McCloy Consulting

working with

Hydraulics Report

Ballyhale, Co. Kilkenny

M02151-01_DG02 | February 2023

WATER & ENVIRONMENTAL CONSULTANTS

[PAGE INTENTIONALLY BLANK]

DOCUMENT CONTROL

DOCUMENT FILENAME	M02151-01_DG02 Ballyhale FRS - Hydraulics Report REV05
DOCUMENT REFERENCE	M02151-01_DG02
TITLE	Hydraulics Report
PROJECT CLIENT	Kilkenny County Council
LEAD CONSULTANT	DBFL Consulting Engineers
MCCLOY PROJECT MANAGER	Kyle Somerville
AUTHOR(S)	Michael Rea
BRANCH	BELFAST Mossley Mill, Lower Ground (West), Carnmoney Road North, Newtownabbey BT36 5QA T: +44 (0) 28 9084 8694 | W: www.mccloyconsulting.com

REVISION HISTORY

Rev. Ref.	Date	Prep	Chk	App	Amendments	Reason for Issue
1	25/11/2020	MR	SN		Original	Working Draft
2	17/02/2021	MR	KS	KS	Amended to reflect updates arising from Hydrology report	Draft Report for Review
3	24/03/2021	MR	KS	KS	Updated to address OPW comments circulated 3/03/20	For Information
4	27/01/2023	MR	KS	KS	Updated to include assessment of proposed scheme.	For Information
5	20/02/2023	MR	KS	KS	Minor text amendments, updated to include blockage assessment of proposed scheme.	For Information

DISTRIBUTION

Recipient	Revision					
	1	2	3	4	5	6
FILE	✓	✓	✓	✓	✓	
DBFL Consulting Engineers	✓	✓	✓	✓	✓	

DISCLAIMER

SUSTAINABILITY

As an environmental consultancy, McCloy Consulting takes its responsibility seriously to try to operate in a sustainable way. As part of this, we try to maintain a paperless office and will only provide printed copies of reports and drawings where specifically requested to do so. We encourage end users of this document to think twice before printing a hard copy - please consider whether a digital copy would suffice. If printing is unavoidable, please consider double sided printing. This report (excluding appendices) contains 78 pages of text – that's equivalent to a carbon footprint of approximately 327.6g CO_2 when printed single sided.

NON-TECHNICAL SUMMARY

The flood relief scheme is centred on Ballyhale village and the Ballyhale and Little Arrigle Rivers previously modelled as part of the South Eastern CFRAM study, undertaken 2012-2016. This report summarises decision making and outputs made as part of the baseline hydraulic build phase for the scheme.

A location specific 1D-2D model was developed using Infoworks ICM using recently commissioned ground based bathymetric and topographic survey data, combined with best available OSi 2m LiDAR to establish baseline flood risk. Upon agreement of the baseline model it will be employed in the assessment of options proposed as part of the flood relief scheme.

Model results indicate flooding within Ballyhale village to the rear of the Main Street houses, Chapel Lane, Sheff's Lane and along Main Street to Station Road. The primary flood mechanism for flooding is attributed to structure / channel incapacity along the Ballyhale River particularly on the western church reach to the Arrigle Business Park. Two substantial overland flow routes upstream of the village emerge affecting lands on Chapel Lane and on Main Street.

The model was validated against available anecdotal accounts of flooding and flood mechanisms established as part of the hydrology report. An internal model audit was completed and reported that the model is stable and suitable for use for the study with variance in parameters assessed within acceptable model tolerance levels.

Sensitivity analysis conducted on the model demonstrated that the model can be deemed reliable and effects on absolute predicted water levels do not exceed normally anticipated inherent uncertainty in flood model estimations in the majority of instances. Due to the extensively culverted nature of the Ballyhale River, the reach is sensitive to changes in flow whereby variation in flow causes or exacerbates culvert incapacity. Uncertainty within the model would be accommodated by ensuring appropriate freeboard allowances for flood protection standards when designing flood relief options.

Blockage analysis was carried out on five key structures identified as having a history of previous blockage and of higher likelihood of blockage. Flood hazard was determined by implementing a blockage for each structure in isolation within the flood model corresponding to 25% / 50% / 75% of the opening sizes coinciding with a 1% AEP flood. The effect of blockage causes flooding which correlates closely with anecdotal records of flooding.

Options were developed and modelled to demonstrate the removal of flood risk to all receptors in Ballyhale for the standard of protection / 1% AEP present day event. Options incorporated berms / flood walls, a diversion channel to reduce flows tending to the rear of the Main Street buildings, channel regarding and the removal of redundant watercourse structures.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

1 INTRODUCTION

1.1 Terms of Reference

This Hydraulics Report was commissioned by Kilkenny County Council and OPW as the funding authority to summarise outputs and decision making made as part of the hydraulic modelling phase for Ballyhale Flood Relief Scheme.

1.2 Statement of Authority

This report and assessment has been prepared and reviewed by qualified professionals with appropriate experience in the fields of flood risk, drainage, wastewater, and hydraulic modelling studies. The key staff members involved in this project are as follows:

- Michael Rea *MEng (Hons)* – Senior Project Engineer with experience in the fields of flood risk assessment, flood modelling, drainage and surface water management design.
- Stephen Neill *BEng (Hons) MIEI* – Senior Engineer and modeller specialising in engineering hydrology, flood modelling and flood risk assessment.
- Kyle Somerville *BEng (Hons) CEng* – Director and Chartered Engineer specialising in the fields of flood risk assessment, flood modelling, drainage and surface water management design for public and private sectors.

1.3 Approach to the Assessment

The objective of this report is to provide detail on work undertaken to produce a hydraulic model to inform and assess the Ballyhale Flood Relief Scheme (FRS).

The hydrological approach is outlined in the corresponding hydrology report for the scheme (document reference M02151-01_DG01) hereafter termed "the Hydrology Report".

A location specific detailed 1D-2D model has been developed using Infoworks ICM software (version 10.5) to establish baseline flood risk and to assess options proposed as part of the flood relief scheme. The model was prepared using detailed ground based topographical and bathymetric survey information collected July 2020 and additional information collected December 2020.

The river channel and structures have been represented in 1D, while the floodplain and overland flow routes have been represented in 2D.

The modelling approach for the existing scenario is summarised as follows:

- Watercourses have been modelled using detailed cross section survey data recently commissioned for the purpose of this study.
- Structures have been built into the model based on detailed survey information obtained as part of this study.
- Out of bank flooding has been modelled using a 2D meshed ground model. The ground model was based upon ground based topographical survey within Ballyhale village supplemented by OSi 2m LiDAR.
- Buildings were represented within the model based on threshold survey carried out for key buildings. Non-surveyed buildings were represented using industry standard methodologies.

2 MODEL BUILD

2.1 Model Extent

The model extent which incorporates Ballyhale village and a portion of the Ballyhale and Little Arrigle Rivers is shown in Figure 2-1 overleaf. The model extent was carefully sited to:

- Ensure coverage within Ballyhale village and all key receptors.
- Ensure the boundaries of the model are situated in places to provide sufficient fall from the main area of interest to ensure water levels cannot be artificially influenced by downstream boundary conditions.
- Ensure the downstream effect of any optioneering scenarios can be fully assessed.
- Incorporate the upper Little Arrigle River due to its potential to be utilised as part of the flood relief scheme.
- Provide sufficient distance from the Knocktopher tributary for stability and to assess the impact of any scheme on water levels downstream.
- Incorporate the Ballyhale Tributary which was previously unmodelled and its discharges to the Ballyhale River upstream of the village. Investigations as part of the Hydrology Report indicated the watercourse was the source of the perceived pluvial flooding within the village that was reported to originate from 'Sheff's Lane' per historical accounts. The catchment was applied to the tributary reach and detailed survey information of the overland flow route between the tributary and the main street of the village was captured. As outlined within the Hydrology Report, it is considered that the remaining surface water subcatchments are of insufficient scale to cause significant pluvial risk.

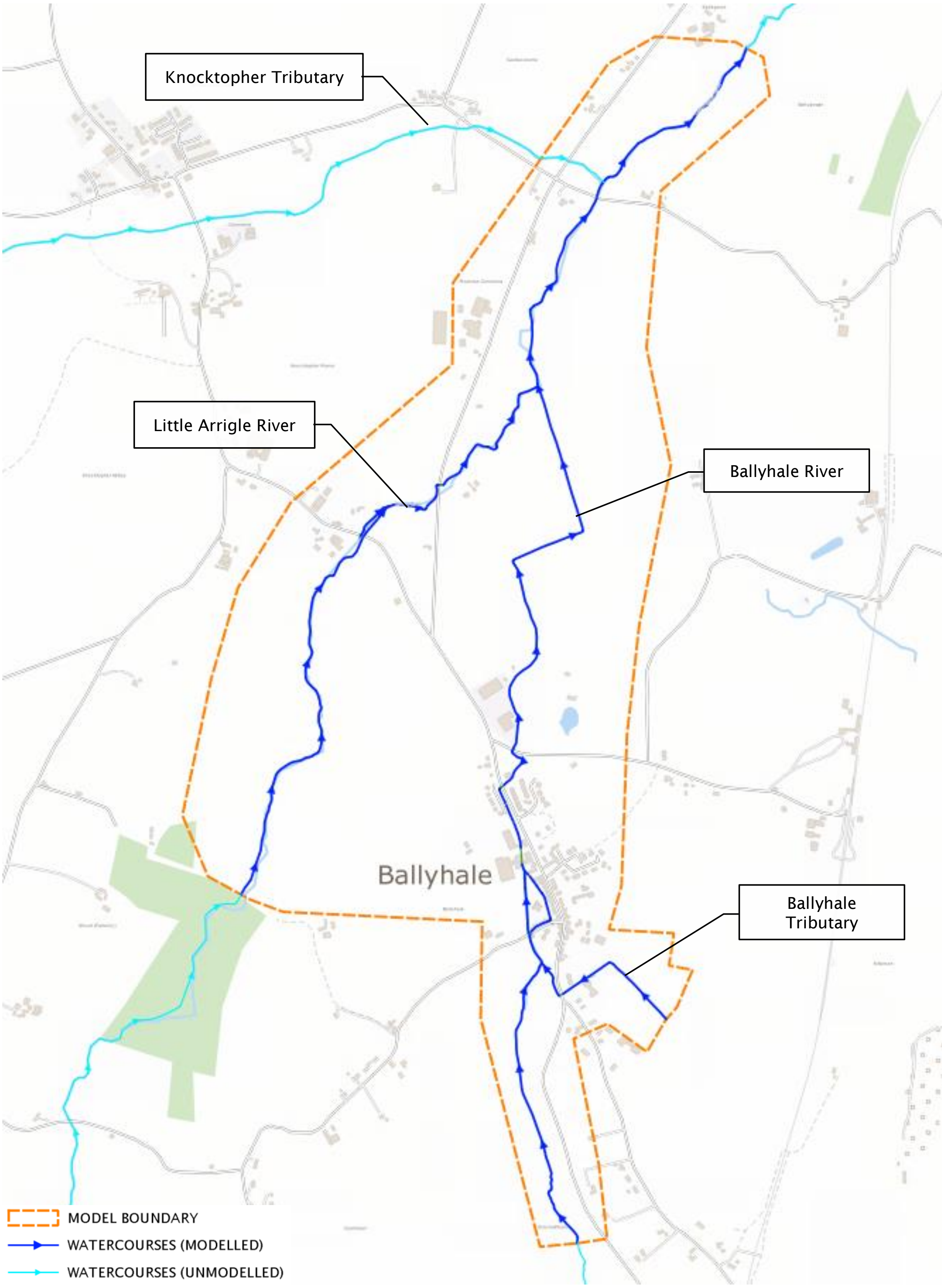

Figure 2-1 Model Extent

2.2 1-Dimensional Model Build

2.2.1 Modelled Watercourses

Watercourses represented within the model build are displayed in Figure 2-1. Cross sectional survey data was collected in a bathymetric survey commissioned for use in this study and completed by a third-party surveyor. Cross sections were taken at minimum 25m intervals in areas of 'high interest' (within Ballyhale Village and potential options locations), increasing to 50m intervals outside areas of interest.

The river centreline was digitised based on bathymetric survey information and OSi Prime2 Mapping, verified on site walkover. Bathymetric survey information was imported directly into ICM. Naming of the sections within the model are as per survey naming.

The roughness of the river reach is represented by applying a Manning's n roughness value to the river sections for floodplains and river channel. Roughness values applied to the watercourses were per site observations and surveyor photographs at time of survey. Typical Manning's N roughness values of 0.04-0.07 were used for the open channel, representing a clean straight channel with stones and weeds up to less effective reaches and slopes increasing to 0.11 for unmaintained excavated channels with dense vegetation to the highest stage of flow. Where appropriate, roughness was varied within the channel to represent more vegetated banks.

2.2.2 Structures

Structures (culverts and bridges) located within the model extents are shown on the following figures and are detailed in the Structures Register (Table 2-1) with corresponding geometries and details. All structures within the model were represented as conduits with dimensions based on survey information.

Where the upstream and downstream opening size varied, the minimum cross-sectional area was applied along the length of the conduit as being the most hydraulically critical. Characteristic Manning's N roughness values were applied based on conduit material and condition per site observations / photographs. Bottom conduit roughness values varied from top roughness due to observed sedimentation / debris / vegetation on the bottom of structures.

Structures were applied with respective culvert inlet / outlet structures to reflect inlet headloss conditions and allowed nominal reverse flow. Culvert inlet / outlet structures were not applied in instances where conduits only represented clear spanning slabs across the watercourse.

Structure parapet walls that would impede overtopping flows were represented using either porous polygons or base linear structures with a porosity of zero and set to the surveyed overtopping height. Mesh level zones were used with survey data to ensure an accurate definition of structure deck levels due to triangulation picking up adjacent channel invert levels.

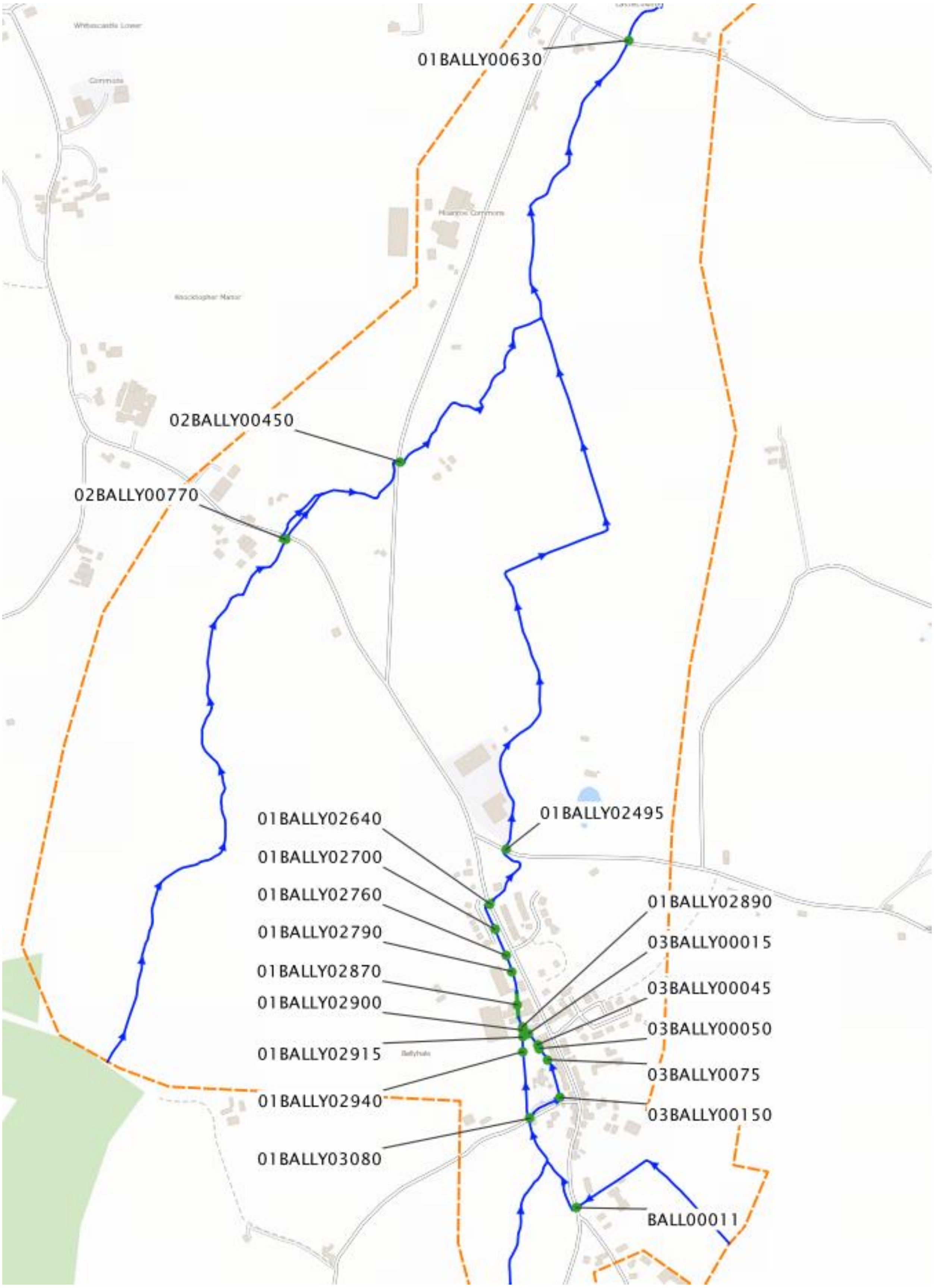

Figure 2-2 Modelled Structures (Overview)

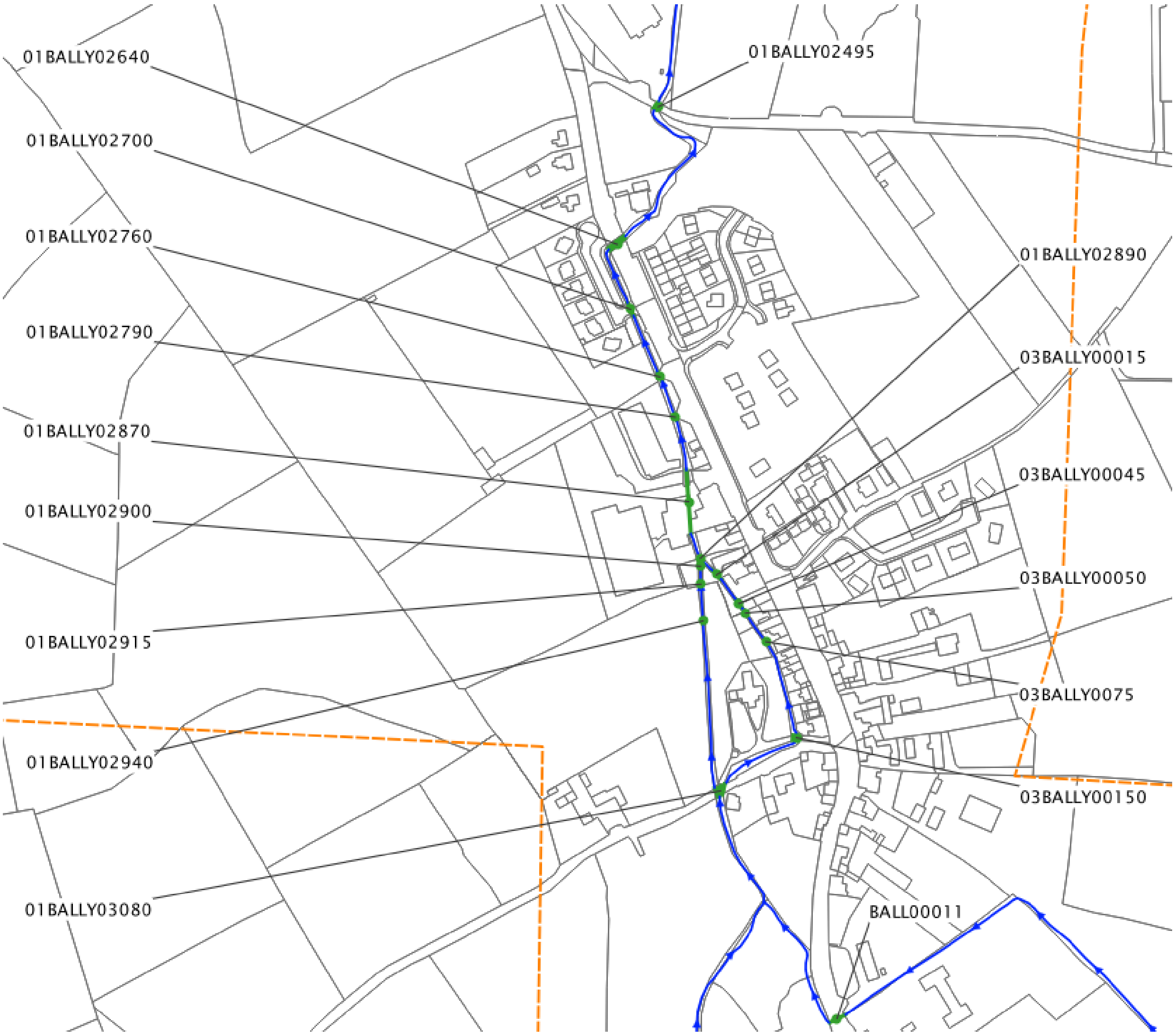

Figure 2-3 Modelled Structures (Within Area of Interest)

Table 2-1 Structure Register

Reference	Shape	Width (mm)	Height (mm)	Bottom Manning's n	Top Manning's n	Comment
BALL00011	Arch	821	1180	0.03 (River Bed)	0.03 (Masonry)	
01BALLY 03080 (Chapel Lane Bridge)	Opening 1					Opening 3 & 4 bifurcates the watercourse diverting flows west of the church and are situated c. 0.44-1m higher than Opening 2 respectively.
	Rectangular	550	1051	0.03 (River Bed)	0.03 (Masonry)	
	Opening 2					
	Arch	2580	1680	0.03 (River Bed)	0.03 (Masonry)	
	Opening 3					
	Rectangular	2690	1200	0.03 (River Bed)	0.03 (Masonry)	
	Opening 4					
	Rectangular	689	655	0.017 (Rough concrete)	0.017 (Rough concrete)	
01BALLY 02940	Rectangular	2880	1100	0.03 (River Bed)	0.013 (Concrete)	
01BALLY 02915	Rectangular	2980	1480	0.03 (River Bed)	0.013 (Concrete)	
01BALLY 02900	Rectangular	2530	1190	0.03 (River Bed)	0.013 (Concrete)	
01BALLY 02890	Rectangular	3660	1650	0.04 (River Bed)	0.013 (Concrete)	Boundary wall structure.
01BALLY 02870 (Arrigle Business Park Culvert)	Rectangular	3300	1440	0.03 (River Bed)	0.03 (Masonry)	Upstream opening assessed as most critical size and adopted for full length. Noted on site to have been previously extended, bridge piers visible on downstream section.
01BALLY 02790	Rectangular	3270	900	0.03 (River Bed)	0.013 (Metal Span)	
01BALLY 02760	Rectangular	3840	953	0.03 (River Bed)	0.013 (Concrete)	
01BALLY 02700	Rectangular	3750	1200	0.03 (River Bed)	0.013 (Concrete)	
01BALLY 02640 Main Street Bridge	Opening 1					Opening 2 vegetated. Channel invert level higher than Opening 1 due to sedimentation from survey.
	Arch	1740	1050	0.03 (River Bed)	0.03 (Masonry)	
	Opening 2					
	Sprung Arch	2060	930	0.04 (River Bed)	0.03 (Masonry)	
01BALLY 02495 Station Road Bridge	Opening 1					Opening 1 highly vegetated.
	Rectangular	2270	1070	0.05 (Highly vegetated River Bed)	0.013 (Concrete)	
	Opening 2					
	Rectangular	2270	1070	0.013 (Concrete)	0.013 (Concrete)	
01BALLY 00630	Sprung Arch	8420	2324	0.03 (River Bed)	0.03 (Masonry)	
	Opening 1					

Reference	Shape	Width (mm)	Height (mm)	Bottom Manning's n	Top Manning's n	Comment
03BALLY 00150 Church Access Bridge	Rectangular	968	1238	0.03 (River Bed)	0.03 (Masonry)	Right bank wall on Chapel Lane immediately upstream observed to be reduced to ground level to permit overland flows to re-enter channel.
	Opening 2					
	Rectangular	968	1250	0.03 (River Bed)	0.03 (Masonry)	
	Opening 3					
	Rectangular	2568	1233	0.03 (River Bed)	0.03 (Masonry)	
03BALLY 0075	Rectangular	2141	900	0.03 (River Bed)	0.013 (Concrete)	
03BALLY 00050	Rectangular	2320	1264	0.03 (River Bed)	0.013 (Concrete)	
03BALLY 00045	Rectangular	1651	850	0.03 (River Bed)	0.013 (Concrete)	
03BALLY 00015	Rectangular	2120	1088	0.03 (River Bed)	0.03 (Masonry)	
02BALLY 00770 R699 Road Bridge	Opening 1					
	Arch	1410	790	0.05 (River Bed)	0.03 (Masonry)	
	Opening 2					
	Arch	1600	805	0.04 (River Bed)	0.03 (Masonry)	
02BALLY 00450	Opening 1					
	Arch	3090	1560	0.04 (River Bed)	0.03 (Masonry)	
	Opening 2					
	Arch	3070	1560	0.04 (River Bed)	0.03 (Masonry)	

2.2.3 Bank Lines

River reach bank lines are used to define the interaction between the 1D channel and 2D ground model and were carefully sited to define top of bank.

Bank coefficients were defined as follows:

- Discharge coefficient – varied based on bank type (1-0.8 for vegetated banks and 1.7 for walled banks).
- Modular limit – reduced to 0.5-0.4 based on model testing to ensure stability and reduction of flow oscillations.

Some secondary channels and land drains were modelled in 2D, where the drains connected into the 1D channels additional detail was added to the bank lines to ensure connectivity of 1D -2D flows.

2.2.4 Formal / Informal Defences

No formal flood defences are present in the modelled area.

Walls that form part of the watercourse bank or intersect overland flow routes were identified by the topographical survey. Structures that are identified by the flood model to withhold or affect routing of floodwater are deemed informal flood defence assets. Those assets are indicated on the following Figure 2-4 and are primarily focused on the bank walls on the eastern church watercourse.

Informal flood defences may be made redundant as part of the flood relief scheme. Informal defence assets will be included in a flood defence asset register on project completion.

