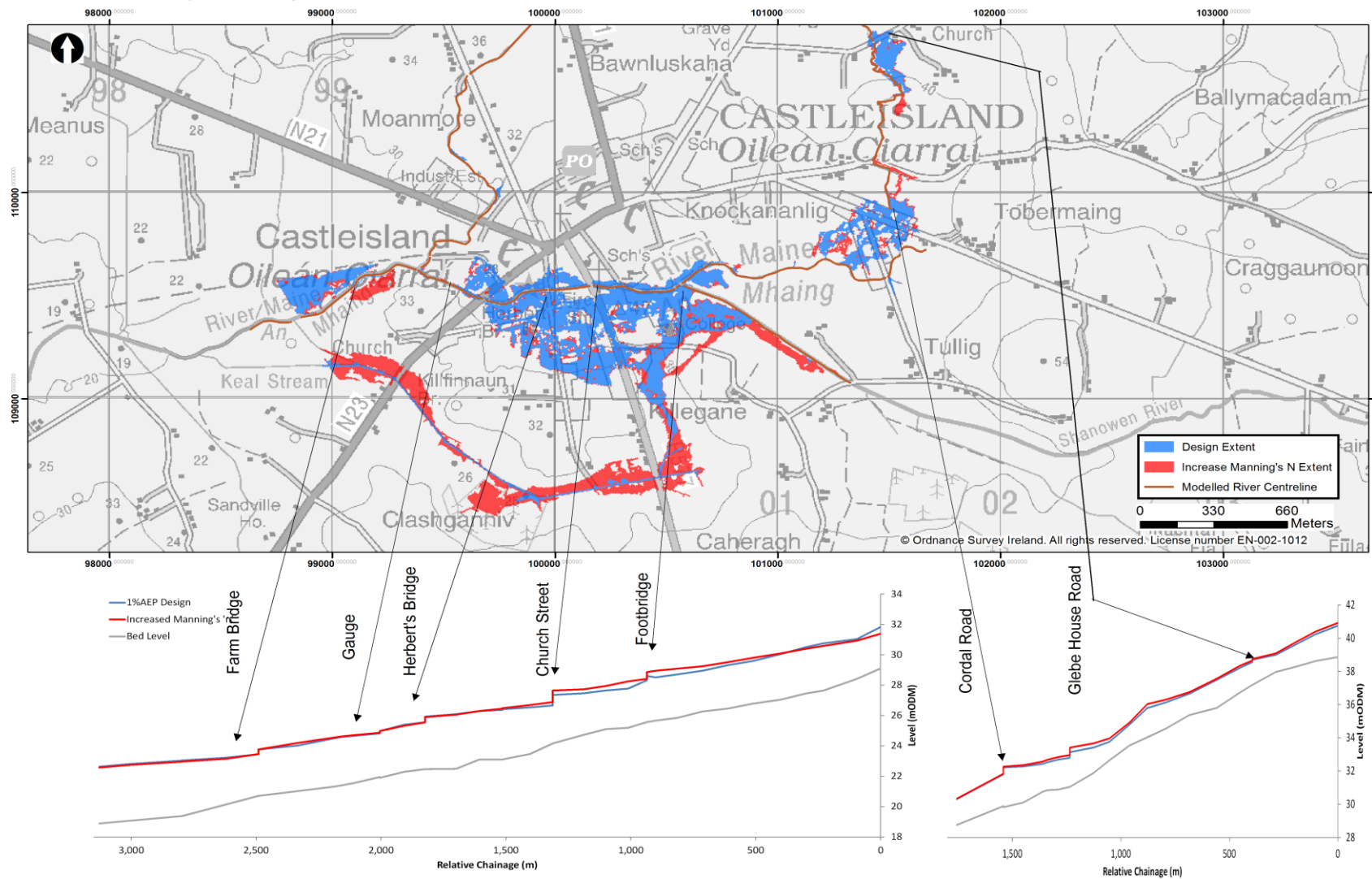
Channel or Surface	Design Manning's 'n'	Sensitivity Manning's 'n'
Active River Channel in Anglore and Flesk	0.050	0.055
Active River Channels elsewhere	0.040	0.045
River Banks/ Medium to Dense Vegetation	0.080	0.100
Buildings	0.200	0.250
Roads and Other Hard Standing	0.030	0.035
Rural/Pasture	0.060	0.080

The greatest increase in flood risk attributed to Manning's 'n' was predicted in Castleisland, resulting in a larger flood extent along the R277 flow path (Map 5.14). Flooding across the N22 also increased due to the increased Manning's 'n' values, although the flood extent did not significantly increase elsewhere (Map 5.15).

The plots for all Manning's 'n' sensitivity tests can be found in the model performance proformas in the relevant Appendices. A summary of the impacts on levels are shown in Table 5.5.



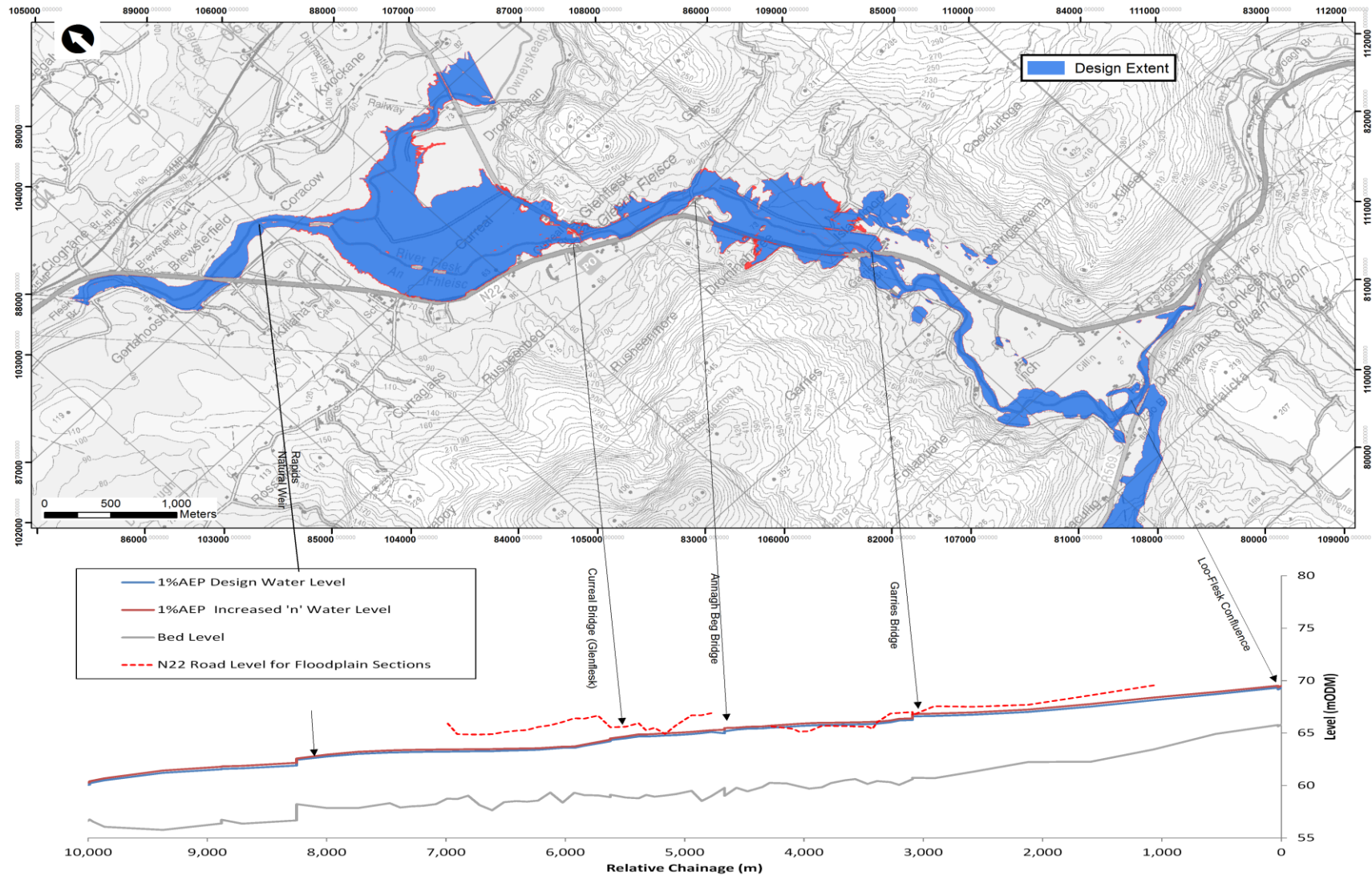
Map 5.14: Sensitivity to Manning's 'n' - Castleisland







Map 5.15: Sensitivity to Manning's 'n' - Glenflesk



#### 5.2.4 Culvert Coefficients in Milltown

The culverts along Old Station Road in Milltown AFA are reported to cause flooding in this area. The CIRIA Culvert Design and Operation Guide (2010) was used to derive the best estimate of inlet and outlet coefficients from a recommended range. A sensitivity test was undertaken on the limit of the recommended range for inlet and outlet coefficients assumed, to establish the impact of the conveyance of these structures on flood risk. All culvert coefficients were changed to the upper limit of the range. Table 5.4 outlines the changes to the circular culvert coefficients as an example.

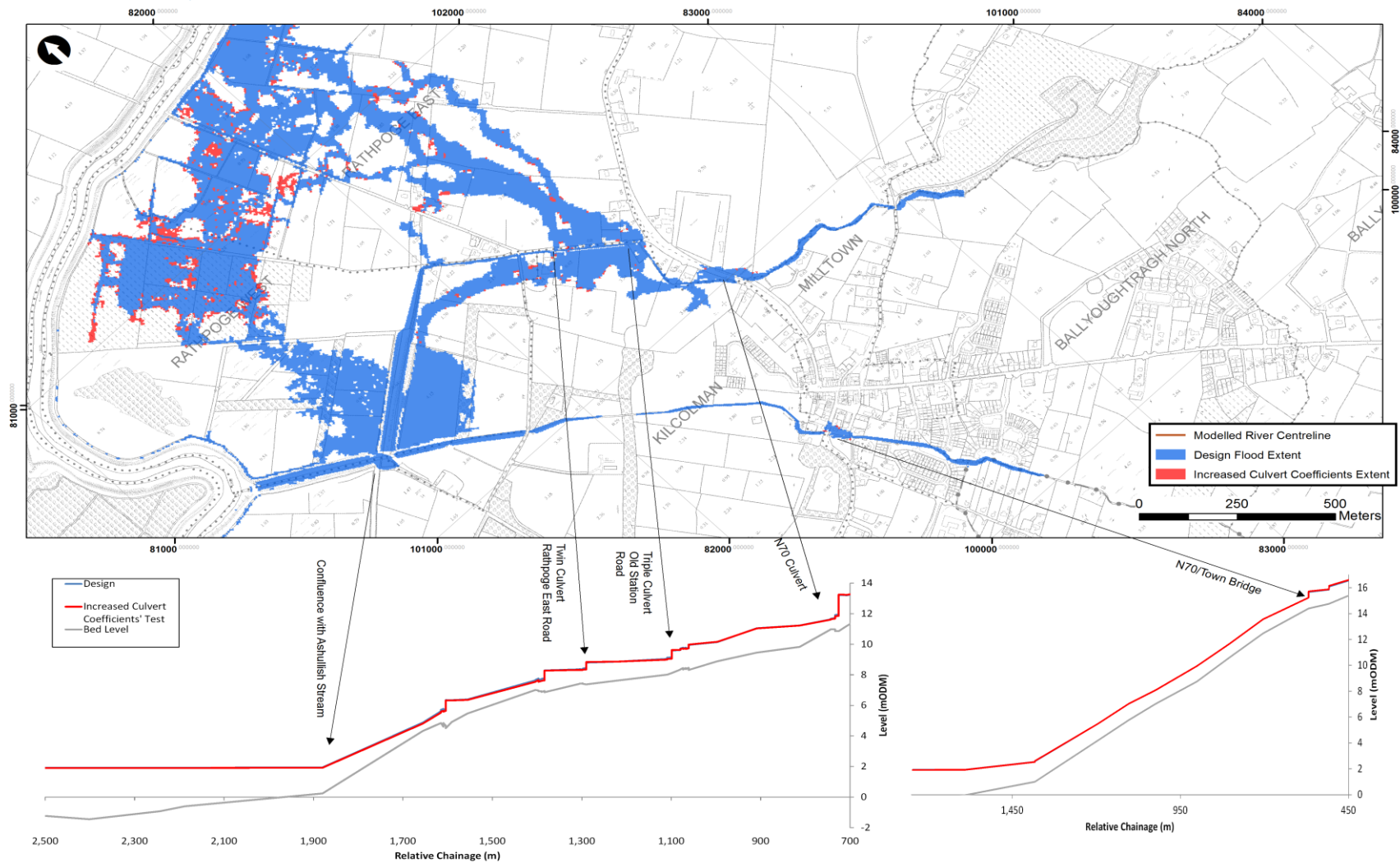
Table 5.4: Sensitivity on Culvert Coefficients

Culvert Coefficients/Parameters	Design (Verified against manual calculations using the CIRIA estimates)	Sensitivity Test (Combination to produce increased head loss)
Unsubmerged inlet control loss coefficient (K)	0.2	0.5
Exponent of Flow Intensity for inlet control (M)	2.0	2.00
Submerged inlet control loss coefficient (c)	0.0398	0.0553
Submerged inlet control adjustment factor (Y)	0.67	0.670

Map 5.16 compares the 1% AEP fluvial current event design results and the 1%AEP fluvial current event with increased loss coefficients along Old Station Road.

The increase in the culvert coefficients did not significantly change the maximum water level ( $<0.05\text{m}$ ) because the 1%AEP design event already causes out-of-bank flooding. However, the increased coefficients increased head loss on the rising limb and reduced the capacity of the culverts by a maximum of  $0.7\text{m}^3/\text{s}$  (20%) as shown in the hydrographs of Map 5.9. This causes flooding out-of-bank earlier and to a greater extent. Therefore, the effective capacity of the culverts and any blockage should be carefully considered when interpreting flood maps, deriving flood risk management options and assessing any future flood events.

Map 5.16: Sensitivity to Culvert Head Loss Assumptions – Milltown





## 5.2.5 Summary

Table 5.5 summarises the findings of the sensitivity tests undertaken on the design models. Each was deemed sensitive to a parameter if there was a significant increase in flooded area (>5%) and increase in water level ( $\pm 0.2\text{m}$ ). In some cases there is a significant increase in level but this does not result in a significant increase in flood extent, such as at Glenflesk.

Table 5.5: Summary of Sensitivity Run Performance

Model	Flow		Level		Manning's 'n'		Culvert Coefficients	
	RMSD (m)	Sensitive?	RMSD (m)	Sensitive?	RMSD (m)	Sensitive?	RMSD (m)	Sensitive?
Castleisland	0.19	Yes	0.05	No	0.11	Yes	N/A	
Maine	0.29	Yes	0.41	Yes	<0.01	No	N/A	
Milltown	0.26	Yes	Assessed as part of Maine		0.06	No	0.02	No
Glenflesk	0.36	Yes <sup>Δ</sup>	0.02	No	0.24	Yes <sup>Δ</sup>	N/A	
Killarney	0.38	Yes	0.09	No	0.09	No	N/A	
Laune	0.41	No	0.55	No	0.28	No	N/A	
Dingle	0.38	No	0.53	Yes	0.07	No	N/A	
Portmagee	N/A		0.55*	No			N/A	

RMSD is Root Mean Square Difference.

\*RMSD for open coast in Portmagee the absolute increase in water level i.e. 0.55m.

<sup>Δ</sup> The increase in water level did not significantly increase flood extent and risk to properties. However, flood risk increased to national infrastructure (N22). Therefore the model has been deemed sensitive to this parameter.

Based on the findings of the sensitivity tests above, the following can be concluded:

- Castleisland, Maine, Milltown and Killarney models are sensitive to assumptions and uncertainties in peak flow. Glenflesk has also been deemed sensitive to flow due to the increased flooding across the N22 in this test rather than an increase in flood extent within the AFA. The uncertainty and sensitivity to peak flow and duration estimates should be considered in the sizing and operation of any flood management options using storage of flood waters.
- Dingle and Maine models are sensitive to the assumptions and uncertainties in the extreme sea levels. The uncertainty in the total tide plus surge levels should also be considered in the development of any flood embankment/walls to protect against coastal flooding.
- Seasonal changes in vegetation or uncertainty in the roughness values only increased flooding in Castleisland and to the N22 in Glenflesk at the 1%AEP. However, maintenance of the channel may provide some benefit for events which are closer to the threshold of flooding.
- The flood risk in Milltown was not deemed sensitive to the culvert coefficients applied at the 1%AEP fluvial event. However, it did reduce the culvert capacity and cause flooding earlier in the event. Therefore, the effective capacity of the culverts and any blockage should be carefully considered when interpreting flood maps and deriving flood risk management options to reduce flooding in more frequent event.

## 6 Design Event Runs and Model Performance

### 6.1 Design Scenarios and Event Runs

Table 6.1 outlines the applicable design scenarios to each model in UoM22 and design event runs simulated.

Both the fluvial and coastal scenarios have been simulated for Dingle AFA, Laune MPW and Maine MPW as these reaches have been identified as being at risk from both fluvial and coastal sources. The joint probability between the fluvial and coastal conditions for these scenarios is outlined in Section 3.4 of this report. The model results from the fluvial-dominated event and coastal-dominated event will be combined to derive the flood zone mapping described in Chapter 9 of this report. However, the fluvial results and coastal results are presented separately for the flood maps.

No fluvial scenarios have been simulated for Portmagee as the AFA was not identified as being at fluvial flood risk.

In order to calculate the undefended extent from the Flood Zone mapping and Defended Areas, additional undefended scenarios were run for the Maine and Milltown models where the water level would vary without the defences in place due to the capacity of the floodplain. The Flood Zone mapping and Defended Areas for the lower Laune was calculated using horizontal projection as these were entirely tidal.

Table 6.1: Design Event Runs- Defended

Source	Scenario	%AEP	Run Name	Castleisland I33CD	Maine I34ME	Milltown I35MN	Glenflesk I36GF	Killarney I37KY	Laune I39LE	Dingle I40DE	Portmagee I41PE
Fluvial	Current	50%	FCD500	✓	✓	✓	✓	✓	✓	✓	N/A
		20%	FCD200	✓	✓	✓	✓	✓	✓	✓	N/A
		10%	FCD100	✓	✓	✓	✓	✓	✓	✓	N/A
		5%	FCD050	✓	✓	✓	✓	✓	✓	✓	N/A
		2%	FCD020	✓	✓	✓	✓	✓	✓	✓	N/A
		1%	FCD010	✓	✓	✓	✓	✓	✓	✓	N/A
		0.50%	FCD005	✓	✓	✓	✓	✓	✓	✓	N/A
		0.10%	FCD001	✓	✓	✓	✓	✓	✓	✓	N/A
	MRFS	50%	FMD500	✓	✓	✓	✓	✓	✓	✓	N/A
		20%	FMD200	✓	✓	✓	✓	✓	✓	✓	N/A
		10%	FMD100	✓	✓	✓	✓	✓	✓	✓	N/A
		5%	FMD050	✓	✓	✓	✓	✓	✓	✓	N/A
		2%	FMD020	✓	✓	✓	✓	✓	✓	✓	N/A
		1%	FMD010	✓	✓	✓	✓	✓	✓	✓	N/A
		0.50%	FMD005	✓	✓	✓	✓	✓	✓	✓	N/A
		0.10%	FMD001	✓	✓	✓	✓	✓	✓	✓	N/A
	HEFS	10%	FHD100	✓	✓	✓	✓	✓	✓	✓	N/A
		1%	FHD010	✓	✓	✓	✓	✓	✓	✓	N/A
		0.10%	FHD001	✓	✓	✓	✓	✓	✓	✓	N/A
Coastal	Current	50%	CCD500	N/A	✓	N/A	N/A	N/A	✓	✓	✓
		20%	CCD200	N/A	✓	N/A	N/A	N/A	✓	✓	✓
		10%	CCD100	N/A	✓	N/A	N/A	N/A	✓	✓	✓
		5%	CCD050	N/A	✓	N/A	N/A	N/A	✓	✓	✓
		2%	CCD020	N/A	✓	N/A	N/A	N/A	✓	✓	✓
		1%	CCD010	N/A	✓	N/A	N/A	N/A	✓	✓	✓
		0.50%	CCD005	N/A	✓	N/A	N/A	N/A	✓	✓	✓
		0.10%	CCD001	N/A	✓	N/A	N/A	N/A	✓	✓	✓

Source	Scenario	%AEP	Run Name	Castleisland I33CD	Maine I34ME	Milltown I35MN	Glenflesk I36GF	Killarney I37KY	Laune I39LE	Dingle I40DE	Portmagee I41PE
	MRFS	50%	CMD500	N/A	✓	N/A	N/A	N/A	✓	✓	✓
		20%	CMD200	N/A	✓	N/A	N/A	N/A	✓	✓	✓
		10%	CMD100	N/A	✓	N/A	N/A	N/A	✓	✓	✓
		5%	CMD050	N/A	✓	N/A	N/A	N/A	✓	✓	✓
		2%	CMD020	N/A	✓	N/A	N/A	N/A	✓	✓	✓
		1%	CMD010	N/A	✓	N/A	N/A	N/A	✓	✓	✓
		0.50%	CMD005	N/A	✓	N/A	N/A	N/A	✓	✓	✓
		0.10%	CMD001	N/A	✓	N/A	N/A	N/A	✓	✓	✓
	HEFS	10%	CHD100	N/A	✓	N/A	N/A	N/A	✓	✓	✓
		0.50%	CHD005	N/A	✓	N/A	N/A	N/A	✓	✓	✓
		0.10%	CHD001	N/A	✓	N/A	N/A	N/A	✓	✓	✓
TOTAL Model Runs				19	38	19	19	19	38	38	19

Table 6.2: Design Event Runs- Undefined

Source	Scenario	%AEP	Run Name	Castleisland I33CD	Maine I34ME	Milltown I35MN	Glenflesk I36GF	Killarney I37KY	Laune I39LE	Dingle I40DE	Portmagee I41PE
Fluvial	Current	5%	FCU050	N/A	✓	N/A	N/A	N/A	N/A	N/A	N/A
		2%	FCU020	N/A	N/A	✓	N/A	N/A	N/A	N/A	N/A
		1%	FCU010	N/A	✓	✓	N/A	N/A	N/A	N/A	N/A
		0.1%	FCU001	N/A	✓	✓	N/A	N/A	N/A	N/A	N/A
	MRFS	1%	FMU010	N/A	✓	✓	N/A	N/A	N/A	N/A	N/A
		0.1%	FMU001	N/A	✓	✓	N/A	N/A	N/A	N/A	N/A
Coastal	Current	0.5%	CCU005	N/A	✓	N/A	N/A	N/A	*	N/A	N/A
		0.1%	CCU001	N/A	✓	N/A	N/A	N/A	*	N/A	N/A
	MRFS	0.5%	CMU005	N/A	✓	N/A	N/A	N/A	*	N/A	N/A
		0.1%	CMU001	N/A	✓	N/A	N/A	N/A	*	N/A	N/A
TOTAL Model Runs				0	9	5	0	0	*	0	0
									Horizontal projection without defences in place		



## 6.2 Model Run Performance

The run performance was investigated for each of the design models for the 1%AEP target event as this represented out-of-bank flooding for the AFAs.

Figures 6.1 to 6.5 show the performance dialog for the 1%AEP fluvial event for the following run performance criteria in AFAs;

- The number of iterations per timestep taken to resolve flow and level in the model;
- The convergence of flow and water level in the model within the recommended tolerance of  $\pm 0.01$  m or  $0.01 \text{ m}^3/\text{s}$  between consecutive timesteps;
- The total inflow and outflow from the model components.

The 1D ISIS models were convergent within the recommended tolerances for the majority of the design events in all models. There is no 1D convergence plot for Portmagee as there are no 1D components for this model. The brief periods of poor convergence can be explained as follows:

- In Milltown, the outflow varies due to the influence of the tide in the Maine preventing free flow at the outfall as expected. The brief 'spikes' of poor convergence are attributed to the opening and closing of the flapped outfall in to the Maine. These spikes do not impact the peak level or flood duration and are therefore acceptable.
- The brief non-convergence in the Glenflesk model is attributed to overtopping of the Loo Bridge. This causes a minor oscillation in the flow at this node, but this normalises after 0.25 hours and does not impact the river sections upstream or downstream of the bridge.
- There are a couple of brief spikes of poor convergence in Dingle as the water reaches the soffit at key structures which changes the hydraulic regime from free-flow conditions to drowned mode and back again. This is particularly evident at the new access bridge opposite the Brewery Gate, and the long culvert under Spa Road.

The cumulative mass balance for the 2D model components is shown in Figures 6.6 to 6.10. The design models were convergent and within the recommended tolerance of  $\pm 1\%$  mass error at the peak flow and/or tide plus surge level with the exception of Portmagee. In this case, the mass error was outside the 1% recommended tolerance due to the small number of wet cells and oscillation in water level with the incoming and outgoing tide. However, the mass error does not affect flood risk as the flood levels are not affected, and the volume overtopping is not critical where the ground rises inland such as Portmagee.

Figure 6.1: 1D Convergence Plot - Castleisland

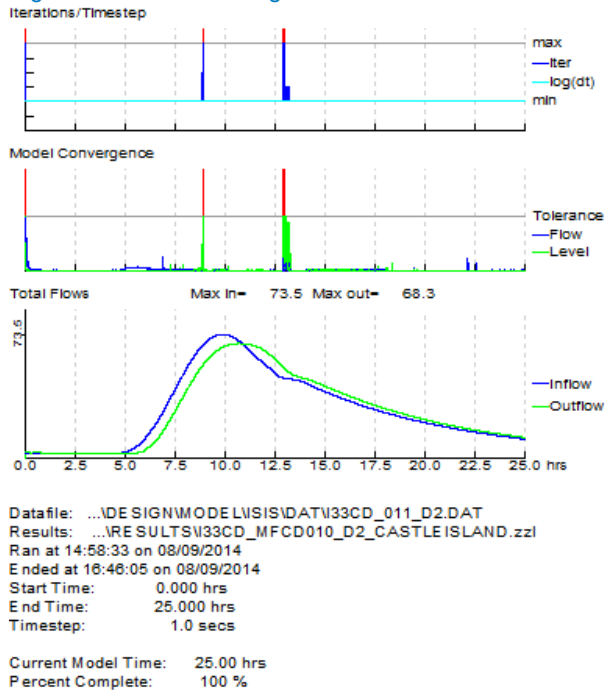


Figure 6.2: 1D Convergence Plot - Milltown

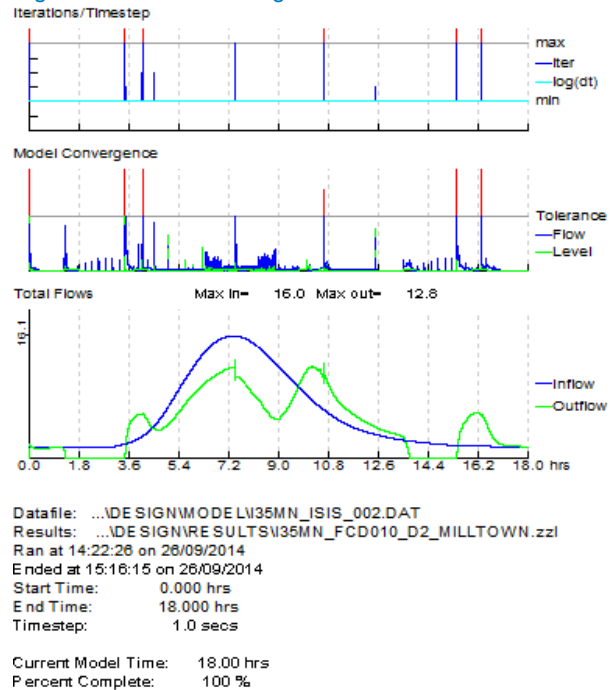


Figure 6.3: 1D Convergence Plot - Glenflesk

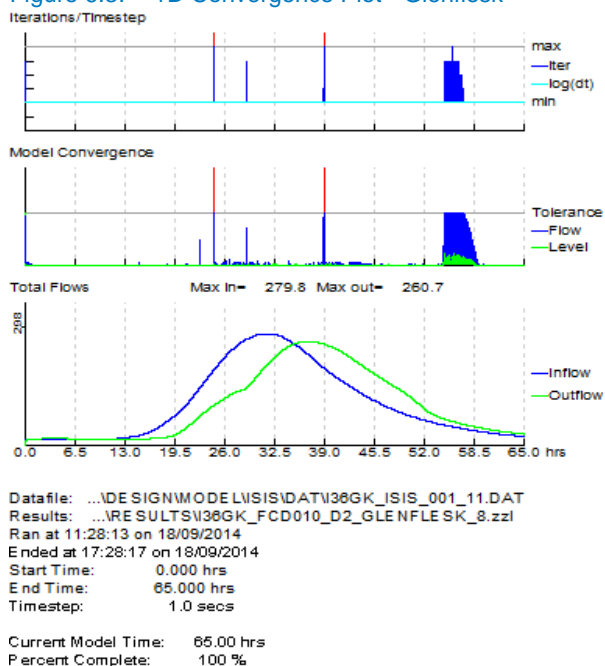


Figure 6.4: 1D Convergence Plot - Killarney

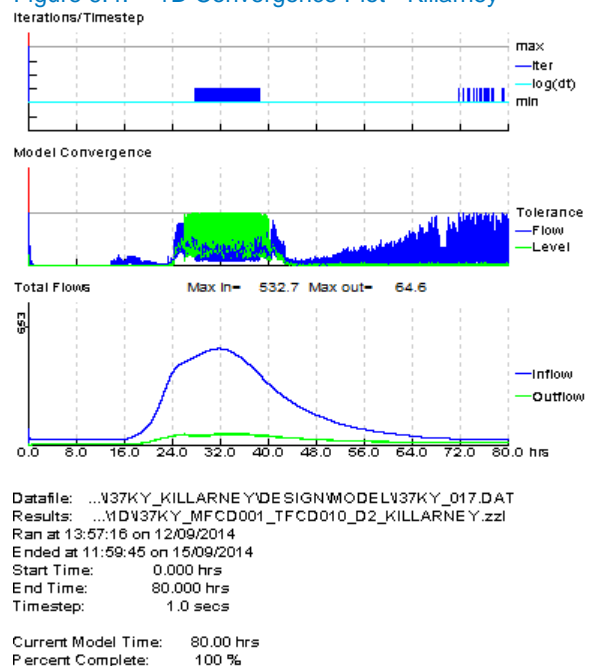


Figure 6.5: 1D Convergence Plot – Dingle

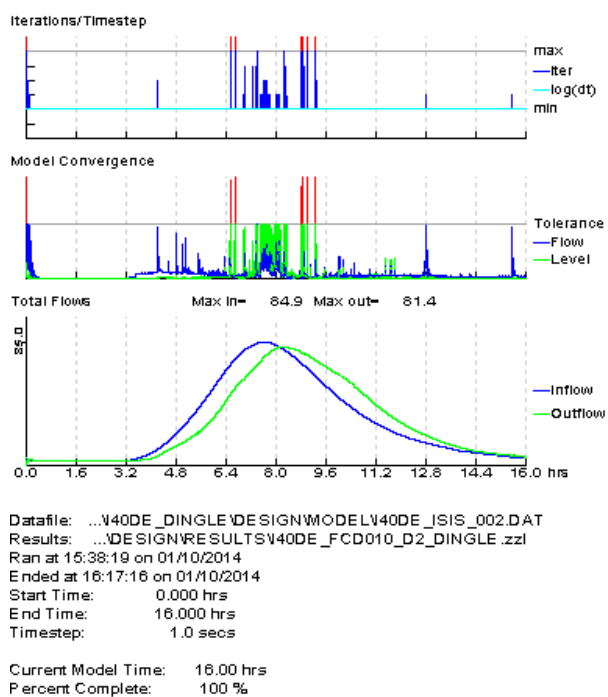


Figure 6.6: 2D Mass Balance Plot - Castleisland

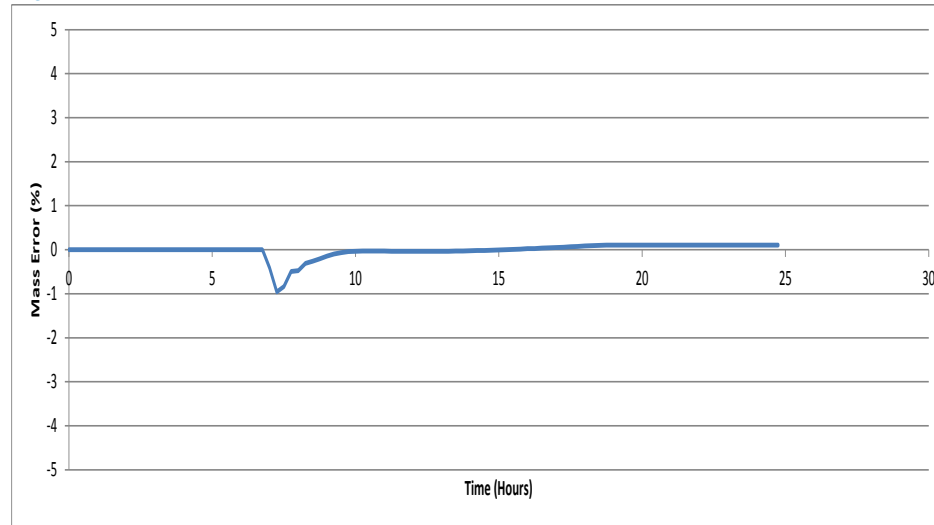


Figure 6.7: 2D Mass Balance Plot - Milltown

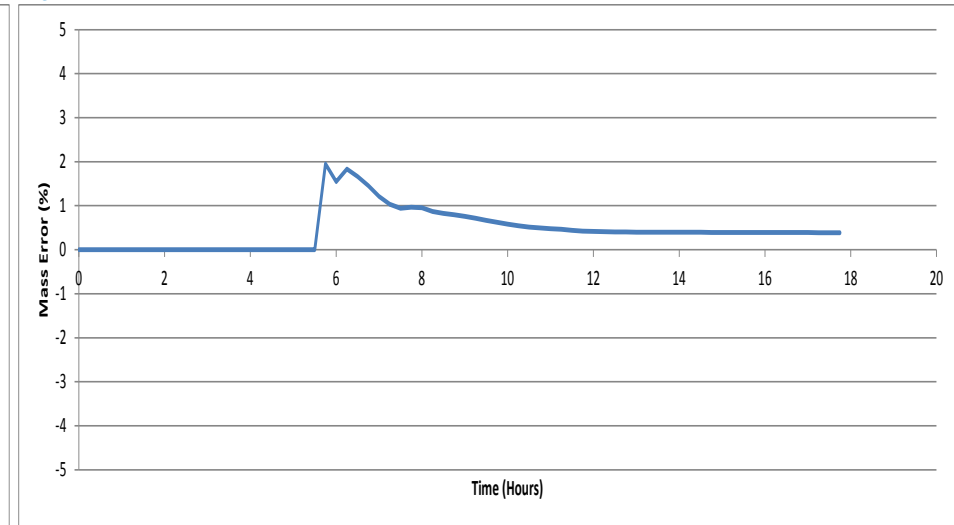


Figure 6.8: 2D Mass Balance Plot – Glenflesk

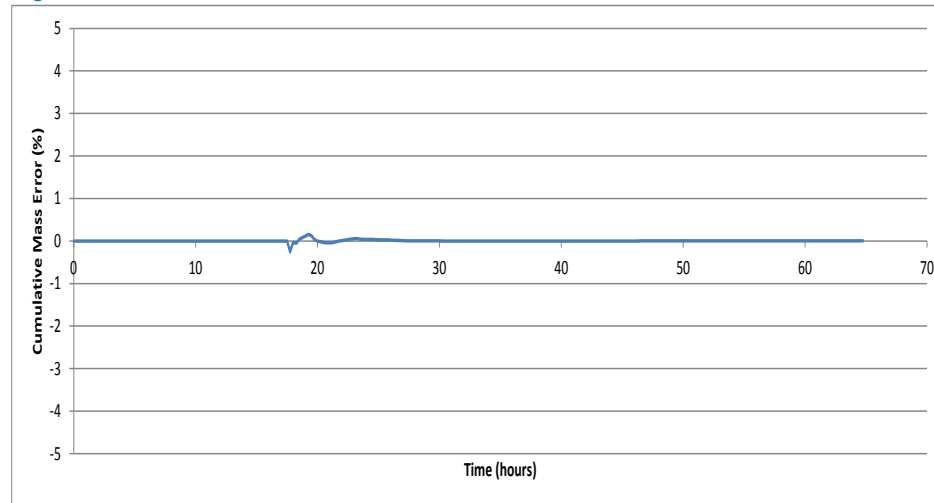


Figure 6.9: 2D Mass Balance Plot – Killarney

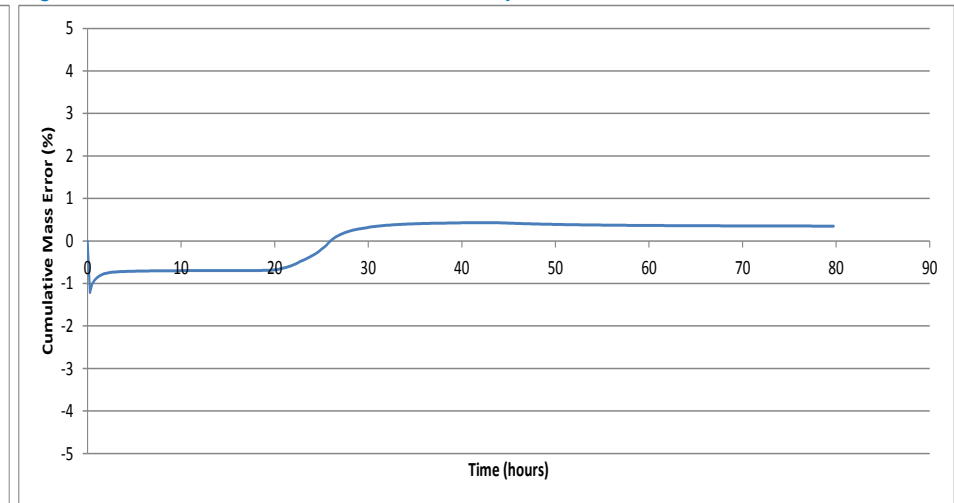




Figure 6.10: 2D Mass Balance Plot - Dingle

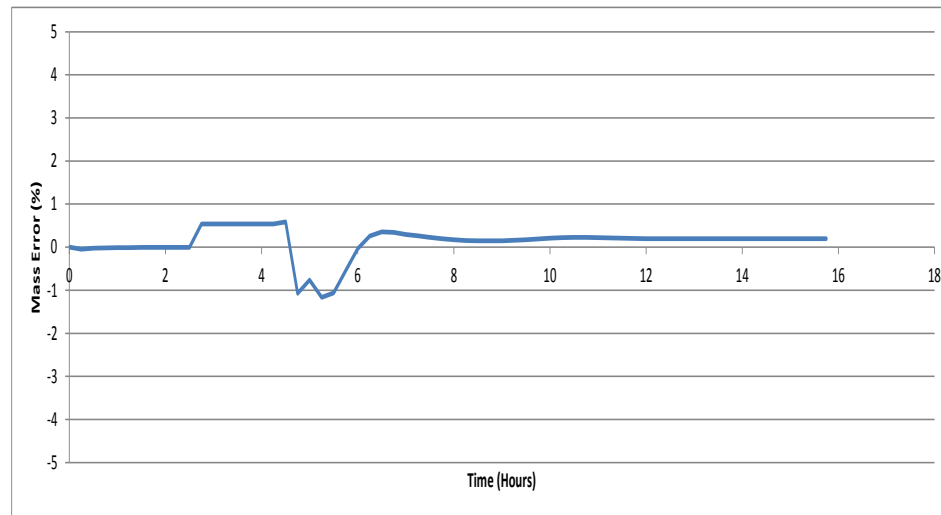
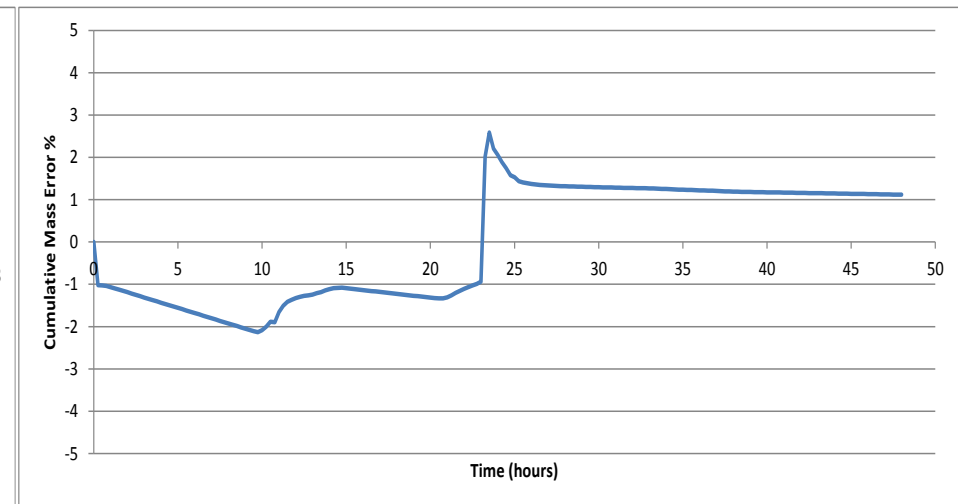


Figure 6.11: 2D Mass Balance Plot - Portmagee



Tables 6.2 compares the model predicted flows with the design peak flows at the target HEPs for the target 1%AEP event.

Modelled flow has been extracted directly from the extended 1D sections from the MPW reaches using a 1D only approach including; the Maine (Castleisland to Currans Bridge); Glenflesk (upstream of Glenflesk); Killarney (N22 to White Bridge); and, Laune models. Modelled flows in AFAs and the lower Maine MPW (downstream of Currans Bridge) have been derived by combining the flows in the 1D channel and across the 2D floodplain to assess the hydrological routing of flows through the catchment. Target flows at HEPs located upstream of confluences were not assessed because these locations are affected by backwater which is not considered in the design hydrology.

Table 6.3: Summary of Hydrological Routing Performance for Key Fluvial Current Events

HEP ID	Location	Model Node	10%AEP			1%AEP			0.1%AEP		
			Design Target Flow (m3/s)	Model Predicted Flow (m3/s)	Difference (m3/s)	Design Target Flow (m3/s)	Model Predicted Flow (m3/s)	Difference (m3/s)	Design Target Flow (m3/s)	Model Predicted Flow (m3/s)	Difference (m3/s)
Castleisland AFA											
22_1589_3	Shanowen downstream	22SHAN00002A	37.2	37.1	0%	54.2	54.8	1%	79.4	80.5	1%
22_1587_3	22014 Castleisland Gauge	22MAIN04748H	43.6	41.5	-5%	61.8	57.6	-7%	91.8	71.2	-22%
	22014 Castleisland Gauge+ flow exiting catchment	22MAIN04748H	43.6	41.5	-5%	61.8	58.8	-5%	91.8	88.4	-4%
22_2098_3	Maine downstream	22MAIN04669A	56.9	51.4	-10%	80.7	75.4	-7%	119.9	113.2	-6%
22_360_2	Glenshearoon downstream	22GLAN00002H	12.6	11.0	-12%	18.7	15.8	-16%	27.8	22.4	-19%
22_1756_3	Anglore downstream	22ANGL00021I	3.3	3.7	12%	4.7	5.7	21%	7.0	8.3	19%
Milltown AFA											
22_3116_1	Ashullish-Ashullish Trib d/s	22ASHU00144H	3.3	3.2	-2%	5	4.9	-1%	7.5	7.4	-1%
22_3116_4	Ashullish-Ballyoughtragh U/s	22ASHU00000H	5.6	5.4	-4%	8.5	8.2	-4%	12.9	12.1	-6%
22_3617_1	Ashullish-Ballyoughtragh D/s	22TOWN00046B	9.8	10.1	3%	14.9	12.6	-15%	22.5	15.5	-31%
22_3958_2	Ashullish Stream d/s	22TOWN00010A	10.6	11.9	12%	16.1	14.1	-13%	24.3	15.4	-37%
22_3425_9	Ballyoughtragh Stream D/S	22TOWN00100A	4.2	4.0	-4%	6.4	6.2	-4%	9.8	9.1	-7%
Glenflesk AFA											
22_1561_2	Flesk/Annagh Beg Confluence	22FLES01721H	143.2	140.46	-2%	207	206	0%	315	312	-1%
22_2859_1	Flesk d/s Owneyskeagh	22FLES01433B	196.1	187.0	-5%	283	277	-2%	432	415	-4%
Killarney AFA											
22_3340_8	Flesk Upstream	22FLES00547H	204.2	203.71	0%	304	295	-3%	450	449	0%
22_3372_1	Flesk downstream Woodford	22FLES00480A	214.2	212.5	-1%	319	305	-4%	472	470.2	0%
22006	Flesk Bridge Gauge	22FLES00201B	224.4	221.9	-1%	334	322	-4%	494	487	-1%
22_3372_11	Flesk downstream survey extent	22FLES00019H	226.5	221.5	-2%	338	321	-5%	494	494	0%
22009	White Bridge gauge	22DEN00094B	15.4	15.02	-2%	24.3	23.6	-3%	36.9	37.0	0%

HEP ID	Location	Model Node	10%AEP			1%AEP			0.1%AEP		
22_3340_8	Flesk Upstream	22FLES00547H	204.2	203.71	0%	304	295	-3%	450	449	0%
Dingle AFA											
22_3437_5	Downstream of Dingle Stream	22DING00003H	7.42	6.5	-12%	11.2	9.0	-20%	16.9	12.0	-29%
22_1712_2	Milltown Gauge (22022)	22MILL00165G	39.7	39.9	1%	62.0	62.3	0%	88.4	89.3	1%
22_3998_1	Milltown Stream-Ballymoreeagh Trib D/S	22MILL00071H	47.58	40.5	-15%	74.3	62.9	-15%	106	89.6	-15%
22_3999_2	Downstream of Milltown Stream	22MILL00002A	48.79	46.6	-4%	76.2	72.4	-5%	108	105	-3%
Portmagee AFA ( No fluvial assessment)											

The modelled flows are typically within 10% of the design flows where the HEP is not bypassed or affected by backwater. The discrepancies in flows at the tidal outfalls (highlighted in the table) are due to backwater effects that limit discharge. This tide-locking is not considered in the design hydrology which assumes free-flow conditions in a fluvial-dominated reach.

The modelled flows tended to underestimate the design flows on the Glenshearoon and overestimate the flows on the Anglore Stream because flow exited the Glenshearoon catchment and were transferred to the Anglore Stream catchment. The modelled peak flows are less than the design flows at Castleisland gauge for extreme events because up to 20 m<sup>3</sup>/s exits the catchment along the main road. The modelled flow is within 5% when this cross-catchment flow is accounted for.



## 7 Assumptions and Limitations

### 7.1 Assumptions

A number of assumptions were made in the development of the hydraulic model and application of the hydrological inflows. They include:

- The lateral inflows representing the intermediate catchments were assumed to be distributed evenly as rainfall across such a small catchment can be expected to be uniform.
- The peak fluvial flows were assumed to coincide with the peak tidal level at each AFA as a conservative estimate of flood risk. However, it is recognised that the phasing of the river flows and tide will vary event to event.
- The urban drainage network is assumed to be at capacity prior to the start of the event as the worst case scenario as observed in several historic flood events. Therefore, the urban drainage network is not explicitly considered in the design model.
- Model grid size is set at 5 m which was assessed as appropriate for the purpose of the Study. Small urban features, such as fences and walls, have not been considered explicitly as they are not designed to retain water during a flood event. However, the additional inefficiencies in flow around street furniture such as fences have been incorporated into the higher general floodplain Manning's 'n' of 0.06 in urban areas.
- Section data for the cross sections was defined with the hard bed levels. This is because the soft bed or silt is likely to be washed away during a flood.
- It is assumed that water can enter a building above a 0.15m threshold whereupon the water is significantly impeded by the internal structure before exiting the building.
- The "stubby" building approach described above can result in the model calculating reduced flood depths and velocities, along with a greater flood extent as flows are not constricted between buildings.
- Utility pipes that cross immediately upstream of or under bridges were assumed to form the soffit as a worst-case scenario for the capacity of the structure.

### 7.2 Limitations

There are a number of uncertainties associated with the flow estimation and hydraulic modelling methodology used in UoM22. They include:

- There is uncertainty in the derivation of design flows for Anglore Stream (Castleisland) due to the subterranean flow paths and influence of groundwater on this karstic system. There was no gauge data but the flood extents have been calibrated to historic flooding along this watercourse. This level of uncertainty must be considered in the interpretation of design flows, flood mapping and in the development of flood mitigation options.
- The absence of river flow or continuous water level data in Milltown catchment to fully calibrate the hydrological routing and hydraulic model.

- The flood maps produced as part of this Study do not show localised flooding resulting from intense rainfall and where surface flow might exceed the capacity of the urban drainage system. The assessment of such surface water flooding is beyond the scope of the CFRAM studies.
- Groundwater flooding has not been included in assessing the risk of flooding and therefore areas susceptible to groundwater flooding may not be identified in the flood maps. This is of particular relevance to the karstic Glenshearoon and Anglore catchments. However, the CFRAMS modelling does consider the karstic system as an alternative flow route during high flows in accordance with local engineers' observations.

## 8 Flood Mapping Approach

### 8.1 Approach

The 1D-2D models are configured such that the 1D flows and levels are resolved and hydrodynamically interact with the 2D flows and levels at each timestep. The combined 1D and 2D results were subsequently used to produce the following outputs in accordance with the CFRAM brief:

- Maximum flood depth maps for each AFA and MPW reach;
- Maximum velocity maps for each AFA;
- Maximum flood hazard maps for each AFA;
- Maximum flood extent maps for each AFA and MPW reach;
- Flood Zone maps for each AFA and MPW reach;
- Specific Risk Number of Inhabitants maps for each AFA and MPW reach;
- Specific risk Types of Economic Activity maps for each AFA and MPW reach; and,
- Specific Risk Density maps for each AFA and MPW reach.

For AFAs, the gridded outputs from the 1D-2D models were used directly or processed to develop the flood maps as discussed below. For MPWs, the maximum water level from the 1D models would be used to derive the flood depth and flood extents. It is important to note that no allowance has been made for the local urban drainage system for either AFAs or MPWs. Therefore, the flood maps assume flooding wherever depth is greater than 0mm.

### 8.2 Flood Depth and Velocity Mapping

Maximum flood depth and velocity are output directly as GIS grids from the 2D model. The flood depth and velocity maps display the raw model results based on the 5m model grid without the need for any further processing. The flood depth and velocity maps are provided in Schedule 4 of each appendix.

1D water level lines (WLLs) were used to extract depth and velocity information from the 1D river channel in order to produce a seamless flood map. The WLLs plot the maximum water level symmetrically against the flow widths from the centreline in ISIS or ESTRY, which may not be appropriate for asymmetrical cross-sections at meander bends. Therefore, the in-channel water depths presented on the flood maps should be considered in conjunction with the detailed channel survey data presented in the 1D model.

For MPW reaches using a 1D only approach, water levels were assigned to the 1D cross-sections and interpolated to create a water level surface TIN which was then intersected with the DTM to derive flood depths. Any isolated or disconnected areas of flooding were manually reviewed to check whether the water level had overtopped the raised feature, such as a road embankment. The isolated flooding was removed if the maximum water level was below the raised feature crest. Conversely, the previously isolated flooding was connected if the maximum water level was above the raised feature crest. The greater spacing between MPW cross-sections may limit the confidence in flood depths in-between.

### 8.3 Flood Hazard Mapping

The flood hazard was also output direct from the 2D model results, whereby flood hazard is a function of depth and velocity which is calculated for every time step to derive the maximum flood hazard. The flood hazard was modified from the DEFRA FD2320 guidance:

$$\text{Flood Hazard} = \text{Depth} \times (\text{Velocity} + 0.5)$$

When interpreting flood hazard maps, it is important to consider that the flood hazard rating value has been calculated at each time-step based on concurrent depth and velocity. The maximum flood hazard rating value is the maximum of these concurrent flood hazard values but does not necessarily coincide with both the maximum depth and maximum velocity. This is produced directly by the TUFLOW model and requires no post-processing to derive flood hazard.

Debris factor has not been considered given the uncertainties associated with variable debris factors based on the underlying land use.

The flood maps categorise the resultant flood hazard values into four broad classes (Table 8.1) which are presented on the flood hazard maps provided in Schedule 4 of each appendix.

Table 8.1: Flood Hazard Categories

Flood Hazard Value	Degree of Flood Hazard	Description
<0.75	Low	Caution - "Flood zone with shallow flowing water or deep standing water"
0.75-1.25	Moderate	Dangerous for some (vulnerable social groups such as children and the elderly) - "Danger: Flood zone with deep or fast flowing water"
1.25-2.00	Significant	Dangerous for most people - "Danger: flood zone with deep fast flowing water"
>2.00	Extreme	Dangerous for all - "Extreme danger: flood zone with deep fast flowing water"

Source: DEFRA FD2320 Table 2 Hazard to People

### 8.4 Flood Extent and Zone Mapping

The maximum flood extent was derived from the maximum flood depth grid and converted to a closed polygon. The GIS processing automatically simplifies the polygon to a smoother outline but this does not differ from the modelled grid extent. No additional processing was undertaken to remove dry islands so that the flood outlines matched the modelled grids.

Raised embankments along the River Maine and Castlemaine Harbour protect the floodplain from coastal flooding. The standard of protection was identified as the %AEP event which was closest to the defence



level but did not cause flooding which ranges from the 50% to 1%AEP in UoM22. The Defended Areas were then derived from the water levels for the 50% to 1%AEP event without the flood embankment in place.

The Flood Zone outlines were derived from the undefended scenarios where there were raised defences e.g. along the River Maine and from the design extents where there were no formal defences. Flood zone A was derived from the 1%AEP fluvial and 0.5%AEP coastal extents. Flood Zone B was derived from the 0.1%AEP fluvial and 0.1%AEP coastal extents.

## 8.5 Combined Flood Source Mapping

Dingle AFA, Laune MPW and Maine MPW are subject to flooding from both fluvial and tidal influence. Therefore, the fluvial-dominant flood extent was merged with the tidal-dominant flood extent to produce the maximum flood extent from both sources. It should be noted that this does not represent a target %AEP assessed in the joint-probability, but provides a useful summary of the maximum extent from both sources.

## 8.6 Flood Risk (Assessment) Mapping

### 8.6.1 General Flood Risk Maps

The potential adverse consequences (risk) associated with flooding in each of the AFA's was assessed and mapped against four risk receptor groups:

- Society (including risk to people)
- The Environment
- Cultural Heritage
- The Economy

Maps were produced by overlaying flood extents for key AEP events on GIS datasets for each of the four receptor groups separately. Depending on the density of the receptors at each AFA, separate maps were prepared for each receptor or combined on a single map.

### 8.6.2 Specific Flood Risk Maps

Specific Flood Risk maps are required for key indicators. These include the following:

- Indicative Number of Inhabitants
- Types of Economic Activity
- Economic Risk Density

#### 8.6.2.1 Indicative Number of Inhabitants

For each AFA, the study area was broken into a number of grids, each 100m<sup>2</sup> (i.e. 1 Ha). The population density per Ha was calculated by summing the number of residential properties within each grid and multiplying by an average occupancy rate determined by the Central Statistics Office.

#### 8.6.2.2 Types of Economic Activity

Each property within an AFA was assigned a use, which was based on the property survey. The types of economic activity were identified and intersected with the 10%, 1% and 0.1%AEP fluvial extents and 10%, 0.5% and 0.1%AEP coastal extents to generate the datasets listed in Table 8.2. The resultant economic activity at risk have then been mapped for these key %AEP events.

Table 8.2: Derived Datasets of Economic Activity at Risk

Economic Activity	Derived Dataset	Description
Buildings	Buildings in flood (DG)	Buildings located in modelled flood extents
Infrastructure	Infrastructure in flood extents(DI)	Existence of infrastructure in flood extent
Commercial	Commercial use within flood extents(DK)	Existence of commercial land use in flood extent
Rural	Rural land use in flood extents(DJ)	Existence of rural land use in flood extent

### 8.6.2.3 Economic Risk Density

The maximum depth of flooding was extracted for each building polygon for the full range of AEP events using the results of the hydraulic modelling and flood mapping.

The calculation of flood damages was based on the Flood Hazard Research Centre Handbook of 2010 (FHRC, 2010) and the “Multi-Coloured Manual” of 2005 (FHRC, 2005) as referred to in FHRC 2010, subject to caveats, amendments and clarifications as set out in the National CFRAM Programme Guidance Note No.27 Rev C.

