



OPW

Oifig na
nOibreacha Poiblí
Office of Public Works



Comhairle Cathrach
& Contae **Luimnigh**

Limerick City
& County Council

ATHEA FLOOD RELIEF SCHEME



HYDRAULIC MODELLING REPORT

JULY 2023



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Abbreviations

AA	Appropriate Assessment
AEP	Annual Exceedance Probability
AFA	Area of further Assessment
CAR	Community at Risk
CBA	Cost Benefit Analysis
CEMP	Construction Environmental Management Plan
CFRAM	Catchment Flood Risk Assessment Management
DDF	Depth Duration Frequency
DEM	Depth Elevation Model (Includes surfaces of structures, vegetation, etc)
DTM	Depth Terrain Model ('bare earth' model; does not includes surfaces of structures, vegetation, etc)
EA	Environmental Agency
EIA	Environmental Impact Assessment
EIAR	Environmental Impact Assessment Report
EPA	Environmental Protection Agency
FSE	Factorial Standard Error
Flood Modeller	One-Dimensional Hydraulic Modelling Software
FRMP	Flood Risk Management Plan
FRS	Flood Relief Scheme
FSR	Flood Studies Report
FSSR	Flood Studies Supplementary Report
FSU	Flood Studies Update
GIS	Geographical Information System
HEFS	High-End Future Scenario

HEP	Hydrological Estimation Point
HGF	Highest Gauged Flow
HPW	High Priority Watercourse
HT	Head time
IFSAR	Interferometric Synthetic Aperture Radar
ING	Irish National Grid
LA	Local Authority
LCCC	Limerick City & County Council
LIDAR	Light Detection and Ranging/ Laser Imaging, Detection and Ranging
MCA	Multi-Criteria-Assessment
mOD	Metres Over Datum (Malin)
MPW	Medium Priority Watercourse
MRFS	Mid-Range Future Scenario
NIS	Natura Impact Statement
NTF	National Transfer Format
OPW	Office of Public Works
OSI	Ordnance Survey Ireland
PCDs	Physical Catchment Descriptors
PFRA	Preliminary Flood Risk Assessment
QMED	Mean Annual Maxima Flood
QT	Flow-time
RBD	River Basin District
SE	Standard Error
SUDs	Sustainable Drainage Systems
S1085	Main-stream Slope
Tp	Time to peak
TUFLOW	Two-Dimensional Hydraulic Modelling Software
UoM	Unit of Management
WRAP	Winter Rainfall Acceptance Potential
WWTP	Wastewater Treatment Plant

1 Introduction

1.1 Background

Ryan Hanley Ltd. were appointed by Limerick City and County Council (LCCC) in September 2019 to undertake a Flood Relief Scheme (FRS) for Athea, Co. Limerick. Extensive flooding took place at Athea village in April 2005, July/ August 2008, September 2009 and again in September 2015. The July 31st/ August 1st 2008 resulted in the production of the “Athea Flood Severity and Impact Report” (JBA Consulting, 2008). In 2012, the National Preliminary Flood Risk Assessment (PFRA) project report and maps were produced, which provided the initial estimation of flood extents for Athea. This highlighted Athea as an Area of Further Assessment (AFA) and Community at Risk (CAR) area for the Catchment Flood Risk Assessment Management (CFRAM) study. Athea AFA was included in Unit of Management (UoM) 23 Tralee Bay-Feale in the Shannon CFRAM study. Jacobs Engineering Group completed the works on the Athea CFRAM study.

The CFRAM study conducted extensive hydrological assessments at catchment level for hydraulic analysis of predicted future design events and from that the initial designs of potential Flood Risk Management Plans (FRMPs), which were finalised in 2018.

In order to assess, progress and implement a FRS for the village of Athea, an assessment of the existing CFRAM study hydraulic model is required in order to determine its validity. This will be updated and amended to ensure that the hydraulic model is representative of the existing conditions of the river system in Athea and environs.

1.2 Scope of Report

This report summarises the hydraulic modelling works for the Athea AFA hydraulic model. This report covers the overall hydraulic modelling process from CFRAM model review and update and development of the updated hydraulic model through to development of design runs, with the aim of providing a detailed understanding of the hydraulic controls and flood mechanisms identified throughout the study. The scope and objectives of this Hydraulic Modelling Report, as per the Project Brief, are as follows:

1. Undertake, in line with the Project Brief, a hydraulic analysis comprising the following:
 - Review and update, where required, the CFRAM hydraulic model with physical changes that have occurred since the CFRAM study or develop a new hydraulic model, based on CFRAM survey data;
 - Establish and replicate the existing hydraulic conditions, through calibration and validation;
 - Hydrological Estimation Points (HEPs) at representative river networks sites;
 - Assessment of likelihood and severity of blockage at key hydraulic structures;
 - Assess and appraise effective flood risk management options;
 - Assessment of the hydraulic performance of the preferred option under design flood conditions.
 - Production of flood maps;
 - For future use, once adapted to the ‘as-built’ condition, in assessing the performance of the Scheme following construction;
 - For possible future adaption as a flood forecasting model and system.
2. Prepare a hydraulics report that fully describes the hydrological analyses and hydraulic modelling under this project. The following shall be included, but not limited to:
 - Any revisions to design flood parameters;
 - Comparative time-series and mass balance plots of water level and flow calibration;
 - Longitudinal and cross-sectional plots of flood profiles, including highlighting locations for structures, formal flood defences and informal effective flood defences;
 - Plots of modelling stability;
 - Detailed commentary in the model files including model headings that clearly identify purpose and revision and include detail of modelling approach at each structure;
 - Locations of formal flood defences and informal effective flood defences;
 - A full and detailed discussion on the survey data used with a full outline of what survey was used;
 - A full and detailed discussion on what hydrometric data was used and if data was excluded, provision of a detailed rationale for such decisions;
 - All limitations contained within the model outlined in full;

- Details must be given of any assumptions made, including the requirement for the assumption and the justification for the assumption made;
- Identify and geographically sequence the locations of all modelled nodes and/or cross-section locations, with a background of suitability scaled OS mapping. Also, for each node and/or cross section location, provide in tabular form the flow, velocity and Froude number, for each of the range of events, design event and the calibration events;
- Full reporting, including long-sections, extents and point-levels of the Sensitivity Analysis;
- Full reporting in respect of model calibration and validation work undertaken to demonstrate model accuracies expected and achieved.

1.3 Watercourse and Catchment Overview

1.3.1 Galey River

Athea village is located in west County Limerick, 15.5km west of Newcastle West and 3km from the Limerick-Kerry border, as shown in Figure 1-1. The village is situated on the R523 Listowel to Ardagh regional road and the R524 Glin to Abbeyfeale regional road. The Galey River, which is within the Shannon River Basin District, rises in Rooskagh West (on the western slopes of Knockanimpuha Hill), to the east of Athea and flows in a westerly direction through Athea before joining the River Feale further downstream. The upstream catchment is located in a steep-sided valley with multiple small tributaries flowing down the valley, joining the Galey River.

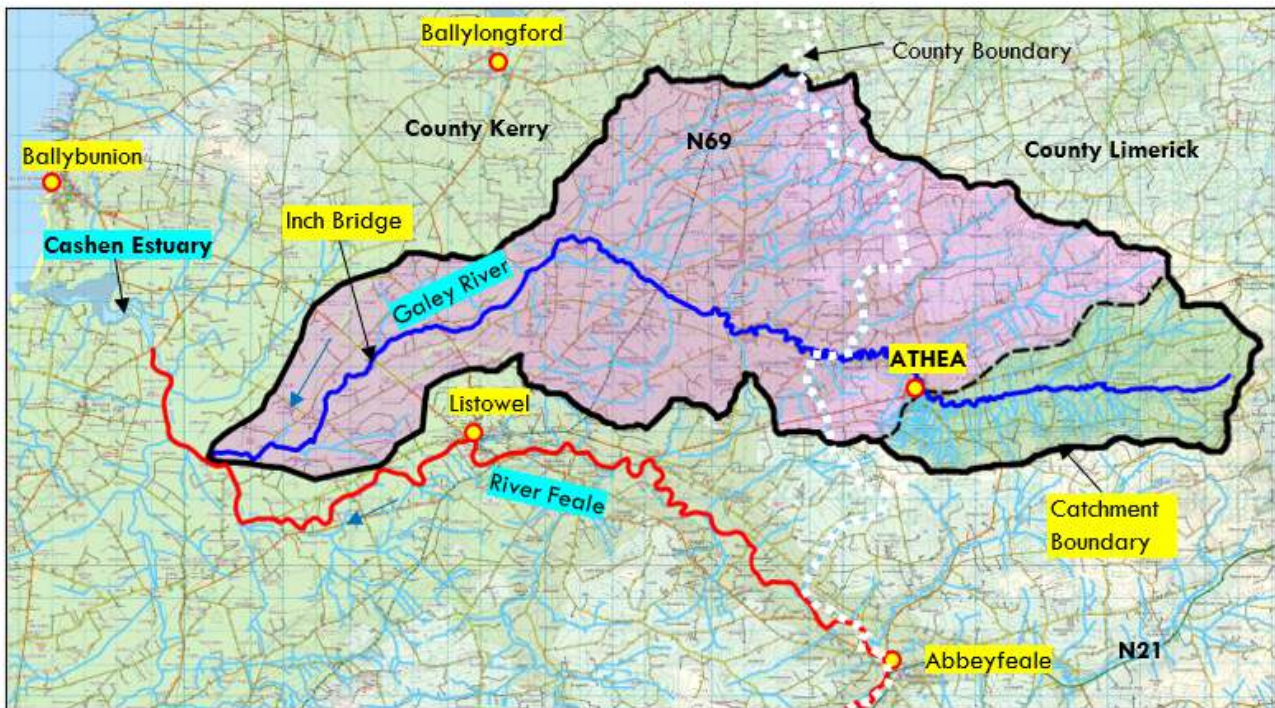


Figure 1-1: Galey River Catchment Overview Map

The Galey River catchment is a sub-catchment of the River Feale (Cashen Estuary) catchment. The River Feale at Ferry bridge near Ballybunion has a catchment area of approximately 1,100km². The Galey River catchment area at Inch Bridge and at its confluence with the River Feale are 191.7km² and 213km² respectively. The Galey River catchment area at Athea Bridge is 19% of that at Inch Bridge.

The upstream Galey River catchment area from Rooskagh West to Athea is 36.6km² and comprises a relatively steep-sided valley with multiple small hillside tributaries (see Figure 1-2). The topography of the upper catchment ('catchment area from Athea' in Figure 1-2) is steep, ranging from 345mOD (Malin) (in Rooskagh West, 9.4km east of Athea) to circa 70mOD at Athea Bridge. The topography continues to drop toward the west with an elevation of approximately 10mOD at Inch Bridge – 26.6km downstream of Athea and approximately 7.2km upstream of the confluence with the River Feale/Cashen River.

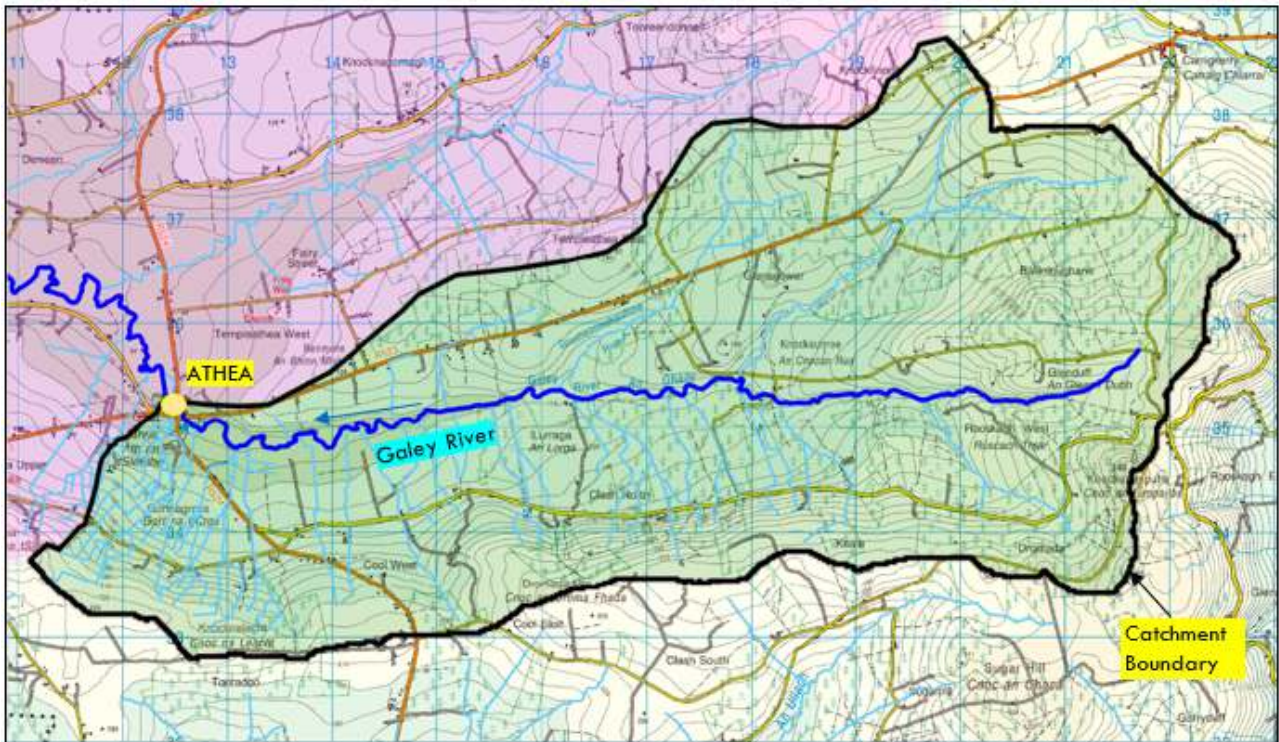


Figure 1-2: Galey River to Athea – Catchment Overview.

The average main river channel slope (S1085) upstream of Athea Bridge is approximated at 12.02m/km, which is considered steep. From Athea Bridge to Inch Bridge the channel gradient reduces with a resultant channel slope of 3.32m/km. The Galey River has a significant tributary contribution, as shown in Figure 1-3.

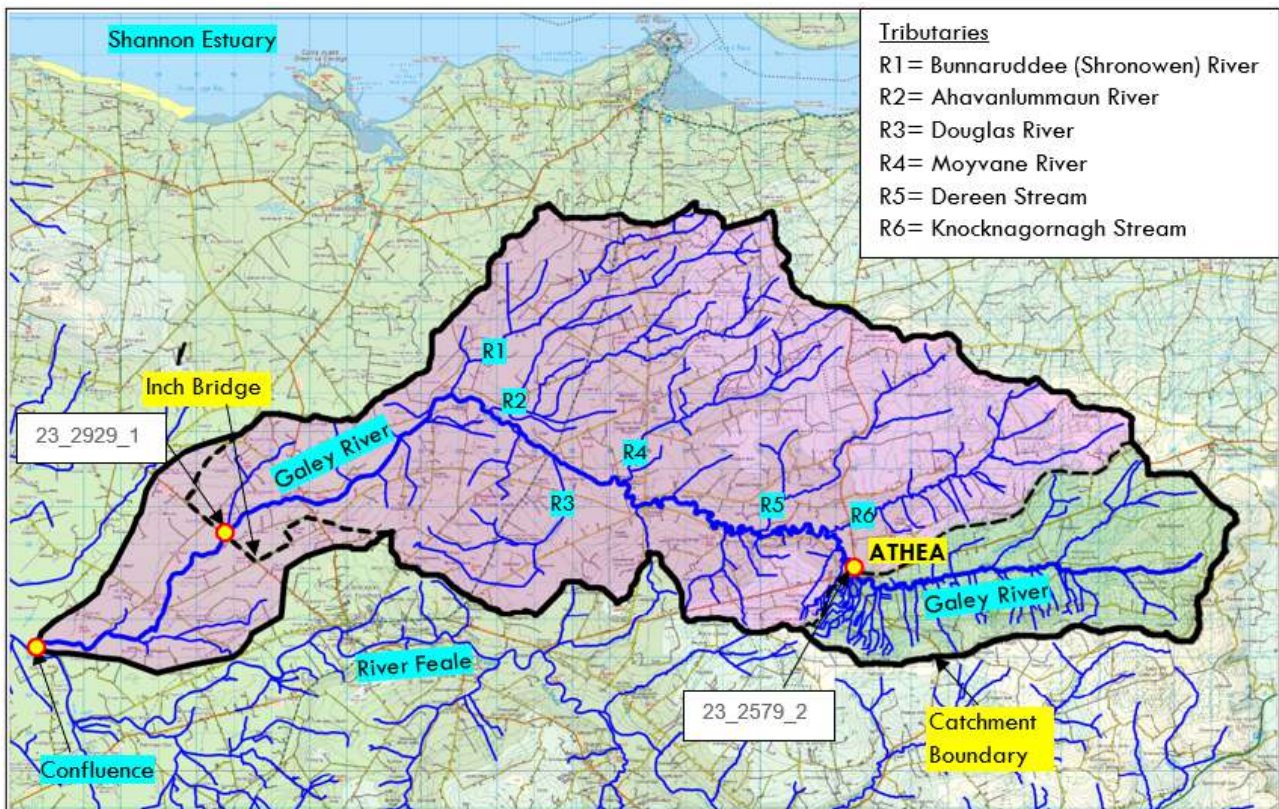


Figure 1-3: Galey River System as far as Confluence with River Feale

Athea Bridge (1820) crosses the Galey River at Athea. The bridge comprises three cut-stone arches - one main arch and two side arches. The bridge piers are protected by cut waters. A pedestrian bridge spans the channel immediately upstream of the bridge.

Based on site walkovers, inspection of photographic evidence, aerial maps and site surveys, it is clear that a significant amount of sediment transport, deposition and erosion occurs in the Galey River reach upstream and at Athea. Large amounts of gravel and cobbles and sediment aggradation is evident at Athea Bridge. This deposition potentially impacts on the conveyance capacity and may therefore be increasing flood risk locally at Athea Bridge. It is understood that historically these deposits were routinely removed by local landowners, however, this practice was reported by locals to have ceased since the river was designated as part of the Lower River Shannon SAC Special Area of Conservation (SAC) (JBA Consulting, 2008). While the Office of Public Works (OPW) removed major flood debris from Athea Bridge following the extreme flood event in 2008 and have undertaken similar works on four other occasions since following consultation with the IFI and NPWS, they do not have the responsibility under the 1945 Arterial Drainage Act to undertake channel maintenance works at Athea.

The reasons for the deposition and erosion at Athea include:

- The upper catchment soils and subsoils are susceptible to erosion, i.e. glacial till deposits and alluvium, blanket peat;
- Steep channel gradient in the upper catchment, high run-off rates and high stream density in the upper catchment.
- Drainage channel improvement associated with forestry developments.
- Natural change of channel alignment in the reach immediately upstream of the bridge with associated bank erosion and deposition;
- A change in channel gradient to slacker grades in the river reach through Athea where the river channel changes from a steep eroding upland river to a floodplain, depositing and meandering river reach downstream of Athea. A review of historical mapping for the Galey River confirms significant channel horizontal alignment changes at Athea in the past 100 years;
- Scouring at the bridge piers during flood events;
- Erosion of the alluvium deposit in the floodplain upstream of Athea Bridge by flash floods in the catchment;
- The pattern of erosion and deposition along the stretch of the River Galey through Athea Town is influenced inter alia by artificial features, which include the bridge, made ground, and the retaining wall protecting the property on the right bank downstream of the bridge.

A comparison of photographic evidence from site walkovers in December 2008, 2019, June and November 2020 by Ryan Hanley demonstrates how the deposition extents at Athea Bridge have changed appreciably over short time scales, as shown in the Athea FRS Hydrology Report (Ryan Hanley, 2021).

1.3.2 Galey River Tributaries

Three stream tributaries have been included in the hydrological study, that drain from the northern slopes of Knockathea and Knocknalaght hills (located to the south of Athea) to the Galey River along the river reach extending 800m upstream to 1,100m downstream of Athea Bridge. These streams, as shown in Figure 1-4, were identified from inspection of aerial mapping and site visits as having the potential of being a source of flood risk to Athea Village. The Athea West and East streams have been assessed in the hydraulics study and the Listowel Road stream has not been included as it joins the Galey River downstream of the Athea Scheme Area. Only the Athea West stream was assessed in the CFRAM study. The extents of these streams' networks have been mapped based on inspection of the CFRAM survey, a site walkover in November 2020 and review of LIDAR topographical data, and current and historic OSI Mapping and aerial photography.

The overall Athea West catchment is shown to include some drainage from urban areas to the west of the Abbeyfeale Road and the drainage along the western extents of Con Colbert Street. The Athea West stream, which flows northwards through Athea village and crosses under the R523, has been culverted for much of its downstream length. The culvert has historically been prone to blockage.

The Athea East stream catchment includes 3 No. wind turbines and associated access road and drainage in its upper area. The Athea East stream flows from the southeast to the northwest and joins the Galey River on the left bank circa. 120m upstream of the Athea Bridge. There are 2 culverts on the Athea East stream – 1 no. access culvert on farmland and 1 no. culvert crossing the R524 Abbeyfeale Road. Table 1-1 presents the catchment characteristics of the Athea East and West streams.

Table 1-1: Catchment Characteristics of Galey Tributaries in Athea

Stream	Area, km ²	MSL, km	Gradient (S1085), m/km	Soil Type
Athea West	0.55	1.56	56.4	Poorly drained, high run-off rate (WRAP Soil Type 4 or 5). FSU BFI Soil approx. 0.33
Athea East	1.1	2.28	67.3	

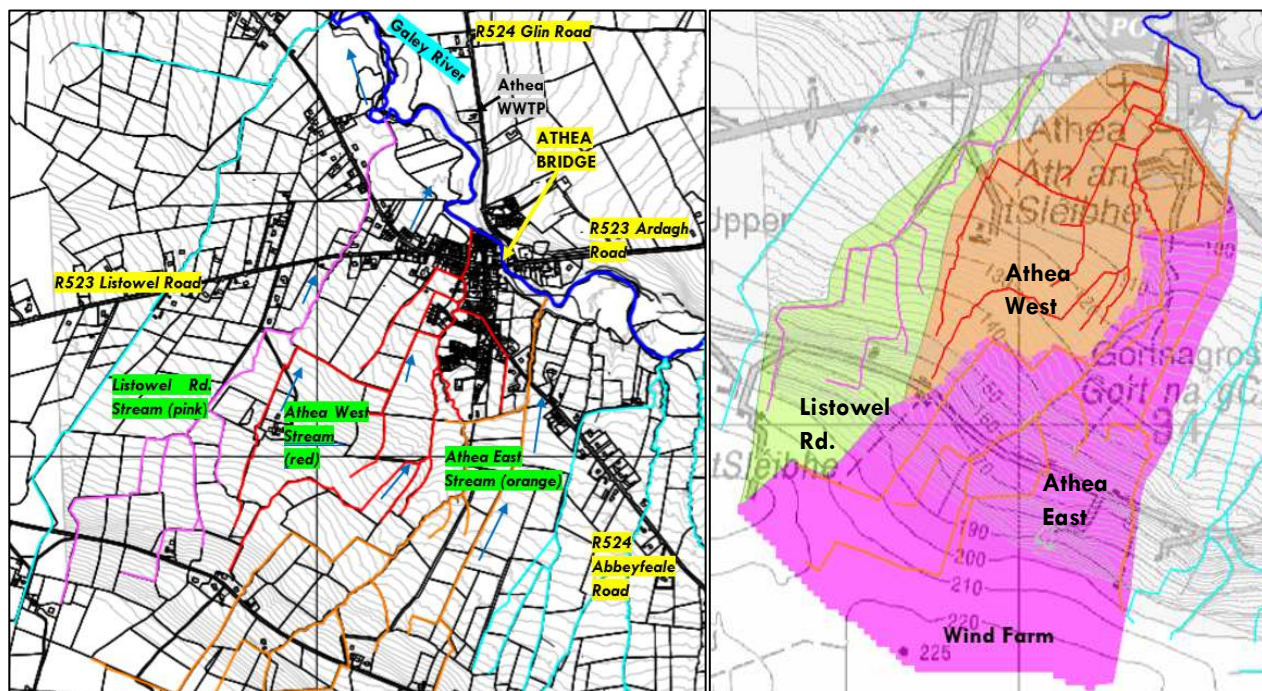


Figure 1-4: Galey River Tributaries in Athea

1.4 Available Data

1.4.1 Survey Data

1.4.1.1 CFRAM Survey

Cross sectional survey data was collected by Blom and Murphy Surveys Ltd. in Athea as part of the CFRAM study and was delivered in July 2013. This survey data comprised the Galey River and its tributaries in Athea, as shown in Figure 1-5. The abbreviated version of each watercourse name as it was surveyed is detailed in Table 1-2.

Table 1-2: Abbreviated Watercourse Names

CFRAM Reference	Description
GALE	Galey River
GALF	Athea West
GALG	Athea West
GALI	Listowel Road
GALK	Athea East

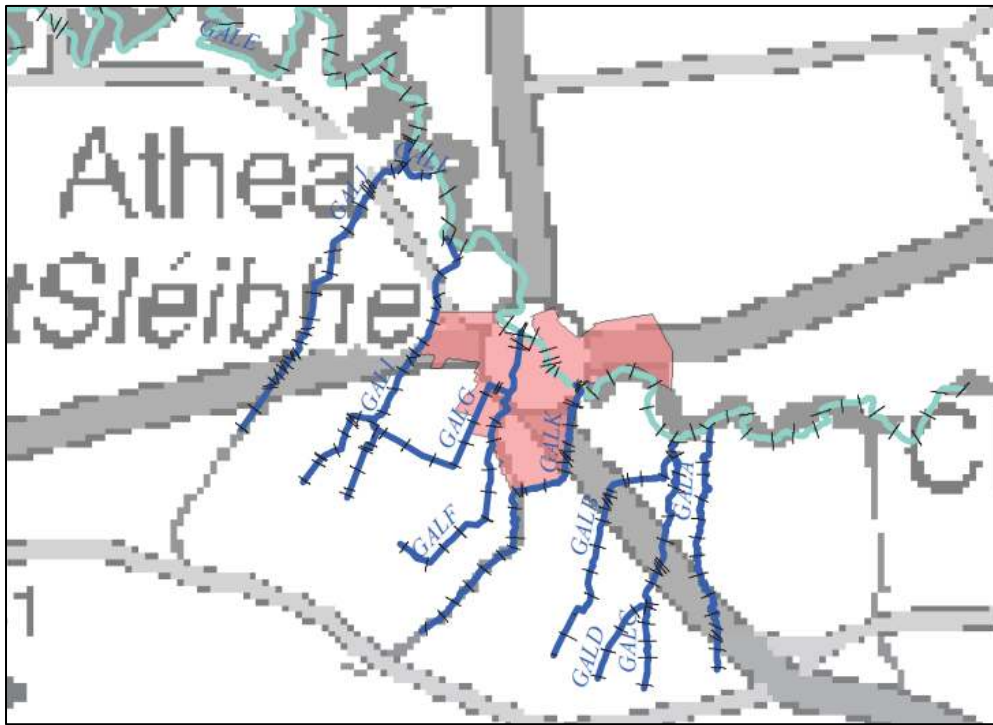


Figure 1-5: CFRAM Surveyed Watercourses

1.4.1.2 Bronra Surveys Ltd. Survey 2020

Additional cross-sectional survey was specified and completed by Bronra Surveys Ltd. in August and September 2020, as part of the Athea FRS, to update cross sectional data in the Galey River and the Athea West stream, as changes had occurred over time to river channels and structures. The locations of the surveyed cross sections are shown in Figure 1-6. Due to the proximity of the survey sections to the existing hydraulic model cross sections, it was deemed suitable to retain the CFRAM model node names and the cross-section data was replaced by the new survey data. Additional topographical survey was completed in areas where flood defences are proposed, as well as in the Galey River channel directly upstream and downstream of Athea Bridge. Table 1-3 shows the updates to the cross-sectional data with the new survey data survey and the incorporation of data into the hydraulic model. More information on the survey data for the study is provided in the Appendix E.