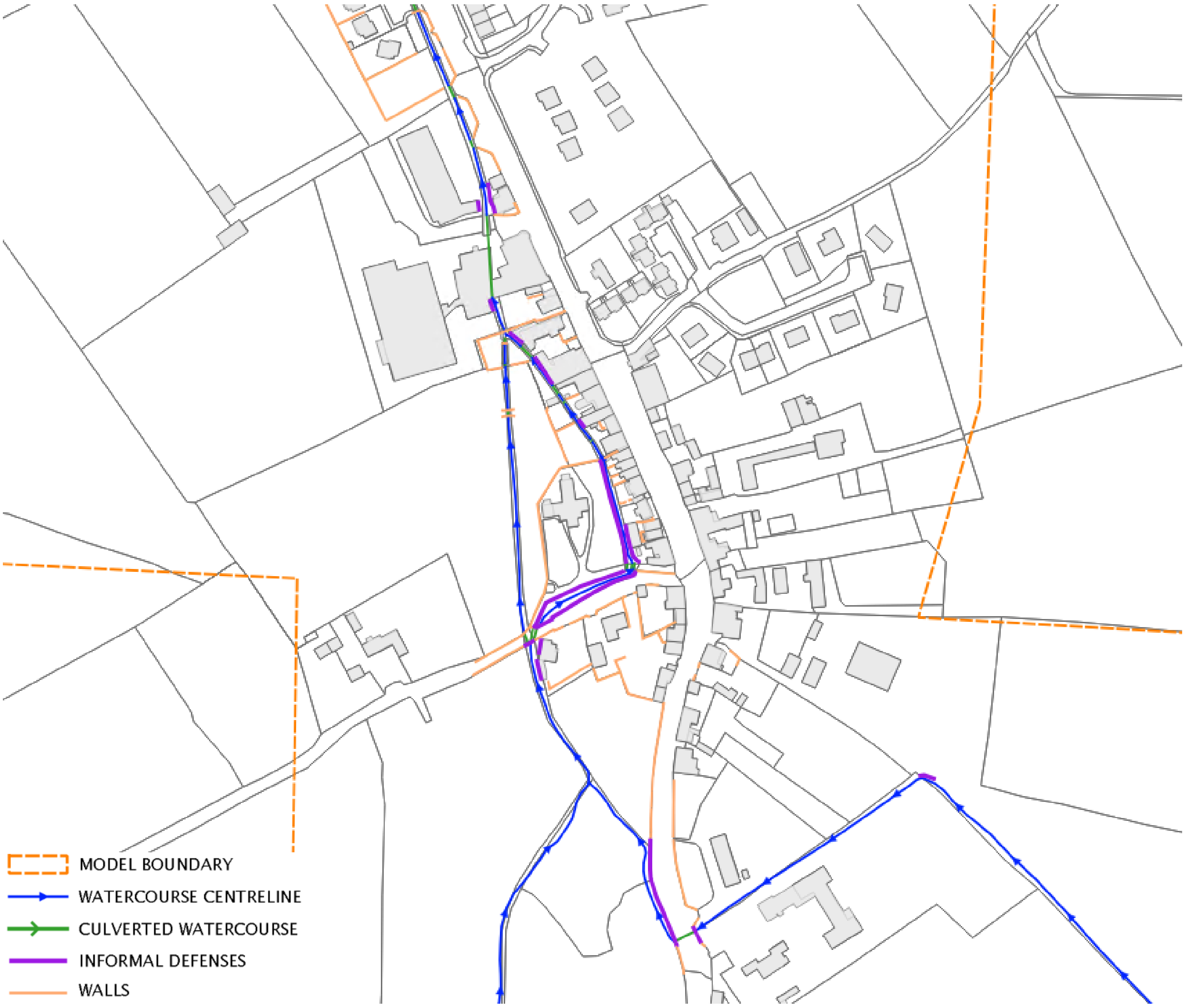

Figure 2-4 Informal Defences within Ballyhale

2.3 2-Dimenisional Model Build

2.3.1 Topography

A composite terrain model was generated based on ground based topographical survey, supplemented by 2m OSi LiDAR. To ensure a good level of representation from the detailed survey data the ground model was exported with 1m resolution, no 'stepping' effect was observed in the 2m LiDAR as a result of the resampling.

A visual check was undertaken to identify any new land forms or changes that would cause LiDAR derived portion of the ground model to be invalidated. No edits were required.

A comparison of survey data versus OSi LiDAR data indicated no major discrepancies, however it was noted that representation of the Ballyhale River from Station Road to its confluence with the Little Arrigle River was poorly defined within the LiDAR. This found to be due to adjacent field drains artificially lowering the top of bank, exacerbated by data cleansing from moderate vegetation coverage and was rectified within the ground model by use of surveyed topographical data in that location.

Figure 2-5 displays the spatial extent of the data sources used to generate the composite terrain model.

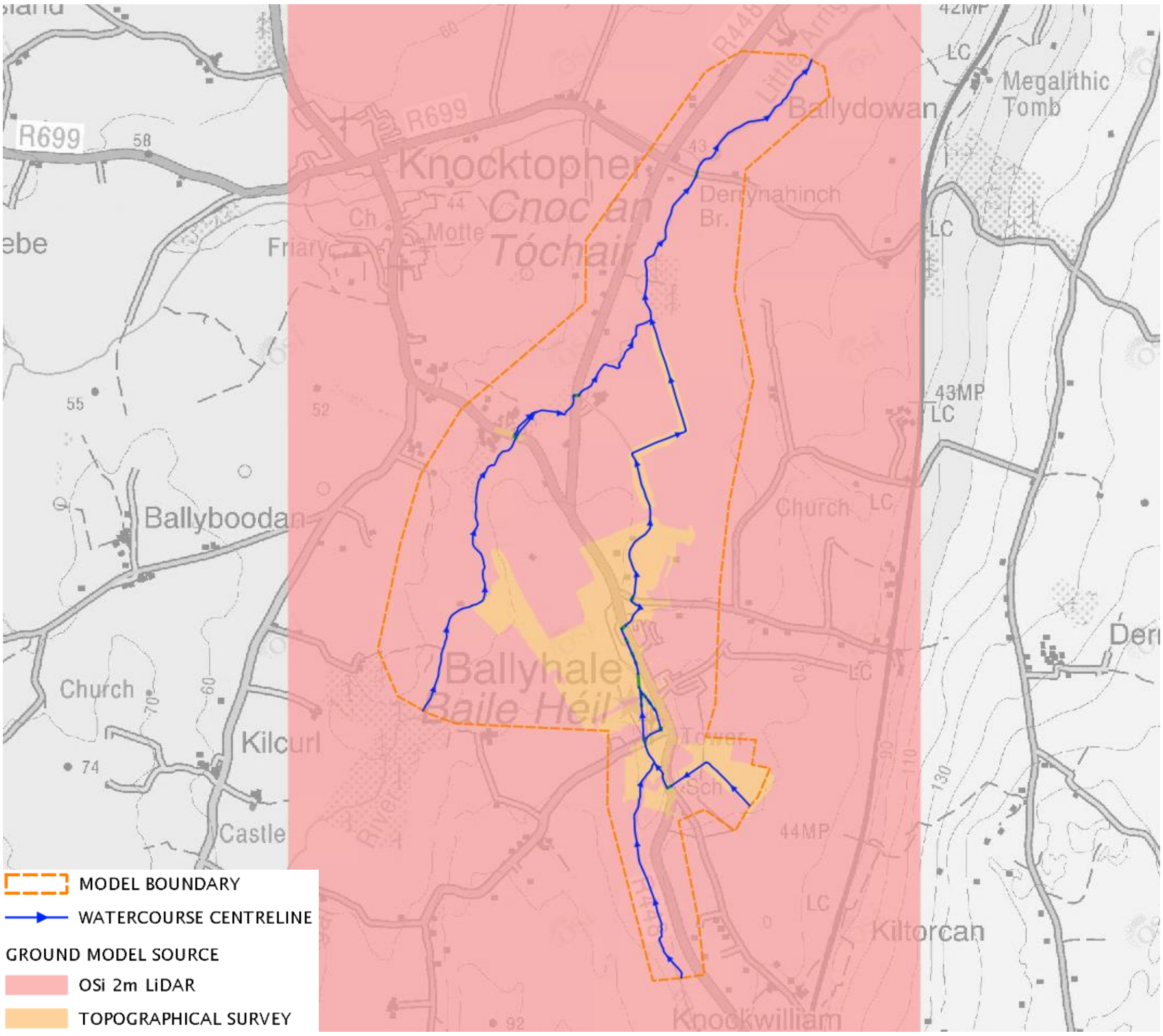

Figure 2-5 Ground Model Data Source

2.3.2 2D Zone

The terrain model was used to create a ground model in InfoWorks ICM, and subsequently converted into a 2D mesh. The 2D zone has a maximum triangle size of 20 m² and minimum size of 2m² with terrain sensitive meshing activated to enhance the representation of the topography in areas that have a large variation in height, without increasing the number of elements in relatively flat areas. A maximum height difference of 0.5m was set for this parameter.

Mesh zones were added to the model to the rear of the properties at Main Street, Chapel Lane and at 'Sheff's Lane' to increase the surface resolution to a maximum triangle size of 5 m² and minimum size of 2m² to ensure accurate representation of overland flow paths.

Additional mesh zones were used at locations of secondary channels and drains modelled in 2D to provide a more accurate conveyance of the channel. All mesh zones used within the model to increase triangulation resolution are displayed in the following Figure 2-6.

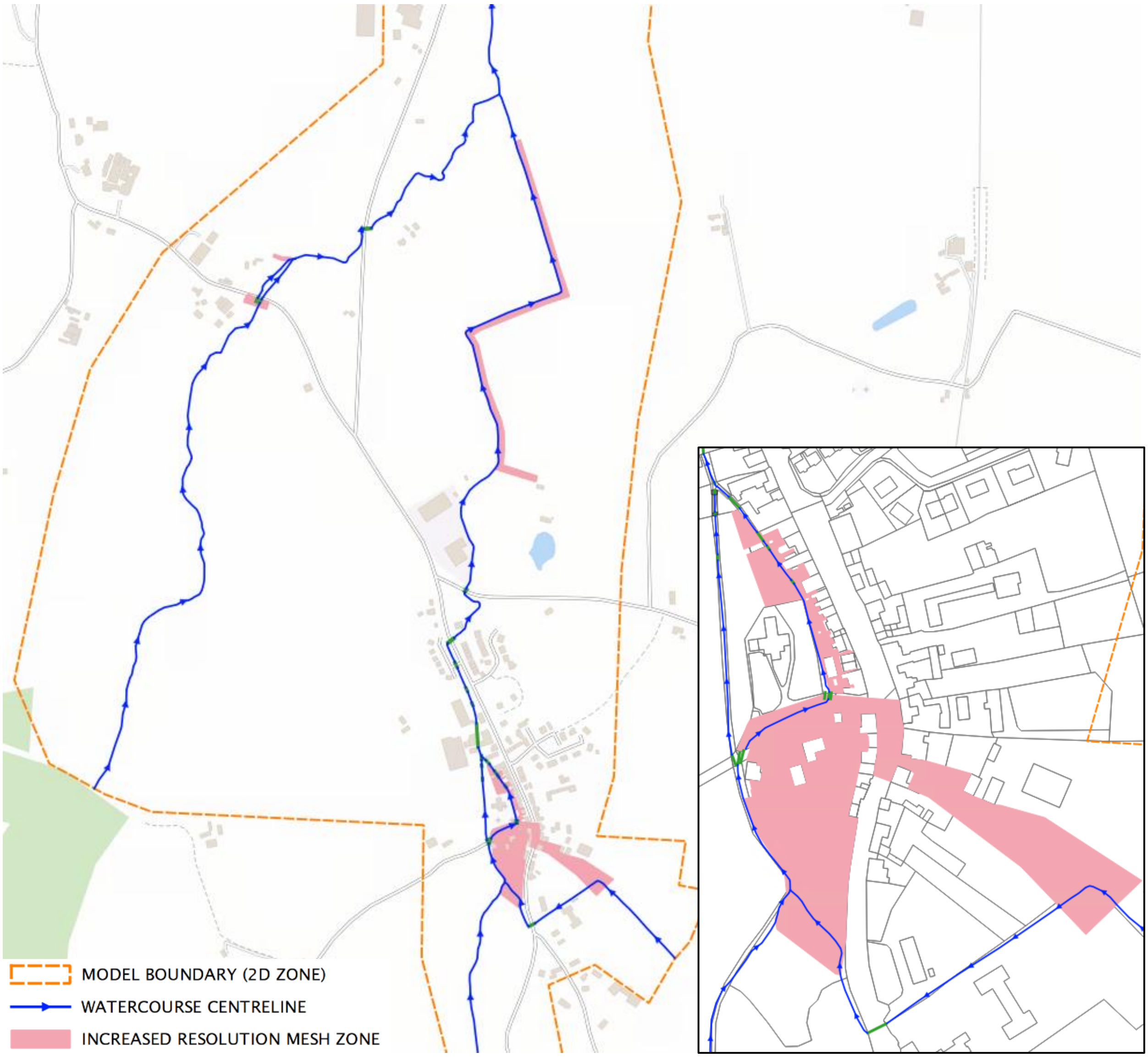

Figure 2-6 Extent of 2D and Mesh Zones (Inset: Ballyhale Village Mesh Zones)

2.3.3 Model Geometry

2.3.3.1 Buildings

Buildings threshold levels were represented within the model by applying mesh zones with the specified level. In instances where no threshold survey was undertaken, threshold data was interpolated using adjacent surveyed threshold levels, site / streetview observations or assumed as averaged height data underneath the height data +0.3m per standard modelling methodology. Figure 2-7 details the buildings where a threshold level was set versus assumed as average height data +0.3m.

Buildings were given a degree of porosity to restrict flow 'through buildings', which activate when water levels breach the threshold level of the building. A porosity of 0.1 was applied as per standard modelling methodology.

OSi Prime2 mapping was used as a basis to define building geometries, updated with topographical surveyed outlines where data was available.

2.3.3.2 Walls

Walls were represented within the model using porous polygons for bridge parapets and base linear structures for key walls that would impede overland flow paths and are shown in the following Figure 2-7.. Wall locations and levels were defined by topographical survey and from site observations and include gaps for walkways / gates etc. that will allow flows to pass (e.g. residential driveway openings and the pathway adjacent to the Main Street bridge. Dependant on observed condition, some residential boundary walls were given a nominal porosity to reflect the inefficiency of the walls to fully retain flood waters. Walls or boundaries that were assessed to perform only minor impediment of flows (due to construction / condition) were not modelled.

Walls forming the watercourse banks were modelled as part of the 1D river reach bank lines.

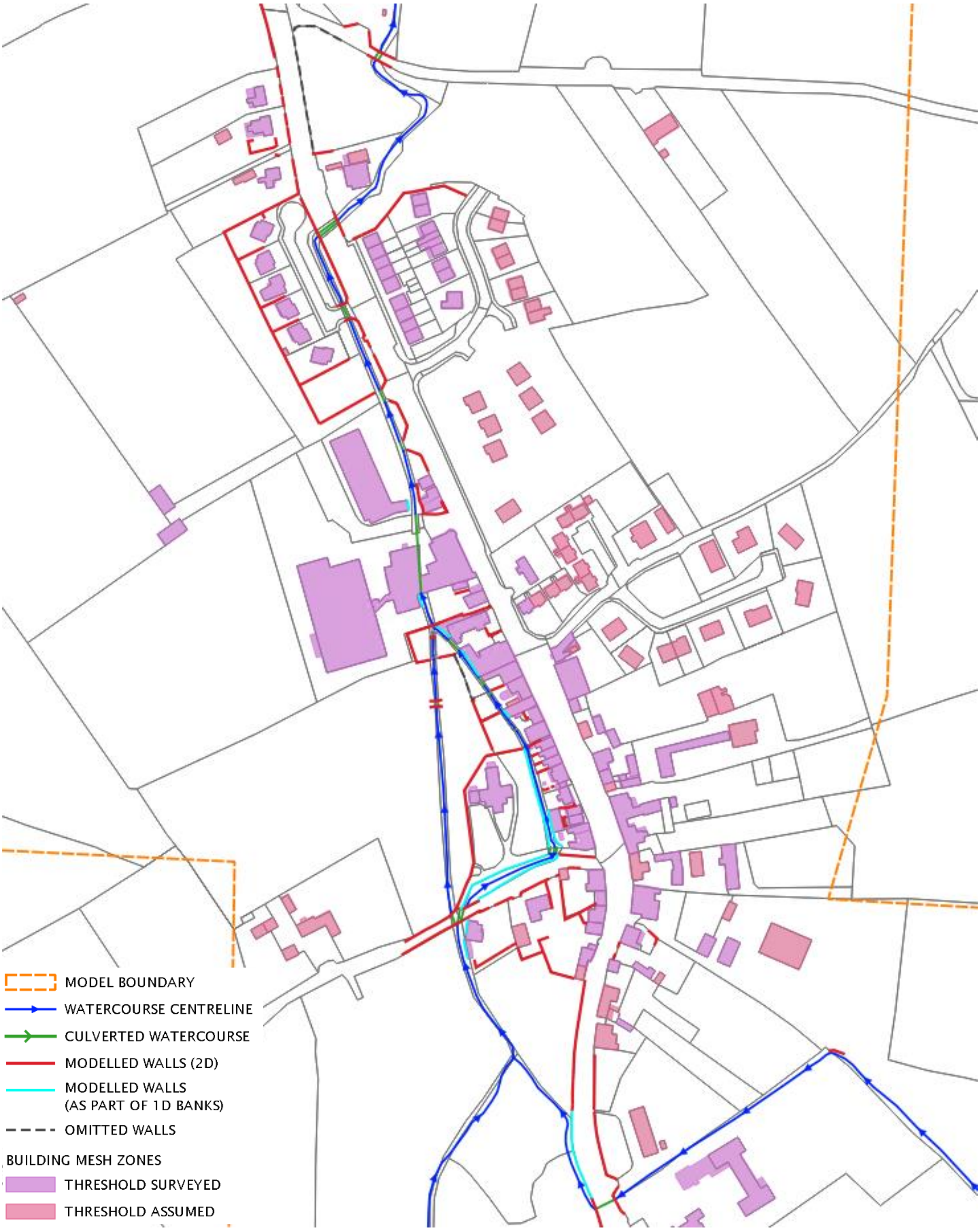

Figure 2-7 Modelled Walls and Building Thresholds

2.3.4 Boundary Conditions

Boundary conditions for the edge of the 2D surface area have been set to normal depth to prevent flows glass walling at the downstream boundary. The 2D surface has been sized conservatively to ensure that the boundary condition is of sufficient distance from the areas of interest so as not to have an impact on flood levels for the maximum AEP simulated.

2.3.5 Roughness Values

Manning's n roughness values have been applied to the 2D zone. The majority of the modelled area comprises agricultural land, a constant and conservative Manning's n value of 0.05 has therefore been applied to the 2D Zone to represent the rural nature of the catchment.

Roughness zones were introduced the model to represent areas of roughness differing to that of the base roughness. Roughness zones were extracted from OS Prime2 mapping and updated based on recent aerial imagery and site observations are categorised as follows and displayed in Figure 2-8.

- Brush and trees – 0.07-0.1;
- Asphalt Roads – 0.013;
- Concrete Laneways – 0.02
- Earth Laneway – 0.025

Watercourse bank roughness's are represented within the 1D channel.

Due to their size, smaller areas of hardstanding such as private driveways, pathways etc are not defined within the OS Prime2 dataset and have not been represented within the model.

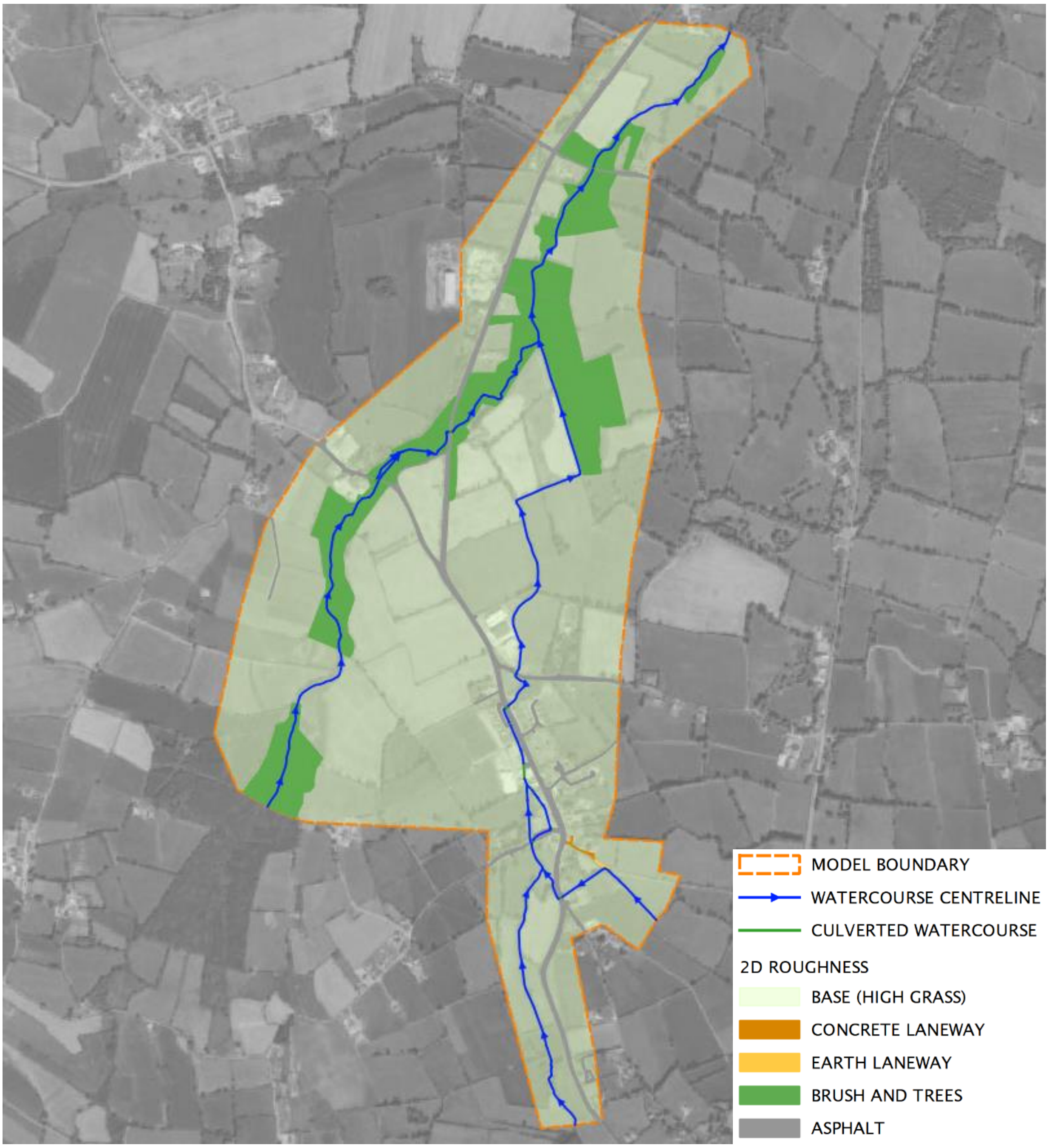

Figure 2-8 2D Model Roughness

2.4 Model Scenarios

2.4.1 Baseline

The modelling exercise sought to establish baseline conditions within the village and included all reaches that were initially considered for optioneering. The model extent was carefully sited to ensure the downstream effect of optioneering scenarios can be fully assessed. Table 2-1 details the hydrology scenarios considered.

Table 2-2 Simulated Design Flows

Present Day	Mid-Range Future Scenario (+20%)	High End Future Scenario (+30%)
50%	50%	-
20%	20%	-
10%	10%	10%
5%	5%	-
2%	2%	-
1%	1%	1%
0.5%	0.5%	-
0.1%	0.1%	0.1%

2.4.2 Sensitivity Scenarios

Scenarios testing the base model sensitivity to roughness parameters, bank coefficients and boundary conditions were carried out as part of the model validation and auditing process for the 1% AEP fluvial event. Sensitivity analysis is discussed further in Section 5.

2.4.3 Blockage Analysis

Six structures were identified as being critical in terms of blockage per site observations and historical flooding accounts. The structures were modelled in isolation with a 25%, 50%, and 75% blockage of the upstream opening areas coinciding with a 1% AEP flood. Blockage analysis is discussed further in Section 6.

2.5 Application of Hydrology

Distributed hydrology was applied to the model to accurately represent the application of flows to the watercourse network and enable verification of the model to available data.

Inflows were applied to the model using a combination of lateral (distributed) inflows along the length of all reaches and point inflows at the upstream limit of watercourses and coinciding with tributary confluences inflows as indicated by the hydrological analysis.

A model wide peak flow assessment was conducted of the model results upon completion of the baseline modelling. The assessment informed that anticipated peak flows were achieved at locations of confluence, ensuring the model represented the calculated hydrology and maximum flood extent.

Point inflow locations are shown on the following Figure 2-9, lateral flows were applied along the modelled reaches.

Refer to the Hydrology Report for details on calculation of hydrology.