Damage costs were converted to euro by applying a Purchasing Price Parity multiplication factor and an inflation factor. For Residential Properties damage costs were calculated based on the depth of flooding and the corresponding unit cost of damage for property type. For Non-residential Properties damage costs were calculated based on the depth of flooding and the unit cost of damage for property type per m<sup>2</sup>.

Following the calculation of the estimated cost of damages for the full range of AEP events, the Annual Average Damage (AAD) for each property will be calculated. The AAD for each property within each 100m<sup>2</sup> (i.e. 1 Ha) grid was summed and represented on a map providing the economic risk density (€ AAD / Ha).

## 9 Model and Mapping Results

### 9.1 Overview

Based on the model predicted results and flood maps, the greatest fluvial flood risk to properties and infrastructure in UoM22 is located in Castleisland where flooding starts at the 5%AEP. Flood risk is also significant in Dingle and Milltown AFAs from the 10%AEP and the N22 along the Flesk is affected by the 50%AEP and larger events. There is also extensive fluvial flooding of agricultural and pastoral land along the Maine and Lower Laune from the 5 %AEP fluvial event and 50%AEP coastal current event.

Regular fluvial flooding was predicted in Killarney AFA, but this was contained to the valley floodplain and Killarney National Park areas. However, properties were not affected until the 0.1%AEP.

The following sections summarise the key findings for each AFA to highlight the flooding issues identified in the flood maps. A more detailed assessment of receptors at risk and implications for the receptors is discussed in the subsequent Flood Risk Assessment.

### 9.2 Castleisland AFA

Map 9.1 summarises the fluvial flood risk in Castleisland for the 10%, 1% and 0.1%AEP design scenarios. The key flow routes and flooding mechanisms predicted by the model are as follows:

- Overtopping of the Glanshearoon right bank at Crag Cottages into a swallow hole and connected to increased flows and flooding along Anglore Stream (Figure 9.1)
- Overtopping of the left bank of Anglore Stream at Glebe House Road Bridge and flowing across the road to flood properties.
- Backwater from the downstream culvert on Anglore Stream flooding properties in Tullig – This corresponds with regular flooding along Cordal Road. However the flooding is shallow and the extent may be reduced by local urban drainage not considered in this model.
- Backwater from Herbert's and Barrack Lane Bridge cause overtopping of the Maine downstream of Church Street bridge to flood properties on the left bank.
- Backwater from Church Street Bridge causes overtopping of the Maine upstream of the bridge to flood properties on the right bank.
- In the most extreme events, flood waters flow across the road at Castleisland Community College and into the neighbouring catchment towards Killfinnaun Bridge.

The key thresholds and areas affected by flooding in Castleisland are:

- 50%AEP fluvial event overtops the river bank at Crag Cottages and enters the Crag Cave.
- 50%AEP fluvial event exceeds the downstream culvert on Anglore road to flood Tullig (Approximately 50 properties).
- 2% AEP fluvial event overtops the left bank downstream of Church Street but no properties are affected.
- 1% AEP fluvial event overtops the left bank downstream of Church Street and causes limited flooding to less than ten properties.
- 0.1% AEP fluvial event overtops the right bank upstream of Church Street and causes extensive property flooding (> 300 properties).
- 0.1% AEP fluvial event floods across the Community College and into the Killfannaun catchment.



The greatest risk to life is associated with deep and fast flowing water flooding on the left bank downstream of Church Street, and along the R577 from the Maine and across Glebe House Road from Anglore Stream. However, the risk to life at Tullig is low to moderate because the flooding is shallow.

The critical structures in determining fluvial flood risk include:

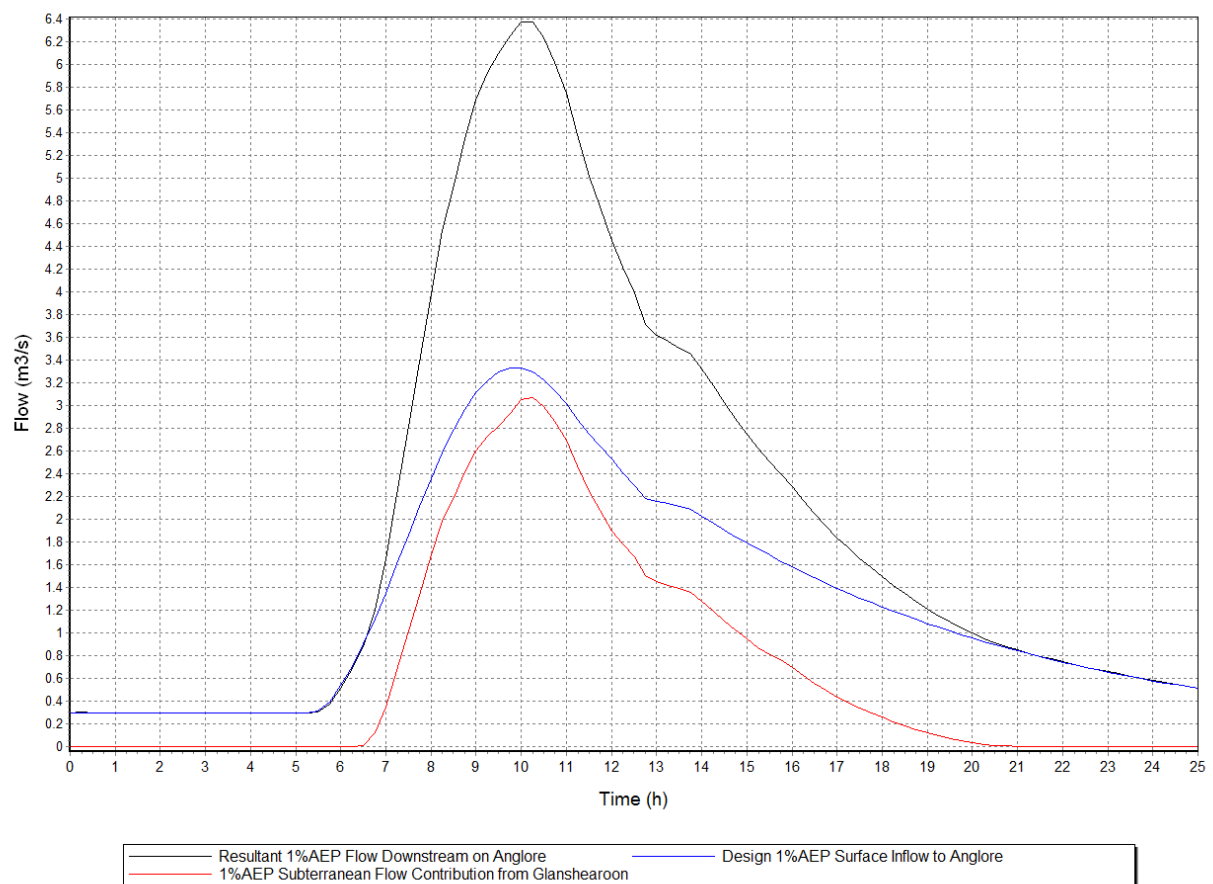
- Herbert's, Barrack Lane and Church Street Bridges on the River Maine including the utility crossing below the soffit on Hebert's and Barrack Lane Bridge.
- The raised river bank at Crag Cottages which determines the threshold at which the Glanshearoon floods into the swallow hole, thereby increasing flows through the cave system to Anglore Stream.
- Glebe House Road Bridge and the downstream culvert on Anglore Stream.

The areas flooded are consistent with the recorded flooded areas in 2008 and the more recent event in January 2014. The subterranean flow path between Glanshearoon and Anglore was highlighted by local authority staff during the flood risk review and confirmed by site visits during this study. The exact route, capacity of the cave system, and travel time of these subterranean flows, are not easily quantified. However, the model was calibrated well with the flood extent in the 2008 event. Therefore there is reasonable confidence in the flood mapping in Castleisland based on the information available at the time of this study.

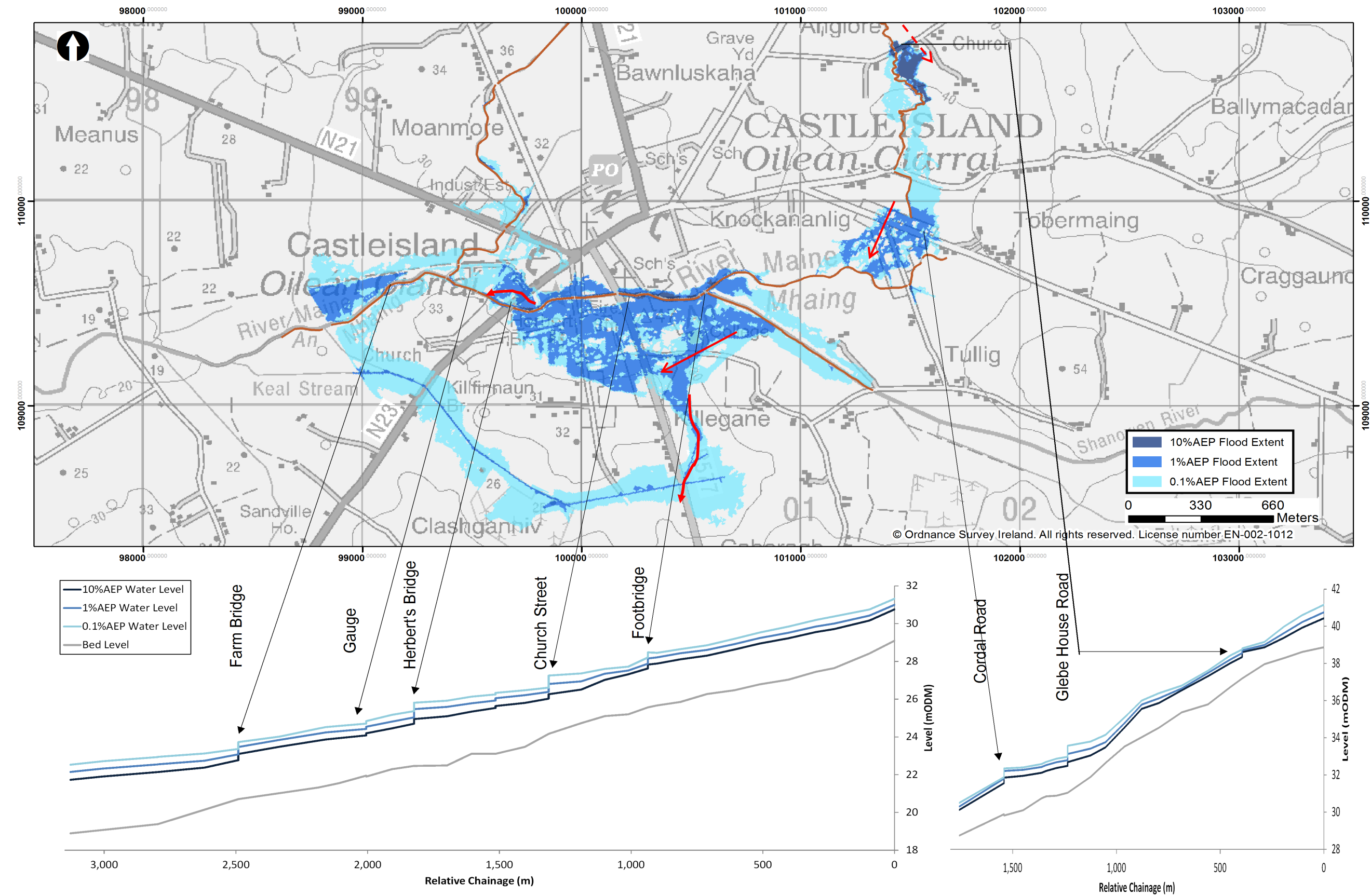
The following recommendations for flood risk management option development can be made:

- Improved conveyance at and around the Maine bridges identified to increase channel capacity without increased erosion.
- Improved conveyance through Glebe House Road Bridge and the downstream culvert on Anglore Stream to improve channel capacity.
- Raised river banks and/or other protection measures to limit the amount of water entering swallow holes from the Glanshearoon.
- Flood warning is likely to be effective given the > 6 hours' time to peak for both the Glenshearoon and Upper Maine catchments.

Figure 9.1: Increased Flow on Anglore Stream from the Glanshearoon-Crag Cave Subterranean route



Map 9.1: Summary of Fluvial Flood Risk – Castleisland



### 9.3 Milltown AFA

Map 9.2 summarises the fluvial flood risk in Milltown for the 10%, 1% and 0.1%AEP design scenarios. The key flow routes and flooding mechanisms predicted by the model are as follows:

- Overtopping of Ballyoughtrough along Old Station Road due to the capacity of the culverts and flooding towards Rathpoge East. Less than 10 houses are affected by flooding.
- Overtopping of Ballyoughtrough along Old Station Road due to the capacity of the twin culvert and flooding towards Ashullish Stream.
- Backing up from the N70 bridge and bypassing of the footbridge upstream in Milltown.
- Overtopping of the right bank and bypassing of the N70 bridge on Bridge Street in predicted climate change conditions.
- Backing up of water in the raised embankment reach during periods of high tide in the Maine, combined with high fluvial flows overtopping the raised embankments at the confluence of Ballyoughtrough and Ashullish Streams.
- The raised embankments at the outfall protect 0.425km<sup>2</sup> from flooding up to and including the 2%AEP fluvial event.

The key thresholds and areas affected by flooding are:

- 50%AEP event exceeds the capacity of the Ballyoughtragh Stream downstream of the N70 causing water to spill over the right bank in two locations. This is modelled to impact a single property.
- 50%AEP overtops at the confluence of the Ballyoughtragh and Ashullish Streams at low points in the embankments to flood fields.
- 10%AEP causes shallow flooding by the N70 at Hurley's Bridge.
- 2%AEP event causes additional sections of the Ballyoughtragh Stream downstream of the N70 to spill, impacting additional properties.
- 1%AEP event floods the N70 at Town Bridge on the Ashullish Stream
- 0.5%AEP event bypasses town bridge
- Approximately 17 properties are affected by the 1%AEP fluvial event.

It should be noted that the drainage system and tributaries towards Cloonmore and Kilburn has not been modelled as part of the CFRAM study as these are not MPW or HPWs.

The greatest risk to life is associated with deep water on the left bank of Ballyoughtrough Stream upstream of the confluence with Ashullish Stream. However, no properties are affected by flooding in this area. Flooding along Old Station Road is classified as low to moderate risk to life because the flooding is shallow up to the 1%AEP. However, risk to life along Old Station Road increases to significant in the 0.1%AEP fluvial event.

The critical structures in determining fluvial flood risk include:

- The culverts on Ballyoughtrough stream along Old Station road, particularly the downstream triple culvert at 082195,101423 in combination with upstream triple culvert at 082432,101235.
- The raised embankments and flapped outfall at the outfall to the Maine for flood risk to the surrounding low-lying ground.
- The N70 road bridge for flood risk near Bridge Street in Milltown.

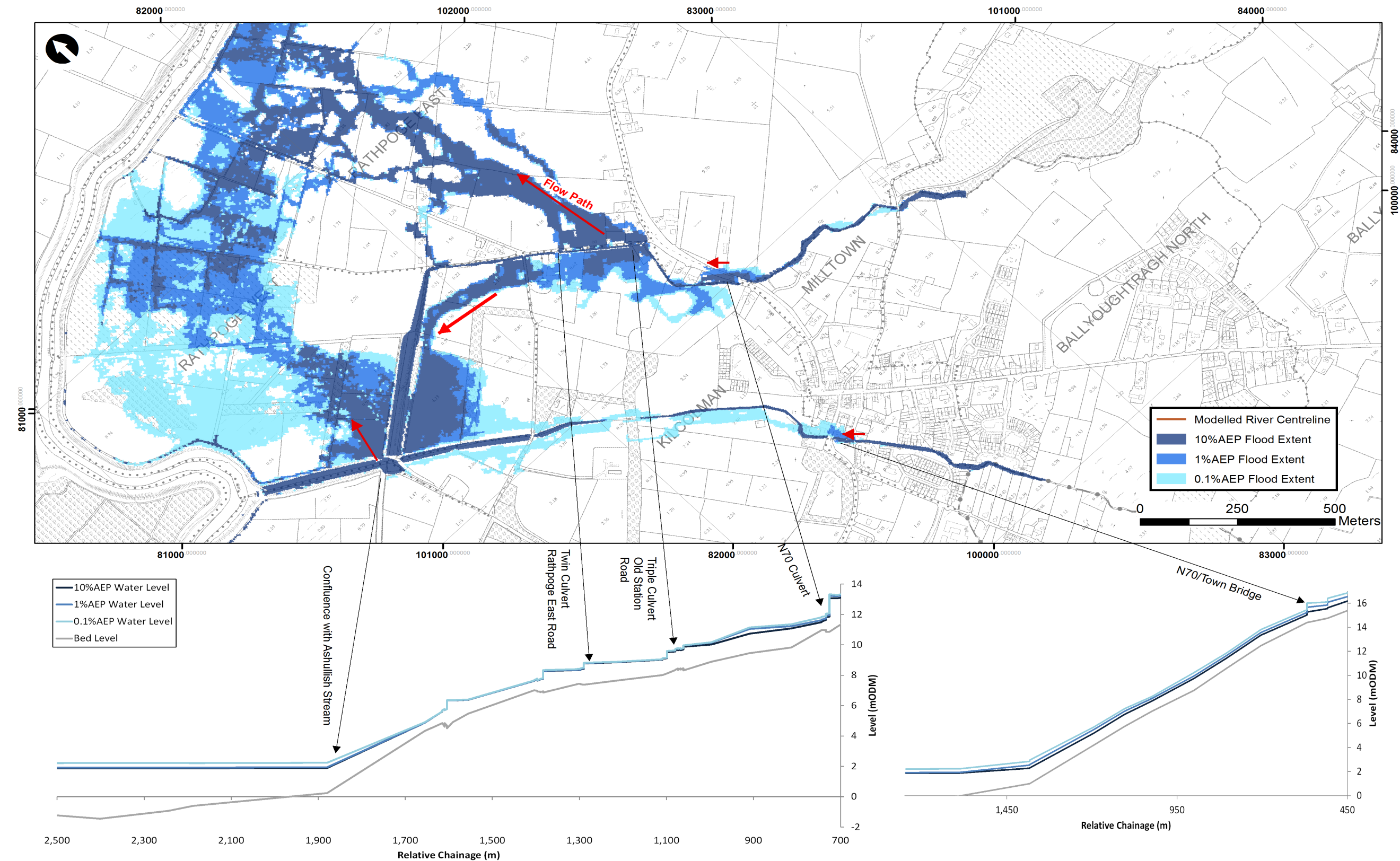
The areas flooded are consistent with the recorded flooded areas in January 2008 and the comments by local authority staff and local residents during the flood risk review. The sensitivity test demonstrated the uncertainty in flow estimates, roughness and culvert coefficients did not significantly increase levels in the upper reaches. Therefore there is reasonable confidence in the flood mapping in the upstream reaches. However, the uncertainty in flow estimates did significantly affect flood risk near the outfall. Therefore, the flood mapping in this area should be carefully considered with the limitations of the ungauged hydrology methodology.

The following recommendations for flood risk management option development can be made:

- Improved conveyance at and around the culverts along Old Station Road.
- Improved conveyance at and around the N70 bridge on Bridge Street.
- Flood storage is more appropriate in the upstream reaches beyond the backwater effect from the Maine.
- Flood warning is unlikely to be effective given the short time to peak for these steep catchments.



Map 9.2: Summary of Fluvial Flood Risk – Milltown



## 9.4 Glenflesk AFA

Map 9.3 summarises the fluvial flood risk in Glenflesk AFA and flood risk to the N22 upstream for the 10%, 1% and 0.1% AEP design scenarios. The key flow routes and flooding mechanisms predicted by the model are as follows:

- Flooding of the N22 raised road embankment between Garries Bridge and Annagh Beg Bridge due to the limited floodplain capacity between the N22 and Islandmore road parallel to the channel.
- Overtopping of the N22 raised road embankment at Loo Bridge due to backing up from the bridge and flood relief structures.
- Backing up from the rapids at 105030,087205 and the confluence to overtop of the right bank of the Flesk at Glenflesk and left bank of the Ownyskeagh, largely flooding fields but limited property flooding (less than 5 in number) upstream of Curreal Bridge.

The key thresholds and areas affected by flooding are:

- 50% AEP inundates the floodplain and encroaches onto the N22. Surface water runoff onto the road is not considered in the CFRAMS model.
- 10% AEP event overtops the N22 downstream of Garries Bridge and 5% AEP floods the N22 from Glenflesk to Garries Bridge.
- 0.1% AEP causes significant flooding along all modelled watercourses. There is extensive inundation in Glenflesk and Islandmore. The N22 and property along its path are completely flooded upstream of the confluence of the River Flesk and Annagh Beg Stream.
- Limited property flooding along the right bank in the 2% AEP and larger fluvial events.

The greatest risk to life is associated with deep water flooding between the Flesk and Ownyskeagh Rivers but does not affect properties or roads. The risk to life upstream of Annagh Beg Bridge was not calculated as it is MPW and hazard is not required.

The critical structures in determining fluvial flood risk include:

- The rapids at 105030,087205 which determine water levels in Glenflesk AFA.
- The raised road embankments of the N22 and Islandmore road.
- Loo Bridge and the flood relief culvert limiting the flow passing under the N22.

The areas flooded are consistent with the recurring flooding along the N22, which is reported almost every year by local authority staff. The sensitivity test demonstrated the uncertainty in flow estimates and roughness which increased water levels but did not significantly increase flood extent and hazard, as the narrow valley is largely flooded even in the 50% AEP event. Therefore there is reasonable confidence in the flood mapping.

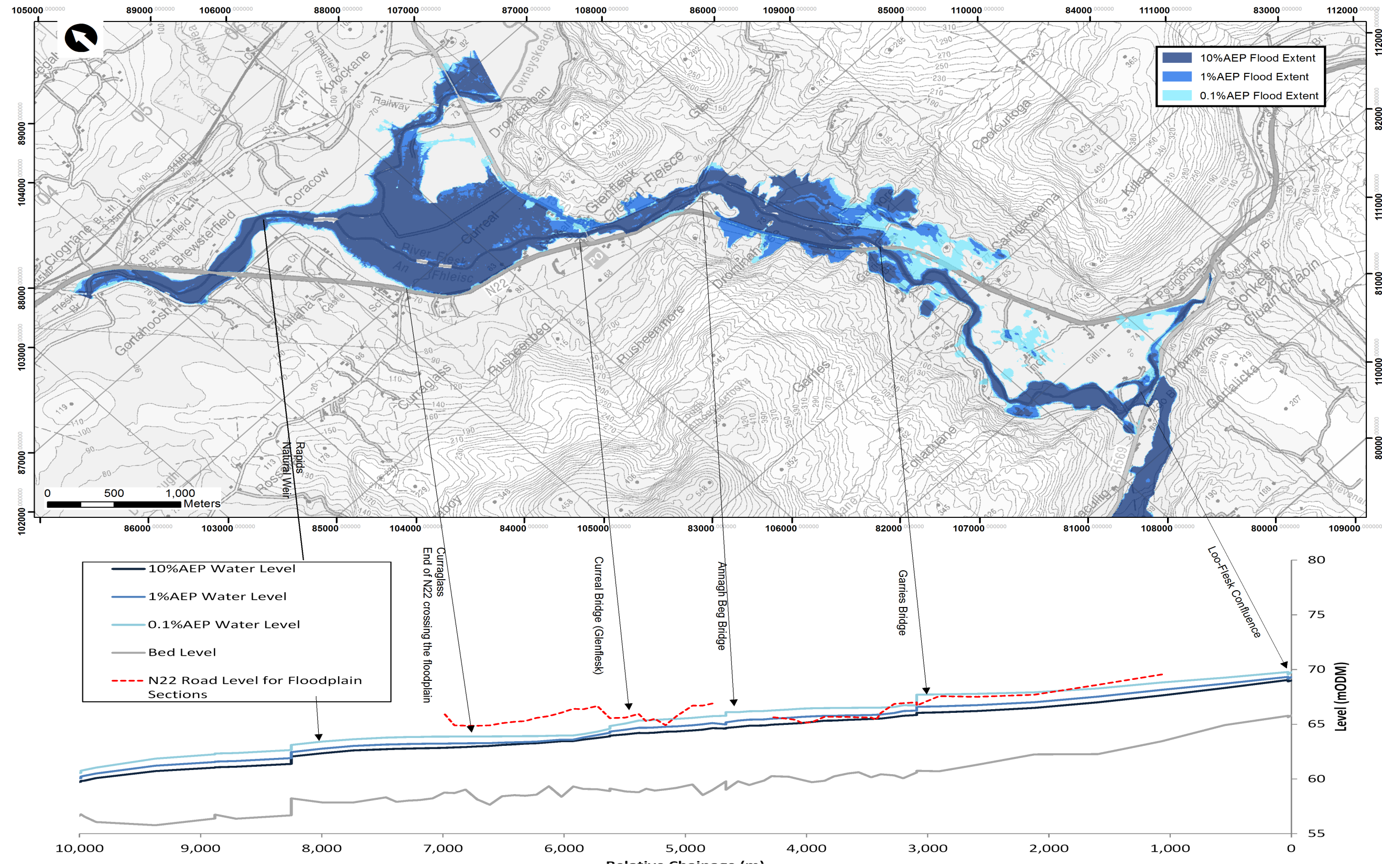
The following recommendations for flood risk management option development can be made:

- Improved conveyance at the rapids downstream of Glenflesk would control water levels upstream.
- Increased storage on the floodplain and/or raising of the road embankments may reduce flood risk upstream of Glenflesk.

- Improved conveyance at and around Loo Bridge and the flood relief culvert could reduce flood levels upstream of Loo Bridge.
- Flood warning is possible for the receptors at risk given the relatively long lead time and gauges in the upper catchments of the Clydagh and Owneyskeagh Rivers.



Map 9.3: Summary of Fluvial Flood Risk- Glenflesk



## 9.5 Killarney AFA

Map 9.4 summarises the fluvial flood risk in Killarney AFA for the 10%, 1% and 0.1%AEP design scenarios. The key flow routes and flooding mechanisms predicted by the model are as follows:

- Backing up from Lough Leane inundating the alluvial forests in the National Park.
- Backing up from White Bridge (Flesk) to bypass on the left and right banks, flooding Ballycasheen and Mill Road.
- Backing up from Flesk Bridge to flood the right bank at Muckcross Grove before flowing along Muckcross Road and towards the Deenagh in extreme events only.
- Backing up from the roundabout and Deenagh Lodge Bridge to overtop the right bank and the N22 in extreme events.

The key thresholds and areas affected by flooding are:

- 50%AEP fluvial event floods the National Park downstream of the town on both the Deenagh and Flesk.
- 1%AEP fluvial event bypasses White Bridge (Flesk) to flood Ballycasheen and Mill Road. Properties affected in the 0.1%AEP event only.
- 0.1%AEP fluvial event overtops the right bank upstream of Flesk Bridge.
- 2%AEP fluvial event overtops left bank upstream of the roundabout and Deenagh Lodge Bridge.

The greatest risk to life is associated with deep and fast flow water on the right bank between White Bridge (Flesk) and Flesk Bridge, but this does not affect properties or roads in the 1%AEP event. In the 0.1%AEP event, risk to life is classed as significant to flooded properties along Muckcross, Muckcross Road and Ballycasheen Road due to the velocity of water.

The critical structures in determining fluvial flood risk include:

- The culvert under the Ballydowney roundabout and old bridge crossing immediately downstream on the Deenagh.
- Deenagh Lodge Bridge for flooding to Port Road.
- White Bridge on the Flesk for properties along Mill Road and Ballycasheen Road in extreme events.
- Flesk Bridge and the weir downstream but only in the most extreme events.

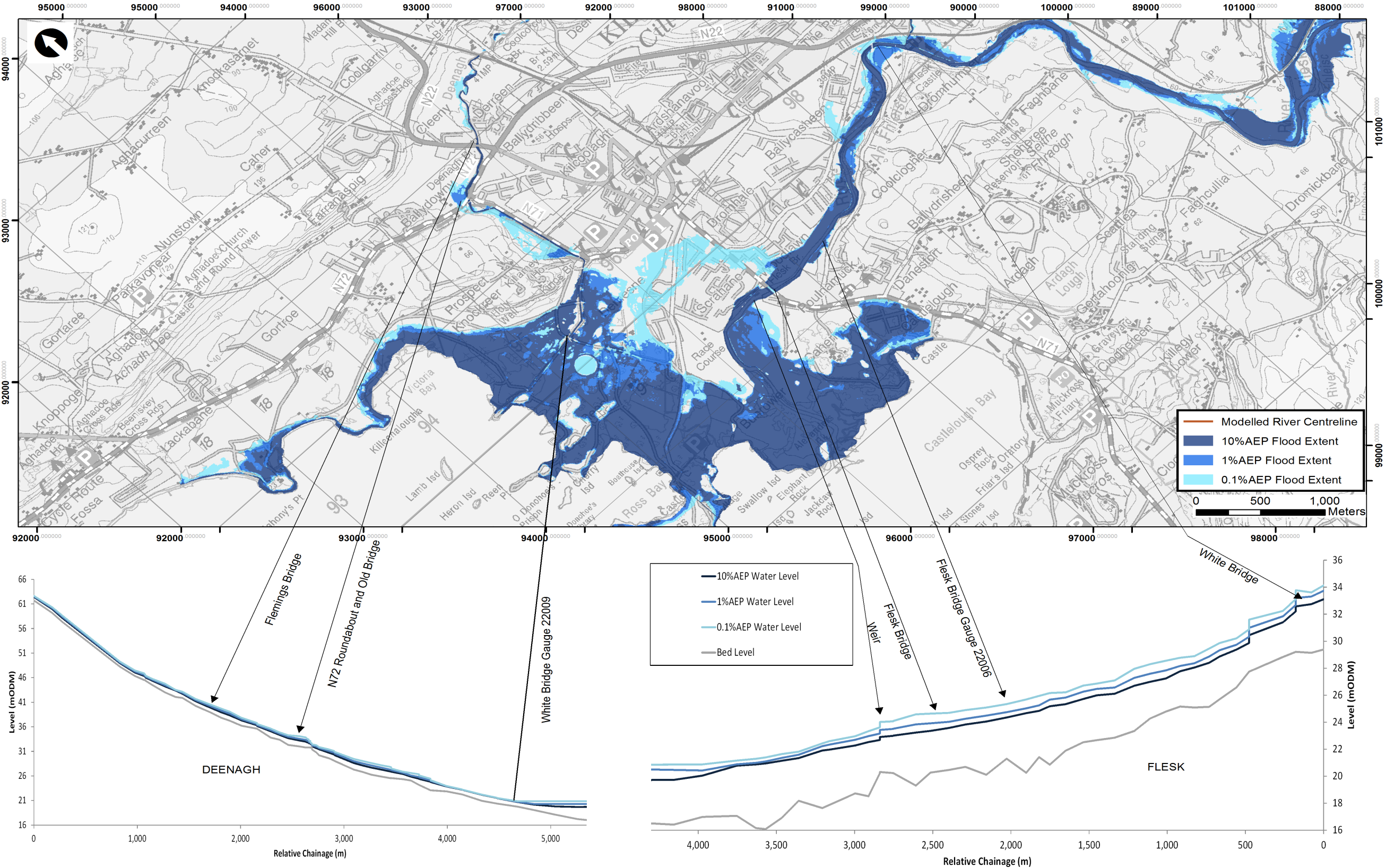
The areas flooded are consistent with the lakeside property flooding reported in 2009 (See Section 5.1.3) and limited property flooding upstream of Flesk Bridge and Deenagh Lodge. Therefore there is reasonable confidence in the flood mapping.

The following recommendations for flood risk management option development can be made:

- Improved conveyance along Port Road, focussing on the critical structures at the roundabout and Deenagh Lodge.
- Flood Warning from Lough Leane and the Flesk is possible given the long lead times to the flood peak and active gauges upstream on the Flesk.
- There is a shorter lead time on the Deenagh but flood warning should still be possible subject to a high flows gauge review at White Bridge (Deenagh).



Map 9.4: Summary of Fluvial Flood Risk - Killarney



## 9.6 Dingle AFA

Map 9.5 summarises the fluvial flood risk in Dingle AFA for the 10%, 1% and 0.1%AEP design scenarios. The key flow routes and fluvial flood mechanisms predicted by the model are as follows:

- Overtopping of the right bank along Spa Road due to flows exceeding the capacity of bridges and culverts although flooding is very shallow (< 0.1m) for smaller events.
- Overtopping of both banks at the low spots of Lana na h'Abhann and Hudson's Bridge causing flooding of The Mall and Bridge Street
- Backing up from Milltown Bridge to overtop the bridge on the right bank and the R459 on the left bank near the junction.

The key fluvial thresholds and areas affected by flooding are:

- 10%AEP Fluvial Current Scenario exceeds the capacity of Dingle Stream to cause very shallow flooding (< 0.1m) along Spa Road and the Mall.
- 2%AEP Fluvial Current Scenario on Milltown Stream overtops Milltown Bridge on the right bank and the R459 on the left bank but does not affect properties.
- 1% - 0.5%AEP Fluvial Current Scenario floods the Library site on Milltown Stream.

The key flow routes and coastal flood mechanisms predicted by the model are as follows:

- Dingle Stream is tidally influenced downstream of the weir near Hudson's Bridge.
- Milltown Stream is tidally influenced downstream of the Ballymoretreagh confluence.
- Overtopping of the road at The Woods but does not affect properties.
- Overtopping of the left bank downstream of the roundabout on Dingle Stream, but does not affect properties.
- Overtopping of Milltown Bridge and the quayside at Strand Street in more extreme events.

The key coastal thresholds and areas affected by flooding are:

- 20%AEP Coastal Current Scenario overtops the road at The Woods, but does not affect properties.
- 10%AEP Coastal Current Scenario overtops the left bank of Dingle Stream downstream of the roundabout but does not affect properties.
- 2%AEP Coastal Current Scenario overtops around Milltown Bridge and the quayside at Strand Street, but does not affect properties.
- 1%AEP Coastal Current Scenario affects properties on Strand Street from overtopping of the quay and flooding upstream of Bridge Street.
- Approximately 20 properties are effected by the 0.5%AEP Coastal Current Scenario.

The greatest risk to life is associated with deep water at Bridge Street and fast flowing water down Spa Road and The Mall, which is classed as significant in the 10%AEP event and greater magnitude events.

The critical structures in determining fluvial flood risk include:

- On Dingle Stream:
  - Access Bridge and river bend downstream of Sruthean Beag estate
  - Brewery Access Bridges
  - Spa Road culvert
  - Lana na hAbhann
  - Hudson's Bridge
  - Bridge Street culvert
- On Milltown Stream:
  - Milltown Bridge

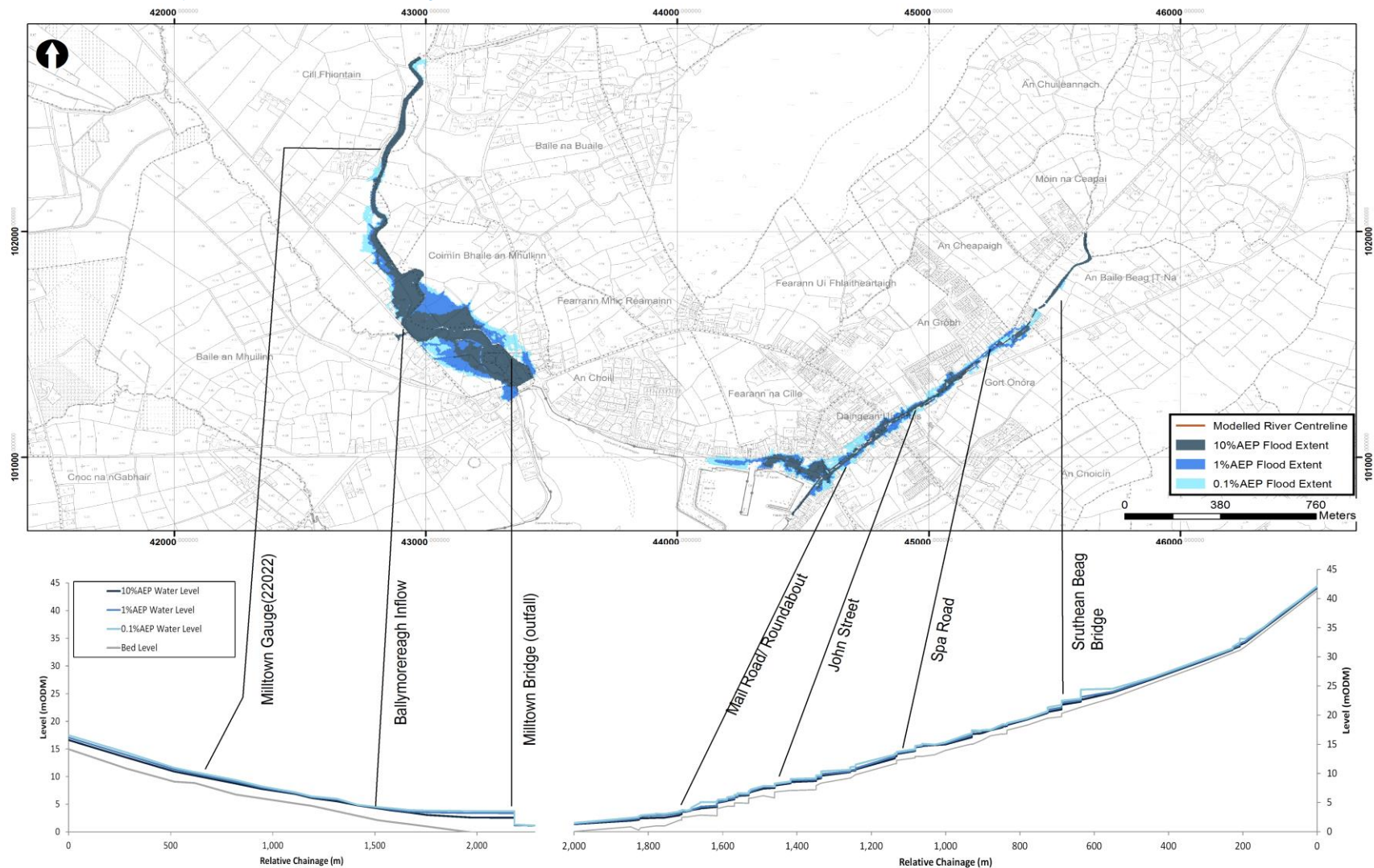
The areas flooded are consistent with those photographed in the January 1988 event and the recurring flood reports on floodmaps.ie. Therefore there is reasonable confidence in the flood mapping.

The following recommendations for flood risk management option development can be made:

- Increased conveyance measures should be considered for the critical structures identified above.
- There is limited storage available upstream of the AFA on Dingle Stream to enable any storage or attenuation measures.
- Flood Warning is not likely to be feasible on Dingle Stream given that the time to peak is less than 5 hours.



Map 9.5: Summary of Fluvial Flood Risk in Dingle



Map 9.6: Summary of Coastal Risk in Dingle





## 9.7 Portmagee AFA

Map 9.6 summarises the coastal flood risk in Portmagee AFA for the 10%, 0.5% and 0.1%AEP design scenarios. The key flow routes and flooding mechanisms predicted by the model are as follows:

- Overtopping of the quayside at the Car Park and behind the Restaurant, but no property flooding under current conditions.
- Minor overtopping at The Old School spillway but no property flooding under current conditions.
- Overtopping of the R565 to the east but this does not affect flood risk in the AFA.

The key thresholds and areas affected by flooding are:

- 10%AEP overtops the R565 to the east of the AFA.
- 10%AEP overtops The Old School slipway but no property flooding under current conditions.
- 0.5%AEP overtops the quayside but no property flooding under current conditions.

Risk to life is classified as low within the AFA for the 0.5%AEP coastal event, increasing to moderate in the 0.1%AEP coastal event under current and future climate conditions.

The critical structures in determining fluvial flood risk include:

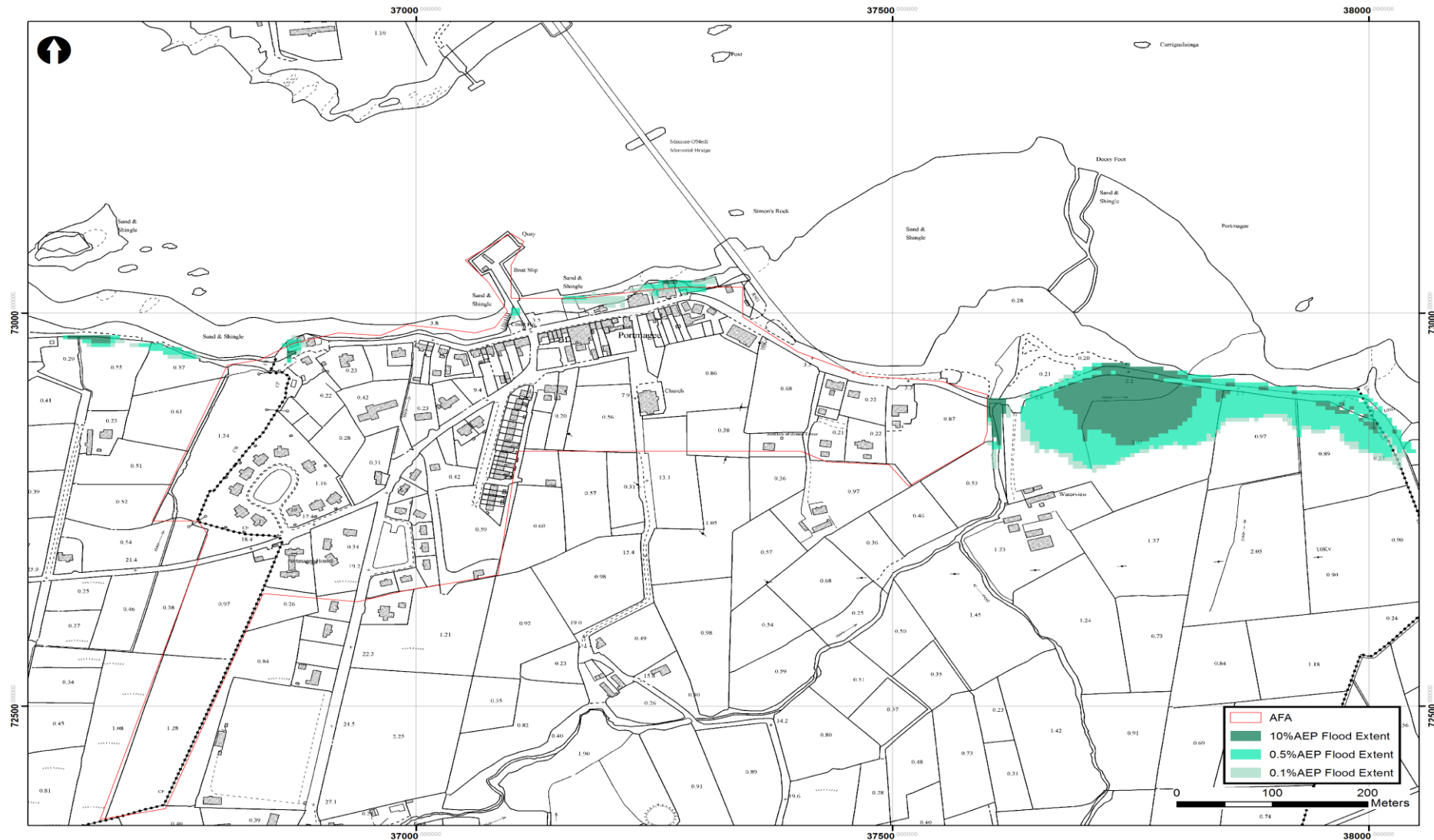
- The quayside wall/car park level.

It should be noted that the R565 levels are based on IFSAR data rather than LIDAR, so the road level is only accurate to +/- 0.7m. However levels in the AFA are based on LIDAR data and are deemed to be accurate to +/- 0.2m. There are no reports of flooding at this AFA. Therefore there is reasonable confidence in the flood mapping within the AFA.

There is very low coastal flood risk to receptors within the AFA under current conditions. This risk could increase marginally to affect less than 5 quayside properties under the HEFS scenario. The following recommendations for flood risk management option development can be made for the HEFS:

- Raised quayside wall levels and individual property protection.
- Flood Warning is possible given the long lead times of storm surge events and known astronomical tides.
- Flood storage is not applicable for coastal flooding because the flooding is not volume dependent on the open coast.

Map 9.7: Coastal Flood Risk in Portmagee



# 10 Summary and Recommendations

## 10.1 Key Findings

The hydraulic analysis for UoM22 has developed eight hydraulic models to assess current and future flood risk from the 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1% AEP fluvial and tidal flood events. The design flood levels and flows were then processed to map flood extent, flood depth, flood velocity and flood hazard in the six AFAs and flood extent and depth maps for MPW reaches downstream.

### Historic flood events

- The Castleisland model matched well with the gauged and flood report information for the 4<sup>th</sup> October 2008 event. The design model outline was also validated with locations which are known to flood.
- The Killarney model tended to overestimate water level by 0.1 to 0.2m following calibration of the weir coefficient downstream. However the flood extent matched well with recorded flooding in both events.
- The in-bank calibration on the Maine indicated good performance of the model at Riverville and Castlemaine. However, concurrent gauge information for flood events was limited to calibrate the model further.
- Validation of the design Glenflesk, Milltown and Dingle models against historic flood reports of recurring flooding also indicated the models were predicted the correct areas at risk.

### Sensitivity test results

- Dingle and Maine models are sensitive to the assumptions and uncertainties in the extreme sea levels.
- Seasonal changes in vegetation or uncertainty in roughness values only increased flooding in Castleisland and to the N22 in Glenflesk at the 1% AEP. However, maintenance of the channel may provide some benefit for events which are closer to the threshold of flooding.
- The flood risk in Milltown was not deemed sensitive to the culvert coefficients applied at the 1% AEP fluvial event. However, increasing coefficients did reduce the culvert capacity and cause flooding earlier in the event. Therefore, the effective capacity of the culverts and any blockage should be carefully considered when interpreting flood maps and deriving flood risk management options to reduce flooding in more frequent event.

## Model and mapping results

The hydraulic modelling and mapping results for the design scenario under current conditions, the mid-range future scenario and high-end future scenario were analysed. The key findings are summarised below.

- The greatest fluvial flood risk to properties and infrastructure in UoM22 is located in Castleisland where flooding of properties starts at the 50%AEP in Tullig and the 5% to 2%AEP through the town itself.
- There is regular flooding in the Milltown AFA from and the N22 along the Flesk is affected by the 50%AEP and larger events.
- There is also extensive flooding of agricultural and pastoral land along the Maine and Lower Laune from the 5%AEP fluvial current event and 50%AEP coastal current event.
- Regular fluvial flooding was predicted Killarney AFA but this was contained to the areas around White Bridge and Killarney National Park. However, properties along Muckross Road were not affected until the 0.1%AEP.

## 10.2 Recommendations

The following recommendations can be drawn from the key findings above for the subsequent flood risk assessment, preliminary option development and FRMP:

- The uncertainty and sensitivity to peak flow and duration estimates should be considered in the sizing and operation of any flood management options based on the storage of flood waters in Castleisland Lower Maine, Killarney, Milltown and Glenflesk.
- The uncertainty in the total tide plus surge levels should also be considered in the development of any flood embankment/walls to protect against coastal flooding in Dingle and the Lower Maine and Laune.
- The effective capacity of the culverts in Milltown and any blockage should be carefully considered when interpreting flood maps and deriving flood risk management options to reduce flooding in more frequent events.
- The crest level of the Lower Maine embankments is quite variable. Therefore, infilling works (temporary or permanent) of the low points should be considered to reduce overtopping and protect the integrity of the defence.

The following recommendations can be drawn from the hydraulic analysis for future analysis in UoM22:

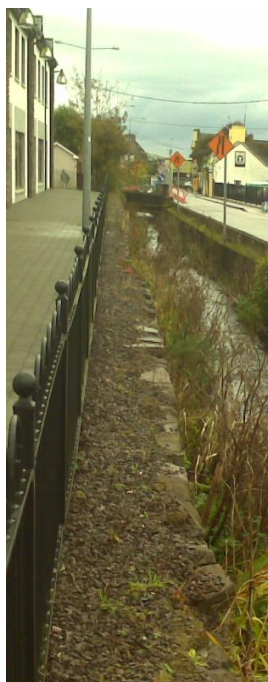
- It is recommended that post-flood surveys are continued for all significant future flood events where properties and/or infrastructure are affected. Data should be collected shortly after the event and include: sources of flooding, timing of overtopping, any actions taken and at what time, blockages of structures, flood levels in the channel and on the floodplain, and accompanying photographs.
- It is recommended that additional calibration be undertaken when concurrent gauge information is available in the Flesk catchment and Maine catchment.



# Glossary

<b>AAD</b>	Annual Average Damage: Average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
<b>AEP</b>	Annual Exceedance Probability; this represents the probability of an event being exceeded in any one year and is an alternative method of defining flood probability to 'return periods'. The 10%, 1% and 0.1% AEP events are equivalent to 10-year, 100-year and 1000-year return period events respectively.
<b>AFA</b>	Area for Further Assessment – Areas where, based on the Preliminary Flood Risk Assessment and the CFRAM STUDY Flood Risk Review, the risks associated with flooding are potentially significant, and where further, more detailed assessment is required to determine the degree of flood risk, and develop measures to manage and reduce the flood risk.
<b>AMAX</b>	Annual Maximum Flood
<b>CFRAM</b>	Catchment Flood Risk Assessment and Management – The 'CFRAM' Studies will develop more detailed flood mapping and measures to manage and reduce the flood risk for the AFAs.
<b>DTM</b>	Digital terrain model; elevation of the bare ground surface without any objects like plants, buildings and man-made structures.
<b>EU</b>	European Union
<b>EPA</b>	Environmental Protection Agency
<b>FRMP</b>	Flood Risk Management Plan. This is the final output of the CFRAM study. It will contain measures to mitigate flood risk in the AFAs.
<b>FRR</b>	Flood Risk Review – an appraisal of the output from the PFRA involving on site verification of the predictive flood extent mapping, the receptors and historic information.
<b>FSU (WP)</b>	Flood Studies Update (Work Package) (2008 to 2011)
<b>FSR</b>	Flood Studies Report (HR Wallingford, 1975)
<b>GIS</b>	Geographical Information Systems
<b>HA</b>	Hydrometric Area. Ireland is divided up into 40 Hydrometric Areas.
<b>HEFS</b>	High-End Future Scenario to assess climate and catchment changes over the next 100 years assuming high emission predictions from the International Panel on Climate Change.
<b>HEP</b>	Hydrological Estimation Point
<b>HPW</b>	High Priority Watercourse. A watercourse within an AFA.
<b>ICPSS</b>	Irish Coastal Protection Strategy Study (2012)
<b>ICWWS</b>	Irish Coastal Water Level and Wave Study (2013)
<b>IFSAR</b>	Inter-ferometric Synthetic Aperture Radar used to derive ground elevation remotely from satellite platforms.

<b>ING</b>	Irish National Grid system, Ordnance Survey of Ireland
<b>LiDAR</b>	Light and Detection Ranging used to derive ground elevations from ground based or aerial platforms.
<b>MPW</b>	Medium Priority Watercourse. A watercourse between AFAs, and between an AFA and the sea.
<b>MRFS</b>	Mid-Range Future Scenario to assess climate and catchment changes over the next 100 years assuming medium emission predictions from the International Panel on Climate Change.
<b>ODM</b>	Ordnance Datum Malin.  The current geodetic datum of Irish National Grid which references the mean sea level at Malin Head between 1960 and 1969.
<b>OPW</b>	Office of Public Works, Ireland
<b>OSi</b>	Ordnance Survey Ireland
<b>PFRA</b>	Preliminary Flood Risk Assessment – A national screening exercise, based on available and readily-derivable information, to identify areas where there may be a significant risk associated with flooding.
<b>QMED</b>	Median annual flood used as the index flood in the Flood Studies Update. The QMED flood has an approximate 50%AEP.
<b>SAAR</b>	Standard average annual rainfall 1961 to 1990
<b>SEA</b>	Strategic Environmental Assessment. A high level assessment of the potential of the FRMPs to have an impact on the Environment within a UoM.
<b>SW CFRAM</b>	South Western Catchment Flood Risk Assessment and Management study
<b>UoM</b>	Unit of Management. The divisions into which the RBD is split in order to study flood risk. In this case a HA.
<b>UPO-ERR Gamma Curve</b>	Unit-Peak-at-Origin Gamma curve coupled with an Exponential Replacement Recession curve. Developed in the Flood Studies Update Work Package 3.1 Hydrograph Width Analysis to derive design flood hydrographs.
<b>WFD</b>	Water Framework Directive. A European Directive for the protection of water bodies that aims to, prevent further deterioration of our waters, to enhance the quality of our waters, to promote sustainable water use, and to reduce chemical pollution of our waters.