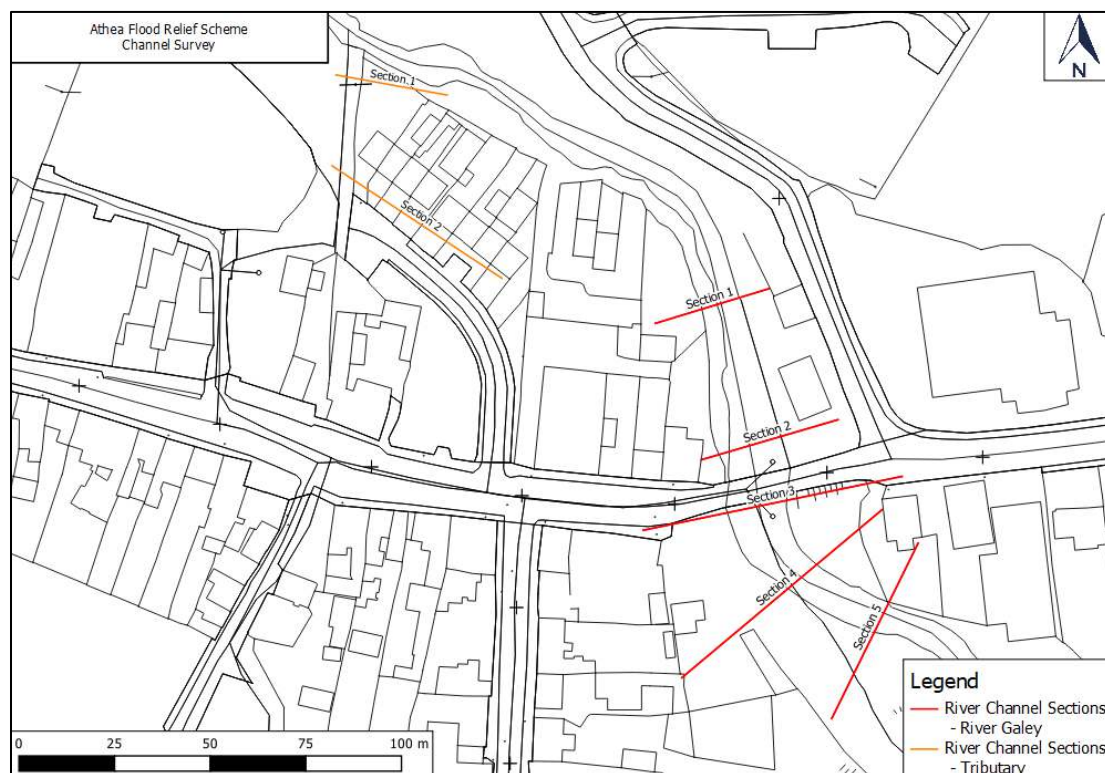


Figure 1-6: Overview of Channel Survey

Table 1-3: Overview of Updates to the Athea Watercourses

Model Reference	Original Survey Reference	2020 Survey Reference	Description
Galey River			
04GAL00227	23GALE03453	Section 5	Inserted updated information into the existing cross sections and updated distance to next section.
04GAL00200	23GALE03450	Section 4	
04GAL00180u / 04GAL00180bu/ 04GAL00180d	23GALE03449D	Section 3	
04GAL00163	23GALE03448	Section 2	
04GAL00124	23GALE03443	Section 1	
Athea West Stream			
01GGR00042	23GALF00005	Section 2	Inserted updated information into the existing cross sections and updated distance to next section.
01GGR00010/ 01 GGR00000u	23GALF00001	Section 1	

1.4.1.3 Bronra Surveys Ltd. Survey 2022

Additional topographical survey was specified and completed by Bronra Surveys Ltd. in October and November 2022, as part of the Athea FRS. The locations of the topographical survey areas are shown in Figure 1-7. The survey completed in Zone 6 comprises topographical survey in the Galey River channel, to record bed levels following removal of gravel from the channel in Summer 2022 and the land downstream of the Athea Bridge on the left bank, to record topographical changes made by the landowner. The survey completed in Zone 7 comprises topographical survey, to record the stream embankment levels. The Athea West stream culvert inlets were also checked and visually inspected during the survey. This topographical survey is to be used to update the 2D domain of the hydraulic model, to better represent current conditions on site. More information on the survey data for the study is provided in the Appendix E.

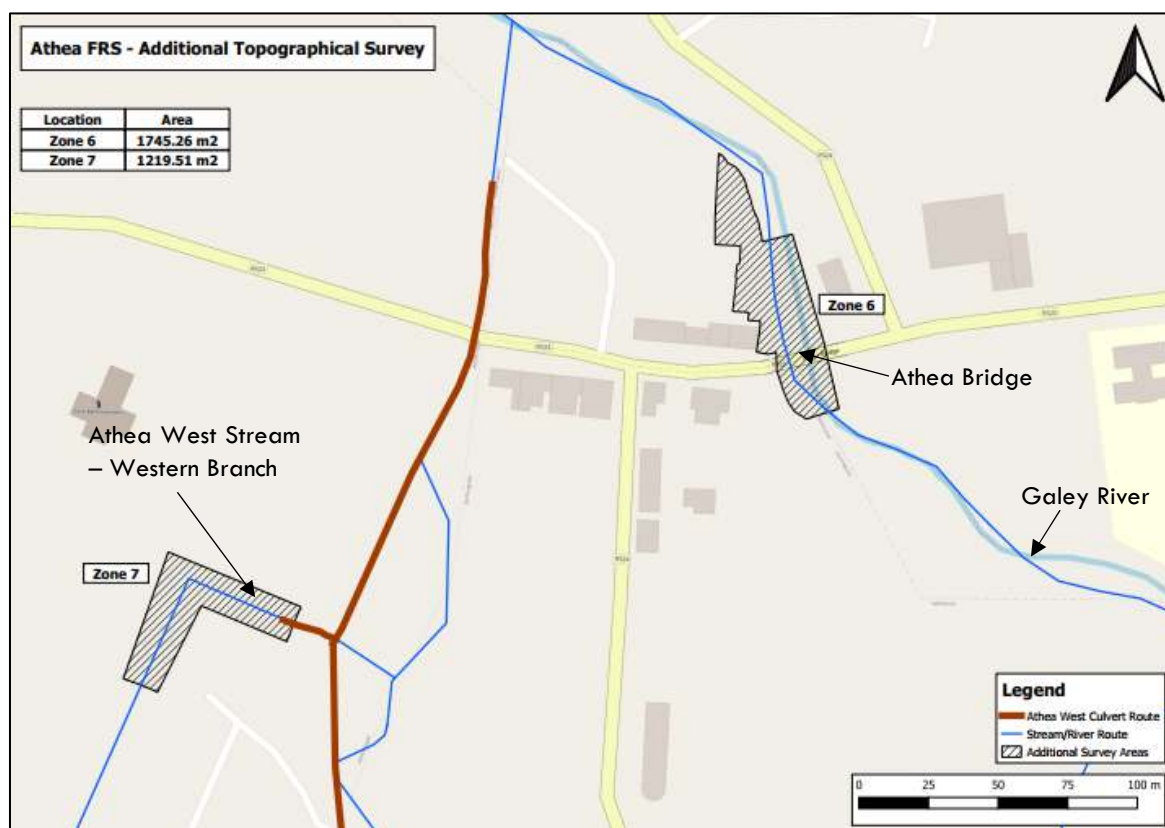


Figure 1-7: Additional Topographical Survey Areas – 2022

1.4.1.4 Ryan Hanley Topographical Survey March 2023

Additional topographical survey was specified and completed by Ryan Hanley in March 2023, as part of the Athea FRS. The locations of the topographical survey areas are shown in Figure 1-8. The survey comprises topographical survey (1.35Ha) in the vicinity of an access culvert on the Athea East stream; Hillside Drive; R253 Abbeyfeale Regional Road; and R253 Newcastle West Regional Road. This topographical survey is to be used for the Athea East stream modelling and to inform the surface water drainage design for Athea. More information on the survey data for the study is provided in the Appendix E.

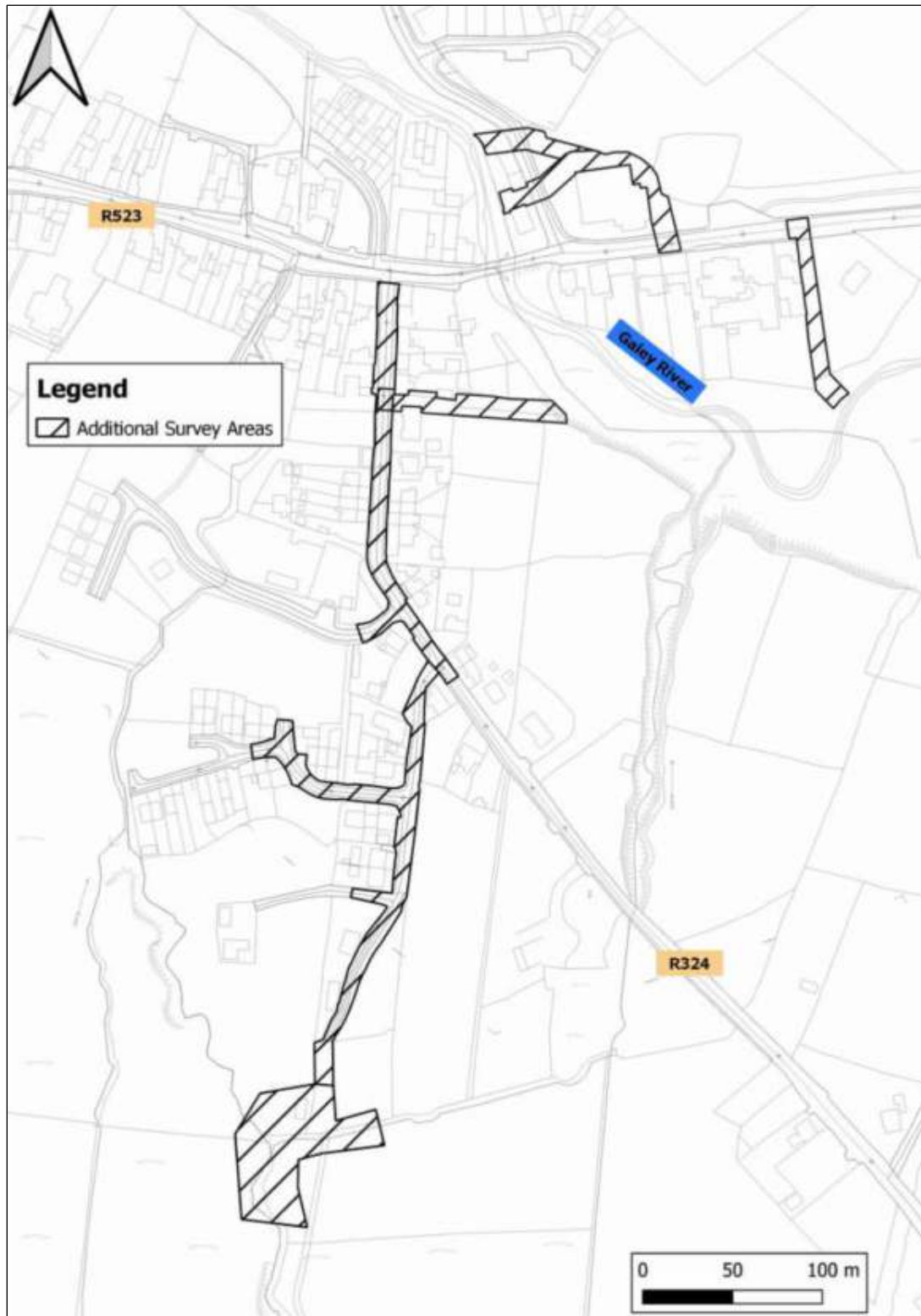


Figure 1-8: Additional Topographical Survey Areas - 2023

1.4.2 CCTV Survey

A detailed CCTV survey of an existing culvert providing connectivity on the Athea West stream was carried out in September and December 2020 by AQS Environmental Solutions, as part of the Athea FRS. The culvert inlet, for the GALF tributary, is located north of the Hillside Drive housing estate, south of the Rathronan housing estate, running in a south to north direction. The culvert inlet, for the GALG tributary, is located north of the Rathronan housing, south of the house, running in a west to east direction. The culvert outlet is located where it flows as an open channel adjacent to Markievicz Park housing estate, before converging with the Galey River, on the left bank, 170m downstream of Athea Bridge. The confirmed route of the culvert is shown in Figure 1-9. Further CCTV survey was completed by AQS Environmental Solutions

in July 2021 on the surface water/ combined network and outfalls in the vicinity of Athea Bridge, as shown in Figure 1-9. More information on the survey data for the study is provided in Section 3.3.3.2 and Appendix E.

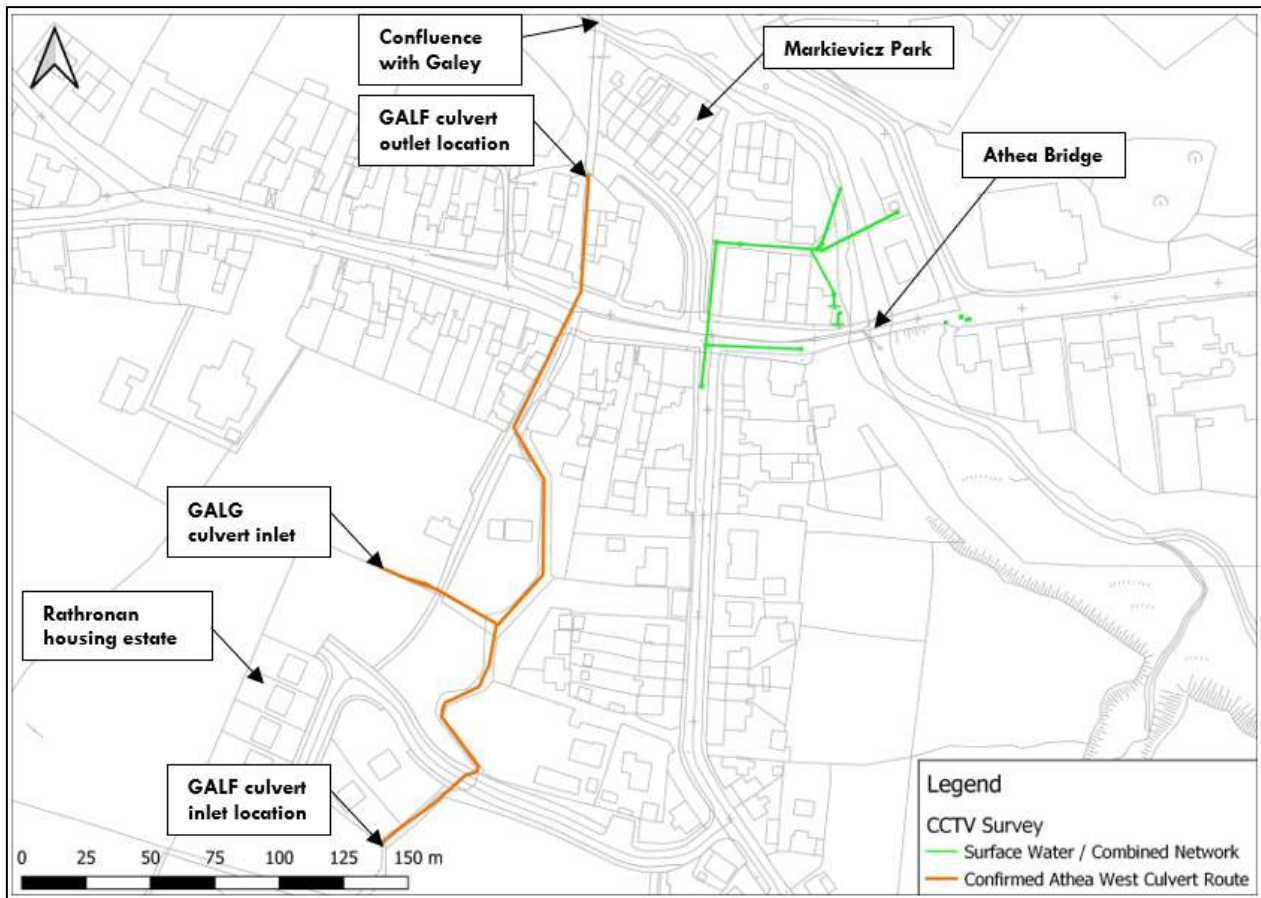


Figure 1-9: Culvert Route Following CCTV Survey

1.4.3 Digital Terrain Model

Light Detection and Ranging/ Laser Imaging, Detection and Ranging (LIDAR) data has been provided by the OPW for use in the Athea FRS hydraulic model for the proposed Athea FRS Scheme Area. For the extent of the model outside of this boundary, lower resolution Interferometric Synthetic Aperture Radar (IFSAR) data from Intermap Inc. was provided by the OPW. The LIDAR data has a 2m resolution with a 2m horizontal accuracy and a 200mm vertical accuracy while the IFSAR data is 5m resolution with a 2m horizontal accuracy and a 1m vertical accuracy.

The LIDAR data was checked for elevation anomalies against the topographical survey points taken by Bronra Surveys Ltd., which determined an average difference of 0.2m. No adjustment to the LIDAR was required and the existing data was deemed suitable for re-use in this study.

1.4.4 Hydrometric Data

There are 3 No. hydrometric gauges located along the Galey River, as shown in Figure 1-10. Station No. 23004 (Galey Bridge) and Station No. 23014 (Athea) are inactive staff gauges while Station No. 23001 (Inch Bridge) is an active recorder gauge and records water level and flow. Athea U/S and Athea D/S gauges were installed as part of the Athea FRS project in April 2021. Table 1-4 summarises the gauges within the Study Area.

Table 1-4: Summary of River Level and Flow Gauges

Station No.	Name	Station Type	Catchment Area (km ²)	Status	Co-ordinates	Record	Gaugings
23001	Inch Bridge	Water level. Realtime Data available. Recorder	191.7	Active	E95729, N136181	1949 to 1959 Pre-Arterial Drainage Scheme and 1960 to present post-arterial drainage scheme. Flow gaugings available since 1972	134 No., 1972 - 2017
23004	Galey Bridge	Water level. Staff gauge	124.1	Inactive	E104397, N138385	1944-1969	None
23014	Athea	Water level. Staff gauge	36.0	Inactive	E112498, N135418	1978-2011	111 No. 1977 - 2011
23051	Athea D/S	Water level. Realtime Data available. Recorder	36.0	Active	E112613, N135129	April 2021 onwards	None
23052	Athea U/S	Water level. Realtime Data available. Recorder	36.0	Active	E112627, N135051	April 2021 onwards	None

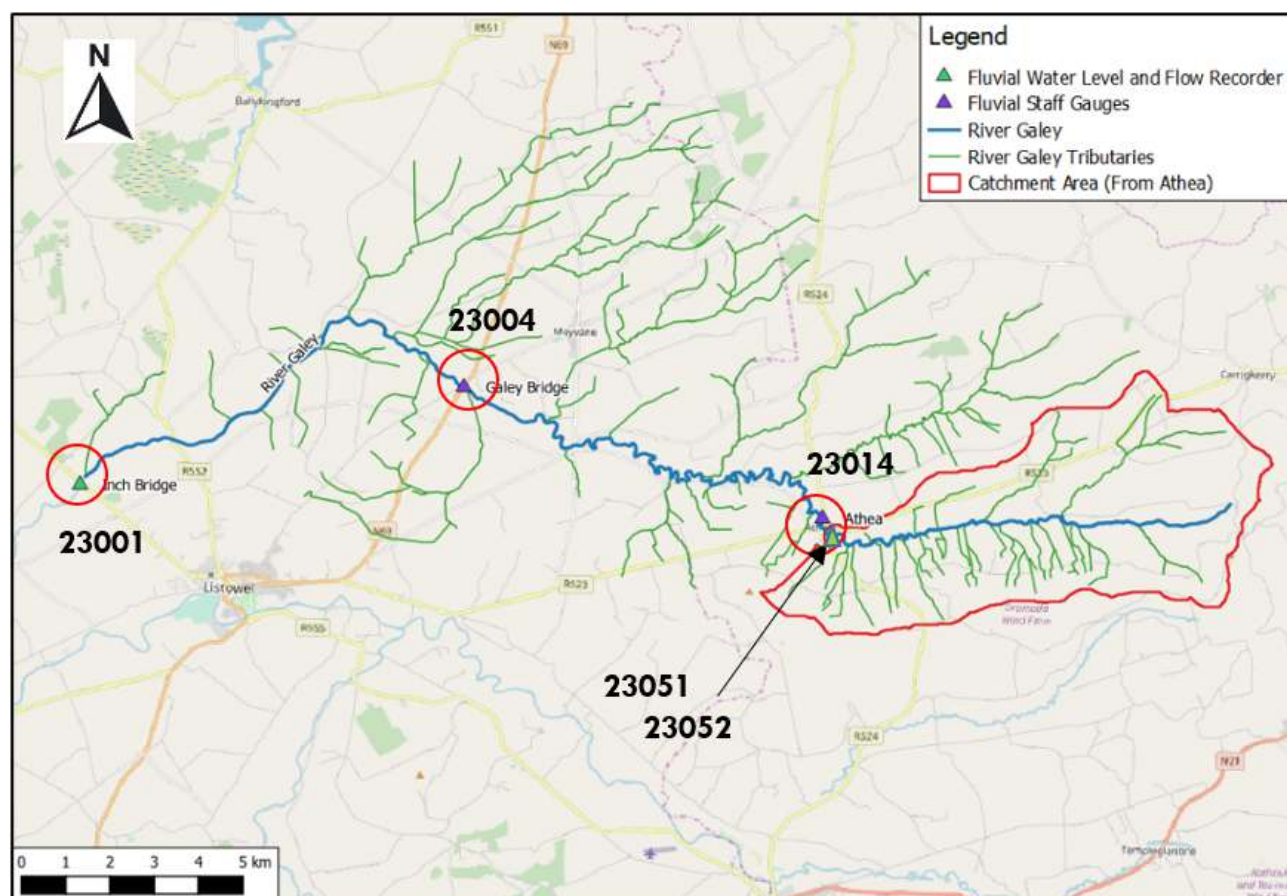


Figure 1-10: Fluvial Gauge Locations

Further information on the available hydrometric data for the catchment, and its suitability in the Athea FRS, can be found in the Athea FRS Hydrology Report (Ryan Hanley, 2021).

1.4.5 Flood History

Key flood risk areas were identified in the CFRAM study and other studies for Athea. For the purposes of the hydraulic modelling work, this data is most beneficial when accompanied by supporting details such as photos or anecdotal evidence, which confirm the maximum extent or depth of flooding at any given location.

There have been 5 No. recorded flood events in Athea, which occurred on:

- April 2005;
- 31st July – 1st August 2008;
- 6th August 2008;
- 2nd September 2009; and
- 11th September 2015.

More information on these events is provided in Section 4.2 of this report and the Athea FRS Hydrology Report (Ryan Hanley, 2021).

Within the Athea Scheme Area, supporting flood history data is available for 2008. For the purposes of this report, the 2008 event has been modelled.

2 Existing CFRAM Data

2.1 Introduction

Athea was an AFA and CAR for the CFRAM study through the national PFRA project in 2012. Athea AFA was included in UoM 23 Tralee Bay-Feale in the Shannon CFRAM. Jacobs Engineering Group completed the works on the CFRAM study for Athea.

The CFRAM study conducted extensive hydrological assessments at catchment level for hydraulic analysis of predicted future design events and from that the initial designs of potential Flood Risk Management Plans (FRMPs), which were published in 2018.

Reports that were issued as part of the CFRAM study for Athea include the following:

- Tralee Bay – Feale River Basin (UoM23) Flood Risk Management Plan
- Tralee Bay – Feale River Basin (UoM23) Flood Risk Review Report
- Tralee Bay – Feale River Basin (UoM23) Inception Report
- Tralee Bay – Feale River Basin (UoM23) Hydrology Report
- Tralee Bay – Feale River Basin (UoM23) Hydraulic Modelling Report
- Tralee Bay – Feale River Basin (UoM23) Preliminary Options Report

2.2 CFRAM Topographical Data

2.2.1 Survey Data

Cross sectional survey data was collected by Blom and Murphy Surveys Ltd. as part of the CFRAM study and was delivered in July 2013. Each watercourse surveyed as part of the CFRAM study is detailed in Table 2-1 with the survey reference, the watercourse name and whether it was included in the Athea AFA hydraulic model. The total number of cross sections used in the CFRAM hydraulic model was 299.

Table 2-1: Abbreviated Watercourse Names

Survey Reference	Description	Model Code	Model Reference
GALA	Unnamed Tributary	No Model	-
GALB	Gortnagross watercourse	No Model	-
GALC	Gortnagross watercourse	No Model	-
GALD	Unnamed Tributary of Gortnagross watercourse	No Model	-
GALE	Galey River	S14-c	GAL
GALF	Unnamed Tributary	S14-c	GGR
GALG	Unnamed Tributary	S14-c	GGR
GALH	Unnamed Tributary	No Model	-
GALI	Athea Upper watercourse	No Model	-
GALJ	Unnamed Tributary	No Model	-
GALK	Unnamed Tributary	No Model	-
GALL	Unnamed Tributary	No Model	-

2.2.2 Digital Terrain Model for CFRAM

LIDAR data was commissioned by the OPW for use in the CFRAM study model. For the extent of the model outside of the AFA boundary, lower resolution IFSAR data has been provided. The LIDAR data has a 2m resolution with a 2m horizontal accuracy and a 200mm vertical accuracy while the IFSAR data is 5m resolution with a 2m horizontal accuracy and a 1m vertical accuracy. Where an overlap of LIDAR outside the AFA boundary took place, the LIDAR data was used.

The LIDAR and IFSAR data were checked for elevation anomalies as part of the CFRAM study carried out by Jacobs Engineering Group with no issues found, although the resolution of the data and its horizontal and vertical accuracy was noted as resulting in some anomalies in the mapping outputs at the LIDAR/IFSAR interface.

2.3 CFRAM Hydrological Inputs

2.3.1 Hydrometric Gauge Review

All 3 gauges (not including the Athea U/S and Athea D/S gauges) shown in Table 1-4 and Figure 1-10 were reviewed during the CFRAM study. Station No's 23004 and 23014, Athea and Galey Bridge, had insufficient historical data to utilise. Neither of these gauges were given a quality rating in Table A1.2 of the Tralee Bay – Feale River Basin (UoM 23) Hydrology Report. Station 23001 Inch Bridge records water level and flow data and has a quality rating of A2 (Highest Gauged Flow (HGF)/Qmed = 1.1). No rating review was conducted on this gauge for the CFRAM study, but it was reviewed against check gaugings from November 1997, January 1998 and March 1998. It was noted as the only appropriate station for flood estimation within the Galey River Study Area.

2.3.2 Application of Hydrology

For each model in the CFRAM study, a detailed hydrological analysis of the river system catchment was carried out in order to produce hydrological inflows to the hydraulic model. This analysis is fully discussed in the CFRAM UoM 23 Hydrology Report for Athea. The hydrological assessment also defined how to distribute the catchment flows within the hydraulic model i.e. flow boundaries are generally set at the upstream extents of a model and also distributed laterally at appropriate HEP locations. The flows are reconciled with hydraulic influences during the HEP calibration process described in Section 5.1 of this report. The critical duration was established by virtue of the hydrological methodology employed (taking the maximum levels from the main and tributary flows) and was not established through hydraulic routing. The method is explained in the CFRAM UoM 23 Hydrology Report for Athea. The peak inflow values used for each modelled design event are included in the relevant model Appendix section, along with the HEP reference name and the model node at which the inflow hydrographs are applied. Tables highlighting the HEP reference numbers, subsequent cross section labels and flows for each design event are included in Section 2.4.5.1 of this report.