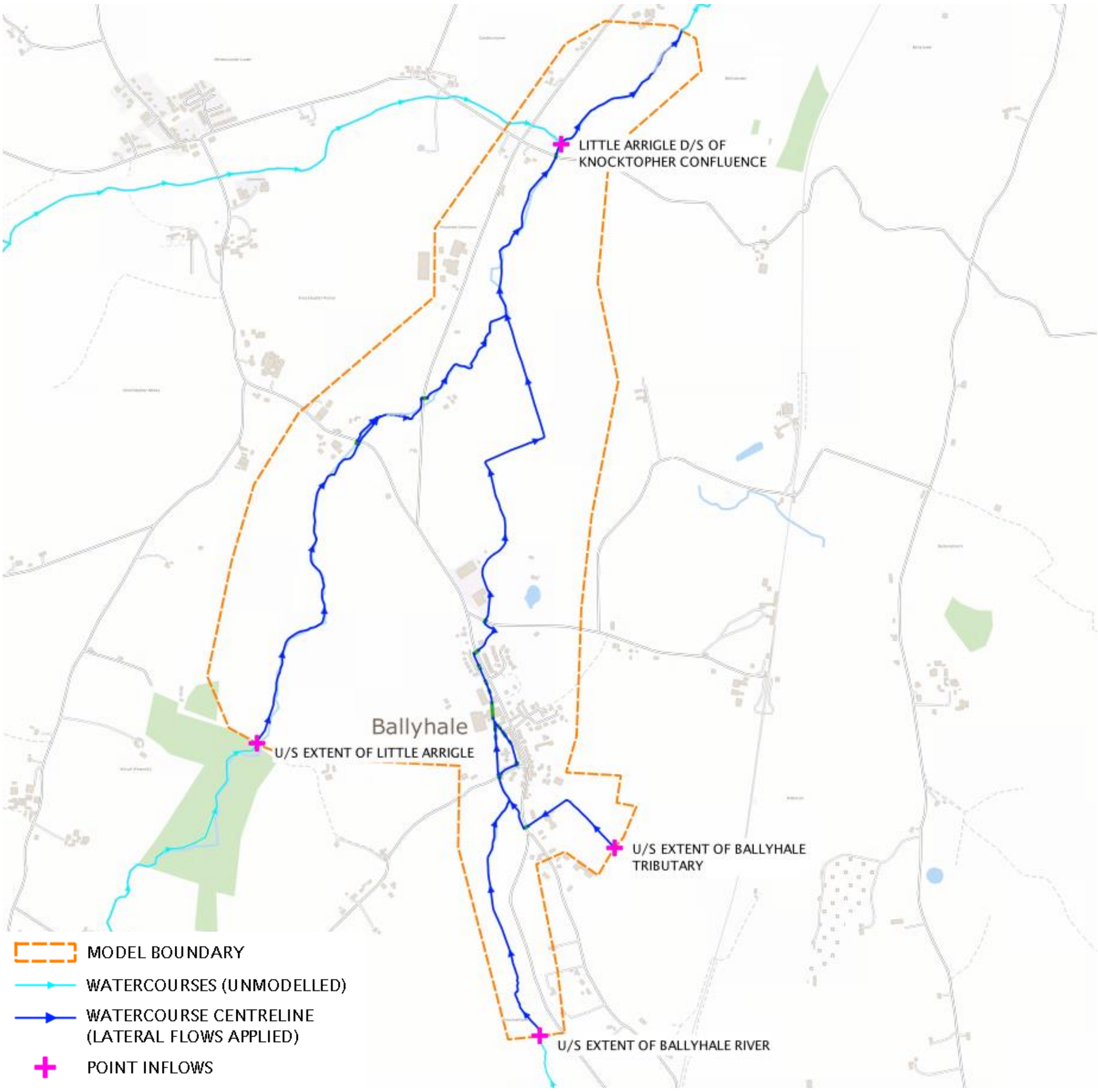

Figure 2-9 Application of Hydrology

2.6 Simulation Timestep and Duration

Simulation timestep and duration used for all scenarios are detailed in Table 2-3. Results were recorded at 300s (5 minute) intervals and simulations were set for a duration sufficiently long enough to cover peak water depths across the model and to allow time for waters to recede.

Table 2-3 Timestep Parameters

Simulation Parameter	Value
Timestep (s)	2
Timestep Multiplier	150
Duration (hours)	80

2.7 Model Build Assumptions & Limitations

The representation of any complex system by a model requires a number of assumptions to be made. In the case of the hydraulic model developed for the purposes of the study it is assumed that:

- The representation of the 1D channel via the survey data is sufficiently detail to represent the conveyance capacity of the watercourses represented.
- The design flows are an accurate representation of flows of a given return period.
- The composite terrain model (based on the ground based topographical survey and supplemented with 2m OSi LiDAR) accurately represents the surface topography and associated flow paths within the model extent.
- Roughness does not vary with time.

The primary limitations of the study are noted as follows:

- Small agricultural ditches within the model extent have been modelled in 2D only. Representation of the small channels and field drains within the 2D domain was assessed as sufficient to their size and scale. Flow contributions from the ditches are accounted for within the hydrology estimation and applied to the model.
- Local sewerage and surface water drainage assets within the village area are not built into the hydraulic model. Surface water drainage infrastructure discharging to the Ballyhale River from the village is small in scale. The flow magnitude that could be conveyed by the scale and nature of drainage present would have no measurable effect on the distribution of flows to the model and is unlikely to significantly influence flood levels. Inflows from the village catchment are accounted for within the hydrology estimation and applied to the respective river reach. The effect of any flood relief scheme on local drainage will be dealt with through detailed design of optioneering.
- No allowance for infiltration has been made within the model, typical of standard modelling methodologies for fluvial hydraulic models to represent maximum potential flood extents.
- The model does not represent any topographic features smaller than the minimum resolution of the underlying terrain model. Key topographical features found smaller than the minimum resolution of the underlying terrain model were implemented as 2D mesh and mesh level zones to ensure adequate representation.

3 BASELINE MODEL RESULTS

3.1 Model Results

Modelling indicates substantial flood risk within Ballyhale village originating from the Ballyhale River. An extract of the 1% AEP model results is shown on the following figure. Full flood mapping outputs from the baseline modelling exercise are enclosed in Appendix A for all scenarios listed in Table 2-2.

The primary flood mechanism for the flooding within the village is caused by structure incapacity with resulting backwater effect causing out of bank flooding along the Ballyhale River resulting in flooding at the rear of the Main Street properties, coupled with two significant overland flow routes from the south of the village.

Channel incapacity upstream of the village from the Ballyhale River creates an overland flow path that flows northerly towards Chapel Lane, re-entering the western church reach of the Ballyhale River at the church access bridge.

A second overland flow route is evident from a previously unmodelled tributary of the Ballyhale River that flows adjacent to the school boundary. A low point in the bank where the channel turns at an approximately 90 degree bend coupled with unmaintained vegetation restricting flows within the channel downstream causes flooding from the right hand bank flowing down 'Sheff's Lane' that emerges onto the Main Street. The flow route diverges at the Chapel Lane junction, flows that tend down Chapel Lane enters the western church reach at the church access bridge. Flows that tend down Main Street enters the main Ballyhale River at the former Garda Station.

In higher flow events, the flow path on the Main Street continues and re-joins the Ballyhale River at either the downstream section of the 'Main Street Bridge' at the Hazelbrook development or downstream of the Station Road bridge.

Figure 3-1 1% AEP Flood Event Extract

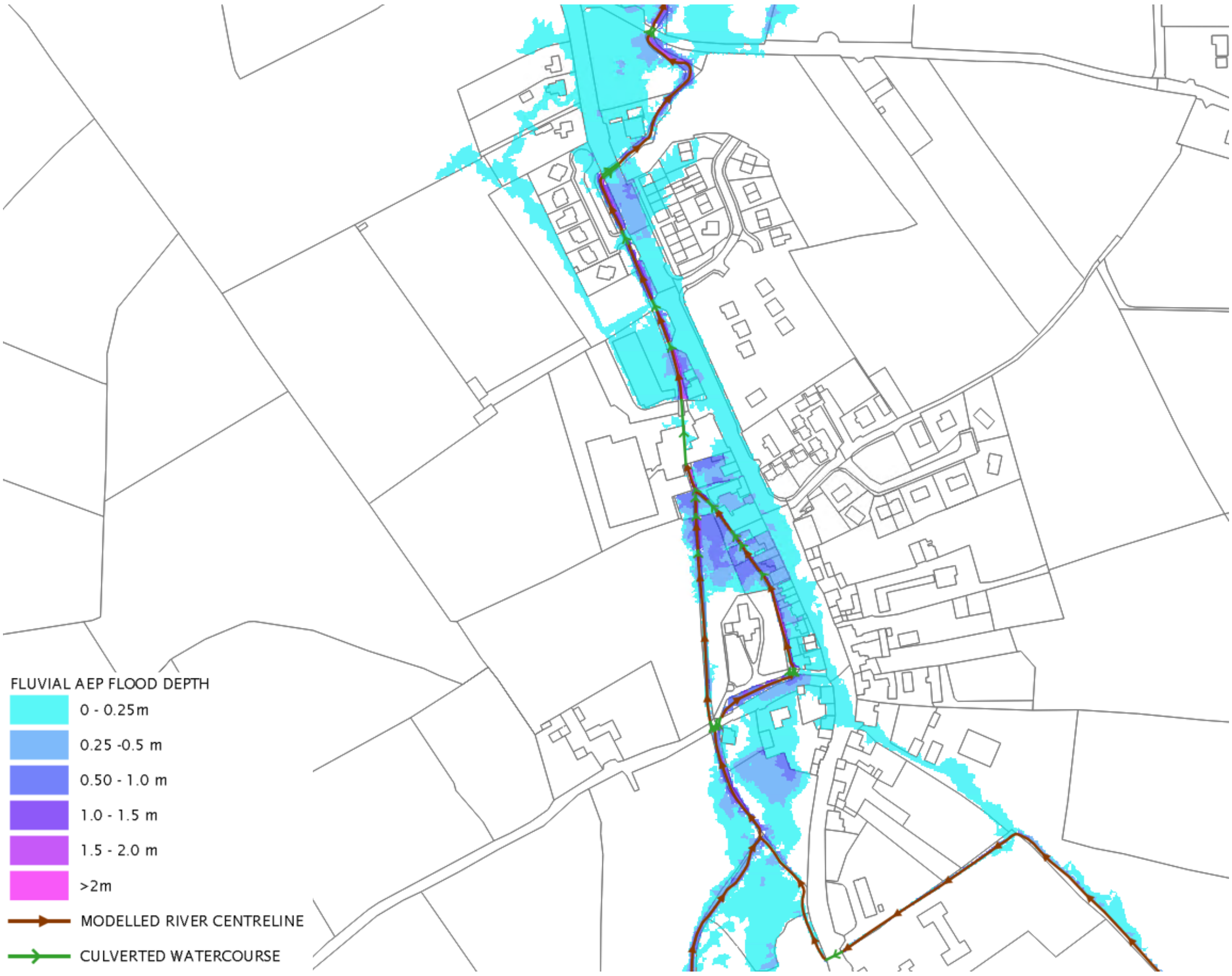

Figure 3-2 0.1% AEP Flood Event Extract

3.2 Properties Affected

The number of properties shown to be affected by fluvial flooding within Ballyhale village are shown in the following tables for the three key return periods for the present day hydrology and mid-range / high-end climate change scenarios.

Table 3-1 Properties Subject to Internal Flooding (Present Day Hydrology)

Return Period	No. of Properties Flooded
10% AEP	0
1% AEP	19
0.1% AEP	44

Table 3-2 Properties Subject to Internal Flooding (MRFS Hydrology)

Return Period	No. of Properties Flooded
10% AEP	10
1% AEP	31
0.1% AEP	47

Table 3-3 Properties Subject to Internal Flooding (HEFS Hydrology)

Return Period	No. of Properties Flooded
10% AEP	12
1% AEP	35
0.1% AEP	47

3.3 Baseline Flood Mapping

Flood results were exported from the model at a depth greater than 0.005m to ensure connection of isolated ‘wet’ islands created from overland flow routing. Flood results were processed to remove remaining isolated pockets of flooding (<40m^2) that were hydraulically disconnected from the watercourse or overland flow routes. Mapping was generated based on maximum flood contours to provide in channel flood depths, triangulated from maximum levels at river sections and bank lines and merged with maximum water depth 2D zone vector polygons results for all out of bank flooding, sampled at a 1m^2 grid raster.

4 MODEL VALIDATION

4.1 Preamble

Model flow checks were carried out to ensure the measured modelled flows were representative of input flows calculated.

An extensive search for calibration / validatory material was carried out and documented within the hydrology report. Only anecdotal evidence was uncovered with few recent dates / flood evidence was found.

The catchment is ungauged, and available rainfall records are insufficiently detailed to allow estimation of a rainfall event / flood magnitude that would permit replication for hydraulic calibration within the study area.

Model validation is reliant on local accounts of flooding and flood mechanisms from primarily the November 2000 flood event.

4.2 Model Flow Checks

Hydrology estimation points (HEPs) as derived and detailed within the modelling report were compared versus modelled flows for key return periods (10%, 1% and 0.1% AEP), and detailed in the following tables.

Due to the significance of the floodplain and its conveyance effect, the peak flood passing at HEP locations is a summation of modelled 1D (i.e. in channel) and 2D (i.e. floodplain) conveyance.

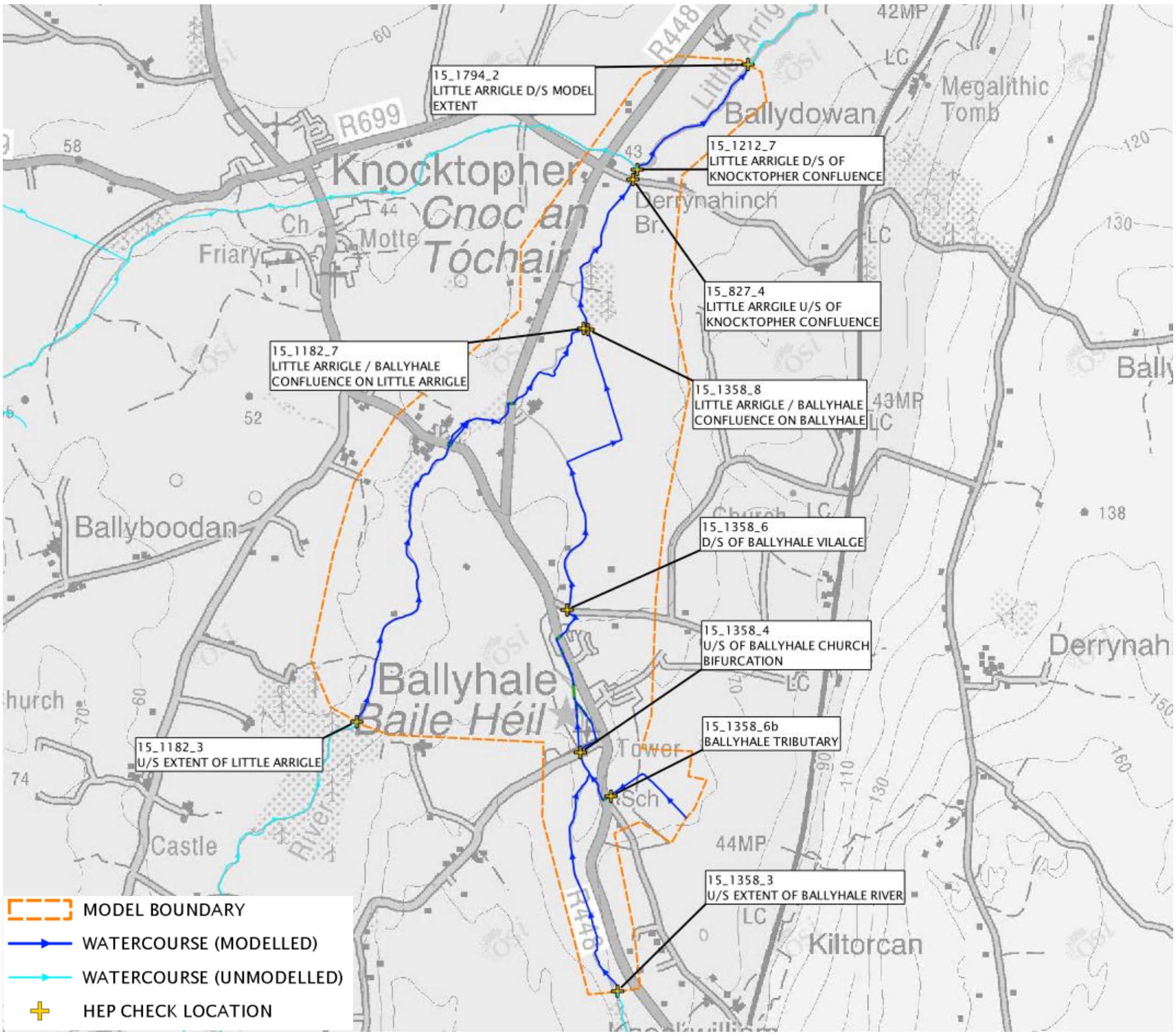

Figure 4-1 HEP Check Locations

Table 4-1 Calculated HEP vs Modelled 10% AEP Flows

HEP No.	Comment	Calculated 10% AEP flows (m^3/s)	Measured (modelled) 10% AEP Flows (m^3/s)		
			1D	2D	Total
15_1358_3	Ballyhale River upstream limit.	2.75	2.75	0	2.75
15_1358_6b	Ballyhale Tributary	0.43	0.43	0	0.43
15_1358_4	Ballyhale bifurcation at church.	3.34	3.34	0	3.34
15_1358_6	Downstream of Ballyhale village.	3.46	3.46	0	3.46
15_1358_8	Upstream of Little Arrigle / Ballyhale confluence on Ballyhale.	4.22	2.35	1.84	4.19
15_1182_3	Little Arrigle model upstream limit.	2.27	2.27	0	2.27
15_1182_7	Upstream of Little Arrigle / Ballyhale confluence on Little Arrigle,	2.48	2.48	0	2.48
15_827_4	Little Arrigle upstream of Knocktopher confluence.	7.00	7.00	0	7.00
15_1212_7	Little Arrigle downstream of Knocktopher confluence.	11.36	11.08	0.28	11.36
15_1794_2	Model downstream limit.	12.03	11.74	0.18	11.92

Table 4-2 Calculated HEP vs Modelled 1% AEP Flows

HEP No.	Comment	Calculated 1% AEP flows (m^3/s)	Measured (modelled) 1% AEP Flows (m^3/s)		
			1D	2D	Total
15_1358_3	Ballyhale River upstream limit.	4.67	4.67	0	4.67
15_1358_6b	Ballyhale Tributary	0.73	0.63	0.1	0.73
15_1358_4	Ballyhale bifurcation at church.	5.68	5.39	0.28	5.67
15_1358_6	Downstream of Ballyhale village.	5.88	5.88	0	5.88
15_1358_8	Upstream of Little Arrigle / Ballyhale confluence on Ballyhale.	7.17	2.85	4.16	7.01
15_1182_3	Little Arrigle model upstream limit.	3.83	3.83	0	3.83
15_1182_7	Upstream of Little Arrigle / Ballyhale confluence on Little Arrigle,	4.18	4.16	0.01	4.17
15_827_4	Little Arrigle upstream of Knocktopher confluence.	11.81	11.80	0	11.80
15_1212_7	Little Arrigle downstream of Knocktopher confluence.	19.71	16.3	3.4	19.70
15_1794_2	Model downstream limit.	20.72	18.47	1.88	20.35

Table 4-3 Calculated HEP vs Modelled 0.1% AEP Flows

HEP No.	Comment	Calculated 0.1% AEP flows (m^3/s)	Measured (modelled) 0.1% AEP Flows (m^3/s)		
			1D	2D	Total
15_1358_3	Ballyhale River upstream limit.	7.69	7.69	0	7.69
15_1358_6b	Ballyhale Tributary	1.20	0.81	0.39	1.20
15_1358_4	Ballyhale bifurcation at church.	9.35	8.37	0.96	9.33
15_1358_6	Downstream of Ballyhale village.	9.68	7.68	2.0	9.68
15_1358_8	Upstream of Little Arrigle / Ballyhale confluence on Ballyhale.	11.80	2.7	9.1	11.80
15_1182_3	Little Arrigle model upstream limit.	6.25	6.25	0	6.25
15_1182_7	Upstream of Little Arrigle / Ballyhale confluence on Little Arrigle,	6.82	5.43	1.35	6.78
15_827_4	Little Arrigle upstream of Knocktopher confluence.	19.31	19.30	0	19.30
15_1212_7	Little Arrigle downstream of Knocktopher confluence.	33.13	23.68	9.44	33.12
15_1794_2	Model downstream limit.	34.62	26.44	7.62	34.06

Model flows are found to correlate well with hydrological estimates derived from the hydrology report. Discrepancies arise downstream of Ballyhale village which are primarily caused by overland flow routes coinciding with drainage ditches modelled in 2D and associated storage within the floodplain.

The maximum magnitude of the discrepancies within the model (c. 2%) were located at the downstream model boundary, c. 2.4km downstream of Ballyhale Village and outside the main area of interest, and at a considerably lower elevation. No top up flows at this location were deemed necessary as it would not affect the overall accuracy of the model. The minor discrepancy is limited to the downstream section of the model only and will not impact results within the area of interest or where options are proposed.

4.3 Model Validation

Insufficient data exists to permit calibration simulations against historical flood events. Table 4-4 details anecdotal evidence previously collated as part of the hydrology report to permit a comparison against modelled flood extents, with a view to ensuring that model results are at least as onerous as recorded flooding.

Table 4-4 Historic Fluvial Flooding Reports vs Modelled Results

Report	**Event Date**	**Details**	**Representation in Model**
Account 1.	November 2000	A commercial unit at the Arrigle Business Park (location 1) was subject to internal flooding.	Side lean-to structure shown to flood within model for the 1% AEP flood. The full building is shown to be subject to flooding for the 0.1% flood. Verbal account 2 indicated a structure blockage downstream coincided with the flood event. The main building was shown to be susceptible to flooding when the 1% AEP flood was combined with a 50% blockage on structure 01BALLY02870.
Account 2.	November 2000	A commercial unit (vehicle repair shop) backing onto the River (location 2) from the main street was externally and internally affected, with flood depths c. 0.5m at the side of the property and 0.3m internally. A downstream culvert was reported to be blocked. Flooding entered the property from a rear door.	For the 1% AEP event combined with a 50% blockage on structure 01BALLY02870 indicates flood depths of 0.55m and 0.16m externally / internally. A 75% blockage on the structure indicates resultant flood depths of 0.76m and 0.33m externally / internally.
Account 3.	November 2000	A resident whose house is indicated on Main Street (location 3) advised that flooding came from the rear of the house (Ballyhale River), and not from the main street. The resident had a flood barrier installed to the front of the house but advised that this was removed to allow flood waters to subside. Internal flood depths within the house rose to approximately 0.3m.	Flooding originates from the river to the rear of the houses within the model at this location. Modelling indicates floodwaters to 'pass through' the houses and spill onto the Main Street. Modelling indicates a predicted flood depth within the dwelling of 0.06m for the 1% AEP and 0.32m for the 0.1% AEP storm event. 1% AEP combined with a 50% blockage on structure 01BALLY0287 indicates flood depths of 0.18m internally. Modelling with a 75% blockage produces flood depths of 0.27m internally. An overland flow path at the front of the house along the Main Street is evident, however flood levels to the rear of the property (i.e. from the watercourse) are higher relative to the threshold level to the house than the Main Street flow route.
Account 4	1947	There was a significant fluvial flood event in 1947. The bifurcation / secondary channel around the church is believed to have been constructed shortly after this.	Present day river geometry differs significantly from time of flood report, unable to recreate within the model.

Report	Event Date	Details	Representation in Model
	1970	There was a significant fluvial flood event in 1970 where all dwellings along the western side of Main Street were reported to have been affected.	For the 1% AEP 12 of 20 properties are shown to be affected. For the 0.1% AEP event 20 of 22 properties on the western side of main street between Chapel Lane and the GAA club entrance are shown to be flooding internally with all properties subject to external flooding.
	Unknown Dates / General Comments	It was reported that the graveyard and church previously flooded with estimated water levels to the top of the wall at Chapel Lane downstream (location 7). Flood waters had entered the church grounds through the stile (c. 56.2mOD).	1% AEP and 0.1% AEP modelled flood indicates 0.88m and 0.6m freeboard respectively to the church stile level (the lowest bank level along the reach). Site observations indicate that the church wall forming the left river bank is made of two distinct construction types - the bottom section of the wall had been constructed with stone and is believed to be the historic top of bank. A c. 1.3m block and render wall had since been added. Historically, the left bank would have been lower than the right bank and flood waters would have spilled towards the church. Current geometry and modelling indicates the right bank to be lower and flows that exceed channel capacity, water would first tend to spill from the right bank at a level of 55.95mOD. Other anecdotal evidence notes that previously the channel at Chapel Lane has been lowered and the road levels risen. No reliance can be therefore be placed on this flood account using present-day channel geometries.
		A house opposite the GAA club entrance (since demolished / replaced by the Brookfield development – location 9) was affected by internal flooding of c. 45cm.	A flow path on the main street at this location is evident during the 1% AEP flood, however it is presumed the Brookfield development has significantly altered ground levels within the location. Historic levels for this area are unknown, therefore reliance cannot be placed on this account with modelled present-day topography.
		There have been flood events where overland flows traverses the fields to rear of properties and across the properties onto Chapel Lane (location 10).	Overland flood route as described is evident on 1% AEP and 0.1% AEP modelled events.

Report	Event Date	Details	Representation in Model
		The channel at Chapel Lane has gradually been lowered and road level has been risen. It was noted that previously cars could be driven directly into river channel (to wash) at Location 7.	N/A
		Arrigle View house at bridge (location 11) and other properties on Chapel Road have previously flooded multiple times.	Arrigle view house is predicted to flood from during a 0.1% AEP event. Flood levels at this locations are sensitive to blockage of the Chapel Lane Bridge, indicating the house to be subject to flooding during a 1% AEP flood event when combined with a low (25%) blockage of the structure immediately downstream. As discussed in Section 6, likelihood of blockage at this location is perceived as high. Two overland flow routes are shown to effect other properties on Chapel Lane. One travelling northerly tending to Chapel Lane routes around the property adjacent to Arrigle House and the flow route emerging from 'Sheff's Lane' effects the row of houses on the corner of Chapel Lane and Main Street.
Account 5		A tributary of the Ballyhale River south of the village (flowing adjacent to the primary school) is noted to flood at a 90 degree bend in the watercourse (location 12). Observations and reports indicate the channel downstream of this point is prone to blockage, exacerbating out of bank flooding at this location. Out of bank flooding from this point in the watercourse tends to flow overland onto 'Sheffs Lane', entering Main Street in the village at location 6 and is likely the most significant contributor to flooding observed within the main street.	The overland flow route from the tributary emerges from the 2% (50 year) immediately downstream of the 90 degree bend and tends to flow overland down 'Sheff's Lane' (location 6) entering the Main Street. The flow path is shown to diverge at the corner of Main Street and Chapel lane with flows tending to re-join the watercourse at Chapel Lane (location 7) or flow down the Main Street and re-join between 'Andy's Pub' (location 8) and the former Garda station. In higher flood events, the flow path is predicted to continue downstream and re-enters the watercourse at the Main Street bridge (location 4) and the Station Road bridge (location 5).

Report	Event Date	Details	Representation in Model
Account 6		No records or photographs are available but it has been noted by Kilkenny County Council that the regional road R699 between Ballyhale and Knocktopher Road has been closed in the past due to flooding of the road. No indication of flood depth or source is provided.	Flooding of the road is noted to occur from the 1% AEP event. The structure is noted to be sensitive to blockage, the 1% AEP flood in conjunction with a 25% structure blockage causes a 0.35m rise in water levels immediately upstream.