# South Western CFRAM Study

Hydraulics and Flood Mapping Appendices,  
Unit of Management 22  
November 2017

The Office of Public Works





# South Western CFRAM Study

Hydraulics and Flood Mapping Appendices,  
Unit of Management 22

November 2017

The Office of Public Works

Johnathan Swift Street,  
Trim,  
Co. Meath



# Issue and revision record

Revision	Date	Originator	Checker	Approver	Description	Standard
A	June 2014	M Piggott	R Gamble B O'Connor	R Gamble	Draft	
B	September 2014	M Piggott	R Gamble B O'Connor	R Gamble	Draft Final	
C	November 2017	M Piggott	B O'Connor	B O'Connor	Final	

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# Appendices

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# Appendix A. Castleisland AFA Model Proformas

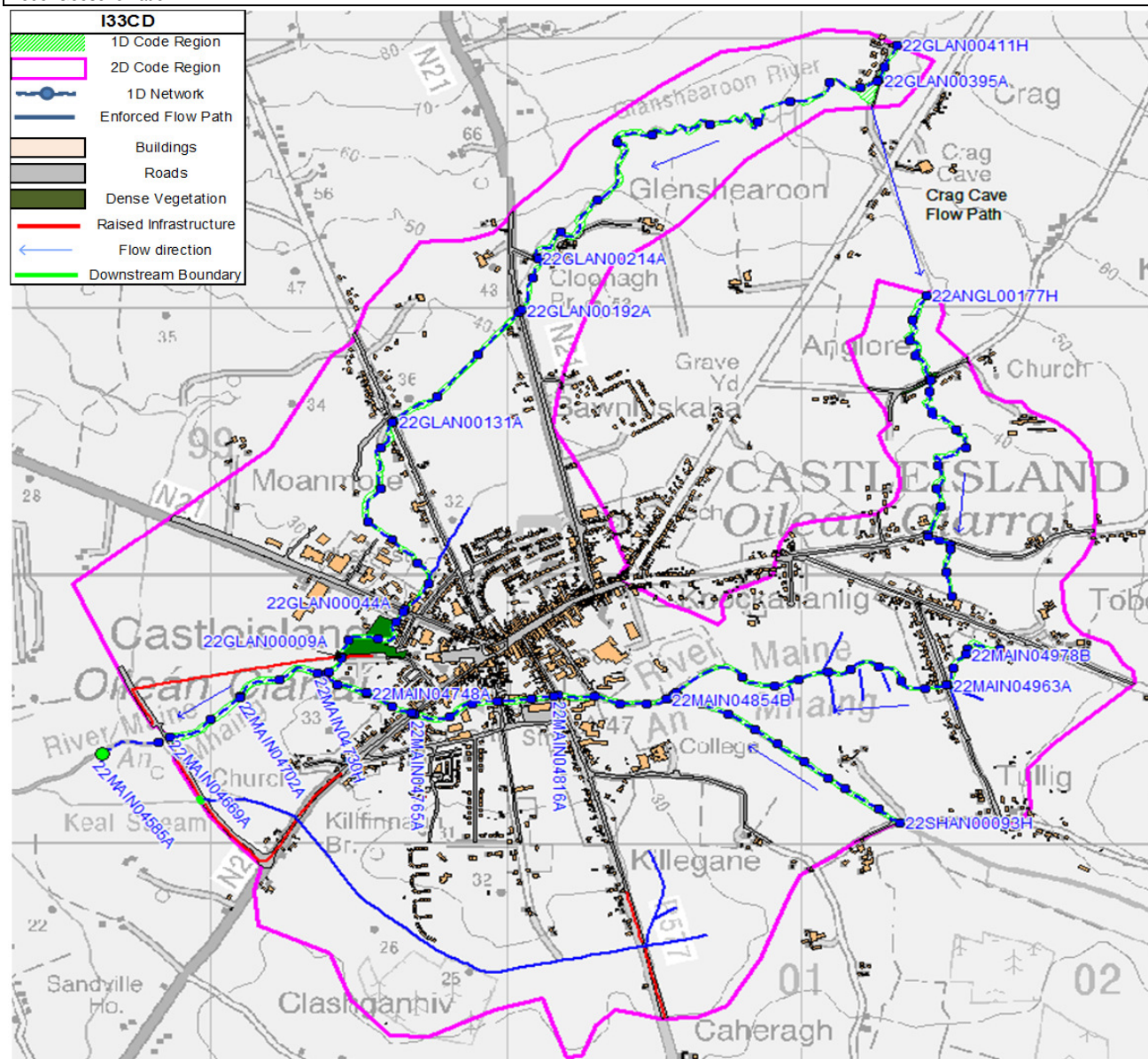
<b>UOM</b>	<b>22</b>		
<b>AFA/ MPW Reach</b>	<b>Castleisland</b>		
<b>Model ID</b>	<b>I33CD</b>		
<b>Purpose of Model Build</b>	<b>Flood Mapping</b>		
<b>Main Watercourse</b>	<b>River Maine</b>	<b>FLUVIAL RISK</b>	Yes
<b>Length Modelled (km)</b>	<b>10</b>	<b>COASTAL RISK</b>	No
<b>Area Modelled (km<sup>2</sup>)</b>	<b>47</b>	<b>VULNERABLE TO WAVES</b>	No

<b>Input Data</b>	
River Channel Topographic Data	Topographic survey by Murphy Surveys Limited. Data captured in September 2012. Refer to Drawing 4674_22MAIN_XS_6
Floodplain Topographic Data	2m DTM LIDAR provided by OPW converted from ITM to ING. Elevations on hard standing were compared with river channel survey and found to be within 0.2 m.
Map data	Ordnance Survey Ireland 1:1000, 1:2500 and 1:5000 and 1:50000 data Vector mapping at 1:1000, 1:2500 and 1:5000 were converted from DWG/DXF to GIS files for modelling purposes





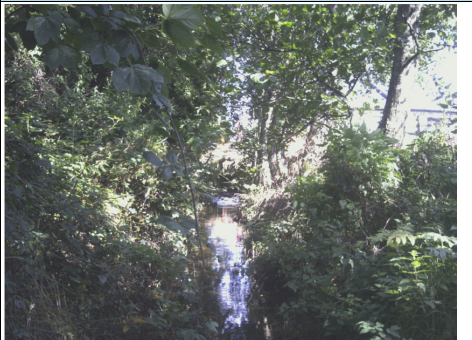
<b>Model Build</b>					
General Schematisation	<p>A 1D/2D ISIS/TUFLOW approach was taken for Castleisland to accurately model flow along the main watercourses and head loss through hydraulic structures whilst enabling multidirectional flow and backwater on the flow through the complex urban floodplain.</p> <p>The local area engineers reported a regular flow route from the Glenshearoon to Anglore Stream during flood when high flows overtop the Glenshearoon right bank, spill into a swallow hole, through Crag Cave and re emerge at the springs at the upstream of Anglore Stream leading to additional flooding at Tullig.</p> <p>A spill unit, set at Glenshearoon surveyed bank level, has been attached to the Glenshearoon sections by the swallow hole and to the upstream section of the Anglore river to simulate the flow route by assuming any water overtopping the right bank of the Glenshearoon by the swallow hole is immediately transferred to the Anglore Stream.</p> <p>The road embankment and dismantled railway have been explicitly enforced in the 2D domain based on LIDAR crest level as they are raised above the floodplain. Site visits to Castleisland and discussions with the local area engineers did not identify any major openings other than the rivers which are represented in the 1D model and 2D QH boundaries.</p> <p>Buildings thresholds have been raised by 0.15m above the DTM level based on site observations and a higher Manning's 'n' value applied to the building footprints to simulate the storage of water once flooded.</p> <p>The 2D floodplain was set to 5m to represent the urban area without compromising run time.</p> <p>Version D2: Improved representation at key structures to better match frequency of flooding discussed with local area engineers. See Schedule 2.</p>				
Software Versions Used	ISIS version 6.6 TUFLOW version 2012-05-AC-iSP-w32				
Total No of 1D nodes	<b>110</b>				
Routing Units	<b>0</b>				
Open channel (H)	<b>75</b>				
Bridges (D)	<b>34</b>				
Culverts (I)	<b>0</b>				
Weirs (W)	<b>1</b>				
Model Extent	Reach/Feature	Upstream Limit (ING)		Downstream Limit (ING)	
	Shanowen	101333, 109071		100574, 109550	
	Maine	101667, 109721		98629, 109333	
	Anglore	101418, 111040		101549, 109701	
	Glenshearoon	101320, 111974		099403, 109635	
Roughness	Reach/Feature	Active Channel	River Banks	Floodplain	Source
	Shanowen	0.040	0.060	N/A	Schedule 1: Photographs
	Maine	0.040 to 0.045	0.060	N/A	Schedule 1: Photographs
	Anglore	0.048	0.085	N/A	Schedule 1: Photographs
	Glenshearoon	0.040	0.060	N/A	Schedule 1: Photographs
	Open pasture	N/A	N/A	0.060	Schedule 1: Photographs
	Dense vegetation	N/A	N/A	0.085	Schedule 1: Photographs
	Buildings	N/A	N/A	0.200	Schedule 1: Photographs
	Roads	N/A	N/A	0.030	Schedule 1: Photographs
Structures	See Schedule 2 for Hydraulic Structure Parameters				
Upstream boundary	<p>Shanowen is the main inflow. This has been located on the downstream of Tullig road bridge taking a conservative assumption that all flows will flow through the bridge or over the road.</p> <p>The Glenshearoon inflow has been applied directly to the upstream limit of the open channel section. The proportion flowing into Crag Cave is determined hydraulically by the left bank spill at the swallow hole.</p> <p>The Anglore inflow was applied directly to the upstream limit of the Anglore Stream but was also attached to the downstream of the Crag Cave spill to enable transfer of flows from the Glenshearoon catchment once the left bank by the swallow hole entrance became overtopped.</p>				

Lateral inflows	Lateral inflows QT hydrographs were distributed equally across open channel sections between the confluences of Shanowne and Glenshearoon (MAIN_M_IC) as there were no obvious natural flow paths into the channel. The intermediate inflow along the Glenshearoon was applied equally at the minor tributaries located at 22GLAN00228 and 22GLAN00059.
Downstream boundary	A NCB DY has been applied in the 1D downstream of the bridge based on the bed level as representative of the longer reach of the River Maine. An automatic HQ has been applied at the d/s limit of Kealgorm stream based on the floodplain slope to allow a small amount of flow under the N23 at this location.
Run Settings	Unsteady simulation of full 45 hour hydrograph. 2.5s timestep Minimum flows of 1m <sup>3</sup> /s on Glan, 0.3m <sup>3</sup> /s on Anglore and 1.7m <sup>3</sup> /s on Shanowne/Maine to maintain stability at low flows. This takes up less than 10% of the channel capacity and does not reduce the volume available for flood storage. All other parameters set to default.  The model was run for the design flood along the Maine River (M for main river model runs) and the design flood along the Glanshearoon River (T for tributary runs). These have then been combined to produce the final flood extent, depth, velocity and hazard results.

Model Geoschematic

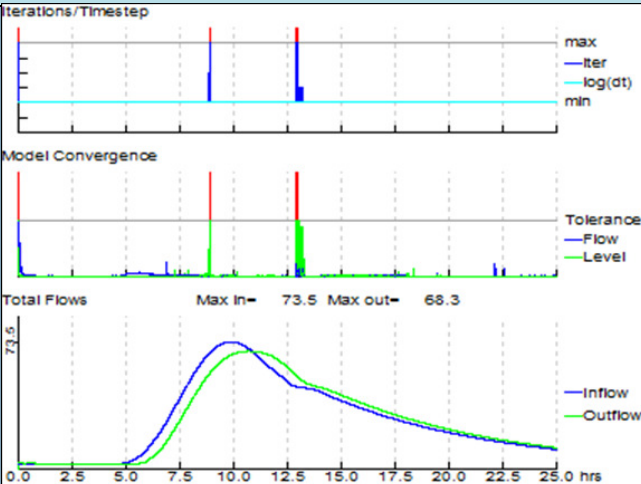
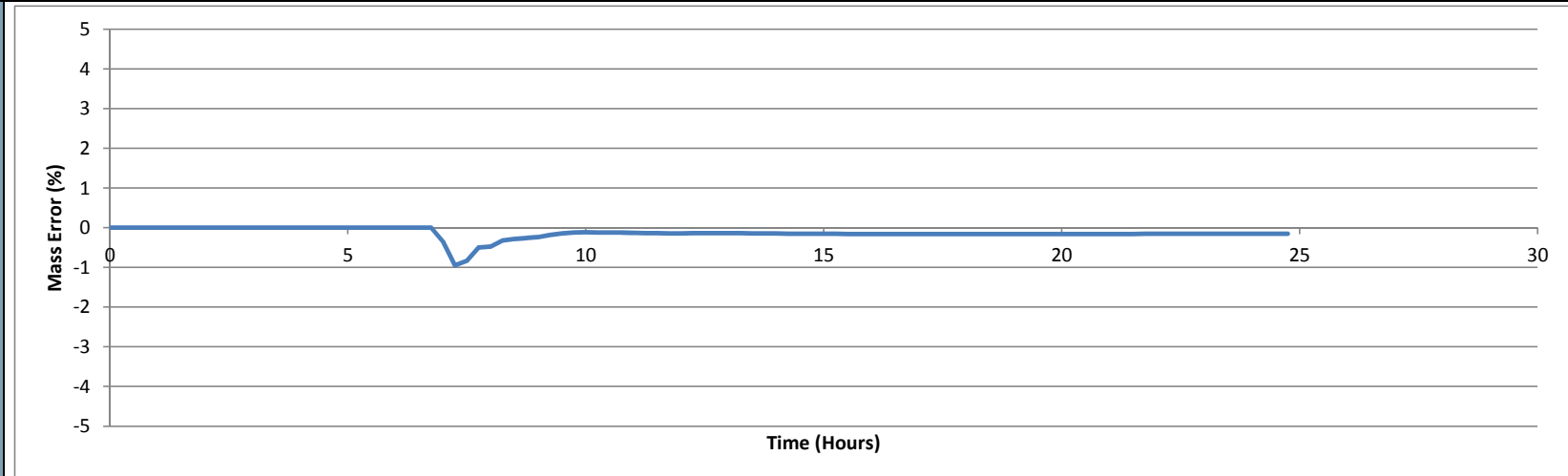




SCHEDULE 1: PHOTOGRAPHS	
<p><b>Photo 1: Shanowen Active Channel</b></p>  <p>IMG 100748, 100749 - captured on 27/09/2012</p>	<p><b>Photo 6: Pasture Floodplain</b></p>  <p>IMG 100750, 100751 - captured on 27/09/2012</p>
<p><b>Photo 2: Maine Active Channel and Banks</b></p>  <p>IMG 100468, 100518 - captured on 12/09/2012</p>	<p><b>Photo 7: Roads and Urban Floodplain</b></p>  <p>IMG 100527, 100528, 100529 - captured on 12/09/2012</p>
<p><b>Photo 3: Anglere Active Channel and Banks</b></p>  <p>IMG 101420, 101421 - captured on 12/09/2012</p>	
<p><b>Photo 4: Glenshearoon Active Channel and Left Bank near Swallow Hole</b></p>  <p>IMG 101252, 1112848 - captured on 05/09/2012</p>	



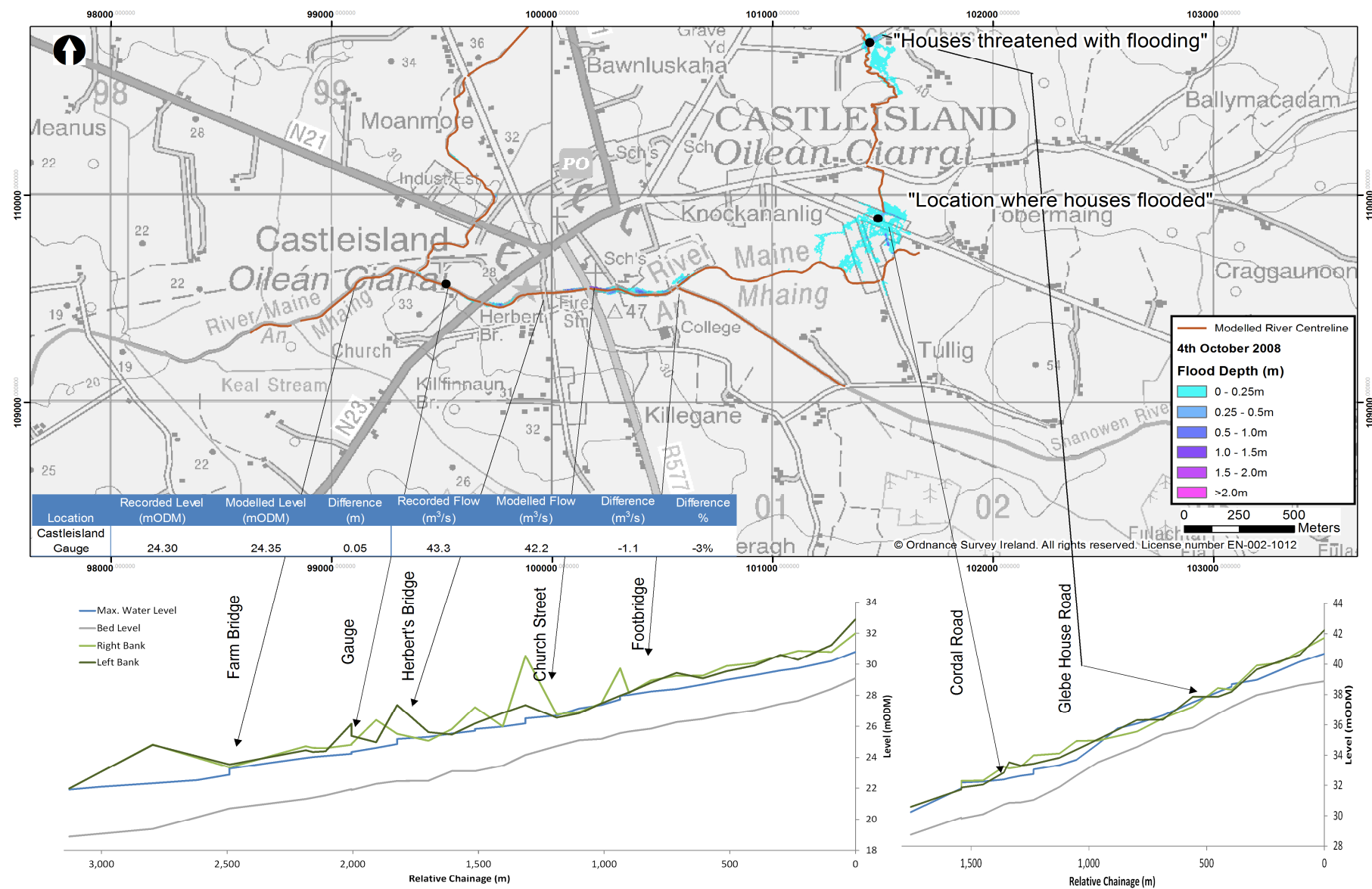
SCHEDULE 2: Structures																												
Data file		P:\Cambridge\Demeter\EVT4\296241 S West CFRAMS EVT Code\Technical\Hydraulics\Build\I33CD_Castleisland\DESIGN\model\ISIS\I33CD_D1_010.DAT																										
Node(s)	Easting	Northing	Structure Type	Bridge Parameters				Weir Parameters				Spill Parameters			Culvert Parameters													Comments/ Justification
				Soffit Elevation	No of Openings	Skew Angle	Calibration Coefficients	Crest Elevation	Breadth	Modular Limit	Velocity Coeff.	Minimum Crest Elevation	Modular Limit	Weir Coeff.	Soffit level (mAOD)	No of Openings	Invert u/s (mAOD)	Invert d/s (mAOD)	Area (m²)	Nominal Width (m)	Length (m)	K	Ki	M	Trash Screen	Trash Screen coefficient	Flapped	
22ANGL000211	101500	109928	Tullig Culvert RECTANGULAR CULVERT+ ORIFICE												31.375	1	29.82	28.749	2.076	1.4 Narrowing to 1.2 under the road	214.922	0.9	0.5	0.7	NO		NO	Rectangular culvert under Tullig Road mdoelled with orifice at upstream to stabilise transition to orifice flow. Culvert is known to reduce in width under the road. Therefore a width of 1.2m was assumed based on discussions with local area engineers and in the absence of confined spaces survey. Additional inlet losses and bend lossed added to reproduce the frequency of flooding reported.
22MAIN0477W MAIN047475R MAIN047475L	99524	109555	Gauge Weir RN Weir + Spill units					22.275	9.508		1	22.878	0.9	1.7														RN Weir representing the formal gauging weir at two flows and spills representing the banks up to bankfull. The weir and spill coefficients wer calibrated to the spot gaugings upstream.
22GLAN00394S	101254	111842	Crag Cave flow route River Bank Spill									58.837	0.9	1.0														Left bank elevations defining the spill into swallow hole which is directly linked to the upstream of Anglore Stream 22ANGL000177H. Spill coefficient represents both the offline flow over the bank and flow through the cave calibrated to reproduce observed flooding on Anglore Stream.
22ANGL00081A	101456	110408	General Head Loss																									General head loss applied to help stabilise low flows over rapid bed changes along the steep Anglore Stream
22MAIN04854D	100539	109540	Old Chapel Lane Footbridge FLAT Bridge	28.22	3	0	1					29.71	0.9	1.5														Flat bridge with three openings. Spill represents flow over the flat wall on the bridge at high flows.
22MAIN04816D	100168	109548	Church Street Bridge ARCH Bridge	26.93	2	0	1					28.42	0.9	1.5														Stone arched bridge with two openings applying HR Wallingford Arch equations. Spill represents flow over the flat wall on the bridge at high flows.
22MAIN04797D	99969	109528	Barrack Street Bridge FLAT Bridge	25.69	3	0	1					27.07	0.9	1.5														Flat soffit bridge with 3 openings.Soffit lowered by the utility pipe that crosses below the soffit. Spill represents flow over the flat wall on the bridge at high flows.
22MAIN04765D	99687	109479	Killarney Road Bridge ARCH Bridge	25.18	2	45	1					27.15	0.9	1.5														Upstream face is a single rectangular opening but downstream face is two arched openings therefore arched bridge approach applied. The downstream arches were applied as most important flow control. Soffit lowered to consider the utility pipe corssing. Survey adjusted to be in line bridge rather and skew angle added to the bridge structure.
22MAIN04700D	99098	109538	Farm Access Bridge FLAT Bridge	23.12	2	0	1					23.57	0.9	1.5														Farm Access bridge modelled as a flat bridge with spil represnet flow over the track
22MAIN04669D	98863	109380	N23 Highways Bridge FLAT Bridge	23.49	1	0	2					24.94	0.9	1.5														Flat highways bridge with spill representing any flow over the road in extreme events
22ANGL00136D	101427	110732	Glebe House Bridge FLAT Bridge	37.98	1	0	1					39.2	0.9	1.5														Flat box bridge under Glebe House Road with spill representing flow over flat wall.
22ANGL00052D	101423	110151	Knockane Bridge FLAT Bridge	32.82	1	0	1					33.38	0.9	1.5														Flat box bridge at Knockane with spill representing flow over flat wall. 2D represents spill over road either side.
22MAIN04963D	101490	109586	Tullig Bridge FLAT Bridge	30.76	2	0	1					31.97	0.9	1.5														Flat soffit bridge under Tullig Road with spill representing flow over flat wall.
22GLAN00395D	101254	111842	Bridge by Crag Cottages FLAT Bridge	59.94	1	0	1					61.238	0.9	1.5														Flat soffit bridge with spill representing flow over flat wall.
22GLAN00214D	100142	111185	Access Bridge FLAT Bridge	41	1	0	1					42.164	0.9	1.5														Flat soffit bridge with spill representing flow over flat wall.
22GLAN00192D	100045	110986	Cloonagh Bridge ARCH Bridge	39.26	2	0	1					40.83	0.9	1.5														HR Wallingofrd Arched methdo usedto better represent arch obstruction with spill representing flow over flat wall.
22GLAN00131D	99615	110572	FLAT Bridge	33.25	2	0	1					34.48	0.9	1.5														Flat soffit bridge with spill representing flow over flat wall.
22GLAN00044D	99616	110569	Tralee Road Bridge ARCH Bridge	27.22	1	0	1					34.96	0.9	1.5														Arched bridge under Tralee Road with spill representing flow over flat wall.
22GLAN00009D	99440	109692	Old Railway Bridge FLAT Bridge	25.24	2	0	1					25.46	0.9	1.5														Flat soffit bridge with spill representing flow over flat wall.

Castleisland Model Performance													
1D Convergence													
Convergence Plot 1% AEP Fluvial Event		 <p>Datafile: ...\\DESIGN\\MODEL\\ISIS\\DATA\\I33CD_011_D2.DAT Results: ...\\RESULTS\\I33CD_MFCD010_D2_CASTLEISLAND.zzi Ran at 14:58:33 on 08/09/2014 Ended at 16:46:05 on 08/09/2014 Start Time: 0.000 hrs End Time: 25.000 hrs Timestep: 1.0 secs  Current Model Time: 25.00 hrs Percent Complete: 100 %</p>											
Comments		The 1D model components were convergent and within the recommended tolerances for the majority of the event. The short periods of instability at 9 and 12 hours occur as the water hits the soffit of the smaller culvert at the downstream of Anglore. however, the culvert is already bypassed and does not affect the flood extent.											
2D Convergence													
Mass Balance Plot 1%AEP Fluvial Event													
Comments		The final cumulative mass balance error was 0.2% or 3381 m³. The 2D model remains within the recommended tolerance throughout the event. There is a spike at 7 hours to -0.99% associated with the wetting of cell but it back to -0.1% before the peak at 10 hours.  The initial negative percentage mass error at 7 hours is exaggerated because there are very few active 2D cells as the water first spills out of bank. However, as flooding increases the mass error reduces to -0.01% by the peak. Therefore, the mass balance of volume entering and leaving the model is accurate within recommended tolerances at the peak and flood depth, velocity and extent can be deemed to be reliable.											
Hydrological Performance				10% AEP m³/s			1%AEP m³/s			0.1%AEP m³/s			
Target Flows		HEP ID	Location	Model Node	Design	Modelled	% Difference	Design	Modelled	% Difference	Design	Modelled	% Difference
		22_1589_3	Shanowen downstream	22SHAN00002A	37.2	37.1	0%	54.2	54.8	1%	79.4	80.5	1%
		22_1587_3	22014 Castleisland Gauge	22MAIN04748H	43.6	41.5	-5%	61.8	57.6	-7%	91.8	71.2	-22%
			22014 Castleisland Gauge+ flow exiting catchment	22MAIN04748H	43.6	41.5	-5%	61.8	58.8	-5%	91.8	88.4	-4%
		22_2098_3	Maine downstream	22MAIN04669A	56.9	51.4	-10%	80.7	75.4	-7%	119.9	113.2	-6%
		22_360_2	Glenshearoon downstream	22GLAN00002H	12.6	11.0	-12%	18.7	15.8	-16%	27.8	22.4	-19%
		22_1756_3	Anglore downstream	22ANGL00021I	3.3	3.7	12%	4.7	5.7	21%	7.0	8.3	19%
Comments		The flows in the 1D ISIS channel were combined with the 2D flow parallel to the channel where there was out-of-bank flows and compared to the design hydrology.  The modelled flow tended to underestimate flows at the gauge compared to the design peak flows in the extreme flood events because some flow was exiting the catchment along the R577 effectively bypassing the gauge. The modelled flows is within 5% (3m³/s) of the design flows when this exit flow is included in the total flow estimate at the gauge as shown.  The modelled flows tended to underestimate the design flows on the Glenshearoon and overestimate the flows on the Anglore Stream because flow exited the Glenshearoon catchment and were transferred to the Anglore Stream catchment.											
Calibration Event 1													
Model Run ID		I33CD_FCC20081004_D1											
Period Modelled		04/10/2008 11:30 to 06/10/2008 02:45 with the peak at 04/10/2008 20:00											
Hydraulic Modification to Design Model		No hydraulic modifications were made to the design model.											
Hydrological inflows		Rainfall runoff FSSR units have been applied to the Glenshearoon, Anglore and Shanowen inflows based on the catchment average rianfall adjusted from Valentia Observatory and calibrated percentage runoff to achieve the flows at the gauge.											
Calibration Plot		See Schedule 3 - Calibration and Sensitivity											
Comments		The model was calibrated to reproduce the recorded flow route through Crag Cave and flooding along the Anglore Stream by calibrating the spill coefficient of the spill at the swallow hole to 1.0. The resultant flood extent matches well with the reported flooding at Glebe House Road and the property flooding at Tullig as the excess flows cause the Anglore to exceed the capacity of Glebe House Bridge and the Tullig culvert.  The water level at the gauge was 0.05m higher than recorded which is within the calibration tolerance of +/- 0.1m.  Overall, the model calibrates well with the mechanisms and extents recorded in the 2008 event.											
Verification Checks													
Locations of known flooding		Flooding was observed around Church Street Bridge and Tullig on 24th January 2014. This event occurred after the model calibration exercise had been completed. Therefore, the photographs provided were used to verify and common sense check flow paths and frequency of flooding.											
Available Gauge Data		The Castleisland gauge was not active for this event. Gauge data was obtained from Riverville but the flow was less than the 50%AEP estimate. The extent of flooding in Castleisland has not been observed as frequently as the 50%AEP (1 in 2 year). Therefore, flows at Riverville are not representative of flood conditions in Castleisland for this event.											
Verification Plot		See Schedule 3 - Calibration and Sensitivity											

Comparison with Design Flood	The photographs verify the flow paths across Tullig Road and on the right bank at Church Street. The extent of flooding at Tullig and around Church Street would be consistent with the 2%AEP design flood extent.
<b>Sensitivity Test 1: Increased Flow</b>	
Model Run ID	I33CD_FHD010_D1
Hydraulic Modification to Design Model	No hydraulic modifications were made to the design model.
Hydrological inflows	All inflows were increased by 30% for the 1%AEP fluvial current design event to account for the uncertainty in the derivation of QMED and the pooling group selected. This is broadly equivalent to the HEFS 1%AEP as the increase in urban extent has less the 1% impact on peak flow. Therefore, the HEFS 1%AEP results (FHD010) have been used as the sensitivity test results.
Sensitivity Plot	See Schedule 3 - Calibration and Sensitivity
Comments	<p>A 30% increase in flows resulted in a significant increase in the flow exiting the Maine catchment along the R277 and therefore an increase in flood extent in this area. The flow increase resulted in flooding along the N21 from the Glenshearoon and flooding at the sewage treatment works at the confluence. The flood extent also increased along Anglore Stream with greater excess flows being transferred from the Glenshearoon catchment.</p> <p>Therefore flood risk in the Castleisland was found to be sensitive to the uncertainties in flow. The design flows were selected based on the best fit to Castleisland gauge data and relative flood frequency of historic events.</p> <p>An allowance should be made when interpreting the design flood outlines and the in the sizing of any flood risk management option due to this uncertainty in flood level and extent caused by the uncertainties in flow.</p>
<b>Sensitivity Test 2: Increased Downstream Level</b>	
Model Run ID	
Hydraulic Modification to Design Model	The downstream stage-flow boundary was increased from 1 in 670 to 1 in 1000 to represent greater backwater from the Maine catchment downstream of the N23.
Hydrological inflows	No modifications were made to the design inflows.
Sensitivity Plot	See Schedule 3 - Calibration and Sensitivity
Comments	The increased backwater from the downstream boundary only affected water levels up to the Glenshearoon confluence and did not significantly increase flood extent. Therefore, the Castleisland model is not sensitive to the assumptions taken for the downstream boundary.
<b>Sensitivity Test 3: Increased Manning's 'n'</b>	
Model Run ID	I33CD_FCSN01_D1
Hydraulic Modification to Design Model	<p>The Manning's 'n' values were increased to the upper limit of the industry recommended ranges.</p> <p>All active channels 0.040 to 0.050  All river banks 0.060 to 0.080  Pasture / parkland / garden 0.060 to 0.080  Buildings 0.200 to 0.300  Roads 0.033 to 0.040</p>
Hydrological inflows	No modifications were made to the design inflows.
Sensitivity Plot	See Schedule 3 - Calibration and Sensitivity
Comments	<p>An increase in roughness values in bank and out-of-bank increased flooding on the left bank of the Shanowen and Maine resulting in a larger flood extent along the R277 flow path. The Manning's 'n' values along the Shanowen and Maine were calibrated for the October 2008 event and spot gaugings at Castlisland gauge. The calibrated Manning's 'n' values were selected as the design values.</p> <p>Water level was also raised along Anglore Stream. However, this did not result in large increase in flood extent given that the 1%AEP already exceeds the capacity of the critical bridges and culverts. The Manning's 'n' values along Anglore Stream were calibrated for the October 2008 event. The calibrated Manning's 'n' values were selected as the design values.</p> <p>An allowance should be made when interpreting the design flood outlines and the in the maintenance of any flood risk management option on the Shanowen and Maine channels due seasonal changes in roughness.</p>

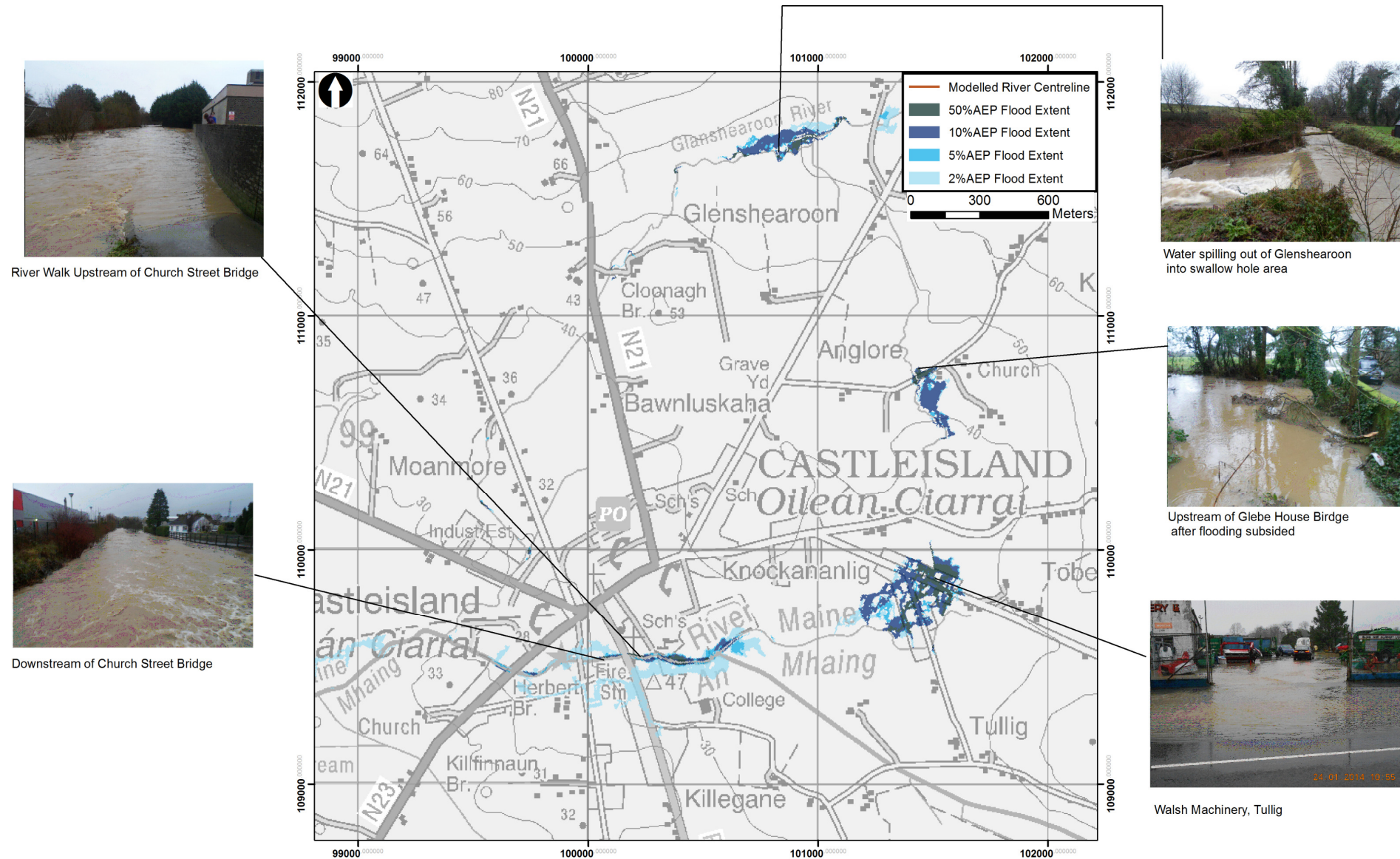


Map A.1: Calibration of the Castleisland Model to 4th October 2008 Fluvial Flood Event

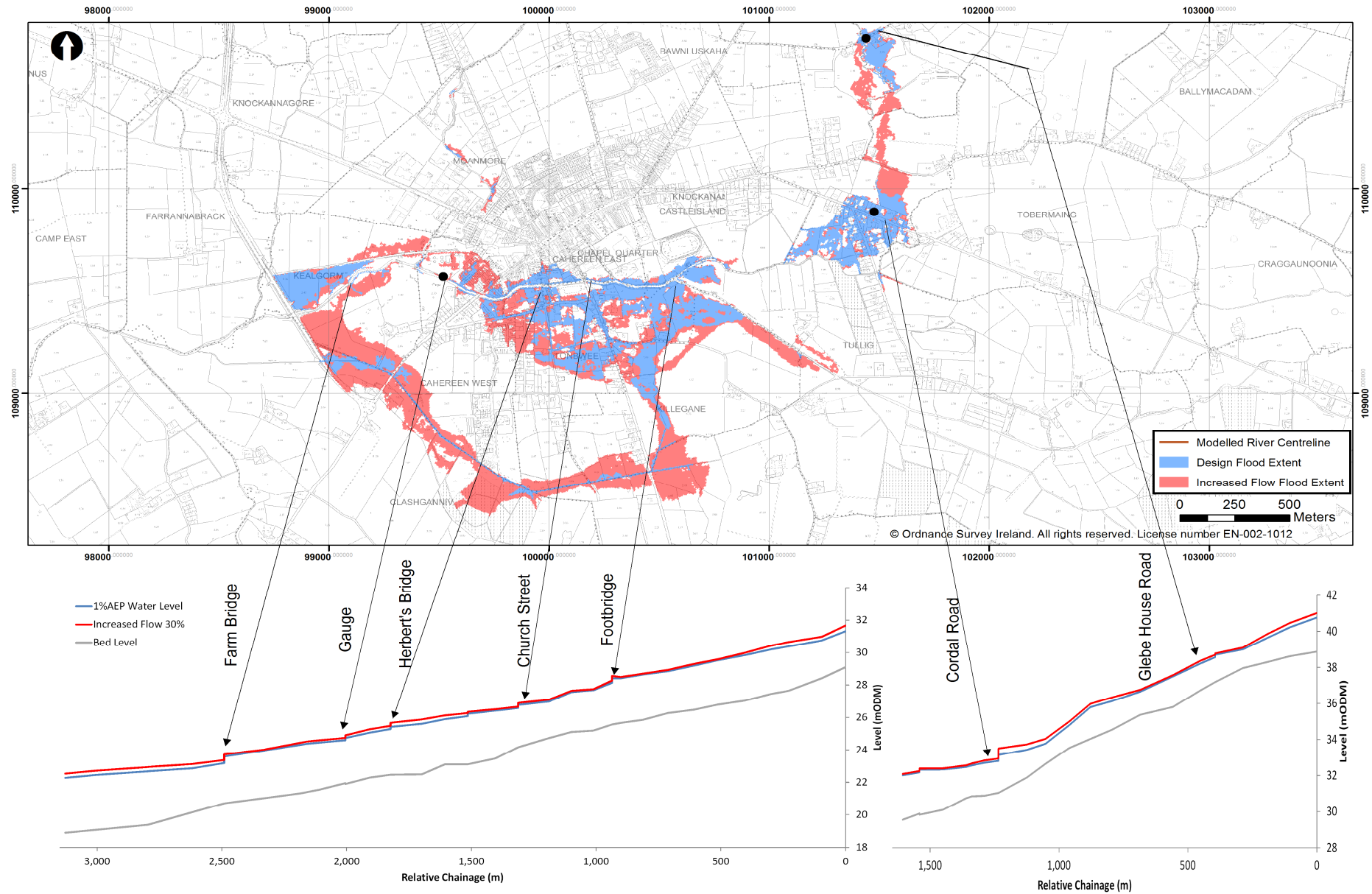




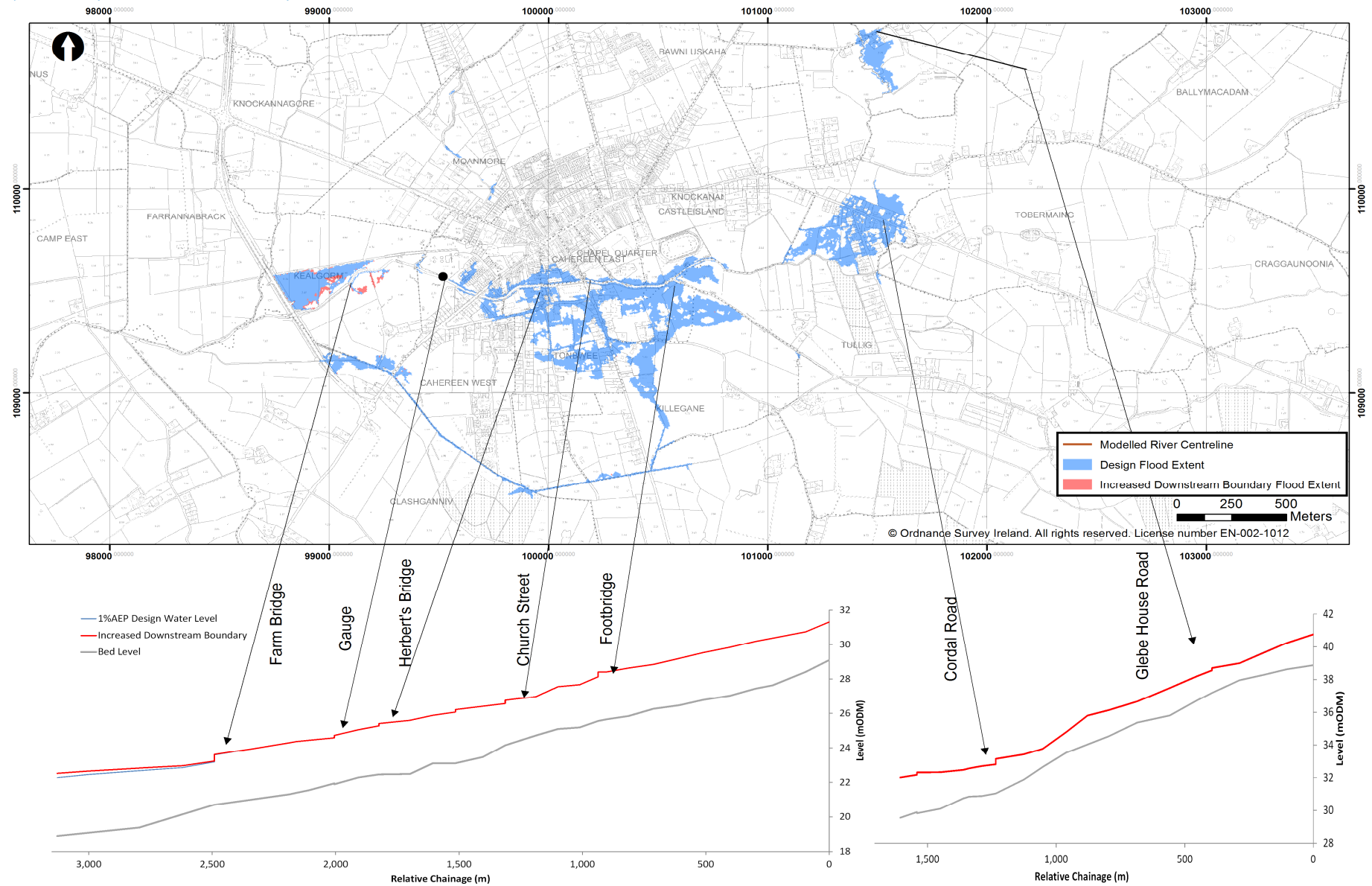
Map A.2: Validation of Flooded Areas in 24<sup>th</sup> January 2014 with Design Flood Outlines



Map A.3: Sensitivity to 30% Increased Peak Flow

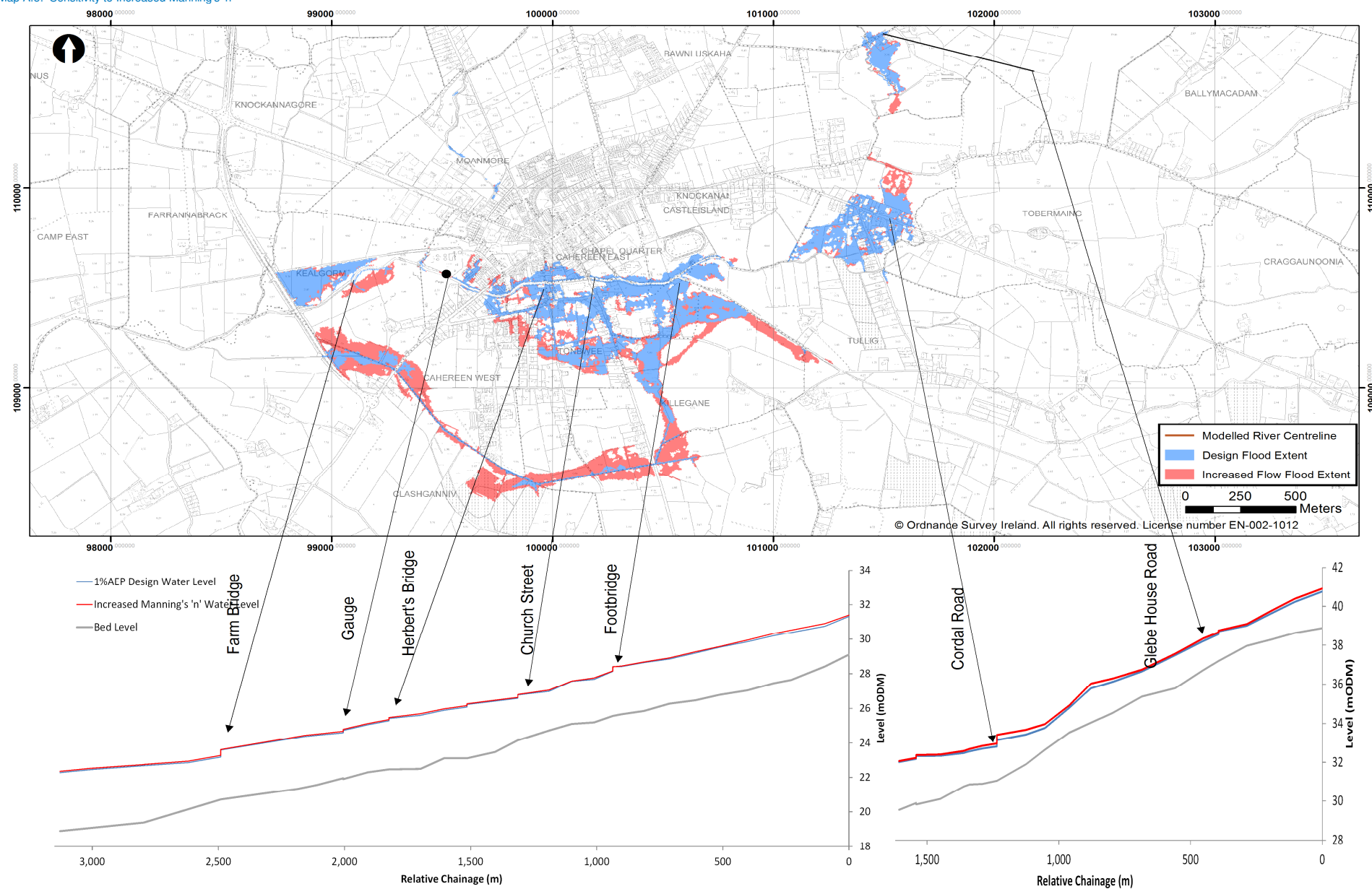


Map A.4: Sensitivity to Increased Downstream Boundary





Map A.5: Sensitivity to Increased Manning's 'n'



Castleisland Model Outputs	
Threshold of Flooding	<p>The key thresholds and areas affected by flooding in Castleisland are:</p> <ul style="list-style-type: none"><li>- 50%AEP event overtops the left bank at the swallow hole to Crag Cave on Glanshearoon</li><li>- 50%AEP event exceeds the capacity of the downstream culvert on Anglore, flooding properties at Tullig</li><li>- 10%AEP event exceeds the capacity of Glebe House Bridge causing water to flow over the road and threaten properties on the left bank.</li><li>- 2%AEP floods riverside areas along the Maine upstream and downstream of Church Street</li><li>- 1%AEP event floods the Technical College, Cahereen East and West areas of Castleisland from the Maine. Surface water flooding is not considered.</li><li>- 1%AEP flows across the catchment boundary along the R277</li><li>- 0.1%AEP exceeds the capacity of the N21 Bridge on the Glenshearoon to flood Castleview Drive and the sewage treatment works</li><li>- Approximately 200 properties are affected by the 1%AEP fluvial event.</li></ul> <p>It should be noted that the CFRAM Study assumes saturated ground conditions as a worst-case scenario for the design flows. The saturation of the catchment preceding the event should be carefully considered when interpreting the flood maps in Castleisland due to karstic geology.</p>
Critical Structures for Flood Risk	<p>The critical structures in determining flood risk include:</p> <ul style="list-style-type: none"><li>- Left bank levels on the Glenshearoon and the flow route through Crag Cave during saturated conditions</li><li>- Glebe House Bridge on the Anglore Stream</li><li>- Downstream culvert on the Anglore Stream at Tullig</li><li>- Church Street Bridge on the Maine</li><li>- Herbert's Bridge on the Maine</li><li>- Farm access bridge downstream of the Maine-Glenshearoon confluence.</li></ul>
Areas affected by flooding	<p>The greatest risk to life is associated with deep fast flowing water upstream of Herbert's Bridge and Church Street Bridge on the right bank.</p>
Risk to people	<p>There is significant and extreme risk to people for the 2%AEP and larger magnitude events.</p>
Consideration for Flood Risk Management Options	<ul style="list-style-type: none"><li>- Increased conveyance at the key structures identified are likely to reduce flood risk.</li><li>- Bank works on the Glenshearoon to limit how much flow can enter the swallow hole may reduce excess flows and flooding on the Anglore Stream.</li><li>- Flood warning on the Shanowen/Maine catchment is likely to be effective as there would several hours before the peak flow at the Castleisland Gauge. This gauge is a good indicator of the expected flow when combined with observations at the swallow hole on Glenshearoon to predict flooding at Tullig and within the town.</li></ul>

Flood Map Outputs					
The following table outlines the print-ready flood mapping deliverables provided in the accompanying digital data.					
Scenario	Flood Extent Map	Flood Zone Map	Flood Depth Map	Flood Velocity Map	Flood Hazard Map
Fluvial Current Design 10%AEP	I21HCD33_EXFCDEXF_D2		I21HCD33_DPFCD100_D2	I21HCD33_VLFCD100_D2	I21HCD33_HZFCDD100_D2
Fluvial Current Design 1%AEP	I21HCD33_EXFCDEXF_D2	I21HCD33_ZN_D2	I21HCD33_DPFCD010_D2	I21HCD33_VLFCD010_D2	I21HCD33_HZFCDD010_D2
Fluvial Current Design 0.1%AEP	I21HCD33_EXFCDEXF_D2	I21HCD33_ZN_D2	I21HCD33_DPFCD001_D2	I21HCD33_VLFCD001_D2	I21HCD33_HZFCDD001_D2
Fluvial Mid Range Future Design 10%AEP	I21HCD33_EXFMDEXF_D2				
Fluvial Mid Range Future Design 1%AEP	I21HCD33_EXFMDEXF_D2				
Fluvial Mid Range Future Design 0.1%AEP	I21HCD33_EXFMDEXF_D2				

GIS Outputs								
The following table outlines the GIS deliverables and model run files provided in the accompanying digital handover.								
Scenario	Model Run	Main River %AEP	Tributary River %AEP	Flood Extent Polygon	Flood Zone Polygon	Flood Depth Grid	Flood Velocity Grid	Flood Hazard Grid
Fluvial Current Design 50%AEP	I33CD_MFCD500_D2_Castleisland.ief	50	50	I33EXFCD500D2		I33DPFCD500D2	I33VLFCD500D2	I33HZFCD500D2
	I33CD_TFCD500_D2_Castleisland.ief	50	50					
	I33CD_MFCD200_D2_Castleisland.ief	20	50					
Fluvial Current Design 20%AEP	I33CD_TFCD200_D2_Castleisland.ief	50	20	I33EXFCD200D2		I33DPFCD200D2	I33VLFCD200D2	I33HZFCD200D2
	I33CD_MFCD100_D2_Castleisland.ief	10	20					
	I33CD_TFCD100_D2_Castleisland.ief	20	10	I33EXFCD100D2		I33DPFCD100D2	I33VLFCD100D2	I33HZFCD100D2
Fluvial Current Design 10%AEP	I33CD_MFCD050_D2_Castleisland.ief	5	20					
	I33CD_TFCD050_D2_Castleisland.ief	20	5	I33EXFCD050D2		I33DPFCD050D2	I33VLFCD050D2	I33HZFCD050D2
	I33CD_MFCD020_D2_Castleisland.ief	2	10					
Fluvial Current Design 2%AEP	I33CD_TFCD020_D2_Castleisland.ief	10	2	I33EXFCD020D2		I33DPFCD020D2	I33VLFCD020D2	I33HZFCD020D2
	I33CD_MFCD010_D2_Castleisland.ief	1	5					
	I33CD_TFCD010_D2_Castleisland.ief	5	1	I33EXFCD010D2	I33ZN_A_D2	I33DPFCD010D2	I33VLFCD010D2	I33HZFCD010D2
Fluvial Current Design 1%AEP	I33CD_MFCD005_D2_Castleisland.ief	0.5	5					
	I33CD_TFCD005_D2_Castleisland.ief	5	0.5	I33EXFCD005D2		I33DPFCD005D2	I33VLFCD005D2	I33HZFCD005D2
	I33CD_MFCD001_D2_Castleisland.ief	0.1	1					
Fluvial Current Design 0.1%AEP	I33CD_TFCD001_D2_Castleisland.ief	1	0.1	I33EXFCD001D2	I33ZN_B_D2	I33DPFCD001D2	I33VLFCD001D2	I33HZFCD001D2
Fluvial Mid Range Future Design 50%AEP	I33CD_MFMD500_D2_Castleisland.ief	50	50					
	I33CD_TFMD500_D2_Castleisland.ief	50	50	I33EXFMD500D2		I33DPFMD500D2		
	I33CD_MFMD200_D2_Castleisland.ief	20	50					
Fluvial Mid Range Future Design 20%AEP	I33CD_TFMD200_D2_Castleisland.ief	50	20	I33EXFMD200D2		I33DPFMD200D2		
	I33CD_MFMD100_D2_Castleisland.ief	10	20					
	I33CD_TFMD100_D2_Castleisland.ief	20	10	I33EXFMD100D2		I33DPFMD100D2		
Fluvial Mid Range Future Design 10%AEP	I33CD_MFMD050_D2_Castleisland.ief	5	20					
	I33CD_TFMD050_D2_Castleisland.ief	20	5	I33EXFMD050D2		I33DPFMD050D2		
	I33CD_MFMD020_D2_Castleisland.ief	2	10					
Fluvial Mid Range Future Design 2%AEP	I33CD_TFMD020_D2_Castleisland.ief	10	2	I33EXFMD020D2		I33DPFMD020D2		
	I33CD_MFMD010_D2_Castleisland.ief	1	5					
	I33CD_TFMD010_D2_Castleisland.ief	5	1	I33EXFMD010D2		I33DPFMD010D2		
Fluvial Mid Range Future Design 1%AEP	I33CD_MFMD005_D2_Castleisland.ief	0.5	5					
	I33CD_TFMD005_D2_Castleisland.ief	5	0.5	I33EXFMD005D2		I33DPFMD005D2		
	I33CD_MFMD001_D2_Castleisland.ief	0.1	1					
Fluvial Mid Range Future Design 0.5%AEP	I33CD_TFMD001_D2_Castleisland.ief	1	0.1	I33EXFMD001D2		I33DPFMD001D2		
Fluvial Mid Range Future Design 0.1%AEP	I33CD_MFHD100_D2_Castleisland.ief	10	20					
	I33CD_TFHD100_D2_Castleisland.ief	20	10	I33EXFHD100D2		I33DPFHD100D2		
	I33CD_MFHD010_D2_Castleisland.ief	1	5					
Fluvial High End Future Design 10%AEP	I33CD_TFHD010_D2_Castleisland.ief	5	1	I33EXFHD010D2		I33DPFHD010D2		
	I33CD_MFHD001_D2_Castleisland.ief	0.1	1					
	I33CD_TFHD001_D2_Castleisland.ief	1	0.1	I33EXFHD001D2		I33DPFHD001D2		

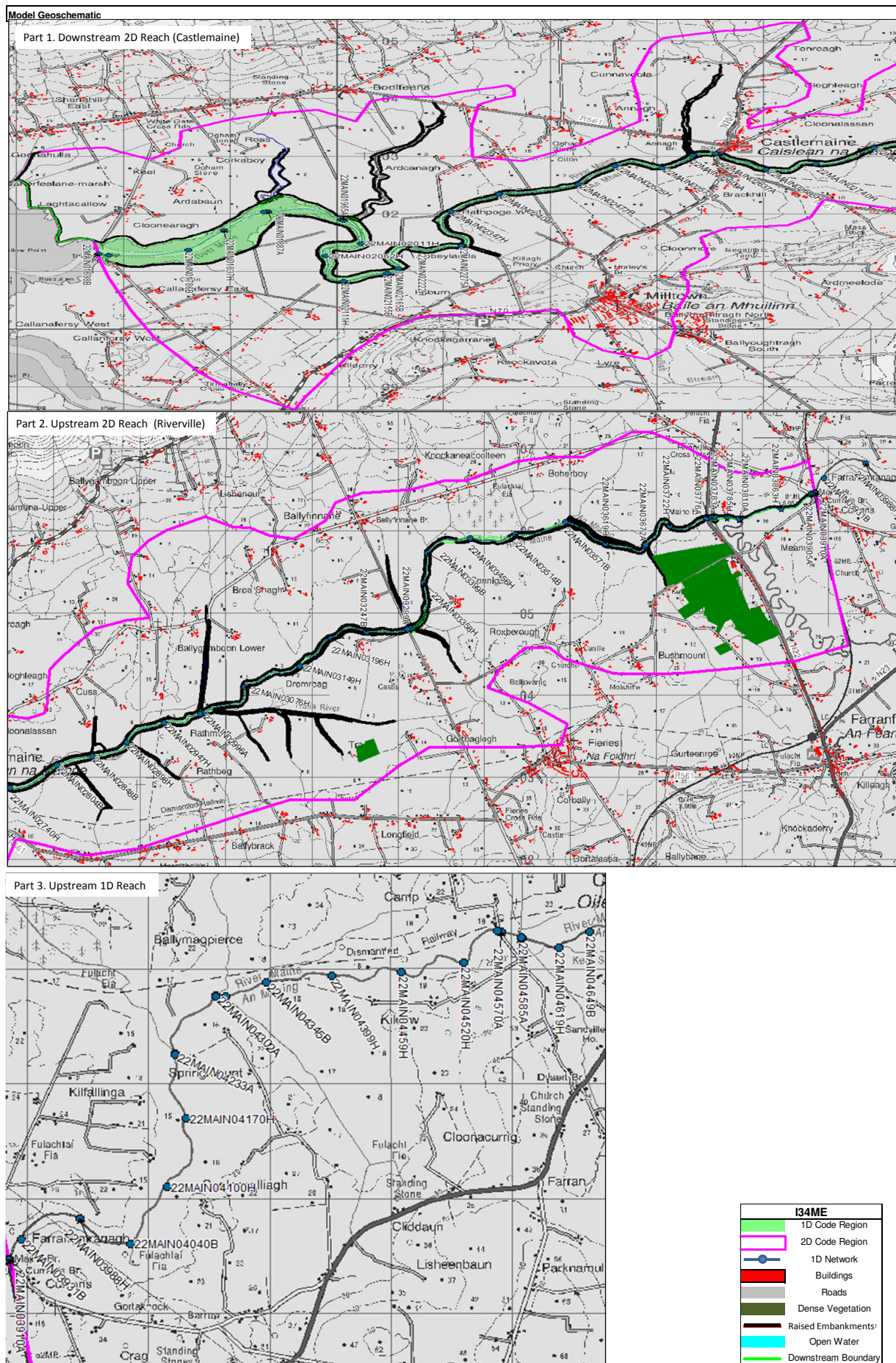


## Appendix B. Maine MPW Model Proformas

UOM	22		
AFA/ MPW Reach	Maine		
Model ID	I34ME		
Purpose of Model Build	Flood Mapping		
Main Watercourse	River Maine	FLUVIAL RISK	Yes
Length Modelled (km)	29.5	COASTAL RISK	Yes
Area Modelled (km <sup>2</sup> )	54.1	VULNERABLE TO WAVES	No