2.4 CFRAM Hydraulic Model

2.4.1 Overview

There was one hydraulic model for the Athea AFA within the CFRAM study. Its relevant model code, within the Tralee Bay – Feale River Basin (UoM 23), was S14-c and it comprised a linked 1D-2D hydraulic model (Flood Modeller – TUFLOW), which included the Galey River and two branches of the Athea West stream. Athea East stream was not included in the CFRAM hydraulic model and CFRAM did not remark on any flood risk associated with the Athea East stream.

The upstream extent of the 1D model starts approximately 1.8km upstream of the Athea Scheme Area boundary and the downstream extent of the 1D model finishes at 1.8km downstream of Inch Bridge, on the R553 Regional Road northwest of Listowel town. The model includes both High Priority Watercourse (HPW) and Medium Priority Watercourse (MPW) and served as a tributary to the River Feale Hydraulic model. As stated in Section 2.2.1, the total number of cross sections used in the 1D hydraulic model was 299. The 2D domain was approximately 0.65km², concentrating around the areas at flood risk in Athea.

2.4.2 Labelling System

Nodes within the 1D model were labelled using a 12-digit code. This was compiled from a 2-digit code detailing the river reach, from downstream to upstream and incremented at every confluence with a tributary, a 3-letter code representing the watercourse name, a 5-digit figure representing the chainage along the watercourse reach from its downstream end and a 2-letter code representing the structure and face the section is representing.

In general, as part of the modelling process, identifier labels from the survey which are associated with the channel cross section at a structure have been moved to the structure unit itself within the Flood Modeller model and the open channel has lost the structure suffix code. For consistency, a junction unit was included in the model between all river units and structures.

2.4.3 Hydraulic Roughness Representation

The CFRAM study identified reaches of similar roughness and values reflective of these reaches extracted from published tables from “Open Channel Hydraulics” (Chow, 1984) and “Reducing Uncertainty in River Flood Conveyance: Roughness Review” (UK Environmental Agency 2003).

For 1D only model reaches, Manning’s ‘n’ roughness values for out of bank, floodplain areas were defined and represented in the hydraulic model based on the Environmental Protection Agency (EPA) land use classification. The classification was provided to Jacobs Engineering Group via a GIS shapefile with preassigned Manning’s ‘n’ values. Example roughness values based on the EPA land use classification shapefile is presented in Table 2-2.

Table 2-2: Example Roughness Values based on EPA Land Use Classification

Land Use Classification Level 3 Code	Manning’s ‘n’ Value	Land Use Description
231	0.035	Pastures
243	0.045	Heterogeneous Agricultural Land
122	0.025	Roads
111	0.100	Buildings
324	0.060	Transitional Woodland Scrub
313	0.090	Forests
141	0.035	Green Urban Areas

Similarly, for the linked 1D-2D reach, Manning’s ‘n’ roughness values for out of bank, floodplain areas were defined and represented in the hydraulic model based on GIS shapefile data of land use classification. The data for this reach is Ordnance Survey Ireland’s (OSI) National Transfer Format (NTF) vector mapping classification, one layer of which is land use. As with the EPA land use classification, the NTF vector mapping was provided in the form of a GIS shapefile with pre-assigned Manning’s ‘n’ values. Example roughness values based on the OSI NTF land use classification is shown in Table 2-3.

Table 2-3: Example Roughness Values based on OSI NTF Land Use Classification

OSI NTF Land Use Classification	Manning’s ‘n’ Value	Land Use Description
618	0.045	General Rural Land
557	0.025	Roads
600	0.100	Buildings
611	0.060	General Urban
527	0.080	Woodland/ Dense Vegetation
583	0.035	Parkland/ Sport Grounds

2.4.4 Applied Hydraulic Roughness Values

For river channel roughness values for in-bank areas represented in the CFRAM study hydraulic model, a compound value estimated by comparing photographs, survey information and the roughness guide by the UK Environment Agency (EA) was used. Table 2-4 shows the roughness values used for river reaches between the identified model node sections, and whether the reach is located within or outside of the 2D domain.

Table 2-4: Manning’s ‘n’ Values for 1D Model Cross Sections

River Name	Model Node Reference	Manning’s ‘n’ Value	Domain Area
Galey River	04GAL02614 to 04GAL02214	0.048	1D only
Galey River	03GAL11913 to 02GAL04013	0.053	1D only
Galey River	02GAL03511u to 01GAL05410	0.047	1D only
Galey River	04GAL02106 to 04GAL00516	0.047	1D-2D
Galey River	04GAL00417 to 03GAL13097	0.050	1D-2D
Galey River	03GAL12515 to 03GAL12145	0.040	1D-2D

Galey River	03GAL12958 to 03GAL12594	0.050	1D-2D
Galey River	03GAL12048 to 03GAL11964	0.045	1D-2D
Unnamed tributary (east branch)	01GGR00593 to 01GGR00000u	0.040	1D-2D
Unnamed tributary (west branch)	01GGR00321 to 01GGR00044u	0.055	1D-2D

Floodplain roughness values for out-of-bank areas represented in the CFRAM study hydraulic model were defined and represented in the hydraulic model based on GIS shapefile data of land use classification. 1D only reaches were based on the EPA land use classification, while the 2D domain areas were based on OSI NTF classification. Roughness values used for the study are shown in Table 2-5. Reaches of similar hydraulic roughness have been identified through review of the Athea FRS hydraulic model, survey photos/ videos, aerial photographs and drawings. Manning's 'n' roughness values applied to the riverbed and left and right banks within each of these reaches is shown in Table 3-6. Along with the land use categorisation, the source of the classification and the domain it is located in. Due to the use of the filtered LIDAR to represent the topography of the 2D domain, buildings were not accurately represented in the grid. To adequately model the obstruction to flow, a Manning's 'n' value of 0.01 were used for the building footprint.

Table 2-5: Manning's 'n' Values for Floodplain Land Use

Land Use Classification	Manning's 'n' Value	Classification Source	Domain Area
Pastures	0.035	EPA Land Use	1D Domain
Mixed Vegetation	0.080	EPA Land Use	1D Domain
Road Network	0.025	EPA Land Use	1D Domain
Buildings	0.100	EPA Land Use	1D Domain
Buildings	0.100	OSI NTF Land Use	2D Domain
Short Grass, Parks	0.035	OSI NTF Land Use	2D Domain
General Urban	0.060	OSI NTF Land Use	2D Domain
General Rural	0.045	OSI NTF Land Use	2D Domain
Dense Vegetation	0.080	OSI NTF Land Use	2D Domain
Roads	0.025	OSI NTF Land Use	2D Domain
Rail	0.050	OSI NTF Land Use	2D Domain
Waterbodies	0.020	OSI NTF Land Use	2D Domain

2.4.5 Application of Hydrology

2.4.5.1 Model Boundaries – Inflows

A flow boundary was included at the upstream extent of the Galey River at a HEP "23_1853_1". The upstream extents of the two unnamed tributaries also includes for inflow flow-time boundaries, both being sub versions of the difference between HEP "23_2579_2" and "23_2579_1". The inflows were labelled "23_2579_00a" for the western portion of the unnamed tributary and "23_2579_00b" for the eastern portion. The division of target flows was based on sub catchment percentages.

Additional flow- time boundaries were included in the model to account for tributary inflows and were applied either directly to specific individual cross sections or laterally along a reach of cross sections where appropriate. The flows were reconciled with hydraulic influences during the HEP calibration process.

The Critical Duration was established by taking the maximum levels from the main and tributary flows. The peak inflow values used for each modelled design event are included in Table 2-6 to Table 2-8, along with the HEP reference name and the model node at which the inflow hydrographs were applied.

Table 2-6: CFRAM Current Scenario Model Inflows

River	HEP Reference	Location	Annual Exceedance Probability (AEP) %							
			50%	20%	10%	5%	2%	1%	0.5%	0.10%
Galey	23_1853_1	04GAL02614 (U/S extent)	27.5	37.9	44.4	50.7	58.7	64.8	70.8	84.8
	23_1920_2	04GAL00979	2.4	3.4	3.9	4.5	5.2	5.7	6.3	7.5
	23_2579_3	03GAL12594	0.42	0.58	0.68	0.78	0.90	0.99	1.1	1.3
	23_2580_2	03GAL12048	0.97	1.3	1.6	1.8	2.1	2.3	2.5	3.0
	23_2514_2	03GAL11524	13.9	19.2	22.4	25.6	29.7	32.7	35.8	42.8
	23_1756_1	03GAL07078	6.2	8.5	9.9	11.3	13.1	14.5	15.8	19.0
	23_2517_2	03GAL06087	3.4	4.7	5.5	6.3	7.3	8.0	8.8	10.5
	23_2954_2	03GAL02001	0.78	1.1	1.3	1.4	1.7	1.8	2.0	2.4
	23_1755_3	03GAL00000	7.4	10.2	12.0	13.6	15.8	17.4	19.1	22.8
	23_2650_2	02GAL08855	1.3	1.8	2.2	2.5	2.9	3.2	3.5	4.1
	23_2650_5	02GAL07752	7.8	10.7	12.5	14.3	16.6	18.3	20.0	23.9
	23_2696_1	02GAL07213	1.8	2.4	2.8	3.2	3.7	4.1	4.5	5.4
	23_2567_2	02GAL05514	15.3	22.5	29.6	35.1	40.6	46.1	53.2	60.3
	23_1852_3	02GAL04013	6.4	10.9	15.3	18.5	21.8	25.0	28.9	32.7
	23_2558_2	02GAL03511	5.2	16.8	28.3	36.3	44.2	52.2	60.2	68.2
	23_2371_2	01GAL10909	2.0	2.7	3.2	3.7	4.2	4.7	5.1	6.1
Unnamed Tributary – Western Branch	23_2579_0 0a	01GGR00593	0.18	0.25	0.29	0.33	0.39	0.43	0.47	0.56
Unnamed Tributary – Eastern Branch	23_2579_0 0b	01GGR00321	0.63	0.86	1.01	1.15	1.33	1.47	1.61	1.93

Table 2-7: CFRAM MRFS Model Inflows

River	HEP Reference	Location	Annual Exceedance Probability (AEP) %							
			50%	20%	10%	5%	2%	1%	0.50%	0.10%
Galey	23_1853_1	04GAL02614 (U/S extent)	33.0	45.5	53.3	60.8	70.4	77.8	85.0	101.8
	23_1920_2	04GAL00979	2.9	4.1	4.7	5.4	6.2	6.8	7.6	9.0
	23_2579_3	03GAL12594	0.5	0.7	0.8	1.0	1.1	1.2	1.3	1.6
	23_2580_2	03GAL12048	1.2	1.6	1.9	2.2	2.5	2.8	3.0	3.6
	23_2514_2	03GAL11524	16.7	23.0	26.9	30.7	35.6	39.2	43.0	51.4
	23_1756_1	03GAL07078	7.4	10.2	11.9	13.6	15.7	17.4	19.0	22.8
	23_2517_2	03GAL06087	4.1	5.6	6.6	7.6	8.8	9.6	10.6	12.6
	23_2954_2	03GAL02001	1.0	1.3	1.6	1.7	2.0	2.2	2.4	2.9
	23_1755_3	03GAL00000	8.9	12.2	14.4	16.3	19.0	20.9	22.9	27.4
	23_2650_2	02GAL08855	1.6	2.2	2.6	3.0	3.5	3.8	4.2	4.9
	23_2650_5	02GAL07752	9.4	12.8	15.0	17.2	19.9	22.0	24.0	28.7
	23_2696_1	02GAL07213	2.2	2.9	3.4	3.8	4.1	4.9	5.4	6.5
	23_2567_2	02GAL05514	18.4	27.0	35.5	42.1	48.7	55.3	63.8	72.4
	23_1852_3	02GAL04013	7.7	13.1	18.4	22.2	26.2	30.0	34.7	39.2
	23_2558_2	02GAL03511	6.2	20.2	34.0	43.6	53.0	62.6	72.2	81.8
	23_2371_2	01GAL10909	2.4	3.2	3.8	4.4	5.0	5.6	6.1	7.3
Unnamed Tributary – Western Branch	23_2579_00a	01GGR00593	0.2	0.4	0.4	0.4	0.5	0.5	0.6	0.7

Unnamed Tributary – Eastern Branch	23_2579_00b	01GGR00321	0.7	1.1	1.2	1.4	1.6	1.8	1.9	2.3
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Table 2-8: CFRAM HEFS Model Inflows

River	HEP Reference	Location	Annual Exceedance Probability (AEP) %		
			10%	1%	0.10%
Galey	23_1853_1	04GAL02614 (U/S extent)	57.7	84.2	110.2
	23_1920_2	04GAL00979	5.1	7.4	9.8
	23_2579_3	03GAL12594	0.9	1.3	1.7
	23_2580_2	03GAL12048	2.1	3.0	3.9
	23_2514_2	03GAL11524	29.1	42.5	55.6
	23_1756_1	03GAL07078	12.9	18.9	24.7
	23_2517_2	03GAL06087	7.2	10.4	13.7
	23_2954_2	03GAL02001	1.7	2.3	3.1
	23_1755_3	03GAL00000	15.6	22.6	29.6
	23_2650_2	02GAL08855	2.9	4.2	5.3
	23_2650_5	02GAL07752	16.3	23.8	31.1
	23_2696_1	02GAL07213	3.6	5.3	7.0
	23_2567_2	02GAL05514	38.5	59.9	78.4
	23_1852_3	02GAL04013	19.9	23.5	42.5
	23_2558_2	02GAL03511	36.8	67.9	88.7
	23_2371_2	01GAL10909	4.2	6.1	7.9
Unnamed Tributary – Western Branch	23_2579_00a	01GGR00593	0.4	0.5	0.8
Unnamed Tributary – Eastern Branch	23_2579_00b	01GGR00321	1.3	2.0	2.5

2.4.5.1 Model Boundaries – Downstream Conditions

The downstream boundary condition selected for the fluvial model was a free flow boundary set at the downstream limit in the 1D model. This equated to the flow being at “normal depth” for the channel slope at the downstream limit of the model. Checks were made to ensure the normal depth assumption was reasonable and flood flows “leaving” the model were not subject to a backing up effect.

2.4.6 Model Calibration

2.4.6.1 Calibration to Historical Events

Full calibration to historical events was not achieved during the CFRAM model build due to insufficient hydrometric data. Instead, a verification took place within the Athea AFA against the observations reported for the historical event of the 31st July and 6th August 2008.

The validation of the model to the 2008 events was achieved by comparing the predicted flood extent of the 0.1% Annual Exceedance Probability (AEP) (1 in 1000 years) flood event against the observations from the 2008 events, which was estimated as a 0.15% AEP (1 in 650 years) event. This was achieved using a second model to represent the vegetation, debris and sediment build up reported in the vicinity of Athea Bridge prior to the flood event.

The post-flood event report from JBA Consulting includes photographs of Athea Bridge and riverbed after the 2008 flood events. Local residents provided observations of sediment build-up of up to 1.5m in the central arch and a significant blockage in the right arch. The CFRAM study hydraulic model replicated these blockages by raising the bed level by 1.5m

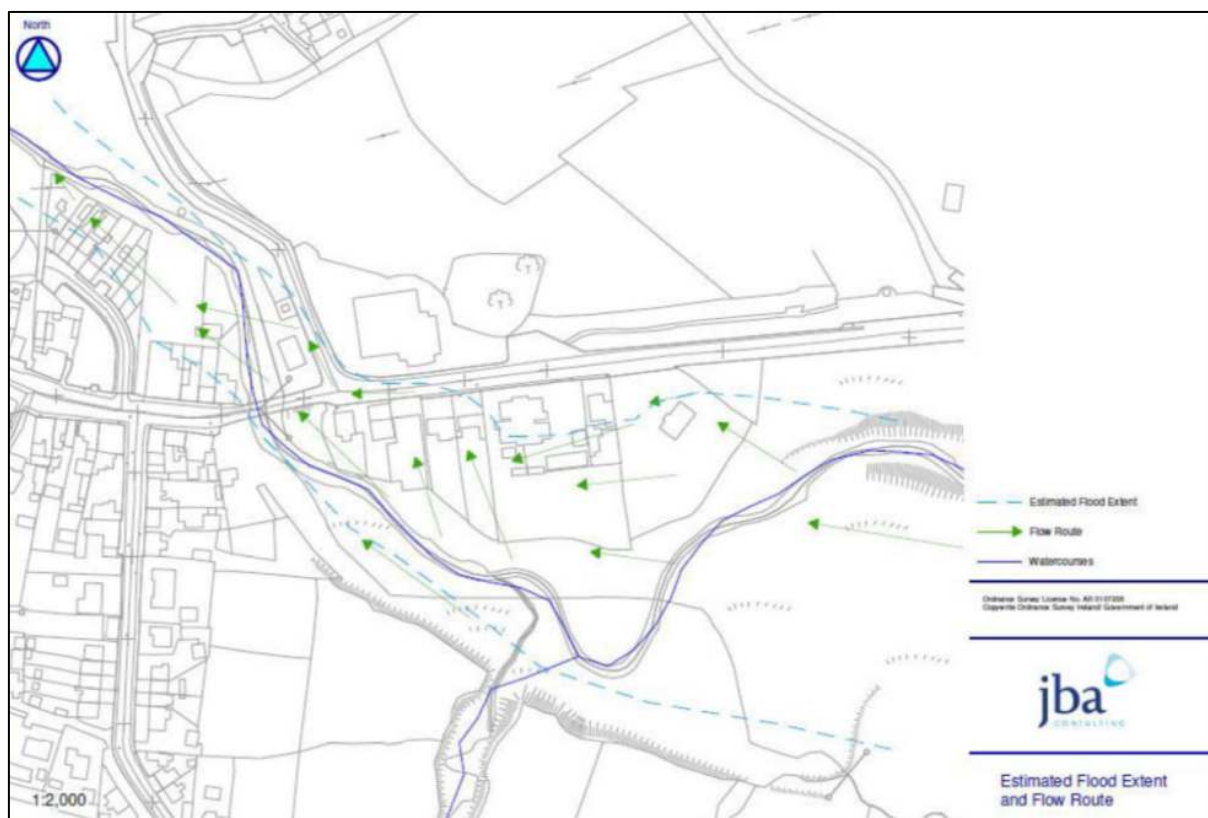


Figure 2-2: JBA Consulting Estimated Flood Extent and Flow Route (2008)

2.4.6.2 Calibration to HEPs

Inflow flow-time (QT) boundaries were derived from the CFRAM hydrological analysis and adjusted individually in time to replicate the peak time propagating wave as it travels along the Gale River. The total peak flow predicted at the HEP location within the model were then compared to the derived values from the hydrological analysis.

Inflows were scaled up/ down, where appropriate to achieve modelled total peak tolerances of 10% of the target HEP flows. The flows at “23_2567_2”, “23_1852_3” and “23_2558_2” were increased individually by varying amounts to achieve the desired tolerance. For the CFRAM analysis, the average percentage differences for all of the HEP nodes are 1.5% for the 10% AEP event, 2.1% for the 1% AEP event and 0.9% for the 0.1% AEP event.

3 Hydraulic Modelling

3.1 Overview

3.1.1 Athea FRS Main Model

The Athea FRS hydraulic model for this study comprises a single 1D-2D Flood Modeller – TUFLOW model. The original model was built by Jacobs Engineering Group as part of the CFRAM study. The model has been modified and updated with additional topographical and CCTV survey data as part of this study. The model extent has also been reduced. The Athea FRS hydraulic model extent includes the Galey River and the Athea West stream, with the Athea East stream represented by a point inflow on the Galey River. It should be noted that there have been no previous in-depth reviews and analysis of the Athea West and Athea East streams, which have been included in this project. Details of the model and updates that have been applied to the model are detailed in the following sections and in Appendix E of this report.

The reaches of the Galey River modelled outside of the Scheme Area have been constructed using cross section survey data only. Cross sections are located at 500m to 1000m intervals and at key hydraulic structures, such as bridges, embankments and significant weirs and are extended using IFSAR data.

The section of the model within the Scheme Area has been constructed using both the cross-section survey to represent the channel and LIDAR data to represent the floodplain in the 2D domain. Cross sections are located at approximately 50-100m intervals and at all structures. The 1D model comprises the river channel itself and extends to the top of the riverbank. The 2D model comprises the floodplain beyond the river channel and has been updated from the LIDAR data, which forms a grid of floodplain levels. Bank top survey collected within the Scheme Area provides greater detail at the interface of the 1D and 2D model. This modelling approach accounts for 5.1km of the Galey River and unnamed tributaries. An overview of the 1D model extent and the 2D model domain are shown in Figure 3-1.

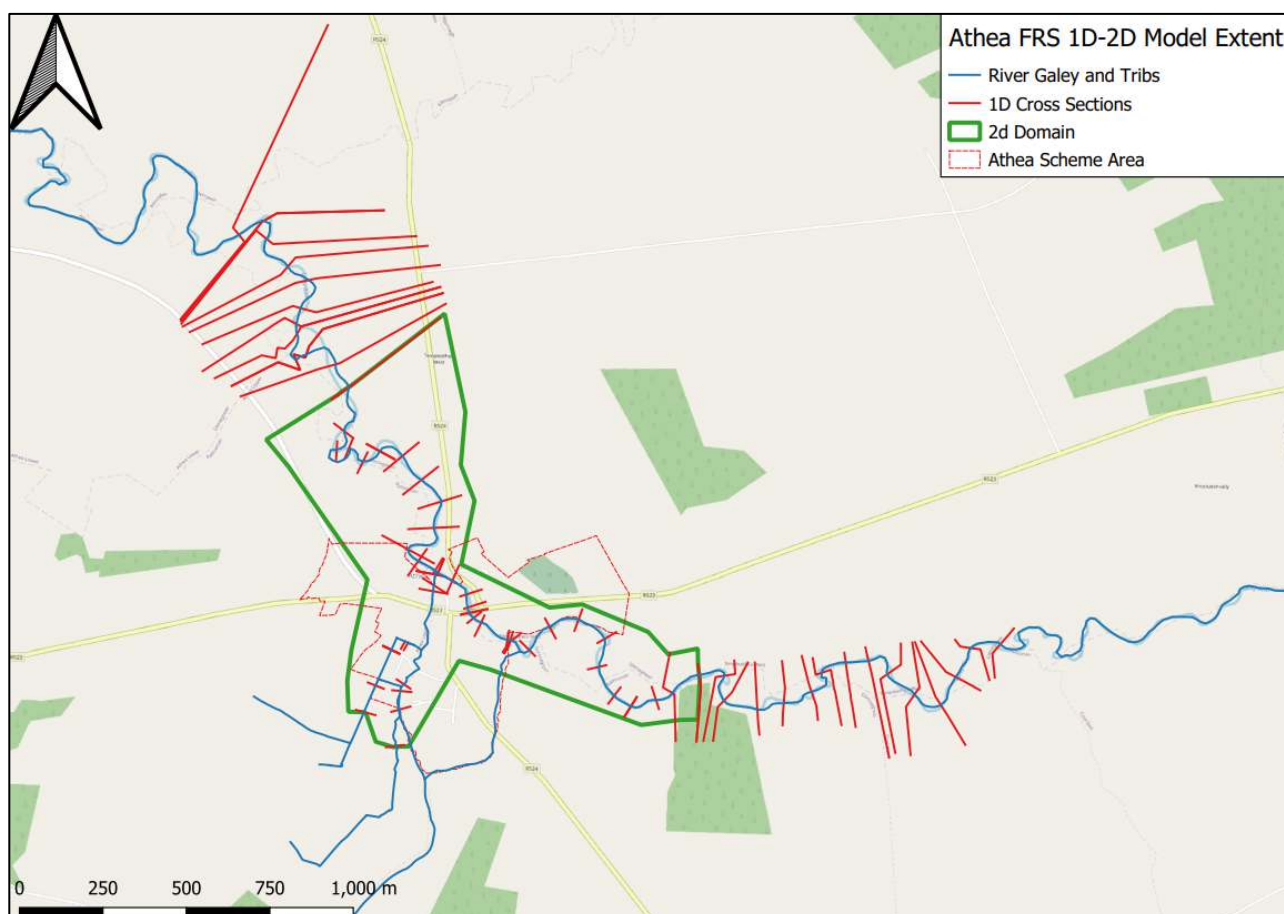


Figure 3-1: Athea FRS 1D-2D Model Overview

3.1.2 Athea East Stream Model

The fluvial flood risk associated with the Athea East stream is assessed separately to the Galey River and Athea West stream in a standalone hydraulic model.

The Athea East stream hydraulic model is a single 1D-2D Flood Modeller – TUFLOW model, built by Ryan Hanley, utilising CFRAM cross section survey data, additional survey data captured by Ryan Hanley in March 2023 and Lidar data. The model extent includes the 0.71km of the Athea East stream. The 1D model comprises the stream channel itself and extends to the top of the banks. The 2D model comprises the floodplain beyond the river channel and has been updated from the LIDAR data, which forms a grid of floodplain levels. Bank top survey provides greater detail at the interface of the 1D and 2D model. The downstream extent of the model is towards the downstream of the Athea East stream, where it joins the Galey River. Details of the model are detailed in the following sections and in Appendix E of this report. An overview of the 1D model extent and the 2D model domain are shown in Figure 3-2.

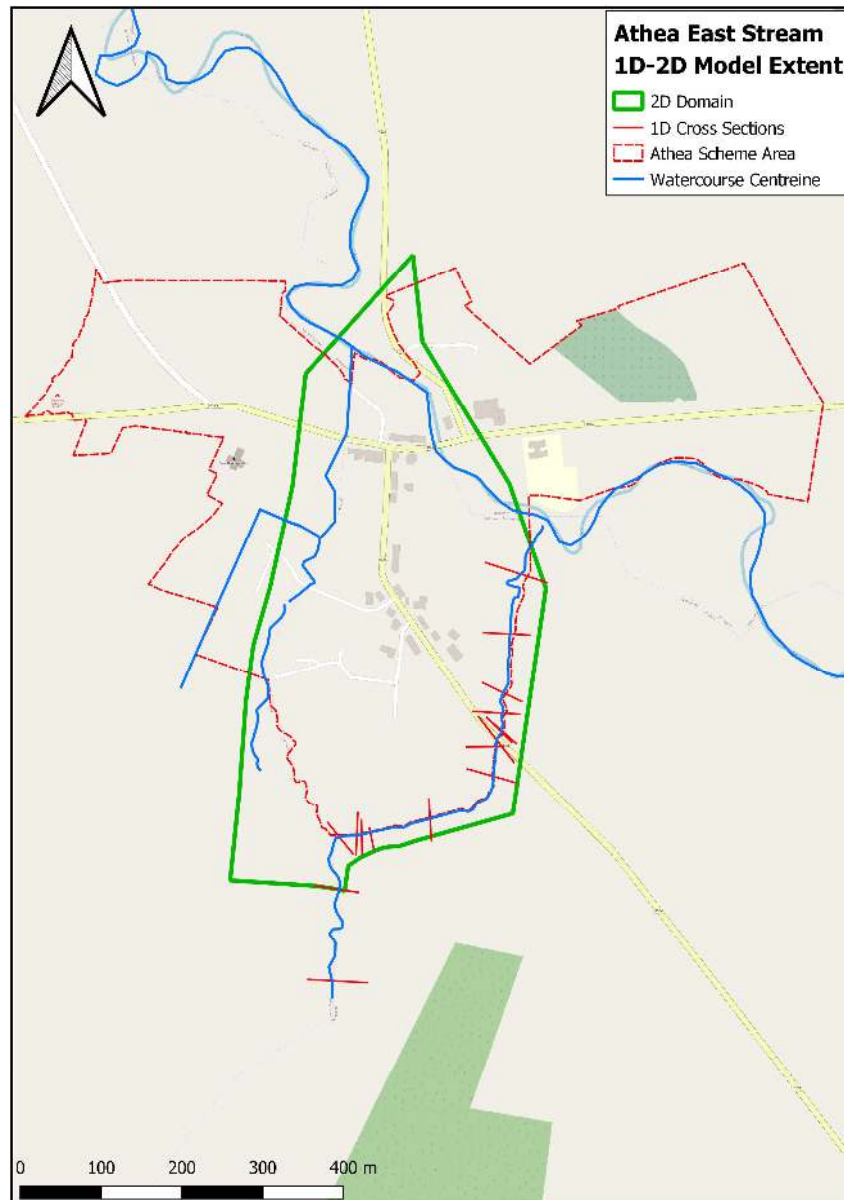


Figure 3-2: Athea East Stream 1D-2D Model Overview

3.2 Labelling System

A review of the labelling system utilised for the CFRAM study has been undertaken and been deemed acceptable for use in the hydraulic model for this study. In general, as part of the modelling process, identifier labels from the survey which are associated with the channel cross section at a structure have been moved to the structure unit itself within the Flood Modeller model and the open channel has lost the structure suffix code. For consistency, a junction unit has been included in the model between all river units and structures.