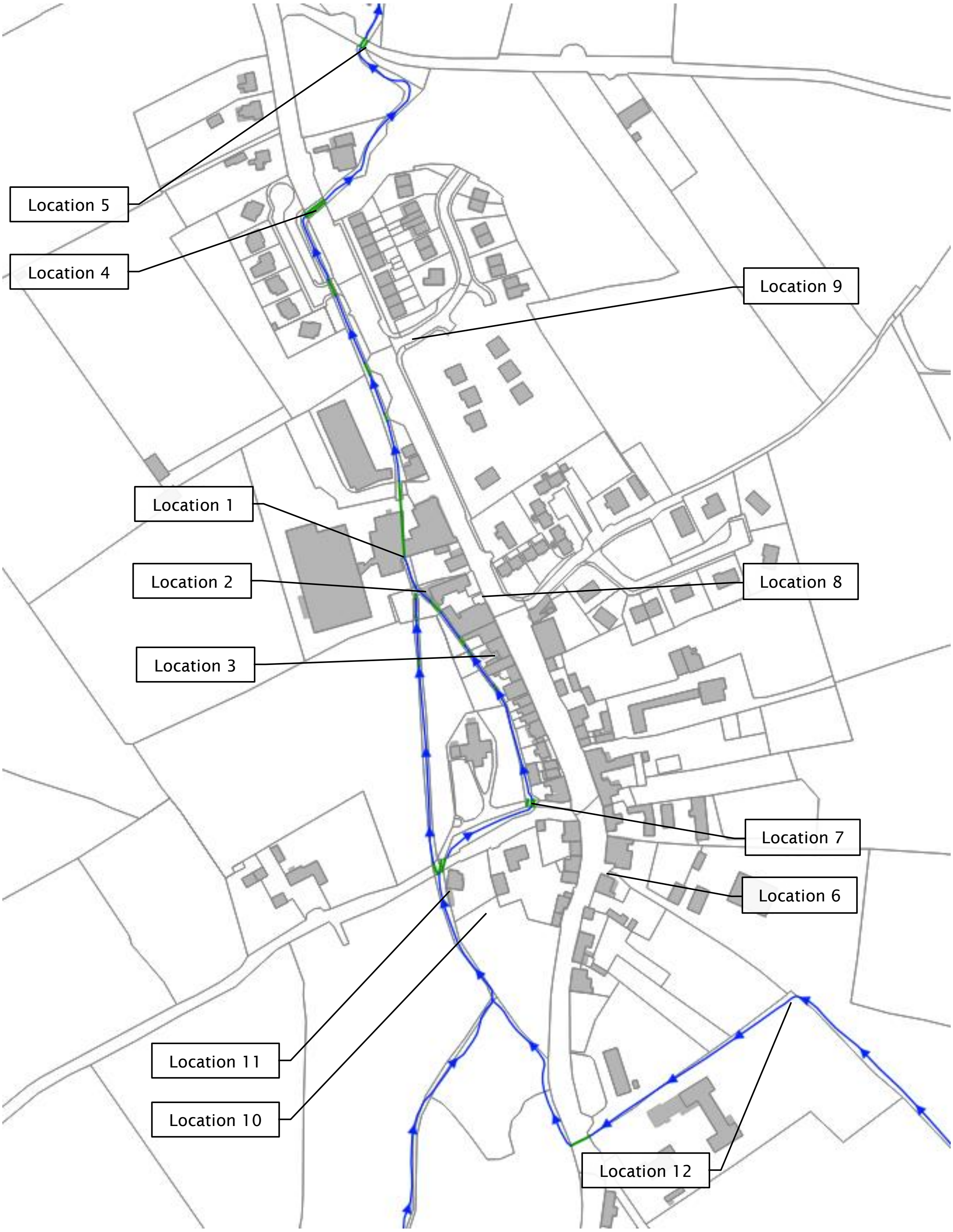

Figure 4-2 Historic Flooding Locations

It is noted that some of the observations pre-date works to channel geometry and so are unable to be used for validation purposes with present day geometries. It is also noted the accounts were obtained at time of study (2020), c. 20 years after the last major recorded flood event which may affect their accuracy.

The model is shown to replicate key overland flow routes and flooding locations. Flooding reports / knowledge disseminate mainly from the November 2000 flood, during which there was known to be blockages of culverts in at least one location. No indication of the magnitude of flood was able to be obtained through records and insufficient rainfall records exist for the area to replicate the event.

Based on the available historical evidence, the model is considered to provide a good correlation with accounts and results obtained are deemed representative.

4.4 Model Stability

An internal model audit has been completed to assess key model build detail and model stability. Several parameters were checked to assess the model stability:

- The mass balance is considered to give an indicator of model stability and relates to the flow entering and leaving the model. The mass balance values for all events are below 0.001%, which is well within the acceptable tolerance level (generally stated as <5%).
- A review of stage hydrographs was undertaken across the model to locate any significant spikes in graphs that would suggest issues with model stability. A review of graphs indicated that the model exhibited no abnormal stage variations that would tend to indicate a model instability within the area of interest (Ballyhale Village).
- A review of flows was undertaken across the model to locate significant spikes in hydrographs that would suggest issues with model stability. Review of graphs indicate no abnormal flow variations within the area of interest that would tend to indicate model instabilities.
- At the downstream extent of the model, review of stage hydrographs indicates no abnormal stage variations that tend to indicate model instabilities. Review of flow hydrographs indicate minor flow variations associated with the quantity of out of channel flooding and 1D-2D exchange of flows. Efforts to reduce the instability include lowering of the modular limit bank coefficients to reduce fluctuations. Flow fluctuations had an unmeasurable impact on the stage hydrograph indicating no effect on flood extents.
- Moderate flow instabilities were exhibited during initial model results at the Little Arrigle / Ballyhale River confluence to the quantity of out of channel flooding and complex geometries at this location. Efforts to reduce the instability at this location include the lowering of the modular limit bank coefficient to bring fluctuations within tolerable levels. It is noted that this location is approximately 1.2km downstream of the main area of interest and any residual instabilities do not affect flood results upstream.

Review of the model results indicate that the model is stable and suitable for use with this study.

5 SENSITIVITY ANALYSIS

5.1 Preamble

Model sensitivity analysis was carried out to assess the sensitivity of the simulation to changes in base parameters. The sensitivity testing makes comparisons to the baseline model within the vicinity of the site and was carried out for the 1% AEP duration flood event as the key standard of protection event.

Comparative analysis was undertaken at cross section locations to assess effect in the 1D across the entire model and within the main area of interest (taken as modelled reaches between section and at specific sample locations in the 2D zone as indicated in the following figure.

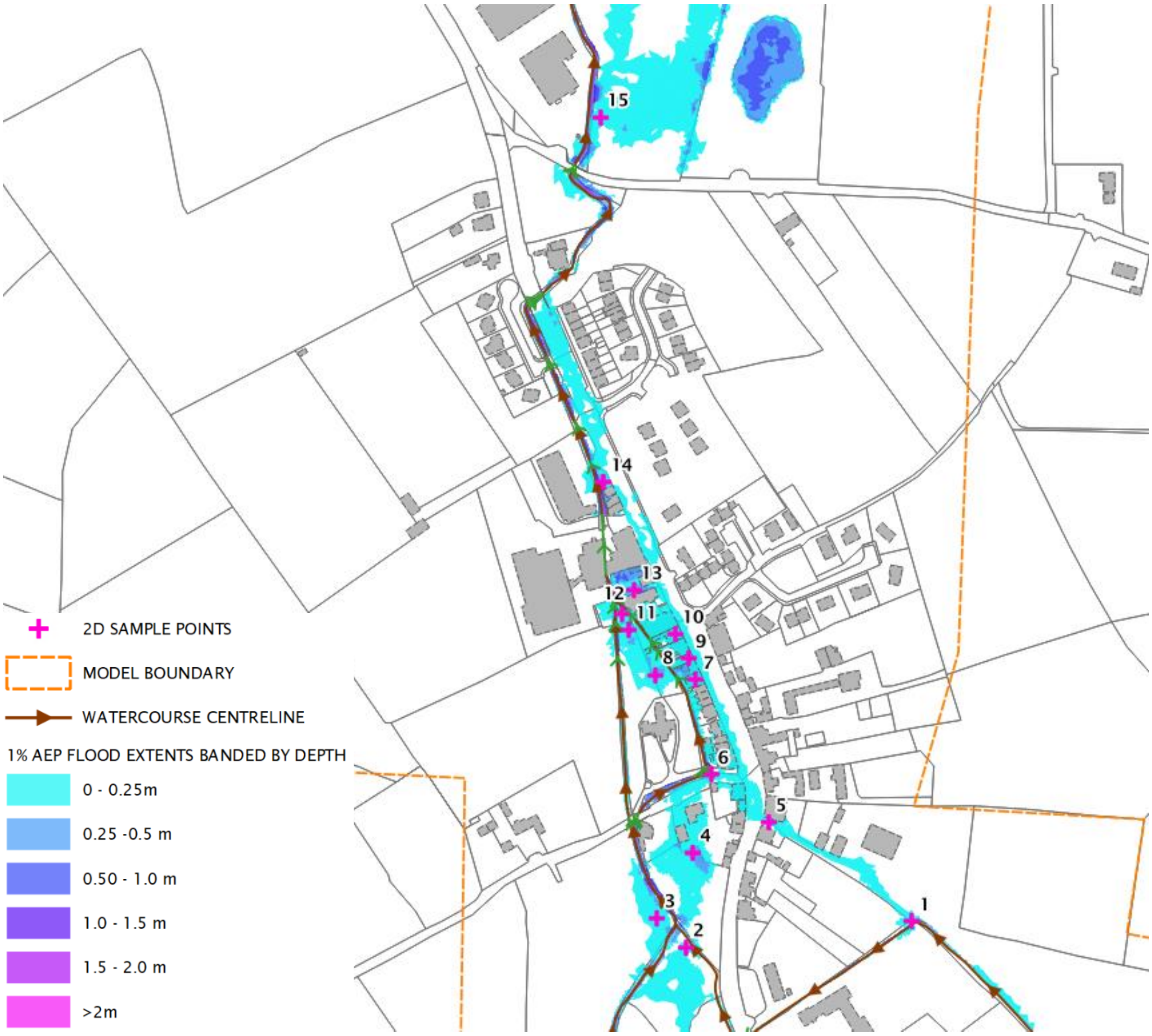

Figure 5-1 Sample 2D Result Locations underlaid by 1% AEP Flood Extent

5.2 Sensitivity to Roughness

5.2.1 1D Roughness

The sensitivity of the modelled water levels to 1D roughness (in channel and structures) was assessed by increasing the Manning's n values adopted for the base model by 20%. A summary of results is detailed in Table 5-1. Figure 5-2 displays the spatial variation of model sensitivity to roughness within Ballyhale village for the 1% AEP event.

Table 5-1 1D Roughness Sensitivity Summary

	Change in Depth (m)		
	1D (Entire Model)	1D (Area of Interest)	2D Sample Points
Average Difference	0.06	0.08	0.04
Maximum Difference	0.24	0.24	0.09

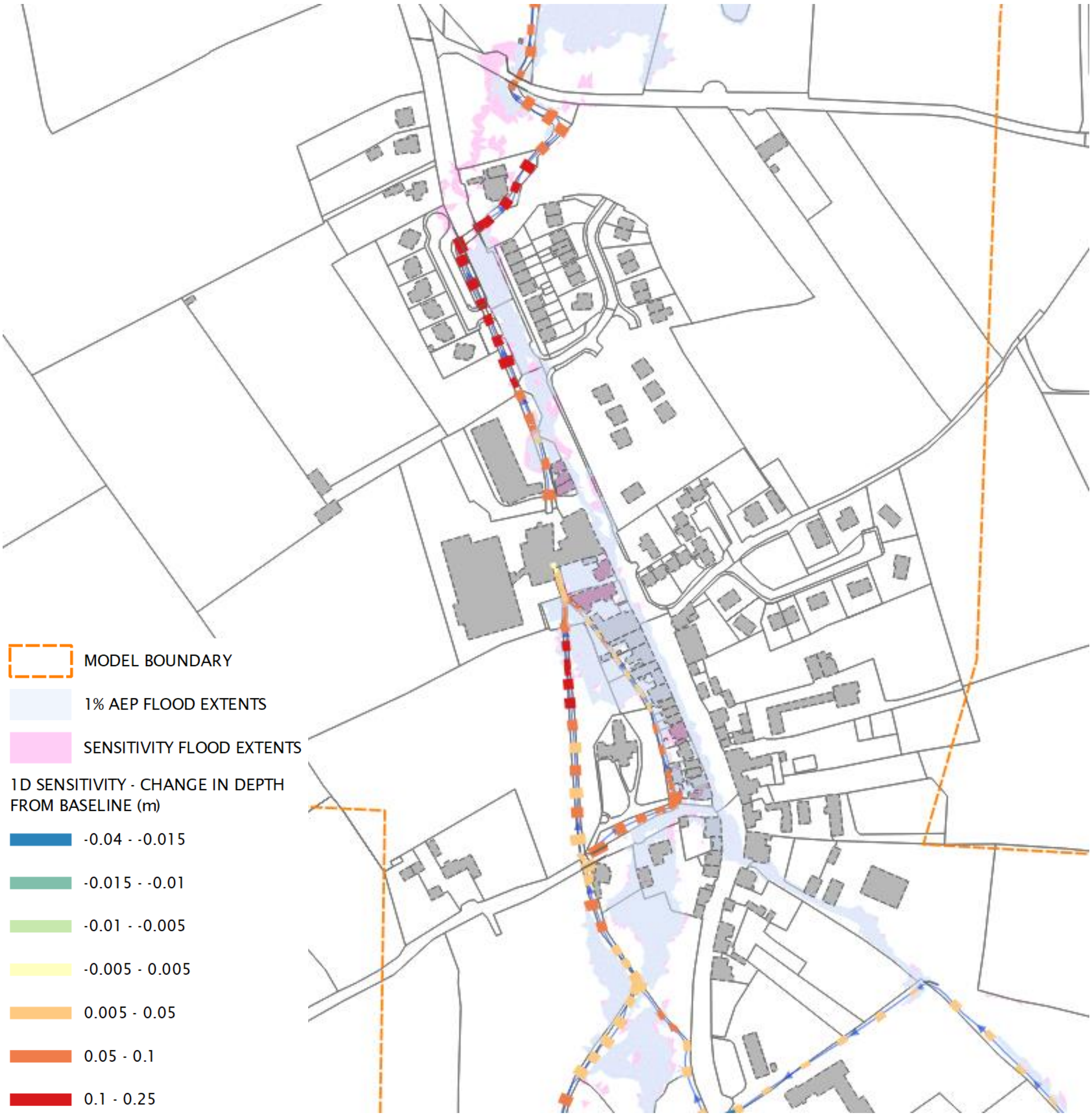

Figure 5-2 1D Roughness Sensitivity

Review of the sensitivity results informs that the 1D roughness causes up to a maximum 0.24m increase in flood levels within the 1D channel, and up to a 0.08m increase in 2D flood levels for the points sampled within the area of interest causing a minor increase in flood extents.

The difference in levels are generally within acceptable limits. Careful consideration has been given to conservatively specifying Manning's n 1D values and there is therefore reasonable confidence in model results. The model therefore does not exhibit a significant sensitivity to 1D roughness variation and would not cause the ultimate findings of the model to be unreliable, uncertainty due to roughness will be accommodated by freeboard within the proposed flood relief options.

5.2.2 2D Roughness

The sensitivity of the modelled water levels to overland roughness was assessed by varying the standard values of Manning's n represented in the 2D for the base model by 20%. A summary of results is detailed in Table 5-2. Figure 5-3Figure 5-2 displays the spatial variation of model sensitivity to roughness within Ballyhale village for the 1% AEP event.

Table 5-2 2D Roughness Sensitivity

	Change in Depth (m)		
	1D (Entire Model)	1D (Area of Interest)	2D Sample Points
Average Difference	0.00	0.00	0.00
Maximum Difference	0.02	0.01	0.01

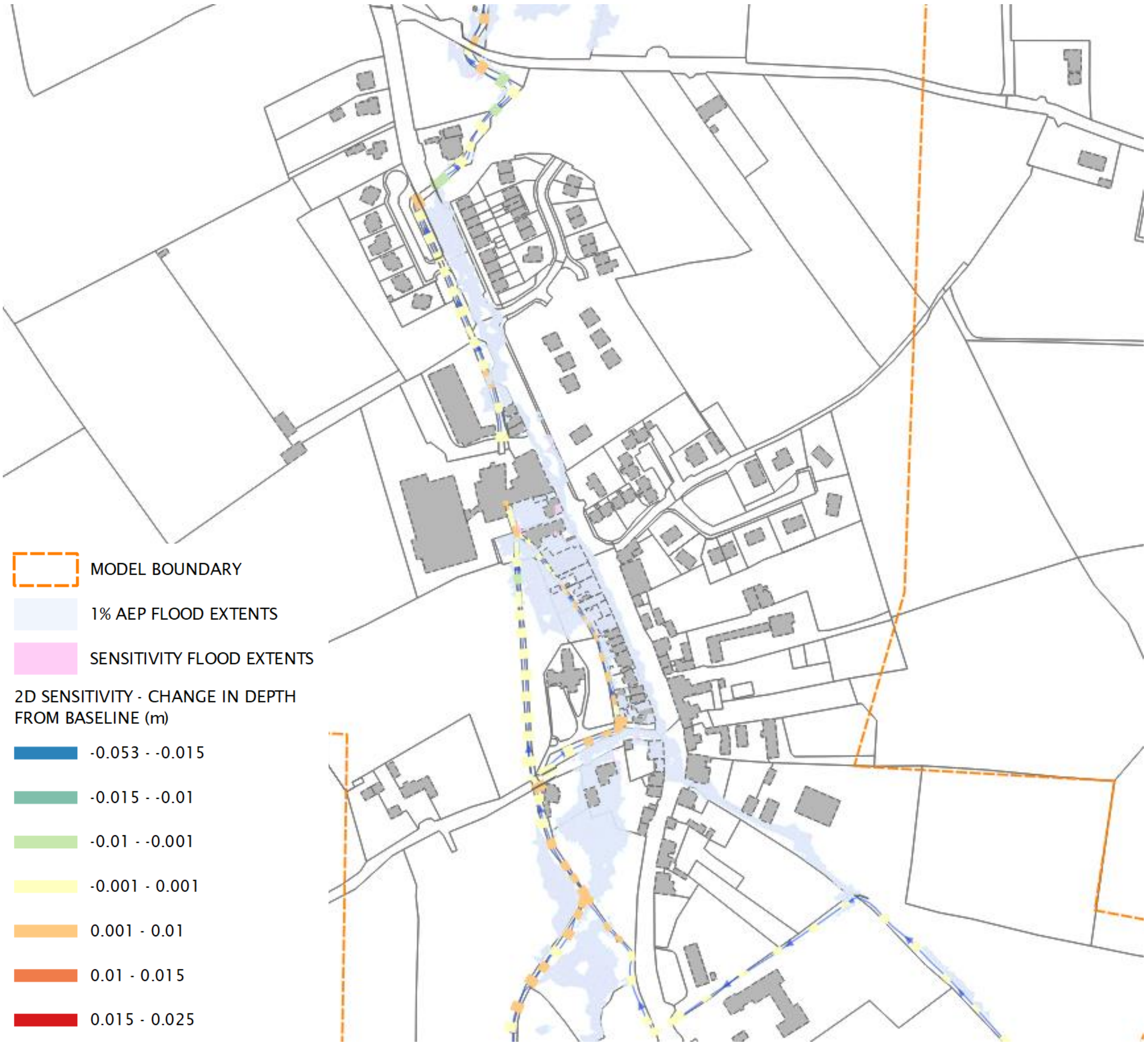

Figure 5-3 2D Roughness Sensitivity

Increasing the roughness value of the 2D Zone and roughness zones by 20% causes a negligible increase in water levels within the area of interest in the 1D and 2D domains (< 0.01m), and up to a maximum 0.02m across the entire model. Results for the sensitivity testing show no significant differences within the model output – flow paths and flood extents remain largely the same.

The difference in levels are generally within acceptable limits. The model therefore does not exhibit a significant sensitivity to 2D roughness variation and would not cause the ultimate finding of the model to be unreliable.

5.3 Sensitivity to Bank Coefficients

The sensitivity of the model to edits made to bank coefficients was assessed by reverting the discharge coefficient and modular limit, to default values (1 and 0.9 respectively). A summary of results is detailed in Table 5-3. Figure 5-4Figure 5-3Figure 5-2 displays the spatial variation of model sensitivity to roughness within Ballyhale village for the 1% AEP event.

Table 5-3 Bank Coefficient Sensitivity

	Change in Depth (m)		
	1D (Entire Model)	**1D (Area of Interest)**	**2D Sample Points**
Average Difference	0.01	0.00	0.01
Maximum Difference	0.10	0.01	0.08

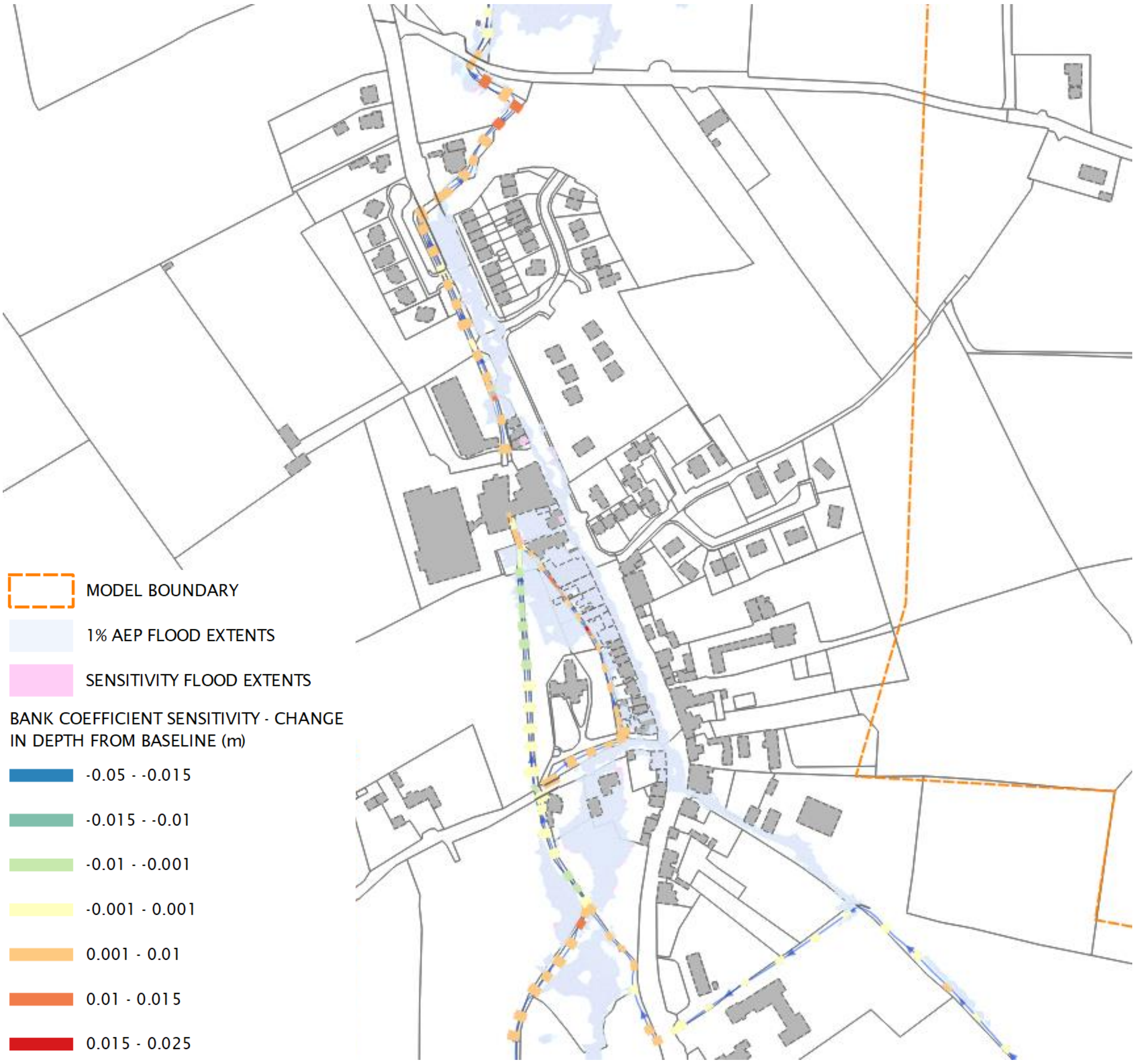

Figure 5-4 Bank Coefficient Sensitivity

Reverting the discharge coefficient (taken as 1-0.8 for vegetated banks and 1.7 for walled banks) and modular limit (taken as 0.5-0.4) with the base scenario to system default values causes a maximum difference of 0.01m within the 1D channel and up to 0.08m increase in 2D levels within the area of interest.

The area of maximum difference within the model (0.1m) is attributed to a portion of the Ballyhale River upstream of its confluence with the Little Arrigle that experiences a significant amount of 1D-2D interaction due to the representation of a secondary channel in 2D alongside the main 1D channel.

The difference in levels are generally within acceptable limits. Careful consideration has been given in adopting representative discharge coefficients and appropriate modular limit coefficients and therefore there is reasonable confidence in model results.

5.4 Sensitivity to Downstream Boundary

A normal boundary condition was applied to the 2D zone. The model boundary was carefully sited sufficiently downstream of the study area to limit the possibility of levels within the area of interest being artificially influenced by the boundary conditions.

Water level from the baseline 1% AEP event was extracted and raised by 1m and applied as a downstream level boundary to assess impact on water levels and flows, indicating no effect upstream within Ballyhale village. The extent of the effect was to c. 450m upstream of the downstream boundary of the model (c.

150m downstream of the Knocktopher tributary. The downstream boundary provides 10m fall in favour of the downstream extent of the village (Station Road) and therefore considered sufficiently robust against any uncertainty in downstream boundary condition.

5.5 Sensitivity to Model Flows

The flows for the model were derived using best industry techniques, as outlined in the Hydrology Report.

The underlying hydrological analysis is per the best available industry techniques for ungauged catchments. The QMED calculations are limited by the lack of flood data between 2004 to date on the FSU portal. Analysis undertaken as part of the hydrology using the AMAX dataset on the effect of the additional flood data since 2004 indicated that sensitivity testing to avoid underestimation should exceed c. 5% (refer to analysis carried out within Section 7 of the Hydrology Report).

Factorial Standard Error (FSE) is a measure used to describe uncertainty and can be used to assess the potential range of flood flows for given confidence intervals (68% and 95%) based on the calculated unadjusted QMED. The FSE upper and lower bounds indicate the likelihood of an under or overestimation of flows at the different confidence intervals, i.e. flows at or exceeding the upper bound have a 68%/95% confidence rating of being an overestimate based on a normal distribution.

The adjusted QMED estimation for the hydrological estimation points was assessed within the Hydrology Report against the FSE 68% and 95% confidence intervals. The maximum variance (calculated as Upper/Lower Limit / Qmed (adjusted) per Table 7-5 of the Hydrology Report for the chosen pivotal site) is detailed in the following table. The maximum variances are approximately equal across all HEPs considered per the Hydrology Report, Table 7-5.

Table 5-4 FSE Maximum Variances

Confidence Level	Lower Bound – Maximum Underestimation	Upper Bound – Maximum Overestimation
68% Confidence	43%	7%
95% Confidence	58%	46%

Analysis was undertaken using the higher probability events with the 95% upper confidence bound (i.e. QMED x 1.46) that indicated adoption of the 95% certainty of overestimation caused significant flooding, including internal flooding of dwellings, that is unrealistically conservative and frequent, and is not reflected in the limited history of flooding in the area. The 95% certainty of overestimation is discounted as unrealistic.