Input Data	
River Channel Topographic Data	Topographic survey by Murphy Surveys Limited. Data captured in October 2012. Refer to Drawing 22MAIN_Maine_V1.dwg
Floodplain Topographic Data	2m DTM LIDAR provided by OPW converted from ITM to ING. Elevations on hard standing were compared with river channel survey and found to be within 0.2 m.
Map data	Ordnance Survey Ireland 1:1000, 1:2500 and 1:5000 and 1:50000 data Vector mapping at 1:1000, 1:2500 and 1:5000 were converted from DWG/DXF to GIS files for modelling purposes

Model Build					
General Schematisation	<p>A 1D ISIS approach with extended sections over the floodplain was taken for the MPW Maine between the N23 at Castleisland to the Currans Bridge because the floodplain is fully connected with the river channel and 1D approach was deemed sufficient to provide flood extent and depth mapping for this reach.</p> <p>The survey indicates that the river bank is not consistently above the floodplain between the cross sections i.e. there are low spots inbetween connecting the river channel and floodplain. Therefore it would not be appropriate to assume the floodplain was fully disconnected. A higher Manning's 'n' has been applied to simulate the inefficient flow over the banks.</p> <p>Downstream of Currans Bridge, a 1D/2D approach was taken to better represent the disconnected floodplain from the channel due to the raised embankments. A 2D approach is also better suited to simulate the multidirectional flow paths across the floodplain during coastal flooding.</p> <p>The 2D floodplain was set to a 10m grid resolution to improve run time over a large coastal floodplain whilst maintaining accuracy suitable for a MPW reach.</p> <p>Defended scenarios: The raised embankments have been enforced in the 2D domain based on the flood defence asset survey and form the interface between the 1D and 2D components. The defence level was increased by 0.2m from downstream boundary up to Castlemaine Bridge, in order to replicate the gauged level at Castlemaine Bridge.</p> <p>Undefended scenarios (for flood zone mapping): The raised embankments have been removed from the 2D domain based on surveyed elevations at the based embankments to smooth the river banks to floodplain level and form the interface between the 1D and 2D components.</p> <p>Buildings thresholds have been raised by 0.15m above the DTM level based on site observations and a higher Manning's 'n' value applied to the building footprints to simulate the storage of water once flooded.</p> <p>Areas of dense tree plantation or densely vegetated bog have been assigned a higher manning's 'n' value to represent the increased roughness.</p>				
Software Versions Used	<p>ISIS version 6.6 TUFLOW version 2012-05-AE-IDP-w64</p>				
Total No of 1D nodes	104				
Routing Units	0				
Open channel (H)	81				
Bridges (D)	7				
Spill (S)	7				
Culverts (I)	0				
Weirs (W)	9				
Model Extent	Reach/Feature	Upstream Limit (ING)		Downstream Limit (ING)	
	Maine	98629, 109333		77744, 101293	
	Annagh Beg	83595, 104612		83326, 103013	
Roughness	Reach/Feature	Active Channel	River Banks	Floodplain	Source
	Maine Upstream of Currans	0.040 to 0.045	0.08 to 0.1	0.1	Schedule 1: Photographs
	Maine downstream of Currans	0.040 to 0.045	0.06 to 0.08	N/A	Schedule 1: Photographs
	Annagh and other open channels	0.040 to 0.045	N/A	N/A	Schedule 1: Photographs
	Open pasture	N/A	N/A	0.060	Schedule 1: Photographs
	Dense vegetation	N/A	N/A	0.085	Schedule 1: Photographs
	Buildings	N/A	N/A	0.200	Schedule 1: Photographs
	Roads	N/A	N/A	0.030	Schedule 1: Photographs
Structures	See Schedule 2 for Hydraulic Structure Parameters				
Upstream boundary	The upstream inflow from Castleisland and tributary inflows have been applied directly to 1D ISIS model, as per FSU WP 3.4 guidelines, which simplify the interaction at confluences. However, this approach is deemed sufficient to assess the flood extent and depth of flooding from the Maine which the classified MPW in this reach.				
Lateral inflows	Lateral inflows QT hydrographs were distributed at low points in the banks between the confluences of key tributaries.				
Downstream boundary	<p>A full level-time (HT) tidal boundary has been applied directly to the outfall of the Maine into Castlemaine Harbour (estuary) based on the design tidal conditions transferred from Inch Spit based on Admiralty Prediction Points. The tidal level has been increased by 0.3m to replicate the gauged level at Castlemaine bridge.</p> <p>The HT boundary extends along the coastal defence on the right bank of the Maine to Gortnahulla to model any interaction with tidal overtopping along this reach.</p> <p>The peak tide has been phased to coincide with the peak fluvial flow at Castlemaine in this MPW reach.</p>				
Run Settings	<p>Unsteady simulation for 65 hours to enable the fluvial flood to reach the outfall and covering 5 tidal cycles ( 2 before and after the peak tide)</p> <p>2.5s timestep</p> <p>All other parameters set to default.</p>				

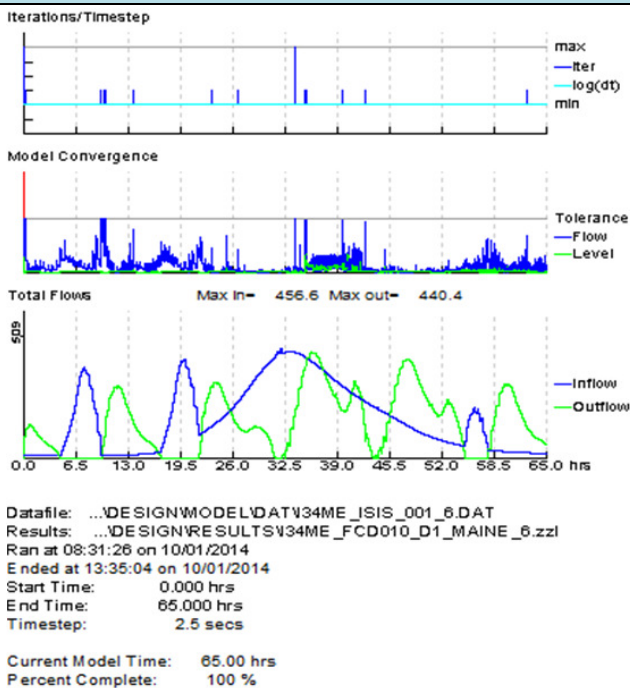
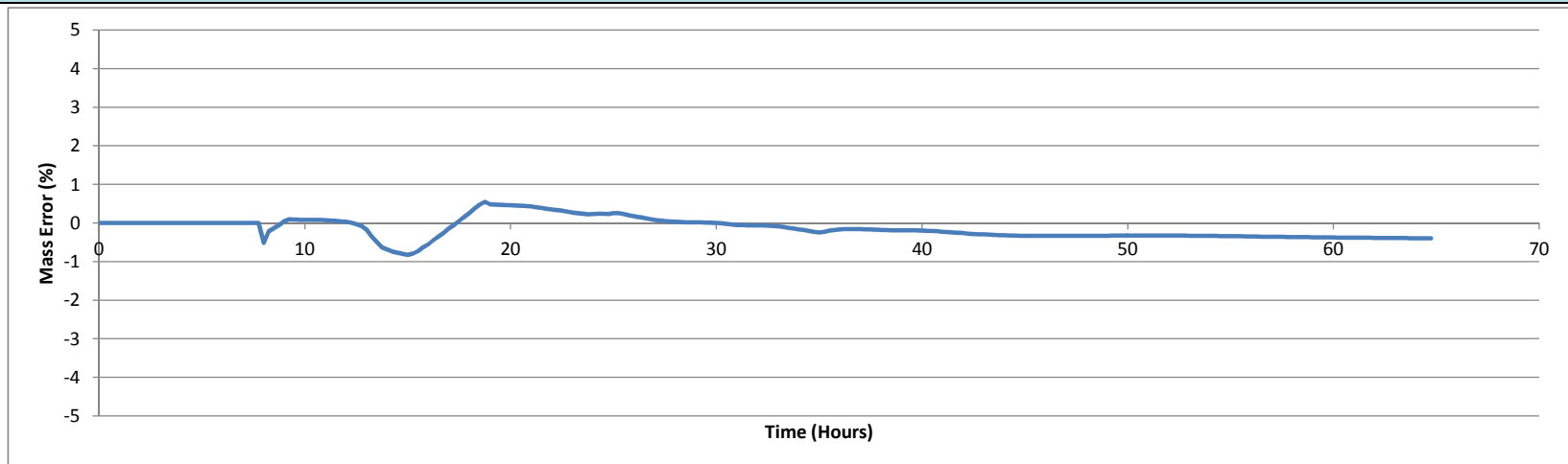




SCHEDULE 1 : PHOTOGRAPHS	
<p>Photo 1: Maine Active Channel and River Banks</p> 	<p>Photo 4: Upper Maine Floodplain</p> 
<p>Photo 2: Densely Wooded River Banks</p> 	<p>Photo 5: Coastal Floodplain and Houses</p> 
<p>Photo 3: Lower Maine Near Castlemaine</p> 	

SCHEDULE 2: Structures																													
Data file Node(s)	P:\Cambridge\Demeter\EVT4\296241 S West CFRAMS EVT Code\Technical\Hydraulics\Build\134ME_Maine\DESIGN\model\ISIS\134ME_ISIS_001_6.DAT		Structure Type	Bridge Parameters				Weir Parameters				Spill Parameters			Culvert Parameters												Comments/ Justification		
	Easting	Northing		Soffit Elevation	No of Openings	Skew Angle	Calibration Coefficients	Crest Elevation	Breadth	Modular Limit	Velocity Coeff.	Minimum Crest Elevation	Modular Limit	Weir Coeff.	Soffit level (mAOD)	No of Openings	Invert u/s (mAOD)	Invert d/s (mAOD)	Area (m²)	Nominal Width (m)	Length (m)	K	K1	M	Trash Screen	Trash Screen coefficient		Flapped	
22MAIN04570D	97901	109330	Ahaclare Bridge USBPR Bridge	20.29	2	22.5	1	N/A	N/A	N/A	N/A	20.26	0.9	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Spill represents flow over parapet and across road on floodplain in 1D approach	
22MAIN03905D	93805	106451	Currans Bridge USBPR Bridge	13.49	3	44.8	1	N/A	N/A	N/A	N/A	14.55	0.9	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Lowered soffit to account for the pipe influence. Soffit without pipe 13.63 to 13.76mODM	
22MAIN03783D	92668	106152	N22 bridge USBPR Bridge	14.15	3	0	1	N/A	N/A	N/A	N/A	15.38	0.9	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
22MAIN03297D	89147	104787	Cloonmealane Road Bridge USBPR Bridge	6.12	3	0	1	N/A	N/A	N/A	N/A	7.04	0.9	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
22MAIN02636D	83569	103009	Castlemaine N70 Bridge USBPR Bridge	3.4	3	0	1	N/A	N/A	N/A	N/A	4.32	0.9	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
22MAIN03910D	93833	106469	Rail bridge ARCH Bridge	18.78	3	0	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No spill over the bridge modelled because the maximum water level modelled is lower than the soffit and nearly 7m lower than minimum spill elevation (21.48mODM).	
22MAIN03776D	92598	106150	Maine Road Bridge ARCH Bridge	14.02	3	0	1	8.02	23.19	N/A	0.8	14.43	0.9	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Arched bridge downstream of Riverville gauge. Weir represents bed drop across the section calibrated to match the gauge rating curve.The spill represents flow over the parapet.	
MAINE03785W1 to 4	92672	106163	Riverville Weir RN WEIR and SPILL	N/A	N/A	N/A	N/A	9.14 9.16 9.19 9.14	5.92 5.11 5.73 6.26	N/A	1	9.38	0.7	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Four formal weirs represented by the RN WEIR units. Intervening structures and river banks in 1D represented by SPILL unit. Coefficient represents inefficient flow over vegetated banks.	
(22_3102_14 Inflow)	92570	106165	Riverville Bypass Culvert Hydrological assumption No hydraulic structure	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	The Riverville bypass takes excess flows from the Brown Flesk via a weir at 093072,105680 and under the N22 in a rectangular culvert to outfall into the Maine downstream of the archd bridge and gauge. There is a short gauge record of flows this bypass which was used to establish the distribution between the Brown Flesk and bypass culvert. This struture has not been hydyaually modelled because the Brown Flesk is not a classified MPW and is beyond the scope of this study.	



Maine (MPW) Model Performance														
1D Convergence														
Convergence Plot 1% AEP Fluvial Event		<div></div> <div><p>Datafile: ...\\DESIGN\\MODEL\\DAT\\V34ME_ISIS_001_6.DAT</p><p>Results: ...\\DESIGN\\RESULTS\\V34ME_FCD010_D1_MAINE_6.zzi</p><p>Ran at 08:31:26 on 10/01/2014</p><p>Ended at 13:35:04 on 10/01/2014</p><p>Start Time: 0.000 hrs</p><p>End Time: 65.000 hrs</p><p>Timestep: 2.5 secs</p><p>Current Model Time: 65.00 hrs</p><p>Percent Complete: 100 %</p></div>												
Comments		The 1D model components were convergent and within the recommended tolerances for the majority of the event. The higher number of iterations used at the start of the simulation quickly stabilise within 0.5 hours and do not affected the flood event. The inflow peaks at approximately 7hrs, 20hrs and 56hrs represent the the incoming tide along the lower maine. The fluvial flood event extends over several hours and peaks at approxiamtely 33 hours.												
2D Convergence														
Mass Balance Plot 1%AEP Fluvial Event		<div></div>												
Comments		The final cumulative mass balance error was -0.4% or 287367 m <sup>3</sup> . The 2D model remains within the recommended tolerance throughout the event. The mass error temporarily increases between 8 and 20 hours as the 2D cells start to wet but remains within +/- 1% tolerance. The mass error then reduces to less than +/-0.1% 10 hours before the fluvial peak. A negative mass balance means that there is less volume in the model than expected from the volume entering and leaving the 2D domain so depth could be under predicted at the initial wetting of cells as the 2D cells are rapidly wetting and the flow through the model is relatively small such as at the start of flooding. The negative percentage mass error is exaggerated because there are very few active 2D cells as the first cells wet however, as flooding increases the mass error reduces to -0.05% by the peak. Therefore, the mass balance of volume entering and leaving the model is accurate within recommended tolerances at the peak and flood depth, velocity and extent can be deemed to be reliable.												
Hydrological Performance		Fluvial events				10% AEP m <sup>3</sup> /s			1%AEP m <sup>3</sup> /s			0.1%AEP m <sup>3</sup> /s		
Target Flows		HEP ID	Location	Model Node	Design	Modelled	% Difference	Design	Modelled	% Difference	Design	Modelled	% Difference	
		1D only reach												
		22_721_1	Maine downstream of Brogheen	22MAIN04585B	99	98.6	0%	159.1	151.2	-5%	262.7	244.7	-7%	
		22_2090_1	Maine downstream of Ballymacpierce	22MAIN04302B	110.6	104.3	-6%	177.6	170.9	-4%	293.3	265.4	-10%	
		22_3375_1	Maine downstream of Little Maine	22MAIN04233B	144.3	126.6	-12%	231.7	230.7	0%	382.6	300.9	-21%	
		1D-2D reach (hydrodynamically linked to 1D only reach upstream)												
		22_3101_1	22003 Riverville Gauge	22MAIN03780B	209.5	199.8	-5%	334.8	333.2	0%	550.2	553.0	1%	
		22_3306_1	Maine downstream of Inchinveema	22MAIN03672B	222.7	189.9	-15%	357.7	307.7	-14%	590.7	468.3	-21%	
		22_3754_1	Maine downstream of Coolmealane (Coolmealane Bridge)	22MAIN03291B	242	189.8	-22%	388.7	306.7	-21%	641.8	525.0	-18%	
		22_3970_3	Maine downstream of Annagh (Castlemaine)	22MAIN02609B	276.4	204.2	-26%	444	220.9	-50%	733.1	269.7	-63%	
		22_3958_1	Maine Downstream	22MAIN01698B	304.3	407.0	34%	488.9	431.0	-12%	807.3	454.0	-44%	
Comments		The 1D flows were compared directly with the design flows upstream of Currans Bridge in 1D only reach. Downstream of Currans Bridge, the flows in the 1D ISIS channel were combined with the 2D flow parallel to the channel where there was out-of-bank flows and compared to the design hydrology. The modelled flows at Riverville Gauge were calculated using the 1D flows in the gauge sections, the flows along the bypass culvert and any 2D out-of-bank flow to be comparable with the design flow assumptions.  The modelled flows were within 10% of the design flows upstream and including Riverville Gauge which are entirely fluvially-dominated. The modelled fluvial flows increasingly underestimated the design flows downstream of inchiveema due to the following: 1. Water stored on the floodplain and unable to re-enter the channel due to the raised embankment. i.e. the floodplain is attenuating the peak flow 2. An increasing tidal influence effectively tide-locking the Lower Maine and reducing peak flows.  The flows at the outfall 22_3948_1 are entirely tidally dominated and the peak flows represent tidal race on the turn of the tide rather than the fluvial flood. Therefore, the peak flows are not comparable with the design flood flows which assume free flow and fluvial dominance.  The downstream boundary was increased by 0.3m to replicate the gauged level at Castlemaine bridge.												
Calibration: There are no detailed flood reports available to calibrate flood extent along the Maine MPW due to the limited property that could be affected. However, gauge information was used to calibrate in-bank flows for two events.														
Calibration Event 1														
Model Run ID		I34CD_FCC20081004_D1												
Period Modelled		04/10/2008 11:30 to 06/10/2008 02:45 with the peak at 04/10/2008 20:00												
Hydraulic Modification to Design Model		No hydraulic modifications were made to the design model.												
Hydrological inflows		Rainfall runoff FSSR units have been applied based on the catchment average rainfall adjusted from Valentia Observatory and calibrated percentage runoff to achieve the flows at the riverville. The rainfall and calibrated rainfall paramaters were than trasnferred to the tributary inflows based on daily rain gauge totals.												
Calibration Plot		See Schedule 3 - Calibration and Sensitivity												
Comments		The model was calibrated to reproduce the water level and flow at Riverville gauge (22003). No Gauge information was available at Castlemaine 22061 for this event. The resultant gauge and long profile plots are included Schedule 3. The modelled peak flow at Riverville gauge was within 0.5% and peak water levels were within 0.02m at Riverville. No out of bank flooding was reported along the Lower Maine during this period and the model confirms this.  Overall, the model calibrates well with the gauge data available for 4th October 2008.												
Calibration Event 2														
Model Run ID		I34CD_FCC20100112_D1												
Period Modelled		12/01/2010 00:00 to 14/01/2010 23:45 with the peak at 12/01/2010 19:45 at Riverville												
Hydraulic Modification to Design Model		No hydraulic modifications were made to the design model.												

Hydrological inflows	<p>This event is less than QMED/ 50%AEP. It was selected to calibrate in-bank with concurrent gauge information at Riverville and Castlemaine.</p> <p>The observed rainfall at Valentia was transferred to various HEPS based on the daily rainfall gauge totals and the flood hydrograph derived and apply to the HEP inflows and lateral inflows. The astronomic predicted tide was derived for Castlemaine Harbour and applied directly to the downstream of the Maine model. The surge residual at Castletown Bearhaven was less than 0.1m therefore surge was not considered.</p>
Calibration Plot	See Schedule 3 - Calibration and Sensitivity
Comments	<p>The model was calibrated to reproduce the water level and flow at Riverville gauge (22003) and the level at the tidally influence Castlemaine gauge ( 22061).</p> <p>The resultant gauge and long profile plots are included Schedule 3. The modelled peak flow at Riverville gauge was within 0.5% and peak water levels were within 0.03m at both gauges. No out of bank flooding was reported during this period and the model confirms this.</p> <p>Overall, the model calibrates well with the gauge data available for 12th January 2010.</p>
<b>Verification to Anecdotal Flood Information</b>	
Locations of known flooding	Recurring flooding was reported at observed around Church Street Bridge and Tullig on 24th January 2014. This event occurred after the model calibration exercise had been completed. Therefore, the photographs provided were used to verify and common sense check flow paths and frequency of flooding.
Available Gauge Data	The Castleisland gauge was not active for this event. Gauge data was obtained from Riverville but the flow was less than the 50%AEP estimate. The extent of flooding in Castleisland has not been observed as frequently as the 50%AEP (1 in 2 year). Therefore, flows at Riverville are not representative of flood conditions in Castleisland for this event.
Verification Plot	See Schedule 3 - Calibration and Sensitivity
Comparison with Design Flood	The photographs verify the flow paths across Tullig Road and on the right bank at Church Street. The extent of flooding at Tullig and around Church Street would be consistent with the 2%AEP design flood extent.
<b>Sensitivity Test 1: Increased Flow</b>	
Model Run ID	I34ME_FHD010_D1
Hydraulic Modification to Design Model	No hydraulic modifications were made to the design model.
Hydrological inflows	<p>All inflows were increased by 30% for the 1%AEP fluvial current design event to account for the uncertainty in the derivation of QMED and the pooling group selected. This is broadly equivalent to the HEFS 1%AEP as the increase in urban extent has less the 1% impact on peak flow. Therefore, the HEFS 1%AEP results (FHD010) have been used as the sensitivity test results.</p>
Sensitivity Plot	See Schedule 3 - Calibration and Sensitivity
Comments	<p>A 30% increase in flows resulted in a 0.2m increase in water level typically along the fluvial dominated reach. However this did not significantly increase flood extent and risk upstream of the Traila confluence because the design 1%AEP flood extent already inundates the floodplain to the valley sides.</p> <p>Downstream of the Traila confluence, water level was increased by approximately 0.4m due to the increase in flows. This resulted in a significant increase in flood extent upstream and downstream of Castlemaine although flood extent through the town of Castlemaine did not change because the town is on slightly higher ground.</p> <p>Therefore flood risk upstream of the Traila confluence and within Castlemaine itself is not found to be sensitive to the uncertainties in flow. However, flood risk between Traila and Castlemaine and downstream of Castlemaine was found to be sensitive to uncertainties in flow. The design flows were selected based on the best fit to Riverville gauge data and water levels at Castlemaine gauge.</p> <p>An allowance should be made when interpreting the design flood outlines and the in the sizing of any flood risk management option due to this uncertainty in flood level and extent caused by the uncertainties in flow.</p>
<b>Sensitivity Test 2: Increased Downstream Level</b>	
Model Run ID	I34ME_CMD010_D1
Hydraulic Modification to Design Model	A 0.5m increase in water level was applied to the downstream boundary. This is broadly equivalent to the MRFS which increases sea level by 0.55m. Therefore, the MRFS 1%AEP results (CMD010) have been used to conduct the sensitivity test.
Hydrological inflows	No modifications were made to the design inflows.
Sensitivity Plot	See Schedule 3 - Calibration and Sensitivity
Comments	<p>A 0.5m increase in level resulted in a significant increase in flood extent along the Lower Maine up to Riverville. However flood extent did not significantly change in Castlemaine because the town is on higher ground. Flood risk upstream Riverville did not significantly change as it is fluvially dominated.</p> <p>Therefore flood risk at the suspension bridge and downstream of the Cromwell's Bridge on the Finnihy was deemed to be sensitive to the uncertainties in level. Flood risk upstream of Cromwell's Bridge was deemed to be insensitive to the downstream level.</p> <p>An allowance should be made when interpreting the design flood outlines and the in the sizing of any flood risk management option due to this uncertainty in flood level and extent caused by the uncertainties in levels.</p>
<b>Sensitivity Test 3: Increased Manning's 'n'</b>	
Model Run ID	I34ME_FCN010_D1
Hydraulic Modification to Design Model	<p>The Manning's 'n' values were increased to the upper limit of the industry recommended ranges.</p> <p>All active channels 0.040 to 0.050 All river banks 0.080 to 0.100 Pasture / parkland / garden 0.060 to 0.080 Buildings 0.200 to 0.300 Roads 0.033 to 0.040</p>
Hydrological inflows	No modifications were made to the design inflows.
Sensitivity Plot	See Schedule 3 - Calibration and Sensitivity
Comments	<p>The increase in Manning's 'n' did not significantly increase flood extent as the 1%AEP design extent already fills the floodplain where it overtops the defences. The increase in Manning's 'n' did not significantly increase water level and locations where the embankments overtopped.</p> <p>Therefore, the Maine model is not deemed sensitive to assumptions in Manning's 'n' at the 1%AEP.</p>

Figure B.1 In-Bank Calibration of the Maine Model to 4th October 2008 Fluvial Flood Event

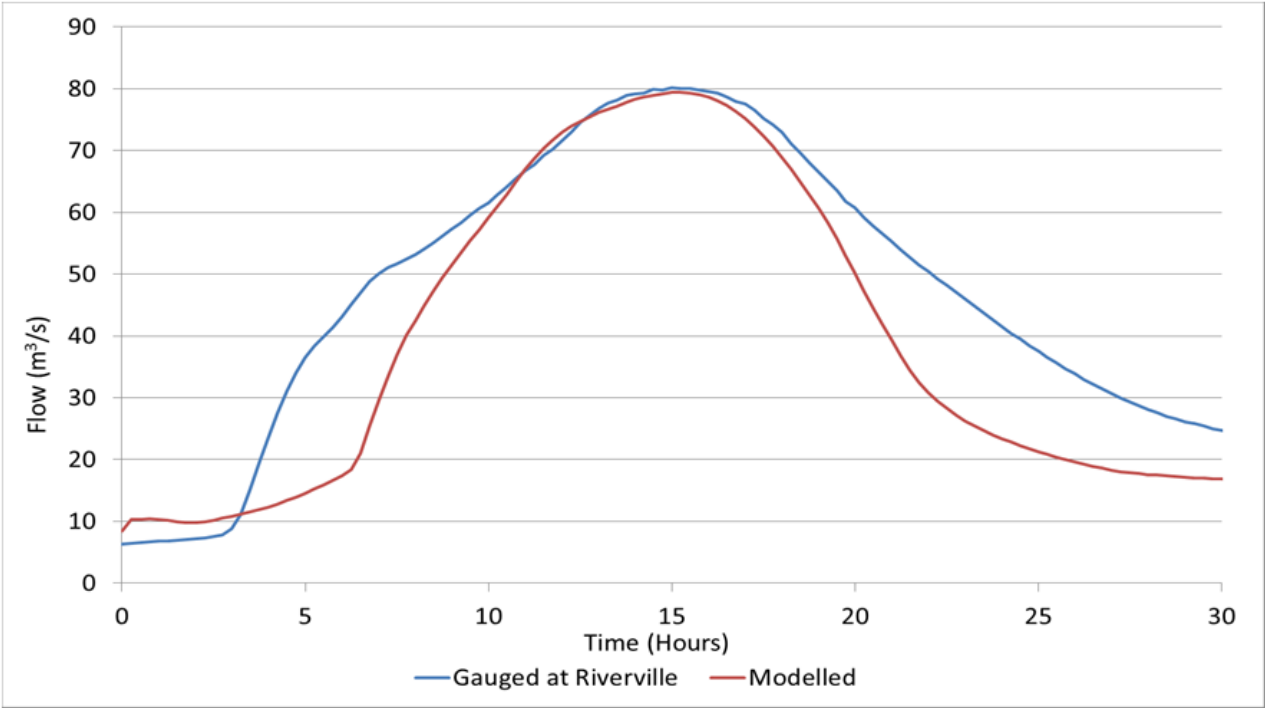
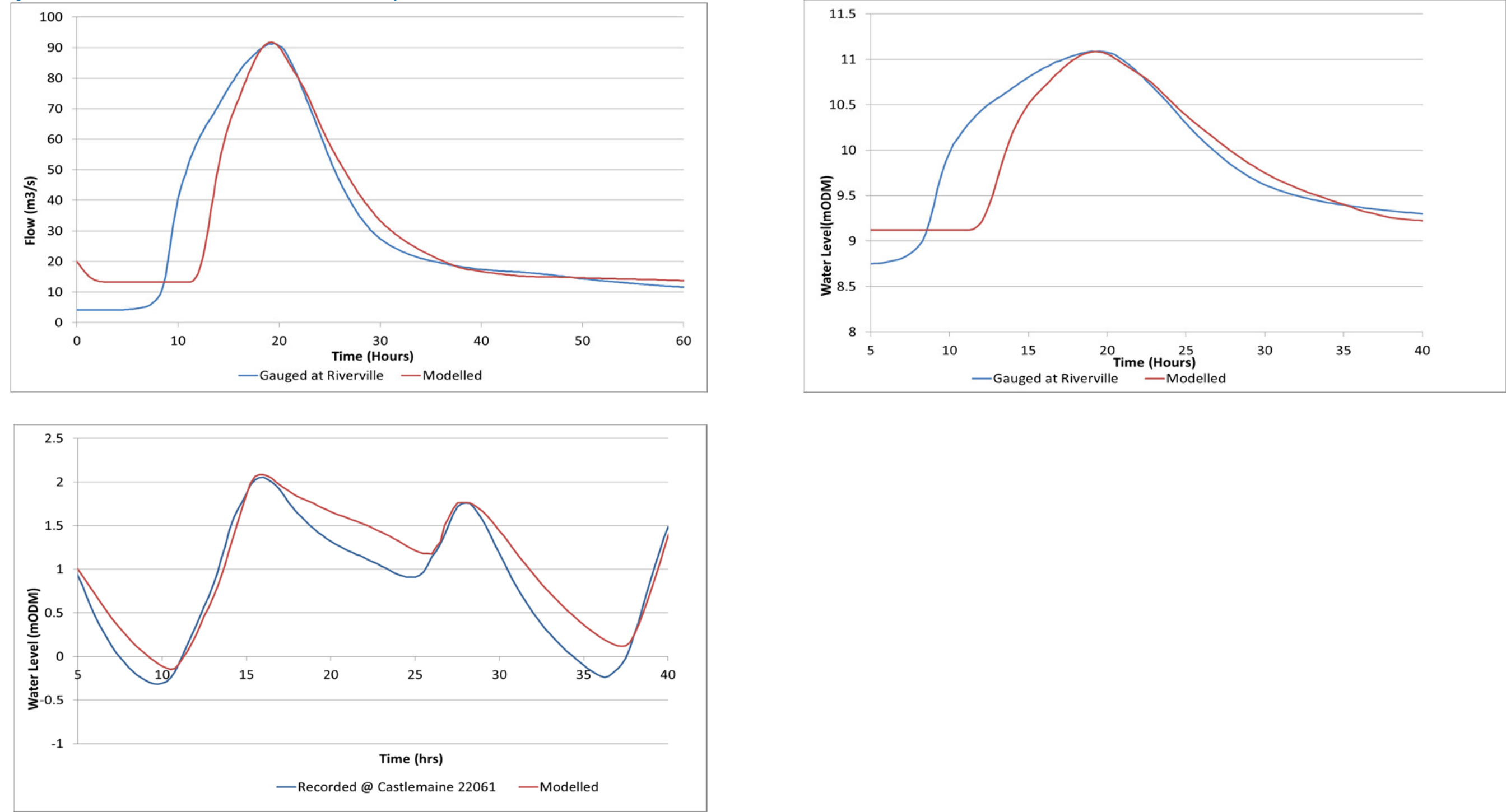
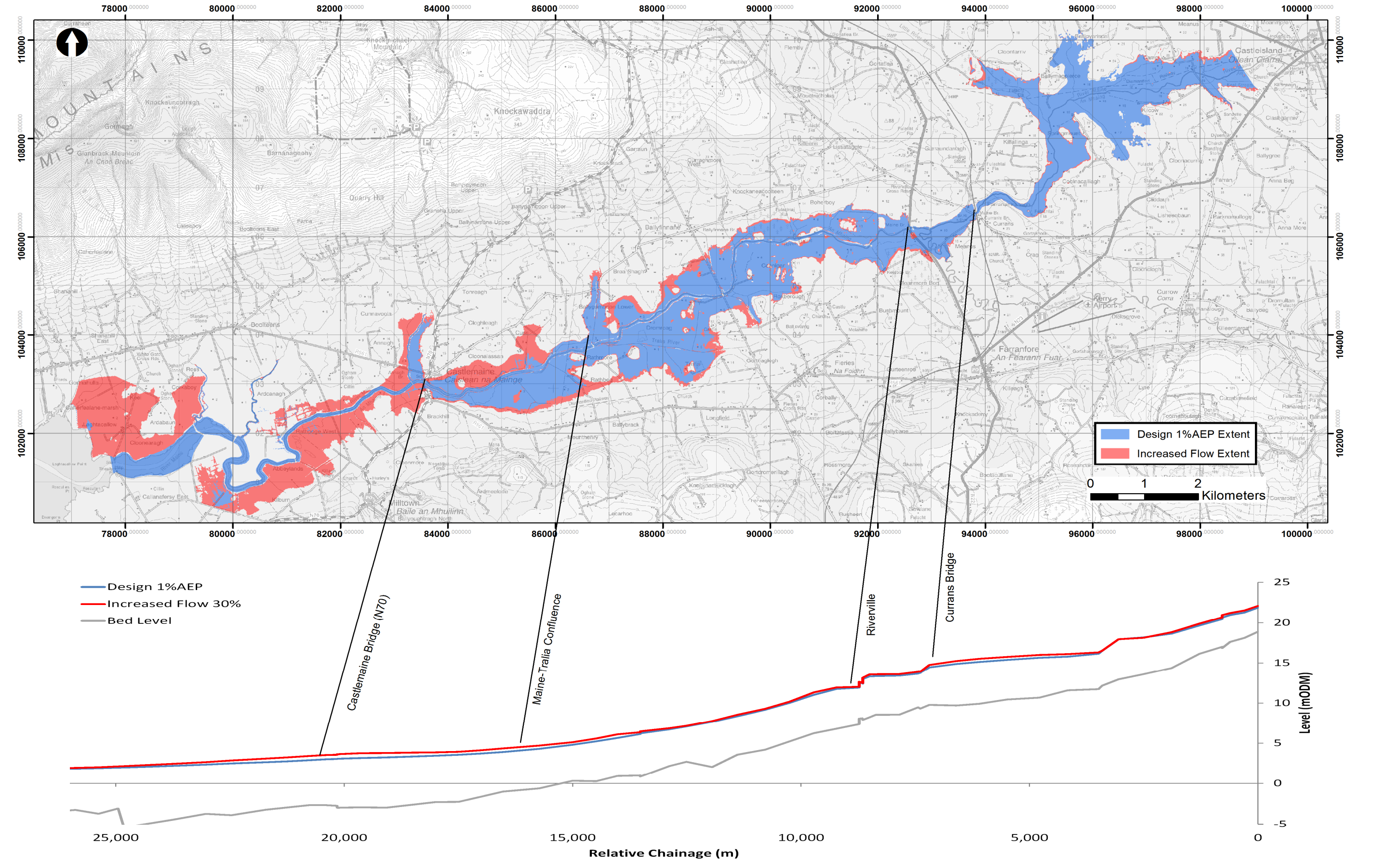


Figure B.2 In-Bank Calibration of the Maine Model to 12th January 2010 Fluvial Flood Event



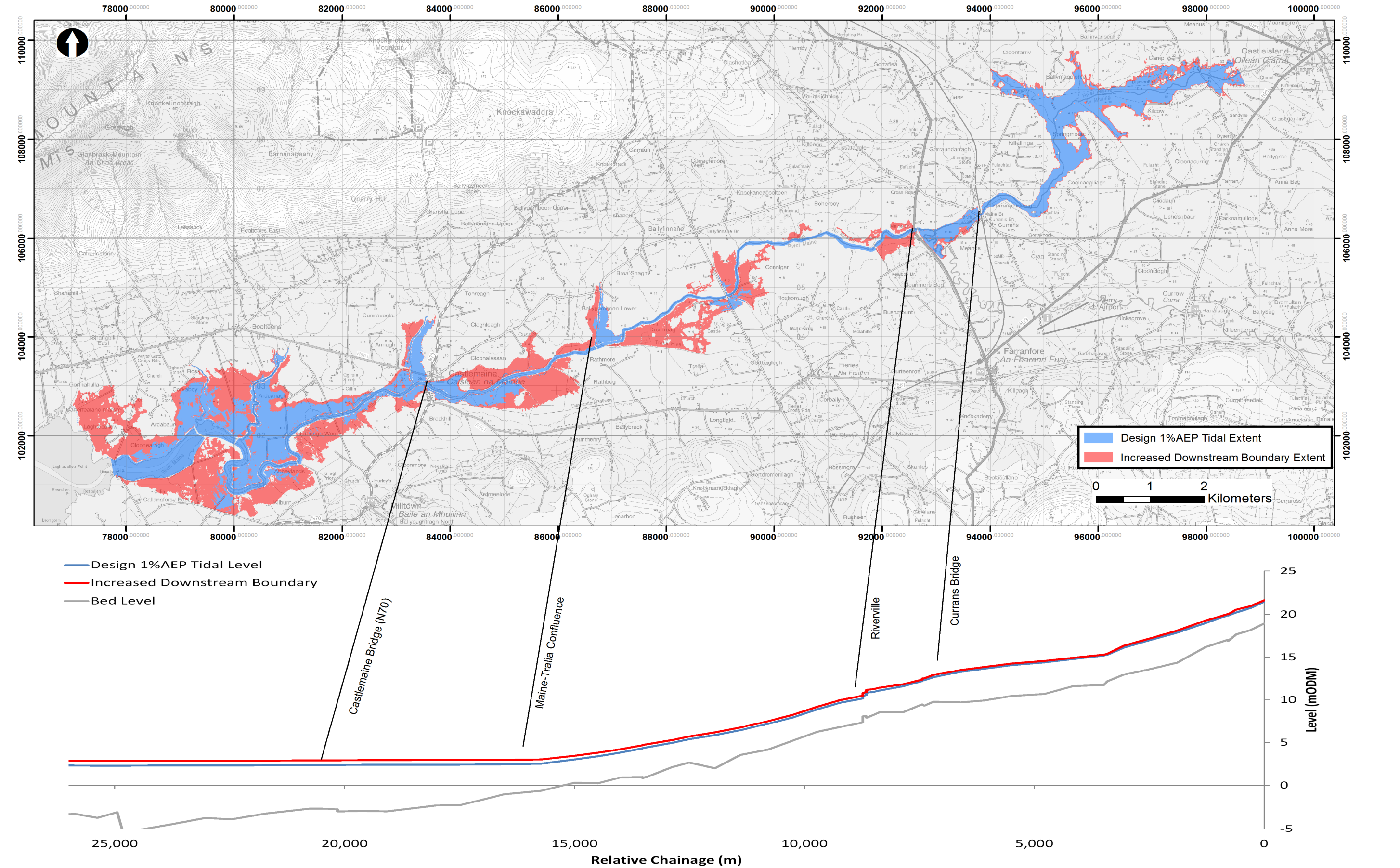


Map B.1: Sensitivity to 30% Increased Peak Flow



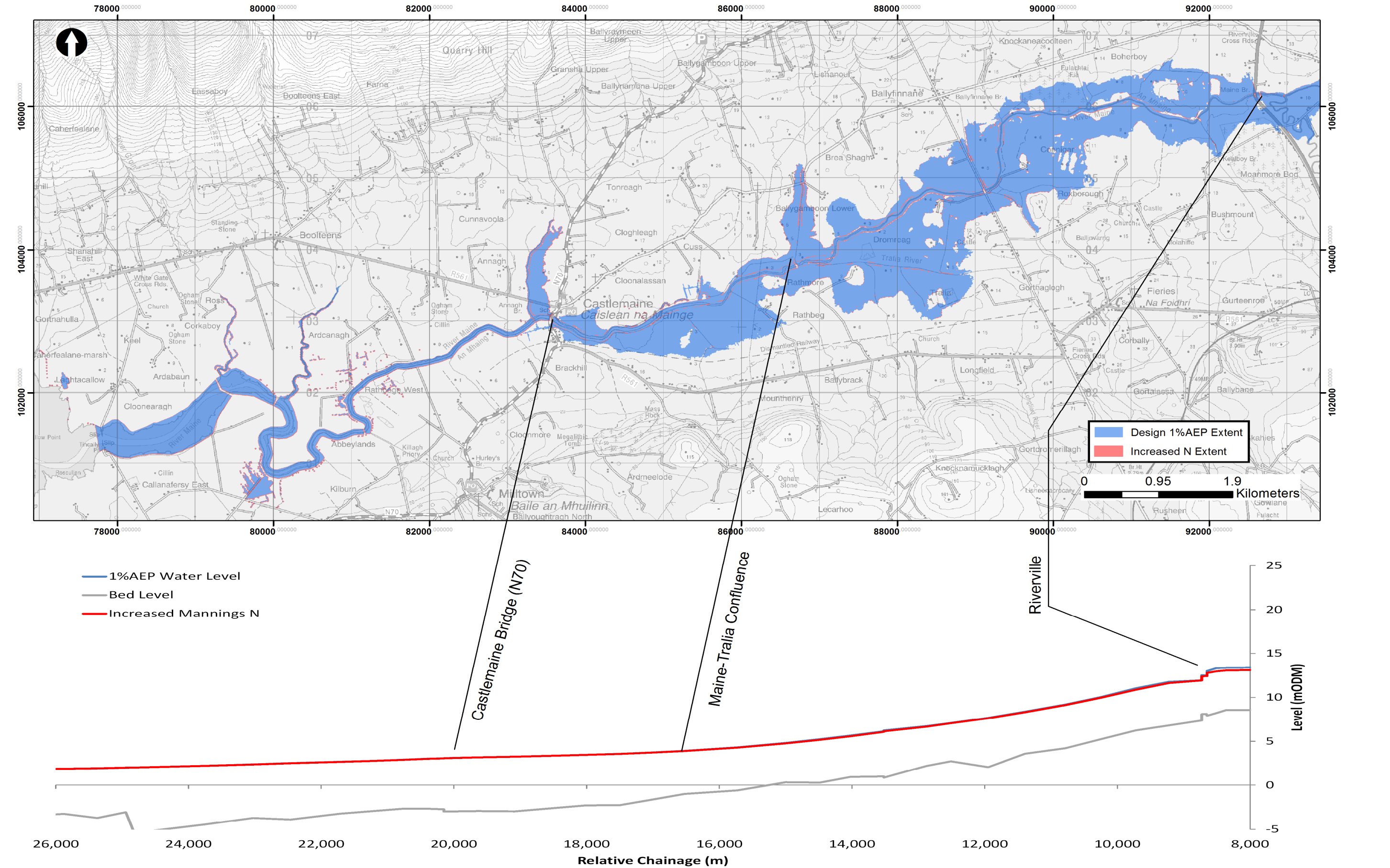


Map B.2: Sensitivity to Increased Downstream Boundary





Map B.3: Sensitivity to Increased Manning's 'n'



Maine Model Outputs	
	<p>The key thresholds and areas affected by tidal flooding along the Maine MPW are:</p> <ul style="list-style-type: none"><li>- 50%AEP tidal event exceeds the raised embankment at 080903,101921 to flooded the right bank towards Ardcanagh.</li><li>- 50%AEP tidal event overtops the left bank of the Annagh River on the outskirts of Castlemaine</li><li>- 20%AEP tidal event overtops the bank upstream of Castlemaine, at Rathpoge West and near Ardabaun causing extensive flooding on the right bank</li><li>- 10%AEP tidal event overtops the left embankment at 80605,101151 flooding towards the Abbeylands</li><li>- Less than 15 properties are affected by the 0.5%AEP tidal event.</li></ul> <p>The key thresholds and areas affected by fluvial flooding along the Maine MPW are:</p> <ul style="list-style-type: none"><li>- 50% AEP floods the confluence of the Maine and Brown Fiesk but does not overtop the N22</li><li>- 20%AEP floods fields downstream of Riverville and around Coolmealane Bridge to Tralia River.</li><li>- 2%AEP overtops the left bank downstream of Tralia River to Castlemaine</li><li>- 1%AEP overtops the right bank upstream of Castlemaine</li><li>- 1%AEP bypasses the Riverville Culvert to overtop the N22.</li><li>- 0.5%AEP spills over the N70 upstream of Castlemaine to flood areas on the left bank downstream of Castlemaine</li><li>- Less than 60 properties are affected by the 1%AEP fluvial event.</li></ul>
Threshold of Property Flooding	
Critical Structures for Flood Risk	<p>The critical structures along the Maine include:</p> <ul style="list-style-type: none"><li>- The raised embankments and channel capacity downstream of Riverville determine flood risk to the lower Maine</li><li>- The weir and bridge structures at Riverville control backwater and flooding over the N22</li><li>- Currans Bridge controls backwater upstream but flooding does not necessarily affect properties.</li></ul>
Areas affected by flooding	<p>The majority of fluvial and tidal flooding is constrained to the agricultural and pastoral fields at Riverville, Castlemaine and the downstream Ferry Crossing once the raised embankments are overtopped. The impact of pumped drainage in removing water is not considered for this study as worst case scenario. Fluvial flooding also occurs around the Little Maine confluence.</p> <p>Limited properties are affected by flooding as this reach is relatively unpopulated and the largest town of Castlemaine is on raised ground compared with the surrounding floodplain.</p>
Risk to people	<p>Flood hazard is not calculated for MPW reaches. However, the deepest tidal flooding occurs near Ardcanagh and the deepest fluvial flooding occurs between Coolmealane and Tralia. In both cases flooding exceeds 2m deep.</p>
Consideration for Flood Risk Management Options	<ul style="list-style-type: none"><li>- Increased channel capacity in riased-embankment section</li><li>- Raising of the embankment levels at low points identified by the survey/modelling.</li><li>- Flood warning on the Maine catchment is likely to be effective as there is &gt; 12 hours lead time at Riverville.</li></ul>

Flood Map Outputs					
The following table outlines the print-ready flood mapping deliverables provided in the accompanying digital data.					
Scenario	Flood Extent Map	Flood Zone Map	Flood Depth Map	Flood Velocity Map	Flood Hazard Map
Fluvial Current Design 10%AEP	I21HME34_EXFCDEXF_D2		I21HME34_DPFCDD100_D1	Flood Velocity Maps are not required along MPW reaches	Flood Hazard Maps are not required along MPW reaches
Fluvial Current Design 1%AEP	I21HME34_EXFCDEXF_D2	I21HME34_ZN_D2	I21HME34_DPFCDD010_D1		
Fluvial Current Design 0.1%AEP	I21HME34_EXFCDEXF_D2	I21HME34_ZN_D2	I21HME34_DPFCDD001_D1		
Fluvial Mid Range Future Design 10%AEP	I21HME34_EXFMDEXF_D2				
Fluvial Mid Range Future Design 1%AEP	I21HME34_EXFMDEXF_D2				
Fluvial Mid Range Future Design 0.1%AEP	I21HME34_EXFMDEXF_D2				
Coastal Current Design 10%AEP	I34HME34_EXCCDD_D3		I34HME34_DPCCDD200_D3		
Coastal Current Design 0.5%AEP	I34HME34_EXCCDD_D3		I34HME34_DPCCDD005_D3		
Coastal Current Design 0.1%AEP	I34HME34_EXCCDD_D3		I34HME34_DPCCDD001_D3		
Coastal Mid Range Future Design 10%AEP	I34HME34_EXCMD_D3				
Coastal Mid Range Future Design 0.5%AEP	I34HME34_EXCMD_D3				
Coastal Mid Range Future Design 0.1%AEP	I34HME34_EXCMD_D3				

GIS Outputs								
The following table outlines the GIS deliverables and model run files provided in the accompanying digital handover.								
Scenario	Model Run	Main River %AEP	Coastal %AEP	Flood Extent Polygon	Flood Zone Polygon	Flood Depth Grid	Flood Velocity Grid	Flood Hazard Grid
Fluvial Current Design 50%AEP	I34ME_FCD500_D1_Maine.jef	50	MHWS	I34EXFCD500D1		I34DPFCD500D1		
Fluvial Current Design 20%AEP	I34ME_FCD200_D1_Maine.jef	20	MHWS	I34EXFCD200D1		I34DPFCD200D1		
Fluvial Current Design 10%AEP	I34ME_FCD100_D1_Maine.jef	10	MHWS	I34EXFCD100D1		I34DPFCD100D1		
Fluvial Current Design 5%AEP	I34ME_FCD050_D1_Maine.jef	5	MHWS	I34EXFCD050D1		I34DPFCD050D1		
Fluvial Current Design 2%AEP	I34ME_FCD020_D1_Maine.jef	2	MHWS	I34EXFCD020D1		I34DPFCD020D1		
Fluvial Current Design 1%AEP	I34ME_FCD010_D1_Maine.jef	1	MHWS	I34EXFCD010D1	I34ZN_A_D2	I34DPFCD010D1		
Fluvial Current Design 0.5%AEP	I34ME_FCD005_D1_Maine.jef	0.5	MHWS	I34EXFCD005D1		I34DPFCD005D1		
Fluvial Current Design 0.1%AEP	I34ME_FCD001_D1_Maine.jef	0.1	MHWS	I34EXFCD001D1	I34ZN_B_D2	I34DPFCD001D1		
Fluvial Mid Range Future Design 50%AEP	I34ME_FMD500_D1_Maine.jef	50	MHWS	I34EXFMD500D1		I34DPFMD500D1		
Fluvial Mid Range Future Design 20%AEP	I34ME_FMD200_D1_Maine.jef	20	MHWS	I34EXFMD200D1		I34DPFMD200D1		
Fluvial Mid Range Future Design 10%AEP	I34ME_FMD100_D1_Maine.jef	10	MHWS	I34EXFMD100D1		I34DPFMD100D1		
Fluvial Mid Range Future Design 5%AEP	I34ME_FMD050_D1_Maine.jef	5	MHWS	I34EXFMD050D1		I34DPFMD050D1		
Fluvial Mid Range Future Design 2%AEP	I34ME_FMD020_D1_Maine.jef	2	MHWS	I34EXFMD020D1		I34DPFMD020D1		
Fluvial Mid Range Future Design 1%AEP	I34ME_FMD010_D1_Maine.jef	1	MHWS	I34EXFMD010D1		I34DPFMD010D1		
Fluvial Mid Range Future Design 0.5%AEP	I34ME_FMD005_D1_Maine.jef	0.5	MHWS	I34EXFMD005D1		I34DPFMD005D1		
Fluvial Mid Range Future Design 0.1%AEP	I34ME_FMD001_D1_Maine.jef	0.1	MHWS	I34EXFMD001D1		I34DPFMD001D1		
Fluvial High End Future Design 10%AEP	I34ME_FHD100_D1_Maine.jef	10	MHWS	I34EXFHD100D1		I34DPFHD100D1		
Fluvial High End Future Design 1%AEP	I34ME_FHD010_D1_Maine.jef	1	MHWS	I34EXFHD010D1		I34DPFHD010D1		

## Appendix C. Milltown AFA Model Proformas

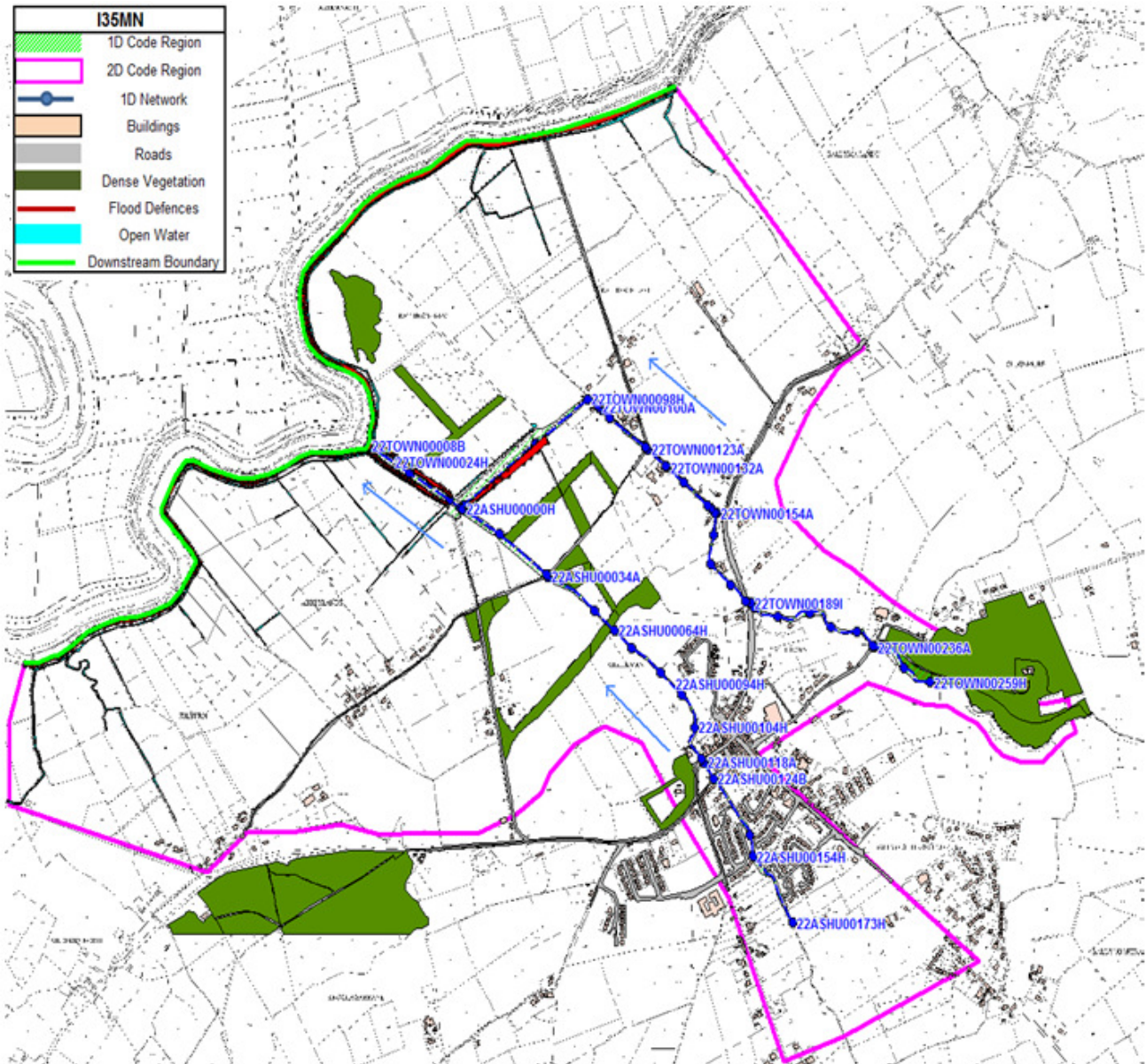
UOM	22		
AFA/ MPW Reach	Milltown		
Model ID	I35MN		
Purpose of Model Build	Flood Mapping		
Main Watercourses	Ashullish and Ballyoughtrough Streams	FLUVIAL RISK	Yes
Length Modelled (km)	4.4	COASTAL RISK	No (Tidal risk to lower end of catchment considered in Maine model)
Area Modelled (km <sup>2</sup> )	4.6	VULNERABLE TO WAVES	No

Input Data	
River Channel Topographic Data	Topographic survey by Murphy Surveys Limited. Data captured in October 2012. Refer to Drawing 22AHSU_Ashullish_V1.dwg and 22TOWN_Milltown_V1.dwg
Floodplain Topographic Data	2m DTM LIDAR provided by OPW converted from ITM to ING. Elevations on hard standing were compared with river channel survey and found to be within 0.2 m.
Map data	Ordnance Survey Ireland 1:1000, 1:2500 and 1:5000 and 1:50000 data Vector mapping at 1:1000, 1:2500 and 1:5000 were converted from DWG/DXF to GIS files for modelling purposes