3.3 Key Hydraulic Structures

The Athea FRS hydraulic model includes three hydraulic structures – one bridge and two culverts. It should be noted that the Athea footbridge, located immediately upstream of the Athea Road Bridge has not been represented in the model as it was adjudged to pose no influence on the hydraulic conditions of the road bridge, due to its soffit being at a higher level to that of the Athea Road Bridge. All structures included in the hydraulic model are within the Scheme Area.

3.3.1 Representation of Bridges

Bridge (Arch) units have been used to represent the bridge within the model. Additionally, the orifice mode option has been activated to allow for orifice flow when a structure becomes surcharged. Bridge skew has been represented by entering the angle in the unit. This is consistent with the format the survey has been delivered in, which surveyed the full face of the bridge and recorded the skew angle. The bridge has an associated spill unit to allow for spilling over the bridge under extreme conditions.

3.3.2 Representation of Culverts

3.3.2.1 Athea West Stream

The culverts within the model comprise two upstream culverts that converge into one culvert for the Athea West stream. The culverts are modelled using appropriate conduit, inlet and outlet units, while junction units have been utilised where a change in dimension and shape have occurred. Roughness coefficients used for the culvert barrel are selected based on the material of construction from the survey photographs, video footage and surveyor comments.

For the Athea West culvert, a CCTV survey was undertaken to determine the exact locations where the two upstream culverts come together and where the shape and dimension changes occur. Condition surveys of the Athea West culvert inlets were also completed in November 2022. Thus, the resulting culvert is much more representative than that in the CFRAM model.

3.3.2.2 Athea East Stream

The culverts within the Athea East stream model comprise 2 no. culverts. The most upstream culvert is a land access culvert, adjacent to a farmyard, modelled using an orifice unit. An orifice unit is utilised due to the short length of culvert, its drowned-out state in flood conditions and for model stability purposes. The throat invert, throat soffit, sill level and bore area are taken from the survey information to represent the culvert accurately. A spill unit is not included for this structure, as overtopping is accounted for in the 2D domain.

The R524 road culvert is modelled using appropriate conduit, inlet and outlet units. A roughness coefficient used for the culvert barrel is selected based on the material of construction from the survey photographs, video footage and surveyor comments. A spill unit is not included for this structure, as there is no potential for overtopping due to the size of the culvert.

3.3.3 Key Hydraulic Structures within Scheme Area

There are 4 key hydraulic structures within the Athea Scheme Area: Athea Bridge on the Galey River; one culvert on the Athea East stream; and two culverts, which join converge into one, on the Athea West stream. Table 3-2 provides a summary of the key hydraulic structures within the Athea FRS main hydraulic model and the Athea East stream hydraulic model. All structures were inspected during site visits as part of this project.

3.3.3.1 Athea Bridge

Athea Bridge comprises three cut-stone arches – one main arch and two side arches. Historically, the river at this location, and upstream, was maintained by riparian landowners until 1995, as stated in the “*Athea Flood Severity and Impact Report*” (JBA Consulting, 2008). It was noted that as part of the maintenance works, gravel clearing from the bed was undertaken by local landowners in areas of high deposition, however, this practice was reported by locals to have ceased since the river was designated as part of the Lower River Shannon SAC (JBA Consulting, 2008). While the OPW removed major flood debris from Athea Bridge following the extreme flood event in 2008 and have undertaken similar works on four other occasions since following consultation with the IFI and NPWS, they do not have the responsibility under the 1945 Arterial Drainage Act to undertake channel maintenance works at Athea. The deposition of gravel at Athea Bridge reduces flow conveyance through the arches and poses a flood risk to a number of properties along Main Street.

3.3.3.2 Athea West Stream Culverts

The culvert on the western branch of the Athea West stream is a 0.75m diameter concrete pipe culvert, which connects to another culvert, a 0.9m diameter concrete pipe culvert, on the eastern branch of Athea West stream via a junction. The culvert from this point is a rectangular 1200mm x 600mm concrete culvert with galvanised sheets as a roof until it reaches Main Street, where a dividing structure splits the culvert into 2 no. 600mm x 600mm box masonry culverts, which discharge to an open channel adjacent to the Markievicz Park housing estate. From the CCTV survey report, there are minor defects to the culverts, but nothing noteworthy to amend how they are represented in the hydraulic model.

The Athea West stream and its culverts pose an additional flood risk to the houses adjacent to the stream, as well as properties on Main Street. Table 3-1 presents the condition of the lengths of culvert that comprise the Athea West stream culverts, while Table 3-1 shows where the dimension changes of the culverts occur. Appendix E – Model Check File includes more detail on these culverts.

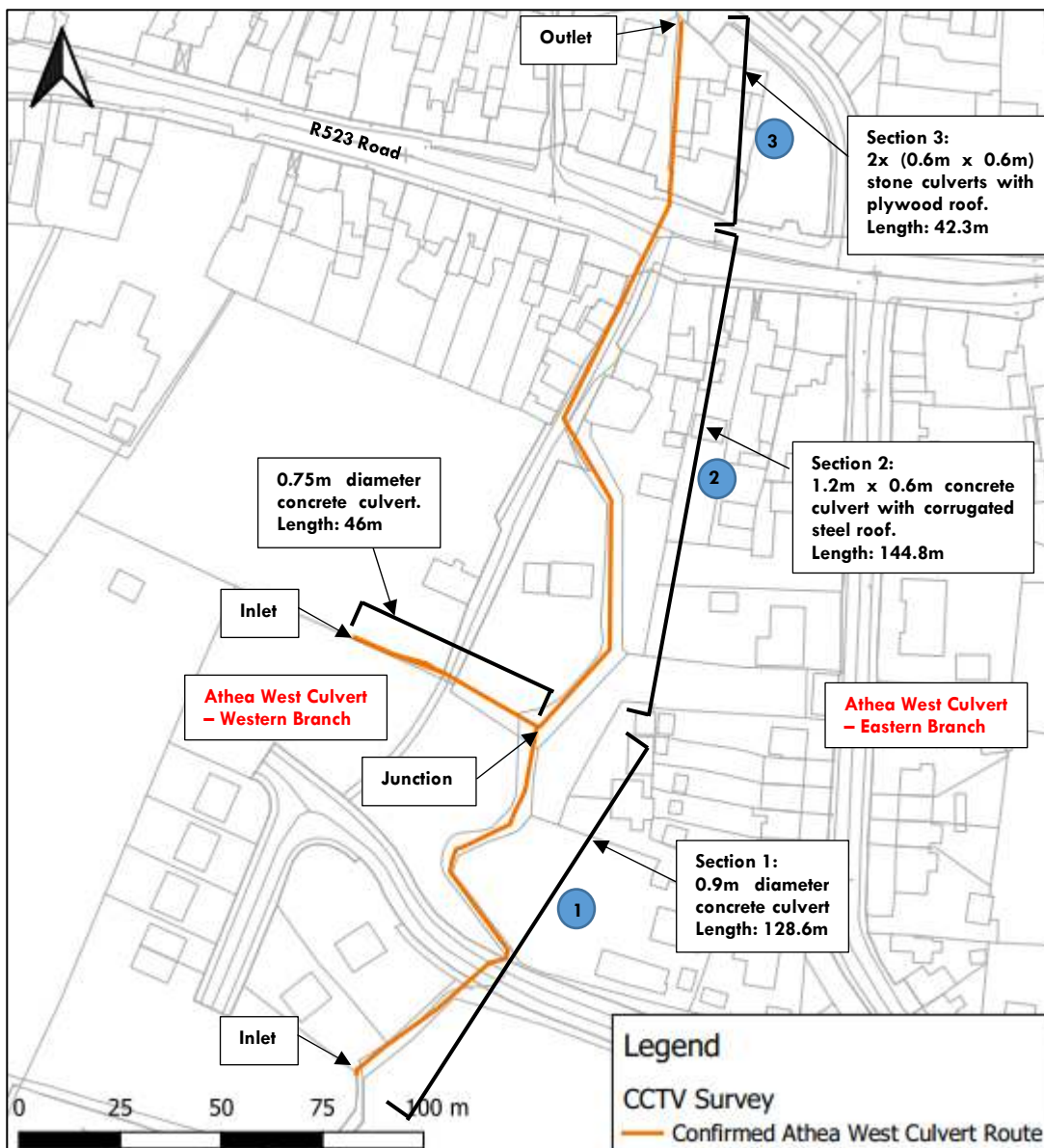


Figure 3-3: Athea West Stream Culverts – Breakdown of Lengths

Table 3-1: Condition of Lengths of Athea West Stream Culverts


Section	Dimensions/Type/Materials	Length	Condition from CCTV Survey
Athea West – Eastern Branch Section 1	0.90m diameter concrete pipe culvert	128.6m	Good condition in general. Some deposits, encrustation and roots noted, but only a small area (5% of cross-sectional area). Some infiltration occurring along length of culvert. Minor fractures noted.
Athea West – Eastern Branch Section 2	1.2m x 0.6m concrete culvert with corrugated steel roof	144.8m	Good condition. Upgraded recently by LCCC. Some deposits, encrustation and roots noted, but only a small area (5-10% of cross-sectional area). Some infiltration occurring along length of culvert. Minor cracks/fractures noted, as well as some deformities.
Athea West – Eastern Branch Section 3	2 x (0.6m x 0.6m) stone culverts with plywood roofs	42.3m	Ok condition. Some coarse, settled deposits noted over 10-25% of cross-sectional area. Minor fractures noted. Point repair noted with localised lining. 2 outfalls recorded.
Athea West – Western Branch	0.75m diameter concrete pipe culvert. Trash screen on inlet.	46m	Ok condition. Vegetation recorded at trash screen on culvert inlet.





For the CFRAM hydraulic model, the culvert on the western branch was modelled as a 0.75m diameter concrete pipe culvert, which connected to the eastern branch culvert via a junction. For the eastern branch of the culvert upstream of the junction, the culvert was modelled as a 0.9m diameter concrete pipe culvert, which changed to a 0.984m x 1.030m concrete culvert until it discharged to the Athea West stream open channel. The lengths of each section differ in the CFRAM to that recorded on the CCTV survey for this project. Roughness values within the culvert also differ from the CFRAM hydraulic model to the current hydraulic model. Appendix E of this report includes more detailed updates that have been applied to the hydraulic model for this project.




3.3.3.3 Athea East Stream Farm Access Culvert

The Athea East stream farm access culvert is a 0.90m diameter concrete pipe culvert and is 6.11m in length. There is a farm access road crossing over this culvert. Appendix E – Model Check File includes more detail on this culvert.

Table 3-2: Key Hydraulic Structures

Structure Name	Description	Photograph
Galey River		
Athea Bridge	The Galey River passes under Athea Bridge (1820) at Athea. The bridge comprises three cut-stone arches, one main arch and two side arches. The bridge piers are protected by cut waters. A pedestrian bridge spans the channel immediately upstream of the bridge. Photo taken on 24/11/2020.	
Athea West Stream		

<p>Culvert inlet at 01GGR00393u</p>	<p>This 0.9m diameter concrete pipe culvert is located on Athea West stream, north of Rathronan housing estate. This converges with the culvert which has its inlet located at 01GGR00044u before heading north along a laneway, crossing Athea Main Street and emerging adjacent to Markievicz Park. Photo 1 was taken from the original survey undertaken in 2012. Photo 2 was taken during a site visit in 2021, as part of this study.</p>	 <p>2012 photo.</p>  <p>2021 photo.</p>
<p>Culvert inlet at 01GGR00044u</p>	<p>This 0.75m diameter concrete pipe culvert is located on an unnamed tributary between Hillside Drive housing estate and Rathronan housing estate. The photos for this structure are taken from the original survey undertaken in 2012 and from 2021 site visits.</p> <p>Downstream of where the 2 culverts meet, the culvert changes shape to a 1200 x 600mm rectangular concrete culvert.</p> <p>An additional visual survey was undertaken in November 2022.</p>	 <p>2012 photo.</p>  <p>2021 photo.</p>

		 <p>2022 photo.</p>
Culvert outlet at 01GGR0060d	<p>At Main Street, the 1200 x 600mm culvert diverges into 2 no. 600 x 600mm box masonry culverts, which discharge to an open channel adjacent to the Markievicz Park housing estate.</p> <p>The photo was taken during a site visit in 2021, as part of this study.</p>	
Athea East Stream		
Culvert at 23GAL00059O	<p>Towards the upstream extent of the Athea East stream, there is a 0.900m diameter concrete culvert, located adjacent to a farmyard, providing access to farmland. The photo for this structure was taken from a 2023 site visit.</p>	

3.4 Hydraulic Roughness

Hydraulic roughness, or friction, is represented by Manning's coefficient "n" in the hydraulic model. Values of 'n' are representative and dependant on a range of factors that influence overall roughness either in the channel or across the floodplain. The factors that influence Manning's 'n' include bed materials and size, vegetation, surface irregularities, channel bed forms, erosional and depositional features, channel sinuosity, and obstructions, all of which influence channel and floodplain conveyance. For the 1D model, hydraulic roughness is represented by Manning's 'n' across the three panels of the channel for each cross section as follows:

- Left bank

- Channel bed
- Right bank

For the 1D only reaches of the model, the extension of cross sections to represent floodplain roughness will generally result in additional Manning's 'n' values being applied then in the three locations listed above, to fully represent the floodplain. The determination of suitable hydraulic roughness values for each watercourse was based upon a combination of review of survey photographs/ videos and notes on survey drawings, review of aerial and observations from site visits.

3.4.1 Applied Hydraulic Roughness Values

A review and update of hydraulic roughness values to the 1D model was undertaken using the values highlighted in Table 3-3 and Table 3-4 for in channel roughness's and Table 3-5 for the 2D model.

Typical roughness values to use for riverbed materials used in the Athea FRS are derived from "Reducing Uncertainty in River Flood Conveyance, Roughness Review" table 10 and are summarised in Table 3-3. Typical roughness values to use for riverbanks are derived from "Reducing Uncertainty in River Flood Conveyance, Roughness Review" table 16 and table 23 and are summarised in Table 3-4. Where there was a mix of substrates and materials, the modeller would use their judgement to determine the most appropriate roughness value. One roughness value is applied to each of the three panels across a cross section.

The majority of critical storms are expected to be winter storms. High roughness values based on summer vegetation in these instances are not appropriate, thus more permanent vegetation is assessed when determining bank roughness values.

Table 3-3: Channel Bed Roughness Values

Channel Substrate	Roughness Values (Manning's 'n')
Bedrock	0.025
Cobbles (64 – 256mm)	0.055
Coarse Gravel	0.035
Gravel (2 – 64mm)	0.030
Sands	0.025
Silt	0.022
Clay	0.020
Concrete	0.020

Simplified version of Table 10 from Reducing Uncertainty in River Flood Conveyance, Roughness Review. By Karen Fisher and Hugh Dawson. DEFRA/ Environment Agency Flood and Coastal Defence R&D Programme, Project W5A-057, July 2003.

Table 3-4: Channel Bank Roughness Values

Bank Material	Roughness Values (Manning's 'n')
Scrub/ Long Grass	0.04
Bushes	0.06
Trees – flood level not reaching branches	0.07
Trees – flood level reaching branches	0.15

Simplified version of Table 16 and 23 from Reducing Uncertainty in River Flood Conveyance, Roughness Review. By Karen Fisher and Hugh Dawson. DEFRA/ Environment Agency Flood and Coastal Defence R&D Programme, Project W5A-057, July 2003.

Floodplain roughness values for out-of-bank areas represented in the 2D domain are defined and represented in the hydraulic model based on GIS shapefile data of land use classification. The 2D domain roughness values are based on OSI NTF classification data and the roughness values used for the Athea FRS 2D domain are shown in Table 3-5 along with the land use categorization.

Due to the use of the filtered LIDAR to represent the topography of the 2D domain, buildings are not accurately represented in the grid. To adequately model the obstruction to flow, a Manning's 'n' value of 0.300 is used for the building footprint. within the Study Area to model the effect of the obstruction to flow. This is not a "true" Manning's 'n' value for a building, but allows the building to be factored in to the 2D domain. The correct order for these surfaces to incorporate into the model, where the last surface in the list will override all previous surfaces, is as follows:


- Inland Water
- General Natural Surfaces
- Coniferous Trees
- Mixed Vegetation
- Non-coniferous Woodland
- Rock
- Roads, Tracks and Paths
- General Manmade Surfaces
- Glasshouses
- Buildings
- Stability Patches




Table 3-5: Manning's 'n' Values for 2D Floodplain Land Use




2D Model Order	Land Use Classification	Manning's 'n' Value
1	Inland Water	0.035
2	General Natural Surfaces	0.040
3	Coniferous Trees	0.100
4	Mixed Vegetation	0.080
5	Non-coniferous Woodland	0.070
6	Rock	0.050
7	Roads, Tracks and Paths	0.015
8	General Manmade Surfaces	0.017
9	Glasshouses	0.200
10	Buildings	0.300
99	Stability Patches	0.500




Reaches of similar hydraulic roughness have been identified through review of the Athea FRS hydraulic model, survey photos/ videos, aerial photographs and drawings. Manning's 'n' roughness values applied to the riverbed and left and right banks within each of these reaches is shown in Table 3-6.




Table 3-6: Reach Hydraulic Roughness Values




Upstream and Downstream Cross Section	Roughness Values (Manning's 'n') and materials	Photograph
Galey River		
04GAL02614 to 04GAL01718	Bed: 0.045 – Coarse gravel Left & Right Banks: 0.055 – Long grass/ bushes/ trees	 <p>Section 04GAL01822</p>





<p>04GAL01616 to 04GAL01217d</p>	<p>Bed: 0.045 – Mix of coarse gravel/ cobbles</p> <p>Left & Right Banks: 0.060 – grass/bushes and trees</p>	 <p>Section 04GAL01417</p>
<p>04GAL01117 to 04GAL00516</p>	<p>Bed: 0.045 – Mix of coarse gravel/ cobbles</p> <p>Left Bank: 0.060 – bushes/ trees/ grass</p> <p>Right Bank: 0.050 – bushes and grass</p>	 <p>Section 04GAL00919</p>
<p>04GAL00417 to 04GAL00323</p>	<p>Bed: 0.045 – Mix of coarse gravel/ cobbles</p> <p>Left Bank: 0.065 – Trees/ bushes</p> <p>Right Bank: 0.045 –grass/ scrub and some bushes</p>	 <p>Section 04GAL0341</p>



<p>04GAL00227 to 04GAL00180d</p>	<p>Bed: 0.045 – Mix of coarse gravel/ cobbles</p> <p>Left Bank: 0.065 – Trees/ bushes</p> <p>Right Bank: 0.045 – Grass with some bushes</p>	 <p>Section 04GAL00227</p>
<p>04GAL00163 to 04GAL00060</p> <p>Note: this section includes additional cross sections from Bronra Survey in September 2020</p>	<p>Bed: 0.045 – Mix of coarse gravel/ cobbles</p> <p>Left& Right Banks: 0.060– Bush/ trees/ grass</p>	 <p>Section 04GAL00124</p>
<p>04GAL00011 to 03GAL13097</p>	<p>Bed: 0.040 – Coarse gravel/ cobbles</p> <p>Left Bank: 0.050 – Bushes/ grass</p> <p>Right Bank: 0.040 – Grass/ scrub</p>	 <p>Section 04GAL00011</p>

<p>03GAL12958 to 03GAL12875</p>	<p>Bed: 0.040 – Coarse gravel/ cobbles</p> <p>Left Bank: 0.040 – Grass</p> <p>Right Bank: 0.060 – Bushes</p>	 <p>Section 04GAL12958</p>
<p>03GAL12787 to 03GAL12594</p>	<p>Bed: 0.040 – Coarse gravel/ cobbles</p> <p>Left & Right Banks: 0.040 – Pastures/ grass/ scrub</p>	 <p>Section 03GAL12594</p>
<p>03GAL12515 to 03GAL12359</p>	<p>Bed: 0.040 – Coarse gravel/ cobbles</p> <p>Left & Right Banks: 0.050 – Bushes and grass</p>	 <p>Section 03GAL12459</p>

03GAL12232 to 03GAL11593	<p>Bed: 0.040 – Coarse gravel/ cobbles</p> <p>Left & Right Banks: 0.040 – Grass/ scrub</p>	 <p>Section 03GAL11913</p>
03GAL11524 to 03GAL11524d	<p>Bed: 0.040 – Coarse gravel/ cobbles</p> <p>Left Bank: 0.040 – Grass/ scrub</p> <p>Right Bank: 0.07 – Trees</p>	 <p>Section 03GAL11524</p>
03GAL11410	<p>Bed: 0.040: Coarse gravel/ cobbles</p> <p>Left & Right Banks: 0.045 – Pastures/ bushes</p>	 <p>Section 03GAL11410</p>

Athea West Stream		
01GGR00593 to 01GGR00060d	Bed: 0.030 – Mud and coarse gravel Left & Right Banks: 0.065 – Dense bushes and trees	 <p>Section 01GGR00417</p>
01GGR00042 to 01GGR00000u Note: this section includes additional cross sections from Bronra Survey in September 2020	Bed: 0.027 – Gravel and mud Left & Right Banks: 0.050 – Grass/shrubs/ trees	 <p>Section 01GGR00042</p>
01GGR00321 to 01GGR00044u	Bed: 0.025 – Mud and gravel Left & Right Banks: 0.080 – Dense bushes and trees	 <p>Section 01GGR00234</p>

Athea East Stream		
23GALK00079 and 23GALK00069	Bed – 0.05 Stone Cobbles Banks – 0.06 Scrub, Trees, Hedgerows	 <p>Upstream view of 23GALK00079</p>
23GALK00060	Bed – 0.05 Stone Cobbles Left Bank – 0.04 Grass, Scrub Right Bank – 0.06 Scrub, Trees, Hedgerows	 <p>Upstream view of 23GALK00060</p>
23GALK00059I and 23GALK00059J	Bed – 0.045 Stone Cobbles Left Bank – 0.06 Scrub, Trees, Hedgerows Right Bank – 0.045 Grass, Scrub, Hedgerows	 <p>Downstream view of 23GALK00059J</p>
23GALK00057	Bed – 0.05 Stone Cobbles Banks – 0.045 Grass, Scrub, Hedgerows	 <p>Downstream view of 23GALK00057</p>

23GALK00049	<p>Bed – 0.05 Stone Cobbles</p> <p>Left Bank – 0.06 Scrub, Trees, Hedgerows</p> <p>Right Bank – 0.045 Grass, Scrub, Hedgerows</p>	 <p>Downstream view of 23GALK00049</p>
23GALK00039 to 23GALK00010	<p>Bed – 0.05 Stone Cobbles</p> <p>Banks – 0.06 Scrub, Trees, Hedgerows</p>	 <p>Downstream view of 23GALK00035</p>

3.5 1D-2D Boundary

The hydraulic boundary between the 1D and 2D model domains is typically positioned along the crest of the riverbanks. Crest levels, and hence the point at which water transfers from the 1D to the 2D domain, are determined by extracting bank heights from LIDAR data or applying surveyed left and right bank levels. Within the Scheme Area, the surveyed cross sections extended approximately 20m from the top of each riverbank. This allowed comparison of surveyed sections with LIDAR data. There are two methods for 'removing' the out of bank sections from each cross section – i.e. to determine the location where the 1D model is connected to the 2D model domain:

- Deactivation markers are assigned in Flood Modeller usually at the left and right bank markers - the portion of cross section outside of the left and right deactivation marker is deactivated from the model simulations.

In some instances, it is necessary to situate the hydraulic boundary beyond the crest of the riverbanks. Low volume/ narrow channels can cause model instability or significant fluctuations in water levels when proportionately large volumes, compared to the capacity of the channel, discharge into the 2D domain. In these instances, the capacity of the channel has been increased in the following ways:

- By widening the channel in the 1D domain but the level at which water spills into the 2D domain has remained fixed at the riverbank crest level. The additional volume allowed for in the 1D channel is small in comparison to the volume in the floodplain and so should have a minimal effect on the final model results.
- By moving the bank crest markers out from the channel top and extracting the elevations from the topographic survey or LIDAR, this retains the volume in-channel, whilst increasing the stability of the model.

The approach taken was influenced by the geometry of the specific channel and the quality of the elevation data that was available.

3.5.1 Athea FRS Main Model

A review of the 1D-2D boundary used in the CFRAM study hydraulic model highlighted a domestic dwelling located within the inactive 2D area, whilst not being fully represented within the 1D cross section. This domestic dwelling is located immediately downstream of Athea Bridge on the right bank. Additional changes were made to the 1D-2D boundary,

through realignment to surveyed locations in the 2D domain and updating the location of deactivation markers within the 1D model. A comparison of the 1D-2D boundary from the CFRAM study and that of Athea FRS are shown in Figure 3-4.

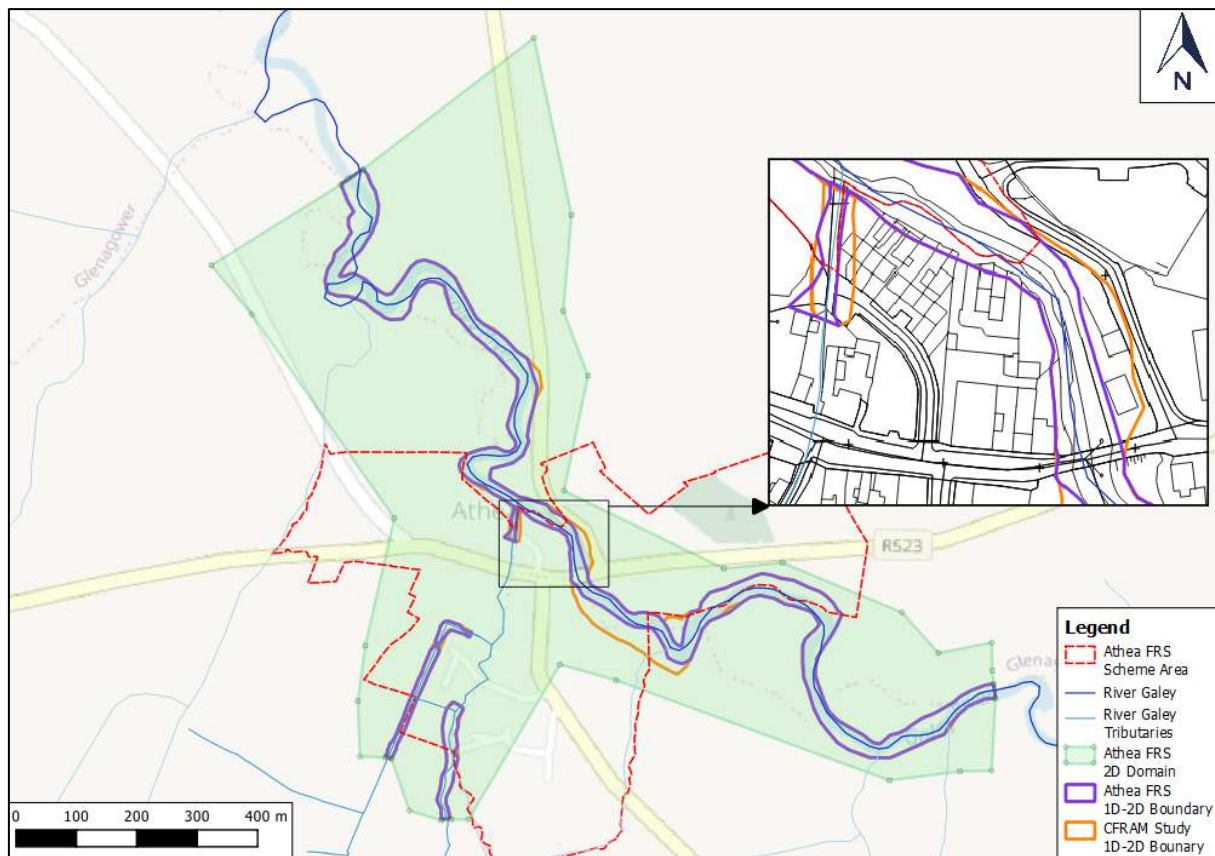


Figure 3-4: Comparison of 1D-2D Boundaries

3.6 2D Domain Grid Cell Size

The 2D domain, or model floodplain, is a ground level grid constructed from 2m LIDAR data, provided by the OPW for this study. The domain size is defined depending on the level of detail required to pick up the appropriate features in the 2D domain that will impact on the local hydraulics. The domain grid square size is typically in the range 5m to 20m, with the smaller grid sizes used in very urbanised areas, where there are multiple features that could not be suitably represented. The model grid is orientated in the main direction of the floodplain flow.