Assessment of sensitivity to model flows was carried out using the 68% certainty of overestimation (+7%) plus uncertainty arising from the lack of flood data from 2004 on the FSU portal (+5%) resulting in a total uncertainty of +12%. This uncertainty is captured by sensitivity testing of flood flows up to +20%.

A summary of sensitivity results with flows increased by 20% is detailed in Table 5-5. Figure 5-5 displays the spatial variation of model sensitivity to roughness within Ballyhale village for the 1% AEP extents.

Table 5-5 Model Flow Sensitivity

	Change in Depth (m)		
	1D (Entire Model)	1D (Area of Interest)	2D Sample Points
Average Difference	0.09	0.12	0.07
Maximum Difference	0.28	0.28	0.15

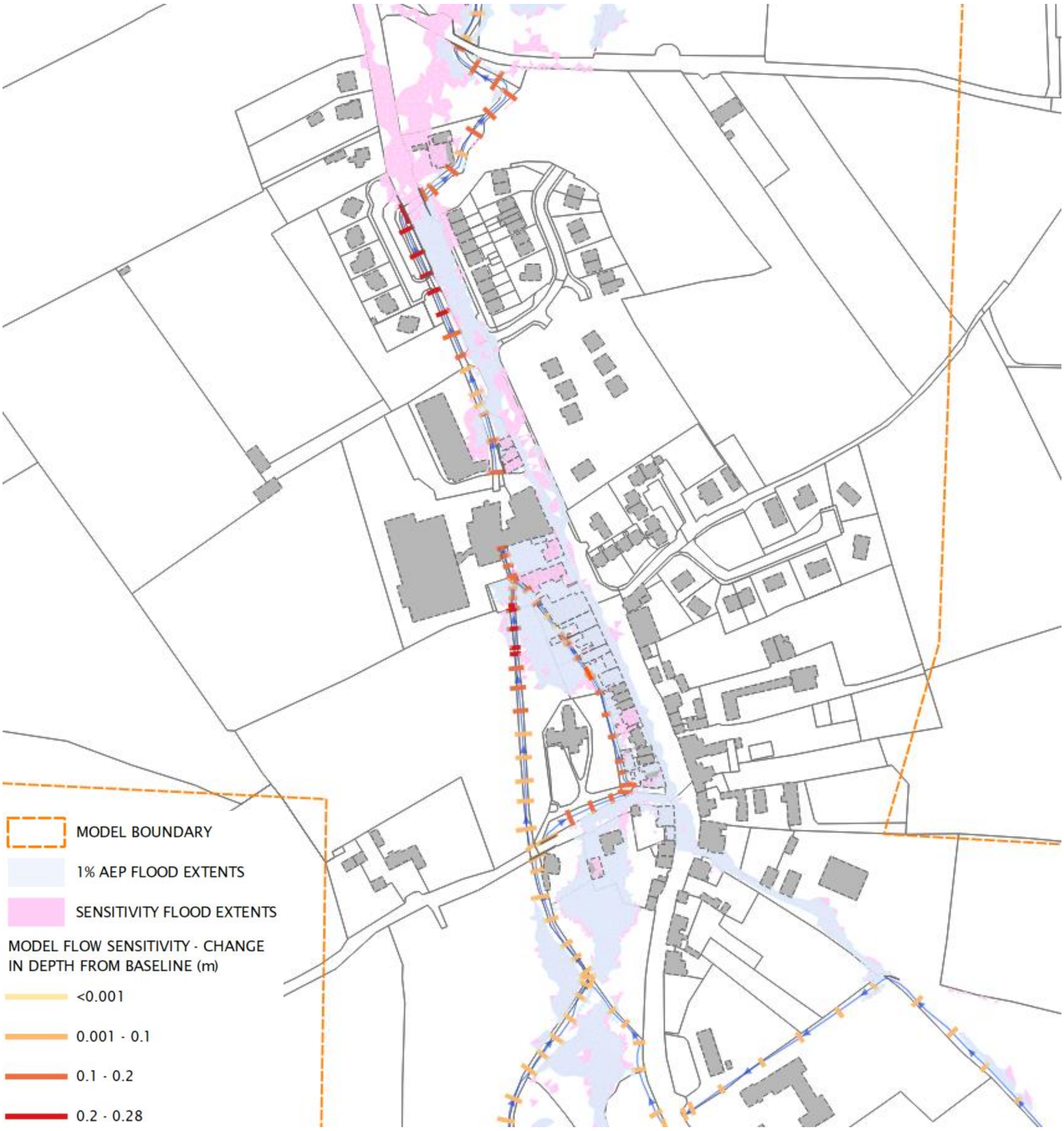

Figure 5-5 Model Flow Sensitivity

Increasing the model flows by 20% causes an average increase in water levels of 0.12m within the area of interest, up to a maximum 0.28m across the entire model.

Areas of greatest sensitivity are observed where the flow increase broaches a downstream culvert capacity or exacerbates existing incapacity, causing a more severe afflux / backwater effect. Options are likely to include measures to replace, daylight, or bypass these structures and as such the uncertainty is less likely to be realised within any scheme.

Potential underestimation of flows is inherent in all hydrological analyses and accepted as a limitation of modelling exercises. Proposed options to include sufficient freeboard to accommodate any uncertainty in flows and any scheme in areas where sensitivity is >0.2m will include additional testing and specification of additional freeboard to suit. The maximum sensitivity would be contained by the nominal minimum freeboard applied to any OPW defence (0.3m).

5.6 Sensitivity Analysis Summary

The sensitivity analysis demonstrates that parameters selected for the model build are appropriate. Effects on absolute predicted water levels generally do not exceed normally anticipated inherent uncertainty in flood model estimation, and in terms of end-use would be accommodated within industry standard freeboard allowances with regards to flood protection standards.

Where schemes are proposed in areas noted to be susceptible to sensitivity to flow, additional sensitivity testing will be included in the scheme assessment with a view to increasing freeboard / scheme capacity if required.

6 BLOCKAGE ANALYSIS

6.1 Preamble

Six locations were identified for blockage analysis, as detailed in the following table. The flood hazard has been determined by implementing a blockage for each structure in isolation within the flood model corresponding to 25% / 50% / 75% of the opening sizes coinciding with a 1% AEP flood.

Kilkenny County Council have confirmed that there is no regular maintenance programme for the watercourses / structures within Ballyhale, increasing the likelihood of blockages.

Table 6-1 Structure Blockage Rationale

Structure	Rationale for Analysis
BALLY00011 - Main Street Culvert on Ballyhale Tributary	Visibly blocked upon site inspection from debris. Unmaintained highly vegetated channel upstream likely to create blockage debris.
01BALLY03080 – Chapel Lane Bridge on Ballyhale River.	Land use upstream likely to create blockage debris, first structure where debris has an opportunity to get trapped before entering the urban area where there is less vegetation. Metal pipes traverse the opening on the upstream side which is likely to promote blockage.
01BALLY02890 – Garage Boundary Wall Structure on Ballyhale River.	Anecdotal reports of potential previous blockage had occurred and exacerbated flooding upstream.
01BALLY02870 – Arrigle Business Park Culvert on Ballyhale River.	Anecdotal reports of previous blockage. Culvert is built over and so flows may get 'trapped' on upstream face creating large increases in flood levels upstream.
01BALLY02640 – Main Street Bridge on Ballyhale River.	Local reports that the structure is prone to siltation build up and has previously had sedimentation on the upstream face removed.
02BALLY00770 – R699 Ballyhale to Knocktopher Road Bridge on Little Arrigle River	Land use upstream (forested + dense vegetation) likely to create blockage debris, first structure along reach where debris has an opportunity to get trapped.

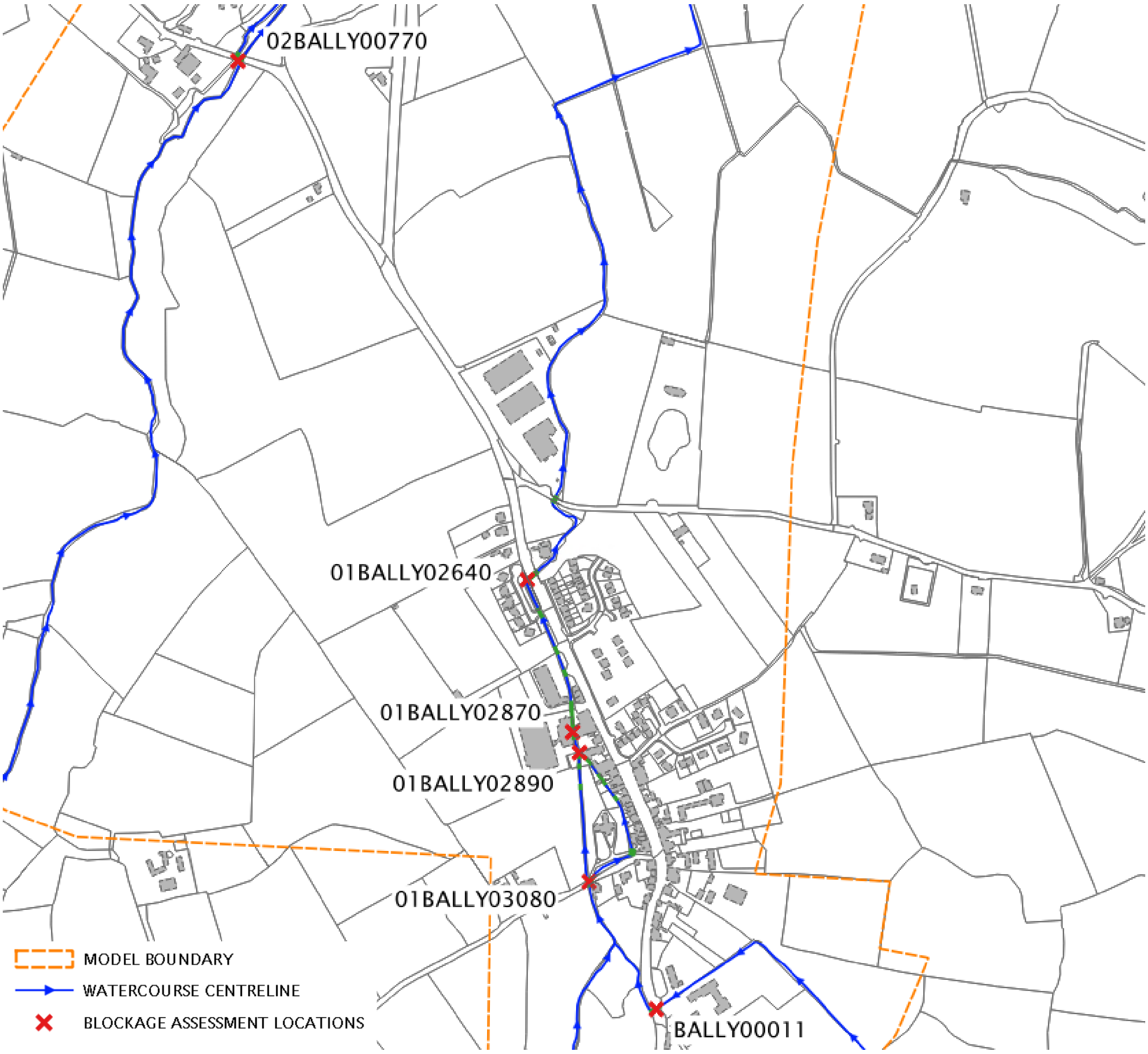

Figure 6-1 Structure Blockage Locations

6.2 Blockage Likelihood Assessment

The likelihood of blockage for all conduits is elevated due to the lack of a formal maintenance programme on the watercourse. The likelihood of blockage has been qualitatively assessed based on the structure type and environmental surroundings, to include:

- Upstream land use / historical blockages – densely vegetated areas are more likely to produce blockage debris and previous reports or observed blockages.
- Access / Visibility – poor access and poor visibility of the structure will inhibit any informal maintenance carried out and to clear existing debris and blockages.
- Geometry of Structure – if the culvert is narrow (i.e. width is less than height), this may lead to blockage. Multiple openings or pillars may encourage entrapment of debris on the upstream side.
- Structure Entrance / Exit conditions – condition of inlet structures, approach of watercourse or any services / pipe crossings in proximity to the structure may all promote blockage. It is noted that no trash screens were observed on any structure.

Each category was assigned an individual likelihood factor contributing to blockage and assign a score as follows:

- Low – 1
- Moderate – 2
- High – 3

The scores were totalled and used to assess the overall structure likelihood of blockage, assessed as follows:

- Low – 1-4
- Moderate – 4-8
- High – 8-12.

This assessment excludes the effect of any future maintenance likely to be associated with implementation and maintenance of a future flood relief scheme.

Table 6-2 Baseline Blockage Likelihood Assessment

Structure	Upstream Land Use / Historic Blockages	Access / Visibility	Structure Geometry	Entrance / Exit Conditions	Likelihood of Blockage
BALLY00011	Rural with dense vegetation along banks of watercourse, particularly at culvert inlet location. Observed to be partially blocked.	Vegetation and c. 1.5m drop impedes access on upstream face. Poor visibility of culvert inlet.	Single arch structure. Width less than height.	Sharp 90 degree bend at culvert outlet.	High (8.5)
Likelihood Factor	High (3)	Moderate (2)	Moderate (2)	Low- Moderate (1.5)	
01BALLY03080	Rural with vegetated banks. No upstream structures for blockage.	Accessible from Chapel Lane or via agricultural lands. Structure visible from adjacent house and church lands.	Four openings, two openings have a width less than height.	Pipe partially blocks the upstream face of the openings. Eastern reach sharp bend at outlet.	High (8)
Likelihood Factor	High (3)	Low (1)	Moderate (2)	Moderate (2)	

Structure	Upstream Land Use / Historic Blockages	Access / Visibility	Structure Geometry	Entrance / Exit Conditions	Likelihood of Blockage
01BALLY02890	Debris material likely domestic. Previously partially blocked.	Poor access via the rear of properties on Main Street. Structure visibility poor.	One clear span opening the width of the channel.	Straight clear inlet/outlet conditions.	Moderate (6.5)
Likelihood Factor	Moderate (2)	Moderate – High (2.5)	Low (1)	Low (1)	
01BALLY02870	Debris material likely domestic. Previously partially blocked.	Poor access on U/S face via the rear of properties on Main Street. U/S structure visibility poor.	Clear span opening the width of the channel. Former bridge piers in situ from when bridge was extended promoting blockage.	Straight clear inlet/outlet conditions. Services on outlet.	High (8)
Likelihood Factor	Moderate (2)	Moderate – High (2.5)	Moderate (2)	Low - Moderate (1)	
01BALLY02640	Debris material likely domestic. Dense vegetation on banks upstream. Reported to be prone to sedimentation.	Access to U/S and D/S faces from adjacent lands. Good visibility U/S from adjacent development.	Twin arched structure, second opening vegetated and raised slightly upstream.	Sharp 90 degree bend at culvert inlet. Vegetated banks.	Moderate (7)
Likelihood Factor	Moderate - High (2.5)	Low (1)	Moderate (2)	Low – Moderate (1.5)	
02BALLY00770	Rural with dense vegetation along banks of watercourse, particularly at culvert inlet and outlet locations.	Poor access via road due to levels and vegetation. Structure visibility poor.	Twin arch structure (openings situated c. 8m apart)	Straight inlet / outlet conditions. Large distance between structure openings.	High (9.5)
Likelihood Factor	High (3)	High (3)	Moderate (2)	Low-Moderate (1.5)	

6.3 Blockage Hazard Assessment

6.3.1 BALLY00011 - Main Street Culvert on Ballyhale Tributary

Structure BALLY00011 is an arch culvert c. 1180mm high x 821mm wide, located under the main street on the Ballyhale Tributary. Due to land use upstream (unmaintained channel with heavily vegetated banks), observed blockage on site, lack of formal maintenance and no other likely blockage locations upstream, the likelihood of blockage is assessed as high. The effect of blockage for each scenario is displayed in the following figures.

Blockage at this location causes a localised increased in water levels upstream of the structure for the 25% and 50% blockage scenario, shown to be retained in bank. Due to the elevation difference, blockage at this location does not affect flooding from the overland flow route down 'Sheff's Lane' upstream. The maximum modelled (75%) blockage causes a maximum increase in flood levels of up to 1.86m immediately upstream of the structure, water routes around the wall structure on the road and forms an overland flow route down the Main Street.

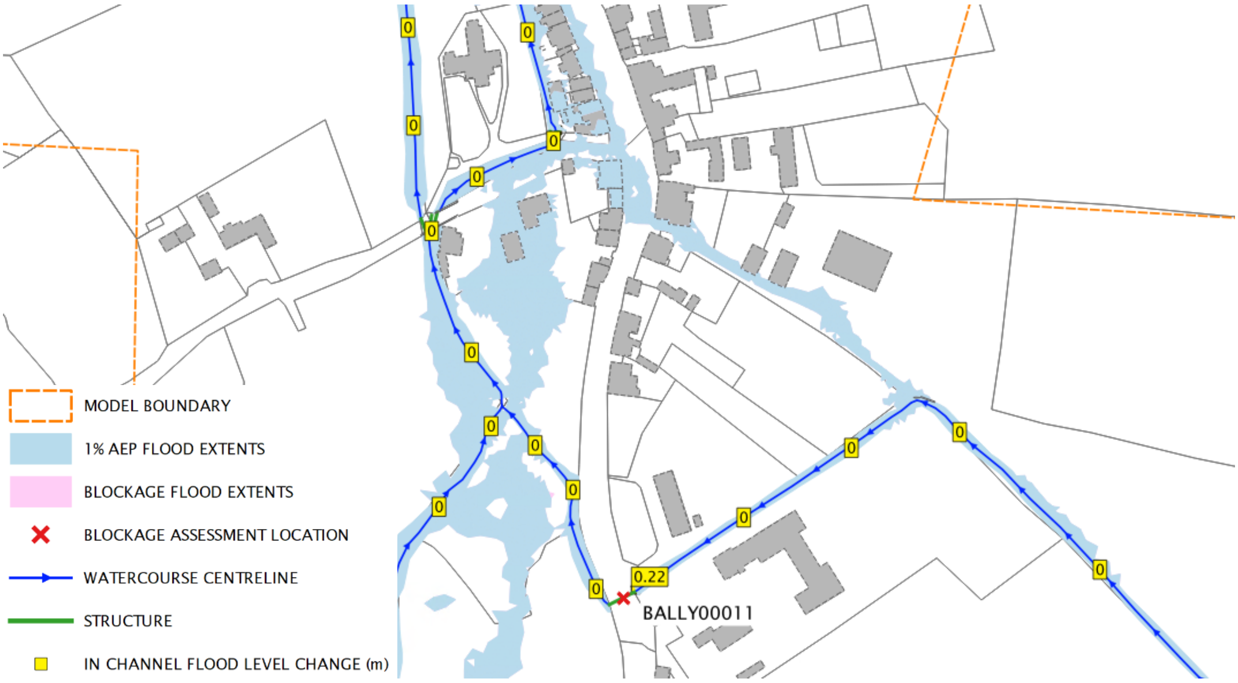

Figure 6-2 BALLY00011 -25% Blockage

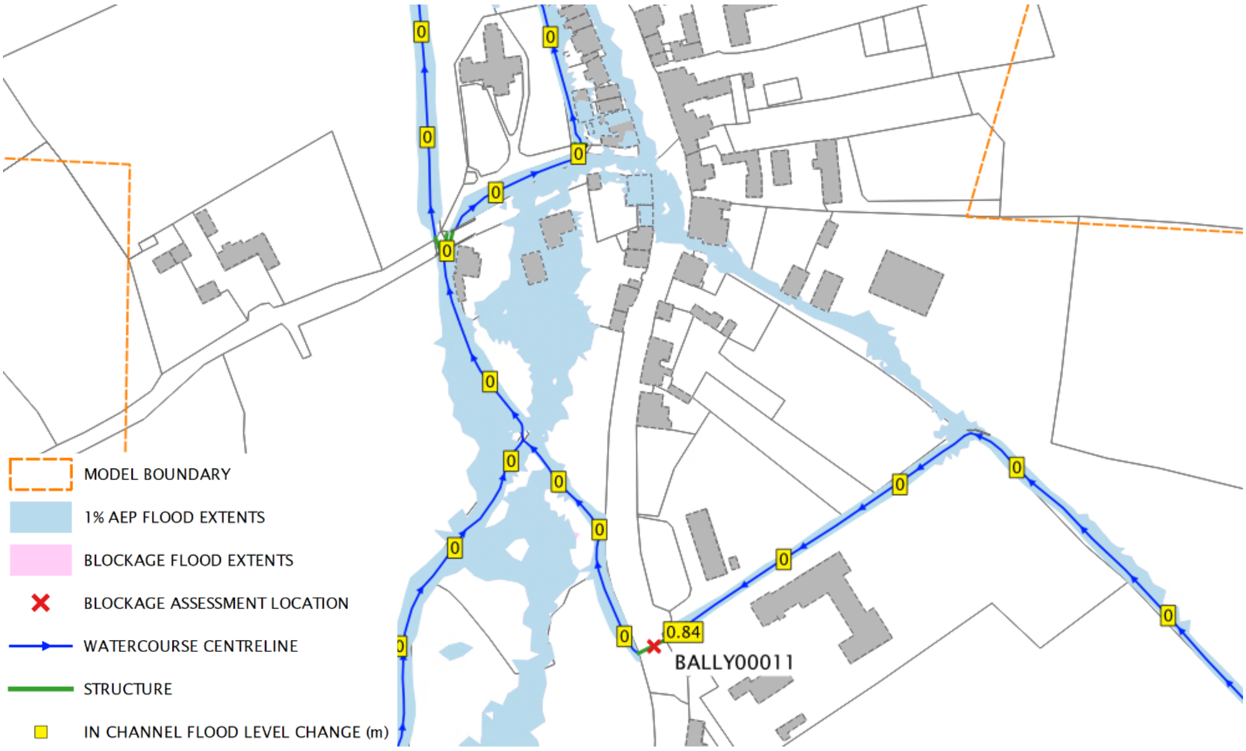

Figure 6-3 BALLY00011 - 50% Blockage

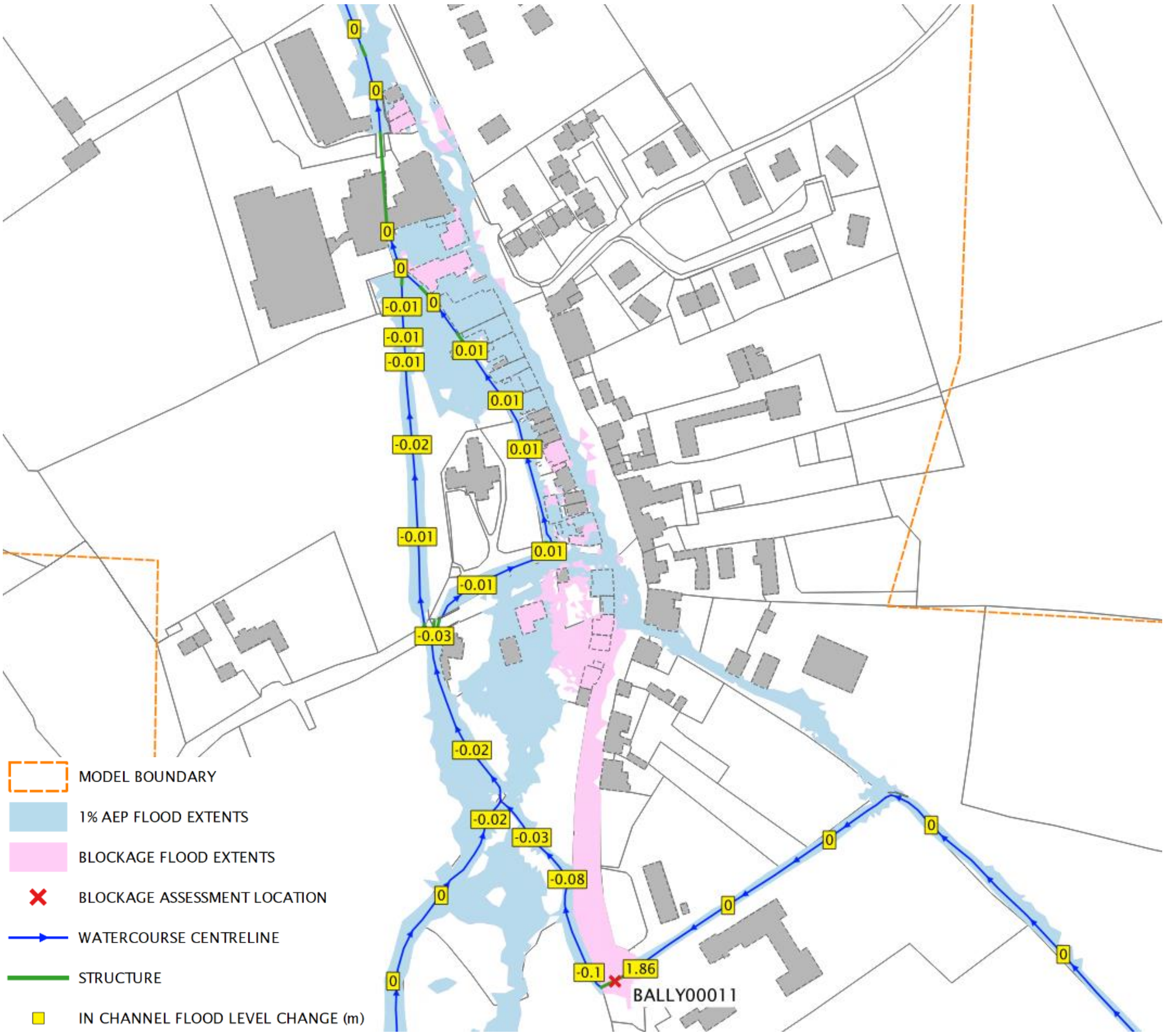

Figure 6-4 BALLY00011 - 75% Blockage

6.3.2 01BALLY03080 – Chapel Lane Bridge on Ballyhale River

The Chapel Lane bridge is the first structure upstream of the Ballyhale urban area and consists of four openings at differing invert levels which bifurcate the watercourse to two reaches around the church. Two rectangular openings c. 2690mm x 1200mm and 689mm x 655mm discharge to the western reach, and an arched culvert 2580mm x 1680mm and rectangular culvert 550mm x 1051mm discharge to the eastern reach.

Due to land use upstream (rural with vegetated banks / overhanging trees), lack of formal maintenance and no other likely blockage locations upstream, the likelihood of blockage is assessed as high. The effect of blockage for each scenario is displayed in the following figures.