Model Build					
General Schematisation	<p>A 1D/2D ISIS/TUFLOW approach was taken for Milltown to accurately model flow along the main watercourses and head loss through hydraulic structures whilst enabling multidirectional flow across the wide floodplain downstream of the N70.</p> <p>Building thresholds have been raised by 0.15m above the DTM level based on site observations and a higher Manning's 'n' value applied to the building footprints to simulate the storage of water once flooded. Areas of dense vegetation and plantations have been assigned higher Manning's 'n' to represent the increased roughness. the drainage channels with standing water were assigned with a lower Manning's 'n' to ensure these acted as flow pathways based on OSI mapping and site visit observations</p> <p>The 2D floodplain was set to 5m to represent the urban area without compromising run time.</p> <p>Version D2: Improved representation at culverts to better match local area engineer's comments. Improved representation of absolute flood defence crest and 1D extent.</p>				
Software Versions Used	<p>ISIS version 6.6</p> <p>TUFLOW version 2012-05-AC-iSP-w32</p>				
Total No of 1D nodes	120				
Routing Units	0				
Open channel (H)	54				
Bridges (D)	4				
Culverts (I)	6 structures using 50 culvert units (inlet, conduit and outlet)				
Penstock (P)	1				
Weirs (W)	0				
Model Extent	Reach/Feature	Upstream Limit (ING)		Downstream Limit (ING)	
	Ashullish	08265, 100032		081685, 101169	
	Ballyoughtrough (TOWN)	083164, 100739		081237, 101431	
Roughness	Reach/Feature	Active Channel	River Banks	Floodplain	Source
	Ashullish and Ballyoughtrough	0.040	0.060	N/A	Schedule 1: Photographs
	Open pasture	N/A	N/A	0.060	Schedule 1: Photographs
	Dense vegetation	N/A	N/A	0.085	Schedule 1: Photographs
	Standing Water	N/A	N/A	0.04	Schedule 1: Photographs
	Buildings	N/A	N/A	0.200	Schedule 1: Photographs
	Roads	N/A	N/A	0.030	Schedule 1: Photographs
Structures	See Schedule 2 for Hydraulic Structure Parameters				
Upstream boundary	The design inflows were applied directly to the Ashullish and Ballyoughtrough upstream limits of the model as flow-time inflows QT.				
Lateral inflows	Lateral inflows were distributed evenly across the rest of the catchment at low points in the bank.				
Downstream boundary	<p>The water level-time (HT) series extracted from the Maine MPW model was applied at the downstream of the flapped penstock to accurately simulate the period of tide-locking.</p> <p>The same HT boundary was applied along the banks of the River Maine to permit outflow from the model if flood levels exceed the embankment crest. The banks of the River Maine form the downstream limit of the active 2D code region (2D domain).</p>				



Run Settings	<p>Unsteady simulation of full 45 hour hydrograph. 2.5s timestep</p> <p>Minimum flows of 0.86m<sup>3</sup>/s on the Ashullish Stream and 0.38m<sup>3</sup>/s on the Ballyoughtrough (TOWN) were applied to maintain stability at low flows. This minimum flow is comparable to the calculated base flow.</p>
Model Geoschematic	



SCHEDULE 1 : PHOTOGRAPHS

Photo 1: Ashullish Active Channel and Banks



Photo 2: Ballyoughtrough Channel and Banks



Photo 3: Pasture and Wooded Floodplain

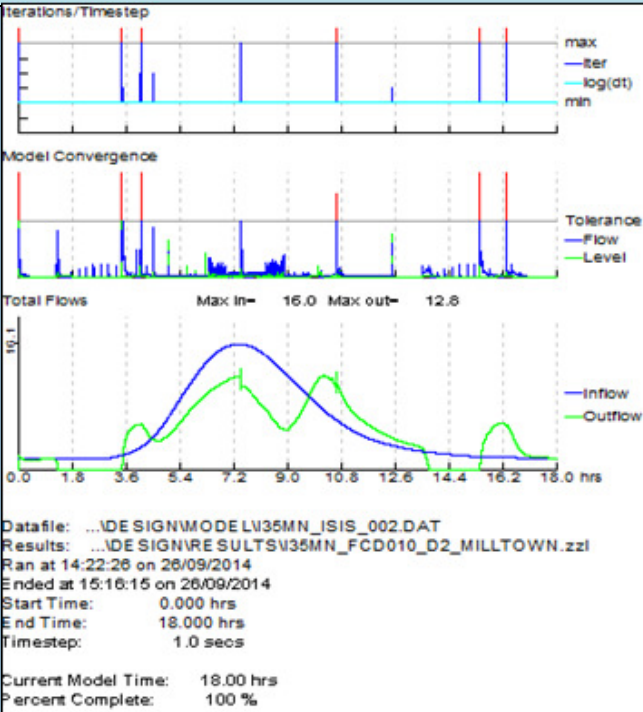
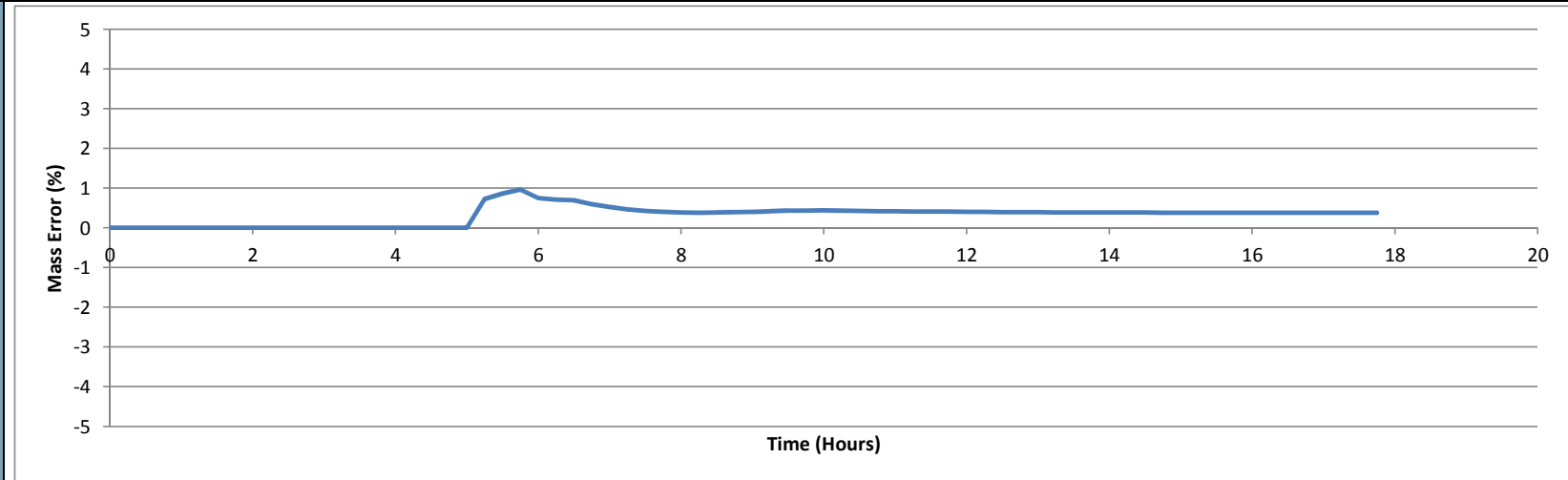


Photo 4: Urban Floodplain, Roads and Buildings



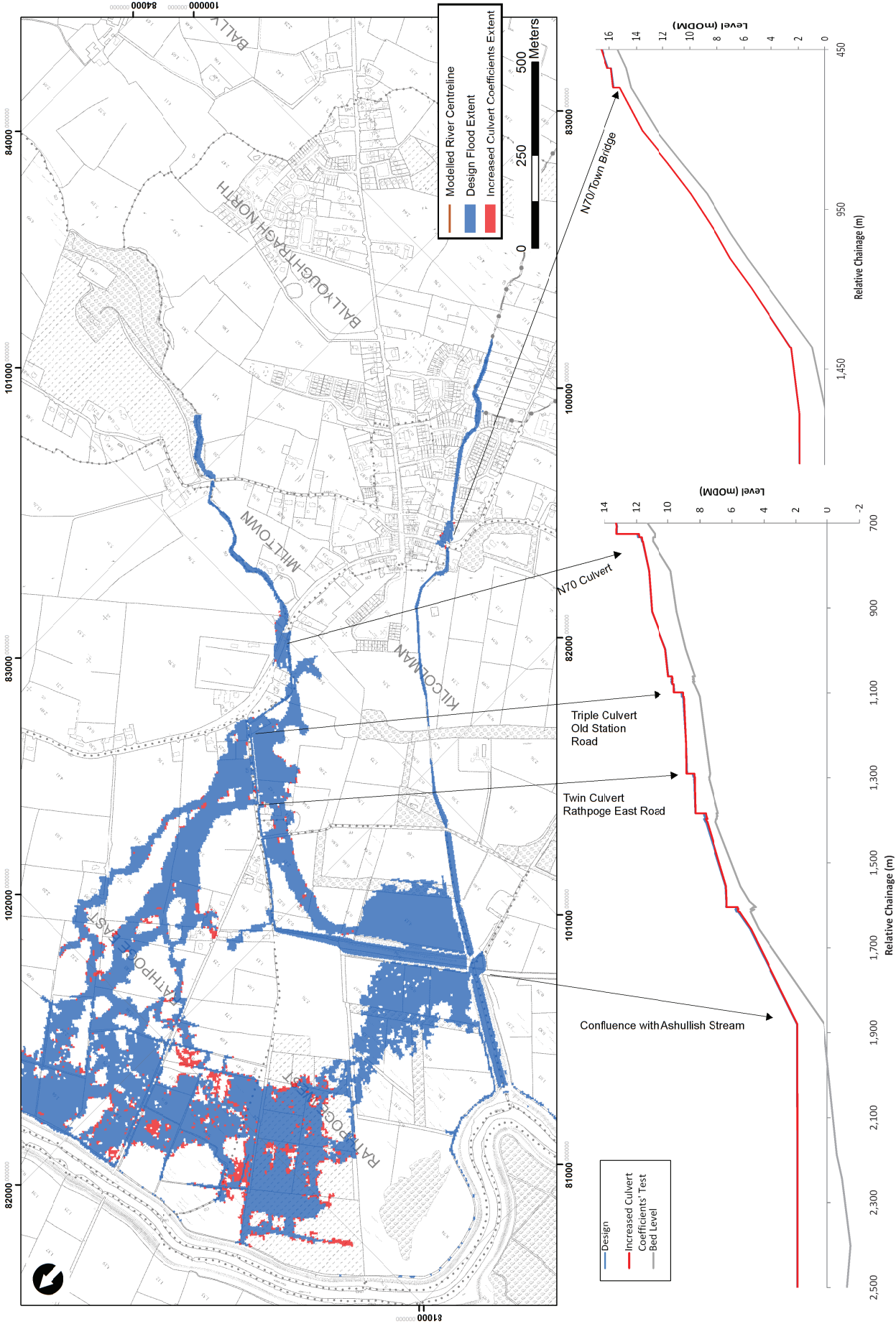
SCHEDULE 2: Structures																													
Data file	P:\Cambridge\Demeter\EVT4\296241_S West CFRAMS EVT Code\Technical\Hydraulics\Build\I35MN_Milltown\DESIGN\model\I35MN.DAT																												
Node(s)	Easting	Northing	Structure Type	Bridge Parameters				Weir Parameters				Spill Parameters			Culvert Parameters														Comments/ Justification
				Soffit Elevation	No of Openings	Skew Angle	Calibration Coefficients	Crest Elevation	Breadth	Modular Limit	Velocity Coeff.	Minimum Crest Elevation	Modular Limit	Weir Coeff.	Soffit level (mAOD)	No of Openings	Invert u/s (mAOD)	Invert d/s (mAOD)	Area (m²)	Nominal Width (m)	Length (m)	K	Ki	M	Trash Screen	Trash Screen coefficient	Flapped		
22ASHU00124D	82425	100457	Footbridge USBPR Bridge	15.64	1	0	1	N/A	N/A	N/A	N/A	15.476	0.9	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	22ASHU00124D is a flat soffit footbridge with in only 0.2m difference between the soffits on the left and right banks. It is not possible to model a sloping/ asymtetical soffit in the bridge geomerty therefore a symetrical soffit has been assumed for ISIS.	
22ASHU00118D	82390	100504	N70 Town Bridge ARCH Bridge	15.67	2	0	1.2	N/A	N/A	N/A	N/A	17.011	0.9	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	d/s arched face used to the constricting point as old bridge rather than the rectangular us face from widening	
22ASHU00034D	81852	101050	Access Bridge ARCH Bridge	3.22	1	0	1	N/A	N/A	N/A	N/A	3.62	0.9	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	22ASHU00034D has been modelled with an ARCH bridge unit as the survey drawing and photos show an arched bridge with a springing height of at least 0.5m	
TOWN0023601 and 2	82966	100844	Chapel Bridge ORIFICE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	21.21	0.9	1	20.305 20.265	2	19.371	19.359	2.109 0.715	2.23 0.80	5.9	0.7	0.5	0.7	N/A	N/A	N/A	Two low soffit rectangular bridge openings modelled as orifice units because the bridge would be orifice mode in the 50%AEF event and the length across the bridge is < 10m. Increased loss with inlet coefficient (k) to better match blockage reported by local area engineer.	
22TOWN00189I	82550	100971	N70 Culvert SPRUNG ARCH CONDUIT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12.74	1	10.864	10.981	3.202	2.8	18.255	0.7	0.7	0.75	N/A	N/A	N/A	Sprung arch conduit under N70 which sharp 90 degree bend near entrance. A culvert bend unit has been added to simulate the loss around the bend using a loss coefficient of 0.5. Increased inlet losses to better match local area engineer comments	
22TOWN00154I	82432	101235	Culvert under access bridge CIRCULAR CULVERT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10.421	0.9	1	8.74	3	8.37	8.47	2.5434	0.9	6.1	0.1	0.5	2	N/A	N/A	N/A	Triple circular culvert with flat headwall Increased inlet losses to better match local area engineer comments	
22TOWN00151I	82411	101251	Culvert under access bridge RECTANGULAR CULVERT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	9.34	0.9	1	9.227	1	8.12	8.02	2.5484	2.3	10.166	0.7	0.5	0.667	N/A	N/A	N/A	Single rectangular corrugated culvert Increased inlet losses to better match local area engineer comments	
22TOWN00132I	82263	101370	Culvert under access bridge RECTANGULAR CULVERT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8.69	0.9	1	8.43	2	7.739	7.415	1.31 0.73	1.4 0.79	7.558	0.7	0.5	0.667	N/A	N/A	N/A	Double rectangular corrugated culvert Increased inlet losses to better match local area engineer comments	
22TOWN00123I	82195	101423	Culvert under access bridge CIRCULAR CULVERT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8.05	0.9	1	7.85	3	6.95	6.88	2.5434	0.9	6.757	0.1	0.5	2	N/A	N/A	N/A	Triple circular culvert with flat headwall Increased inlet losses to better match local area engineer comments	
22TOWN00100I	82030	101548	Culvert under access bridge CIRCULAR CULVERT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	6.81	0.9	1	5.57	2	4.67	4.851	2.5434	0.9	5.378	0.1	0.5	2	N/A	N/A	N/A	Double circular culvert with flat headwall Increased inlet losses to better match local area engineer comments	
TOWN0001001 and 2	81259	101423	Outfall Penstock ORIFICE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.32 0.32	2	-1.13 -1.13	-1.15 -1.24	1.67 1.53	1.15 1.07	22.3	1	0.5	0.7	N/A	N/A	FLAPPED	Flapped penstocks under the embankment. Dimensions estimated from upstream face as downstream was submerged during survey.	



Milltown Model Performance												
1D Convergence												
Convergence Plot 1% AEP Fluvial Event		<div></div>										
Comments		<p>The 1D model components were convergent and within the recommended tolerances for the majority of the event.</p> <p>The outflow varies due to the influence of the tide in the Maine preventing free flow at the outfall.</p> <p>The brief 'spikes' of poor convergence at 3.5, 4, 6.5, 11.5, 15.5 and 16.25 hours are attributed to the opening and closing of the flapped outfall in to the Maine. These spikes do not impact the peak level or flood duration and therefore acceptable.</p>										
2D Convergence												
Mass Balance Plot 1% AEP Fluvial Event		<div></div>										
Comments		<p>The final cumulative mass balance error was 0.4% or 1261 m3. The mass error rises to a maximum of 1% as the cells wet at 6 hours. However mass error reduces to less than the 0.4% at the peak (8 hours). Therefore the mass error is within the +/- 1% recommended tolerance and is therefore acceptable.</p> <p>A positive mass balance means that there is more volume in the model than expected from the volume entering and leaving the 2D domain so depth could be over predicted at the initial wetting of cells as the 2D cells are rapidly wetting and the flow through the model is relatively small such as at the start of flooding.</p> <p>The positive percentage mass error is exaggerated because there are very few active 2D cells as the first cells wet at 5 to 6 hours however, as flooding increases the mass error reduces to less than 1% by the peak. Therefore, the mass balance of volume entering and leaving the model is accurate within recommended tolerances at the peak and flood depth, velocity and extent can be deemed to be reliable.</p>										
Hydrological Performance				10% AEP m3/s			1% AEP m3/s			0.1% AEP m3/s		
Target Flows	HEP ID	Location	Model Node	Design	Modelled	% Difference	Design	Modelled	% Difference	Design	Modelled	% Difference
	22_3116_1	Ashullish-Ashullish Trib d/s	22ASHU00144H	3.3	3.2	-2%	5	4.9	-1%	7.5	7.4	-1%
	22_3116_4	Ashullish- Ballyoughtragh U/s	22ASHU00000H	5.6	5.4	-4%	8.5	8.2	-4%	12.9	12.1	-6%
	22_3617_1	Ashullish- Ballyoughtragh D/s	22TOWN00046B	9.8	10.1	3%	14.9	12.6	-15%	22.5	15.5	-31%
	22_3958_2	Ashullish Stream d/s	22TOWN00010A	10.6	11.9	12%	16.1	14.1	-13%	24.3	15.4	-37%
	22_3425_9	Ballyoughtragh Stream D/S	22TOWN00100A	4.2	4.0	-4%	6.4	6.2	-4%	9.8	9.1	-7%
Comments		<p>The flows in the 1D ISIS channel were combined with 2D flows parallel to the channel where there were out-of-bank flows and compared to the design hydrology.</p> <p>The modelled flow tended to underestimate flows at the HEP locations compared to the design peak flows in all flood events. Flows taken from the two downstream locations on the Ashullish Stream (22_3617_1 and 22_3958_2) both show significant under- and over-estimation of flow across these three return periods. These nodes are both influenced by backwater from the River Maine, which becomes more significant in the higher return periods, thereby explaining these discrepancies.</p>										
Verification Checks												
Locations of known flooding	Flooding was observed from the Ballyoughtragh Stream downstream of Hurley's bridge on the N70 on 4th January 2008 and from the Ashullish Stream along the N70 at Bridge Street between 1998-2000. No specific details for these events were available so photographs provided were used to verify and common sense check flow paths and frequency of flooding.											
Available Gauge Data	None in vicinity											
Verification Plot	See Schedule 3 - Validation of flooded areas											
Comparison with Design Flood	The photographs and discussion verify the modelled flood extents at the locations discussed above. The extent of flooding from the Ballyoughtragh Stream is consistent with a modelled 10% AEP flood event.											
Sensitivity Test 1: Increased Flow												
Model Run ID	I35MN_FHD010_D1_MILLTOWN_3											
Hydraulic Modification to Design Model	No hydraulic modifications were made to the design model.											
Hydrological inflows	<p>All inflows were increased by 30% for the 1% AEP fluvial current design event to account for the uncertainty in the derivation of QMED and the pooling group selected.</p> <p>This is broadly equivalent to the HEFS 1% AEP as the increase in urban extent has less the 1% impact on peak flow. Therefore, the HEFS 1% AEP results (FHD010) have been used as the sensitivity test results.</p>											
Sensitivity Plot	See Schedule 3 - Calibration and Sensitivity											
Comments	<p>A 30% increase in flows resulted in flooding along the Ashullish Stream and Ballyoughtragh Stream immediately south of the N70 where before it was minimal. These two sources both increased the overall flood extent as the additional flow resulted in new flow paths being utilised.</p> <p>The increase in downstream water level increases the period of tide locking for this lower section. The increased downstream level was not of sufficient length or magnitude to induce a backwater impact in Milltown. It instead caused additional flooding in the floodplain from additional spill from the lower Ashullish Stream.</p> <p>Therefore flood risk in Milltown was found to be sensitive to the uncertainties in flow.</p> <p>An allowance should be made when interpreting the design flood outlines and in the sizing of any flood risk management option due to this uncertainty in flood level and extent caused by the uncertainties in flow.</p>											

Sensitivity Test 2: Increased Manning's 'n'	
Model Run ID	I35MN_FCN010_D1_MILLTOWN_3
Hydraulic Modification to Design Model	The Manning's 'n' values were increased to the upper limit of the industry recommended ranges. All active channels 0.040 to 0.048 All river banks 0.060 to 0.070 Pasture / parkland / garden 0.060 to 0.070 Buildings 0.200 to 0.300 Roads 0.033 to 0.040 Dense vegetation 0.085 to 0.1 Standing water 0.04 to 0.045
Hydrological inflows	No modifications were made to the design inflows.
Sensitivity Plot	See Schedule 3 - Calibration and Sensitivity
Comments	An increase in roughness values in bank and out-of-bank has a minimal impact on the flood extent from the Ashullish Stream but did result in more extensive flooding from the Ashullish Stream downstream of the N70. The most notable impact of this is immediately downstream of Hurley's Bridge where the increased roughness results in water spilling out from the Ballyoughtragh Stream in a westerly direction.  In general the increase in roughness did not have a notable impact on water level in both streams. Therefore the model is not deemed sensitive to the assumptions in assigning Manning's 'n'.
Sensitivity Test 3: Increased culvert parameters	
Model Run ID	I35MN_FCS010_D1_MILLTOWN_3
Hydraulic Modification to Design Model	The Manning's 'n' values attached to the culvert sections were increased from 0.025 to 0.03. Culvert inlet parameters were also modified to represent a 20% increase in accordance with Table 6.4 CIRIA C689 Culvert Design and Operation Guide (2010).
Hydrological inflows	No modifications were made to the design inflows.
Sensitivity Plot	See Schedule 3 - Calibration and Sensitivity
Comments	A change in the culvert parameters resulted in only minor changes to the maximum level and flood extent because the 1%AEP is already out of bank. However, the stage plot shows that there is a greater head loss on the rising and falling limb causing water to spill out-of-bank earlier and flood duration to be longer.  Therefore the Milltown model is not deemed sensitive to the culvert coefficients at the 1%AEP but would be more sensitive for less severe events on threshold of flooding along Old Station Road.





Milltown Model Outputs					
	The key thresholds and areas affected by flooding in Milltown are: - 50% AEP event exceeds the capacity of the Ballyoughtragh Stream downstream of the N70 causing water to spill over the right bank in two locations. This is modelled to impact a single property. - 50% AEP overtops at the confluence of the Ballyoughtragh an Ashullish Streams at low points in the embankments to flood fields. - 10% AEP causes shallow flooding by the N70 at Hurley's Bridge. - 2% AEP event causes additional sections of the Ballyoughtragh Stream downstream of the N70 to spill, impacting additional properties. - 1% AEP event floods the N70 at Town Bridge on the Ashullish Stream - 0.5% AEP event bypasses town bridge - Approximately 17 properties are affected by the 1% AEP fluvial event. It should be noted that the drainage system and tributaries towards Cloonmore and Kilburn has not been modelled as part of the CFRAM study as these are not MPW or HPWs.				
Threshold of Property Flooding					
Critical Structures for Flood Risk	The critical structures in determining flood risk include: - N70 bridge on Bridge Street, Ashullish Stream - Hurley's Bridge, Ballyoughtragh Stream - The several small culverts on the Ballyoughtragh Stream downstream of Hurley's Bridge.				
Areas affected by flooding	The floodplain areas downstream of the N70 on both streams are modelled to be affected most from flooding. The greatest impact on property and infrastructure is modelled to be along the access tracks leading west off the N70.				
Risk to people	The greatest risk to life is associated with deep fast flowing water in channel and along the Ballyoughtragh Stream downstream of the N70 where risk from overland flow would be highest. There is also risk along Bridge Street in the 0.1% AEP magnitude event.				
Consideration for Flood Risk Management Options	- Increased conveyance at the key structures identified are likely to reduce flood risk.				
Flood Map Outputs					
The following table outlines the print-ready flood mapping deliverables provided in the accompanying digital data.					
Scenario	Flood Extent Map	Flood Zone Map	Flood Depth Map	Flood Velocity Map	Flood Hazard Map
Fluvial Current Design 10% AEP	I22HMN35_EXFCDEXF_D2	I22HMN35_ZN_D2	I22HMN35_DPFCDD100_D2	I22HMN35_VLFCDD100_D2	I22HMN35_HZFCDD100_D2
Fluvial Current Design 1% AEP	I22HMN35_EXFCDEXF_D2	I22HMN35_ZN_D2	I22HMN35_DPFCDD010_D2	I22HMN35_VLFCDD010_D2	I22HMN35_HZFCDD010_D2
Fluvial Current Design 0.1% AEP	I22HMN35_EXFCDEXF_D2	I22HMN35_ZN_D2	I22HMN35_DPFCDD001_D2	I22HMN35_VLFCDD001_D2	I22HMN35_HZFCDD001_D2
Fluvial Mid Range Future Design 10% AEP	I22HMN35_EXFMDEXF_D2				
Fluvial Mid Range Future Design 1% AEP	I22HMN35_EXFMDEXF_D2				
Fluvial Mid Range Future Design 0.1% AEP	I22HMN35_EXFMDEXF_D2				

GIS Outputs								
The following table outlines the GIS deliverables and model run files provided in the accompanying digital handover.								
Scenario	Model Run File	Main River %AEP	Tributary River %AEP	Flood Extent Polygon and Nodes	Flood Zone Polygon	Flood Depth Grid	Flood Velocity Grid	Flood Hazard Grid
Fluvial Current Design 50% AEP	I35MN_FCD500_D2_MILLTOWN.jef	50	50	I35EXFCD500D2		I35DPFCD500D2	I35VLFCDD500D2	I35HZFCD500D2
Fluvial Current Design 20% AEP	I35MN_FCD200_D2_MILLTOWN.jef	20	20	I35EXFCD100D2		I35DPFCD100D2	I35VLFCDD100D2	I35HZFCD100D2
Fluvial Current Design 10% AEP	I35MN_FCD100_D2_MILLTOWN.jef	10	10	I35EXFCD100D2		I35DPFCD100D2	I35VLFCDD100D2	I35HZFCD100D2
Fluvial Current Design 5% AEP	I35MN_FCD050_D2_MILLTOWN.jef	5	5	I35EXFCD050D2		I35DPFCD050D2	I35VLFCDD050D2	I35HZFCD050D2
Fluvial Current Design 2% AEP	I35MN_FCD020_D2_MILLTOWN.jef	2	2	I35EXFCD020D2		I35DPFCD020D2	I35VLFCDD020D2	I35HZFCD020D2
Fluvial Current Design 1% AEP	I35MN_FCD010_D2_MILLTOWN.jef	1	1	I35EXFCD010D2	I35ZN_A_D2	I35DPFCD010D2	I35VLFCDD010D2	I35HZFCD010D2
Fluvial Current Design 0.5% AEP	I35MN_FCD005_D2_MILLTOWN.jef	0.5	0.5	I35EXFCD005D2		I35DPFCD005D2	I35VLFCDD005D2	I35HZFCD005D2
Fluvial Current Design 0.1% AEP	I35MN_FCD001_D2_MILLTOWN.jef	0.1	0.1	I35EXFCD001D2	I35ZN_B_D2	I35DPFCD001D2	I35VLFCDD001D2	I35HZFCD001D2
Fluvial Mid Range Future Design 50% AEP	I35MN_FMD500_D2_MILLTOWN.jef	50	50	I35EXFMD500D2		I35DPFMD500D2		
Fluvial Mid Range Future Design 20% AEP	I35MN_FMD200_D2_MILLTOWN.jef	20	20	I35EXFMD100D2		I35DPFMD100D2		
Fluvial Mid Range Future Design 10% AEP	I35MN_FMD100_D2_MILLTOWN.jef	10	10	I35EXFMD100D2		I35DPFMD100D2		
Fluvial Mid Range Future Design 5% AEP	I35MN_FMD050_D2_MILLTOWN.jef	5	5	I35EXFMD050D2		I35DPFMD050D2		
Fluvial Mid Range Future Design 2% AEP	I35MN_FMD020_D2_MILLTOWN.jef	2	2	I35EXFMD020D2		I35DPFMD020D2		
Fluvial Mid Range Future Design 1% AEP	I35MN_FMD010_D2_MILLTOWN.jef	1	1	I35EXFMD010D2		I35DPFMD010D2		
Fluvial Mid Range Future Design 0.5% AEP	I35MN_FMD005_D2_MILLTOWN.jef	0.5	0.5	I35EXFMD005D2		I35DPFMD005D2		
Fluvial Mid Range Future Design 0.1% AEP	I35MN_FMD001_D2_MILLTOWN.jef	0.1	0.1	I35EXFMD001D2		I35DPFMD001D2		
Fluvial High End Future Design 10% AEP	I35MN_FHD100_D2_MILLTOWN.jef	10	10	I35EXFHD100D2		I35DPFHD100D2		
Fluvial High End Future Design 1% AEP	I35MN_FHD010_D2_MILLTOWN.jef	1	1	I35EXFHD010D2		I35DPFHD010D2		
Fluvial High End Future Design 0.1% AEP	I35MN_FHD001_D2_MILLTOWN.jef	0.1	0.1	I35EXFHD001D2		I35DPFHD001D2		

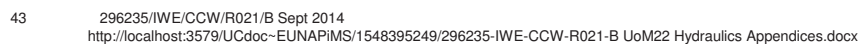
## Appendix D. Glenflesk AFA Model Proformas

UOM	22		
AFA: MPW Reach	Glenflesk		
Model ID	I36GK		
Purpose of Model Build	Flood Mapping		
Main Watercourse	Flesk	FLUVIAL RISK	Yes
Length Modelled (km)	16.7	COASTAL RISK	No
Area Modelled (km <sup>2</sup> )	3.819	VULNERABLE TO WAVES	No

Input Data	
River Channel Topographic Data	River channel survey was undertaken by Murphy Surveys Limited as part of the CFRAM Study. 22FLES_B_Flesk_V2.dwg surveyed in March 2013, drawing corrected in July 2013 to rectify drawing errors with skew angle at the downstream N22 road bridge. Otherwise the survey data were found to be consistent with independent spot checks. 22DAGH_Clydagh River_V1.dwg, 22LOOR_Loo_V1.dwg, 22LOOT_Loo Tributary_V1.dwg and 22OWNE_Owneyskeagh River_V1.dwg surveyed in March 2013 : No errors or gaps were found within the survey and these data was found to be consistent with independent spot checks.
Floodplain Topographic Data	Filtered LIDAR DTM "22FLS_DTM_2m_ING.asc" 2m grid resolution with +/- 0.1m RMSE captured in September 2012 as part of the Kilarney aerial survey. The LIDAR DTM was used as the basis for the 2D model of the floodplain. The LIDAR was checked against the river channel survey on expansive flat surfaces such as roads and found to be within +/- 0.1m of the surveyed level. Upstream of Annagh Beg, the IFSAR data were used to extend the surveyed river channel sections and represent the valley floodplain sections. The IFSAR was found to be within 0.4m of the surveyed levels on the wide flat floodplain but tended to be less accurate towards the river banks. In these areas, elevations were interpolated between the detailed river channel survey and IFSAR data.
Map data	1:5000 Osi mapping tiles 6132, 6133, 6179 and 6180 The OSI mapping was found to include all current developments and was consistent with site observations, the river channel survey and aerial photography.

Model Build																																							
General Schematisation	<p>The AFA for Glenflesk is defined as the areas downstream of the Annagh Beg Bridge down to the confluence with the Owneyskeagh River. Therefore a 1D-2D approach was taken to full assess the floodplain storage and interactions between the Flesk and Owneyskeagh. The 2D domain extends from the Garries Bridge to the downstream N22 bridge to capture all floodplain flow routes and potential backwater impacts.</p> <p>ISIS has been used to calculate flows in bank and TUFLOW has been used to calculate flows out of bank. The 2D domain has a 5m cell resolution to accurately model the AFA without excessive simulation times. In the 2D domain, river banks have been enforced using 2d_zln layers based on the surveyed spot levels. The various drainage ditches have been represented using a lowered Manning's 'n' to simulate these flow paths. Dense vegetation (forestry areas), buildings and roads have also been represented with appropriate Manning's 'n' values. Building footprints have also been raised by 0.15m above the floodplain to represent the typical property threshold for this AFA.</p> <p>The Lower Clydagh River, Lower Loo River and Flesk River until Annagh Beg Bridge were identified as MPW by the Local Authority because the main road (N22) is at risk of flooding based on the local engineer's knowledge and floodmaps.ie reports. Therefore the 1D model was extended up to the N22 on the Clydagh and the access bridge on the Loo. The river channel sections were extended based on the IFSAR data to model the floodplain. Muskingum Routing units have been used to route the flows from the Clydagh gauge to the upstream limit of the model based on DTM dimensions of the floodplain and typical channel sections.</p> <p>Version D2: Extended 2D extent upstream of Garries Bridge to better represent the offline storage between the River Flesk and the N22 and bridge coefficients calibrated to better match the reported frequency of flooding across the road. The LIDAR DTM was found to be within 0.1m of the topographic survey within the AFA (Near Mountain House). However the reported vulnerable section is upstream outside the AFA and the road embankment was beyond the extent of the surveyed river sections. Road crest levels were requested from the National Roads Authority but the elevations were not readily available. Therefore the road embankments were reviewed from the LIDAR and enforced in the 2D domain as a best estimate.</p>																																						
Software Versions Used	TUFLOW version 2012-05-AC-ISP-w32																																						
Total No of 1D nodes	120																																						
Routing Units	4																																						
Open channel (H)	103																																						
Bridges (D)	10																																						
Culverts (I)	1																																						
Weirs (W)	2																																						
Model Extent	<table><tr><th>Reach/Feature</th><th colspan="2">Upstream Limit (ING)</th><th colspan="2">Downstream Limit (ING)</th></tr><tr><td>Flesk</td><td colspan="2">108466, 81433</td><td colspan="2">103587, 87658</td></tr><tr><td>Owneyskeagh</td><td colspan="2">106991, 86664</td><td colspan="2">105420, 86796</td></tr><tr><td>Clydagh</td><td colspan="2">109709, 81836</td><td colspan="2">108466, 81433</td></tr><tr><td>Loo River</td><td colspan="2">106978, 80038</td><td colspan="2">108531, 81421</td></tr></table>				Reach/Feature	Upstream Limit (ING)		Downstream Limit (ING)		Flesk	108466, 81433		103587, 87658		Owneyskeagh	106991, 86664		105420, 86796		Clydagh	109709, 81836		108466, 81433		Loo River	106978, 80038		108531, 81421											
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Clydagh	109709, 81836		108466, 81433																																				
Loo River	106978, 80038		108531, 81421																																				
Roughness	<table><tr><th>Reach/Feature</th><th>Active Channel</th><th>River Banks</th><th>Floodplain</th><th>Source</th></tr><tr><td>Clydagh</td><td>0.04 to 0.07</td><td>0.06 to 0.07</td><td>0.07 to 0.085</td><td>Schedule 1: Photographs</td></tr><tr><td>Loo, Flesk and Owneyskeagh</td><td>0.04 to 0.06</td><td>0.06 to 0.07</td><td>0.06 to 0.085</td><td>Schedule 1: Photographs</td></tr><tr><td>Open pasture</td><td>N/A</td><td>N/A</td><td>0.06</td><td>Schedule 1: Photographs</td></tr><tr><td>Dense vegetation</td><td>N/A</td><td>N/A</td><td>0.085</td><td>Schedule 1: Photographs</td></tr><tr><td>Buildings</td><td>N/A</td><td>N/A</td><td>0.2</td><td>Schedule 1: Photographs</td></tr><tr><td>Roads</td><td>N/A</td><td>N/A</td><td>0.03</td><td>Schedule 1: Photographs</td></tr></table>				Reach/Feature	Active Channel	River Banks	Floodplain	Source	Clydagh	0.04 to 0.07	0.06 to 0.07	0.07 to 0.085	Schedule 1: Photographs	Loo, Flesk and Owneyskeagh	0.04 to 0.06	0.06 to 0.07	0.06 to 0.085	Schedule 1: Photographs	Open pasture	N/A	N/A	0.06	Schedule 1: Photographs	Dense vegetation	N/A	N/A	0.085	Schedule 1: Photographs	Buildings	N/A	N/A	0.2	Schedule 1: Photographs	Roads	N/A	N/A	0.03	Schedule 1: Photographs
Reach/Feature	Active Channel	River Banks	Floodplain	Source																																			
Clydagh	0.04 to 0.07	0.06 to 0.07	0.07 to 0.085	Schedule 1: Photographs																																			
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Dense vegetation	N/A	N/A	0.085	Schedule 1: Photographs																																			
Buildings	N/A	N/A	0.2	Schedule 1: Photographs																																			
Roads	N/A	N/A	0.03	Schedule 1: Photographs																																			
Structures	See Schedule 2 for Hydraulic Structure Parameters																																						
Upstream boundary	<p>The upstream boundaries of the model were located at the upstream limits of the Clydagh and Loo Rivers as surveyed. The 2D domain starts at Garries Bridge to model the flooding to the N22 and ensure all flow routes into the AFA are considered.</p> <p>The Owneyskeagh upstream boundary is located at the first surveyed node (22OWNE00212H) and connected to the 2D downstream of the bridge to simulate the interaction at the confluence.</p> <p>Both the Clydagh and Loo rivers are 1D only so are modelled for the entire surveyed extent.</p>																																						
Lateral inflows	<p>The Annagh Beg Stream inflows are added directly to the Flesk at node 22FLES01730H. The other intermediate inflows were distributed depending on the contributing area along the modelled reach.</p>																																						
Downstream boundary	<p>The downstream boundary of the 2D was located at node 22FLES01400H, being a relatively narrow section of valley and downstream of all major tributaries. A HX boundary was applied to the downstream of the 2D, connected to the next downstream 1D node, to represent floodplain flow and prevent glass-walling.</p> <p>The River Flesk 1D only model continues downstream to node 22FLES01203H. A Normal Critical Depth boundary was set at this node with a gradient set based on the downstream bed gradient of the River Flesk.</p>																																						
Run Settings	<p>Unsteady simulation of the full 65 hour hydrograph.</p> <p>The 1D timestep was set to 1s which is divisible in to the 2D timestep of 2s which is less than half the grid cell size as recommended by TUFLOW.</p> <p>No minimum flows were set for this model.</p> <p>All other parameters set to default.</p>																																						





SCHEDULE 1 : PHOTOGRAPHS

Photo 1: Clydagh Active Channel & Vegetated Banks



ING 109635, 081770 captured on 02/04/2013

Photo 2: Loo Active River Channel



ING 107382, 080310 captured on 22/03/2013

Photo 3: Flesk Active River Channel



ING 105525, 086223 captured on 21/03/13

Photo 4: Flesk River Banks and Floodplain



ING 105438, 086510 captured on 21/03/13

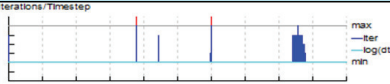
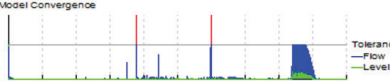
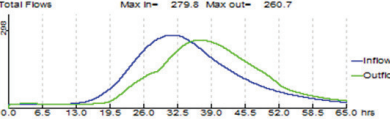
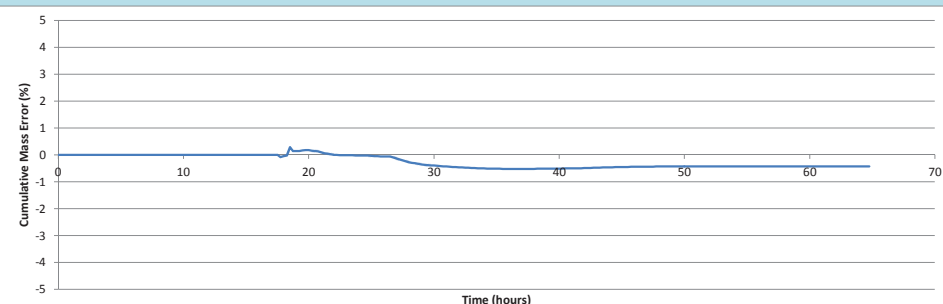
Photo 5: Owenyskeagh Active River Channel



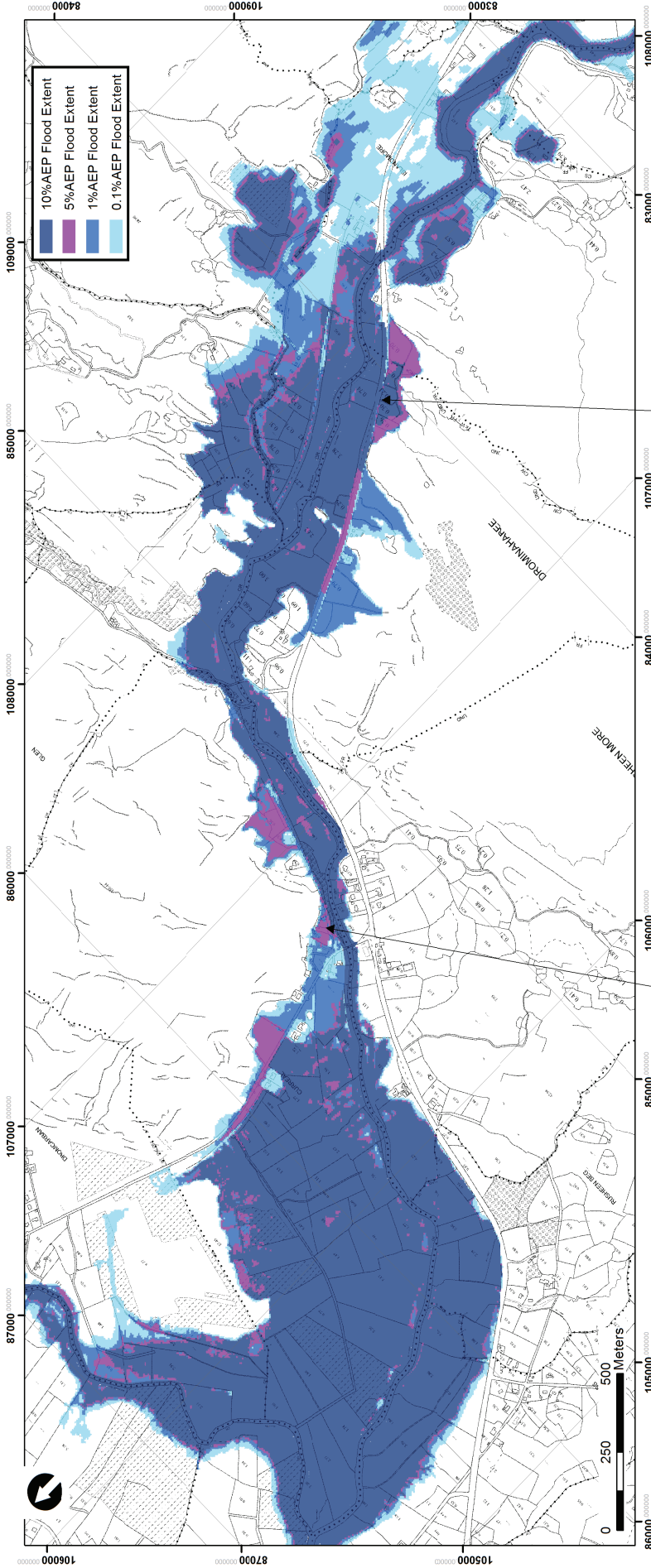
ING 105420, 089795 captured on 02/04/2013



SCHEDULE 2: Structures														
Data file Node	P:\Cambridge\Demeter\EV4\296241 S West CFRAME EVT Code\Technical\Hydraulics\Build\136GK_Glenflesk\DESIGN\model\136GK_135_001_8.dat		Bridge Parameters			Weir Parameters			Office Parameters			Spill Parameters		
	Eastings	Northing	Structure Type	Soffit Elevation	No of Openings	Skew Angle	Calibration Coefficients	Crest Elevation	Length	Throat Invert Level	Bore Area	Modular Limit	Minimum Crest Elevation	Comments/ Justification
22LOOT00023D	107420	80238	Bridge USBPR+ WEIR+SPILL	70.255	4	0	1	68.52	1	n/a	n/a	n/a	68.889	Access bridge
22LOOR00262R	107541	79893	SPILL	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	68.860	spill between Loo River and Tributary along dismantled railway
22LOOR00208D	107383	80309	Bridge USBPR+ SPILL	69.89	2	0	1	N/A	N/A	n/a	n/a	n/a	69.478	Loo access/footbridge on Loo river
22LOOR00014D	108558	81354	Bridge ARCHED+ SPILL + FLOOD RELIEF CULVERT (AS ORIFICE)	69.41	1	0	1	N/A	N/A	67.97	1.164	0.7	70.020	Loo Road Bridge - The river section at the upstream of the bridge face is below the road embankment and bridge deck across the entire floodplain. Therefore the extended section was entered in the bridge unit to fully consider the blockage ratio ( >90% once out of bank) but below the road level.
22FLES02202D	108438	81438	Bridge USBPR+ SPILL	71.01	3	0	1	N/A	N/A	N/A	N/A	N/A	71.235	Access Bridge - The extended valley section was not considered in the bridge unit to avoid overestimation to the blockage ratio as the floodplain was not significantly below the spill level.
22FLES01896D	108099	83703	Bridge USBPR+ SPILL	67.35	1	45	1.5	N/A	N/A	N/A	N/A	N/A	68.200	Garies Bridge (surveyed skew 46.560 approximate to 45degree limit) Version D2: Additional calibration coefficient to better match flood mechanisms and frequency of flooding reported by local engineers.
22FLES01741D	107510	85043	Bridge USBPR+ SPILL	64.58	3	0	1.5	N/A	N/A	N/A	N/A	N/A	64.075	Armagh beg bridge - Bridge section matches 1D model extent. Floodplain modelled in 2D. Version D2: Additional calibration coefficient to better match flood mechanisms and frequency of flooding reported by local engineers.
22FLES01644D	106651	85379	Bridge ARCHED+ SPILL	65.04	3	0	1	N/A	N/A	N/A	N/A	N/A	66.2300	Curral Bridge - Glenflesk
22FLES01382W	105028	87206	RN WEIR + SPILL	n/a	n/a	n/a	n/a	58.327	111.5	N/A	N/A	N/A	60.5930	Dummy weir to allow for bed change through rapids/rock section, lower coefficient to represent inefficiencies
22FLES01318D	104423	87133	Bridge USBPR	64.32	3	35.75	1	N/A	N/A	N/A	N/A	N/A	N/A	Road bridge/ end of 2D domain, HFSS flows do not reach soffit therefore no spill over deck required
22FLES01205D	103619	87675	Bridge ARCHED+ SPILL + FLOOD RELIEF CULVERT	61.78	5	0	1	N/A	N/A	N/A	N/A	N/A	60.985	Fleek bridge
22OWNE00180D	106815	86928	Bridge ARCHED+ SPILL	65.12	2	0	1	N/A	N/A	N/A	N/A	N/A	66.71	R570 road bridge

Glenflesk Model Performance													
1D Convergence													
Convergence Plot 1% AEP Fluvial Event													
Model Convergence													
Total Flows													
		<p>Max In= 279.8 Max out= 260.7</p> <p>Datefile: ...DESIGNMODE\UISIS\DAT\36GK_ISIS_001_11.DAT Results: ...RESULTS\36GK_FCD010_D2_GLENFLESK_8.zzi Ran at 11:28:13 on 18/09/2014 Ended at 17:28:17 on 18/09/2014 Start Time: 0.000 hrs End Time: 65.000 hrs Timestep: 1.0 secs Current Model Time: 65.00 hrs Percent Complete: 100 %</p>											
Comments		The 1D model components were convergent and within the recommended tolerances for the majority of the event, with the period of peak flow being fully convergent. Poor model convergence occurred at 22.4 and 42.8 hours. The first non-convergence can be explained by the the bridge at 22LOOR00014D overlapping with flow passing over the spill unit. This causes a minor oscillation in the flow at this node but this normalises after 0.25 hours and does not impact the river sections upstream or downstream of the bridge. The non-convergence at 42.8 hours can be attributed to flow no longer spilling over the bridge at 22LOOT00023D; this causes a negligible impact on flow.											
2D Convergence													
Mass Balance Plot 1% AEP Fluvial Event													
Comments		The total cumulative mass error was -472516m³ or -0.4%. The 2D model remains within the recommended tolerance of ±1% cumulative mass error throughout the 1% AEP event. Greater mass error is experienced at around 17 hours where water spills out of bank in to the 2D domain. However, the mass error is within the tolerance and the results are deemed to be reliable throughout.											
Hydrological Performance													
Target Flows					10% AEP m³/s			1% AEP m³/s			0.1% AEP m³/s		
		HEP ID	Location	Model Node	Design	Modelled	% Difference	Design	Modelled	% Difference	Design	Modelled	% Difference
		22_1561_2	Flesk u/s @ Flesk/A.B Confluence	22FLES01721H	143.2	140.46	-2%	207.2	206.5	0%	315.7	312.2	-1%
		22_2859_1	Flesk d/s Owneskeagh	22FLES01433B	196.1	187.0	-5%	283.8	277.1	-2%	432.3	415.8	-4%
Comments		The flows in the 1D ISIS channel were combined with 2D flows parallel to the channel where there were out-of-bank flows and compared to the design hydrology. The modelled flow tended to underestimate flows at the HEP locations compared to the design peak flows in all flood events. For all return periods flows were underestimated by 5% or lower. This is deemed acceptable.											
Verification Checks													
Locations of Known flooding		Flooding was observed between Currall Bridge in Glenflesk and Loo Bridge upstream of this on 1st November 1980. Although specific extents are not known, 23 houses and 3009 acres were flooded.  There are reports for recurring flooding along the N22 such as the 23rd October 2008 photographed. The October 2008 event was estimated to have 10% AEP which matches well with the revised design 10% AEP extent flooding the N22. The design 50% AEP encroaches onto the N22 and combined with surface water runoff to flood the N22 on a regular basis.											
Available Gauge Data		None in vicinity											
Verification Plot		See Schedule 3 - Validation of flooded areas											
Comparison with Design Flood		Based on this written evidence of flooding it can be seen that the modelled extent covers this reach in the 10% AEP through to 0.1% AEP flood events.											
Sensitivity Test 1: Increased Flow													
Model Run ID		I36GK_FHD010_D1_GLENFLESK_8											
Hydraulic Modification to Design Model		No hydraulic modifications were made to the design model.											
Hydrological inflows		All inflows were increased by 30% for the 1% AEP fluvial current design event to account for the uncertainty in the derivation of QMED and the pooling group selected.  This is broadly equivalent to the HEFS 1% AEP as the increase in urban extent has less the 1% impact on peak flow. Therefore, the HEFS 1% AEP results (FHD010) have been used as the sensitivity test results.											
Sensitivity Plot		See Schedule 3 - Calibration and Sensitivity											
Comments		A 30% increase in flows resulted in a small increase in flooding along the River Flesk upstream of Glenflesk and small changes to the flood extent along the other reaches. In Glenflesk, there is some additional flooding around Currall Bridge and the R570 heading north west.  Therefore flood risk in Glenflesk was found to only be slightly sensitive to the uncertainties in flow.  An allowance should be made when interpreting the design flood outlines and in the sizing of any flood risk management option due to this uncertainty in flood level and extent caused by the uncertainties in flow.											
Sensitivity Test 2: Increased Downstream Boundary													
Model Run ID		I36GK_FHD010_D1_GLENFLESK_8											
Hydraulic Modification to Design Model		No hydraulic modifications were made to the design model.											
Hydrological inflows		The downstream boundary representing the water level gradient in Lough Leane was reduced to represent greater backwater from the Lough.  No other hydrological inflows were modified.											
Sensitivity Plot		See Schedule 3 - Calibration and Sensitivity											
Comments		An increased downstream boundary did not affect water level upstream of the rapids section. Therefore, the flood levels within the Glenflesk AFAs are not deemed sensitive to the downstream model boundary assumptions.											
Sensitivity Test 3: Increased Manning's 'n'													
Model Run ID		I36GK_FCN010D1_GLENFLESK_8											
Hydraulic Modification to Design Model		The Manning's 'n' values were increased to the upper limit of the industry recommended ranges.  All active channels 0.040 to 0.048 All river banks 0.060 to 0.080 Pasture / parkland / garden 0.060 to 0.080 Buildings 0.200 to 0.300 Roads 0.03 to 0.040 Dense vegetation 0.085 to 0.1 Floodplain channels and ditches 0.04 to 0.048											
Hydrological inflows		No modifications were made to the design inflows.											
Sensitivity Plot		See Schedule 3 - Calibration and Sensitivity											
Comments		An increase in roughness values in bank and out-of-bank increased water levels by over 0.3m. This increase in level did not significantly increase the flood extent because the narrow floodplain was already inundated in the design event. However, the increase in roughness assumptions did increase the depth of flooding across the N22 upstream of Glenflesk.  However, the increase in roughness did not have a significant impact on flood risk therefore the AFA of Glenflesk is not deemed to be sensitive to the assumptions in Manning's 'n' values.											