A 2D grid cell size of 6m has been selected for the Athea FRS hydraulic model, to include all relevant detail of the watercourses and areas of flood risk in Athea. This model has a 2D domain area of 0.65km².

A 2D grid cell size of 2m has been selected for the Athea East stream hydraulic model. This mode has a 2D domain area of 0.20km².

3.7 Defences and Walls

3.7.1 Classification of Defences

Raised structures adjacent to watercourses may provide flood relief, and as such, a review of identified structures adjacent to the watercourses is required to ensure that in-situ conditions are represented accurately within the hydraulic model. The significance of defence identification or classification is considerably high, due to the potential risk of overestimation of flood risk, where a raised structure provides sufficient flood prevention, or underestimation of flood risk, where a structure may not be constructed to a suitable standard to withstand elevated water levels and flows.

All raised structures adjacent to watercourses identified through site surveys, known OPW defences or the CFRAM study have been reviewed and classified between formal and informal, as well as effective and ineffective based on their functionality/ suitability as a flood defence. Formal defences are engineered schemes, constructed specifically for flood prevention and can be sub-categorised between effective and ineffective based on how they have been maintained.

Informal defences are structures that are not designed specifically for flood prevention, but are used to provide defence and can be property-specific or a road/ rail wall or embankment.

3.7.1.1 Effective Defences

A structure is deemed to be effective when it is continuous and ties into other defences or high ground. Failure of these structures occurs by overtopping or failure in the event of a breach. Within the hydraulic model domain, these structures are represented as surveyed, i.e. the crest level of the defence is included in the model as a spill unit with floodplain and reservoir units located behind the spill unit.

3.7.1.2 Ineffective Defences

Ineffective structures fail in different ways to that of effective defences and the way they are likely to fail has dictated the way in which they are represented in hydraulic models. To help explain the different modes of failure, a further three sub-classifications have been developed and details of which are provided in Table 3-7.

Table 3-7: Ineffective Defence Overview

Ineffective Structure Type	Description	Modelling Approach
Type 1 – Structures with gaps or structures that are less than 0.6m high.	Where there is a route for the structure to be bypassed, via gaps or low points in the structure or because the structure does not tie-in to high ground at one or both ends. The structure may be adequate in its design and materials to resist flood water causing it to overtop or breach. Structures less than 0.6m may provide flood defence in low flood scenarios, but may become ineffective for larger flood events where they are overtopped/ drowned or bypassed.	Model as surveyed
Type 2	Structures that were not designed as flood defences and would be expected to fail in the event of a flood. The depth at which the hydraulic pressure on these structures will result in failure has been modelled at 0.6m. Structures where this depth is not exceeded in the 1% AEP event have been classified as Type 1.	Exclude from the model
Type 3	Structures which could, in the future, form part of a flood defence but are either currently bypassed, as described in the Type 1 classification, or the base is above the current 1% AEP flood level.	Model as surveyed

3.7.2 Defences Within the Athea Study and Scheme Areas

3.7.2.1 Formal Defences

Formal effective defences are located within the Study Area, downstream of the Scheme Area. Earthen embankments, as part of an OPW Arterial Drainage Scheme, are located on both banks of the Galey River for approximately 6.3km, between upstream of Galey Bridge in Drommurher and downstream of Pollagh Bridge, halfway between Pollagh and Drombeg. The defences were included within the CFRAM study hydraulic model, but since the model was trimmed for this study, they are no longer within the 1D-2D model domain. An overview of the existing embankments along the Galey River and its tributaries are shown in Figure 3-5. There are no formal effective defences included in the Athea FRS hydraulic model.

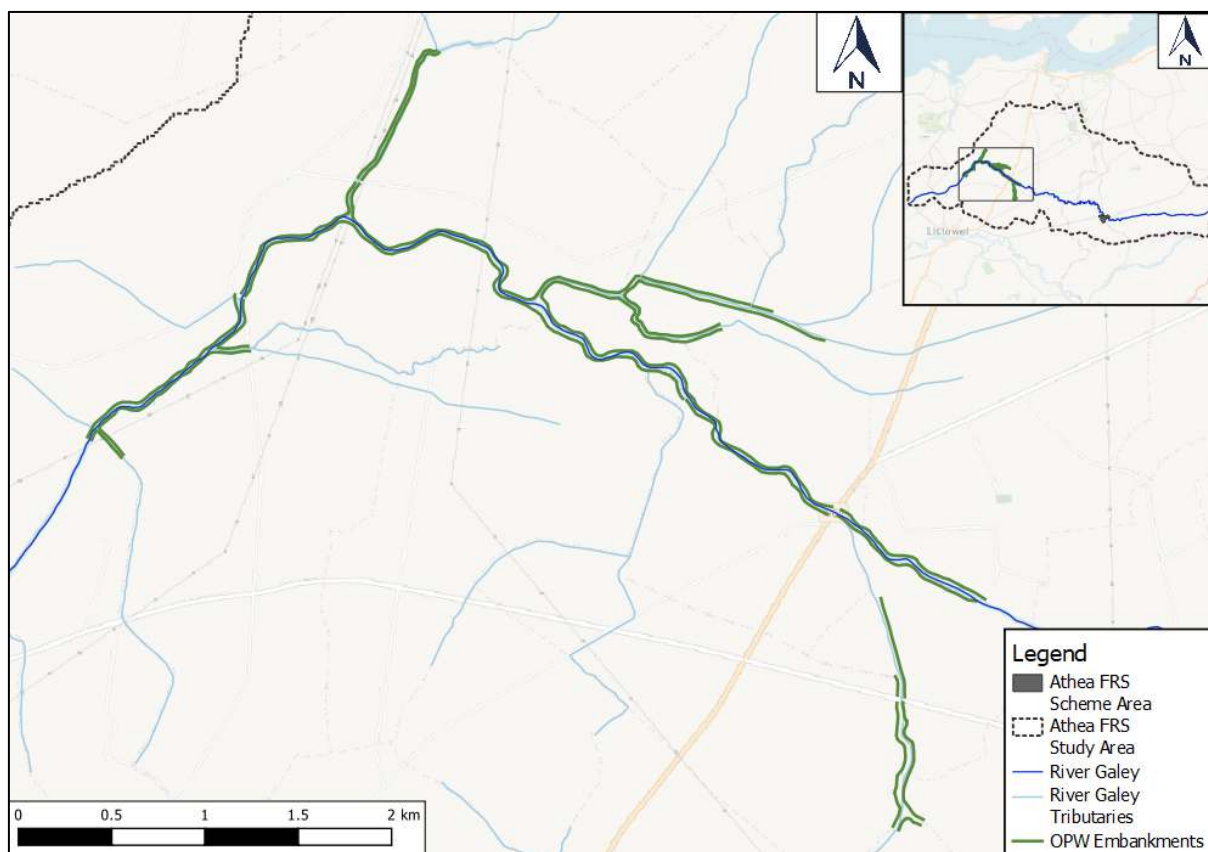



Figure 3-5: OPW Arterial Drainage Embankments

3.7.2.1 Informal Defences

Informal ineffective geographical features that could have an impact on the flow paths across the floodplain are represented as break lines in the 2D domain. Features such as walls and surveyed bank tops, bridge parapets etc. can be included using break lines where the TUFLOW fixed grid discretisation does not guarantee that the crest along the feature is picked up from the LIDAR. Table 3-8 present the informal effective defences within the Athea FRS main and the Athea East stream 2D model domains.

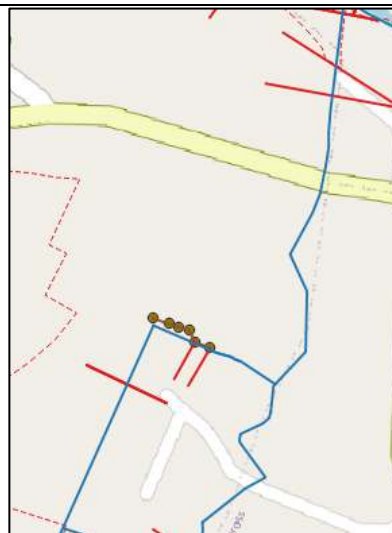
Table 3-8: Informal Ineffective Defences

Description and Location	Photograph
Athea FRS Main Model	
The upstream side of Athea Bridge, the central parapet is included within the 1D model as a spill unit while the lowered parapet walls on the approach road on both left and right bank have not been included. These have been added as 'thin' walls within the 2D domain using surveyed points. These are classified as ineffective, given they are only tied into a defence, the main parapet, at one end. They account for an elevation increase of approximately 1m on the right bank and 1.2m on the left bank.	


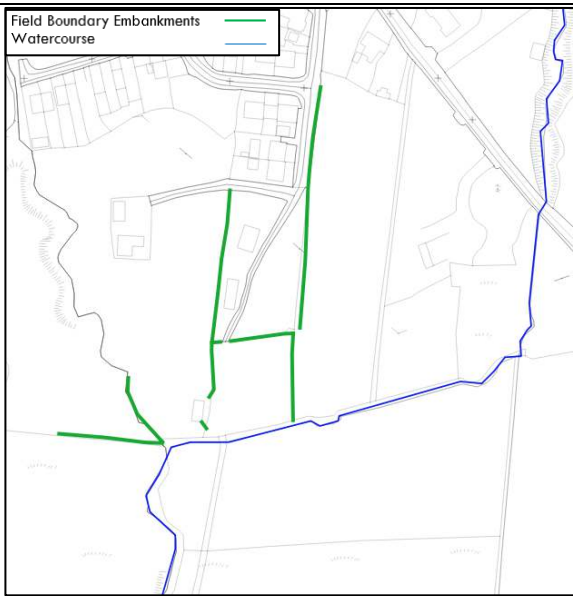
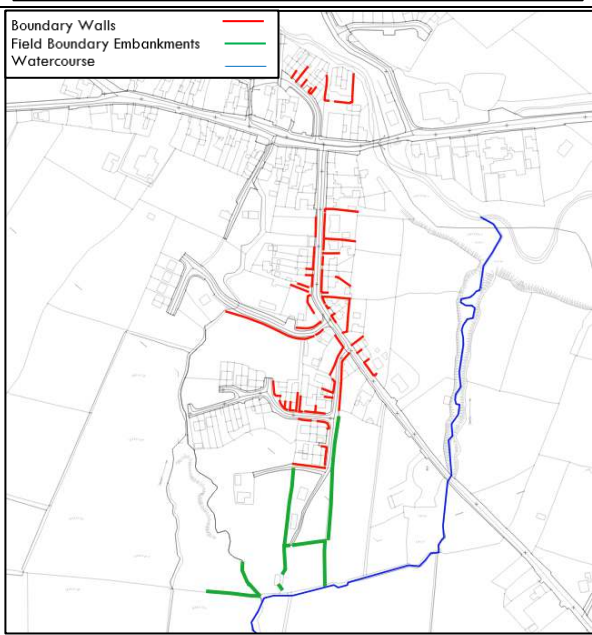
The boundary wall of the Con Colbert community centre is included within the 2D domain as a 'thin' wall. It has been given an elevation of 71.13mOD, with an approximate height of 1 to 1.4m. This is identified as an informal defence due to the gate openings to the entrance of the community centre and to the parking are adjacent to it. However, this wall protects the flow path of the flood waters from the bridge from inundating the community centre.



The crest level of an earthen embankment is included along the right bank of the western branch of the Athea West stream. The crest levels were based on the right bank levels provided from the Blom and Murphy surveys, as well as LIDAR data, however, additional survey of the embankment was completed in November 2022. The embankment has been included as a 'thick' wall within the 2D domain, using the 2022 topographical survey points.



Athea East Stream Model

<p>Earthen Embankment along Athea East stream</p> <p>This structure runs along the western bank of the Athea East stream for a length of 13m.</p> <p>The embankment is heavily overgrown and has been represented in the 2D domain using a 'thick' embankment line, which uses the surveyed crest level points. Towards the north of the embankment there is a gap where a field drain can discharge to the Athea East stream. This gap in the embankment is also included in the 2D domain.</p>	
<p>Earthen Field Boundary Embankments</p> <p>During site visits to the Athea East stream and surrounding area, a number of field boundary earthen dividing embankments were apparent. These embankments were typically 1m-1.5m in height and circa. 1m in width. They are typically overgrown with trees, scrub and hedgerows. These boundary embankments have a significant impact on overland flow paths and as such, are represented in the 2D domain. The embankments are added as a polyline z shape on the DTM, where they are represented as an increase on the DTM of +1m or +1.5m depending on the approximate height above the local ground level.</p>	
<p>Boundary Walls</p> <p>Boundary walls within the urban area of Athea are included in the 2D domain. Their influence on the flow paths is significant. The location and height of the boundary walls were applied based on photos and notes taken during site visits and aided with imagery from Google Streetview in some cases. The embankments are added as a polyline z shape on the DTM where they are represented as an increase on the DTM of around +1m depending on the approximate height above the local ground level.</p>	

3.8 Pluvial Flood Risk

Pluvial (surface water) flood risk has not been included for in the hydraulic river model for Athea. The Athea FRS Hydrology Report (Ryan Hanley, 2021) takes into account this flood risk, by means of reviewing detailed rainfall data, producing

rainfall runoff models and estimating the pluvial flood risk associated with Athea. Indicative flood extents for the 2008 flood event have been included in Section 4.3.1 of this report.

3.9 Hydro-Morphology

The Athea FRS Hydrology Report (Ryan Hanley, 2021) reviews the hydro-morphology associated with the Galey River in Athea. For this study, the hydraulic model represents the best estimate of river channel bed levels from recent and historic topographic surveys and aerial photography. A review of bed conditions will need to be undertaken during the Options Assessment stage of the Athea FRS.

4 Flood History, Model Calibration and Sensibility Checking

4.1 Categorisation

The objective of model calibration is to highlight the accuracy of the hydraulic model in representing hydraulic conditions in-situ through replication of historical events and thus, providing confidence in suitably predicting future events. The replication of historical events is heavily dependent on the availability of accurate data from the event, such as gauge data, flood extent photographs, flood depth indicators and other records. Three general levels of checking suitability are listed as follows:

- Calibration - gauge data and flood records are available for multiple events;
- Partial calibration - where a full record and/or gauge data is not available;
- Sensibility check - where there is no gauge and no record of flooding.

The availability of gauge data is discussed in Section 1.4.4 of this report and in greater detail in the Athea FRS Hydrology Report (Ryan Hanley, 2021). The historical events associated with Athea are included in Section 4.2. Historical flood data is evidence or anecdotal records from a given flood collected by Local Authorities, other organisations such as the OPW or the local community. Historical flood records were collected by Jacobs Engineering Group as part of the CFRAM study. One additional flood recording has come to light since the CFRAM study, which was the September 2015 event and is discussed in Section 4.2. The nearest hydrometric gauge that was in operation at the time of the historic flood events is Inch Bridge gauge, located 26.6km downstream of Athea. In the absence of flow data, it is also theoretically possible to calibrate the model using recorded rainfall data and a rainfall run-off model.

4.1.1 Calibration

Model calibration provides the greatest confidence in the model's ability due to gauge data availability and available records of flood impacts at a number of locations (either flood extents or spot levels). The process involves inputting the recorded flow as model inflows and varying model parameters, such as Manning's n , to match the recorded impacts, such as flood extents or levels that were observed. Where possible, further historical events are run through the amended/updated model and the results compared to the event recordings to confirm the validation work.

4.1.2 Partial Calibration

The process for partial calibration is similar to that for calibration, bar the ability to amend specific parameters due to the lack of available data. It involves checking that the model is producing an expected outcome, such as amending design inflows to recreate recorded flood extents or producing a reasonable flood extent for the largest recorded event, but without a high degree of confidence in the overall outputs. This level of checking does not provide the best confidence in the model's ability, but will flag up where there are obvious inconsistencies between the model and reality.

4.1.3 Sensibility Check

If there is no gauge data, and / or no record of flooding, model checking is limited to a sensibility check on model outputs, based on topography and local knowledge. This is the approach most commonly taken on tributaries which are ungauged.

4.2 Flood History

There have been 5 No. significant recorded flood events in Athea, which occurred on:

- April 2005;
- 31st July – 1st August 2008;
- 6th August 2008;
- 2nd September 2009; and
- 11th September 2015.

Three large flood events were recorded during the 1960s for which there is no information available regarding the flood impact at Athea Village. There were no floods of note recorded at Athea Bridge through the 1970s (except 1973) and through the entire 1980s. A significant flood event was recorded on the River Feale at Listowel on the 11th August 1986 but there are no reports of flooding at Athea Village associated with this event. There are no reports of historical flooding from the Athea East stream.

4.2.1 April 2005

There is little information available on the reported April 2005 flood event. Floodinfo.ie presents a map from Limerick County Fire Service, which highlights areas affected by flooding and the type of flooding that occurred throughout Co. Limerick. Heavy rainfall was the reported reason for the flood event at Athea. The FRMP for UoM 23 states that the area adjacent to Athea Bridge and one residential property flooded (no further information available). The peak water level on the staff gauge at Inch bridge in April 2005 was recorded at 1.2m (8.34mOD) on the 2nd April. The highest recorded rainfall event recorded at Athea in April 2005 was on the 5th and 6th April when 18.9mm and 12.3mm total rainfall were recorded.

4.2.2 July/August 2008

Between 31st of July and 1st of August 2008, a severe localised rainfall event took occurred in the upper Galey River catchment at Athea when 63.3mm and 8.6mm were recorded at Athea rain gauge on the 31st July and 1st August. The upstream catchment was likely saturated and river flows already elevated before this event due to heavy rainfall on the on the 27th and 28th July (17.2mm and 22.9mm total rainfall depth respectively). Based on a review of the “Athea Flood Severity and Impact Report” by JBA Consulting Engineers and topographical surveying carried out for this study it is concluded that during the flood event that:

- Flood levels peaked at Athea Bridge around midnight.
- The peak flood level at Athea Bridge was approximately 0.3m below the soffit of the central arch (Note: this equates to a peak level of **70.24mOD**).
- The peak flood level at Bridge House (downstream of the bridge on the left bank) was approximately 1.1m above the basement floor level which equates to approximately **69.78mOD**. (Note: the peak flood at the property on the 6th August reached 69.28mOD).
- The peak flood level at the houses at Cois na Gaile exceeded **69.1mOD**.
- There was localised flooding of the R523 to the east of Athea Bridge and it was temporarily impassable. (Note: The road becomes flooded when upstream flood levels exceed 70.1mOD)
- The flood levels are reported to have risen rapidly for a period of 25 minutes from about 11:20pm onwards on the 31st July and to have receded appreciable by the next morning (1st August).
- 21 No. properties (JBA, Oct 2008) were reported to have flooded or impacted by flooding including:
 - the two houses immediately downstream of Athea Bridge, the Gables pub, 4 No. houses at Cois na Gaile and 8 No. houses at Markievicz Park.
 - Right bank upstream of Athea Bridge including 5 No. houses, 1 No. office (note: approximate flood level <70.27mOD) and dancehall (note: approximate flood level **c70.3mOD**).
- The Athea Wastewater Treatment Plant (WWTP) was impacted during the flood event. (note: the JBA reported that the WWTP site flooded, which would imply a flood level of circa 68mOD at the plant).
- Athea National School yard flooded (flood level of >70.4mOD)
- Flow conveyance in the river channel was reported to have been reduced due to flood debris and gravel accumulations at Athea Bridge, and due to flood debris, overgrowth and vegetation along the channel downstream of the bridge into addition to large accumulation of gravel behind Markievicz Park.
- The associated extreme rainfall event had an estimated return period > 250years.

Figure 4-1 shows the properties impacted by the flood event between the 31st of July and 1st of August 2008. The water level at Inch Bridge gauge peaked at 2.72m (9.85mOD) on the 1st August 2008, the 9th highest on record.

Based on the information provided, a preliminary estimate of the peak flood flow during the event, for indicative purposes only, has been carried out here.

- The flow area under the bridge at the peak of the flood event has been estimated at approximately 35m² (based on a flood level of 70.15mOD under the bridge).
- The flood level difference across the bridge was of the order of 0.30m to 0.4m (70.2mOD to 69.8-69.9mOD).
- Based on a flow of velocity of say 1.8 - 2.1m/s, the discharge rate under the bridge would have been of the order of 75.5m³/s and 77.5m³/s downstream of the bridge. This flow has been applied to the hydraulic model for the 2008 flood event. This has been determined using NASA rainfall data during the time of the flood event.
- The overflow depth across the R523 did not likely exceed 0.2m and the flow width was of the order of 12m (road width), giving an approximate flow area of 1.8m². If the road overflow velocity was, say, 0.5 to 1.0m/s, the peak flow across the R523 was of the order of <1.5m³/s.

- Therefore, as a preliminary estimate, the total peak flow, during the 1st August 2008 event was of the order of 64.5 to 75m³/s.

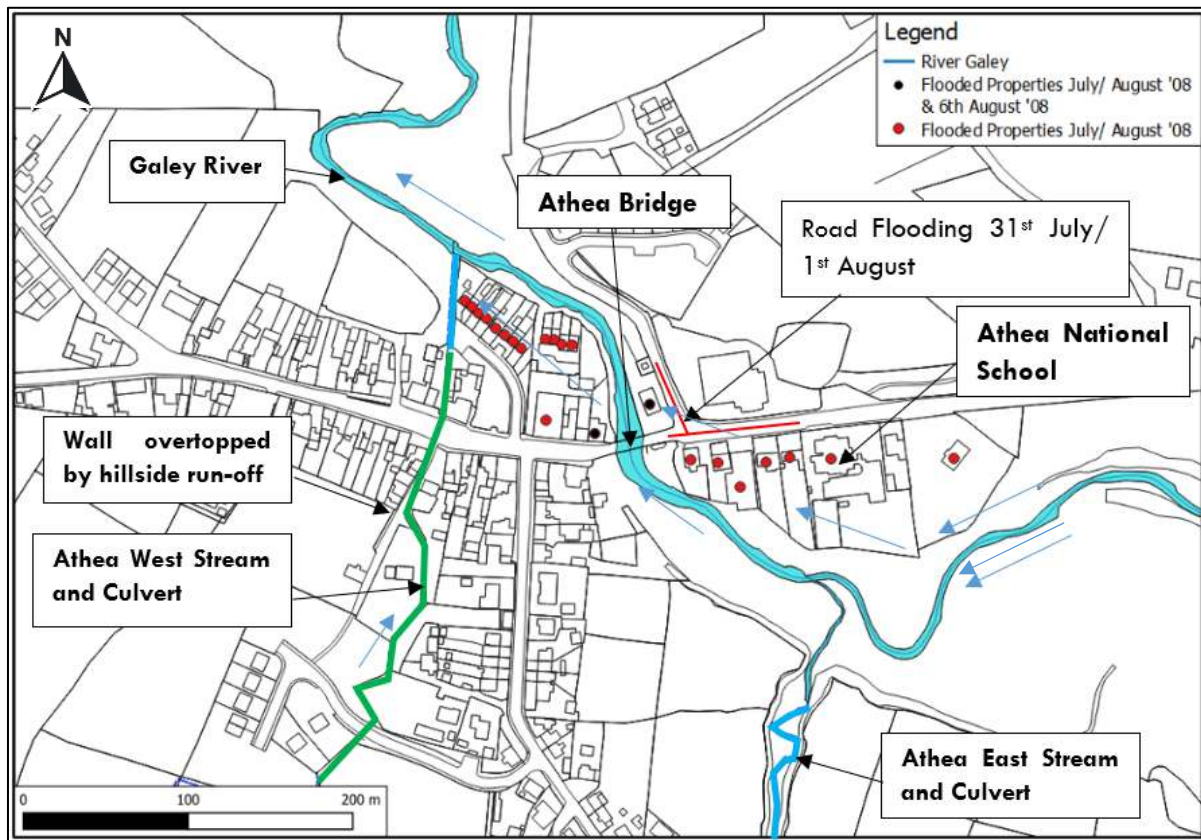


Figure 4-1: Impacted Properties during the 2008 Flood Events

4.2.3 6th August 2008

On the 6th of August 2008, a second localised flood event occurred in Athea due to intense rainfall (53mm rainfall recorded at Athea). In the CFRAM Inception Report (UoM 23), it was noted that the rainfall was less intense than that of the 31st of July/1st of August 2008. However, due to deposition and debris, the capacity at Athea Bridge was greatly reduced and the river overtopped its banks and flooded 2 No. properties, as shown in Figure 4-1. On the 6th August 2008 Shannon rain gauge reported a record hourly rainfall total of 38mm between 5pm and 6pm. If a similar rainfall event occurred in the Athea catchment, it would likely have resulted in a significant spate flood event. The water level at Inch Bridge staff gauge peaked at 2.10m (9.22mOD) at around 2am on the 7th August 2008 which further suggests that the rainfall event and flood event was localised to the Athea Bridge catchment.

4.2.4 September 2009

On the 2nd of September 2009, a heavy rainfall event (daily total 26mm to 32mm rainfall) was recorded at the catchment rain gauges. Locals reported that the days preceding the event had been 'very wet' and that the rainfall on the 2nd September 2009 was intense. The Shannon rain-gauge reported rainfall intensities of up to 7.7mm/hr on the morning of the event. A major blockage to the 'Athea West stream' culvert located between Rathronan housing estate and Markievicz Park housing estate, was reported to have occurred within the culvert at the inlet to the twin culverts downstream of Con Colbert Street. This major blockage caused surcharging of the culvert and overland flows downhill towards Con Colbert Street (R523). At least 6 No. properties flooded, and roads and other property damaged. Local Authority (LA) staff resolved the issue by removing the blockage. This culvert has since been upgraded (see Figure 2-27 above and the CCTV survey report included with the Athea FRS Hydraulics Report). The inlet screens to the culvert are prone to being blinded with debris and vegetation, but this channel is known to be maintained on a regular basis.

Figure 4-2 shows the flooding and road damage as a result of the 2nd September 2009 rainfall event and blocked culvert at Athea and Figure 4-3 shows a map of the 6 No. affected properties. In summary, the localised flood event appears to

have been due to blockage in the culvert coinciding with a moderately intense rainfall event. The water level on the Inch Bridge staff gauge peaked at 2.26m (9.39mOD) at 8:15pm on the 2nd September 2009.