Blockage at this location causes an increase in flows overtopping the eastern bank and tending towards Chapel Lane, re-entering the channel at the lowered wall section at the channel. The maximum modelled (75%) blockage causes a maximum increase in flood levels of up to 0.95m immediately upstream of the structure.

It is shown that for the 25% and 50% blockage scenarios, levels on the western reach at the church are raised due to the structure 01BALLY03080 opening higher invert and available capacity to this reach. During the 75% blockage scenario, significantly more flow overtops the eastern bank upstream of the structure, tending to Chapel Lane causing a rise in levels within the eastern reach at the church.

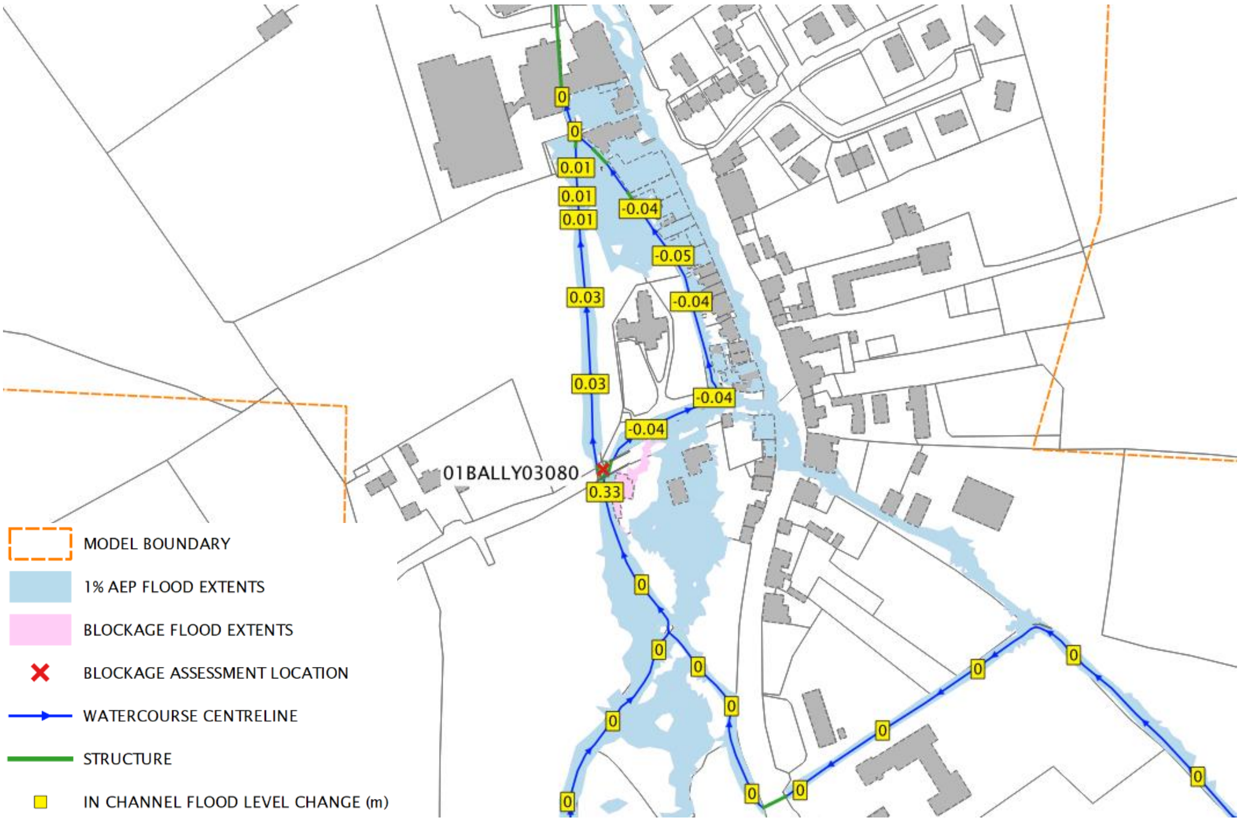

Figure 6-5 01BALLY03080 - 25% Blockage

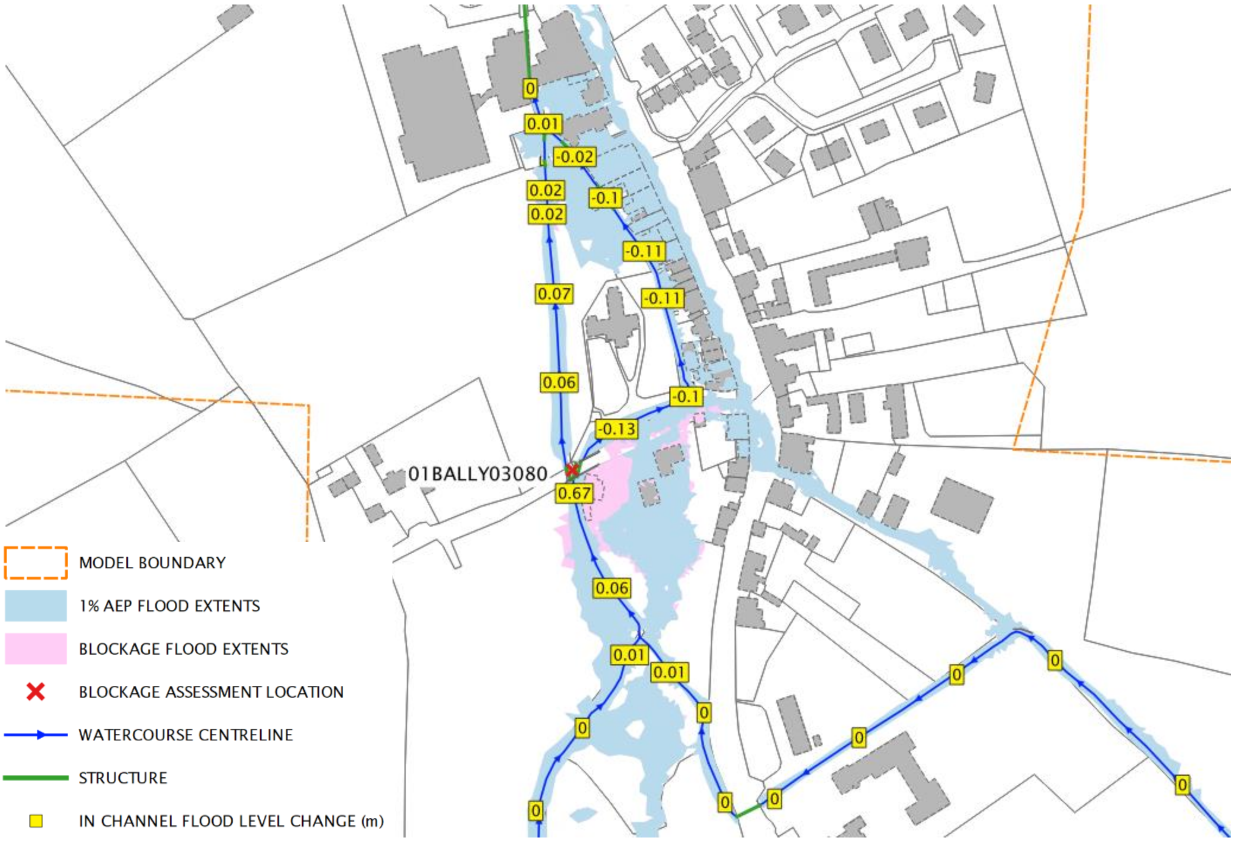

Figure 6-6 01BALLY03080 - 50% Blockage

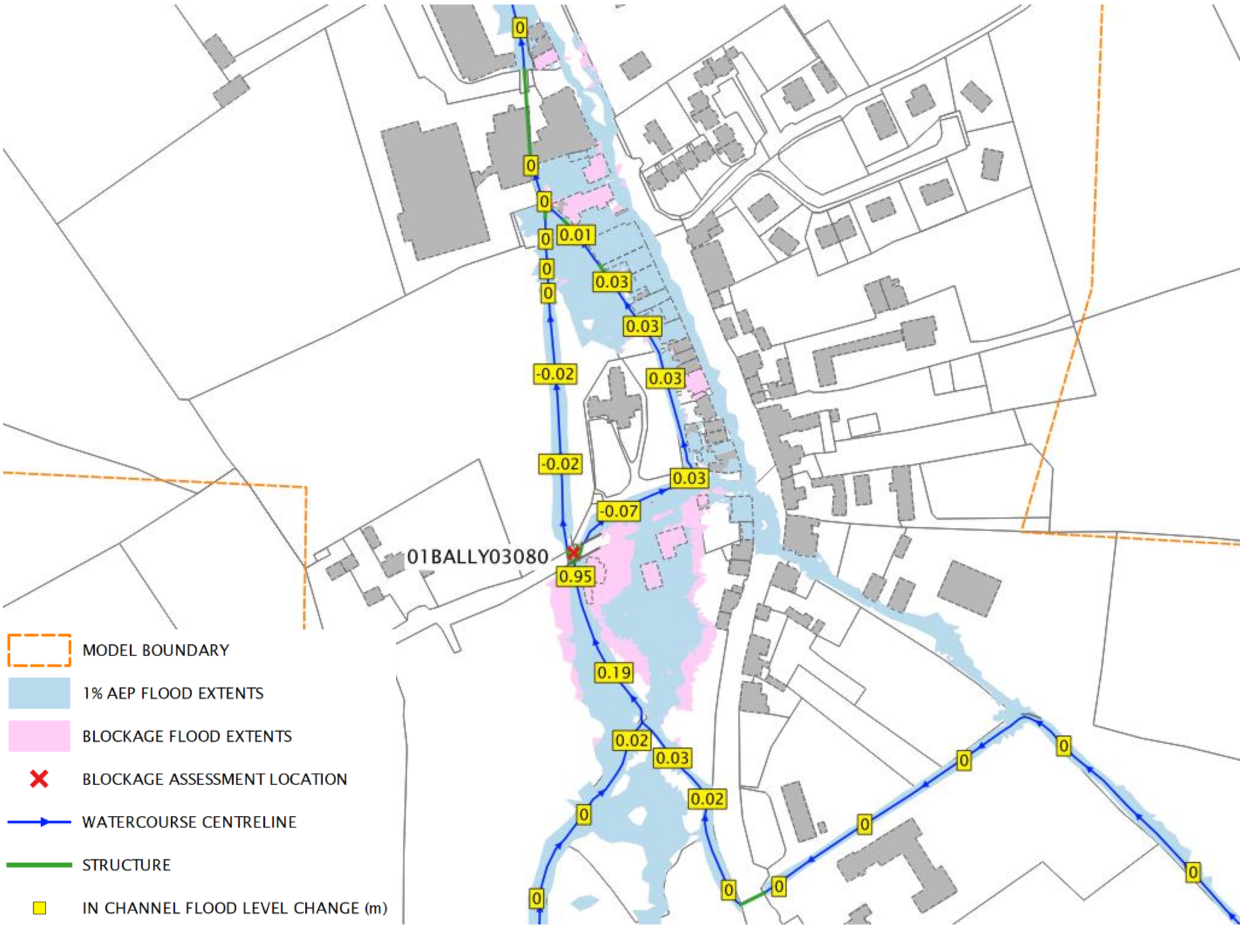

Figure 6-7 01BALLY03080 - 75% Blockage

6.3.3 01BALLY02890 – Garage Boundary Wall

The garage boundary wall structure spans the Ballyhale River immediately after the confluence of the eastern and western church reaches producing an opening of 3660mm x 1650mm. Anecdotal reports indicated blockage downstream of the main street houses and businesses at this location. Due to poor access, vegetation upstream in the channel and lack of formal maintenance, the likelihood of blockage is assessed as moderate.

Modelling of a 25% blockage shows little effect on flood levels in the vicinity due to the structure's available capacity. Increased blockage severity to 50%/75% causes a maximum increase in flood levels of 0.13 and 0.39m respectively immediately upstream of the structure. The increase in flood levels causes further encroachment of flood extents on adjacent surrounding lands.

It is perceived that blockage of structure 01BALLY02890 may have been in conjunction with the subsequent more hydraulically critical structure downstream (01BALLY02870), analysed in Section 6.3.4

Figure 6-8 01BALLY02890 – 25% Blockage

Figure 6-9 01BALLY02890 – 50% Blockage

Figure 6-10 01BALLY02890 – 75% Blockage

6.3.4 01BALLY02870 – Arrigle Business Park

The Arrigle business park structure has a critical opening area of 3300mm x 1440mm and is located immediately downstream of the garage wall structure. Anecdotal reports indicated blockage downstream of the main street houses and businesses. The structure is noted to have been extended from its construction and former bridge piers were observed which are likely to promote blockage. Due to this, poor access and lack of formal maintenance, the likelihood of blockage is assessed as high.

The culvert is built over and the channel upstream is manmade with steep walled banks therefore blockage at this location causes a substantial increase in flood levels of up to 1m as waters are not easily able to route around the structure. The increase in flood levels results in an increase of flood depths to the properties on Main Street and the creation of a significant overland flow path routing around the structure onto the Main Street flowing northerly, eventually returning to channel at Station Road.

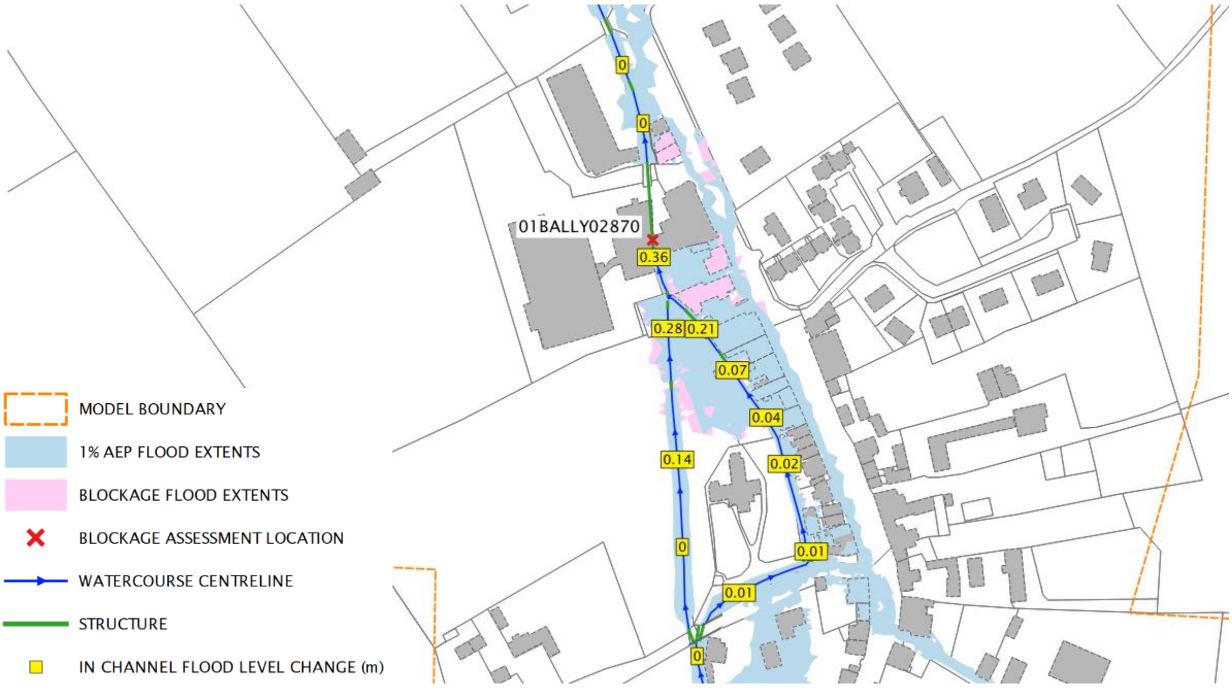

Figure 6-11 01BALLY02870 – 25% Blockage

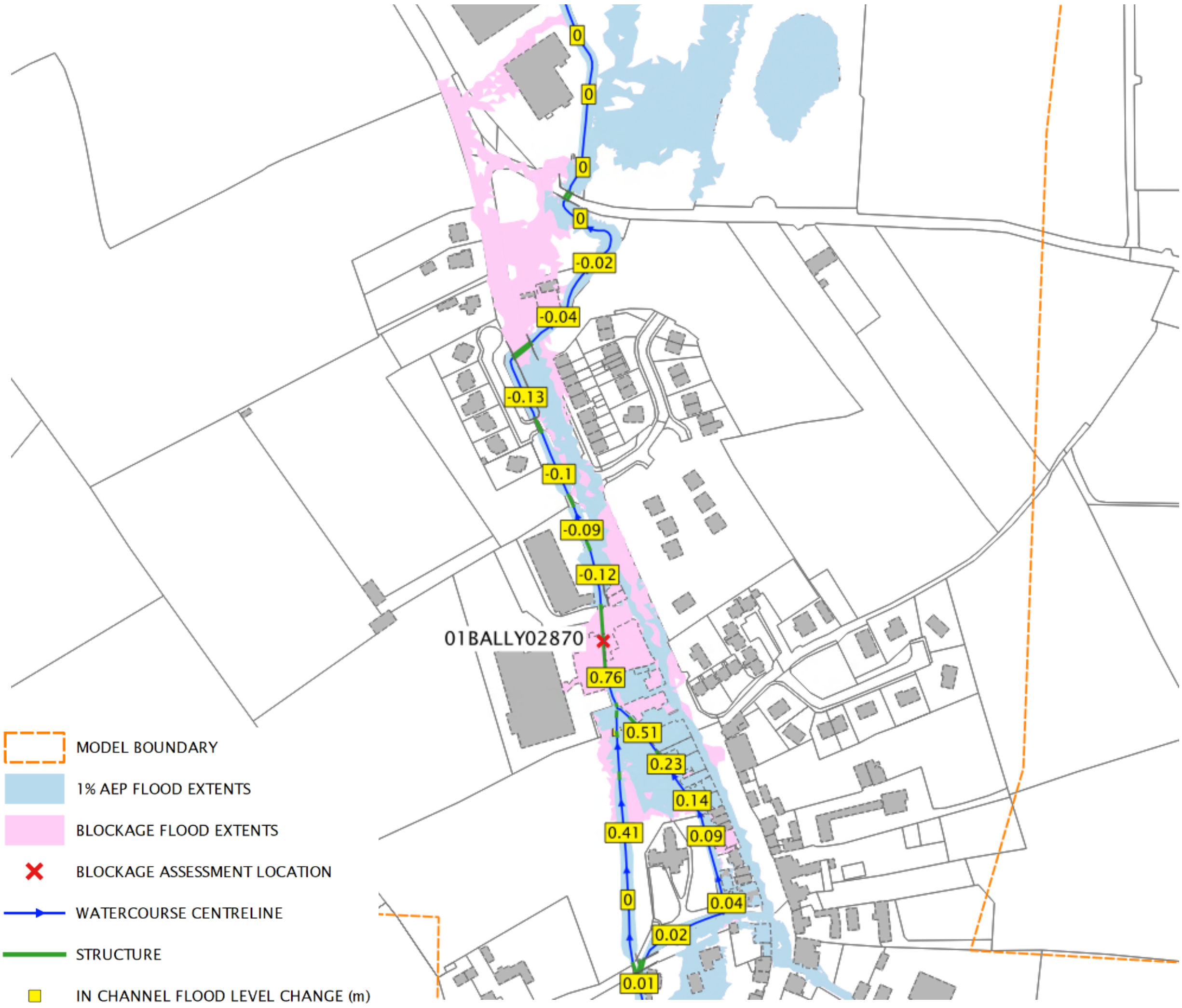

Figure 6-12 01BALLY02870 - 50% Blockage

Figure 6-13 01BALLY02870 - 75% Blockage

6.3.5 01BALLY02640 – Main Street Bridge

The Main Street bridge is twin arch structure sized 2060mm x 930mm and 1740mm x 1050mm and is reported to be prone to sedimentation. The invert of one opening of the bridge was surveyed as being 0.11m higher than the second opening due to sedimentation and vegetation upstream.

Due to the observed sedimentation, vegetation, and lack of formal maintenance the likelihood of blockage is assessed as moderate.

Blockage at this location results in a maximum increase in flood levels of 0.48m immediately upstream of the structure, causing an overland flow route from the left bank of the bridge flows across the main street through an opening in the Hazelbrook development boundary wall, tending north easterly and returning to channel downstream of the Station Road crossing.

Figure 6-14 01BALLY02640 - 25% Blockage

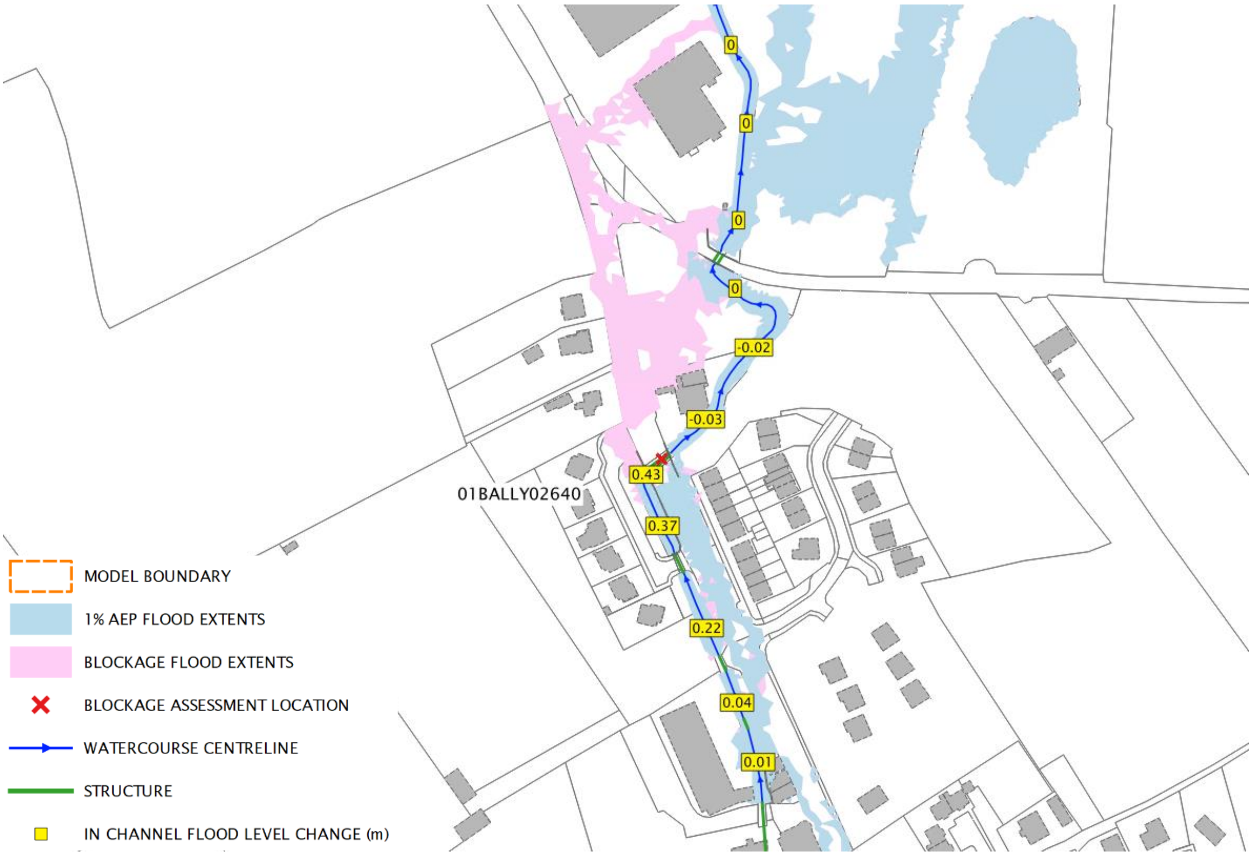

Figure 6-15 01BALLY02640 - 50% Blockage

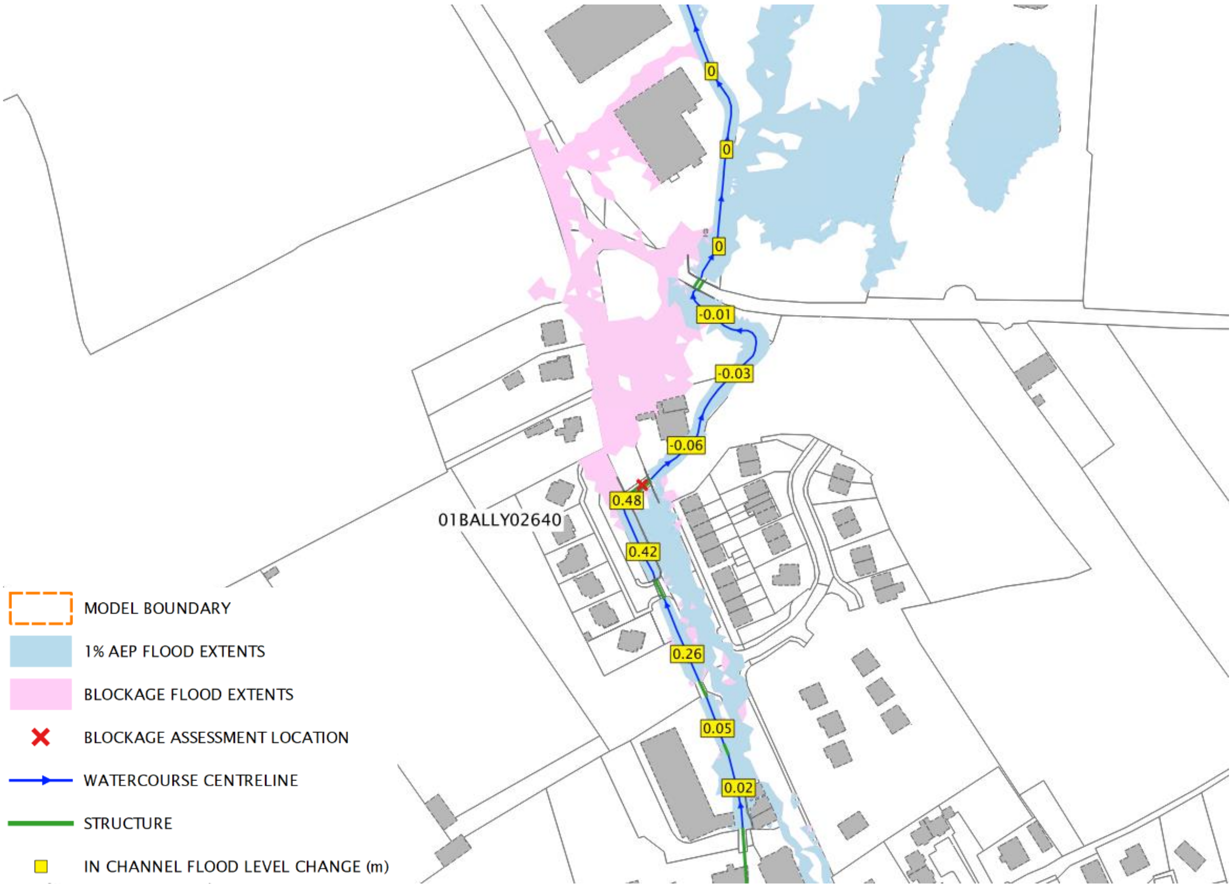

Figure 6-16 01BALLY02640 - 75% Blockage

6.3.6 02BALLY00770 – R699 Ballyhale to Knocktopher Road Bridge

The road bridge along the R699 Ballyhale to Knocktopher road is a twin arch structure. Lands upstream are heavily vegetated, including lands within the channel between the two arches. There is no formal maintenance and no other likely blockage locations upstream, therefore the likelihood of blockage is assessed as high. The effect of blockage for each scenario is displayed in the following figures.