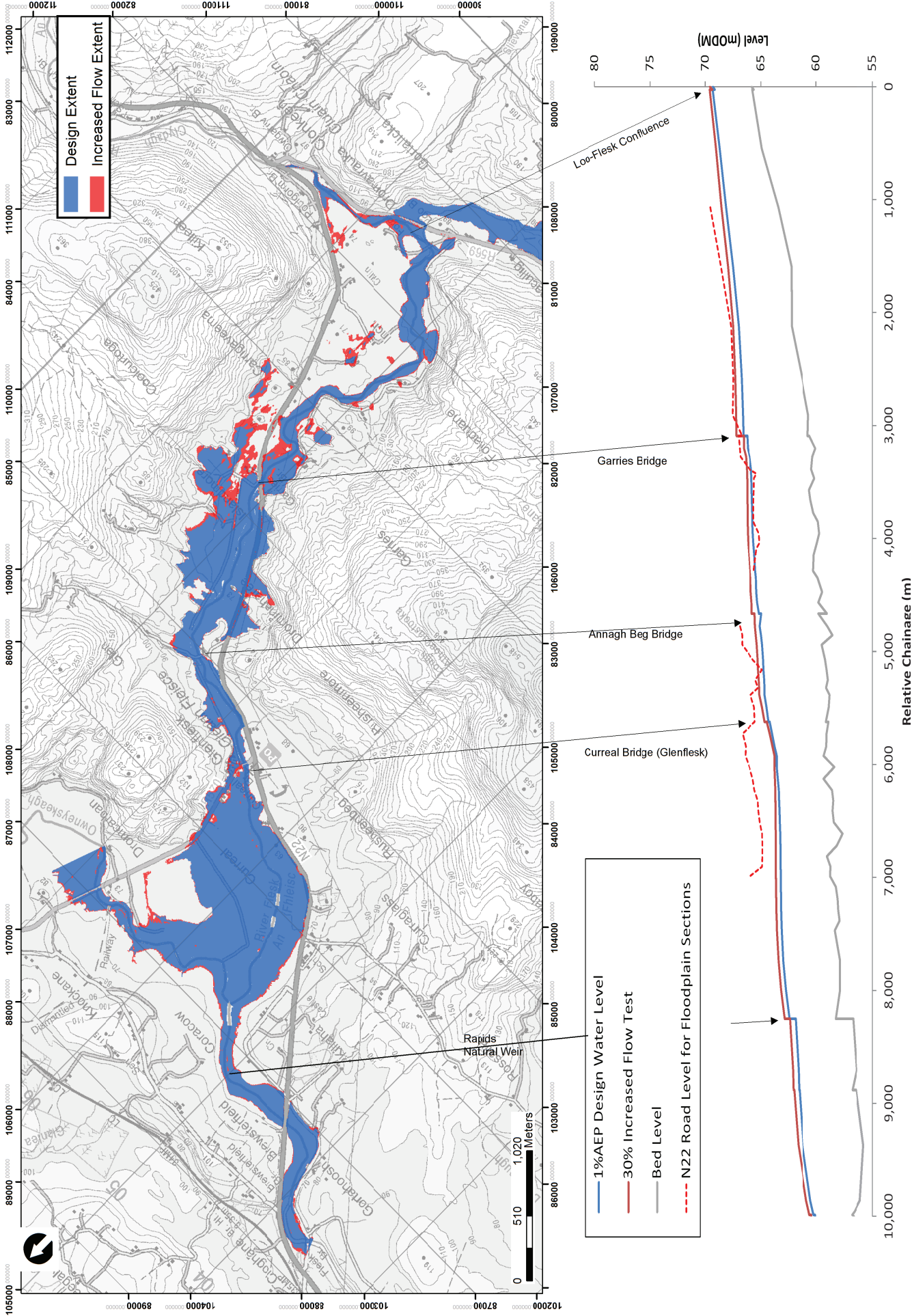


23 houses and 3009 acres flooded between  
Currell Bridge and Loo Bridge (01/11/1980)

Recurring flooding along the N22 East of Killarney  
(photograph from 23 October 2008 Event)

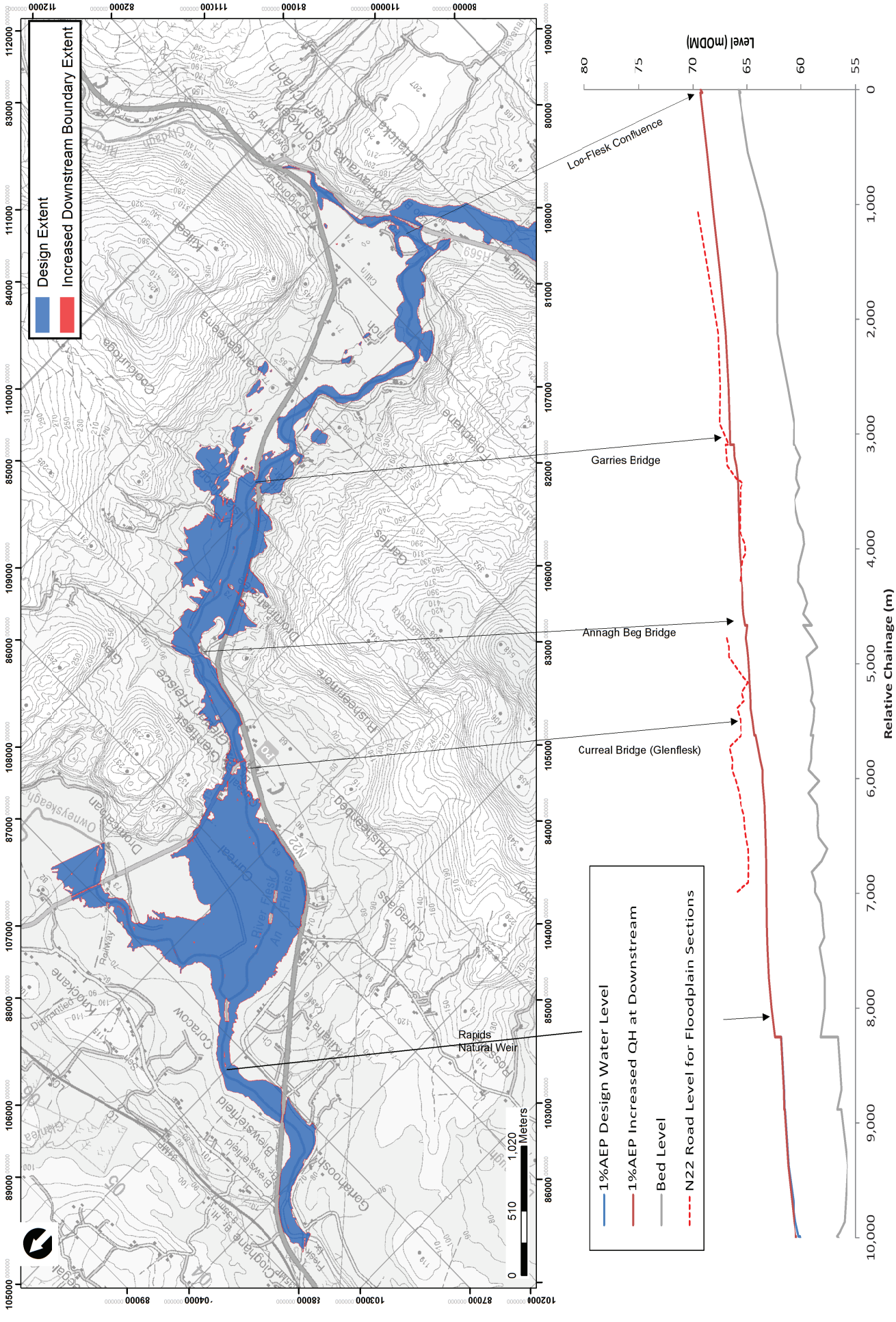


Map D.2: Sensitivity to 30% Increased Peak Flow

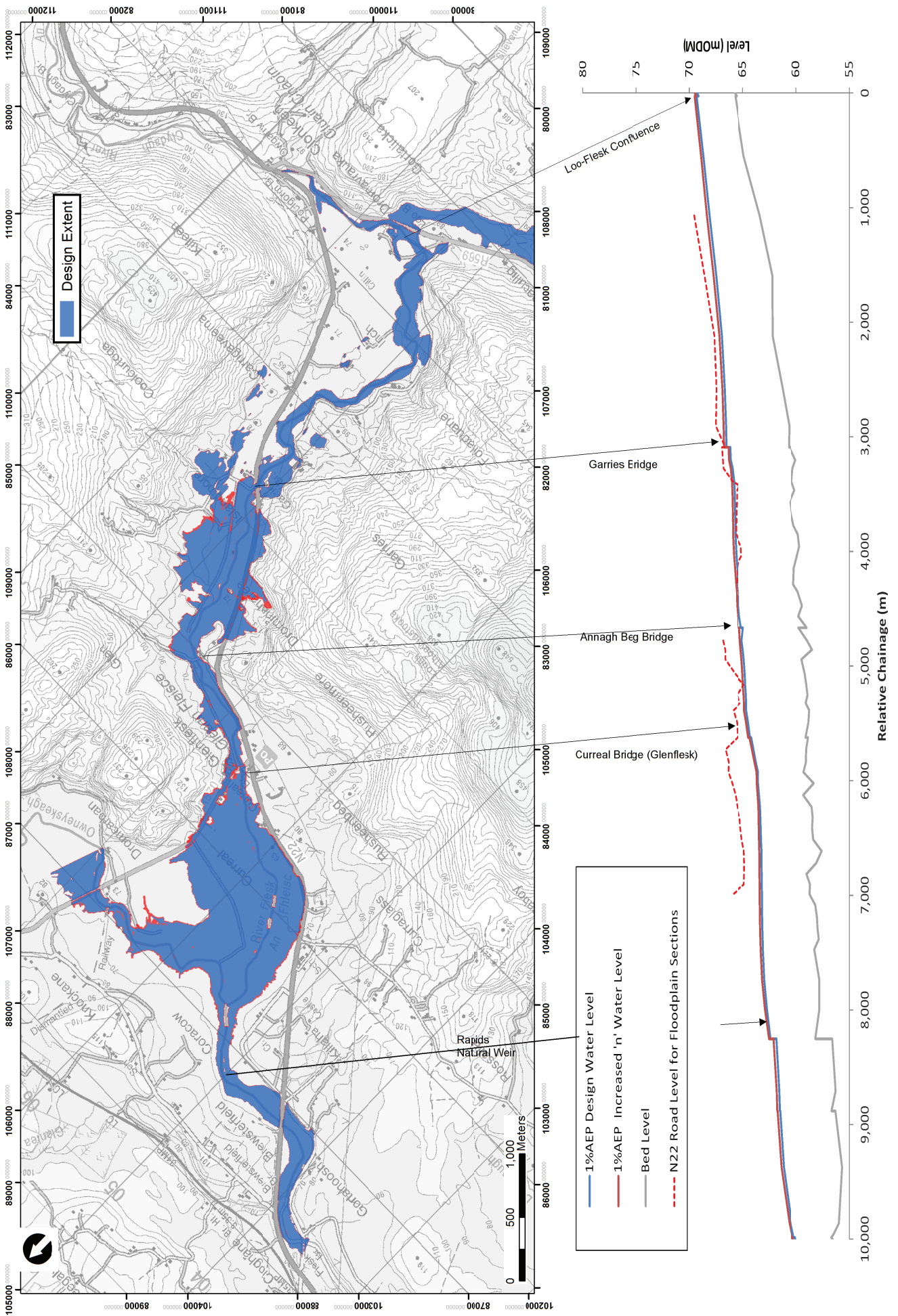




Map D.3: Sensitivity to Increased Downstream Boundary



Map D.4: Sensitivity to Increased Manning's 'n'





Glenflesk Model Outputs	
	<p>The key thresholds and areas affected by flooding in Glenflesk are:</p> <ul style="list-style-type: none"> <li>- 50% AEP inundates the floodplain and encroaches onto the N22. Surface water runoff onto the road is not considered in the CFRAMS model.</li> <li>- 10% AEP event overtops the N22 downstream of Garies Bridge and 5% AEP floods the N22 from Glenflesk to Garies Bridge.</li> <li>- 0.1% AEP causes significant flooding along all modelled watercourses. There is extensive inundation in Glenflesk and Islandmore. The N22 and property along its path are completely flooded upstream of the confluence of the River Flesk and Annagh Beg Stream.</li> <li>- Approximately 17 properties are affected by the 1% AEP fluvial event within the Glenflesk AFA.</li> </ul> <p>It should be noted that the CFRAM Study assumes saturated ground conditions as a worst-case scenario for the design flows. The saturation of the catchment preceding the event should be carefully considered when interpreting the flood maps.</p>
Threshold of Property Flooding	
Critical Structures for Flood Risk	<p>The critical structures in determining flood risk include:</p> <ul style="list-style-type: none"> <li>- Effective weir/ natural rapid section downstream of the Flesk-Owenskeagh confluence</li> <li>- Curra Bridge in Glenflesk.</li> <li>- Annagh Beg Bridge, Garies Bridge and the offline storage between the Flesk and the N22.</li> </ul>
Areas affected by flooding	The floodplain area downstream of Glenflesk is shown to be the main flood storage area in this model. The greatest impact on property and infrastructure is modelled to be in Glenflesk and alongside the N2, both being significantly affected in the 0.1% AEP flood event. Low lying land on both banks of the River Flesk and its tributaries are at risk from flooding.
Risk to people	The greatest risk to life is associated with flooding in Glenflesk and Islandmore where both property and access routes are modelled to be inundated. Flooding of the N22 upstream of Glenflesk presents a risk to people and emergency access to numerous isolated properties in the valley.
Consideration for Flood Risk Management Options	<ul style="list-style-type: none"> <li>- Increased conveyance of the channel and effective weir downstream of the LFesk-Owenskeagh confluence is likely to reduce flood levels in the AFA.</li> <li>- Most of the flooding currently impacts floodplain and agricultural areas. If flood storage was identified as a flood management option, maintenance and possible enhancement of these areas for this purpose would be beneficial.</li> <li>- Localised protection of key infrastructure.</li> </ul>

Flood Map Outputs					
The following table outlines the print-ready flood mapping deliverables provided in the accompanying digital data.					
Scenario	Flood Extent Map	Flood Zone Map	Flood Depth Map	Flood Velocity Map	Flood Hazard Map
Fluvial Current Design 10% AEP	I22HGK36_EXFCDEXF_D2		I22HGK36_DPFC0100_D2	I22HGK36_VLFC0100_D2	I22HGK36_HZFC0100_D2
Fluvial Current Design 1% AEP	I22HGK36_EXFCDEXF_D2	I22HGK36_ZN_D2	I22HGK36_DPFC0010_D2	I22HGK36_VLFC0010_D2	I22HGK36_HZFC0010_D2
Fluvial Current Design 0.1% AEP	I22HGK36_EXFCDEXF_D2	I22HGK36_ZN_D2	I22HGK36_DPFC0001_D2	I22HGK36_VLFC0001_D2	I22HGK36_HZFC0001_D2
Fluvial Mid Range Future Design 10% AEP	I22HGK36_EXFCDEXF_D2				
Fluvial Mid Range Future Design 1% AEP	I22HGK36_EXFCDEXF_D2				
Fluvial Mid Range Future Design 0.1% AEP	I22HGK36_EXFCDEXF_D2				

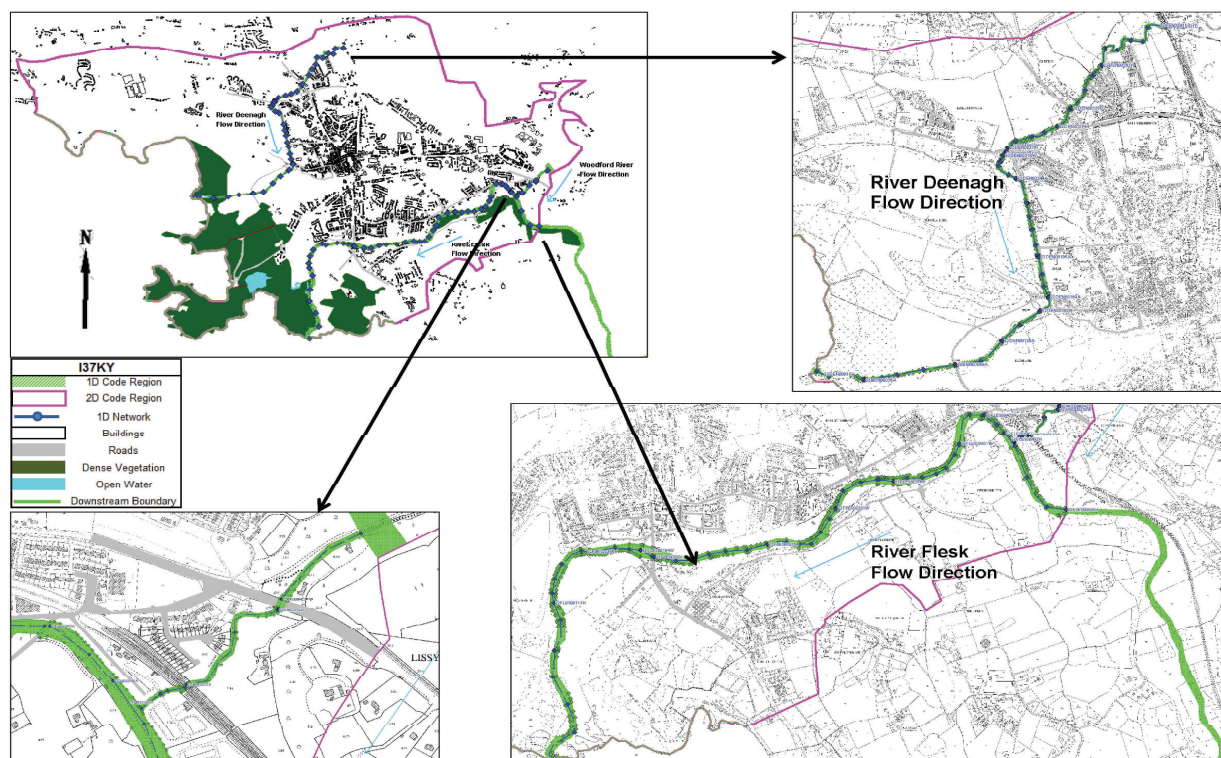
GIS Outputs								
The following table outlines the GIS deliverables provided in the accompanying digital handover.								
Scenario	Model Run ID	Flesk %AEP	Loe and Owenskeagh %AEP	Flood Extent Polygon and Nodes	Flood Zone Polygon	Flood Depth Grid	Flood Velocity Grid	Flood Hazard Grid
Fluvial Current Design 50% AEP	I36GK_FCD500_D2_Glenflesk.ief	50	50	I36EXFCD050002		I36DPFCD050002	I36VLFC050002	I36HZFC050002
Fluvial Current Design 20% AEP	I36GK_FCD200_D2_Glenflesk.ief	20	20	I36EXFCD010002		I36DPFCD010002	I36VLFC010002	I36HZFC010002
Fluvial Current Design 10% AEP	I36GK_FCD100_D2_Glenflesk.ief	10	10	I36EXFCD010002		I36DPFCD010002	I36VLFC010002	I36HZFC010002
Fluvial Current Design 5% AEP	I36GK_FCD050_D2_Glenflesk.ief	5	5	I36EXFCD005002		I36DPFCD005002	I36VLFC005002	I36HZFC005002
Fluvial Current Design 2% AEP	I36GK_FCD020_D2_Glenflesk.ief	2	2	I36EXFCD002002		I36DPFCD002002	I36VLFC002002	I36HZFC002002
Fluvial Current Design 1% AEP	I36GK_FCD010_D2_Glenflesk.ief	1	1	I36EXFCD001002	I36ZN_A_D2	I36DPFCD001002	I36VLFC001002	I36HZFC001002
Fluvial Current Design 0.5% AEP	I36GK_FCD005_D2_Glenflesk.ief	0.5	0.5	I36EXFCD000502		I36DPFCD000502	I36VLFC000502	I36HZFC000502
Fluvial Current Design 0.1% AEP	I36GK_FCD001_D2_Glenflesk.ief	0.1	0.1	I36EXFCD000102	I36ZN_B_D2	I36DPFCD000102	I36VLFC000102	I36HZFC000102
Fluvial Mid Range Future Design 50% AEP	I36GK_FMD500_D2_Glenflesk.ief	50	50	I36EXFMD050002		I36DPFMD050002		
Fluvial Mid Range Future Design 20% AEP	I36GK_FMD200_D2_Glenflesk.ief	20	20	I36EXFMD010002		I36DPFMD010002		
Fluvial Mid Range Future Design 10% AEP	I36GK_FMD100_D2_Glenflesk.ief	10	10	I36EXFMD010002		I36DPFMD010002		
Fluvial Mid Range Future Design 5% AEP	I36GK_FMD050_D2_Glenflesk.ief	5	5	I36EXFMD005002		I36DPFMD005002		
Fluvial Mid Range Future Design 2% AEP	I36GK_FMD020_D2_Glenflesk.ief	2	2	I36EXFMD002002		I36DPFMD002002		
Fluvial Mid Range Future Design 1% AEP	I36GK_FMD010_D2_Glenflesk.ief	1	1	I36EXFMD001002		I36DPFMD001002		
Fluvial Mid Range Future Design 0.5% AEP	I36GK_FMD005_D2_Glenflesk.ief	0.5	0.5	I36EXFMD000502		I36DPFMD000502		
Fluvial Mid Range Future Design 0.1% AEP	I36GK_FMD001_D2_Glenflesk.ief	0.1	0.1	I36EXFMD000102		I36DPFMD000102		
Fluvial High End Future Design 10% AEP	I36GK_FHD100_D2_Glenflesk.ief	10	10	I36EXFHD10002		I36DPFHD10002		
Fluvial High End Future Design 1% AEP	I36GK_FHD010_D2_Glenflesk.ief	1	1	I36EXFHD01002		I36DPFHD01002		
Fluvial High End Future Design 0.1% AEP	I36GK_FHD001_D2_Glenflesk.ief	0.1	0.1	I36EXFHD00102		I36DPFHD00102		

## Appendix E. Killarney AFA Model Proformas

UOM	22		
AFA/ MPW Reach	AFA-Killarney		
Model ID	I37KY		
Purpose of Model Build	Flood Mapping		
Main Watercourse	River Flesk	FLUVIAL RISK	Yes
Length Modelled (km)	12.12 (Flesk) 18.09 (Total)	COASTAL RISK	No
Area Modelled (km <sup>2</sup> )	330.1	VULNERABLE TO WAVES	No

Input Data	
River Channel Topographic Data	River channel survey was undertaken by Murphy Surveys Limited as part of the CFRAM Study. 22FLES-A_Flesk_V0 surveyed April 2013. The bridge at 22FLES00463D has not been modelled as surveyed and has instead been represented by a Bernoulli loss unit due to the irregular shape of the bridge-this is to improve model accuracy. 22DEEN_Deenagh_V1 surveyed November 2012 : No errors or gaps were found within the survey. 22WOOD_Woodford River_V0 surveyed April 2013. No errors or gaps were found within the survey.
Floodplain Topographic Data	Filtered LIDAR DTM "Killarney_spliced_004.asc" 2m grid resolution captured in April 2012. The LIDAR DTM covered the entirety of the urban area but was absent along sections of the banks of Lough Leane and between some squares of LIDAR DTM to the north west of the model. 5m SAR data were used to cover these areas, adjusted to the closest match with the LIDAR DTM using known points of solid and flat ground. These grids were named; _95000_85000_0_5.asc, _90000_90000_0_6.asc and _90000_85000_0_8.asc.
Map data	1:5000 Osi mapping tiles 6131, 6083, 6040, 6039, 6038, 6085, 6084 The OSI mapping was found to include all current developments and was consistent with site observations, the river channel survey and aerial photography.

Model Build					
General Schematisation	A 1D/TUFLOW approach was taken to model Killarney to accurately model flow along the main watercourses and head loss through hydraulic structures whilst enabling multidirectional flow across the urban areas.				
	The 1D model represents the Rivers Flesk and Deenagh as the main watercourses which flow in a south westerly direction in to Lough Leane. The Woodford River which joins the River Flesk up stream of Killarney is also represented due to its catchment size and potential for flood risk. The River Deenagh is modelled through its complete extent through the AFA but in 1D only upstream of the bridge at 22DEN00431D. This approach has been taken as peak flows down the river do not generally reach bank full and at the locations where it does this is minimal. As the Finnow tributary is located outside of the AFA the design flows were input directly to the main watercourses at the confluence with the River Flesk.				
	The 2D domain covered the AFA extent to consider flood risk from the Rivers Flesk and Deenagh as well as the risk from rising water levels in Lough Leane. The 2D model was set to a 5m grid size to represent the urban area without compromising run time. River banks were explicitly enforced using the 2D_zins in the 2D domain based on the river channel survey spot levels. Buildings were raised above the floodplain by 0.15m to represent the threshold and then a high Manning's 'n' value of 0.2 applied to represent the storage of the building. This approach means accurate flood depths can be extracted for flood damage analysis.				
	Version D2: The downstream boundary was updated to a water level -time boundary to better represent the Lough levels. The head loss at the rail bridge on the Woodford Stream was increased to better represent flooding upstream.The 1D-2D interface (2d_bc_hxi) was adjusted to the top of bank along the lower Deenagh to improve stability under high backwater from the Lough.				
Software Versions Used	ISIS version 6.6 TUFLOW version 2012-05-AC-ISP-w32				
Total No of 1D nodes	172				
Open channel (H)	147				
Bridges (D)	15				
Culverts (I)	2				
Weirs (W)	8				
Model Extent	Reach/Feature	Upstream Limit (ING)	Downstream Limit (ING)		
	Flesk	103587, 87658	96085, 88014		
	Woodford	99400, 90608	98954, 90216		
	Deenagh	97240, 92782	94466, 90215		
Roughness	Reach/Feature	Active Channel	River Banks	Floodplain	Source
	Flesk	0.04	0.06	0.06	Schedule 1: Photographs
	Woodford	0.04	0.06	0.06	Schedule 1: Photographs
	Deenagh	0.04	0.06	0.06	Schedule 1: Photographs
	Global Floodplains	N/A	N/A	0.06	Schedule 1: Photographs
	Scrub	N/A	N/A	0.085	Schedule 1: Photographs
	Buildings	N/A	N/A	0.2	Schedule 1: Photographs
	Standing water	N/A	N/A	0.04	Schedule 1: Photographs
	Roads	N/A	N/A	0.03	Schedule 1: Photographs
Structures	See Schedule 2 for Hydraulic Structure Parameters				
Upstream boundary	The River Flesk upstream boundary was located at 22FLES00547H at the upstream of the AFA where all flows were within the narrow valley and no flows were likely to enter the AFA across the floodplain. The Woodford River upstream boundary was located at 22WOOD00067H where the channel is constrained by the narrow valley and the flow will not be influenced by the road bridge downstream. The Deenagh upstream boundary is located at 22DEN00542H at the upstream of the AFA and where the channel is constrained by the narrow valley.				
Lateral inflows	Flows down the Woodford River were lumped at the upstream boundary as <10% of the peak flow would be accounted for by lateral flows. This gives a conservative estimate of flood extent. Lateral inflows to the River Flesk were distributed and weighted along its modelled length based on known and likely inflow locations and using intermediate catchment extents. Lateral flows in to the River Deenagh were distributed and weighted along its modelled length based on known and likely inflow locations.				
Downstream boundary	The downstream boundary of the 1D was located at the outfall of the Rivers Flesk and Deenagh into the Lough Leane at nodes 22FLES00000H and 22DEN00002H respectively and applied as a water level -time (HT) boundary type. The design Lough Leane levels were applied to the downstream of the model based on the extreme 2009 hydrograph as a typical rate of rise and duration of other extreme events on record.				
Run Settings	Unsteady simulation of the full 80 hour hydrograph. The 1D timestep was set to 1s which is divisible in to the 2D timestep of 2s which is less than half the grid cell size as recommended by TUFLOW. All other parameters set to default.				



**SCHEDULE 1 : PHOTOGRAPHS**

**Photo 1: Flesk Active Channel**



**Photo 2: River Banks**



**Photo 3: Natural Bed Drop/ Rapids on the River Flesk**

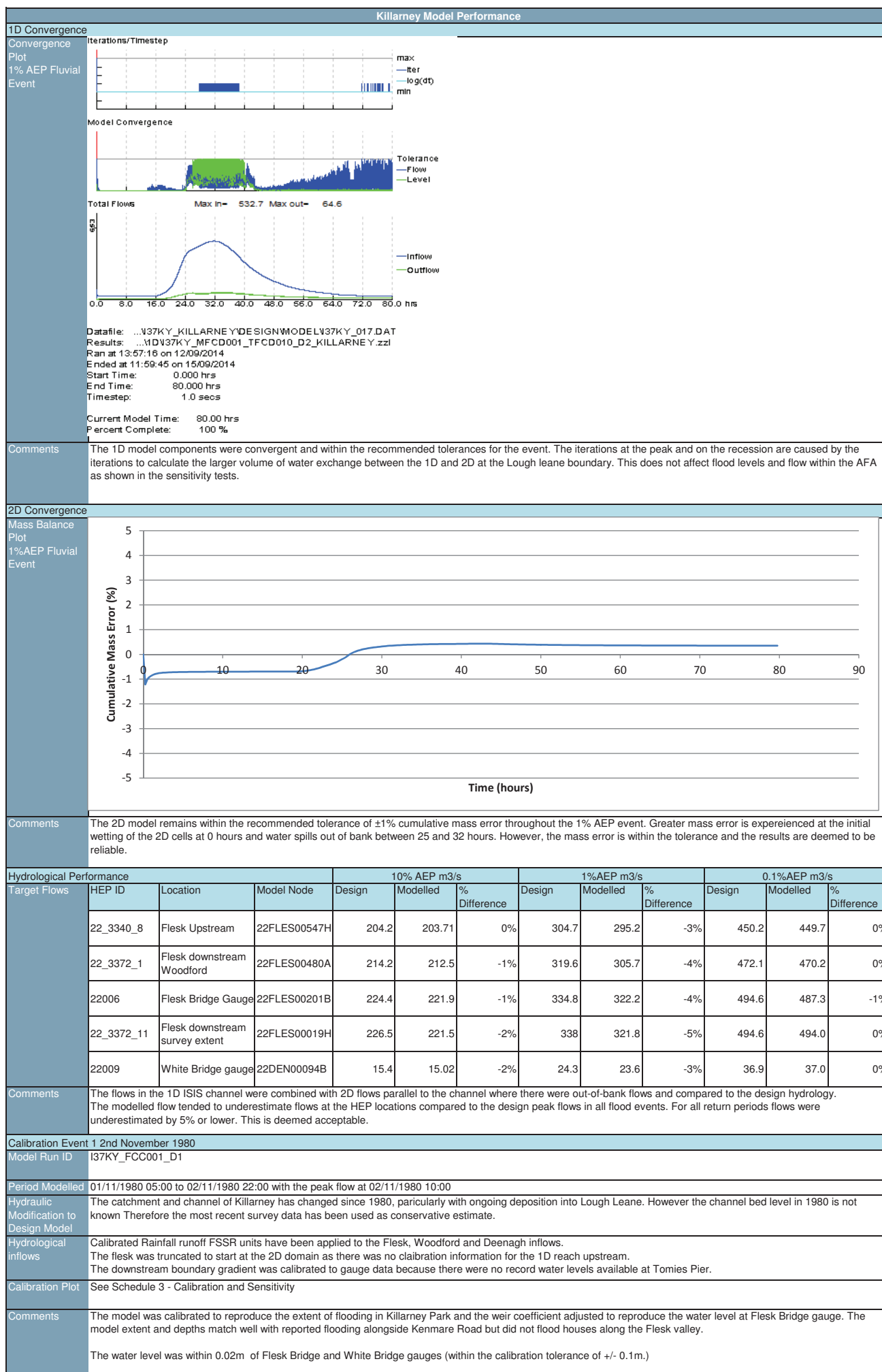


**Photo 4: Urban Floodplain**



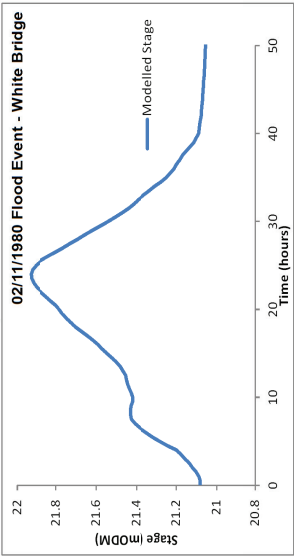
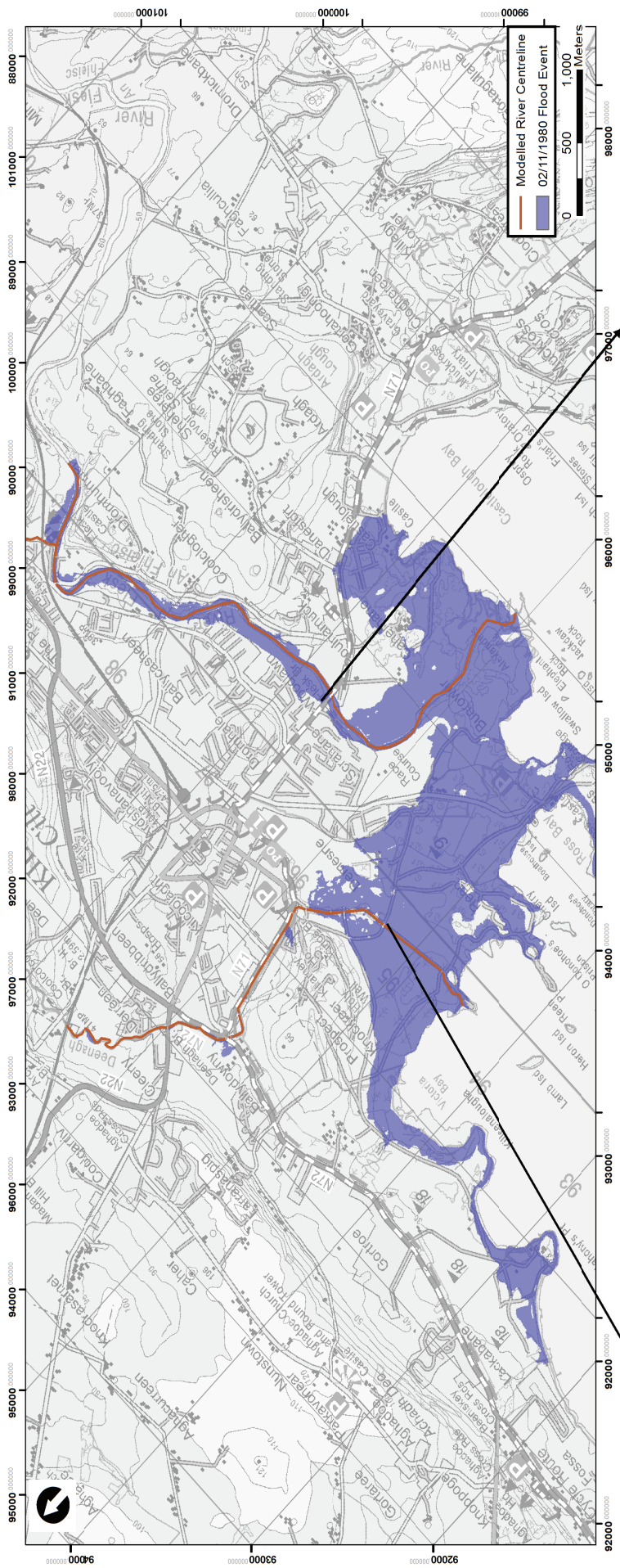






<b>Calibration Event 2 19th November 2009</b>	
Model Run ID	I37KY_FCC002_D1
Period Modelled	18/11/2009 02:30 to 19/11/2009 13:30 with peak at 19/11/2009 04:30.
Hydraulic Modification to	No hydraulic modifications were made to the design model to represent geometry in 2009.
Hydrological inflows	Calibrated Rainfall runoff FSSR units have been applied to the Flesk, Woodford and Deenagh inflows. The flesk was truncated to start at the 2D domain as there was no calibration information for the 1D reach upstream. The recorded water level at Tomies Pier gauge forms the downstream HT boundary.
Calibration Plot	See Schedule 3 - Calibration and Sensitivity
Comments	The model was calibrated to reproduce the extent of flooding in Killarney Park and the weir coefficient adjusted to reproduce the water level at Flesk Bridge gauge. The model extent and depths match well with reported floodign at the Lakeside hotel and golf course on Lough Leane.
<b>Sensitivity Test 1: Increased Flow</b>	
Model Run ID	I37KY_MFHD001_TFHD010_D1_001_KILLARNEY_001
Hydraulic Modification to Design Model	No hydraulic modifications were made to the design model.
Hydrological inflows	All inflows were increased by 30% for the 1%AEP fluvial current design event to account for the uncertainty in the derivation of QMED and the pooling group selected.
Sensitivity Plot	See Schedule 3 - Calibration and Sensitivity
Comments	A 30% increase in flows resulted in a small increase in flood extent along the River Flesk upstream of Flesk Bridge. The increase in flow did cause additional spill out of the right bank immediately upstream of this bridge, creating a flow path through the town. This joins with an increased flood extent from the River Deenagh along Port Road.  Therefore flood risk in Killarney was found to only be sensitive to the uncertainties in flow.  An allowance should be made when interpreting the design flood outlines and in the sizing of any flood risk management option due to this uncertainty in flood level and extent caused by the uncertainties in flow.
<b>Sensitivity Test 2: Increased Downstream Boundary</b>	
Model Run ID	I37KY_FCH010_D1
Hydraulic Modification to Design Model	No hydraulic modifications were made to the design model.
Hydrological inflows	The downstream boundary representing the Lough Leane was increased by 0.34m to assess the impact on flood risk in Killarney based on the confidence limits in the Lough Leane level analysis. No other hydrological inflows were modified.
Sensitivity Plot	See Schedule 3 - Calibration and Sensitivity
Comments	An increased downstream boundary resulted in raised levels up to the Flesk Weir and towards White Bridge gauge on the Deenagh. This increased flood risk to Killarney National Park but did not increase risk through Killarney town itself because the increased backwater was limited to the downstream reaches.
<b>Sensitivity Test 3: Increased Manning's 'n'</b>	
Model Run ID	I37KY_FCSN01_D1
Hydraulic Modification to Design Model	The Manning's 'n' values were increased to the upper limit of the industry recommended ranges. All active channels 0.040 to 0.048 All river banks 0.060 to 0.080 Pasture / parkland / garden 0.060 to 0.080 Buildings 0.200 to 0.300 Roads 0.03 to 0.040 Dense vegetation 0.085 to 0.1 Floodplain channels and ditches 0.04 to 0.048
Hydrological	No modifications were made to the design inflows.
Sensitivity Plot	See Schedule 3 - Calibration and Sensitivity
Comments	An increase in roughness values in bank and out-of-bank has a minimal impact on the flood extent in the majority of Killarney AFA with the following exceptions: Water levels increased by 0.1m around White Bridge due to the increase in Manning 'n' which resulted in a greater floodign to the Ballycasheen Road area. Increased flooding was also predicted in Killarney National Park from the Deenagh and at the Castletough area from the Flesk/Lough Leane. on average however the changes in flood extent were limited to  In general the increase in roughness did not have a significant impact on flood risk therefore Killarney is not deemed to be sensitive to the assumptions in Manning's 'n' values.

Map E.1: Calibration to 02/11/1980 Flood Event

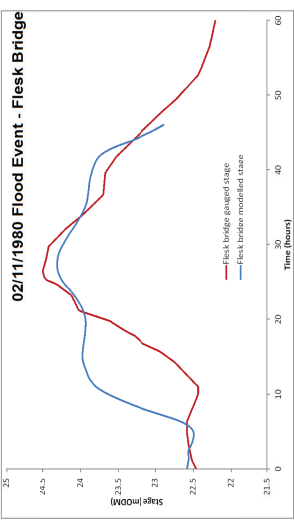


02/11/1980 event	Gauged Peak Flow no gauge data	Modelled Peak Flow 15.89	Gauged Peak Stage no gauge data	Modelled Peak Stage 21.93
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White Bridge 22006



Unidentified location - 1980 Flood Extent

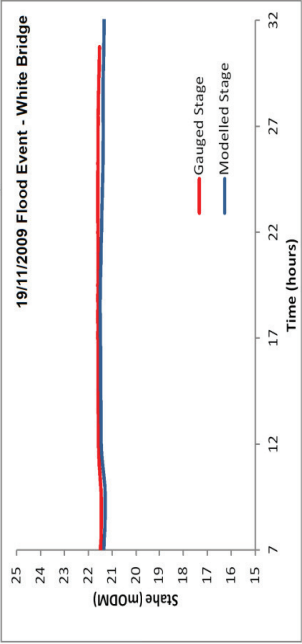
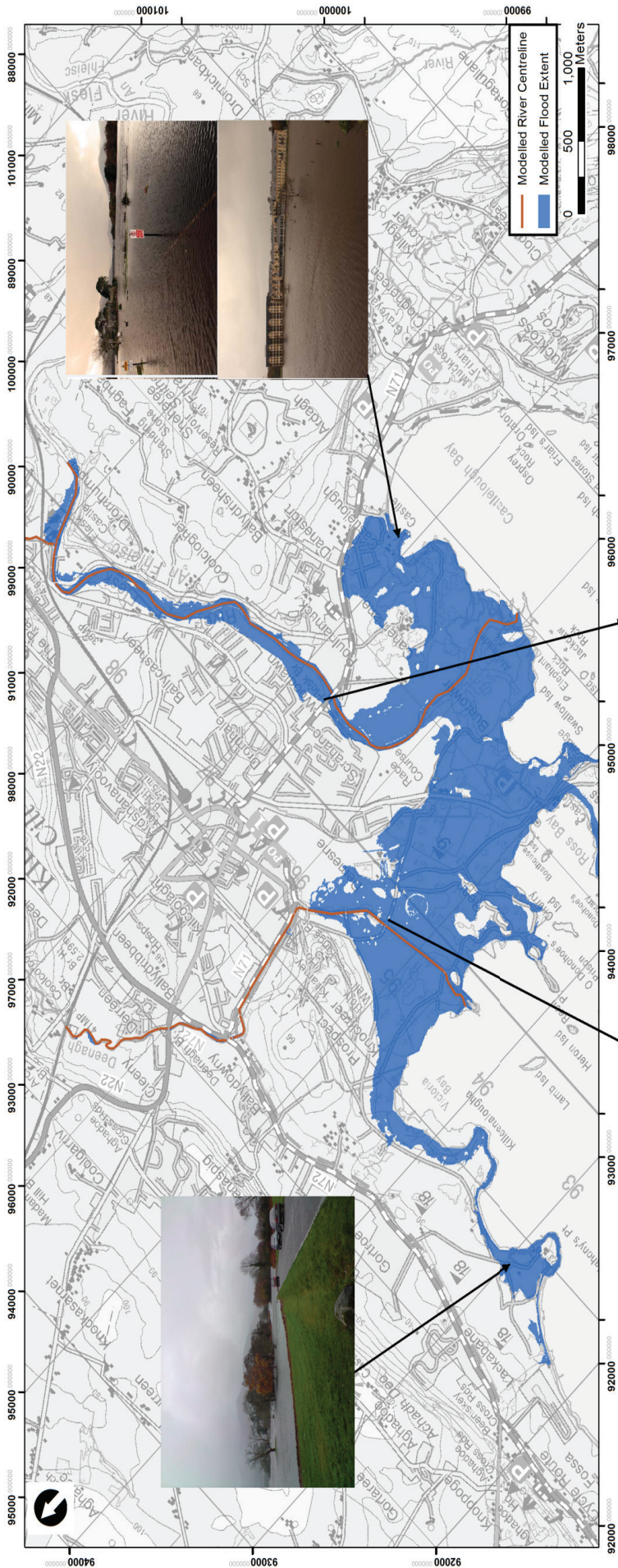


02/11/1980 event	Gauged Peak Flow 255.8	Modelled Peak Flow 275.15	Gauged Peak Stage 24.49	Modelled Peak Stage 24.31
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Flesk Bridge 22006

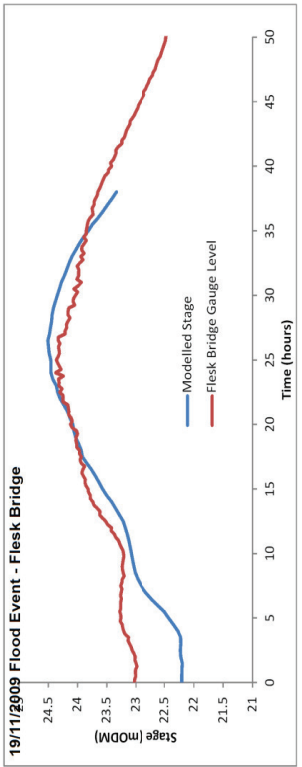


Map E.2: Calibration to 19/11/2009 Flood Event



19/11/2009 event	Gauged Peak Flow	Modelled Peak Flow	Gauged Peak Stage	Modelled Peak Stage
	10.59	9.92	21.61	21.51

White Bridge 22006

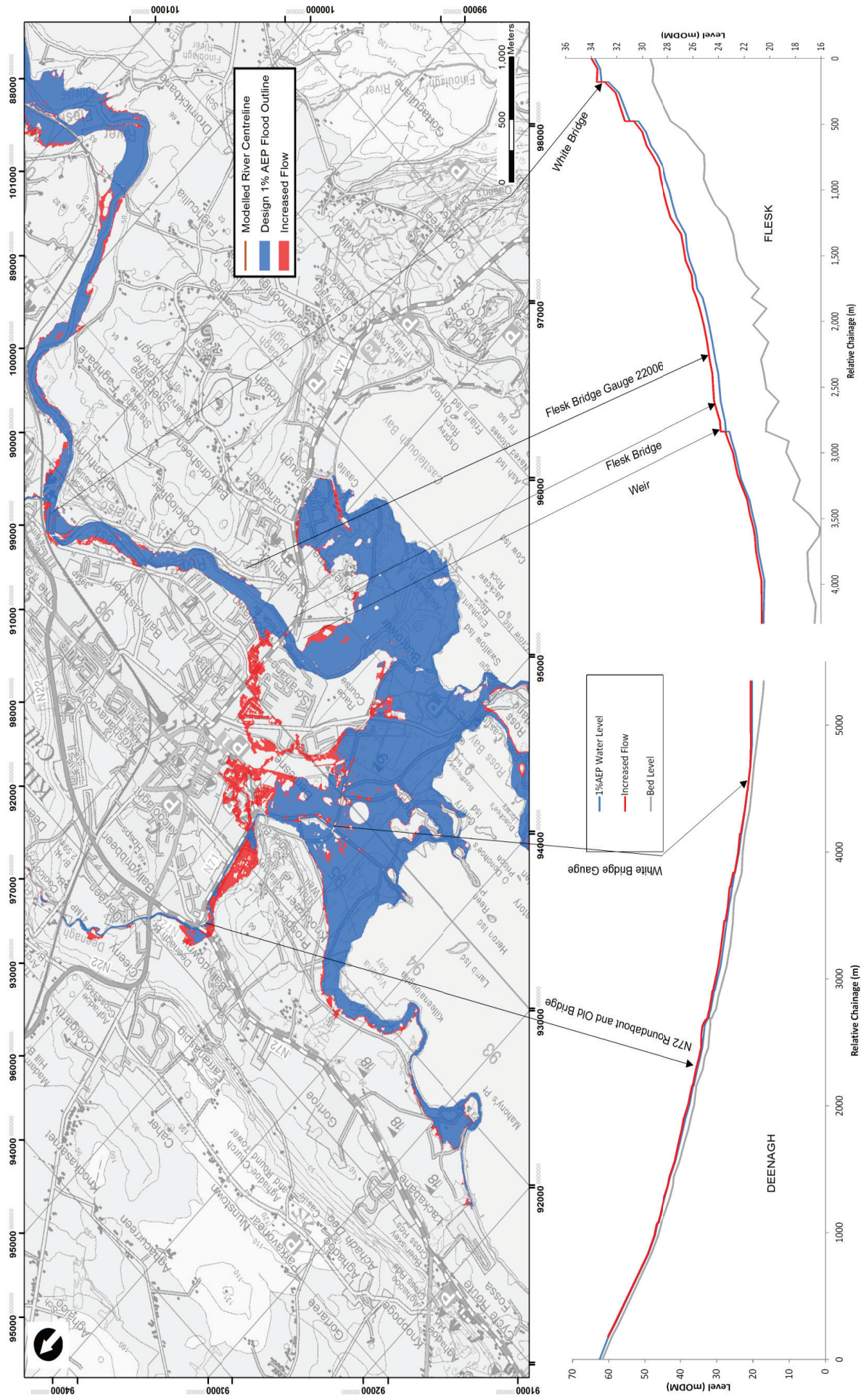


19/11/2009 event	Gauged Peak Flow	Modelled Peak Flow	Gauged Peak Stage	Modelled Peak Stage
	237.66	240.8	24.37	24.51

Fleck Bridge 22006

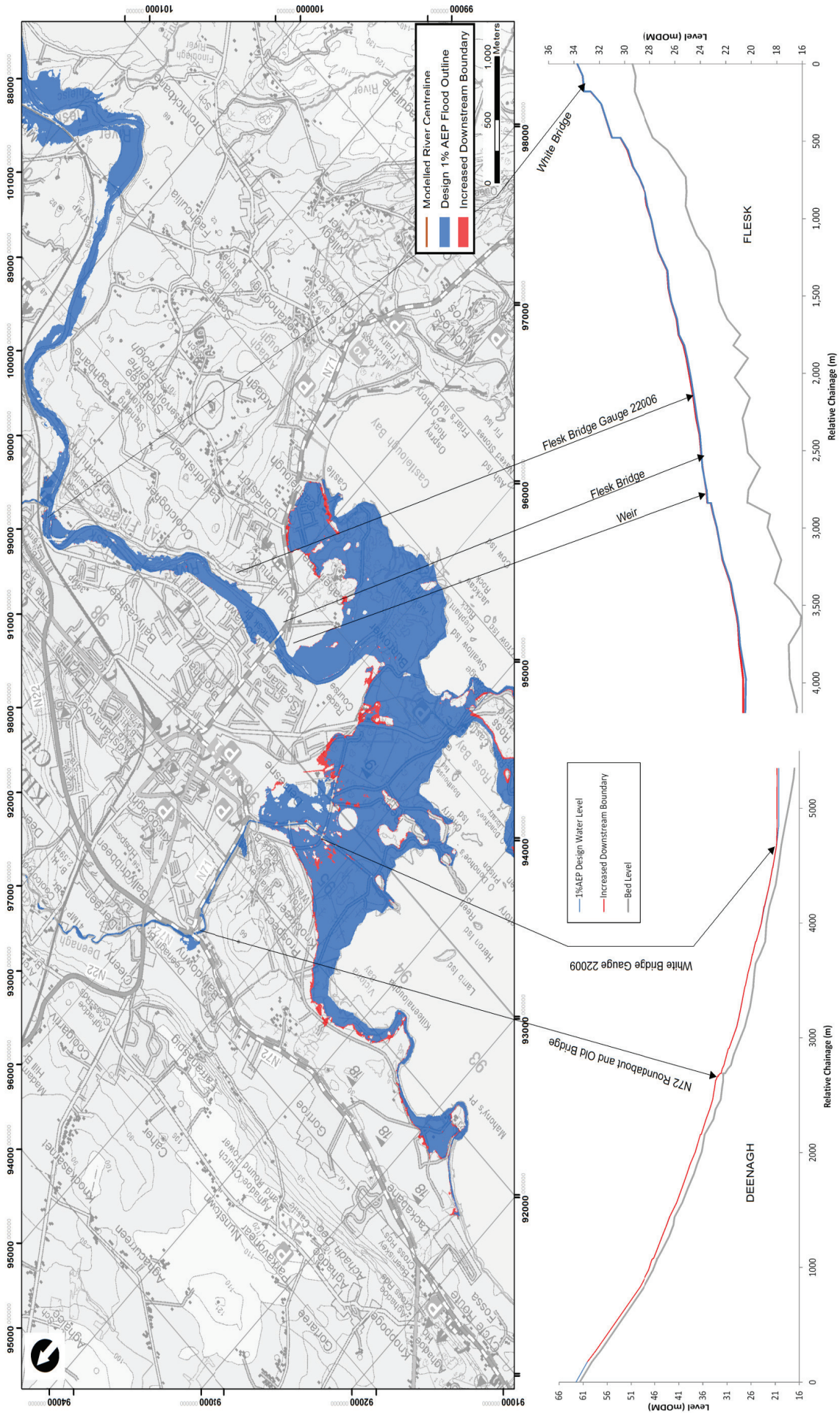


Map E.3: Sensitivity to 30% Increased Peak Flow



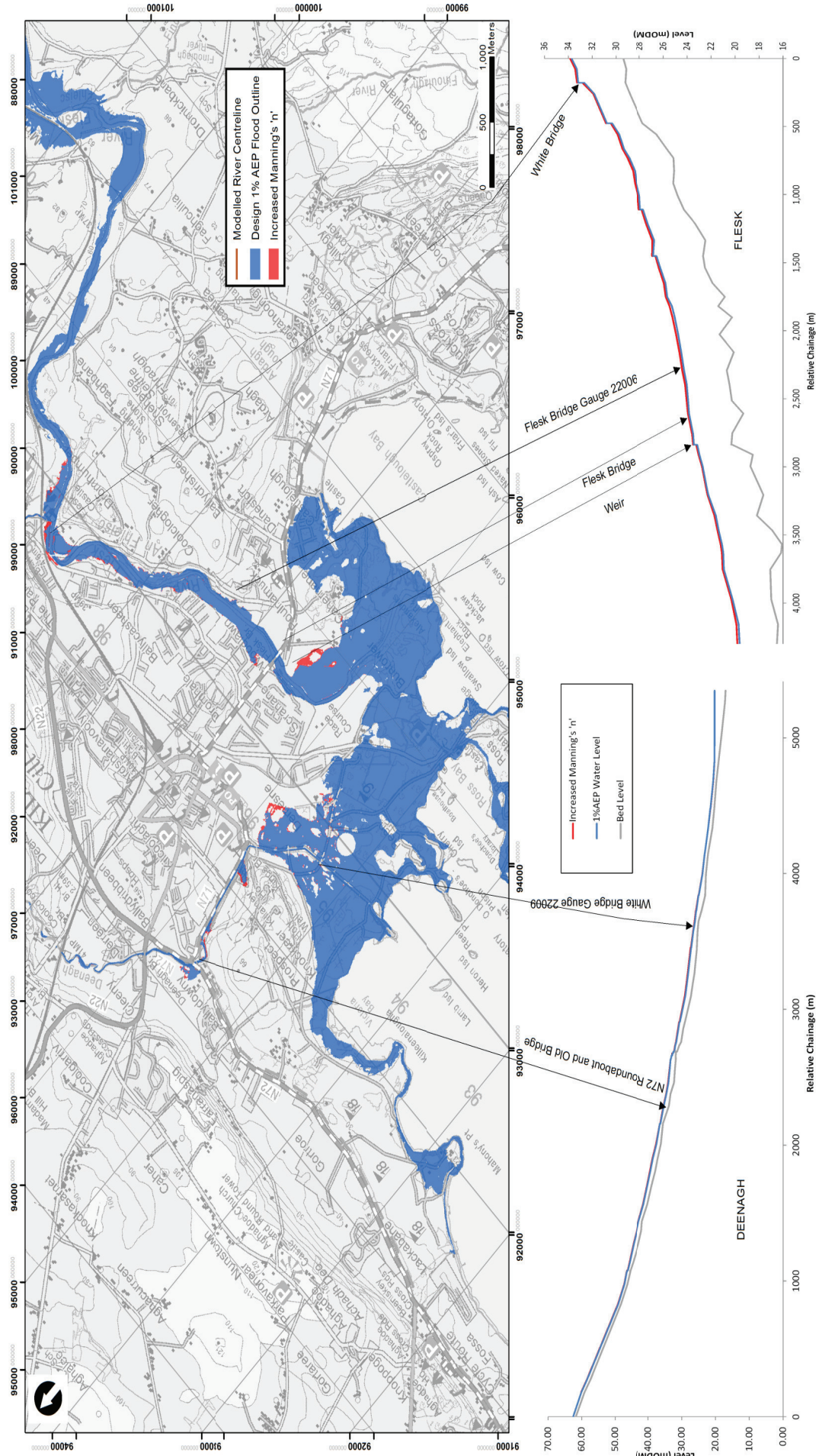


Map E.4: Sensitivity to increased gradient attached to the downstream boundary





Map E.5: Sensitivity to Manning's 'n'





Killarney Model Outputs	
	<p>The key thresholds and areas affected by flooding in Killarney are:</p> <ul style="list-style-type: none"> <li>- 10% AEP event exceeds the capacity of the River Flesk immediately upstream of its confluence with the Woodford River flooding the Caravan Park on the right bank. There is also flooding of the River Flesk upstream of Flesk Bridge but this is restrained to the floodplain on both banks.</li> <li>- 5% AEP causes an increase in the flood extent on the floodplains and across the delta with Lough Leane.</li> <li>- 2% AEP causes flood water to start extending up Muckross Grove upstream of Flesk Bridge. The Sewage Treatment Works situated in the Demense floodplain becomes flooded and the River Deenagh starts spilling out of bank upstream of King's Bridge.</li> <li>- 1% AEP causes further progression of flooding in to Killarney town and a significant increase in extent upstream of White Bridge on the River Flesk.</li> <li>- 0.1% AEP causes a significant increase in flood extent notably through Killarney town, approximately along the length of Flesk Road. Flooding continues out of the floodplain in Ballycasheen on the River Flesk and along Port Road (River Deenagh).</li> </ul> <p>Flooding of the factory on the Right bank of White Bridge.</p> <p>- Approximately 20 properties are affected by the 1% AEP fluvial event in the Killarney AFA.</p>
Threshold of Property Flooding	
Critical Structures for Flood Risk	<p>The critical structures in determining flood risk include:</p> <ul style="list-style-type: none"> <li>- White Bridge and Flesk Bridge on the River Flesk as both impact flow progression.</li> <li>- Woodford Bridge. Currently there is minimal flooding from the Woodford River but any restriction in flow by this bridge could promote flood risk.</li> <li>- Upstream of King's Bridge on the River Deenagh there are several bridges and culverts, all are critical for flood risk.</li> </ul>
Areas affected by flooding	<p>The delta area on the banks of Lough Leane is affected by flooding in all modelled return periods. Agricultural and floodplain areas along the River Flesk through Killarney are also affected at all modelled return periods.</p> <p>For the larger return period events the area around Flesk Road and along the N71 towards the River Deenagh are at particular risk.</p>
Risk to people	<p>The greatest risk to life is associated with flooding in Killarney during the higher return period events where flooding from both the Rivers Flesk and Deenagh join. The 10% AEP and higher events cause flooding at the caravan site at Woodford Bridge. This is a significant risk to life should this site be occupied.</p> <p>Deep and potentially fast flowing water in the recreational parkland on the banks of Lough Leane present a risk to people considering land use in this area.</p> <p>Flooding of the Sewage Treatment Works situated in the Demense floodplain in return periods higher than 2% AEP presents a risk to critical infrastructure in Killarney.</p>
Consideration for Flood Risk Management Options	<ul style="list-style-type: none"> <li>- Increased conveyance at the key structures identified are likely to reduce flood risk.</li> <li>- Most of the flooding currently impacts floodplain and agricultural areas. If flood storage was identified as a flood management option, maintenance and possible enhancement of these areas for this purpose would be beneficial.</li> <li>- Localised protection of key infrastructure.</li> <li>- Removable flood defences in urban areas to restrict flow during the high return period events.</li> <li>- Flood warning on the Flesk catchment is likely to be effective as there would be several hours before the peak flow at the Flesk Bridge Gauge.</li> </ul>

Flood Map Outputs					
The following table outlines the print-ready flood mapping deliverables provided in the accompanying digital data.					
Scenario	Flood Extent Map	Flood Zone Map	Flood Depth Map	Flood Velocity Map	Flood Hazard Map
Fluvial Current Design 10% AEP	I21HKY37_EXFCD0100_D2		I21HKY37_DPFC0100_D2	I21HKY37_VLFCD0100_D2	I21HKY37_HZFC0100_D2
Fluvial Current Design 1% AEP	I21HKY37_EXFCD0100_D2	I21HKY37_ZN_D2	I21HKY37_DPFC0100_D2	I21HKY37_VLFCD0100_D2	I21HKY37_HZFC0100_D2
Fluvial Current Design 0.1% AEP	I21HKY37_EXFCD0100_D2	I21HKY37_ZN_D2	I21HKY37_DPFC0100_D2	I21HKY37_VLFCD0100_D2	I21HKY37_HZFC0100_D2
Fluvial Mid Range Future Design 10% AEP	I21HKY37_EXFMD0100_D2				
Fluvial Mid Range Future Design 1% AEP	I21HKY37_EXFMD0100_D2				
Fluvial Mid Range Future Design 0.1% AEP	I21HKY37_EXFMD0100_D2				

GIS Outputs							
The following table outlines the GIS deliverables and model run files provided in the accompanying digital handover.							
Scenario	Model Run	Main River % AEP	Tributary River % AEP	Flood Extent Polygon	Flood Zone Polygon	Flood Depth Grid	Flood Velocity Grid
Fluvial Current Design 50% AEP	I37KY_MFCD500_D2_Killarney.ief	50	50	I37EXFCD500D2		I37DPFCD500D2	I37VLFCD500D2
Fluvial Current Design 20% AEP	I37KY_MFCD200_D2_Killarney.ief	20	20	I37EXFCD200D2		I37DPFCD200D2	I37VLFCD200D2
Fluvial Current Design 10% AEP	I37KY_MFCD100_D2_Killarney.ief	10	10	I37EXFCD100D2		I37DPFCD100D2	I37VLFCD100D2
Fluvial Current Design 5% AEP	I37KY_MFCD050_D2_Killarney.ief	5	5	I37EXFCD050D2		I37DPFCD050D2	I37VLFCD050D2
Fluvial Current Design 2% AEP	I37KY_MFCD020_D2_Killarney.ief	2	2	I37EXFCD020D2		I37DPFCD020D2	I37VLFCD020D2
Fluvial Current Design 1% AEP	I37KY_MFCD010_D2_Killarney.ief	1	1	I37EXFCD010D2	I37ZN_A_D2	I37DPFCD010D2	I37VLFCD010D2
Fluvial Current Design 0.5% AEP	I37KY_MFCD005_D2_Killarney.ief	0.5	0.5	I37EXFCD005D2		I37DPFCD005D2	I37VLFCD005D2
Fluvial Current Design 0.1% AEP	I37KY_MFCD001_D2_Killarney.ief	0.1	0.1	I37EXFCD001D2	I37ZN_B_D2	I37DPFCD001D2	I37VLFCD001D2
Fluvial Mid Range Future Design 50% AEP	I37KY_MFMD500_D2_Killarney.ief	50	50	I37EXFMD500D2			
Fluvial Mid Range Future Design 20% AEP	I37KY_MFMD200_D2_Killarney.ief	20	20	I37EXFMD200D2			
Fluvial Mid Range Future Design 10% AEP	I37KY_MFMD100_D2_Killarney.ief	10	10	I37EXFMD100D2			
Fluvial Mid Range Future Design 5% AEP	I37KY_MFMD050_D2_Killarney.ief	5	5	I37EXFMD050D2			
Fluvial Mid Range Future Design 2% AEP	I37KY_MFMD020_D2_Killarney.ief	2	2	I37EXFMD020D2			
Fluvial Mid Range Future Design 1% AEP	I37KY_MFMD010_D2_Killarney.ief	1	1	I37EXFMD010D2			
Fluvial Mid Range Future Design 0.5% AEP	I37KY_MFMD005_D2_Killarney.ief	0.5	0.5	I37EXFMD005D2			
Fluvial Mid Range Future Design 0.1% AEP	I37KY_MFMD001_D2_Killarney.ief	0.1	0.1	I37EXFMD001D2			
Fluvial High End Future Design 10% AEP	I37KY_MFHD100_D2_Killarney.ief	10	10	I37EXFHD100D2			
Fluvial High End Future Design 1% AEP	I37KY_MFHD010_D2_Killarney.ief	1	1	I37EXFHD010D2			
Fluvial High End Future Design 0.1% AEP	I37KY_MFHD001_D2_Killarney.ief	0.1	0.1	I37EXFHD001D2			

## Appendix F. Laune MPW Model Proformas

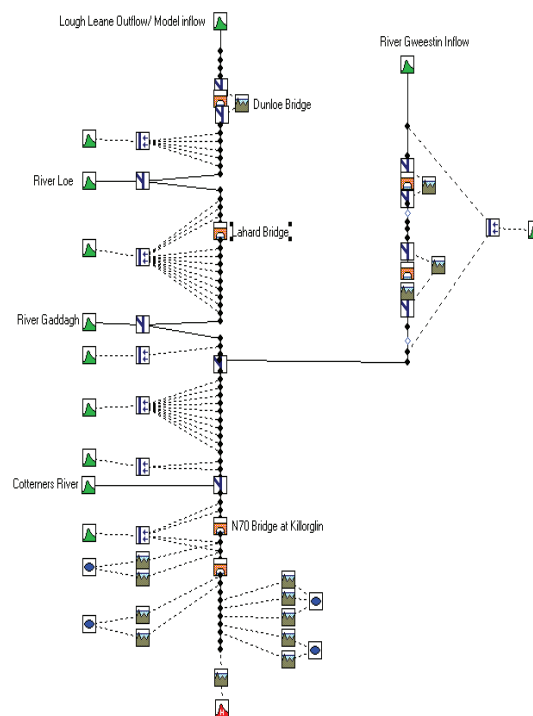
Includes Lough Leane and Castlemaine Harbour Maps

<b>UOM</b>	<b>22</b>		
<b>AFA/ MPW Reach</b>	<b>MPW - Laune</b>		
<b>Model ID</b>	<b>I39LE</b>		
<b>Purpose of Model Build</b>	<b>Flood Mapping</b>		
<b>Main Watercourse</b>	<b>River Laune</b>	<b>FLUVIAL RISK</b>	Yes
<b>Length Modelled (km)</b>	<b>22.4</b>	<b>COASTAL RISK</b>	Yes
<b>Area Modelled (km<sup>2</sup>)</b>	<b>817.9</b>	<b>VULNERABLE TO WAVES</b>	No

Input Data	
River Channel Topographic Data	River channel survey was undertaken by Murphy Surveys Limited as part of the CFRAM Study. 22LAUN_Laune (River)_V1 surveyed March 2013. Added weir and extra nodes at 22LAU00119W to allow for steady water gradients.
Floodplain Topographic Data	Filtered LIDAR DTM "Laune_spliced_001.asc" 2m grid resolution captured in April 2012 The LIDAR DTM covered the MPW downstream of the Gweestin tributary. IFSAR data was lowered by 0.5m to meet the LIDAR and survey elevations and combined with the detailed LIDAR data to provide a single DTM for the MPW.  IFSAR was also used to generate a DTM for Lough Leane and Castlemaine Harbour which are included with the Laune model files.
Map data	1:5000 Osi mapping tiles 5933, 5989, 5990, 6035, 6036, 6037, 6082 The OSI mapping was found to include all current developments and was consistent with site observations, the river channel survey and aerial photography.