Figure 4-2: Pluvial Flooding and Road Damage due to September 2009 Flood Event

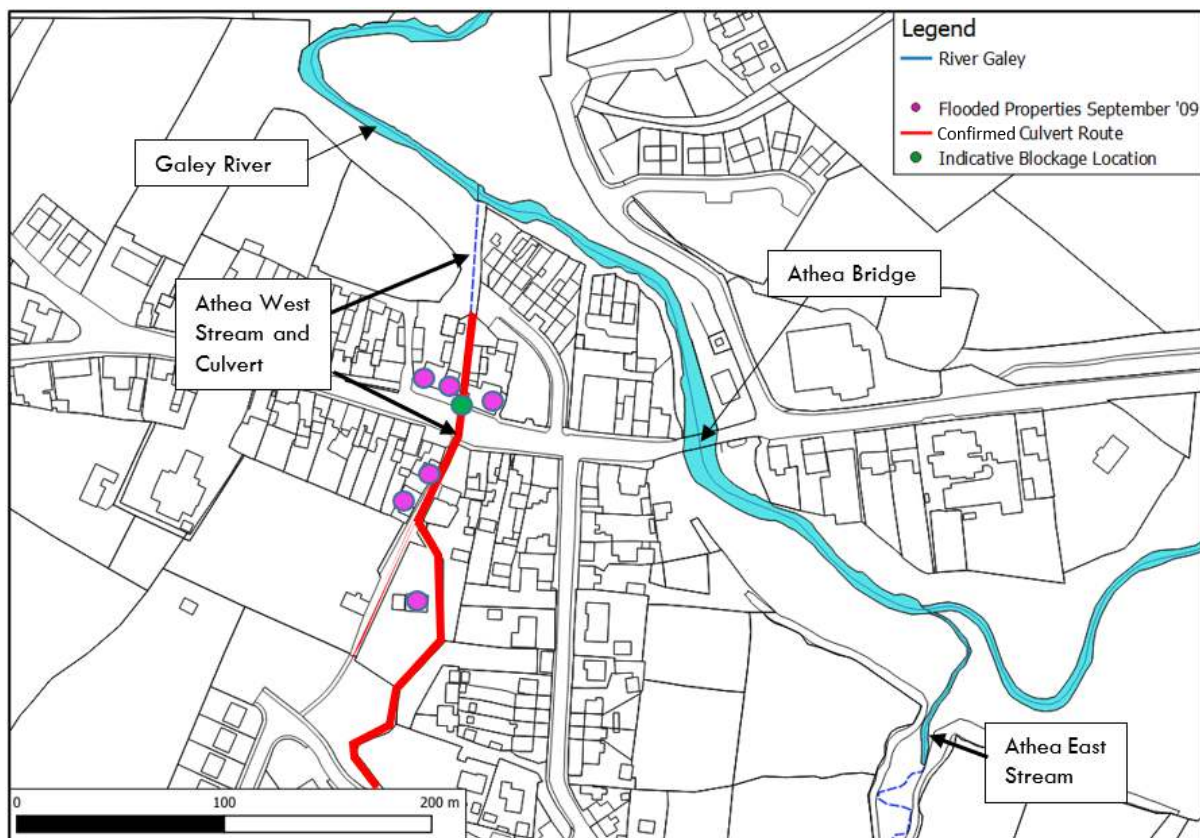


Figure 4-3: Properties Flooded during the September 2009 Pluvial Flood Event

4.2.5 September 2015

On the 11th of September 2015, a flood event occurred in Athea due to intense rainfall event in the upper Galey catchment (47.6mm the 6th highest on record at Athea (Templeathea) rain gauge). At the peak of the flood, the river was reported (in the Limerick Leader newspaper) to have been 0.1m below the soffit of the right bank arch (note: flood level of circa **69.3mOD** or circa 1m lower than the Jul/Aug 2008 peak flood level) at Athea Bridge, while at least 2 No. properties are likely to have flooded (properties on the left and bank downstream of the bridge to a depth of <0.6m).

Figure 4-4 and Figure 4-5 present photographs taken from the September 2015 event. Two days after a further heavy rainfall event was recorded (34.6mm on the 13th September). There is no record of flooding associated with this second rainfall event.



Figure 4-4: Flood Waters Directly Upstream of Athea Bridge



Figure 4-5: Flood Waters Downstream of Athea Bridge (Looking Upstream at Athea Bridge)

4.3 Model Calibration

Partial calibration is being undertaken for the Galey River in the Athea FRS main hydraulic model due to the lack of available data – i.e. there was no hydrometric gauge in the vicinity of Athea for any historic flood event. A sense check is being undertaken based on information gathered for the July/August 2008 flood event.

4.3.1 July/ August 2008 Flood Event

The details of the July/August 2008 flood event are outlined in Section 4.2.2 of this report, including the information gathered and details of reports previously produced. Figure 4-1 shows an overview of the properties and roads impacted from the flooding during the 2008 flood event in Athea and includes the locations of where flood levels were observed.

The Athea FRS hydraulic model has been calibrated using the estimated flow at Athea, based upon the relationship with Inch Bridge gauge, downstream of Athea on the Galey River. The flood hydrographs used are the same as that used in the design run scenarios, due to the model not being sensitive to flow duration. A full detailed review of the model schematisation and application of survey data has been carried out. Roughness values, 1D and 2D model domains were all reviewed and amended, where necessary and applicable, to replicate the 2008 flood event observed levels. These changes were adapted to the design event scenarios. Due to the changing conditions of the channel – substantial movement of gravels – a number of scenarios were run for the 2008 calibration event, where known bed level changes have occurred at Athea Bridge, as follows:

1. As surveyed in September 2020 (increase of circa. 0.4m between 2012 and 2020);
2. 2012 survey base level with a 0.5m increase in bed level due to gravel deposition;
3. 2012 survey base levels with a 0.5m increase in bed level in the left arch and 1.5m increase in the central and right arches;
4. 2012 survey base levels with a 0.5m increase in bed level in the left arch and 1.1m increase in the central and right arches;
5. 2012 survey base levels with a 0.5m increase in bed level in the left arch and 1.1m increase (variation) in the central and right arches.

The basis of these scenarios comes from the JBA Flood Severity Report, where it was noted that a local observed gravel build-up of 0.5m in the left arch and approximately 1.5m in the central and right arches.

Figure 4-6 shows the various bed levels at Athea Bridge for the above-listed scenarios. Due to the quick-changing conditions at Athea Bridge and due to the 2008 flood event occurring during the night, it was difficult to determine the amount of gravel build up in the channel at the time of the event.

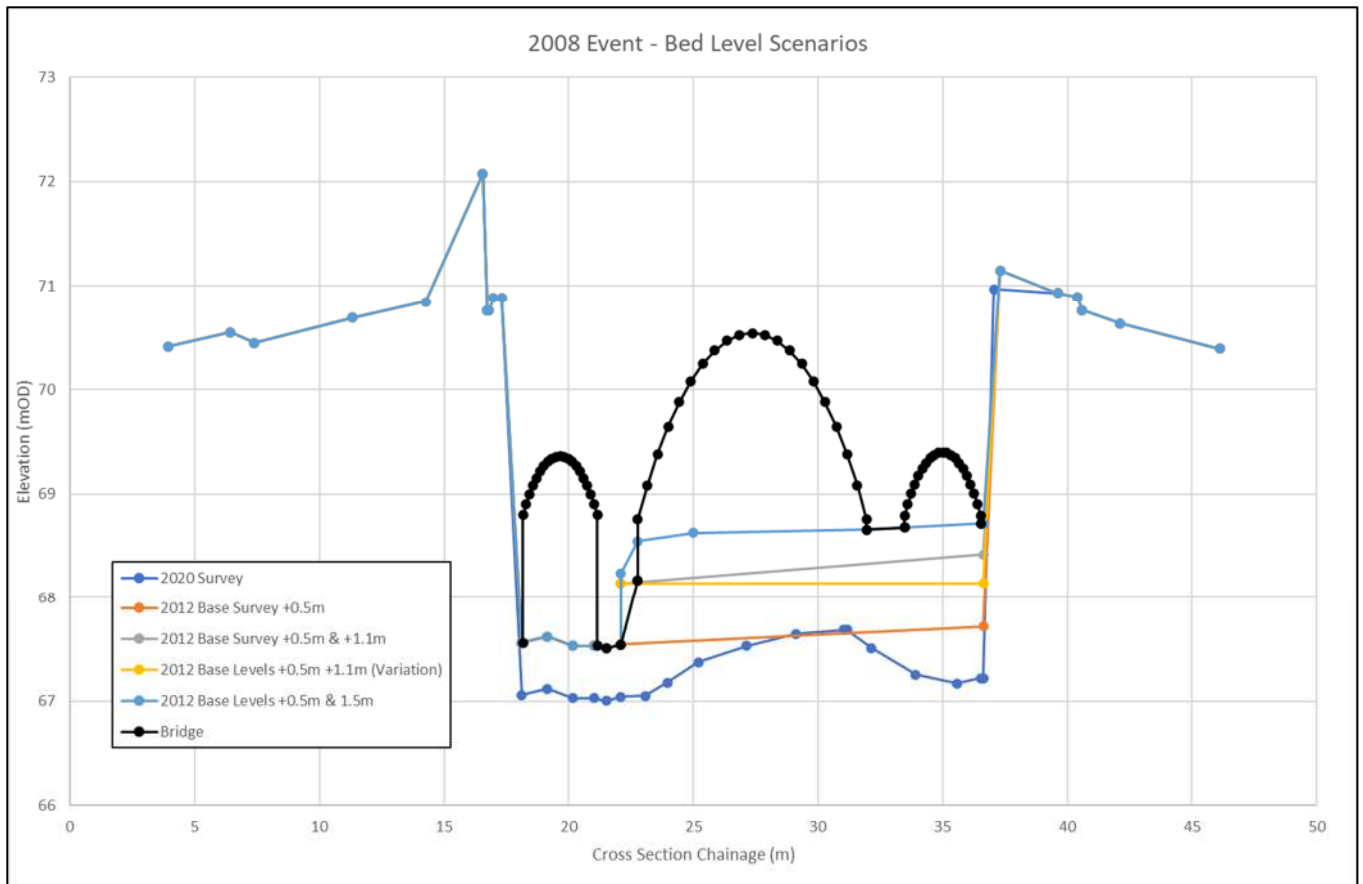


Figure 4-6: 2008 Event – Bed Level Scenarios

Figure 4-7 shows the modelled fluvial flood extents from the July/August 2008 flood event from Scenario No. 5 “2012 survey base levels with a 0.5m increase in bed level in the left arch and 1.1m increase (variation) in the central and right arches”, while Figure 4-8 shows the pluvial flood extent from the 2008 flood event. This has been computed using rainfall-runoff modelling and NASA rainfall radar data. More detail on this analysis is presented in the Athea FRS Hydrology Report (Ryan Hanley, 2021). Figure 4-9 shows the long section of maximum stage and total energy gradient for the July/August 2008 flood event from the 1D fluvial model. Table 4-1 shows a comparison of observed flood levels and modelled flood levels at key locations in the vicinity of Athea and Figure 4-7 shows the locations of where flood levels were observed. There is no recorded flood information on the Athea West stream and the Athea East stream, therefore, the Galey River will be reviewed for this calibration event.

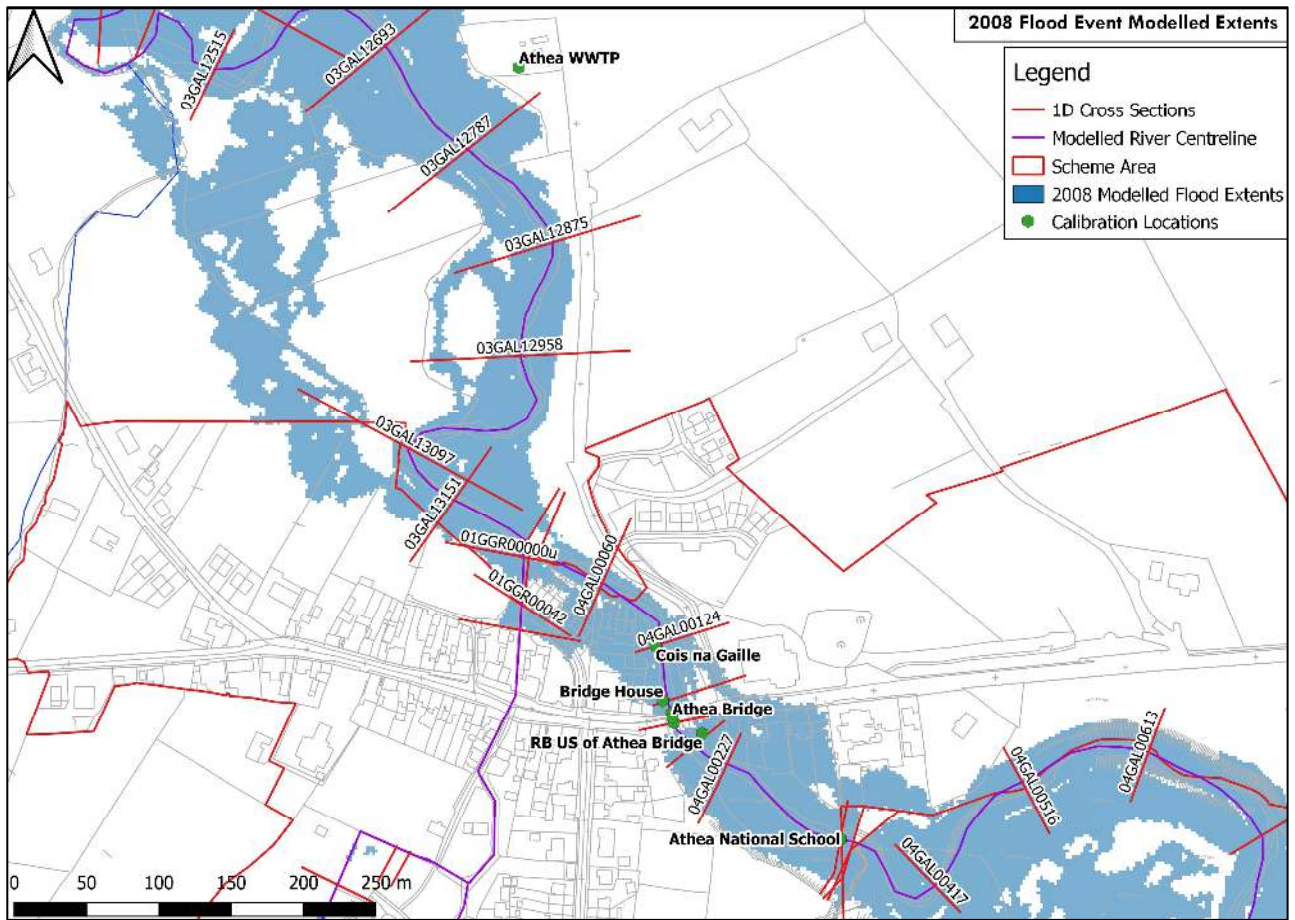


Figure 4-7: 2008 Modelled Fluvial Flood Extents

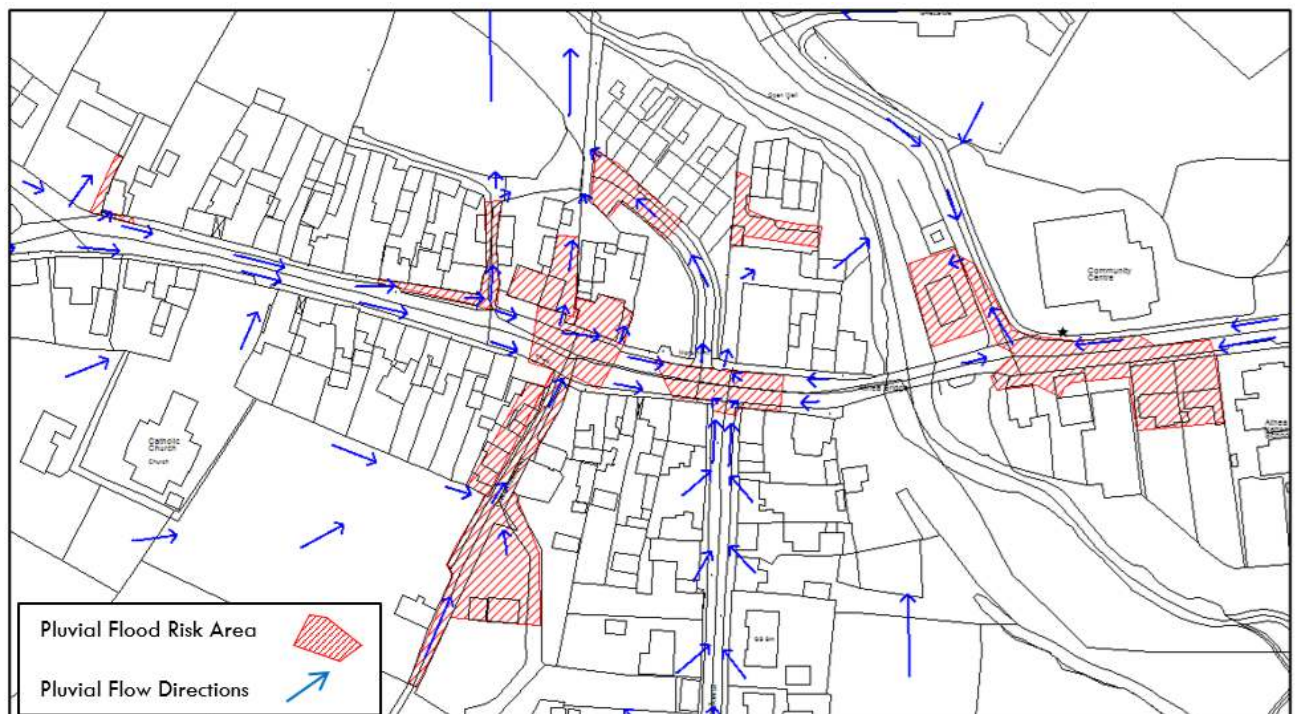


Figure 4-8: Pluvial (Surface Water) Flood Risk Areas

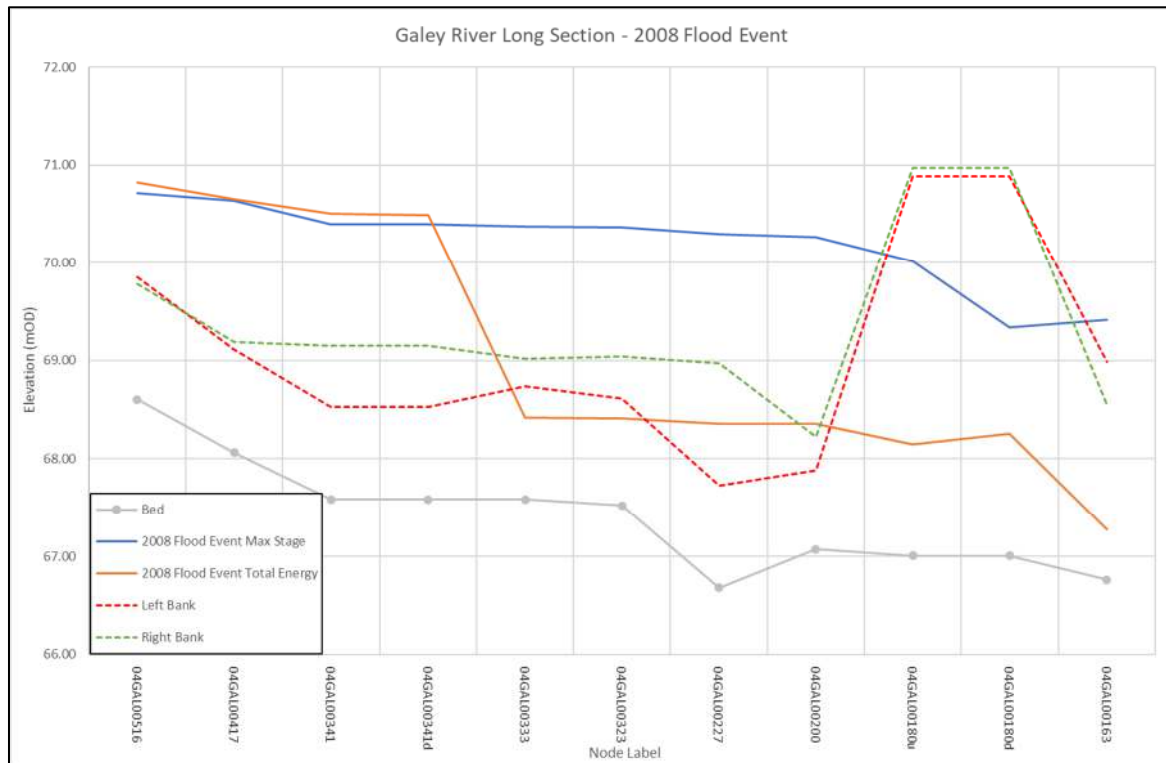


Figure 4-9: 2008 Flood Event - Long Section from 1D Model

Table 4-1: Comparison of Observed and Modelled Water Levels from the 2008 Flood Event

Location	Model Node	Observed Level (mOD)	Source of Observed Level/ Confidence	Modelled Level (mOD)	Difference (m)
Athea National School	04GAL00323	>70.40	Estimated from JBA Report 2008.	70.36	0.04
Right Bank Upstream of Athea Bridge	04GAL00200	70.3	JBA Report 2008.	70.26	0.04
Athea Bridge (US)	04GAL00180u	70.2	JBA Report 2008.	70.02	0.18
Athea Bridge	04GAL00180bu	70.24	JBA Report 2008.	70.02	0.22
Athea Bridge (DS)	04GAL00180d	69.8	JBA Report 2008.	69.34	0.46
Bridge House	04GAL00163	69.78	Estimated from JBA Report 2008.	69.41	0.37
Cois na Gaile	04GAL00124	>69.1	JBA Report 2008	69.24	-0.14
Athea WWTP	03GAL12787	68	Estimated from JBA Report 2008. Low confidence.	65.77	2.24

For very good model calibration, modelled water levels should be within 0.25m of observed water levels. The modelled water levels match the observed levels quite well upstream of Athea Bridge and at Cois na Gaile housing estate, while the model underestimates maximum water levels directly downstream of Athea Bridge and at the Athea WWTP, for which there is low confidence in the observed level. Bed levels in the vicinity of Athea Bridge are constantly changing due to deposition and the model representation for the 2008 flood event is the best estimate, from information gathered. All levels observed are indicative. In general, there is a good and consistent agreement between observed and modelled levels. It should also be noted that from reviewing aerial mapping of the riverbank behind Markievicz Park, it looks like work was undertaken to widen the channel or else some gravel deposition was washed away between 2005 and 2013. The 2012 river cross sections have been utilised in the model, however, these may not fully represent the channel conditions behind Markievicz Park during the 2008 flood event.

It was noted during the 2008 event that the R523 Road was flooded. Pluvial flooding, which is not shown in the hydraulic model, could have contributed to this. In addition, the WWTP site was flooded. Again, this could be due to heavy rainfall and the flood risk may not have been directly from the river, but a combination of river levels and waterlogged land. The JBA Flood Severity Report shows an overland flow route on the right bank, upstream of Athea Bridge. The CFRAM and Ryan Hanley models have not replicated this. Again, this overland flow route could have occurred due to a combination of pluvial and fluvial flood mechanisms. Further analysis of rainfall data and rainfall runoff modelling (see Athea FRS Hydrology Report (Ryan Hanley, 2021)) indicates that the flooding from the R523 occurred due to surface water flows and backing up of the drainage network in Athea. The indicative flood extents have been included in Figure 4-7 and Figure 4-8.

It is difficult to fully calibrate the model with the 2008 event due to the changes that constantly occur in the Galey River and the absence of a hydrometric gauge in Athea at the time of the flood event. However, with partial calibration, there is a general consistency within the Athea Scheme Area and the model is representative (as much as possible) of the physical conditions in Athea.

5 Application of Hydrology

5.1 Hydrological Estimation Points

The CFRAM design flows at HEPs were reviewed as part of the Hydrology Study for the Athea FRS and have been revised and updated throughout the Athea FRS Study Area. Full details on the review and subsequent development of revised flows are provided within the Athea FRS Hydrology Report (Ryan Hanley, 2021). There are 25 No. HEPs within the Athea FRS Study Area, as presented in Figure 5-2 and Figure 5-2, and include the following:

- 13 No. HEP on the Galey River from Inch Bridge to 500m upstream of Athea Bridge;
- 3 No. HEP on tributaries immediately downstream of Athea, one HEP each on the Knocknagornagh, Athea Upper and Listowel Rd. streams;
- 5 No. HEP on the Athea West stream;
- 2 No. HEP on the Athea East stream;
- 2 No. Urban Drainage HEP at Con Colbert Street and Ardagh Road.

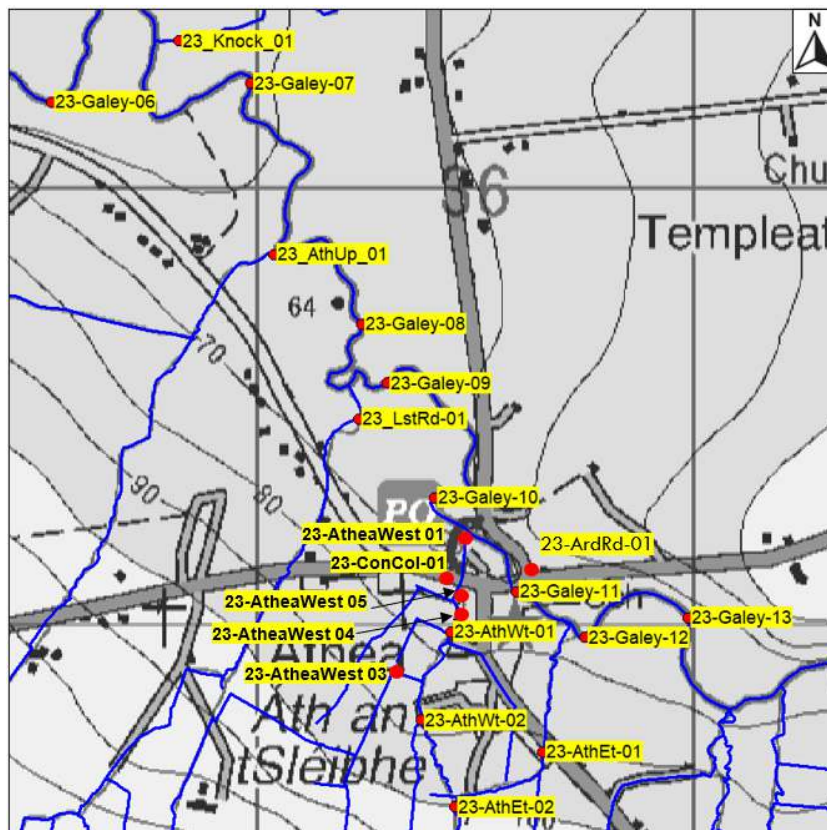


Figure 5-1: HEPs Locations for Athea

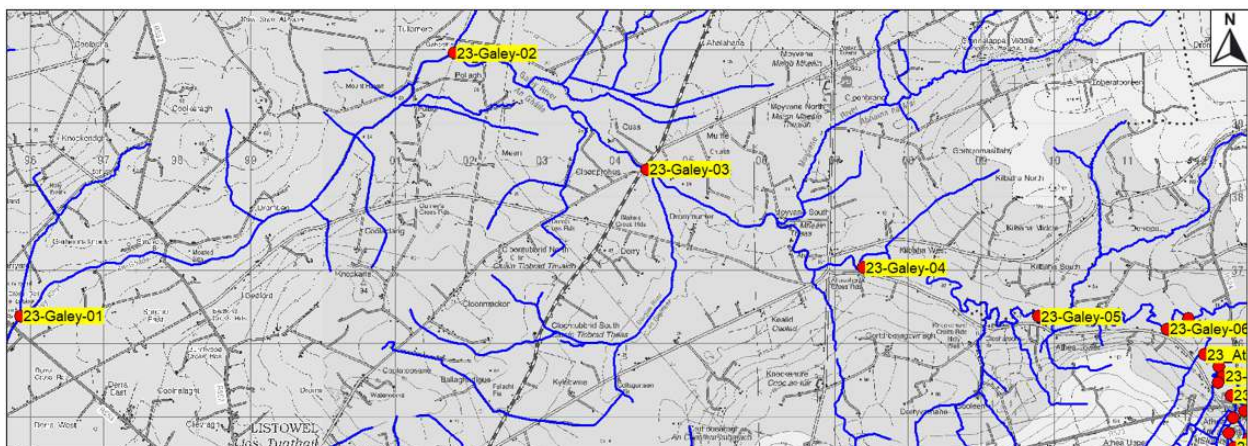


Figure 5-2: HEP Locations for the Galey River Downstream of Athea

Table 5-1 details the predicted peak flow estimates for a range of return periods at each of the Athea FRS HEPs.