Blockage at this location causes an increase in flood depths upstream of the bridge, flood waters continue to overtop the road and re-join the river reach downstream. The bridge is reported to flood frequently, however no detail around this was able to be obtained in the initial data collection exercise. The maximum modelled (75%) blockage causes a maximum increase in flood levels of up to 0.37m immediately upstream of the structure.

The road is showing to overtop in the baseline 1% AEP simulation, partial blockage of the structure is shown to exacerbate this and is likely to cause overtopping during lower return period events.

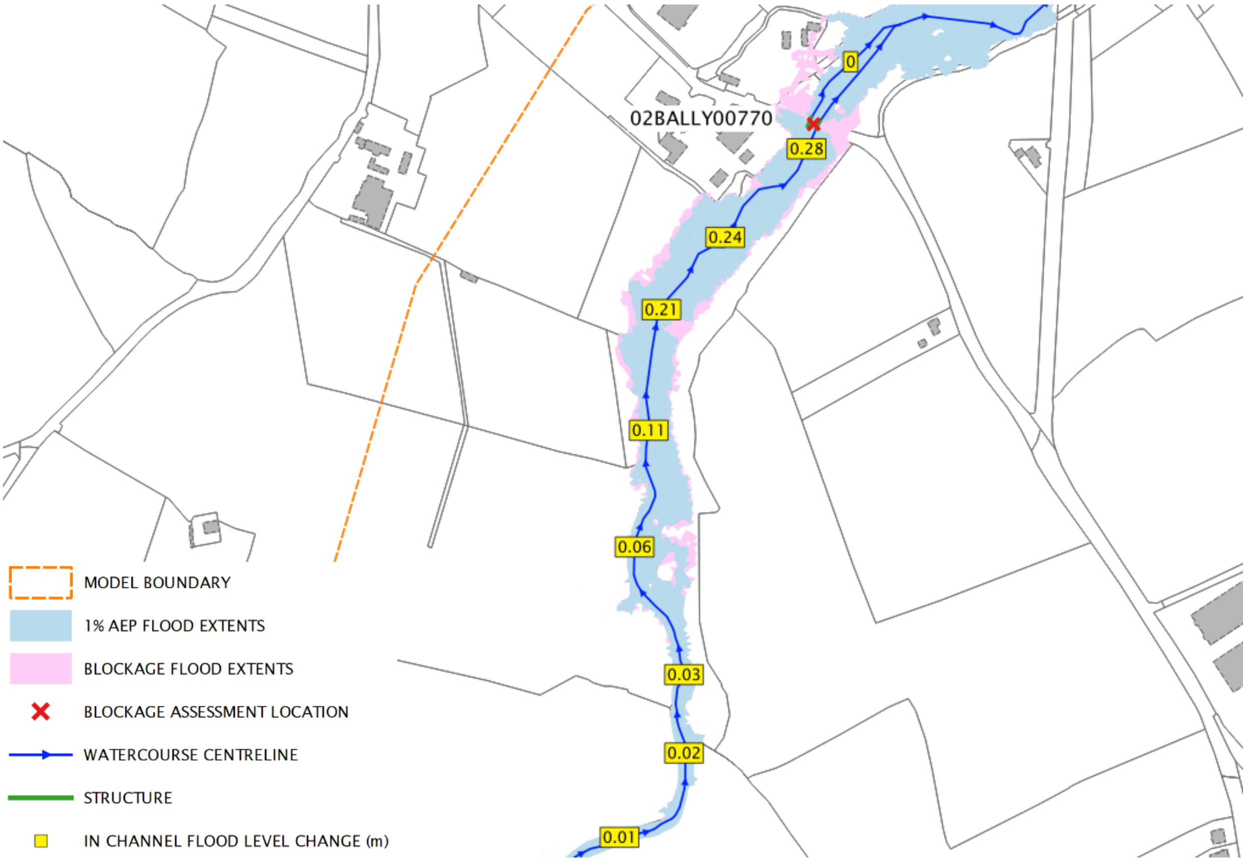

Figure 6-17 02BALLY00770 - 25% Blockage

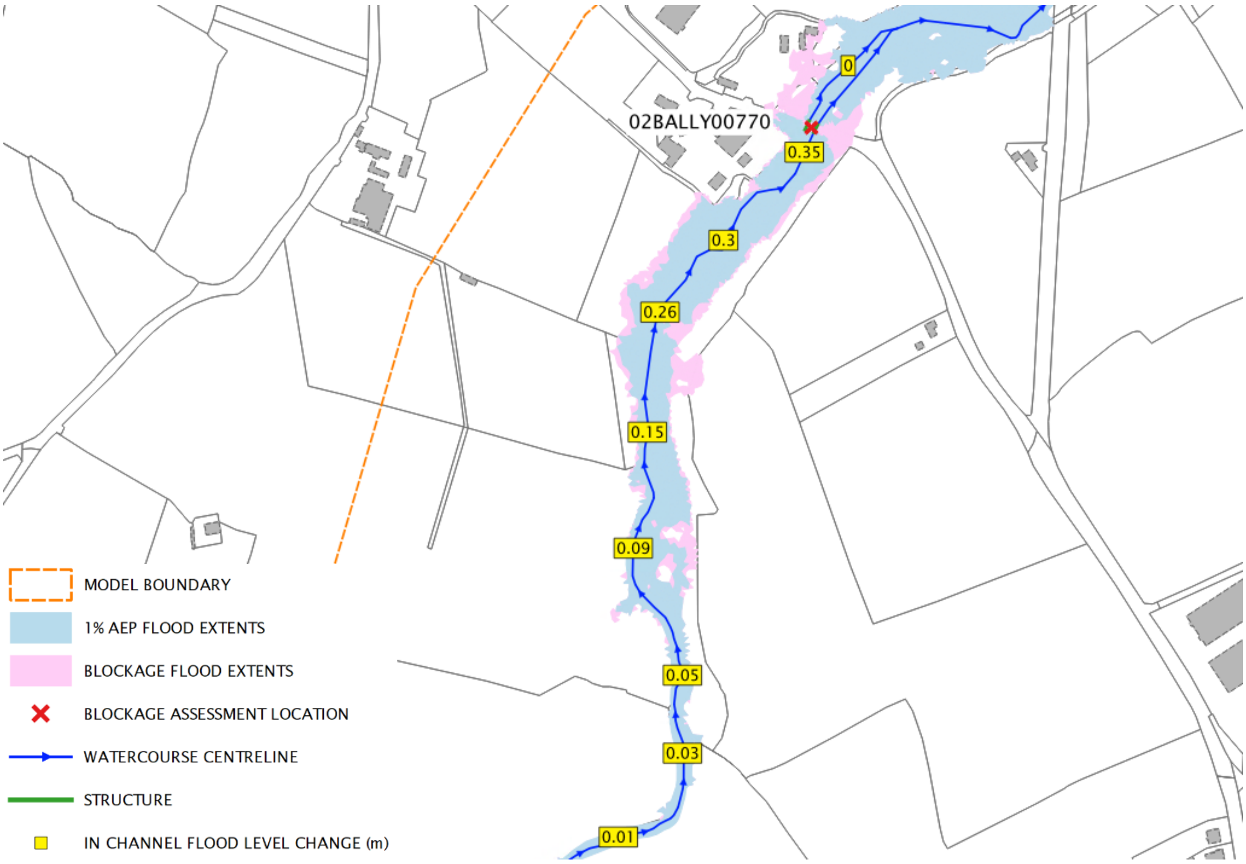

Figure 6-18 02BALLY00770 - 50% Blockage

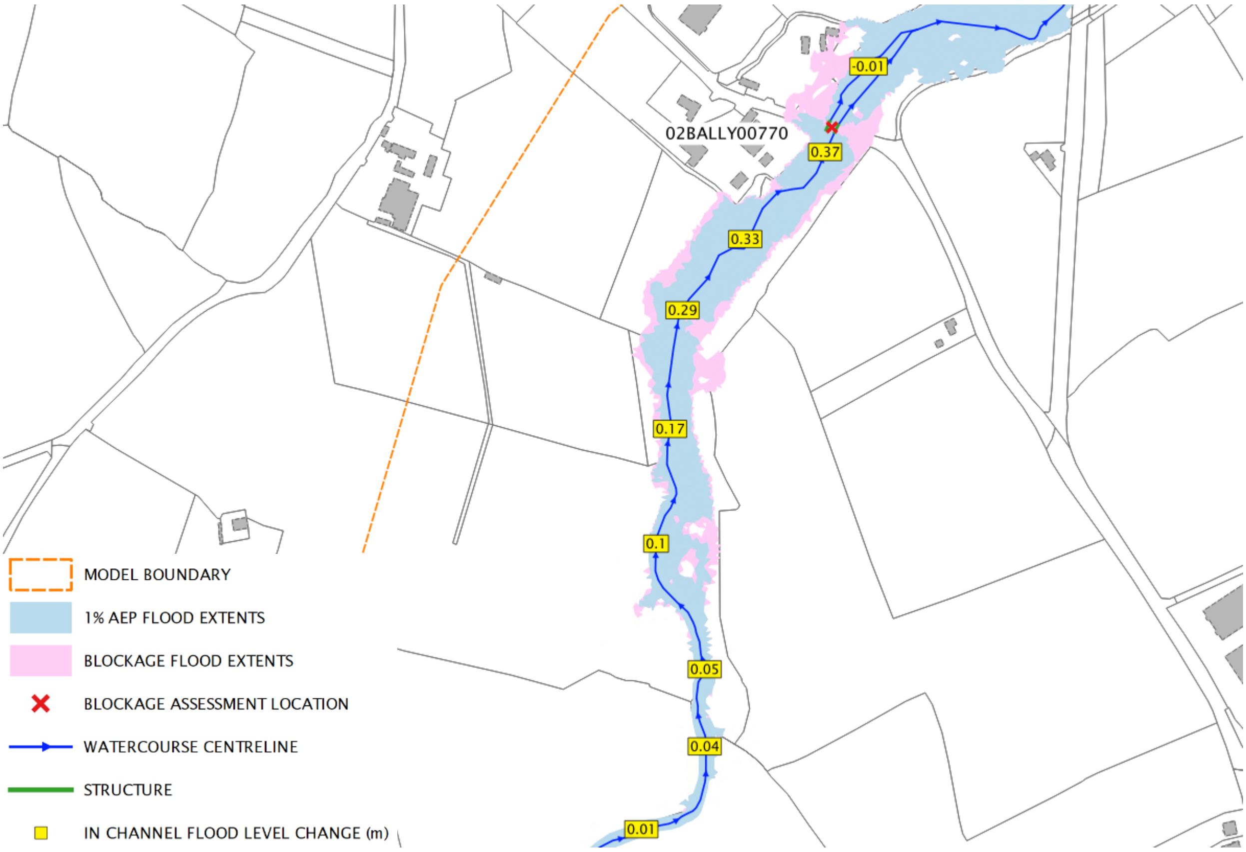

Figure 6-19 02BALLY00770 - 75% Blockage

6.4 Blockage Analysis Summary

The following table summarises the blockage analysis results:

Table 6-3 Blockage Analysis Summary

Structure	Width (mm)	Height (mm)	Likelihood of Blockage	25% Max. WL Increase (m)	50% Max. WL Increase (m)	75% Max. WL Increase (m)
BALLY00011	821	1180	High	0.22	0.84	1.86
01BALLY03080	550 2580 2690 689	1050 1680 1200 655	High	0.33	0.67	0.95
01BALLY02890	3660	1650	Moderate	0.01	0.12	0.39
01BALLY02870	3300	14400	High	0.36	0.76	1.0
01BALLY02640	1740 2060	1050 930	Moderate	0.26	0.43	0.48
02BALLY00770	1410 1600	790 805	High	0.28	0.35	0.39

7 OPTIONS APPRAISAL

7.1 Preamble

This chapter details the means of representation of proposed flood alleviation works within the baseline flood model and provides commentary on their predicted effect.

Options were developed by DBFL Consulting Engineers and are described in detail in supporting drawings and reporting. A multi-criteria analysis of individual options were assessed, and the proposed scheme was developed with aid of preliminary modelling results to target key flow routes and receptors within the village.

The modelling assessment described here assesses the effectiveness of the proposed scheme in defending Ballyhale village from flooding and impact on downstream receptors. No updates to inflow hydrology were required to represent the proposed scheme.

7.2 Option Schematisation

The proposed scheme is schematised in the following figure. Key modelled components of the proposed scheme include:

- Embankments located upstream of the village to prevent overland flooding.
- Flood wall to western perimeter of "Arrigle View".
- A section of new river channel re-connecting all outlets from the Chapel Lane bridge into the western river channel and removing the flow split. This will require excavation of the existing church pedestrian access and replacement via a new pedestrian connection which also serves to form a new bank to the redirected stream.
- Landscaping of eastern river channel to allow for a low flow channel to reflect reduced flow conditions.
- Diversion of eastern river channel into a 600⌀ culvert along Main Street with an outlet downstream of the Arrigle business park structure to prevent flows from the western channel backing up into the eastern channel.
- Flood Defences (wall and embankments) between the western channel and the properties at risk on Main Street. Lands acquired for these flood defences will be landscaped to provide a riverside walkway/park.
- Removal of one of two existing minor private bridges providing access across the river to a private land parcel.
- Removal of a boundary wall spanning the watercourse.
- Removal of the existing weir at the Ballyhale Business Park access and regrading of channel to improve channel capacity.
- Replacement of the Ballyhale Business Park access bridge and relocating immediately downstream to facilitate the removal of the existing weir.
- Low flood wall alongside the road opposite Brookfield to prevent out of bank flows emerging onto the road surface.
- Provision of rock ramp to existing weir at Ballyhale Shamrocks access to improve fish pass conditions.
- Channel reprofiling at the existing Main St bridge to improve bridge inlet conditions.
- Provision of additional conveyance capacity to the Main Street Bridge. The additional conveyance will be provided by an additional bridge opening (box culvert) set at high level to provide capacity for extreme flood events.
- Provision of rock ramp to downstream face of the Main Street Bridge to improve fish pass conditions.
- Provision of a temporary construction compound.
- Fencing, accommodation works and all site development and landscaping works.

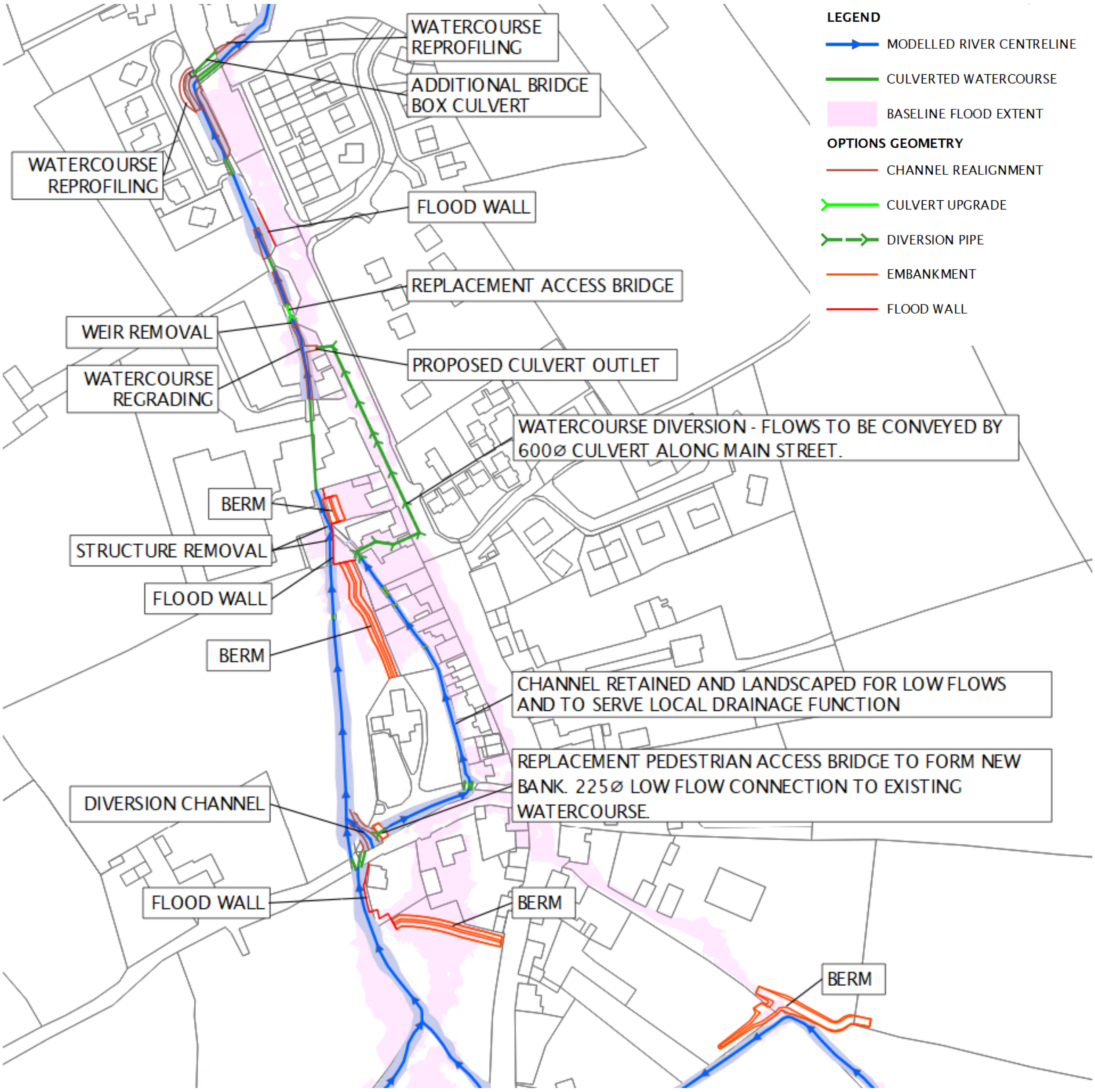

Figure 7-1 Proposed Scheme - Key Model Updates to Baseline

7.3 Results

Simulations were conducted for the design standard 1% AEP present day flood event and checked against the mid-range (+20%) and high end (+30%) climate change scenarios. The option was developed to ensure the removal of flooding of all key receptors within the village for the 1% AEP present day event. Refer to Appendix B for design scenario detailed mapping and corresponding defended areas, extracts of flood mapping are shown in the following figures, with associated change in flood levels.

All receptors are shown to be protected for the standard of protection (SoP) 1% AEP present day event, freeboard provided to the scheme over the 1% present day is sufficient to provide a level of protection up to and including the 1% AEP + HEFS CC event.

The berms upstream of Ballyhale prevent out of channel overland flooding from the system to the town, corresponding in a slight increase in flood levels upstream.

The diversion channel conveys the majority of flows to the western channel. The right diversion channel bank is formed by the replacement pedestrian access. A 225mmØ pipe provides a restricted baseflow from the diversion channel to the eastern channel under the pedestrian access. The eastern channel continues to provide a drainage function; existing catchment inflows are applied per the baseline scenario. The eastern channel is diverted downstream by a 600mm⌀ culvert to prevent any backing up in the eastern channel due to elevated flood levels in the western channel.

Flood levels within the western channel are elevated versus baseline due to the additional flows. Two structures along the river have been removed to improve conveyance, and berms and flood walls contain the additional flood waters away from main receptors within the town.

Downstream of the Arrigle business park structure, flood levels are significantly reduced and contained within channel. Model results indicate no adverse effect as a result of the scheme downstream of the proposed interventions.