Model Build				
General Schematisation	A 1D ISIS approach was taken to model the River Laune to model flow along the main watercourses and head loss through hydraulic structures.			
	The 1D model represents the River Laune as the main watercourse which flows in a south westerly direction out of Lough Leane towards the coast. The Gweestin River has been modelled in 1D and joins the main River Laune model at Ballymalis. The mill leat was not modelled as flood flows would bypass the sluice entrance and flow down the Gweestin. The Gweestin is deemed the major source of risk at the bridges. The three other tributaries downstream are all input in to the model as point inflows. A spill has been added to 22LAU00120S as initial runs led to large and unstable water gradients at the downstream extent caused by the tidal boundary.			
	Defended scenarios: Four reservoir units have been included along the banks south of the road bridge at Killorglin to represent storage areas behind the embankments bordering the main watercourse.			
	Undefended scenarios (use to map the flood zones) Assumes that the raised embankments downstream of Killorglin are ineffective and are removed. The river channel levels have been extended across the entire floodplain as part of the mapping process to derive the undefended extent to inform the flood zones.			
	There are no hydraulic models of Lough Leane and Castlemaine Harbour. Instead design water level profiles were derived during the hydrological analysis based on available gauge information for Lough Leane			
Software Versions Used	ISIS version 6.6			
Total No of 1D nodes	67			
Open channel (H)	63			
Bridges (D)	4			
Culverts (I)	0			
Weirs (W)	0			
Model Extent	Reach/Feature	Upstream Limit (ING)		Downstream Limit (ING)
	Laune	89670, 90909		77220, 99221
Roughness	Reach/Feature	Active Channel	River Banks	Floodplain
	Laune	0.04	0.06	0.06
				Schedule 1: Photographs
Structures	See Schedule 2 for Hydraulic Structure Parameters. In addition to the structures listed four reservoirs have been identified within the floodplain and have thus been modelled. The area and topography of these have been extracted from the LIDAR DTM detailed above.			
Upstream boundary	The River Laune upstream boundary was located at 22LAU02319H at the junction with Lough Leane to account for all flow entering from the waterbody.			
Lateral inflows	Lateral inflows down the River Laune were distributed across all nodes within the respective catchment. These were further weighted based on known inflow locations which are not represented by a separate inflow (in the case of the four tributaries).			
Downstream boundary	The downstream boundary of the 1D is located at the confluence of the River Laune with the estuary. The design tide+ surge profile was applied directly to the model and phased to meet the fluvial peak at Killorglin Bridge.			
Run Settings	Unsteady simulation of the first 100 hours of the full hydrograph. This accounts for the entire peak of the inflow hydrographs, tidal boundary and allows all peak levels to propagate through the model. The 1D timestep was set to 2s . All other parameters were set to default.			

#### Model Schematic



SCHEDULE 1 : PHOTOGRAPHS	
<p>Photo 1: Lough Leane</p> 	<p>Photo 4: Floodplain</p> 
<p>Photo 2: River Laune</p> 	
<p>Photo 3: River Banks</p> 	

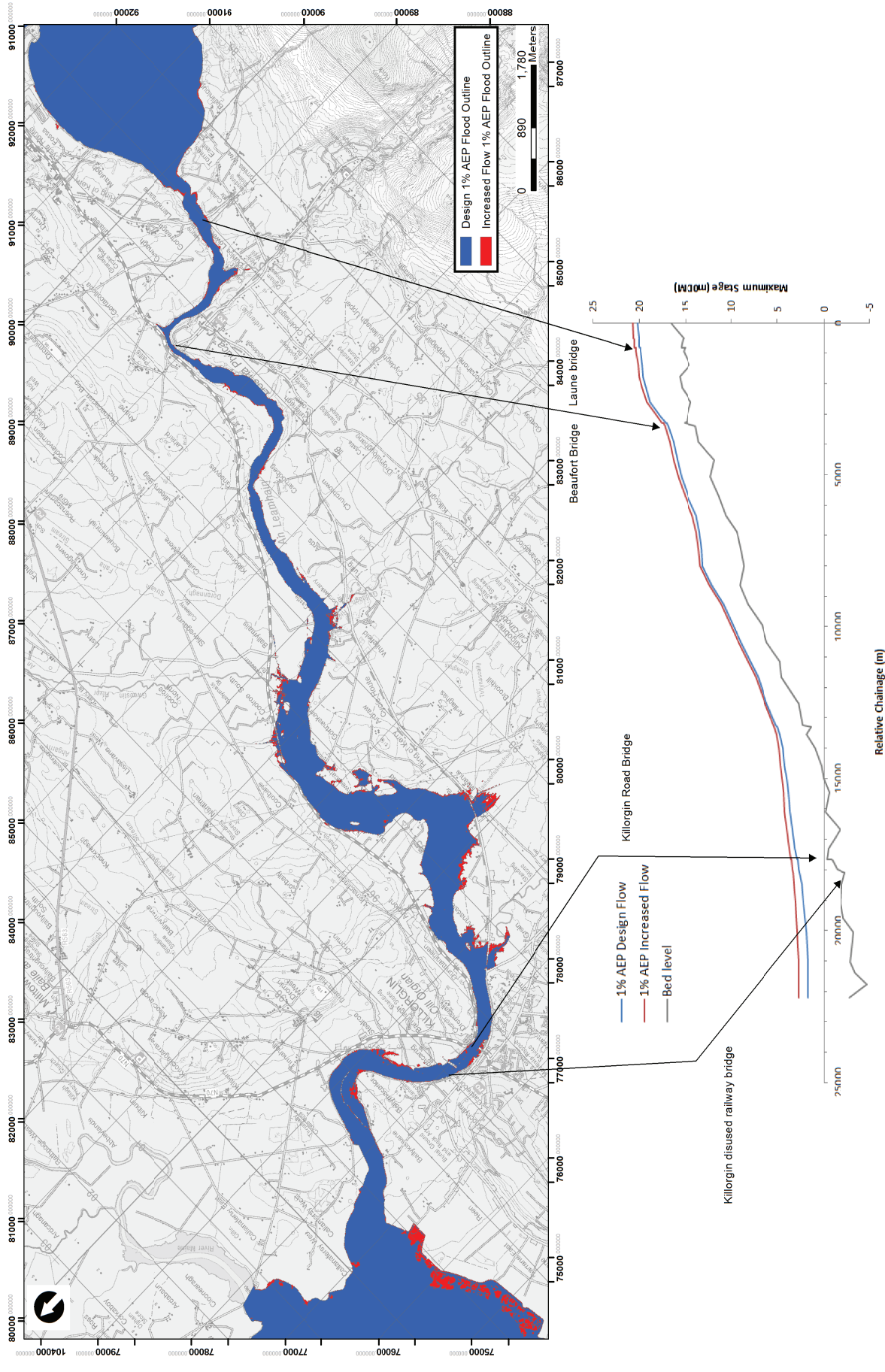


SCHEDULE 2: Structures

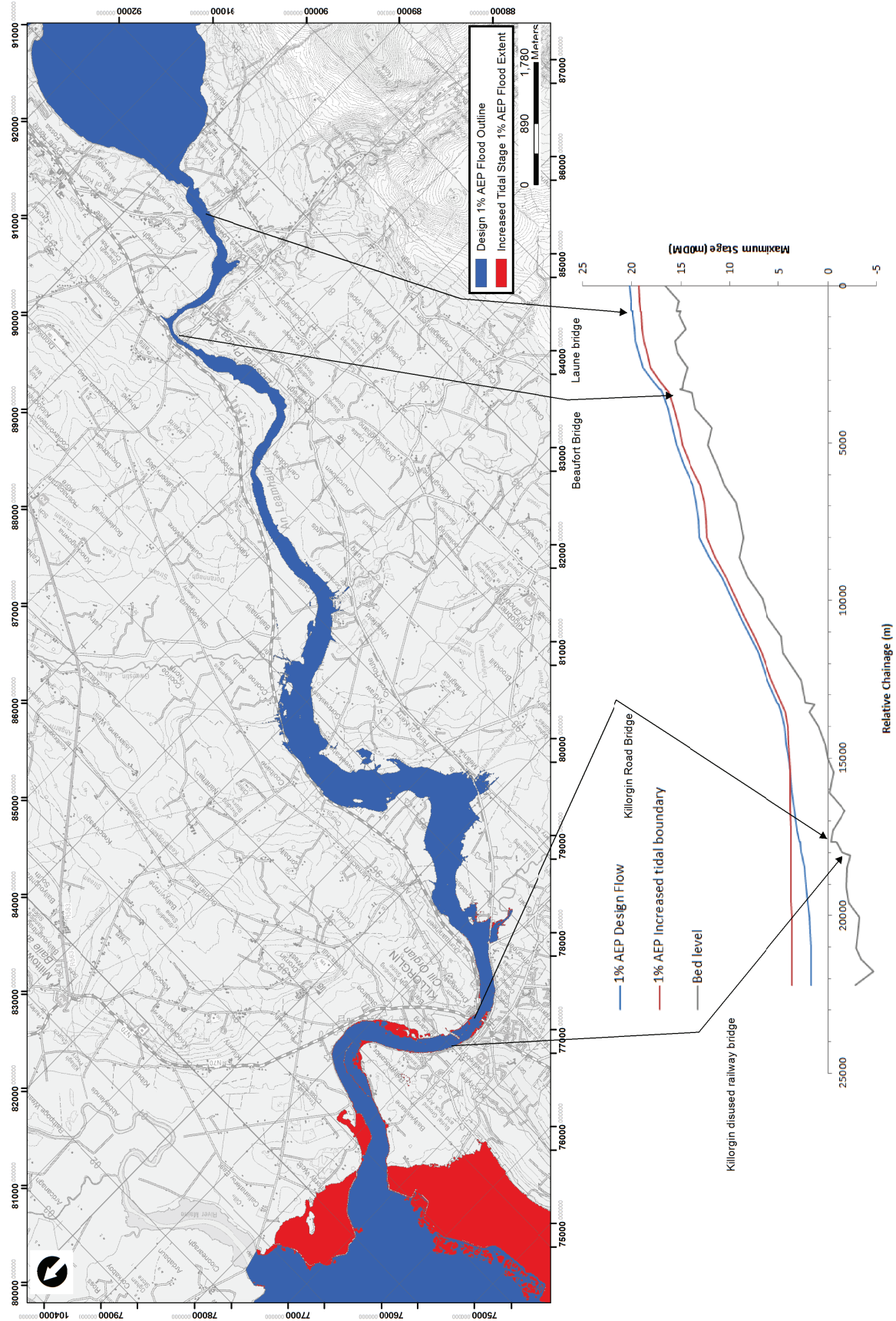
Data file Node	Crossing Name	Structure Type	SWR Code Technical Hydraulics Build Table Layout Description Model 19A-E 010 D-44										Spill Parameters					Coilert Parameters					Comments / Justification	
			Bridge Openings	Span Angle	Calibration Coefficients	Crest Elevation (mAOD)	Length	Modular Limit	Viscous Coeff.	Minimum Crest Elevation (mAOD)	Modular Limit	Wave Coeff.	Seffs level (mAOD)	Revet. U/S (mAOD)	Revet. D/S (mAOD)	Wetted area (m <sup>2</sup> )	Length (m)	K	W	M	Test Screen?	Test Screen coefficient		
22A102240D	88215	91126	Bridge Arched and SPILL	0	1	N/A	N/A	N/A	N/A	21.5	0.9	1.7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Spill represents flow over the bridge; coefficient reduced from 1.7 to 1.2.	
22A101999D	888151	92603	Bridge Arched	0	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Modelled as surveyed. The spill over the parapet has not been modelled as the maximum water level simulated was well below the spill.	
22A100574D	77909	96390	Bridge Arched	0	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Modelled as surveyed. The spill over the parapet has not been modelled as the maximum water level simulated was well below the spill.	
22A100530D	77847	96810	Bridge Arched	0	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Modelled as surveyed. The spill over the parapet has not been modelled as the maximum water level simulated was well below the spill.	
22A100120H	77220	99221	SPILL	N/A	N/A	N/A	N/A	N/A	N/A	-1.7	0.9	1.7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Controlling structure for tidal influence. Bed level of in bank area set at -1.7 determined by stability tests. The spill over the parapet has not been modelled as the maximum water level simulated was well below the spill.	
22ALB00200D	84546	93611	Bridge Arched + SPILL	3	1.5	N/A	N/A	N/A	N/A	16.03	0.9	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Modelled as surveyed with online spill (weir) to represent the spill over the crest and the structure. A calibration coefficient of 1.5 was applied to produce a surveyed water levels and regular flooding at this location.	
22ALB00093D	83802	94968	Bridge Arched + SPILL	3	1.5	10.318	1	0.9	1.4	12.74	0.9	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Modelled as surveyed with online spill (weir) to represent the spill over the crest and the structure. A calibration coefficient of 1.5 was applied to produce a surveyed water levels and regular flooding at this location.	

River Laune Model Performance												
1D Convergence												
Convergence Plot 1% AEP Fluvial Event												
Comments	<p>The 1D model components were convergent and within the recommended tolerances for the majority of this event, and in particular for the period of peak flow. There are five periods of poor convergence, as shown above. These are all generated by poor flow convergence at the bottom six nodes of the model when the tide starts to recede and flow becomes more positive. As during these periods there is significant tidally-generated backwater up the River Laune, the water surface profile is not impacted by the poor convergence and thus there will be no impact on flood levels.</p>											
Hydrological Performance				10% AEP m3/s			1% AEP m3/s			0.1% AEP m3/s		
Target Flows	HEP ID	Location	Model Node	Design	Modelled	% Difference	Design	Modelled	% Difference	Design	Modelled	% Difference
	22035	Laune Bridge	22LAU02240A	148.90	148.54	0%	223.00	222.48	0%	324.50	323.80	0%
	22_2900_1	Laune d/s Loe	22LAU02117B	157.10	161.20	3%	235.40	239.29	2%	342.50	346.34	1%
	22_2208_1	Laune d/s Gaddagh	22LAU01469B	173.20	181.68	5%	259.50	263.58	2%	377.60	376.73	0%
	22_3222_1	Laune d/s Gweestin	22LAU01338B	208.60	232.81	12%	312.40	327.12	5%	454.60	458.00	1%
	22_4001_4+	Laune d/s	22LAU00530D	242.40	275.15	14%	363.10	383.23	6%	528.40	532.13	1%
Comments	<p>The flows in the 1D ISIS channel at key HEP locations were compared to the design hydrology. The modelled flow tended to overestimate flows at the HEP locations compared to the design peak flows in all return periods. Further downstream the difference between design and modelled flow increased for all return periods. This can be explained by the increasing impact from the tidal downstream boundary on the nodes further downstream. This influence means that this maximum flow is peaky as the tidal surge travels upstream. These differences are deemed acceptable because of these reasons and as the surge peak only has a short duration there will be minimal impact on flood levels.</p>											
Sensitivity Test 1: Increased Flow												
Model Run ID	I39LE_FHD010_D1_LAUNE_BZR416											
Hydraulic Modification to Design Model	No hydraulic modifications were made to the design model.											
Hydrological inflows	<p>All inflows were increased by 30% for the 1% AEP fluvial current design event to account for the uncertainty in the derivation of QMED and the pooling group selected.</p> <p>This is broadly equivalent to the HEFS 1% AEP as the increase in urban extent has less the 1% impact on peak flow. Therefore, the HEFS 1% AEP results (FHD010) have been used as the sensitivity test results.</p> <p>The tidal downstream boundary was retained, representing a Mean High Water Spring (MHWS) profile.</p>											
Sensitivity Plot	See Schedule 3 - Calibration and Sensitivity											
Comments	<p>A 30% increase in flows resulted in a small increase in flood extent along the River Laune along its entire length.</p> <p>Therefore flood risk along the River Laune MPW was not found to be sensitive to uncertainties in flow.</p> <p>An allowance should be made when interpreting the design flood outlines and in the sizing of any flood risk management option due to this uncertainty in flood level and extent caused by the uncertainties in flow.</p>											
Sensitivity Test 2: Increased Manning's 'n'												
Model Run ID	I39LE_FCN010_D1_LAUNE_BZR416											
Hydraulic Modification to Design Model	<p>The Manning's 'n' values in the 1D model were increased to the upper limit of the industry recommended ranges.</p> <p>All active channels 0.040 to 0.050</p> <p>All river banks and floodplains 0.060 to 0.080</p>											
Hydrological inflows	No modifications were made to the design inflows.											
Sensitivity Plot	See Schedule 3 - Calibration and Sensitivity											
Comments	<p>Results for this test are displayed in graphical format. Being a 1D model, flood levels are projected across the floodplain for mapping purposes so any increase in stage as a result of an increase in roughness will cause a change in flood extent to one comparable to a lower return period.</p> <p>An increase in roughness values in bank and out-of-bank has a minimal impact on the flood extent from the River Laune.</p> <p>An allowance should be made when interpreting the design flood outlines and in the maintenance of any flood risk management option in locations which may be susceptible to extreme seasonal changes in roughness.</p>											
Sensitivity Test 3: Increased Downstream Tidal Stage												
Model Run ID	I39LE_CMD010_D1_LAUNE_BZR416											
Hydraulic Modification to	<p>The Manning's 'n' values were increased to the upper limit of the industry recommended ranges.</p> <p>All active channels 0.040 to 0.048</p>											
Hydrological	No modifications were made to the design inflows.											
Sensitivity Plot	See Schedule 3 - Calibration and Sensitivity											
Comments	<p>An increase in the downstream stage had a significant impact on the flood extent on the downstream of the model but no impact upstream of Killorglin. The extent of flooding increased along the Estuary boundary to cover a number of small settlements north of the N70.</p> <p>Therefore flood risk along the River Laune MPW was found to be sensitive to uncertainties in the downstream tidal boundary.</p> <p>An allowance should be made when interpreting the design flood outlines and in the maintenance of any flood risk management option along the lower reach of the River Laune.</p>											

Map F.1: Sensitivity to 30% Increased Peak Flow

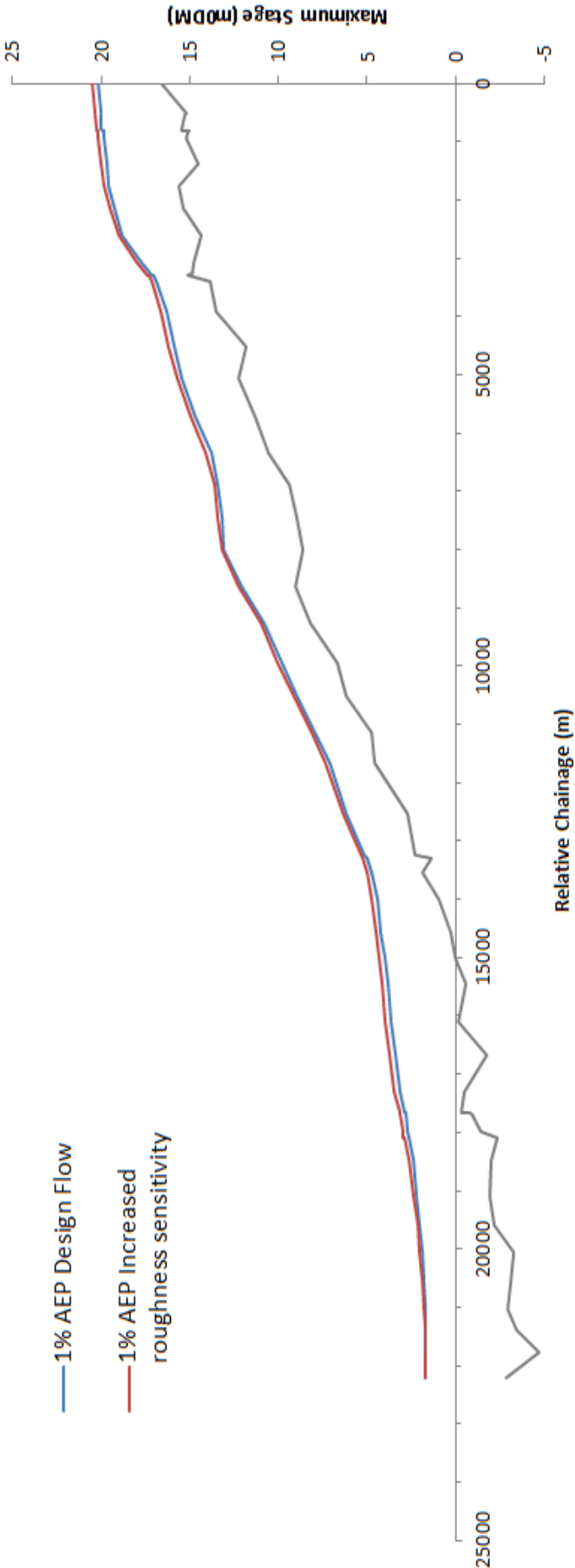


Map F.2: Sensitivity to increased downstream tidal stage





Map F.3: Sensitivity to Increased Manning's 'n'



River Laune Model Outputs	
	<p>The key thresholds and areas affected by tidal flooding along the River Laune MPW are:</p> <ul style="list-style-type: none"> <li>-50% AEP tidal event remains within the flood defences</li> <li>-10% AEP tidal event overtops the defence on the northern bank of Castlemaine Estuary at Rosculien Island</li> <li>-2% AEP tidal event overtops the defence on the southern bank of Castlemaine Estuary and generates a small increase in flood extent on the north bank</li> <li>-1% AEP tidal event overtops the defence on the eastern bank of Castlemaine Estuary</li> <li>-Approximately 100 properties are affected by the 0.5% AEP tidal event.</li> </ul> <p>The key thresholds and areas affected by fluvial flooding along the River Laune MPW are:</p> <ul style="list-style-type: none"> <li>-50% AEP floods the immediate floodplains of the River Laune. Some flooding of minor roads in the proximity of Dungleigh, upstream of Killorglin</li> <li>-0.1% AEP causes some further flooding in this area. The remainder of the flood extent remains roughly consistent through the return periods.</li> <li>-Approximately 25 properties are affected by the 1% AEP fluvial event.</li> </ul> <p>Please note that basements have not been represented in CFram models. Therefore the recorded flooding of the basement at the B&amp;B on the downstream of Killorglin Bridge is not fully represented. However, the model does show flooding across the car park and the basement of the property is below car park level. basement therefore flooding of the property can be assumed.</p>
Threshold of Property Flooding	
	<p>The critical structures along the Laune include:</p> <ul style="list-style-type: none"> <li>- The raised embankments and channel capacity downstream of Killorglin determine flood risk to the lower Laune</li> <li>- Laune Bridge</li> </ul>
Critical Structures for Flood Risk	
	<p>The majority of fluvial and tidal flooding is constrained to the agricultural fields on the banks on the river and Castlemaine Estuary. When the defences of the lower Laune and Castlemaine Estuary become overtopped in the high return period events, large areas of land, including some urban, become at risk to flooding.</p>
Areas affected by flooding	
	<p>Flood hazard is not calculated for MPW reaches. However, the greatest risk to urban area and thus people is behind the flood defences on the southern shore of Castlemaine Estuary. Should these become overtopped or breached, water at high velocity and significant depth present notable risk.</p>
Risk to people	
Consideration for Flood Risk Management Options	<ul style="list-style-type: none"> <li>- Increased channel capacity in raised embankment section</li> <li>- Raising of the embankment levels at low points and sections at risk of overtopping as identified by the survey/modelling.</li> </ul>

Flood Map Outputs					
The following table outlines the print-ready flood mapping deliverables provided in the accompanying digital data.					
Scenario	Flood Extent Map	Flood Zone Map	Flood Depth Map	Flood Velocity Map	Flood Hazard Map
Fluvial Current Design 10% AEP	(22MLE39_EXFCDEXP_D2		(22MLE39_DPFCD100_D2	No velocity mapping required for MPW reaches	No hazard mapping required for MPW reaches
Fluvial Current Design 1% AEP	(22MLE39_EXFCDEXP_D2	(22MLE39_ZN_D2	(22MLE39_DPFCD010_D2		
Fluvial Current Design 0.1% AEP	(22MLE39_EXFCDEXP_D2	(22MLE39_ZN_D2	(22MLE39_DPFCD001_D2		
Fluvial Mid Range Future Design 10% AEP	(22MLE39_EXFMDEXF_D2				
Fluvial Mid Range Future Design 1% AEP	(22MLE39_EXFMDEXF_D2				
Fluvial Mid Range Future Design 0.1% AEP	(22MLE39_EXFMDEXF_D2				
Coastal Current Design 10% AEP	(22MLE39_EXCCDEXC_D2		(22MLE39_DPFCD100_D2		
Coastal Current Design 0.5% AEP	(22MLE39_EXCCDEXC_D2	(22MLE39_ZN_D2	(22MLE39_DPFCD005_D2		
Coastal Current Design 0.1% AEP	(22MLE39_EXCCDEXC_D2	(22MLE39_ZN_D2	(22MLE39_DPFCD001_D2		
Coastal Mid Range Future Design 10% AEP	(22MLE39_EXCMDEXC_D2				
Coastal Mid Range Future Design 0.5% AEP	(22MLE39_EXCMDEXC_D2				
Coastal Mid Range Future Design 0.1% AEP	(22MLE39_EXCMDEXC_D2				

GIS Outputs									
The following table outlines the GIS deliverables and flood run files provided in the accompanying digital data.									
Scenario	Model Run	Main River %AEP	Tributary River %AEP	Coastal %AEP	Flood Extent Polygon	Flood Zone Polygon	Flood Depth Grid	Flood Velocity Grid	Flood Hazard Grid
Fluvial Current Design 50% AEP	(39LE_MFCD500_D2_Laune.jef	50	50	MHWS	(39EXFCD500D2		(39DPFCD500D2		
	(39LE_TFCD500_D2_Laune.jef	50	50	MHWS					
	(39LE_MFCD200_D2_Laune.jef	20	50	MHWS	(39EXFCD200D2		(39DPFCD200D2		
Fluvial Current Design 20% AEP	(39LE_TFCD200_D2_Laune.jef	50	20	MHWS					
	(39LE_MFCD100_D2_Laune.jef	10	20	MHWS					
Fluvial Current Design 10% AEP	(39LE_TFCD100_D2_Laune.jef	20	10	MHWS	(39EXFCD100D2		(39DPFCD100D2		
	(39LE_MFCD050_D2_Laune.jef	5	20	MHWS					
Fluvial Current Design 5% AEP	(39LE_TFCD050_D2_Laune.jef	20	5	MHWS	(39EXFCD050D2		(39DPFCD050D2		
	(39LE_MFCD020_D2_Laune.jef	2	10	MHWS					
Fluvial Current Design 2% AEP	(39LE_TFCD020_D2_Laune.jef	10	2	MHWS	(39EXFCD020D2		(39DPFCD020D2		
	(39LE_MFCD010_D2_Laune.jef	1	5	MHWS					
Fluvial Current Design 1% AEP	(39LE_TFCD010_D2_Laune.jef	5	1	MHWS	(39EXFCD010D2	(39ZN_A_D2	(39DPFCD010D2		
	(39LE_MFCD005_D2_Laune.jef	0.5	5	MHWS					
Fluvial Current Design 0.5% AEP	(39LE_TFCD005_D2_Laune.jef	5	0.5	MHWS	(39EXFCD005D2		(39DPFCD005D2		
	(39LE_MFCD001_D2_Laune.jef	0.1	1	MHWS					
Fluvial Current Design 0.1% AEP	(39LE_TFCD001_D2_Laune.jef	1	0.1	MHWS	(39EXFCD001D2	(39ZN_B_D2	(39DPFCD001D2		
Fluvial Mid Range Future Design 50% AEP	(39LE_MFMD500_D2_Laune.jef	50	50	MHWS			(39DPFMD500D2		
	(39LE_TFMD500_D2_Laune.jef	50	50	MHWS	(39EXFMD500D2				
	(39LE_MFMD200_D2_Laune.jef	20	50	MHWS					
Fluvial Mid Range Future Design 20% AEP	(39LE_TFMD200_D2_Laune.jef	50	20	MHWS	(39EXFMD200D2		(39DPFMD200D2		
	(39LE_MFMD100_D2_Laune.jef	10	20	MHWS					
Fluvial Mid Range Future Design 10% AEP	(39LE_TFMD100_D2_Laune.jef	20	10	MHWS	(39EXFMD100D2		(39DPFMD100D2		
	(39LE_MFMD050_D2_Laune.jef	5	20	MHWS					
Fluvial Mid Range Future Design 5% AEP	(39LE_TFMD050_D2_Laune.jef	20	5	MHWS	(39EXFMD050D2		(39DPFMD050D2		
	(39LE_MFMD020_D2_Laune.jef	2	10	MHWS					
Fluvial Mid Range Future Design 2% AEP	(39LE_TFMD020_D2_Laune.jef	10	2	MHWS	(39EXFMD020D2		(39DPFMD020D2		
	(39LE_MFMD010_D2_Laune.jef	1	5	MHWS					
Fluvial Mid Range Future Design 1% AEP	(39LE_TFMD010_D2_Laune.jef	5	1	MHWS	(39EXFMD010D2		(39DPFMD010D2		
	(39LE_MFMD005_D2_Laune.jef	0.5	5	MHWS					
Fluvial Mid Range Future Design 0.5% AEP	(39LE_TFMD005_D2_Laune.jef	5	0.5	MHWS	(39EXFMD005D2		(39DPFMD005D2		
	(39LE_MFMD001_D2_Laune.jef	0.1	1	MHWS					
Fluvial Mid Range Future Design 0.1% AEP	(39LE_TFMD001_D2_Laune.jef	1	0.1	MHWS	(39EXFMD001D2		(39DPFMD001D2		
Fluvial High End Future Design 10% AEP	(39LE_MFHD100_D2_Laune.jef	10	20	MHWS			(39DPFHD100D2		
	(39LE_TFHD100_D2_Laune.jef	20	10	MHWS	(39EXFHD100D2				
	(39LE_MFHD010_D2_Laune.jef	1	5	MHWS					
Fluvial High End Future Design 1% AEP	(39LE_TFHD010_D2_Laune.jef	5	1	MHWS	(39EXFHD010D2		(39DPFHD010D2		
	(39LE_MFHD001_D2_Laune.jef	0.1	1	MHWS					
Fluvial High End Future Design 0.1% AEP	(39LE_TFHD001_D2_Laune.jef	1	0.1	MHWS	(39EXFHD001D2		(39DPFHD001D2		

## Appendix G. Dingle AFA Model Proformas

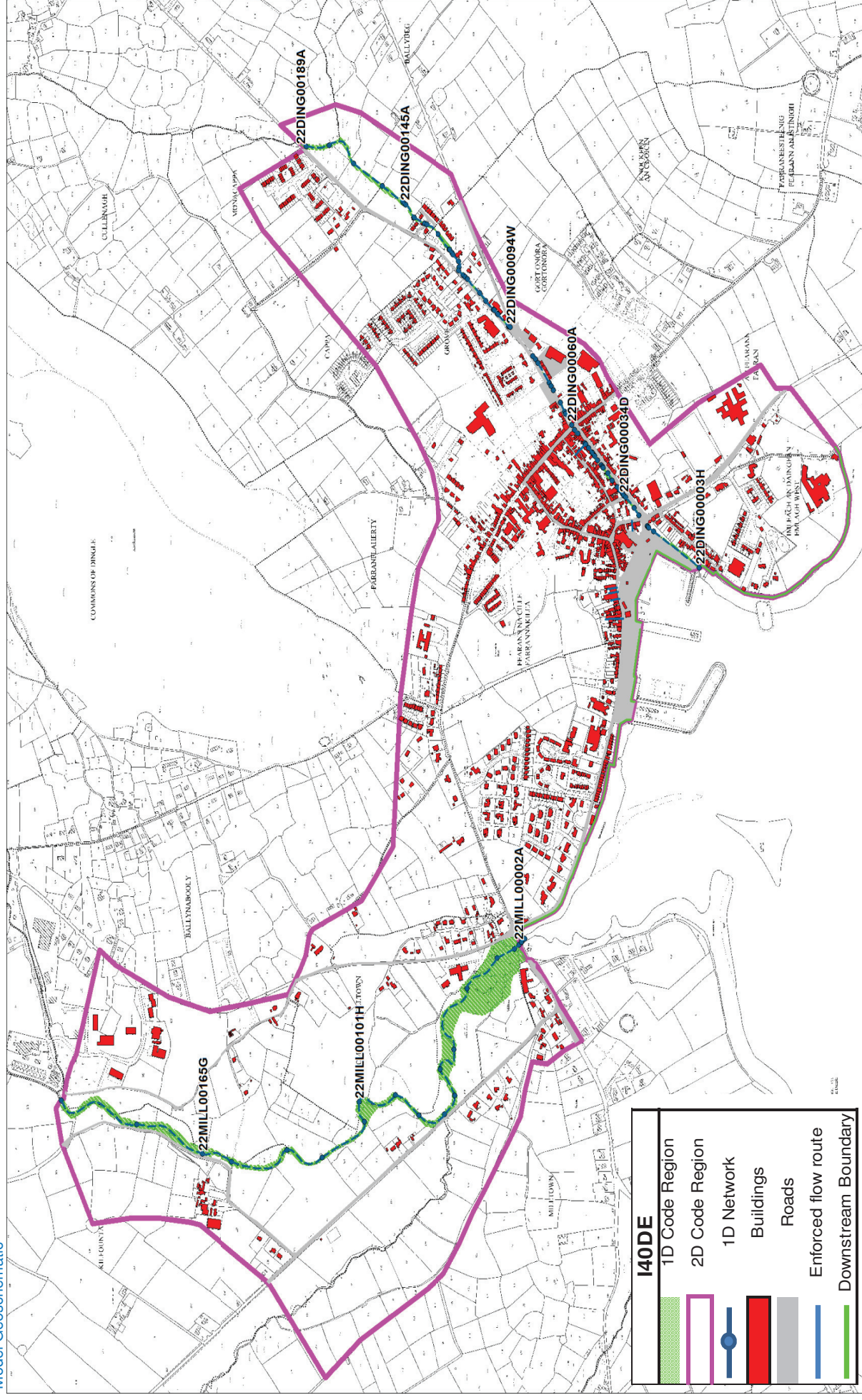
UOM	22		
AFA/ MPW Reach	Dingle		
Model ID	I40DE		
Purpose of Model Build	Flood Mapping		
Main Watercourse	Milltown Stream and Dingle Stream	FLUVIAL RISK	Yes
Length Modelled (km)	4.3	COASTAL RISK	Yes
Area Modelled (km <sup>2</sup> )	3.0	VULNERABLE TO WAVES	Yes

Input Data	
River Channel Topographic Data	Topographic survey by Murphy Surveys Limited. Data captured in September 2012. Refer to Drawings 22DING_Dingle_V1.dwg and 22MILL_Milltown River_V1.dwg  It was unsafe for the original survey to capture structure dimensions at a new access bridge at 22DING00070H due to ongoing construction work. Therefore the dimensions for this structure have been obtained from the development application from Kerry County Council.
Floodplain Topographic Data	2m DTM LIDAR provided by OPW converted from ITM to ING. Elevations on hard standing were compared with river channel survey and found to be within 0.2 m.
Map data	Ordnance Survey Ireland 1:1000, 1:2500 and 1:5000 and 1:50000 data Vector mapping at 1:1000, 1:2500 and 1:5000 were converted from DWG/DXF to GIS files to identify material layers

Model Build					
General Schematisation	<p>A 1D/2D ISIS/TUFLOW approach was taken for Dingle to accurately model head loss through the various hydraulic structures whilst enabling multidirectional flow complex urban floodplain from coastal and fluvial flooding.</p> <p>The 2D floodplain cell size was set to 5m to represent the urban area without compromising run time.</p> <p>The quayside elevations have been defined by survey at the outfall of Dingle and Milltown streams. The seaward wall along the R559 (Milltown Road) was observed to have various openings and expected to be porous under load. There this is not considered as an informal defence. LiDAR has been used to derive coastal shore levels elsewhere in the AFA. However, the LiDAR is deemed to be of sufficient accuracy as the shore is defined by natural sloping ground and wide roads rather than narrow walls in this area,</p> <p>Buildings thresholds have been raised by 0.15m above the DTM level based on site observations and a higher Manning's 'n' value applied to the building footprints to simulate the storage of water once flooded.</p> <p>Version D2: Improved representation of Spa Road culvert, Brewery Bridges, Avondale Bridge and associated structures and banks to better match frequency of flooding reported by the local area engineers.</p>				
Software Versions Used	<p>ISIS version 6.6</p> <p>TUFLOW version 2012-05-AC-ISP-w32</p>				
Total No of 1D nodes	153				
Routing Units	0				
Open channel (H) including interpolates	95				
Bridges (D)	4				
Spills (S)	16				
Culverts (I) including inlet, conduit and outlet	17				
Orifice (O)	14				
Weirs (W)	7				
Model Extent	Reach/Feature	Upstream Limit (ING)		Downstream Limit (ING)	
	Dingle	045666, 102210		044455, 100745	
	Milltown	042976, 102772		043414, 101322	
Roughness	Reach/Feature	Active Channel	River Banks	Floodplain	Source
	Dingle	0.040	0.060	N/A	Schedule 1: Photographs
	Milltown	0.040	0.060	N/A	Schedule 1: Photographs
	Open pasture	N/A	N/A	0.060	Schedule 1: Photographs
	Dense vegetation	N/A	N/A	0.080	Schedule 1: Photographs
	Buildings	N/A	N/A	0.200	Schedule 1: Photographs
	Roads	N/A	N/A	0.030	Schedule 1: Photographs
Structures	See Schedule 2 for Hydraulic Structure Parameters				
Upstream boundary	<p>The gauged inflow at Milltown Gauge (22022) is transferred directly to the upstream limit of the model.</p> <p>The lateral inflow joining at 22MILL00071H represents the tributary inflow and the minor lateral inflow from the intermediate catchment combined.</p> <p>The design HEP inflow has been applied directly to the upstream of Dingle using a flow-time boundary (QT). The intermediate inflows have been areally weighted down the modelled reach and input at an overland flow path (22DING00177L) and surveyed drain outfalls (22DING00119L, 22DING00064L and 22DING00029L).</p>				
Lateral inflows	The intermediate inflows have been areally weighted down the modelled reach and input at an overland flow path (22DING00177L) and surveyed drain outfalls (22DING00119L, 22DING00064L and 22DING00029L)				
Downstream boundary	The derived tidal boundaries have been applied to the downstream limit of each modelled reach on the downstream of a spill unit to allow ISIS to resolve scenarios where extreme fluvial flows increase level at the tidal outfall i.e. FCD, FMD and FHD scenarios.				
Run Settings	<p>Unsteady simulation of the full 16 hours hydrograph for fluvial scenarios coinciding with the MHSW tide.</p> <p>Unsteady simulation between 15 and 26 hours to simulate the tidal scenario over the peak tide + surge.</p> <p>2.5s timestep</p> <p>Minimum flows of 1.1m<sup>3</sup>/s on Dingle and 2.0m<sup>3</sup>/s on Milltown to enable stable flows over these steep gradients. This takes up less than 10% of the channel capacity and does not reduce the volume available for flood storage.</p> <p>The alpha value was lowered from 0.7 to 0.6, and the orifice linearisation parameter was set to 0.5m to help improve the hydraulic transition between orifice and free flow as the flood recedes. This does not affect the peak flow and level.</p>				



## Model Geoschematic





SCHEDULE 1 : PHOTOGRAPHS

Photo 1: Dingle Stream Channel and Urban Banks



Photo 6: Pasture Floodplain



Photo 2: Milltown Active Channel and Banks



Photo 7: Roads and Urban Floodplain

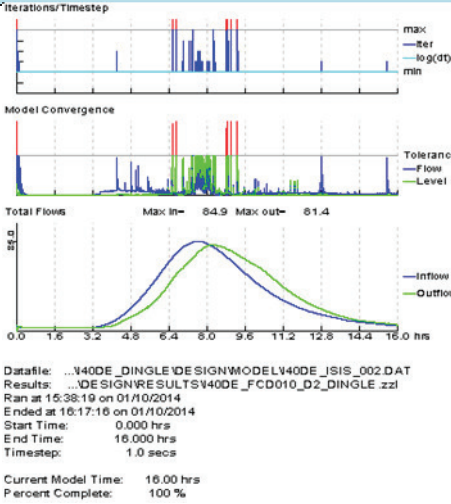
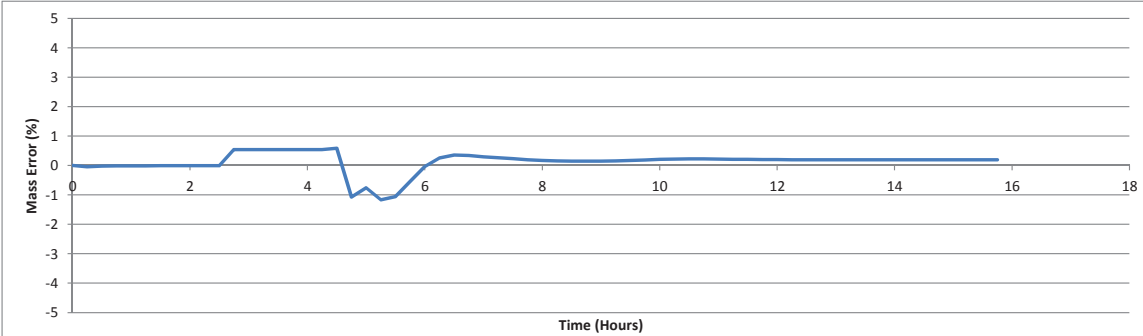


Photo 3: Tidal Outfall (Dingle Bay)



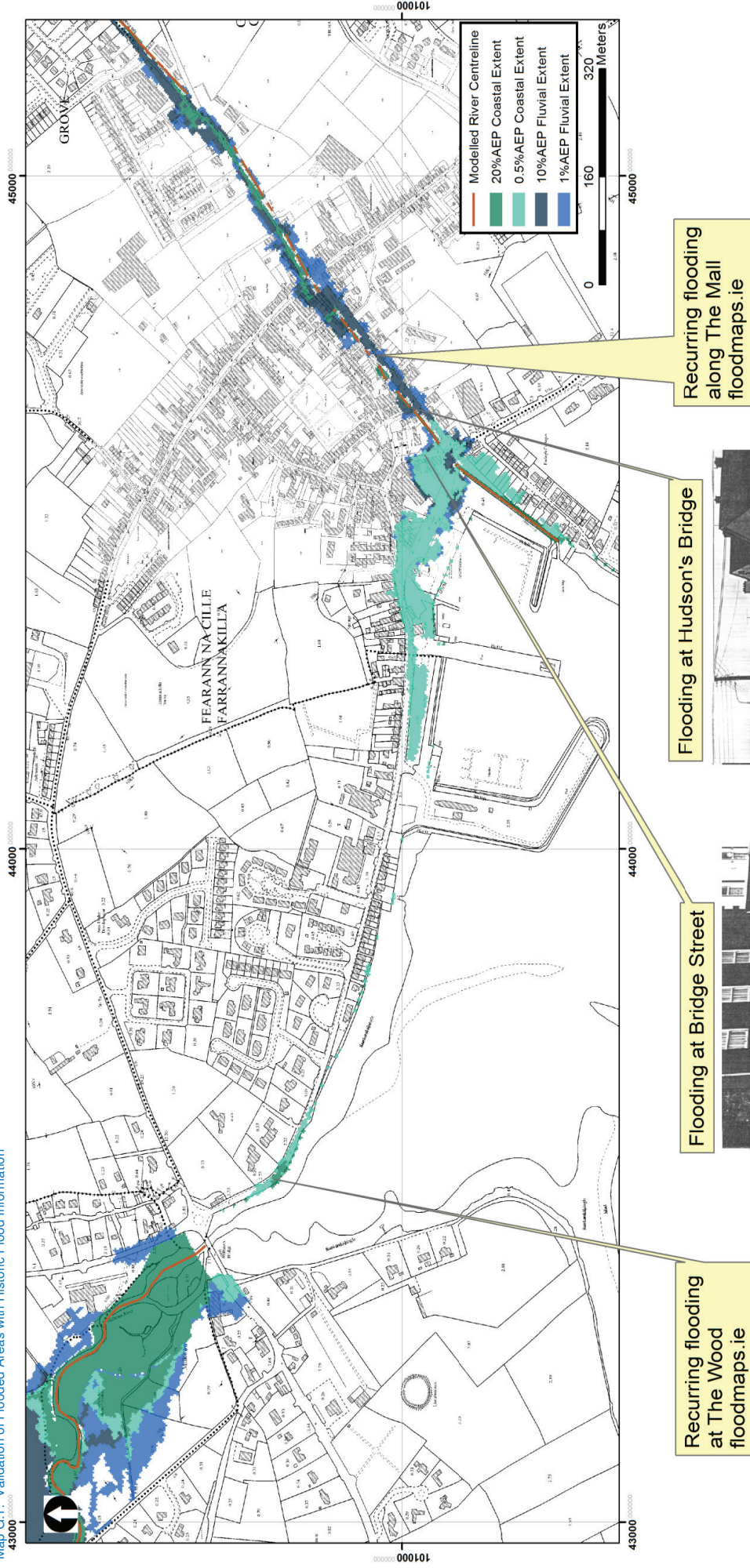
SCHEDULE 2: Structures

SCHEDULE 2: Structures																										
Data file	Node(s)	Easting	Northing	Structure Type	Bridge Parameters				Weir Parameters				Spill Parameters				Culvert/Orifice Parameters					Comments/Justification				
					SAFF Elevation	No. of Openings	Base Angle	Calculation Coefficients	Orifice Elevation	Breakthru	Modular Limit	Modular Limit Weir Coeff.	Spill Level (mOD)	No. of Openings	Invert LWS (mASD)	Area (m <sup>2</sup> )	Normal Width	Length (m)	K	N	Trash Screen		Trash Screen coefficient	Required		
P:\Cambridge\Drawings\BVA\BVA001\5 View\CFRAME BVT\Civil\Technical\Hydraulic\Drawings\Drawings\Drawings\DATA\IDE_001_001\43.46	222IN0001B01	45621	101011	Sea Road Bridge upstream ORIFICE + CIRCULAR CULVERT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	32.01	2	31.155	38.65	1.62	17.4	1	0.5	0.7	N/A	N/A	Two culverts under Sea Road with rectangular foot and circular pipes. Therefore the circular pipes were taken as a conservative estimate of head loss. Head loss checked against water levels. Culvert units used at inlet to stabilise flow over drop. Head loss checked against water levels. Culvert units used at outlet to stabilise flow over drop. Head loss checked against water levels. No spill over road modelled as the most extreme event does not reach the road deck level.	
	222IN0001C01	45465	101082	Field access bridge ORIFICE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	22.585	1	21.359	23.39	2.72	3.45	1	0.5	0.7	N/A	N/A	Short rectangular culvert under field access track. SPWARP above spill to modelled as an orifice unit.	
	222IN0001B0W	45426	101052	WEIR upstream of Southern bog	N/A	N/A	N/A	N/A	20.65	2.585	0.7	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
	222IN0001S01	45411	101618	Southern Road Bridge ARCH BRIDGE	21.05	N/A	0	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Arch bridge at recent development	
	222IN0001Z0W	45337	101540	WEIR upstream of access bog	N/A	N/A	N/A	N/A	17.73	4.429	0.7	1.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Warp modelled as a weir. Velocity coefficient increased to match observed water levels during the over channelled survey for low flows.	
	222IN0001Z01	45330	101530	Sea bridge	17.81	1	0	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Warp modelled as a weir. Velocity coefficient increased to match observed water levels during the over channelled survey for low flows.	
	222IN0001A0	45267	101493	Access bridge	16.37	1	0	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
	222IN0001B01	45172	101400	ARCH BRIDGE	14.42	1	0	1	12.92	1.43	0.7	1	15.42	0.9	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Two bridges in sequence modelled as dual bridge. View downstream represents the bed drop over the mill race.	
	222IN0001D1	45172	101400	ARCH BRIDGE	14.42	1	0	1	12.92	1.43	0.7	1	15.42	0.9	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Version 02: Simplified configuration such that the weir is attached to the immediate downstream face of the bridge to ensure stability. The weir is a 10m wide concrete wall with a 1m high upstream to ensure water is the hydraulic control not the open channel in order to improve head loss calculation.	
	222IN000094W	45121	101348	RA WEIR	N/A	N/A	N/A	N/A	12.25	2.526	0.7	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Weir used to stabilise steep drop in bed for all flows.	
	222IN000084W	44508	101079	Sea drop	N/A	N/A	N/A	N/A	4.95	4.027	0.7	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Conceptualised element used in garden	
	222IN000084W	44733	101052	RA WEIR	N/A	N/A	N/A	N/A	4.01	2.109	0.7	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Version 02: Simplified configuration such that the weir is attached to the immediate downstream face of the bridge to ensure stability. The weir is a 10m wide concrete wall with a 1m high upstream to ensure water is the hydraulic control not the open channel in order to improve head loss calculation.	
	222IN000084W	44661	100991	Upstream of Anovade ORIFICE	N/A	N/A	N/A	N/A	2.53	3.915	0.7	1.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Version 02: Simplified configuration such that the weir is attached to the immediate downstream face of the bridge to ensure stability. The weir is a 10m wide concrete wall with a 1m high upstream to ensure water is the hydraulic control not the open channel in order to improve head loss calculation.	
	222IN000094D	45122	101346	Sea Road culvert ORIFICE + CULVERT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12.89	1	11.66	11.658	3.12	2.58	165	1	0.5	0.7	N/A	N/A	Long culvert modelled using orifice at inlet to stabilise transition to orifice mode in extreme events.
	222IN000090D	45034	101265	Bridge	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10.23	1	9.216	9.216	3.38	3.33	11.8	1	0.5	0.7	N/A	N/A	Long culvert modelled using orifice at inlet to stabilise transition to orifice mode in extreme events.
	222IN000094D	44668	101223	New Development Bridge ORIFICE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	9.17	1	8.337	8.337	2.26	2.68	10.34	0.9	0.5	0.7	N/A	N/A	Long culvert modelled using orifice at inlet to stabilise transition to orifice mode in extreme events.
	222IN0000901	44648	101208	New Development Bridge ORIFICE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8.82	1	7.92	7.195	2.70	2.7	40	1	0.5	0.7	N/A	N/A	Calculated coefficients to match observed water level during survey
	222IN000094D	44889	101173	Access bridge ORIFICE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8.09	1	7.074	7.081	3.28	2.89	5.68	1	0.5	0.7	N/A	N/A	New bridge details from SSO application Court O'Donnell. Modelled as orifice to stabilise flows. Spill over the deck is modelled in 1D flow to begin with.
	222IN000094D	44832	101151	Sea Road bridge ORIFICE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	7.9	1	6.829	5.999	3.44	2.9	15.84	1	0.5	0.7	N/A	N/A	Arch bridge modelled as orifice to stabilise the flows over the 1m bed drop across the structure.
	222IN000093D	44798	101106	Property access bridge ORIFICE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	6.48	1	5.727	4.9	3.08	4.002	11.8	1	0.5	0.7	N/A	N/A	Property access bridge with concrete deck modelled as orifice to stabilise flows over the 1m bed drop across the structure.
	222IN000094D	44774	101083	Property access bridge ORIFICE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5.93	1	4.946	4.946	4.07	4.07	10.19	1	0.5	0.7	N/A	N/A	Property access bridge with concrete deck modelled as orifice to stabilise flows over the 1m bed drop across the structure.
	222IN000092D	44570	100908	Footbridge ORIFICE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.86	1	0.288	0.259	4.01	4.2	1.32	1	0.5	0.675	N/A	N/A	Property access bridge with concrete deck modelled as orifice to stabilise flows over the 1m bed drop across the structure.
	WIL0000201 and 2	43420	101324	Millen Bridge ORIFICE + SPILL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.57	2	-0.809	-0.809	13.31	4.9	10.6	0.64	0.5	0.732	N/A	N/A	Spill models flow over concrete deck. Failings do not obstruct so acts as close to a formal weir.
	222IN000047D	44753	101070	Wall crossing BERNOLLI LOSS	5.27	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Two arches opening under the R509. The road embankment forms a significant barrier to flow entering the fullwidth culvert and the openings are relatively small compared to the channel area upstream. The channel upstream was observed to pond during a normal high tide on the site with resulting in water flow through the arches opening.	
	222IN000044D	44635	100983	Anovade Bridge BERNOLLI LOSS	2.75	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Well crossing channel like a bridge. Modelled as Bernoulli loss to stabilise flows in backwater.	
	222IN0000597	44826	101133	Culvert under Arkhus House (m) BERNOLLI LOSS + RECTANGULAR CULVERT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	7.2157	1	6.171	5.727	4.08	4.09	33.66	N/A	N/A	N/A	N/A	Rectangular bridge modelled as Bernoulli loss to stabilise flows in backwater conditions and meet recurring flooding reports. X values derived from US Highway Bridge Design 1978 equations.	
	222IN0000481	44701	101024	Culvert under Hill House INLET + RECTANGULAR CULVERT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3.76	1	2.845	2.64	2.694	4.19	24.24	0.515	0.5	0.667	N/A	N/A	Bernoulli Loss represents inlet to stabilise hydraulic regime changes based on survey data. Rectangular conduit represents the culvert capacity itself.
	222IN0000271	44603	100937	Culvert under roundabout INLET + RECTANGULAR CULVERT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.28	1	0.88	0.68	5.843	5.2	38.7	0.515	0.5	0.667	N/A	N/A	Rectangular flow culvert under M1 modelled with culvert inlet and rectangular conduits as it is observed for Spill over the top defined by 2D domain.