Table 5-1: HEP Peak Flow Estimates (m³/s)

HEP	Qmed	% AEP							
		50%	20%	10%	5%	2%	1%	0.50%	0.10%
Main Channel at Athea									
23_Galey13	31.59	32.00	40.80	46.80	52.50	60.00	65.60	71.20	84.20
23_Galey12	32.51	32.90	42.00	48.10	54.10	61.80	67.60	73.30	86.70
23_Galey11	33.49	33.90	43.30	49.60	55.70	63.60	69.60	75.50	89.30
23_Galey10	34.23	34.70	44.20	50.70	56.90	65.00	71.10	77.20	91.30
23_Galey09	34.24	34.70	44.20	50.70	57.00	65.10	71.20	77.20	91.30
23_Galey08	34.65	35.10	44.70	51.30	57.60	65.80	72.00	78.10	92.40
23_Galey07	36.11	36.60	46.60	53.50	60.10	68.60	75.00	81.40	96.30
Main Channel downstream of Athea									
23_Galey06	46.43	47.00	60.00	68.70	77.20	88.20	96.50	104.70	123.80
23_Galey05	51.97	52.60	67.10	76.90	86.40	98.70	108.00	117.20	138.60
23_Galey04	53.77	54.50	69.40	79.60	89.40	102.20	111.70	121.30	143.40
23_Galey03	69.06	70.00	89.20	102.30	114.90	131.20	143.50	155.80	184.10
23_Galey02	89.51	90.70	115.60	132.50	148.90	170.10	186.00	201.90	238.70
23_Galey01	95.71	97.00	123.60	141.70	159.20	181.90	198.90	215.80	255.20
Tributaries at Athea									
23_Knock_01	16.99	17.21	21.95	25.16	28.26	32.29	35.31	38.32	45.31
23-AthUp-01	1.67	1.70	2.16	2.48	2.78	3.18	3.48	3.78	4.46
23_LstRd-01	0.58	0.58	0.75	0.85	0.96	1.10	1.20	1.30	1.54
23_AtheaWest01	0.80	0.81	1.03	1.18	1.33	1.52	1.66	1.80	2.13
23_AtheaWest02	0.26	0.27	0.34	0.39	0.44	0.50	0.55	0.60	0.70
23_AtheaWest03	0.34	0.34	0.43	0.50	0.56	0.64	0.70	0.76	0.90
23_AtheaWest04 (inlet)	0.60	0.60	0.77	0.88	0.99	1.13	1.24	1.34	1.59
23_AtheaWest05 (US) Con Colbert	0.76	0.77	0.98	1.13	1.26	1.44	1.58	1.71	2.03
23_AtheaEast01	1.62	1.64	2.09	2.40	2.69	3.08	3.36	3.65	4.32
23_AtheaEast02	1.29	1.30	1.66	1.90	2.14	2.44	2.67	2.90	3.43

All HEP point flows have been checked and show no large jumps/ drops or discrepancies between points. The remaining hydrology for all models is detailed in Section 5.2.

5.2 Application of Design Flow Estimates

5.2.1 Hydrograph Shapes

Inflow hydrograph shapes for the Galey River at Athea, Athea West stream and Athea East stream have been developed from Flood Studies Report (FSR) rainfall runoff method. It was found that the FSR approach to provide best fit against gauge data, and in the absence of gage data in this location, the rainfall runoff method is appropriate. Inflows are located at the upstream limit of each watercourse.

The Galey River at Athea has a critical storm duration of 23 hours. The critical storm duration for the Athea East stream is 7 hours and Athea West stream is 6 hours. The peak of these streams coincides with the peak in the Galey River at Athea, so that the worst-case scenario is assessed in this study.

The FSR method imposes a structure on the model inflows with realistic relative timings of the hydrographs. This avoids the need to apply the FSU regression model for relative timings of hydrographs at a confluence, which is associated with a large standard error. Because the FSR method is being used only to control the shape of the hydrographs rather than the magnitude of the peak flows, there is no need to identify a critical storm duration, i.e. one that results in the highest peak flow or water level. However, in order to ensure a realistic flood duration, the duration of the design storm has been related to the time to peak for the principal watercourse in the model.

5.2.2 Calibration to HEP Points

Calculated design flows on the Galey River increase consistently with increased catchment area between the upstream and downstream limits of the model. The hydrograph shapes have been scaled to match the design flows at the HEP 23_Galey13, located at the upstream extent of the model. This allows flows at all points within the model extent to be matched well to the design flows. To reflect the increase in flows downstream, lateral inflows have been added throughout the length of the Galey River. These have been derived by subtracting the scaled hydrograph shapes at the HEP check points along the length of the Galey River (once the Athea East stream and Athea West stream inflows have been applied).

For the Athea East stream and Athea West stream, the inflow hydrographs have been scaled to 23_AtheaEast02 and 23_AtheaWest01. There is a “top-up” inflow applied to the Athea East stream, just upstream of the R524 road culvert.

The resulting flows in the models have been reviewed against the design flows on the Galey River. These show that the resulting flows are within 3% of the required flows. A summary of the model inflows and application of design hydrology through these is provided in Table 5-2. Note that the calibration to HEPs was completed with no blockage applied to the Athea Bridge and the culverts on the Athea West and East stream culverts.

5.3 Downstream Boundary

5.3.1 Athea FRS Main Model

For the CFRAM study hydraulic model, the downstream boundary was set downstream of Inch Bridge in Co. Kerry. It was determined for this study that the model could be trimmed to downstream of Athea, as the model could not be calibrated at the Inch Bridge. A normal depth downstream boundary is therefore located a sufficient distance downstream such that water levels do not impact on levels within the Scheme Area. Sensitivity analysis has been completed on the location of the downstream model limit.

5.3.2 Athea East Stream Model

The downstream boundary for the Athea East stream model is set as a head-time (HT) boundary (constant head) at the Galey River. During the modelling process and on review of model results, it was determined that there was no flood risk associated with the downstream extent of Athea East stream. Sensitivity analysis was completed for this – see Section 6.

Table 5-2: Summary of Hydraulic Model Design Inflows

HEP	Cross Section Label	Predicted Peak Flows (m ³ /s)								Flow in Model (m ³ /s)								Comment
		50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	
23_Galey13	04GAL00979	32.00	40.80	46.80	52.50	60.00	65.60	71.20	84.20	32.00	40.80	46.80	52.50	60.00	65.60	71.20	84.20	This inflow is applied at the upstream boundary of the Galey River. Min. flow of 3m ³ /s
23_Galey08	03GAL12232	35.10	44.70	51.30	57.60	65.80	72.00	78.10	92.40	0.42	0.53	0.61	0.69	0.79	0.86	0.93	1.10	One inflow is applied to match the HEP check location, due to increase in catchment area.
23_Galey07	03GAL11524	36.60	46.60	53.50	60.10	68.60	75.00	81.40	96.30	1.50	1.91	2.19	2.46	2.81	3.08	3.34	3.95	One inflow is applied to match the HEP check location, due to increase in catchment area.
23_AtheaWest02	01GGR00593	0.27	0.34	0.39	0.44	0.50	0.55	0.60	0.70	0.47	0.60	0.68	0.77	0.88	0.96	1.04	1.23	This inflow is applied at the upstream boundary of the Athea West stream (eastern branch). Min. flow of 0.25m ³ /s
23_AtheaWest03	01GGR00321	0.34	0.43	0.50	0.56	0.64	0.70	0.76	0.90	0.34	0.43	0.50	0.56	0.64	0.70	0.76	0.90	This inflow is applied at the upstream boundary of the Athea West stream (western branch). Min. flow of 0.30m ³ /s
23_AtheaEast02	23GALK00060	1.30	1.66	1.90	2.14	2.44	2.67	2.90	3.43	1.30	1.66	1.90	2.13	2.43	2.66	2.89	3.42	This inflow is applied at the upstream boundary of the Athea East stream. Min. flow of 0.30m ³ /s
23_AtheaEast01	23GALK00035d	1.64	2.09	2.40	2.69	3.08	3.36	3.65	4.32	1.90	2.26	2.50	2.72	3.07	3.31	3.56	4.03	One inflow is applied to match the HEP check location, due to increase in catchment area.

6 Sensitivity Testing

6.1 Screening of Sensitivity Tests

To support the understanding of the uncertainties associated with the model input parameters in the hydraulic modelling process, sensitivity tests have been carried out. These tests investigate in further detail the implications of the assumptions in the development of the hydraulic model and the production of the design flood extents.

CFRAM Study

For the UoM 23 Shannon CFRAM hydraulic model's sensitivity tests included the following:

- Sensitivity to hydraulic roughness;
- Sensitivity to hydrological inflows;
- Sensitivity to afflux at key structures; and
- Sensitivity to downstream conditions.

Athea FRS Study

For this study, the suite of potential sensitivity tests includes for sensitivity to the following:

- Flows;
- Roughness;
- Water level boundaries;
- Building representation;
- Flow volume;
- Afflux at key structures; and
- Timing of tributaries.

For the purpose of testing the Athea FRS models, a screening assessment has been completed to determine which of these sensitivity tests is applicable. The application of the sensitivity tests has been an iterative process, which allowed certain criteria to be screened out. Table 6-1 summarises the full suite of potential sensitivity tests and highlights those which have not been applicable and screened out. Further details of these criteria are provided in the following sections. The results of testing those criteria, which are relevant to Athea are detailed in Section 6.2.

Table 6-1: Sensitivity Test Summary

Sensitivity Test	Relevance to Athea FRS Main Model	Relevance to Athea East Stream Model
Peak flow	Tested	Tested
Flow volume/ critical storm duration	Tested	Screened out
Roughness	Tested	Tested
Building representation	Screened out	Tested
Afflux/ headloss/ blockage at key structures	Tested	Tested
Water level boundaries	Tested	Tested
Timing of tributaries	Screened out	Not applicable
Timing of fluvial and tidal peaks	Not applicable	Not applicable
Cell size	Tested	Screened out

6.1.1 Water Level Boundaries

6.1.1.1 Athea FRS Main Model

The downstream normal depth boundary for the Galey River is calculated using the riverbed slope. To ensure that the boundary does not affect water levels within the Scheme Area, a normal depth boundary sensitivity test will be required. This will be completed by moving the downstream boundary further downstream, as well as editing the river slope and assessing the water levels at specific locations in Athea.

6.1.1.2 Athea East Stream Model

The downstream boundary for the Athea East stream model is the Galey River and the HT boundary (constant head) is determined from the Athea FRS Main model. In order to ensure that the downstream boundary does not affect water levels within the area of interest with regards flood risk for the Athea East stream, a sensitivity test will be required. This will be completed by applying a normal depth boundary instead of a HT boundary and assessing the water levels upstream.

6.1.2 Building Representation

6.1.2.1 Athea FRS Main Model

The current flood risk extents in the 1% AEP event show inundation of a number of properties. Buildings have been represented with high Manning's n roughness values (0.300) and this has been determined as being representative for the buildings within the Scheme Area. Use of filtered LiDAR data to inform the 2D model DTM means that buildings are not inherently represented in the grid. A building is an obstruction to the flow and have impacts on overland flow routes, therefore a high roughness value (0.300) has been attributed to each building within the Scheme Area to model the effect of the obstruction to flow. This is not a "true" Manning's ' n ' value for a building, but allows the building to be factored in to the 2D domain. A sensitivity test for building representation has been screened out for the Athea FRS main model.

6.1.2.2 Athea East Stream Model

By representing buildings within the Scheme Area with high Manning's n roughness values (0.300), overland flow looks to be flowing through buildings, due to the steep slope of the Scheme Area. A sensitivity test for building representation has been included for the Athea East stream. The buildings shapefile from the OSi Prime2 dataset has been stamped on to the Lidar and an additional 0.5m elevation has been added for each building. This will determine how effective the initial representation of buildings is in the 2D domain.

6.1.3 Flow Volume/ Critical Storm Duration

The sensitivity test to flow volume/ critical storm duration is required where the flow hydrograph has been generated from limited or no data. For the Galey River in Athea, the FSR hydrograph method determined a 23-hour hydrograph shape, while the FSU determined a 48-hour hydrograph shape. A 48-hour event will be run and the results of this will be compared with the design event run. This will determine if the Galey River at Athea is influenced by flow volumes, as well as peak flows.

Sensitivity tests for the Athea West and Athea East streams have been screened out, due to their small, steep catchment areas. The applied flow durations are appropriate for such catchments.

6.1.4 Sensitivity to Flow

As flow is the most critical of all sensitivity tests, it is important to consider the quality of data available in the derivation of design flows. A screening exercise was undertaken to determine the extent of sensitivity tests that are required for flow. This assessed the availability of historic hydrometric gauge data, the size of the contributing catchment area and the features within the catchment. Table 6-2 details the flow sensitivity tests required as a result of an initial screening.

Table 6-2: Flow Sensitivity Scaling Factors

Return Period of Event	Galey River	Athea West Stream	Athea East Stream
10%	QMED uncertainty*	QMED uncertainty*	QMED uncertainty*
1%	QMED uncertainty and apply adjustment factor of 1.2	QMED uncertainty and apply adjustment factor of 1.5	QMED uncertainty and apply adjustment factor of 1.5

*QMED uncertainty is assessed using equations for Standard Error (SE) and Factorial Standard Error (FSE) provided in the FSU WP2.2 report.

It should be noted that QMED uncertainty was taken into account when determining QMED and design flows for the current scenario. Therefore, QMED uncertainty is not assessed in the sensitivity analysis, but an adjustment factor is applied to the peak flows.

6.1.5 Timing of Tributaries

6.1.5.1 Athea FRS Main Model

The Athea East stream and Athea West stream's timings have been adjusted so that they peak at the same time as the Galey River. This results in the worst-case scenario with regard flood risk in Athea. Therefore, this test will not be included in the sensitivity analysis for Athea FRS. The sensitivity test for flows will result in a greater impact than the timing for tributaries test.

6.1.6 Sensitivity to Roughness

The limited flood extents in the existing risk design events mean that there is little benefit to testing the sensitivity of the model results to a reduction in roughness values. Such a reduction would only further reduce extents by speeding the passage of water through the model domain.

There is no known specific maintenance regime undertaken in Athea, but from site survey and site walkovers, some of the channels within Athea are overgrown and there is also a build-up of gravels and vegetation in the Galey River at Athea Bridge. This build-up of gravels is a historical issue in Athea. It is assumed that channel and bank roughness may increase within reasonable bounds within Athea. Table 6-3 summarises the current roughness values applied within the model over the various reaches and the increased roughness values to be applied for the 1% AEP event.

For the Athea East stream model, a 20% increase in roughness has been applied to the 2D domain, as well as the changes to the 1D domain, as set out in Table 6-3.

Table 6-3: Sensitivity to Roughness Scenarios

U/S and D/S Cross Section	Roughness Values (Manning's n and materials)	
	Existing Risk	1% AEP Roughness Sensitivity
Galey River		
04GAL02614 to 04GAL01718	Bed: 0.045 – Coarse gravel Left & Right Banks: 0.055 – Long grass/ bushes/ trees	Bed: 0.050 Banks: 0.070
04GAL01616 to 04GAL01217d	Bed: 0.045 – Mix of coarse gravel/ cobbles Left & Right Banks: 0.060 – grass/bushes and trees	Bed: 0.050 Banks: 0.070
04GAL01117 to 04GAL00516	Bed: 0.045 – Mix of coarse gravel/ cobbles Left Bank: 0.060 – bushes/ trees/ grass Right Bank: 0.050 – bushes and grass	Bed: 0.050 Left Bank: 0.070 Right Bank: 0.060
04GAL00417 to 04GAL00323	Bed: 0.045 – Mix of coarse gravel/ cobbles Left Bank: 0.065 – Trees/ bushes Right Bank: 0.045 – grass/ scrub and some bushes	Bed: 0.050 Left Bank: 0.095 Right Bank: 0.050
04GAL00227 to 04GAL00180d	Bed: 0.045 – Mix of coarse gravel/ cobbles Left Bank: 0.065 – Trees/ bushes Right Bank: 0.045 – Grass with some bushes	Bed: 0.50 Left Bank: 0.095 Right Bank: 0.050
04GAL00163 to 04GAL00060	Bed: 0.045 – Mix of coarse gravel/ cobbles Left & Right Banks: 0.060 – Bush/ trees/ grass	Bed: 0.050 Banks: 0.070
04GAL00011 to 03GAL13097	Bed: 0.040 – Coarse gravel/ cobbles Left Bank: 0.050 – Bushes/ grass Right Bank: 0.040 – Grass/ scrub	Bed: 0.045 Left Bank: 0.060 Right Bank: 0.045
03GAL12958 to 03GAL12875	Bed: 0.040 – Coarse gravel/ cobbles Left Bank: 0.040 – Grass Right Bank: 0.060 – Bushes	Bed: 0.045 Left Bank: 0.045 Right Bank: 0.070
03GAL12787 to 03GAL12594	Bed: 0.040 – Coarse gravel/ cobbles Left & Right Banks: 0.040 – Pastures/ grass/ scrub	Bed: 0.045 Banks: 0.045

03GAL12515 to 03GAL12359	Bed: 0.040 – Coarse gravel/ cobbles Left & Right Banks: 0.050 – Bushes and grass	Bed: 0.045 Banks: 0.060
03GAL12232 to 03GAL11593	Bed: 0.040 – Coarse gravel/ cobbles Left & Right Banks: 0.040 – Grass/ scrub	Bed: 0.045 Banks: 0.045
03GAL11524 to 03GAL11524d	Bed: 0.040 – Coarse gravel/ cobbles Left Bank: 0.040 – Grass/ scrub Right Bank: 0.070 – Trees	Bed: 0.045 Left Bank: 0.045 Right Bank: 0.100
03GAL11410	Bed: 0.040 – Coarse gravel/ cobbles Left & Right Banks: 0.045 – Pastures/ bushes	Bed: 0.045 Banks: 0.050
Athea West Stream		
01GGR00593 to 01GGR00060d	Bed: 0.030 – Mud and coarse gravel Left & Right Banks: 0.065 – Dense bushes and trees	Bed: 0.033 Banks: 0.095
01GGR00042 to 01GGR00000u	Bed: 0.027 – Gravel and mud Left & Right Banks: 0.050 – Grass/shrubs/ trees	Bed: 0.030 Banks: 0.060
01GGR00321 to 01GGR00044u	Bed: 0.025 – Mud and gravel Left & Right Banks: 0.080 – Dense bushes and trees	Bed: 0.028 Banks: 0.120
Athea East Stream		
23GALK00079 to 23GALK00069	Bed: 0.050 – Stone and cobbles Banks: 0.060 – Scrub, trees, hedgerows	Bed: 0.055 Banks: 0.070
23GALK00060	Bed: 0.050 – Stone and cobbles Left Bank: 0.040 – Grass, scrub Right Bank: 0.060 Scrub, trees, hedgerows	Bed: 0.055 Left Bank: 0.045 Right Bank: 0.070
23GALK00059I to 23GALK00059J	Bed: 0.045 – Stone and cobbles Left Bank: 0.060 – Scrub, trees, hedgerows Right Bank: 0.045 – Grass, scrub, hedgerows	Bed: 0.050 Left Bank: 0.070 Right Bank: 0.050
23GALK00057	Bed: 0.050 – Stone and cobbles Banks: 0.045 – Grass, scrub, hedgerows	Bed: 0.055 Banks: 0.050
23GALK00049	Bed: 0.050 – Stone and cobbles Left Bank: 0.060 – Scrub, trees, hedgerows Right Bank – 0.045 Grass, scrub, hedgerows	Bed: 0.055 Left Bank: 0.070 Right Bank: 0.050
23GALK00039 to 23GALK00010	Bed: 0.050 – Stone and cobbles Banks: 0.060 – Scrub, trees, hedgerows	Bed: 0.055 Banks: 0.070

6.1.7 Afflux/ Blockage at Key Structures

Key structures identified for this sensitivity test are those that have a controlling influence on local water levels and the resulting influence may be expected to cause flooding to local receptors. These structures have been identified by examination of the long section water level plot through the structure, a review of nearby receptors at risk and an assessment of likely flow routes around the structure.

6.1.7.1 Athea FRS Main Model

Two structures were identified as having significant head loss during the 1% AEP: These are the Athea Bridge on the Galey River and the Athea West stream culvert. Blockage scenarios will be run on both structures, as the Athea West stream culvert has blocked previously and caused flooding, while the channel in the vicinity of Athea Bridge is prone to deposition of gravels. Head losses will also be reviewed for both structures. To review the head losses, additional losses will be applied at the upstream and downstream faces to account for potential additional complexities within the structures. It is important to note that contraction and expansion losses at these faces have already been modelled and these values have been used to consider the implications of additional complexity only.

6.1.7.2 Athea East Stream Model

The Athea East stream farm access culvert was identified as having a blockage risk. In order to assess the sensitivity of the structure with regards blockage, a 67% blockage will be applied the farm access culvert.

6.1.8 2D Model Domain Cell Size

6.1.8.1 Athea FRS Main Model

For the current design scenario, the 2D model domain cell size was initially set to 6m. In order to assess the sensitivity of the model to cell size, scenarios will be run where the cell size is reduced to 4m and 2m. This will determine if all relevant detail is included in flood mapping outputs.

6.1.8.2 Athea East Stream Model

The 2D model domain cell size is set at 2m. This cannot be further reduced, as the cell size cannot be smaller than the 2m grid size of the Lidar data. Therefore, the 2D cell size sensitivity test has been screened out for the Athea East stream model.

6.2 Sensitivity Testing Results

The results of the sensitivity tests have been used to inform the uncertainty bound of the flood extent mapping. The uncertainty bound, in effect, presents the most sensitive hydraulic parameters, as assessed under the heading in Section 6.1 at all model nodes along the model reach. The following sections present the difference in maximum water levels along the modelled reach, as a result of the individual sensitivity tests.

6.2.1 Water Level Boundaries

6.2.1.1 Athea FRS Main Model

The downstream model boundary of the Athea FRS main model is set as a critical depth boundary at cross section 03GAL11410, which is approximately 2km downstream of Athea Bridge. To assess the sensitivity of the downstream boundary, the slope from the normal depth boundary at 03GAL11410 was assessed. In addition, the downstream boundary was re-located a further 750m downstream at cross section 03GAL10586, with a bed slope determined from the cross sections in the model. Table 6-4 presents the difference in water levels at key locations throughout the Athea FRS main model for the 1% AEP design event as a result of changes to the downstream boundary.

Table 6-4: Sensitivity Test for Downstream Water Level Boundary for Athea FRS Main Model

Model Node	Location	1% AEP Max Stage (mOD)	1% AEP + DS Boundary Slope	Difference (m)		1% AEP + DS Boundary Location	Difference (m)
			Max Stage (mOD)			Max Stage (mOD)	
Galey River							
04GAL00180u	Athea Bridge (US)	69.62	69.62	0.000		69.62	0.000
04GAL00180d	Athea Bridge (DS)	69.46	69.46	0.000		69.46	0.000
04GAL00163		69.49	69.49	0.000		69.49	0.000
04GAL00124	Cois na Gaile	69.04	69.04	0.000		69.04	0.000
04GAL00060	Markievicz Park	68.59	68.59	0.000		68.59	0.000
04GAL00011		68.44	68.44	0.000		68.44	0.000
04GAL00000u	Athea West stream junction	68.38	68.38	0.000		68.38	0.000
03GAL12232d	End of 2D domain	61.99	61.99	0.000		61.99	0.000
03GAL11774		59.03	59.03	0.000		59.03	0.000

03GAL11731		58.86	58.86	0.000		58.86	0.000
03GAL11662		58.55	58.55	0.005		58.54	-0.003
03GAL11593		58.41	58.41	-0.001		58.40	-0.007
03GAL11524		58.06	58.04	-0.016		58.07	0.017
03GAL11524d		58.06	58.04	-0.016		58.07	0.017
03GAL11410	Downstream extent of model	57.54	57.20	-0.346		57.63	0.085
03GAL10977		-	-	-		56.64	-
03GAL10782		-	-	-		56.04	-
03GAL10586	DS extent of model (for sensitivity test)	-	-	-		55.41	-

The results from the downstream boundary sensitivity tests shows that there is a change in water levels in the vicinity of the downstream boundary, but no effects on water levels in the Athea FRS Scheme Area. Therefore, it can be concluded that the downstream boundary has no impact on the model results in Athea for the Athea FRS main model.

6.2.1.2 Athea East Stream Model

The downstream model boundary of the Athea East stream model is set as HT boundary at cross section 23GALK00010, which is approximately where the Athea East stream flows into the Galey River. To assess the sensitivity of the downstream boundary and its effect on the areas at flood risk along the Athea East stream, a normal depth boundary was applied at the same cross section, with a bed slope determined from the cross sections in the model. Table 6-5 presents the difference in water levels at key locations throughout the Athea East stream model for the 1% AEP design event, as a result of changes to the downstream boundary.

Table 6-5: Sensitivity Test for Downstream Water Level Boundary for Athea East Stream Model

Model Node	Location	1% AEP Max Stage (mOD)	1% AEP + DS Boundary (Normal Depth)	Difference (m)
			Max Stage (mOD)	
Athea East Stream				
23GALK00079	Upstream extent of model	104.32	104.32	0.00
23GALK00060		96.13	96.15	0.02
23GALK00059I	Upstream of farm access culvert	96.13	96.15	0.02
23GALK00057	Downstream of farm access culvert	94.73	94.71	-0.02
23GALK00034D	Upstream of R524 culvert	86.47	86.46	-0.01
23GALK00032	Downstream of R524 culvert	82.77	82.77	0.00
23GALK00022		79.45	79.45	-0.01
23GALK00010	Downstream extent of model	74.00	73.28	-0.72

The results from the downstream boundary sensitivity tests shows that there is a change in water levels in the vicinity of the downstream boundary, but no effects on water levels in the area of interest with regards flood risk on the Athea East stream. Therefore, it can be concluded that the downstream boundary has no impact on the model results for the Athea East stream.

6.2.2 Building Representation

Buildings are generally represented with high Manning's n roughness values (0.300) to model the effect of the obstruction to flow. By representing buildings within the Scheme Area with high Manning's n roughness values (0.300), overland flow

looked to be flowing through the building, due to the steep slope of the Scheme Area. A sensitivity test for building representation has been completed for the Athea East stream with the Q1000 design flow applied. The buildings shapefile from the OSi Prime2 dataset has been stamped on to the Lidar and an additional 0.5m has been added for each building. Figure 6-1 compares flood extents for the Q1000 design flood extents for the building representation sensitivity test.