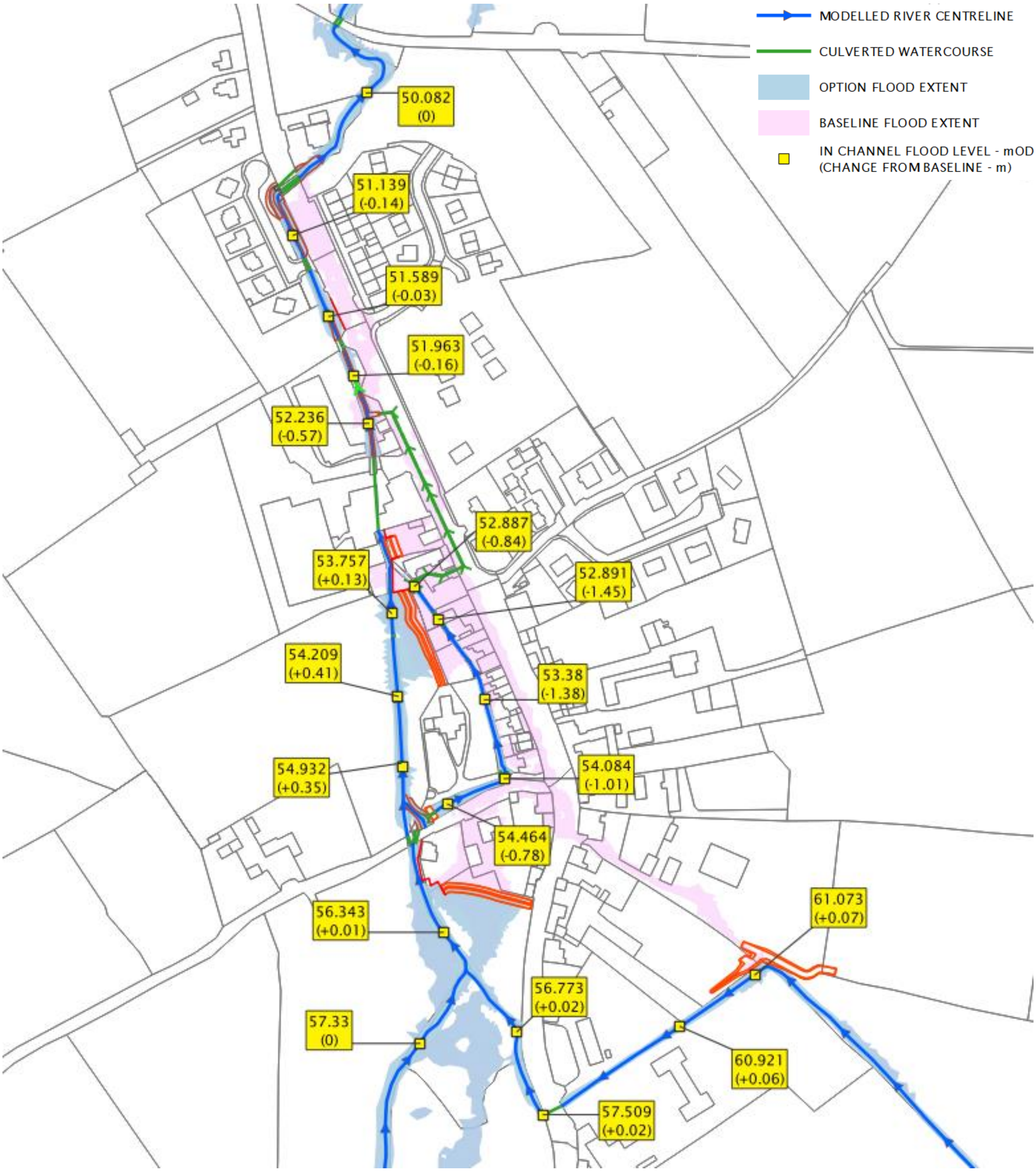

Figure 7-2 Proposed Scheme 1% AEP Present Day Flood Extents Comparison

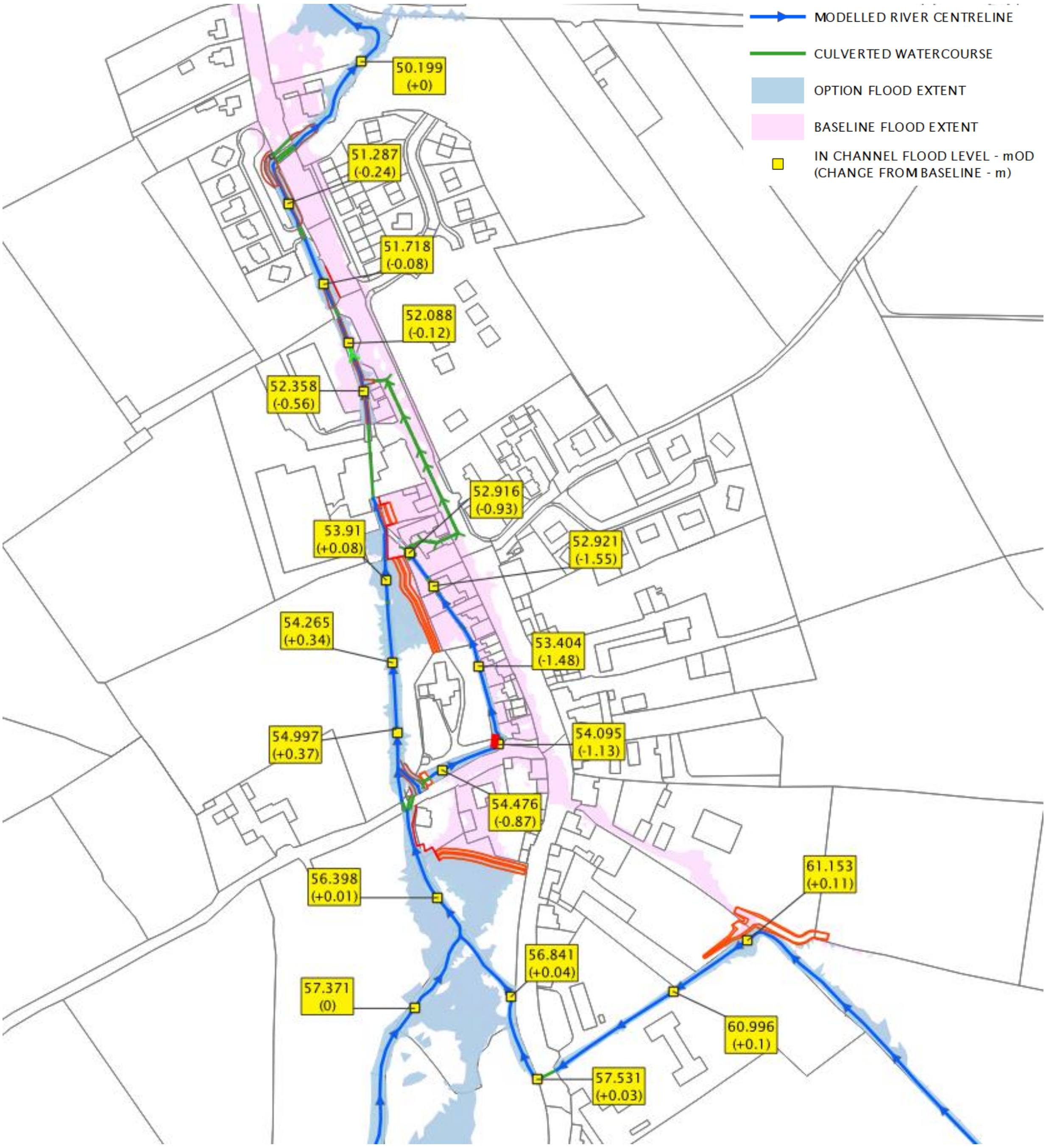

Figure 7-3 Proposed Scheme 1% AEP MRFS Flood Extents Comparison

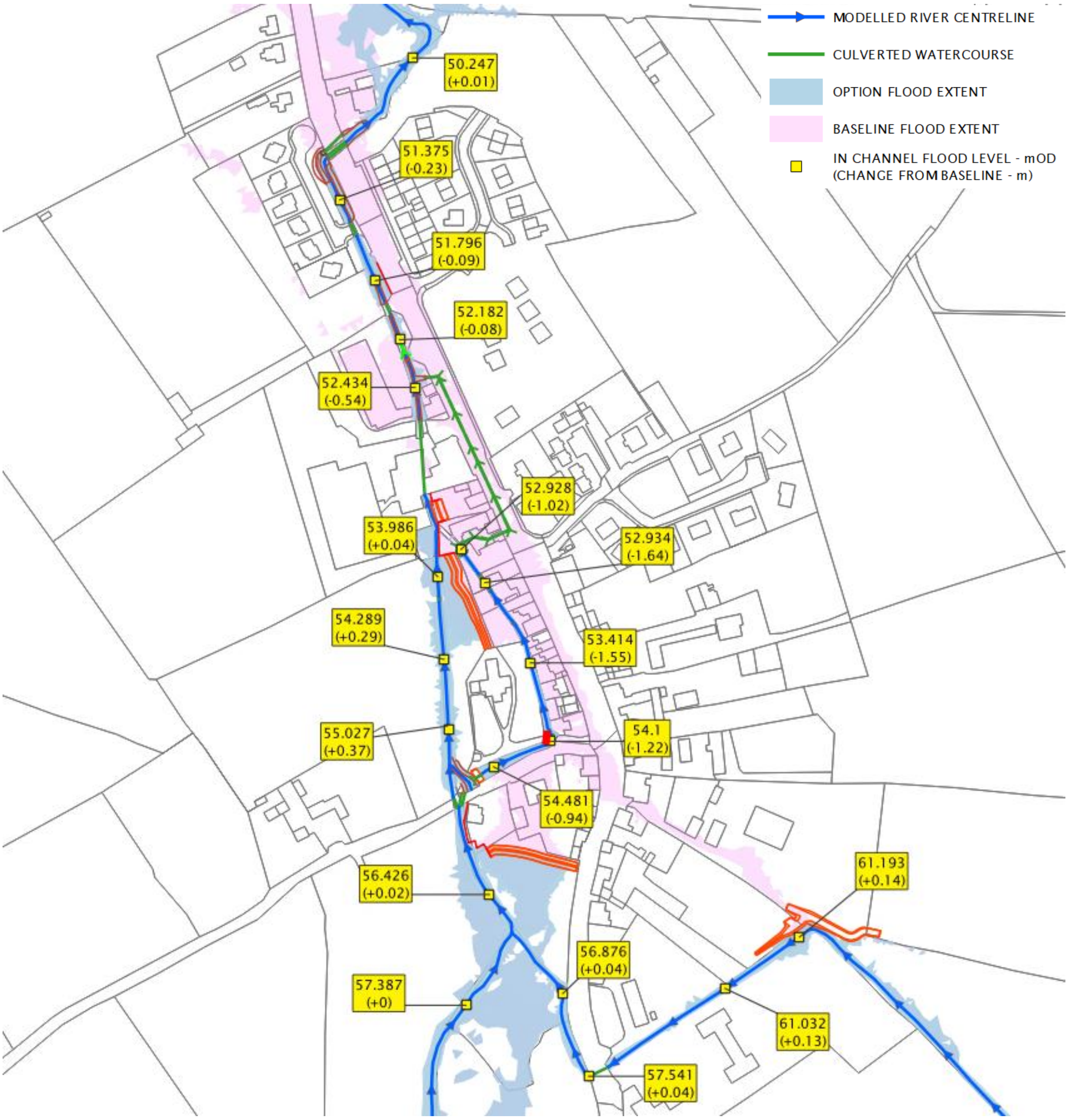

Figure 7-4 Proposed Scheme 1% AEP HEFS Flood Extents Comparison

7.3.1 Results in Excess of the Standard of Protection

Standard of protection for the scheme is 1% AEP present day, it is shown in Figure 7-3 - Figure 7-4 that the proposed scheme meets and exceeds the required standard of protection up to the 1% AEP HEFS scenario.

For the extreme 0.1% AEP present day event (Figure 7-5), out of channel flooding is observed downstream of the Arrigle Business Park. Channels are observed to be at bank full and spill onto Main Street from the Ballyhale Shamrocks access culvert and Hazelbrook access road.

Flood water re-enters the watercourse downstream of the Main Street bridge through an opening in the wall. Flood waters within Hazelbrook escape through a pedestrian opening in a wall and flow downstream. Flood extents and the quantity of effected receptors remain considerably reduced from baseline.

Figure 7-5 Proposed Scheme 0.1% AEP Present Day Flood Extent – Flow Routing

From the 0.1% AEP + MRFS event, the flood waters on the Ballyhale tributary upstream of Ballyhale are at bank full conditions and route around the proposed berm, creating a minor overland flow route that flows down a farm track to the Main Street, similar to baseline flood mechanisms. The overland flow route is increased in the HEFS event.

An extract of the 0.1% AEP + HEFS event is shown in Figure 7-6, displaying the flow path from the Ballyhale Tributary to the Main Street. It is demonstrated that a large proportion of receptors are remain protected because of the scheme beyond the standard of protection design event.

Full flood maps of the 0.1% AEP events are enclosed in Appendix B.

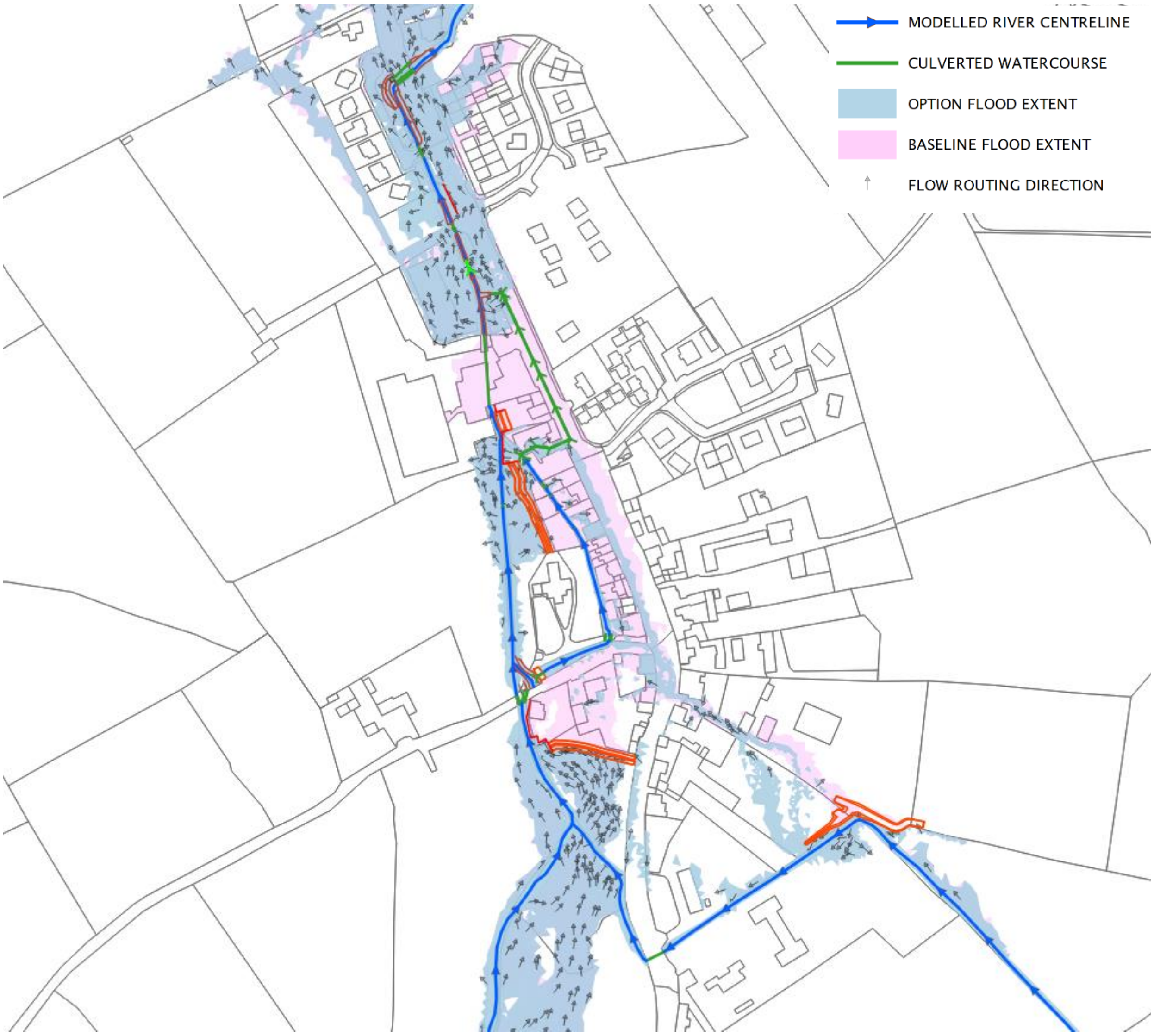

Figure 7-6 Proposed Scheme 0.1% AEP HEFS Flood Extent - Flow Routing

7.3.2 Proposed Scheme Sensitivity to Blockage

Present day baseline modelling included the assessment of six locations for detailed blockage analysis (see Section 6.3) that had identified four critical structures where the proposed scheme should include design to mitigate the increased risk in the event of blockage.

- 01BALLY03080 (Chapel Lane Bridge) – A low level flood wall to the western perimeter of the "Arrigle View" property on Chapel Lane. The property is not predicted to flood during the baseline scenario, however, is at risk of flooding during a blockage, the flood wall will prevent flows bypassing the bridge and defences, affecting downstream receptors.
- 01BALLY02890 (Garage Boundary Wall) – A boundary wall spanned the watercourse is to be removed to reduce blockage risk.
- 01BALLY02870 (Arrigle Business Park) – allowance for increased freeboard to embankments and flood walls along the western channel downstream of the Chapel Lane bridge to the Arrigle Business Park culvert. This culvert is considered to have a higher risk for blockage due to the length of the culvert, change in cross section through the barrel and the level of visibility.
- 01BALLY02640 (Main Street Bridge) – an additional culvert under the bridge situated at a high level to provide additional conveyance capacity for extreme flood events.

The proposed scheme has been designed to mitigate additional flooding arising due to 50% blockage of the identified structures coinciding with a 1% AEP flood. The performance of the proposed scheme with 50% blockages applied to the identified critical structures was assessed, summarised below.

7.3.2.1 01BALLY03080 – Chapel Lane Bridge

A 50% blockage assessment on Chapel Lane Bridge with proposed geometries was shown to raise flood levels immediately upstream of the bridge by 0.8m. Flood defences show containment of flood levels causing minor encroachment of flood extents on agricultural land west and south of Ballyhale versus the proposed scheme geometry 1% AEP extents.

The impoundment of flood extents away from critical receptors causes increased flood levels versus present day geometry baseline levels (see Section 6.3.2),

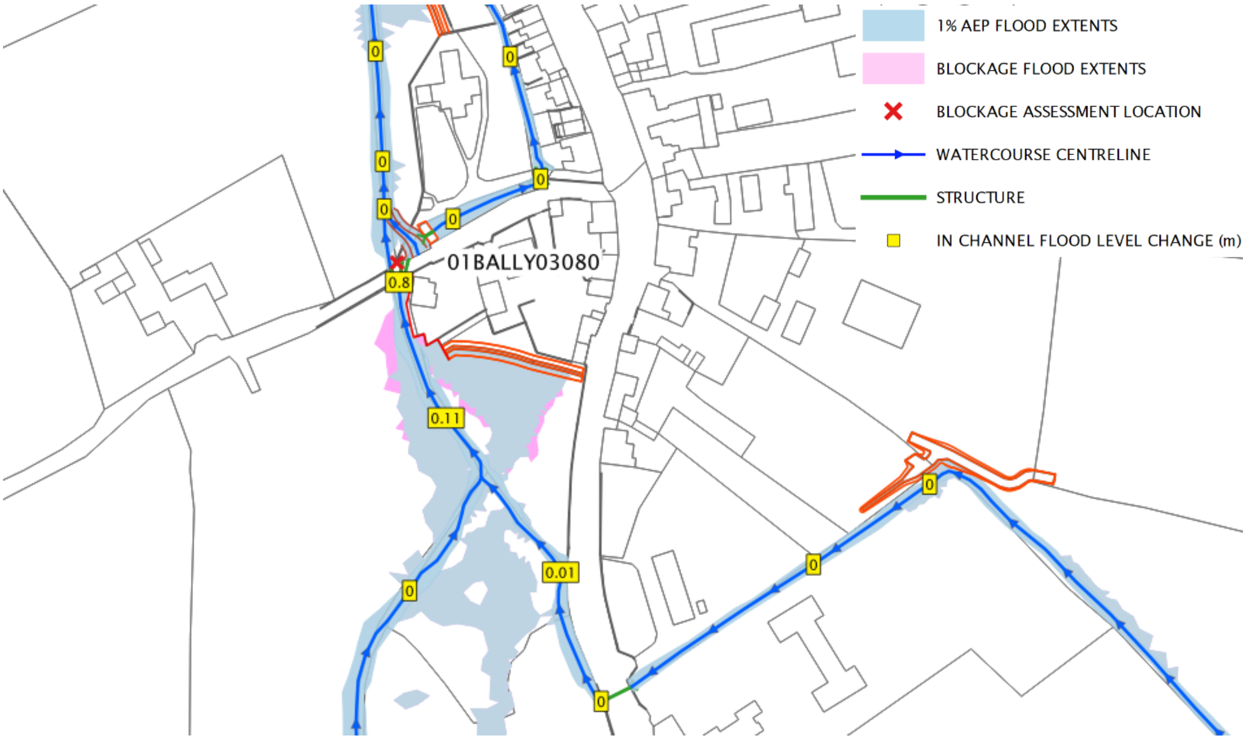

Figure 7-7 Proposed Scheme – 01BALLY03080 - 50% Blockage Extents

7.3.2.2 01BALLY02870 – Arrigle Business Park

A 50% blockage assessment was conducted on the Arrigle business park structure with proposed defences. Results indicate an increase of flood levels of up to 0.83m immediately upstream of the structure retained within channel. Encroachment of flood extents is shown upstream on agricultural lands and a rear garden of a public house versus the proposed scheme geometry 1% AEP extents.

Proposed embankments and walls are shown to be sufficient at defending the Main Street properties and preventing a flow path downstream along main street per the present day geometries blockage scenario (see section 6.3.4)

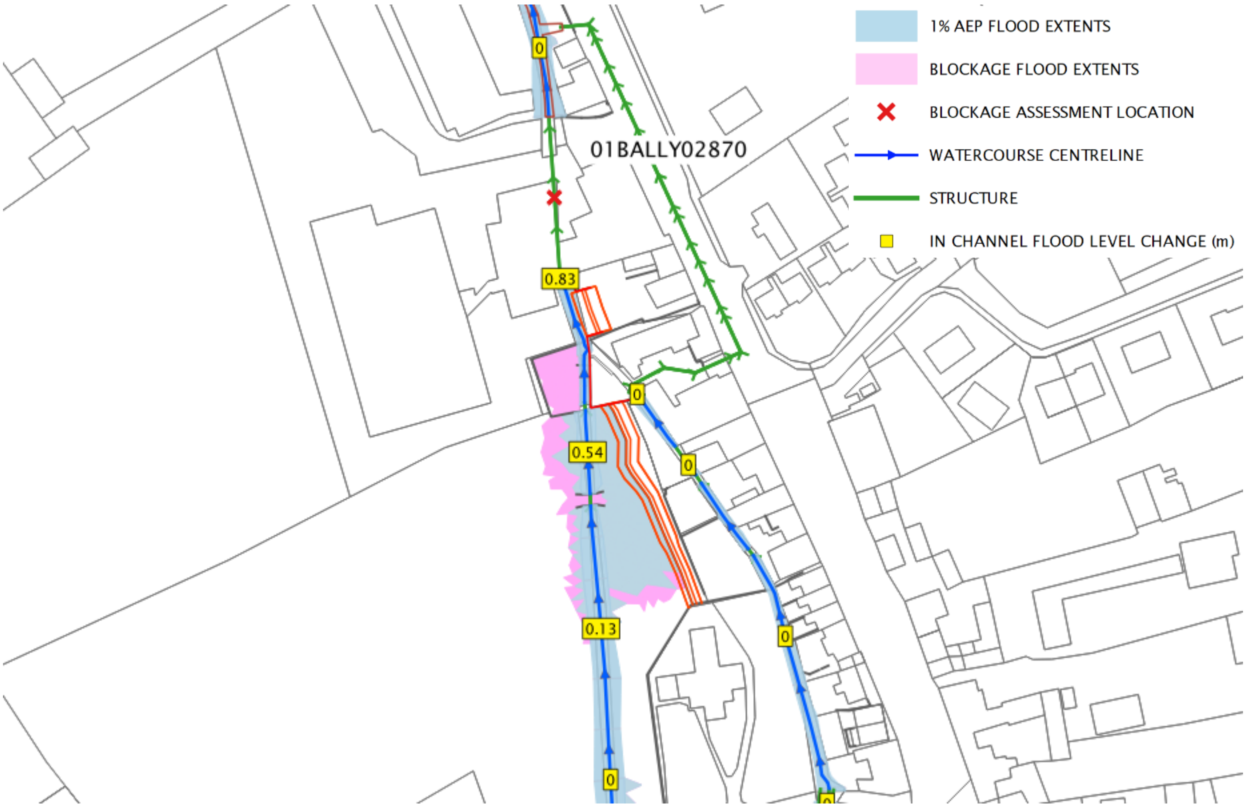

Figure 7-8 Proposed Scheme – 01BALLY02870 - 50% Blockage

7.3.2.3 01BALLY02640 – Main Street Bridge

The Main Street bridge is twin arch structure, the proposed scheme increases conveyance under Main Street through a new box culvert situated at a high level to provide capacity for extreme flood events and to mitigate the risk of blockage.

A 50% blockage assessment was carried out on the original twin arches with the proposed box culvert unrestricted indicating an increase of flood levels of up to 0.17m, reduced from 0.43m from present day geometries. Blockage flood levels are contained within channel.

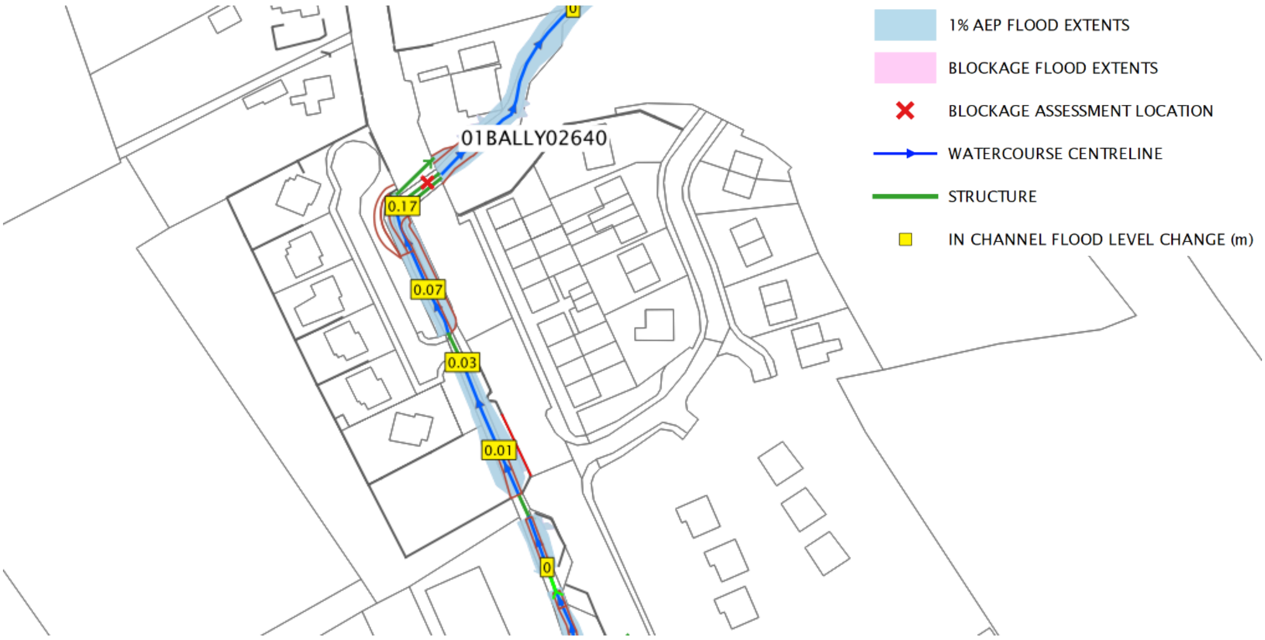

Figure 7-9 Proposed Scheme – 01BALLY02640 - 50% Blockage

8 CONCLUSIONS & FUTURE ACTIONS

8.1 Conclusions

8.1.1 Baseline Modelling

The model extent incorporates the Ballyhale River, Ballyhale Tributary and Little Arrigle Rivers. The extent ensures coverage within Ballyhale Village and potential scheme option locations and provides sufficient fall from the main area of interest.

The underlying ground model comprised of best available OSi LIDAR and survey works carried out in July / August 2020 and December 2020 provides a detailed representation of the ground surface. Additional structures and obstructions captured during the survey were incorporated to ensure accurate flow routing.

Walls as informal defences were included within the model. Informal defences retained by the implemented option will be captured in an asset register on completion.

The hydrology was applied to the model using a combination of lateral (distributed) inflows along the length of all reaches and point inflows at the upstream limit of watercourses and coinciding with tributary confluences per the hydrological analysis. The baseline model was simulated for 8 return periods for the present day and mid-range climate change scenarios and for the key 10% / 1% / 0.1% AEP return periods at the high-end climate change scenario.

Anecdotal evidence collated as part of the hydrology assessment was used to permit a comparison against modelled flood extents, with a view to ensuring that model results are at least as onerous as recorded flooding. Based on the available historical evidence, the model is considered to provide a good correlation with accounts and results obtained are deemed representative.

Scenarios testing the base model sensitivity to roughness parameters, bank coefficients and boundary conditions were carried out as part of the model validation and auditing process for the 1% AEP fluvial event. The sensitivity analysis demonstrates that parameters selected for the model build are appropriate. Effects on absolute predicted water levels generally do not exceed normally anticipated inherent uncertainty in flood model estimation and all variability is captured by standard OPW freeboard allowances (min. 0.3m to hard defence crest). Further action in relation to sensitivity (and particularly sensitivity to flow) is not deemed necessary as part of option assessment or scheme design.

Six locations were identified for detailed blockage analysis due to perceived likelihood, historical accounts and potential impact and modelled in isolation with a 25% / 50% / 75% opening size coinciding with a 1% AEP flood. The largest impact from blockage in terms of property damage was structure 01BALLY02870 (Arrigle Business Park culvert).

8.1.2 Proposed Scheme Modelling

The proposed scheme was developed and modelled to demonstrate the removal of flood risk to all receptors in Ballyhale for the standard of protection / 1% AEP present day event. The proposed scheme incorporated berms / flood walls, a diversion channel to reduce flows tending to the rear of the Main Street buildings, channel regrading and the removal of redundant watercourse structures.

The proposed scheme model was simulated for the 10%/1% and 0.1% return periods for the present day / mid-range climate change and high end climate change scenarios.

Model results indicate that the proposed scheme provides protection from property flooding for the design standard event (1% AEP) and also provides protection for the MRFS and HEFS 1% AEP climate change events.

Events in exceedance of the standard of protection / design event continue to show a reduction in flood risk at key receptors. Analysis of blockage of critical structures was undertaken indicating freeboard provided by the proposed scheme is sufficient to offer resilience to blockages.

Appendix A

Baseline Flood Mapping

Flood Map Schedule

Mapset Reference	Revision	Map Type	Return Period	Hydrology Scenario	Geometry Reference
514_DPFC_10	3	Depth / Extent	10% AEP	Present Day	Present Day
514_DPFM_10	3	Depth / Extent	10% AEP	MRFS	Present Day
514_DPFH_10	3	Depth / Extent	10% AEP	HEFS	Present Day
514_DPFC_1	3	Depth / Extent	1% AEP	Present Day	Present Day
514_DPFM_1	3	Depth / Extent	1% AEP	MRFS	Present Day
514_DPFH_1	3	Depth / Extent	1% AEP	HEFS	Present Day
514_DPFC_01	3	Depth / Extent	0.1% AEP	Present Day	Present Day
514_DPFM_01	3	Depth / Extent	0.1% AEP	MRFS	Present Day
514_DPFH_01	3	Depth / Extent	0.1% AEP	HEFS	Present Day

Appendix B

Proposed Scheme Flood Mapping

Flood Map Schedule

Mapset Reference	Revision	Map Type	Return Period	Hydrology Scenario	Geometry Reference
514_DPFC_10	2	Depth / Extent	10% AEP	Present Day	Design
514_DPFM_10	2	Depth / Extent	10% AEP	MRFS	Design
514_DPFH_10	2	Depth / Extent	10% AEP	HEFS	Design
514_DPFC_1	2	Depth / Extent	1% AEP	Present Day	Design
514_DPFM_1	2	Depth / Extent	1% AEP	MRFS	Design
514_DPFH_1	2	Depth / Extent	1% AEP	HEFS	Design
514_DPFC_01	2	Depth / Extent	0.1% AEP	Present Day	Design
514_DPFM_01	2	Depth / Extent	0.1% AEP	MRFS	Design
514_DPFH_01	2	Depth / Extent	0.1% AEP	HEFS	Design