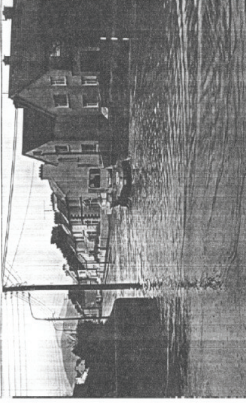
Castleisland Model Performance												
1D Convergence		<div>Convergence Plot</div> <div>1% AEP Fluvial Event</div> <div></div>										
Comments		<p>The 1D model components were convergent and within the recommended tolerances for the majority of the event. The higher number of iterations at the start of the event are to accommodate the low flow in the channel and flow through the steep culverts. However this quickly stabilise within 0.5 hours well before the flood event starts at 3 hours.</p> <p>There are a couple of brief spikes of poor convergence (&lt;0.25 hours) at 7 and 9 hours caused by the transition from bridge or free-floe to orifice flow through the various structures on Dingle Stream. The orifice linearisation and alpha run parameters have been optimised to improve the iterations around this transition. This minor instability does not affect the peak flow.</p>										
2D Convergence		<div>Mass Balance Plot</div> <div>1% AEP Fluvial Event</div> <div></div>										
Comments		<p>The final cumulative mass balance error was 0.2% or 8804 m3. The 2D model remains within the recommended tolerance throughout the event. There are spikes of +/-1% in mass error at 2.5 hours and 4.75 hours as the Milltown and Dingle streams come out of bank respectively. However this reduces to 0.3% at the peak.</p> <p>The initial spikes in mass error are exaggerated because there are very few active 2D cells as the first cells wet however, as flooding increases the mass error reduces to -0.3% by the peak. Therefore, the mass balance of volume entering and leaving the model is accurate within recommended tolerances at the peak and flood depth, velocity and extent can be deemed to be reliable.</p>										
Hydrological Performance												
Target Flows	HEP ID	Location	Model Node	Design	Modelled	% Difference	Design	Modelled	% Difference	Design	Modelled	% Difference
	22_3437_5	Downstream of Dingle Stream	22DING00003H	7.42	6.5	-12%	11.24	9.0	-20%	16.9	12.0	-29%
	22_1712_2	Milltown Gauge (22022)	22MILL00165G	39.7	39.9	1%	62.01	62.3	0%	88.45	89.3	1%
	22_3998_1	Milltown Stream-Ballymoreeagh Trib D/S	22MILL00071H	47.58	40.5	-15%	74.32	62.9	-15%	106.01	89.6	-15%
	22_3999_2	Downstream of Milltown Stream	22MILL00002A	48.79	46.6	-4%	76.21	72.4	-5%	108.71	105.6	-3%
Comments		<p>The flows in the 1D ISIS channel were combined with the 2D flow parallel to the channel where there was out-of-bank flows and compared to the design hydrology.</p> <p>The modelled flow tended to underestimate flows by 1.0 m3/s to 3.0m3/s at the outfall due to the tidal influence and a small amount of attenuation upstream near 22DING00138W Sruthean Beag and overtopping through the town.</p> <p>The modelled flows matched well with flows at Milltown gauge but underestimated flows downstream of the Milltown-Ballymoreeagh confluence due to significant backwater from Milltown Bridge under tide locking and extreme flows. This design hydrology does not consider the influence of backwater from hydraulic structures there the modelled and design flows differ.</p> <p>All HEPS affected by backwater have been highlighted in yellow above.</p>										
Validation Checks												
Locations of known flooding	Flooding was observed around Church Street Bridge and Tullig on 24th January 2014. This event occurred after the model calibration exercise had been completed. Therefore, the photographs provided were used to verify and common sense check flow paths and frequency of flooding.											
Available Gauge Data	The Castleisland gauge was not active for this event. Gauge data was obtained from Riverville but the flow was less than the 50%AEP estimate. The extent of flooding in Castleisland has not been observed as frequently as the 50%AEP (1 in 2 year). Therefore, flows at Riverville are not representative of flood conditions in Castleisland for this event.											
Verification Plot	See Schedule 3 - Calibration and Sensitivity											
Comparison with Design Flood	The photographs verify the flow paths across Tullig Road and on the right bank at Church Street. The extent of flooding at Tullig and around Church Street would be consistent with the 2%AEP design flood extent.											
Sensitivity Test 1: Increased Flow												
Model Run ID	I40DE_FHD010_D1											
Hydraulic Modification to Design Model	No hydraulic modifications were made to the design model.											
Hydrological inflows	All inflows were increased by 30% for the 1%AEP fluvial current design event to account for the uncertainty in the derivation of QMED and the pooling group selected. This is broadly equivalent to the HEFS 1%AEP as the increase in urban extent has less the 1% impact on peak flow. Therefore, the HEFS 1%AEP results (FHD010) have been used as the sensitivity test results.											
Sensitivity Plot	See Schedule 3 - Calibration and Sensitivity											
Comments		<p>A 30% increase in flows resulted in a significant increase in flood levels. The flood extent also increased along Spa Road and the Mall affecting more properties. Therefore, Dingle is considered to be sensitive to estimation of flows.</p> <p>The design flows are deemed appropriate because they have been informed by the gauged flows at Milltown town gauge (22022) within the AFA. However, an allowance should be made when interpreting the design flood outlines and the in the sizing of any flood risk management option due to this uncertainty in flood level and extent caused by the uncertainties in flow.</p>										
Sensitivity Test 2: Increased Downstream Level												
Model Run ID	I40DE_CMD010_D1											
Hydraulic Modification to Design Model	A 0.55m increase in water level was applied to the downstream boundary. This is broadly equivalent to the MRFS which increases sea level by 0.55m. Therefore, the MRFS 1%AEP results (CMD010) have been used to conduct the sensitivity test.											
Hydrological inflows	No modifications were made to the design inflows.											
Sensitivity Plot	See Schedule 3 - Calibration and Sensitivity											



Comments	<p>A 0.55m increase in level resulted in a significant increase in flood extent along the quayside but backwater did not extend beyond the first formal weir on Dingle Stream and stepping stones on Milltown Stream.</p> <p>Therefore the lower reaches of these watercourses and flood risk along the quayside is considered to be sensitive to the uncertainties in estimating coastal levels. Reaches upstream of the the first weir on Dingle Stream and the stepping stones on Milltown are fluvial dominated and are not deemed to be sensitive to coastal levels.</p> <p>An allowance should be made when interpreting the design flood outlines and the in the sizing of any flood risk management option due to this uncertainty in flood level and extent caused by the uncertainties in estimate coastal levels in Dingle Bay.</p>
Sensitivity Test 3: Increased Manning's 'n'	
Model Run ID	I40DE_FCN010_D1
Hydraulic Modification to Design Model	<p>The Manning's 'n' values were increased to the upper limit of the industry recommended ranges.</p> <p>All active channels 0.040 to 0.050</p> <p>All river banks 0.060 to 0.080</p> <p>Pasture / parkland / garden 0.060 to 0.080</p> <p>Buildings 0.200 to 0.300</p> <p>Roads 0.033 to 0.040</p>
Hydrological inflows	No modifications were made to the design inflows.
Sensitivity Plot	See Schedule 3 - Calibration and Sensitivity
Comments	An increase in roughness values in bank and out-of-bank did not significantly increase water level or flood extent in Dingle. Therefore, the Dingle model is not deemed sensitive to assumption in Manning's 'n' values.



Flooding at Bridge Street

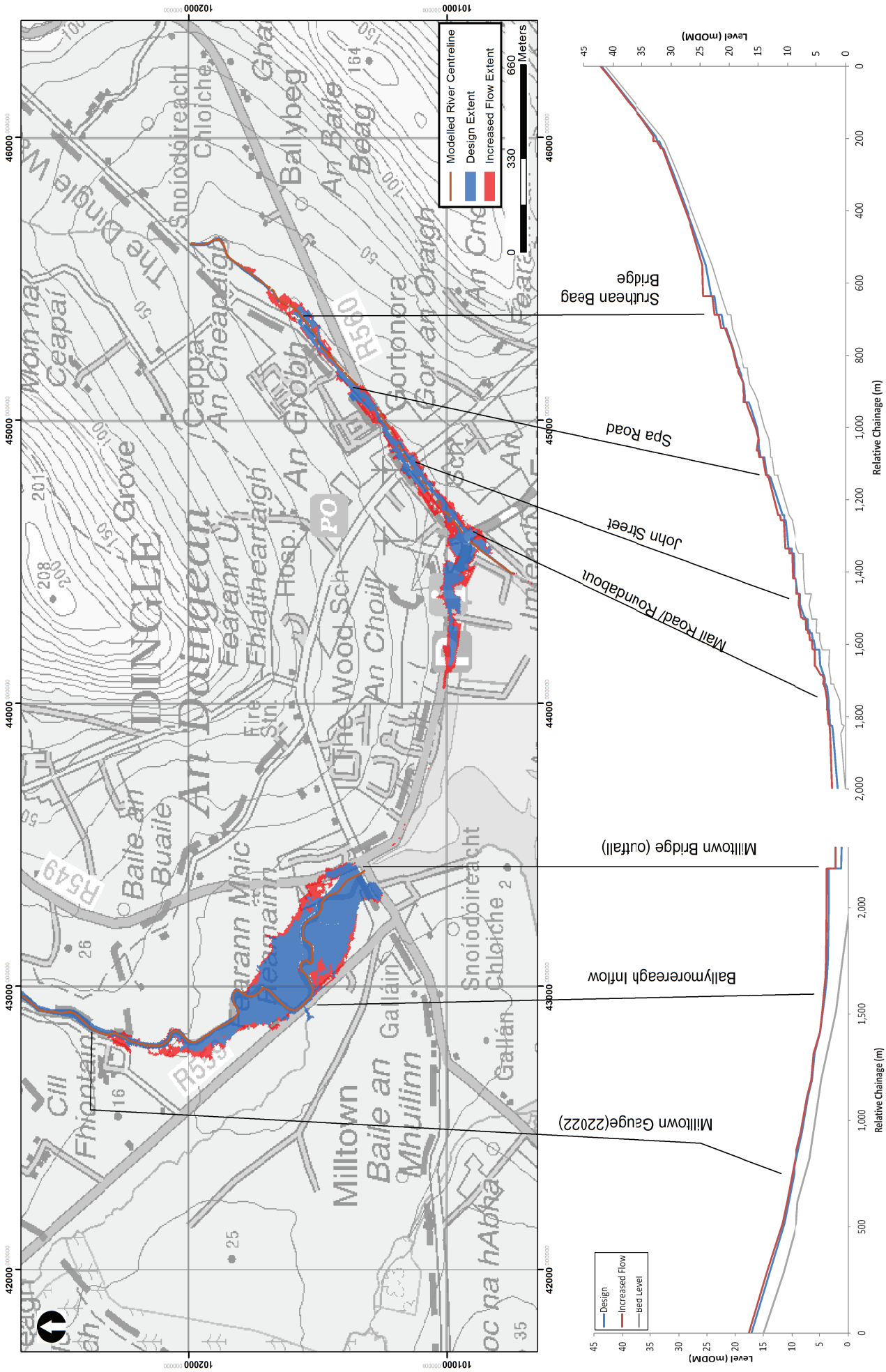


Flooding at Hudson's Bridge

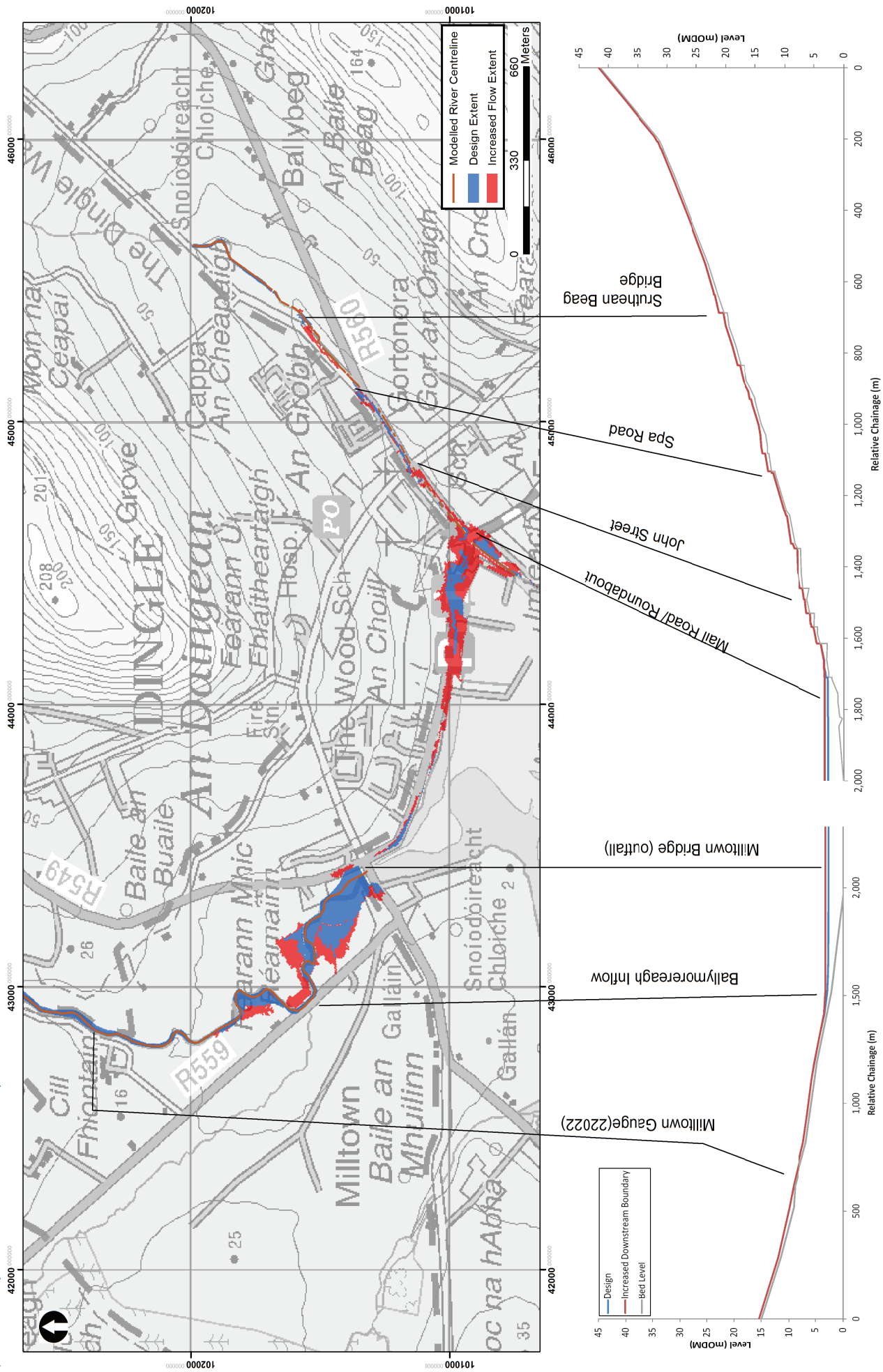
Recurring flooding along The Mall floodmaps.ie

Recurring flooding at The Wood floodmaps.ie

Map G.2: Sensitivity to 30% Increased Peak Flow

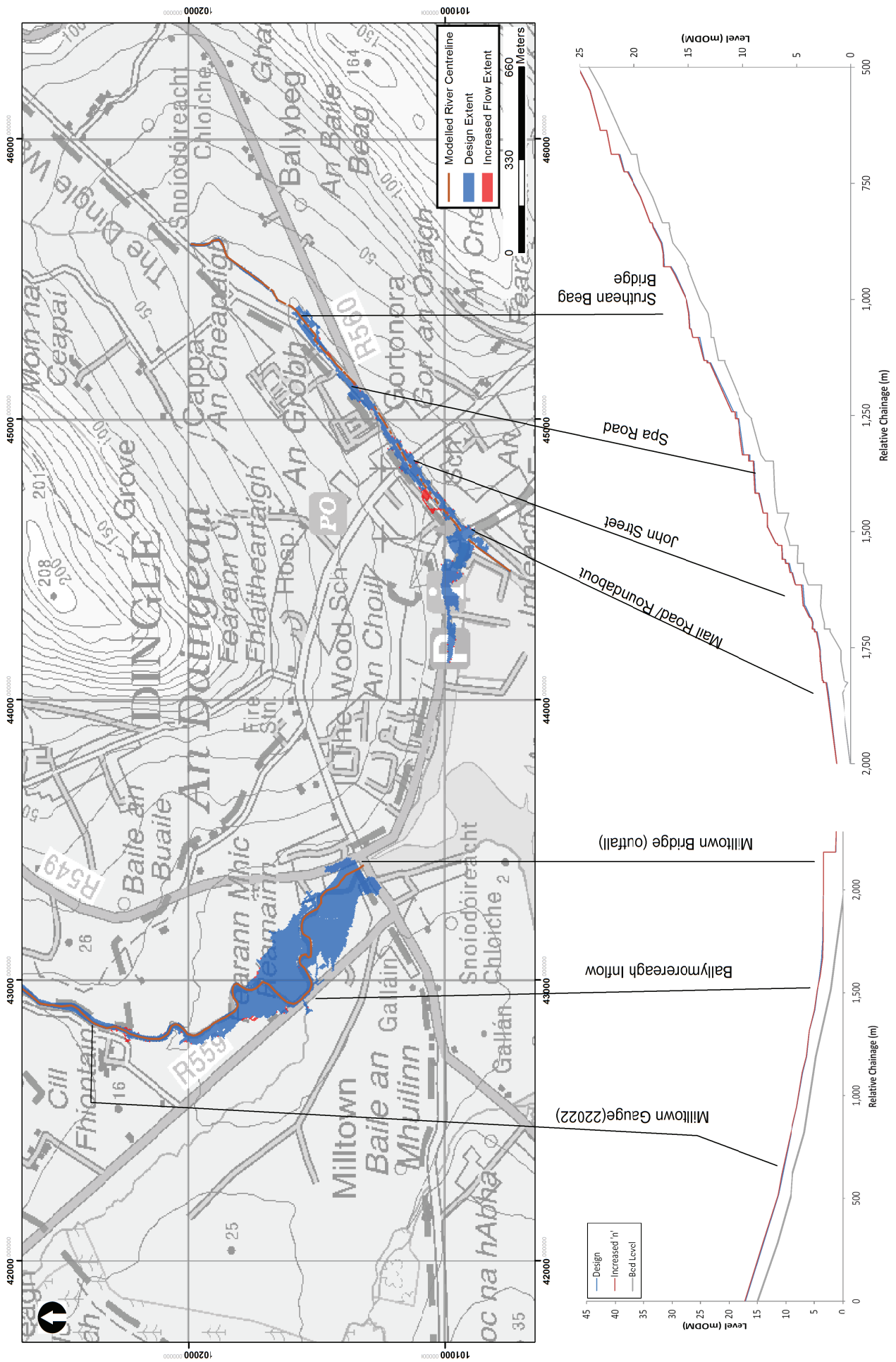








Map G.4: Sensitivity to Increased Manning's 'n'



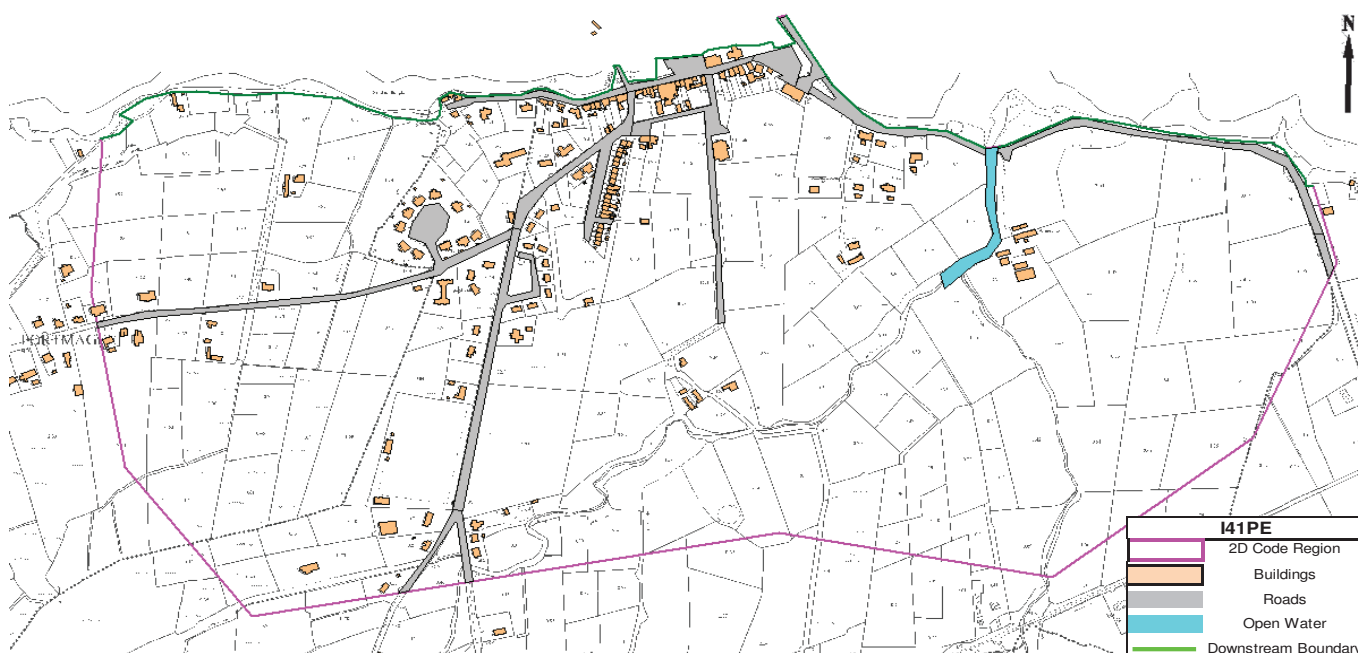
Dingle Model Outputs								
	10% AEP Fluvial Current Scenario exceeds the capacity of Dingle Stream to cause very shallow flooding (< 0.1m) along Spa Road and the Mall affecting < 5 properties at St John's and Bridge Street. The model does not consider the effect of urban drainage which may affect flood when depths are < 0.1m. 2% AEP Fluvial Current Scenario on Milltown Stream overtops Milltown Bridge on the right bank and the R459 on the left bank but does not affect properties. 1% - 0.5% AEP Fluvial Current Scenario floods the Library site on Milltown Stream Approximately 60 buildings are affected by 1% AEP Fluvial Current Scenario							
	The regular flooding in the car park area is caused by the backing up of the drainage network in under high tide conditions. The urban drainage network is not considered by the CFRAM Study. 20% AEP Coastal Current Scenario overtops the road at The Woods but does not affect properties. 10% AEP Coastal Current Scenario overtops the left bank of Dingle Stream downstream of the roundabout but does not affect properties. 2% AEP Coastal Current Scenario overtops around Milltown Bridge and the quayside at Strand Street but does not affect properties. 1% AEP Coastal Current Scenario affects properties on Strand Street from overtopping of the quay and flooding upstream of Bridge Street. Approximately 20 properties are affected by the 0.5% AEP Coastal Current Scenario.							
Threshold of Property Flooding	On Dingle Stream: Access Bridge and river bend downstream of Sutehan Beag estate, Brewery Access Bridges, Spa Road culvert, Lana na hAbhann, Hudsons Bridge and Bridge Street (culvert). On Milltown Stream: Milltown Bridge							
Areas affected by flooding	Fluvial dominated events: Spa Road, The Mall, Bridge Street and Milltown Bridge area. Coastal dominated events: The Woods, Strand Street, The Tracks and Bridge Street.							
Risk to people	There is significant risk to people along Bridge Street for the 10% AEP and larger magnitude events due to the depth of flooding. There is significant risk to peak along The Mall and Spa Road in the 1% AEP and larger magnitude event due to fast flowing water along the roads.							
Consideration for Flood Risk Management Options	The time to peak is less than 5 hours which limits the time available for flood warning. Increased conveyance measures should be considered for the critical structures identified above. There is limited storage available upstream of the AFA on Dingle Stream to enable any storage or attenuation measures. It would be beneficial to quantify interaction with the urban drainage network to better understand the regular flooding of the car park area.							
Flood Map Outputs								
The following table outlines the print-ready flood mapping deliverables provided in Schedule 4.								
Scenario	Flood Extent Map	Flood Zone Map	Flood Depth Map	Flood Velocity Map	Flood Hazard Map			
Fluvial Current Design 10% AEP	122HDE40_EXFCD010_D2		122H40DE_DPFCDD200_D2	122H40DE_VLFCD200_D2	122H40DE_HZFCDD200_D2			
Fluvial Current Design 1% AEP	122HDE40_EXFCD010_D2	122H40DE_ZNFCDD200_D2	122H40DE_DPFCDD010_D2	122H40DE_VLFCD010_D2	122H40DE_HZFCDD010_D2			
Fluvial Current Design 0.1% AEP	122HDE40_EXFCD010_D2	122H40DE_ZNFCDD200_D2	122H40DE_DPFCDD001_D2	122H40DE_VLFCD001_D2	122H40DE_HZFCDD001_D2			
Fluvial Mid Range Future Design 10% AEP	122HDE40_EXFMD010_D2							
Fluvial Mid Range Future Design 1% AEP	122HDE40_EXFMD010_D2							
Fluvial Mid Range Future Design 0.1% AEP	122HDE40_EXFMD010_D2							
Coastal Current Design 10% AEP	122HDE40_EXCCDD010_D2		122H40DE_DPCCDD200_D2	122H40DE_VLCCDD200_D2	122H40DE_HZCCDD005_D2			
Coastal Current Design 0.5% AEP	122HDE40_EXCCDD010_D2		122H40DE_DPCCDD005_D2	122H40DE_VLCCDD005_D2	122H40DE_HZCCDD200_D2			
Coastal Current Design 0.1% AEP	122HDE40_EXCCDD010_D2		122H40DE_DPCCDD001_D2	122H40DE_VLCCDD001_D2	122H40DE_HZCCDD001_D2			
Coastal Mid Range Future Design 10% AEP	122HDE40_EXCMD010_D2							
Coastal Mid Range Future Design 0.5% AEP	122HDE40_EXCMD010_D2							
Coastal Mid Range Future Design 0.1% AEP	122HDE40_EXCMD010_D2							
GIS Outputs								
Print Ready Maps are denoted by the highlighted cells and provided in Schedule 4								
Scenario	Model Run ID	Fluvial %AEP	Coastal %AEP	Flood Extent Polygon and Nodes	Flood Zone Polygon	Flood Depth Grid	Flood Velocity Grid	Flood Hazard Grid
Fluvial Current Design 50% AEP	140DE_FCD500_D2_Dingle	50	MHWS	140EXFCD050D2		140DPFCD050D2	140VLFCD050D2	140HZFCD050D2
Fluvial Current Design 20% AEP	140DE_FCD100_D2_Dingle	20	MHWS	140EXFCD100D2		140DPFCD100D2	140VLFCD100D2	140HZFCD100D2
Fluvial Current Design 10% AEP	140DE_FCD100_D2_Dingle	10	MHWS	140EXFCD100D2		140DPFCD100D2	140VLFCD100D2	140HZFCD100D2
Fluvial Current Design 5% AEP	140DE_FCD050_D2_Dingle	5	MHWS	140EXFCD050D2		140DPFCD050D2	140VLFCD050D2	140HZFCD050D2
Fluvial Current Design 2% AEP	140DE_FCD020_D2_Dingle	2	MHWS	140EXFCD020D2		140DPFCD020D2	140VLFCD020D2	140HZFCD020D2
Fluvial Current Design 1% AEP	140DE_FCD010_D2_Dingle	1	MHWS	140EXFCD010D2	140ZN_A_D2	140DPFCD010D2	140VLFCD010D2	140HZFCD010D2
Fluvial Current Design 0.5% AEP	140DE_FCD005_D2_Dingle	0.5	MHWS	140EXFCD005D2		140DPFCD005D2	140VLFCD005D2	140HZFCD005D2
Fluvial Current Design 0.1% AEP	140DE_FCD001_D2_Dingle	0.1	MHWS	140EXFCD001D2	140ZN_B_D2	140DPFCD001D2	140VLFCD001D2	140HZFCD001D2
Fluvial Mid Range Future Design 50% AEP	140DE_FMD500_D2_Dingle	50	MHWS	140EXFMD500D2		140DPFMD500D2	140VLFMD500D2	140HZFMD500D2
Fluvial Mid Range Future Design 20% AEP	140DE_FMD100_D2_Dingle	20	MHWS	140EXFMD100D2		140DPFMD100D2	140VLFMD100D2	140HZFMD100D2
Fluvial Mid Range Future Design 10% AEP	140DE_FMD100_D2_Dingle	10	MHWS	140EXFMD100D2		140DPFMD100D2	140VLFMD100D2	140HZFMD100D2
Fluvial Mid Range Future Design 5% AEP	140DE_FMD050_D2_Dingle	5	MHWS	140EXFMD050D2		140DPFMD050D2	140VLFMD050D2	140HZFMD050D2
Fluvial Mid Range Future Design 2% AEP	140DE_FMD020_D2_Dingle	2	MHWS	140EXFMD020D2		140DPFMD020D2	140VLFMD020D2	140HZFMD020D2
Fluvial Mid Range Future Design 1% AEP	140DE_FMD010_D2_Dingle	1	MHWS	140EXFMD010D2		140DPFMD010D2	140VLFMD010D2	140HZFMD010D2
Fluvial Mid Range Future Design 0.5% AEP	140DE_FMD005_D2_Dingle	0.5	MHWS	140EXFMD005D2		140DPFMD005D2	140VLFMD005D2	140HZFMD005D2
Fluvial Mid Range Future Design 0.1% AEP	140DE_FMD001_D2_Dingle	0.1	MHWS	140EXFMD001D2		140DPFMD001D2	140VLFMD001D2	140HZFMD001D2
Fluvial High End Future Design 10% AEP	140DE_FHD100_D2_Dingle	10	MHWS	140EXFHD100D2		140DPFHD100D2	140VLFHD100D2	140HZFHD100D2
Fluvial High End Future Design 1% AEP	140DE_FHD010_D2_Dingle	1	MHWS	140EXFHD010D2		140DPFHD010D2	140VLFHD010D2	140HZFHD010D2
Fluvial High End Future Design 0.1% AEP	140DE_FHD001_D2_Dingle	0.1	MHWS	140EXFHD001D2		140DPFHD001D2	140VLFHD001D2	140HZFHD001D2
Coastal Current Design 50% AEP	140DE_CCD500_D2_Dingle	50		140EXCCD500D2		140DPCCD500D2	140VLCDD500D2	140HZCCD500D2
Coastal Current Design 20% AEP	140DE_CCD100_D2_Dingle	50	20	140EXCCD100D2		140DPCCD100D2	140VLCDD100D2	140HZCCD100D2
Coastal Current Design 10% AEP	140DE_CCD100_D2_Dingle	50	10	140EXCCD100D2		140DPCCD100D2	140VLCDD100D2	140HZCCD100D2
Coastal Current Design 5% AEP	140DE_CCD050_D2_Dingle	50	5	140EXCCD050D2		140DPCCD050D2	140VLCDD050D2	140HZCCD050D2
Coastal Current Design 2% AEP	140DE_CCD020_D2_Dingle	50	2	140EXCCD020D2		140DPCCD020D2	140VLCDD020D2	140HZCCD020D2
Coastal Current Design 1% AEP	140DE_CCD010_D2_Dingle	50	1	140EXCCD010D2		140DPCCD010D2	140VLCDD010D2	140HZCCD010D2
Coastal Current Design 0.5% AEP	140DE_CCD005_D2_Dingle	50	0.5	140EXCCD005D2	140ZN_A_D2	140DPCCD005D2	140VLCDD005D2	140HZCCD005D2
Coastal Current Design 0.1% AEP	140DE_CCD001_D2_Dingle	50	0.1	140EXCCD001D2	140ZN_B_D2	140DPCCD001D2	140VLCDD001D2	140HZCCD001D2
Coastal Mid Range Future Design 50% AEP	140DE_CMD500_D2_Dingle	50		140EXCMD500D2		140DPCMD500D2	140VLCMD500D2	140HZCMD500D2
Coastal Mid Range Future Design 20% AEP	140DE_CMD100_D2_Dingle	50	20	140EXCMD100D2		140DPCMD100D2	140VLCMD100D2	140HZCMD100D2
Coastal Mid Range Future Design 10% AEP	140DE_CMD100_D2_Dingle	50	10	140EXCMD100D2		140DPCMD100D2	140VLCMD100D2	140HZCMD100D2
Coastal Mid Range Future Design 5% AEP	140DE_CMD050_D2_Dingle	50	5	140EXCMD050D2		140DPCMD050D2	140VLCMD050D2	140HZCMD050D2
Coastal Mid Range Future Design 2% AEP	140DE_CMD020_D2_Dingle	50	2	140EXCMD020D2		140DPCMD020D2	140VLCMD020D2	140HZCMD020D2
Coastal Mid Range Future Design 1% AEP	140DE_CMD010_D2_Dingle	50	1	140EXCMD010D2		140DPCMD010D2	140VLCMD010D2	140HZCMD010D2
Coastal Mid Range Future Design 0.5% AEP	140DE_CMD005_D2_Dingle	50	0.5	140EXCMD005D2		140DPCMD005D2	140VLCMD005D2	140HZCMD005D2
Coastal Mid Range Future Design 0.1% AEP	140DE_CMD001_D2_Dingle	50	0.1	140EXCMD001D2		140DPCMD001D2	140VLCMD001D2	140HZCMD001D2
Coastal High End Future Design 10% AEP	140DE_CHD100_D2_Dingle	50	10	140EXCHD100D2		140DPCHD100D2	140VLCMD100D2	140HZCMD100D2
Coastal High End Future Design 1% AEP	140DE_CHD010_D2_Dingle	50	0.5	140EXCHD010D2		140DPCHD010D2	140VLCMD010D2	140HZCMD010D2
Coastal High End Future Design 0.1% AEP	140DE_CHD001_D2_Dingle	50	0.1	140EXCHD001D2		140DPCHD001D2	140VLCMD001D2	140HZCMD001D2

## Appendix H. Portmagee AFA Model Proformas

UOM	22		
AFA/ MPW Reach	Portmagee		
Model ID	I41PE		
Purpose of Model Build	Flood Mapping		
Main Watercourse	N/A	FLUVIAL RISK	No
Length Modelled (km)	0	COASTAL RISK	Yes
Area Modelled (km <sup>2</sup> )	1.04	VULNERABLE TO WAVES	Yes

Input Data	
River Channel Topographic Data	Not applicable as an assessment of fluvial flood risk is not required
Floodplain Topographic Data	Filtered LIDAR DTM "Portmagee_DTM.asc" 2m grid resolution with +/- 0.1m RMSE captured in April 2012, covering the mainland portion of the AFA. This was used as the basis for the 2D model of the floodplain.
Map data	1:5000 Osi mapping tiles 6350 and 6351. The OSI mapping was found to include all current developments and was consistent with site observations, the river channel survey and aerial photography.

Model Build					
General Schematisation	<p>A 2D TUFLOW approach was taken for Portmagee to accurately simulate multidirectional flow across the narrow urban area.</p> <p>The 2D domain covered the AFA extent to consider coastal flood risk to the town and low lying land to the east where there is a fluvial inflow.</p> <p>The 2D model was set to 5m to represent the urban area without compromising run time and remain consistent with other CFRAMS models. The 5m cell size was deemed of sufficient resolution to accurately represent the roads, buildings and coastal floodplain in Portmagee.</p> <p>The sea wall and quayside banks were based on LIDAR elevations in the absence of detailed spot levels. Buildings were raised above the floodplain by 0.15m to represent the threshold and then a high Manning's 'n' value of 0.2 applied to represent the storage of the building. This approach means accurate flood depths can be extracted for flood damage analysis.</p> <p>The fluvial channel to the east of the village has been enforced based on LIDAR elevations using the 2d_Zsh layer.</p> <p>The other urban materials such as roads have been represented by varying the Manning's 'n' applied, detailed below.</p>				
Software Versions Used	TUFLOW version 2012-05-AC-ISP-w32				
Total No of 1D nodes	N/A				
Open channel (H)					
Bridges (D)					
Culverts (I)					
Weirs (W)					
Model Extent	Reach/Feature	Upstream Limit (ING)		Downstream Limit (ING)	
	Coastline	36409, 72897		38044, 72836	
Roughness	Reach/Feature	Active Channel	River Banks	Floodplain	Source
	Open pasture	N/A	N/A	0.06	Osi Mapping
	Standing Water	N/A	N/A	0.04	Osi Mapping
	Buildings	N/A	N/A	0.2	Osi Mapping
	Roads	N/A	N/A	0.03	Osi Mapping
	Structures	No hydraulic structures considered in this coastal model.			
Upstream boundary	N/A Coastal boundary only				
Lateral inflows	N/A Coastal boundary only				
Downstream boundary	The tide plus total surge levels were applied as level-time(HT) boundary to the 2D code region along the mainland coastline of Portmagee. The wave overtopping discharges were applied as a discharge-time (QT) on the landward side of the quayside for the relevant scenarios.				
Run Settings	Unsteady simulation of the full 48 hour tide plus surge hydrograph (> 2 days and 5 tidal cycles) to fully consider the surge event.				
	The 2D timestep was set to 2.5s which is half the grid cell size as recommended by TUFLOW.				
	All other parameters set to default.				





SCHEDULE 1 : PHOTOGRAPHS

Photo 1: Portmagee Quayside

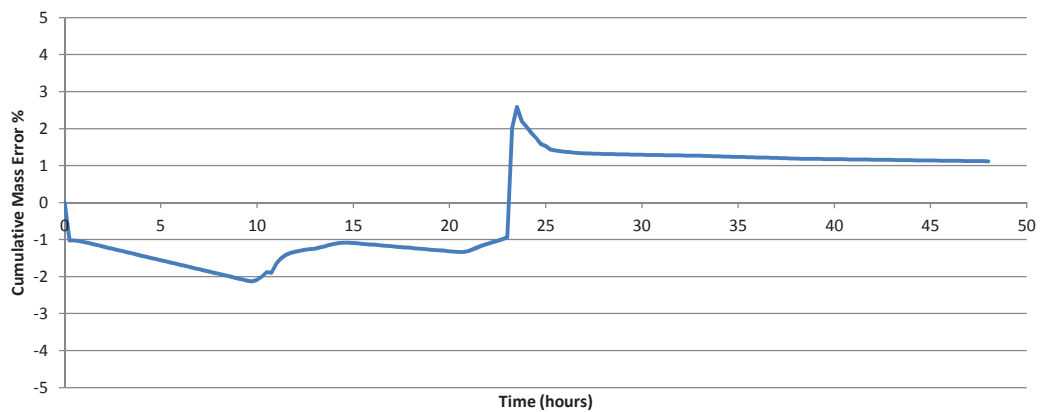


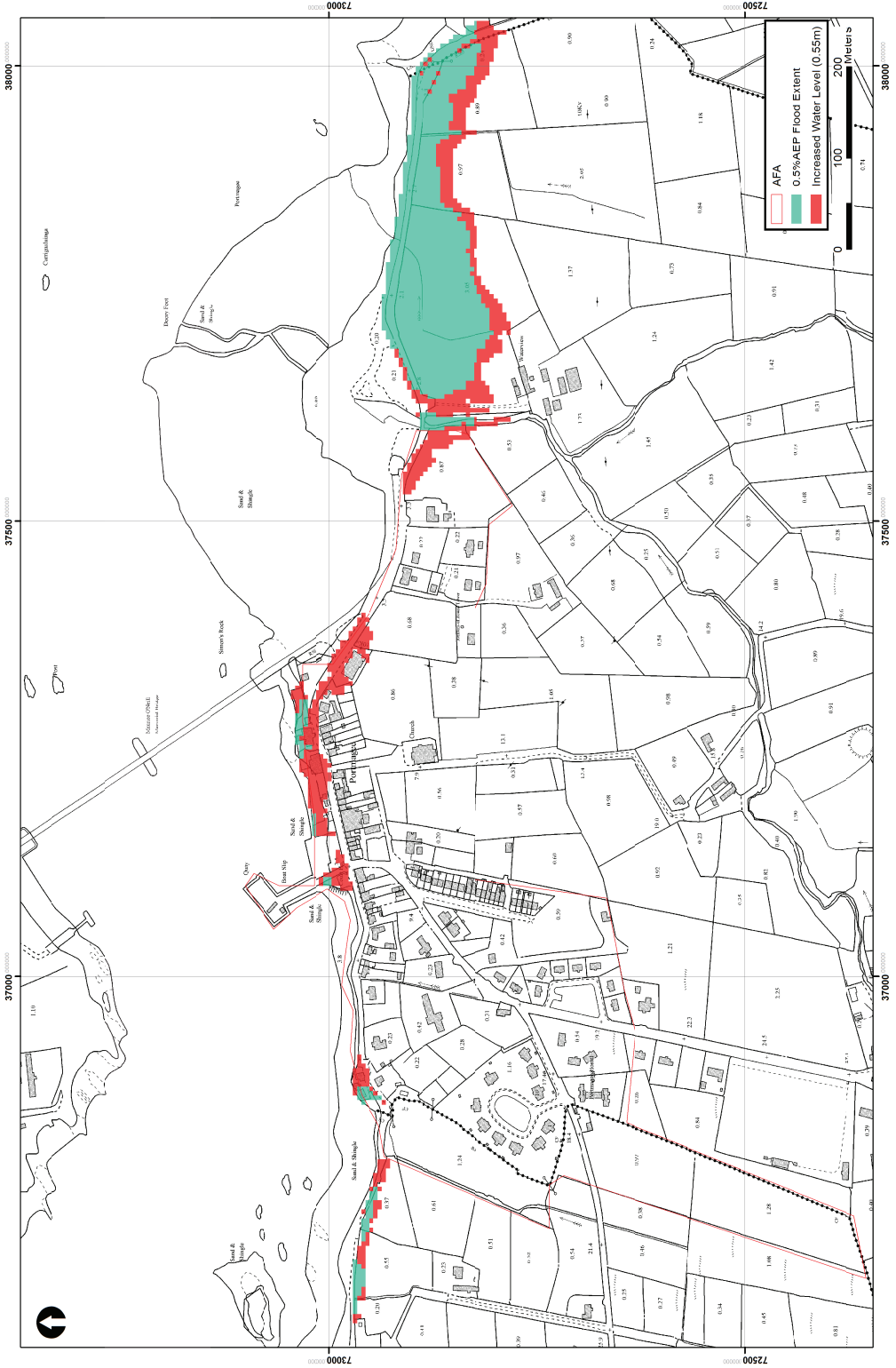
Photo 2: R565 Regional Road (frequently flooded to east of AFA)



**SCHEDULE 2 : STRUCTURES**

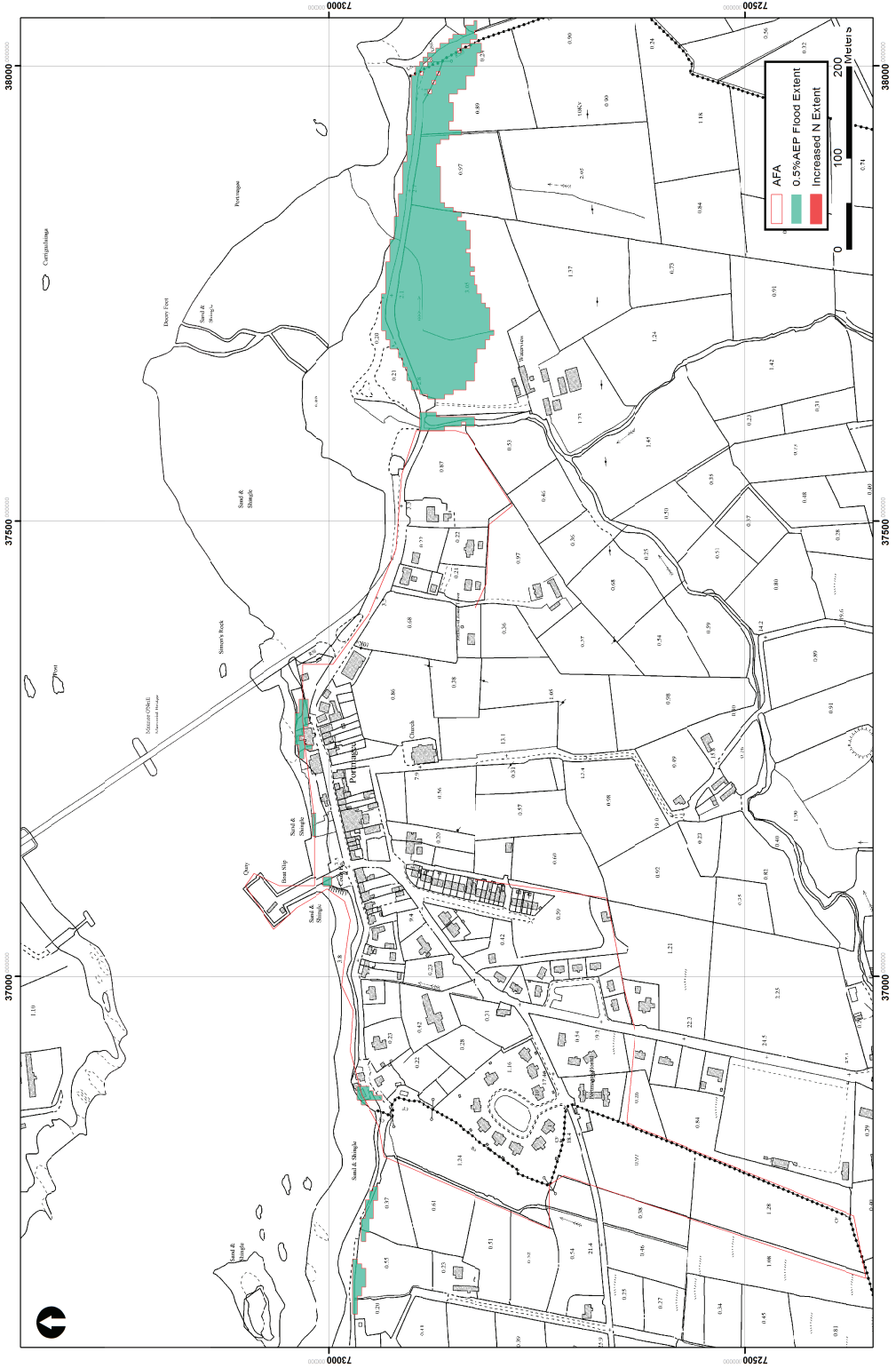
No hydraulic structures identified or modelled in Portmagee AFA.

Model Performance							
1D Convergence							
Convergence Plot		N/A					
Comments		Portmagee is a 2D only coastal model so there are no 1D model components to assess.					
2D Convergence							
Mass Balance Plot 0.5% AEP Coastal Event							
Comments		The mass error is outside the 1% recommended tolerance due to the small number of wet cells and oscillation in water level with the incoming and outgoing tide. However, the mass error does not affect flood risk as the mass error does not affect the flood level and the volume overtopping is not critical where the ground rises inland such as in Portmagee.					
Hydrological Performance							
Target Flows		HEP ID	Location	Model Node	Design Flow (m3/s)	Modelled Flow (m3/s)	Difference
		N/A Coastal Only					
Comments							
Calibration Event 1: N/A Insufficient Calibration Data to Perform Hydraulic Calibration. No records of historic flooding to validate extents.							
Sensitivity Test 1: Increased Downstream Level							
Model Run ID		I31CN_CMD010_D1					
Hydraulic Modification to Design Model		No hydraulic modifications were made to the design model.					
Hydrological inflows		A 0.55m increase in water level was applied which is broadly equivalent to the MRFS which increases sea level by 0.55m. Therefore, the MRFS 1% AEP results (CMD010) have been used to conduct the sensitivity test.					
Sensitivity Plot		See Schedule 3 - Calibration and Sensitivity					
Comments		A 0.55m rise in water level increase the flood extent within the AFA. However, the increased flood extent does not increase flooding to properties. Therefore Portmagee is considered insensitive to the uncertainties in deriving the total tide plus surge level.					
Sensitivity Test 2: Increased Manning's 'n'							
Model Run ID		I31CN_CCN005_D1					
Hydraulic Modification to Design Model		The Manning's 'n' values were increased to the upper limit of the industry recommended ranges. Pasture/ parkland /garden 0.060 to 0.070 Dense vegetations 0.080 to 0.100 Buildings 0.200 to 0.300 Roads 0.030 to 0.035					
Hydrological inflows		No modifications were made to the design inflows.					
Sensitivity Plot		See Schedule 3 - Calibration and Sensitivity					
Comments		The increase in the Manning's 'n' values used in the model resulted in negligible changes to water level within the AFA ( < 0.01m RMSE) and no identifiable increase in extent for the 0.5% AEP event. Therefore, the Portmagee model was not deemed sensitive to the Manning's 'n' values applied to the model.					





Map A.4: Sensitivity to Increased Manning's 'n'



Portmagee Model Outputs						
	The key thresholds and areas affected by tidal flooding in Portmagee are: -10%AEP overlaps the R565 to the east of the AFA which matches with a single flood report of road flooding 8-10 years ago. -10%AEP overlaps The Old School slipway but no property flooding under current conditions. -0.5%AEP overlaps the quayside but no property flooding under current conditions.					
Threshold of Property Flooding						
Critical Structures for Flood Risk	There were no critical hydraulic structures identified for Portmagee.					
Areas affected by flooding	The R565 outside the AFA and quayside area inside the AFA.					
Risk to people	Flood hazard was classified as low in all coastal current scenarios within the AFA.					
Consideration for Flood Risk Management Options	Flood risk is considered low. However, the elevation of the quayside and property thresholds on the quayside could be reviewed if flood risk mitigation was deemed beneficial.					
Flood Map Outputs						
The following table outlines the print-ready flood mapping deliverables provided in the accompanying digital data.						
Scenario	Flood Extent Map	Flood Zone Map	Flood Depth Map	Flood Velocity Map	Flood Hazard Map	
Coastal Current Design 10%AEP	I22HMN35_EXCCDEXF_D2		I22HMN35_DPCCD100_D2	I22HMN35_VLCCD100_D2	I22HMN35_HZCCD100_D2	
Coastal Current Design 1%AEP	I22HMN35_EXCCDEXF_D2	I22HMN35_ZN_D2	I22HMN35_DPCCD010_D2	I22HMN35_VLCCD010_D2	I22HMN35_HZCCD010_D2	
Coastal Current Design 0.1%AEP	I22HMN35_EXCCDEXF_D2	I22HMN35_ZN_D2	I22HMN35_DPCCD001_D2	I22HMN35_VLCCD001_D2	I22HMN35_HZCCD001_D2	
Coastal Mid Range Future Design 10%AEP	I22HMN35_EXCMDXF_D2					
Coastal Mid Range Future Design 0.5%AEP	I22HMN35_EXCMDXF_D2					
Coastal Mid Range Future Design 0.1%AEP	I22HMN35_EXCMDXF_D2					

GIS Outputs							
The following table outlines the GIS deliverables and model run files provided in the accompanying digital handover.							
Scenario	Model Run File	Coastal %AEP	Flood Extent Polygon and Nodes	Flood Zone Polygon	Flood Depth Grid	Flood Velocity Grid	Flood Hazard Grid
Coastal Current Design 50%AEP	I41PE_CCD500_D2.tcf	50	I41EXCCD500D2		I41DPCCD500D2	I41VLCCD500D2	I41HZCCD500D2
Coastal Current Design 20%AEP	I41PE_CCD200_D2.tcf	20	I41EXCCD100D2		I41DPCCD100D2	I41VLCCD100D2	I41HZCCD100D2
Coastal Current Design 10%AEP	I41PE_CCD100_D2.tcf	10	I41EXCCD100D2		I41DPCCD100D2	I41VLCCD100D2	I41HZCCD100D2
Coastal Current Design 5%AEP	I41PE_CCD050_D2.tcf	5	I41EXCCD050D2		I41DPCCD050D2	I41VLCCD050D2	I41HZCCD050D2
Coastal Current Design 2%AEP	I41PE_CCD020_D2.tcf	2	I41EXCCD020D2		I41DPCCD020D2	I41VLCCD020D2	I41HZCCD020D2
Coastal Current Design 1%AEP	I41PE_CCD010_D2.tcf	1	I41EXCCD010D2	I41ZN_A_D2	I41DPCCD010D2	I41VLCCD010D2	I41HZCCD010D2
Coastal Current Design 0.5%AEP	I41PE_CCD005_D2.tcf	0.5	I41EXCCD005D2		I41DPCCD005D2	I41VLCCD005D2	I41HZCCD005D2
Coastal Current Design 0.1%AEP	I41PE_CCD001_D2.tcf	0.1	I41EXCCD001D2	I41ZN_B_D2	I41DPCCD001D2	I41VLCCD001D2	I41HZCCD001D2
Coastal Mid Range Future Design 50%AEP	I41PE_CMD500_D2.tcf	50	I41EXCMD500D2		I41DPCMD500D2		
Coastal Mid Range Future Design 20%AEP	I41PE_CMD200_D2.tcf	20	I41EXCMD100D2		I41DPCMD100D2		
Coastal Mid Range Future Design 10%AEP	I41PE_CMD100_D2.tcf	10	I41EXCMD100D2		I41DPCMD100D2		
Coastal Mid Range Future Design 5%AEP	I41PE_CMD050_D2.tcf	5	I41EXCMD050D2		I41DPCMD050D2		
Coastal Mid Range Future Design 2%AEP	I41PE_CMD020_D2.tcf	2	I41EXCMD020D2		I41DPCMD020D2		
Coastal Mid Range Future Design 1%AEP	I41PE_CMD010_D2.tcf	1	I41EXCMD010D2		I41DPCMD010D2		
Coastal Mid Range Future Design 0.5%AEP	I41PE_CMD005_D2.tcf	0.5	I41EXCMD005D2		I41DPCMD005D2		
Coastal Mid Range Future Design 0.1%AEP	I41PE_CMD001_D2.tcf	0.1	I41EXCMD001D2		I41DPCMD001D2		
Coastal High End Future Design 10%AEP	I41PE_CHD100_D2.tcf	10	I41EXCHD100D2		I41DPCHD100D2		