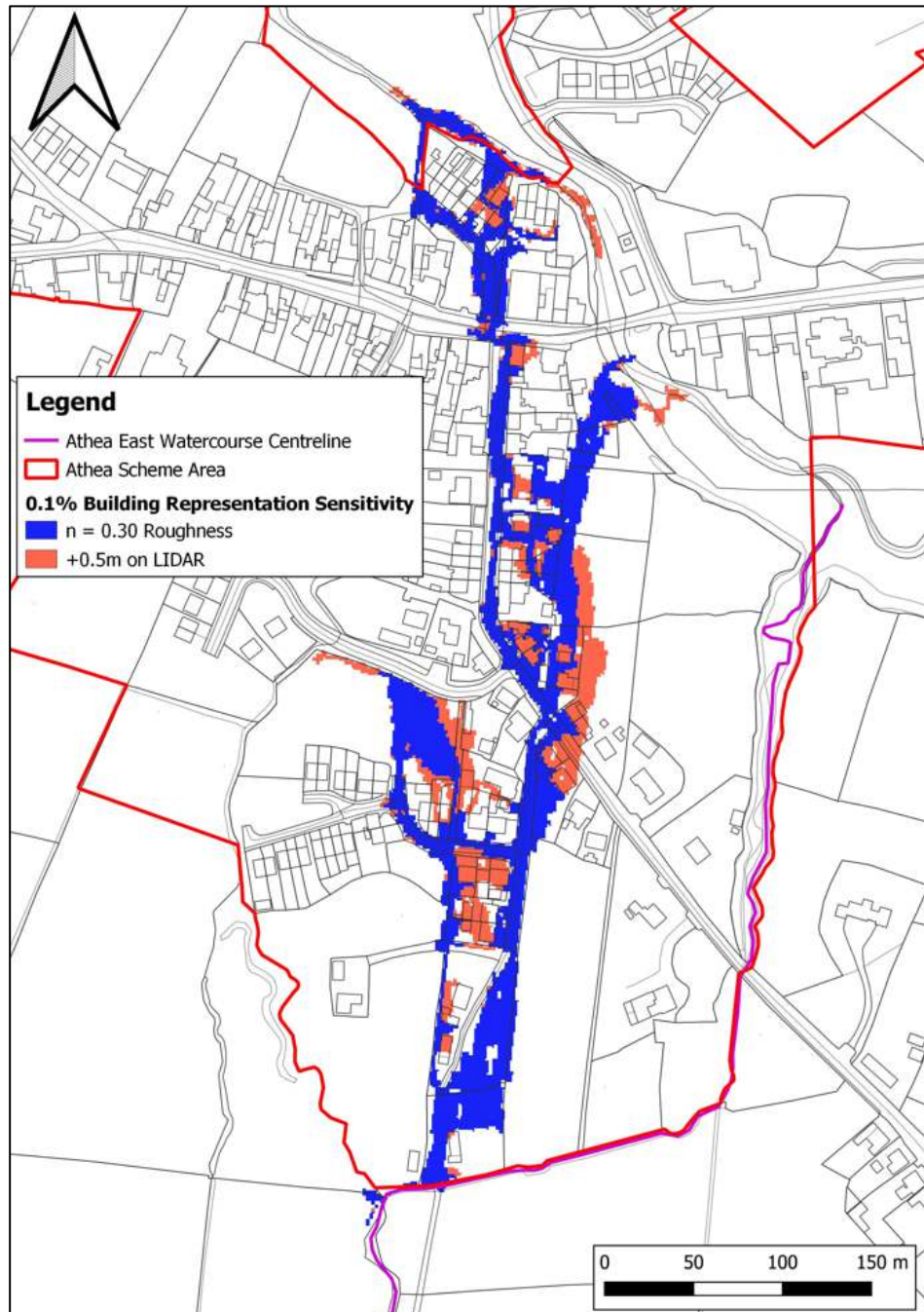


Figure 6-1: Building Representation Sensitivity Test Flood Extent Results for Athea East Stream Model

The building representation using the Prime2 data and increased elevation better represents building in the Scheme Area for the Athea East stream model. The flood extent is smaller, as the buildings are effectively obstructing the overland flow from the Athea East stream.

6.2.3 Flow Volume/ Critical Storm Duration

The current design run applies a 23-hour hydrograph to the Galey River, 7-hour hydrograph to the Athea East stream and 6-hour hydrograph to the Athea West stream. To assess the model sensitivity to flow volume and duration, a 48-hour

hydrograph has been applied to the Galey River for the 1% AEP design event and the resulting water levels have been assessed. The difference in water levels at key locations in the model are presented in Table 6-6.

Table 6-6: Flow Duration Sensitivity Test Results for Galey River

Model Node	Location	23-Hour Hydrograph	48-Hour Hydrograph	Difference (m)
		Max Stage (mOD)	Max Stage (mOD)	
04GAL02614	Upstream extent of model	84.00	84.00	0.000
04GAL01217d	Start of 2D domain	75.76	75.76	0.000
04GAL01117		75.36	75.36	0.000
04GAL01062		75.10	75.10	0.000
04GAL00979	23_Galey13 HEP location	74.20	74.20	0.000
04GAL00341d	Athea East junction	70.06	70.06	0.003
04GAL00333	23_Galey12 HEP location	69.98	69.98	0.003
04GAL00323	Athea National School	70.02	70.02	0.003
04GAL00227		69.74	69.73	0.003
04GAL00200		69.67	69.67	0.004
04GAL00180u	Athea Bridge (US)	69.62	69.62	0.004
04GAL00180d	Athea Bridge (DS)	69.46	69.46	0.003
04GAL00163		69.49	69.49	0.003
04GAL00124	Cois na Gaile	69.04	69.04	0.002
04GAL00060	Markievicz Park	68.59	68.59	0.002
04GAL00011		68.44	68.44	0.002
04GAL00000u	Athea West stream junction	68.38	68.38	0.002
03GAL12232d	End of 2D domain	61.99	61.98	0.001
03GAL11410	Downstream extent of model	57.54	57.54	0.000

It is noted that there is minimal difference in maximum water levels on the Galey River as a result of increases the hydrograph from 23-hours to 48-hours. This confirms that the model is not sensitive to flow duration.

6.2.4 Sensitivity to Flow

6.2.4.1 Athea FRS Main Model

An adjustment factor has been applied to all inflows in the Athea FRS main model to assess the model's sensitivity to peak flows. The adjustment factor for the Galey River was determined to be 1.2, while the adjustment factors for the Athea East and West Streams was determined to be 1.5 for the 1% AEP design event. Table 6-7 presents the difference in water levels throughout the Athea FRS main model as a result of increased flows being applied.

Table 6-7: Peak Flow Sensitivity Test Results for Athea FRS Main Model

Model Node	Location	1% AEP Max. Stage (mOD)	1% AEP + Adjustment Factors	Difference (m)
			Max Stage (mOD)	
Galey River				
04GAL02614	Upstream extent of model	84.00	84.06	0.059
04GAL01217d	Start of 2D domain	75.76	75.94	0.184
04GAL01117		75.36	75.58	0.213
04GAL01062		75.10	75.32	0.216
04GAL00979	23 Galey13 HEP location	74.20	74.40	0.199

04GAL00341d	Athea East junction	70.06	70.37	0.307
04GAL00333	23_Galey 12 HEP location	69.98	70.31	0.328
04GAL00323	Athea National School	70.02	70.36	0.337
04GAL00227		69.74	70.11	0.375
04GAL00200		69.67	70.06	0.382
04GAL00180u	Athea Bridge (US)	69.62	70.01	0.384
04GAL00180d	Athea Bridge (DS)	69.46	69.76	0.293
04GAL00163		69.49	69.79	0.305
04GAL00124	Cois na Gaile	69.04	69.28	0.241
04GAL00060	Markievicz Park	68.59	68.79	0.201
04GAL00011		68.44	68.65	0.210
04GAL00000u	Athea West stream junction	68.38	68.59	0.208
03GAL12232d	End of 2D domain	61.99	62.14	0.158
03GAL11410	Downstream extent of model	57.54	57.65	0.107
Athea West Stream - Eastern Branch				
01GGR00593	Upstream extent of stream	89.57	89.64	0.069
01GGR00534		86.51	86.64	0.122
01GGR00474		83.40	83.47	0.075
01GGR00417	Upstream of Athea West culvert	80.64	80.81	0.164
01GGR00060d	Downstream of Athea West culvert	68.42	68.61	0.186
01GGR00042		68.38	68.59	0.209
01GGR00010		68.38	68.59	0.210
01GGR00000u	Junction with Galey River	68.38	68.59	0.208
Athea West Stream - Western Branch				
01GGR00321	Upstream extent of stream	88.42	88.49	0.070
01GGR00158	Rathronan housing estate	80.70	80.82	0.119
01GGR00117	Rathronan housing estate	78.81	78.94	0.129
01GGR00097		78.23	78.36	0.131
01GGR00067		77.14	77.80	0.661
01GGR00054		76.76	77.79	1.038
01GGR00049	Upstream of Athea West culvert	76.70	77.79	1.094

As a result of the increase of peak flows in the Athea FRS main model, maximum water levels have also increased. The largest increase is 384mm upstream of Athea Bridge, which results from an increase in flow at the same cross section from 69.59m³/s to 84.86m³/s.

There are increases in maximum stage of 210mm on the eastern branch of the Athea West stream and 1.094m on the western branch of the Athea West stream. This 1.094m increase is due to the culvert inlet backing up, as the inlet does not have the capacity for these flows. Since the sensitivity runs were completed using a 1D only model, the water levels rise, rather than spill into the 2D domain. If this water were to spill into the 2D domain, an overland flow route towards Main Street would be the result.

This sensitivity test confirms that the Athea FRS main model is sensitive to increases in flows. This can be true for hydraulic river modes in general. However, it should be noted that the calculation of design flows is noted as being conservative, due to the nature of the catchment and hydrometric gauges with good quality data located downstream of Athea.

6.2.4.2 Athea East Stream Model

An adjustment factor has been applied to all inflows in the Athea East stream model to assess the model's sensitivity to peak flows. The adjustment factor for the Athea East stream was determined to be 1.5 for the 1% AEP design event. Table 6-8 presents the difference in water levels throughout the Athea East stream model as a result of increased flows being applied.

Table 6-8: Peak Flow Sensitivity Test Results for Athea East Stream Model

Model Node	Location	1% AEP Max. Stage (mOD)	1% AEP + Adjustment Factors	Difference (m)
			Max Stage (mOD)	
Athea East Stream				
23GALK00079	Upstream extent of model	104.32	104.43	0.11
23GALK00060		96.13	96.23	0.10
23GALK00059I	Upstream of farm access culvert	96.13	96.26	0.13
23GALK00057	Downstream of farm access culvert	94.73	94.81	0.08
23GALK00034D	Upstream of R524 culvert	86.47	86.80	0.33
23GALK00032	Downstream of R524 culvert	82.77	82.90	0.13
23GALK00022		79.45	79.53	0.08
23GALK00010	Downstream extent of model	74.00	74.00	0.00

As a result of the increase of peak flows in the Athea East Stream model, maximum water levels have also increased. The largest increase is 330mm upstream of the R524 culvert, which results from an increase in flow at the same cross section from 3.32m³/s to 4.59m³/s.

6.2.5 Sensitivity to Roughness

6.2.5.1 Athea FRS Main Model

Manning's n values in the river channel and on the riverbanks have been increased for the 1% AEP design event in order to assess the model's sensitivity to roughness values. Table 6-9 sets out the differences in water levels throughout the Athea FRS main model as a result of applied increased roughness values.

Table 6-9: Roughness Sensitivity Test Results for Athea FRS Main Model

Model Node	Location	1 % AEP Max. Stage (mOD)	1 % AEP + Increased Roughness	Difference (m)
			Max Stage (mOD)	
Galey River				
04GAL02614	Upstream extent of model	84.00	84.09	0.093
04GAL01217d	Start of 2D domain	75.76	75.92	0.164
04GAL01117		75.36	75.53	0.166
04GAL01062		75.10	75.30	0.195
04GAL00979	23_Galey13 HEP location	74.20	74.32	0.117
04GAL00341d	Athea East junction	70.06	70.25	0.191
04GAL00333	23_Galey12 HEP location	69.98	70.19	0.207
04GAL00323	Athea National School	70.02	70.21	0.188
04GAL00227		69.74	69.89	0.157
04GAL00200		69.67	69.82	0.146
04GAL00180u	Athea Bridge (US)	69.62	69.75	0.126
04GAL00180d	Athea Bridge (DS)	69.46	69.57	0.110

04GAL00163		69.49	69.61	0.117
04GAL00124	Cois na Gaile	69.04	69.20	0.156
04GAL00060	Markievicz Park	68.59	68.77	0.178
04GAL00011		68.44	68.61	0.168
04GAL00000u	Athea West Stream junction	68.38	68.56	0.178
03GAL12232d	End of 2D domain	61.99	62.07	0.082
03GAL11410	Downstream extent of model	57.54	57.59	0.049
Athea West Stream - Eastern Branch				
01GGR00593	Upstream extent of stream	89.57	89.61	0.038
01GGR00534		86.51	86.55	0.039
01GGR00474		83.40	83.45	0.056
01GGR00417	Upstream of Athea West culvert	80.64	80.68	0.040
01GGR00060d	Downstream of Athea West culvert	68.42	68.58	0.154
01GGR00042		68.38	68.56	0.179
01GGR00010		68.38	68.56	0.178
01GGR00000u	Junction with Galey River	68.38	68.56	0.178
Athea West Stream - Western Branch				
01GGR00321	Upstream extent of stream	88.42	88.44	0.024
01GGR00158	Rathronan housing estate	80.70	80.78	0.086
01GGR00117	Rathronan housing estate	78.81	78.90	0.092
01GGR00097		78.23	78.34	0.107
01GGR00067		77.14	77.22	0.087
01GGR00054		76.76	76.83	0.073
01GGR00049	Upstream of Athea West culvert	76.70	76.73	0.030

The difference in water levels due to increased roughness values applied to the river channel and banks varies along the modelled reaches. The maximum differences in water levels are 207mm, 179mm and 107mm for the Galey River, Athea West stream – eastern branch and Athea West stream – western branch. In the vicinity of areas of flood risk, the maximum increase in water levels is 178mm on the Galey River, adjacent to Markievicz Park.

6.2.5.2 Athea East Stream Model

Manning's n values in the river channel and on the riverbanks have been increased for the 1% AEP design event in order to assess the model's sensitivity to roughness values. Table 6-10 sets out the differences in water levels throughout the Athea East stream model as a result of applied increased roughness values. Figure 6-2 shows the difference in flood extent in the 2D model domain.

Table 6-10: Roughness Sensitivity Test Results for Athea East Stream Model

Model Node	Location	1% AEP Max. Stage (mOD)	1% AEP + Increased Roughness	Difference (m)
			Max Stage (mOD)	
Athea East Stream				
23GALK00079	Upstream extent of model	104.32	104.34	0.02
23GALK00060		96.13	96.17	0.04
23GALK00059I	Upstream of farm access culvert	96.13	96.16	0.03
23GALK00057	Downstream of farm access culvert	94.73	94.74	0.01

23GALK00034D	Upstream of R524 culvert	86.47	86.35	0.12
23GALK00032	Downstream of R524 culvert	82.77	82.80	0.03
23GALK00022		79.45	79.47	0.02
23GALK00010	Downstream extent of model	74.00	74.00	0.00

The difference in water levels due to increased roughness values applied to the river channel and banks varies along the watercourse reach. The maximum difference in water levels is 120mm, but this is localised to one location. The increase in stage in the model overall is very small.

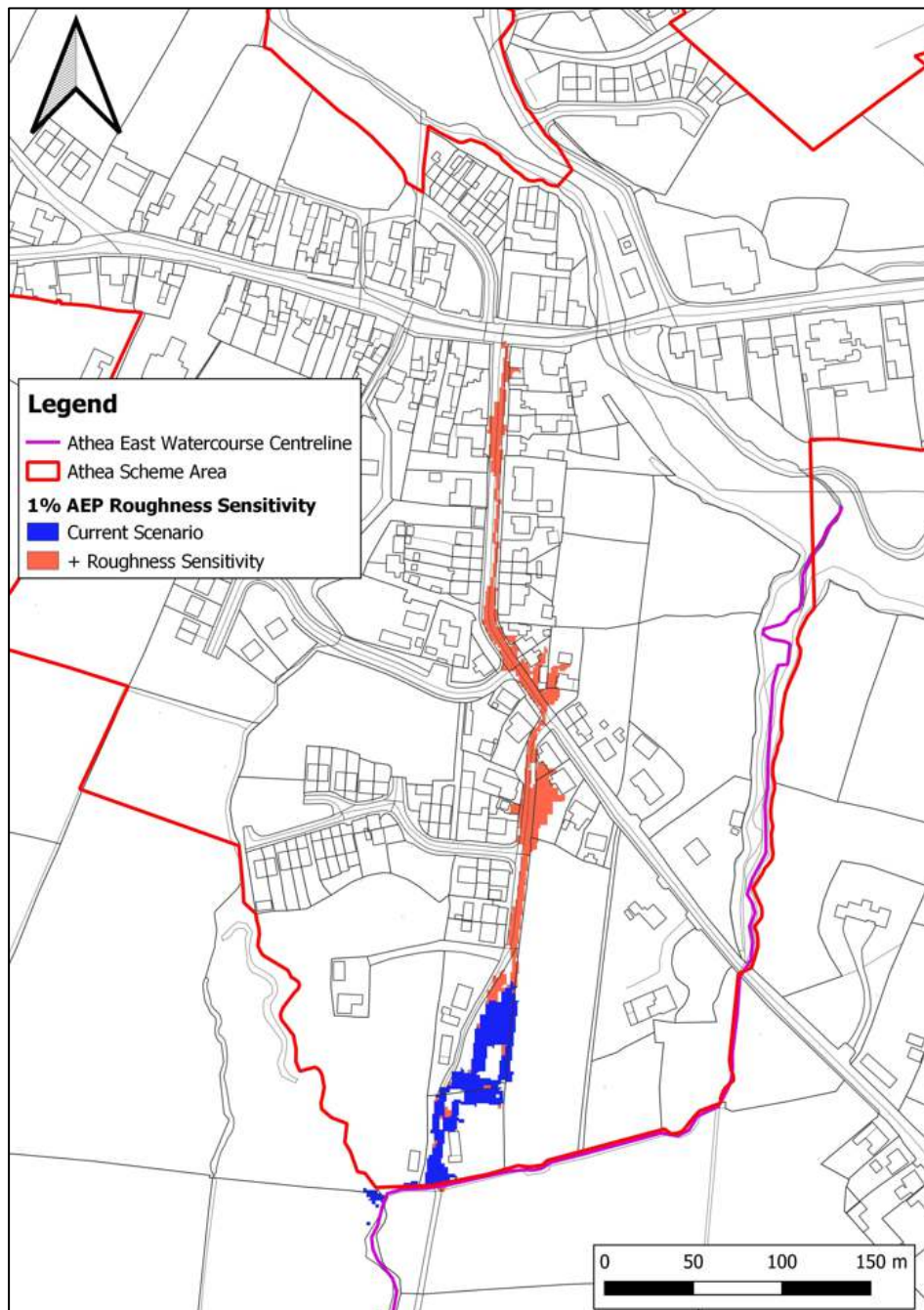


Figure 6-2: Roughness Sensitivity Test Flood Extent Results for Athea East Stream Model

The flood extent has increased due to increased roughness values applied to both the 1D and 2D domains. Therefore, this concludes that the model is sensitive to increase roughness, due to the shallow depths of flood flow in the 2D domain.

However, the original Mannings n roughness values applied to the model are deemed to be representative of on-site conditions.

6.2.6 Afflux/ Blockage at Key Structures

6.2.6.1 Blockage – Athea FRS Main Model

Blockage scenarios have been undertaken for key hydraulic structures in the Athea FRS main model, namely the Athea Bridge and the Athea West culvert – western and eastern branches. Gravel deposition is an ongoing problem at Athea Bridge on the Galey River and to represent this in the model, bed levels have been increased in the vicinity of the bridge. For this scenario, bed levels have been increased by 0.5m in the left arch and up to 1.5m in the central and right arches of Athea Bridge to represent sediment deposition.

For the Athea West culvert - eastern branch, the capacity of Section 1 of the culvert has been reduced in size from a 900mm culvert to a 700mm culvert. The trash screen also allows for build-up of debris over 70% of the culvert in the sensitivity test. This represents a blockage at the inlet of the culvert.

For the Athea West culvert – western branch, a blockage scenario has not been applied. However, the embankment at the culvert inlet has been removed from the 2D domain. If water levels back up at the inlet, this scenario will show the impact with regards flood risk on Athea Main Street if the left bank is overtopped.

The 1% AEP design event has been run for the above sensitivity tests to assess the differences in water levels as a result of the blockage scenarios at key structures. Table 6-11 presents the results of these tests on Athea Bridge and Athea West culvert – eastern branch, while Figure 6-3 shows the tests results from the Athea West culvert – western branch.

Table 6-11: Blockage Sensitivity Test for Athea FRS Main Model

Model Node	Location	1% AEP Max. Stage (mOD)	1% AEP + Blockage	Difference (m)
			Max Stage (mOD)	
Galey River				
04GAL02614	Upstream extent of model	84.00	84.00	0.000
04GAL01217d	Start of 2D domain	75.76	75.76	0.001
04GAL01117		75.36	75.36	0.001
04GAL01062		75.10	75.10	0.001
04GAL00979	23_Galey13 HEP location	74.20	74.20	0.001
04GAL00417		70.44	71.13	0.696
04GAL00341		70.06	71.03	0.968
04GAL00341d	Athea East junction	70.06	71.03	0.968
04GAL00333	23_Galey12 HEP location	69.98	71.02	1.037
04GAL00323	Athea National School	70.02	71.03	1.012
04GAL00227		69.74	70.97	1.236
04GAL00200		69.67	70.96	1.286
04GAL00180u	Athea Bridge (US)	69.62	70.87	1.251
04GAL00180d	Athea Bridge (DS)	69.46	69.58	0.116
04GAL00163		69.49	69.49	-0.002
04GAL00124	Cois na Gaile	69.04	69.04	-0.002
Athea West Stream - Eastern Branch				
01GGR00593	Upstream extent of stream	89.57	89.56	-0.012
01GGR00534		86.51	86.55	0.032
01GGR00474		83.40	83.38	-0.018
01GGR00417	Upstream of Athea West culvert	80.64	80.72	0.075
01GGR00393u	Athea West Stream culvert inlet	80.19	80.58	0.381

01GGR00393cu		79.70	79.77	0.069
01GGR00060d	Downstream of Athea West culvert	68.42	68.42	0.000

The blockage scenario on the Athea Bridge shows an increase in water levels up to 1.286m upstream of Athea Bridge, which is due to an increase in bed levels of between 0.5m and 1.5m at the bridge. There is a slight decrease in water levels directly downstream of the bridge as a result of the blockage scenario.

The blockage scenario on the culvert inlet on the Athea West stream – eastern branch shows a very local increase in water levels in the vicinity of the inlet.

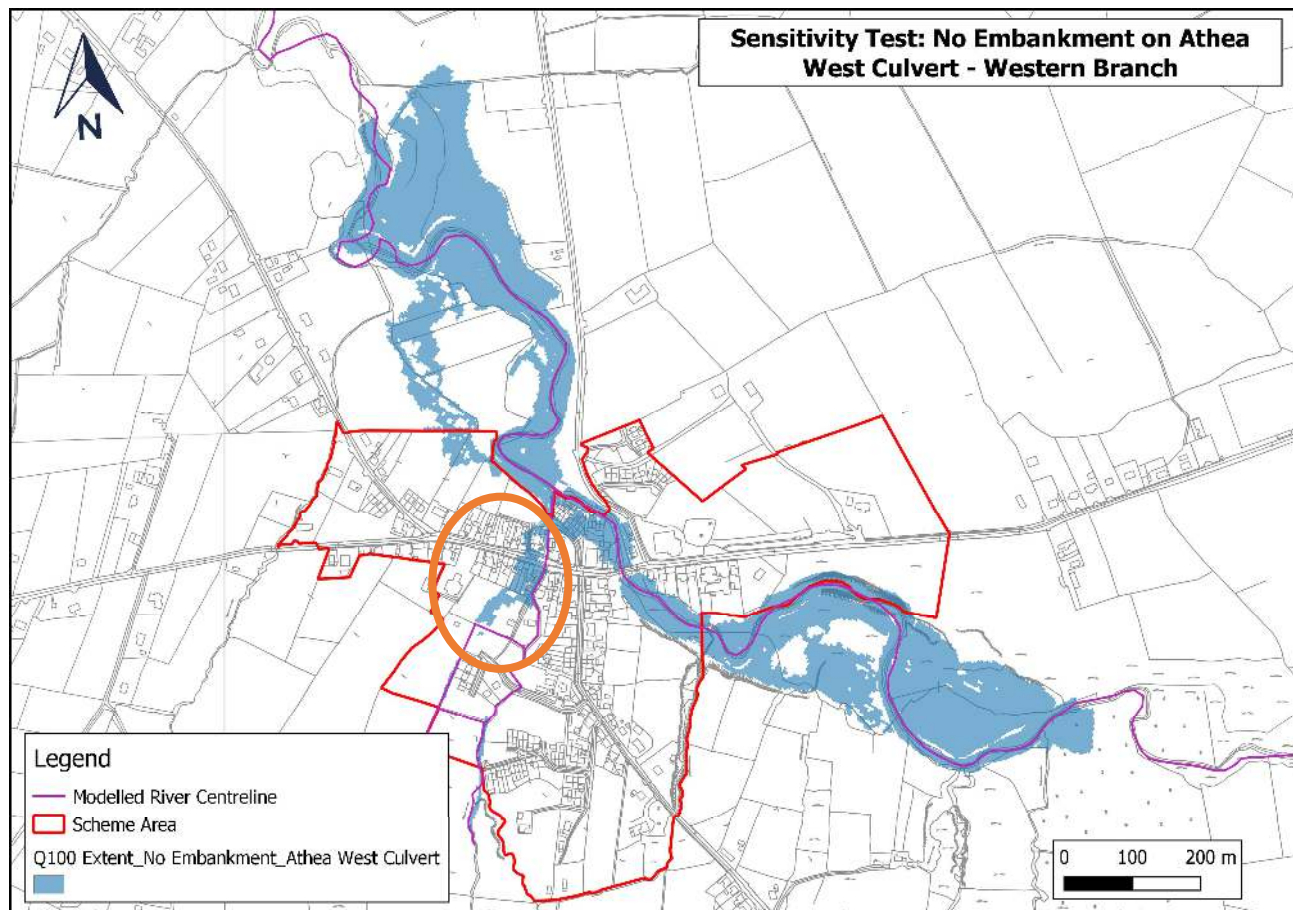


Figure 6-3: Sensitivity Test: Flood Extent (Q100) when embankment removed from left bank of Athea West Stream – Western Branch

The scenario where the left bank is removed from the Athea West stream – western branch shows that a new flow path is created for the 1% AEP flood extent. Flood water overtops the left bank and flows down the steep hill towards Athea Main Street and causes flooding to a number of properties (see orange circle in Figure 6-3). This scenario highlights the importance of maintaining this embankment, to ensure that the properties on Main Street are not at flood risk.

6.2.6.2 Blockage – Athea East Stream Model

For the farm access culvert on the Athea East stream, a blockage scenario has been applied – 67% blockage of the culvert inlet. The 1% AEP design event has been run for this sensitivity tests to assess the differences in water levels as a result of the blockage scenario. Table 6-11 and Figure presents the results of this test on the Athea East farm access culvert.

Table 6-12: Blockage Sensitivity Test for Athea East Stream Model

Model Node	Location	1% AEP Max. Stage (mOD)	1% AEP + 67% Blockage at Farm Access Culvert	Difference (m)
			Max Stage (mOD)	
Athea East Stream				
23GALK00079	Upstream extent of model	104.32	104.32	0.00
23GALK00060		96.13	96.24	0.11
23GALK00059I	Upstream of farm access culvert	96.13	96.26	0.13
23GALK00057	Downstream of farm access culvert	94.73	94.70	-0.04
23GALK00034D	Upstream of R524 culvert	86.47	86.37	-0.10
23GALK00032	Downstream of R524 culvert	82.77	82.74	-0.03
23GALK00022		79.45	79.43	-0.02
23GALK00010	Downstream extent of model	74.00	74.00	0.00

There are increases in maximum stage upstream of the blockage and decreases in water level downstream of the blockage, due to water being displaced from the channel at the blockage location.

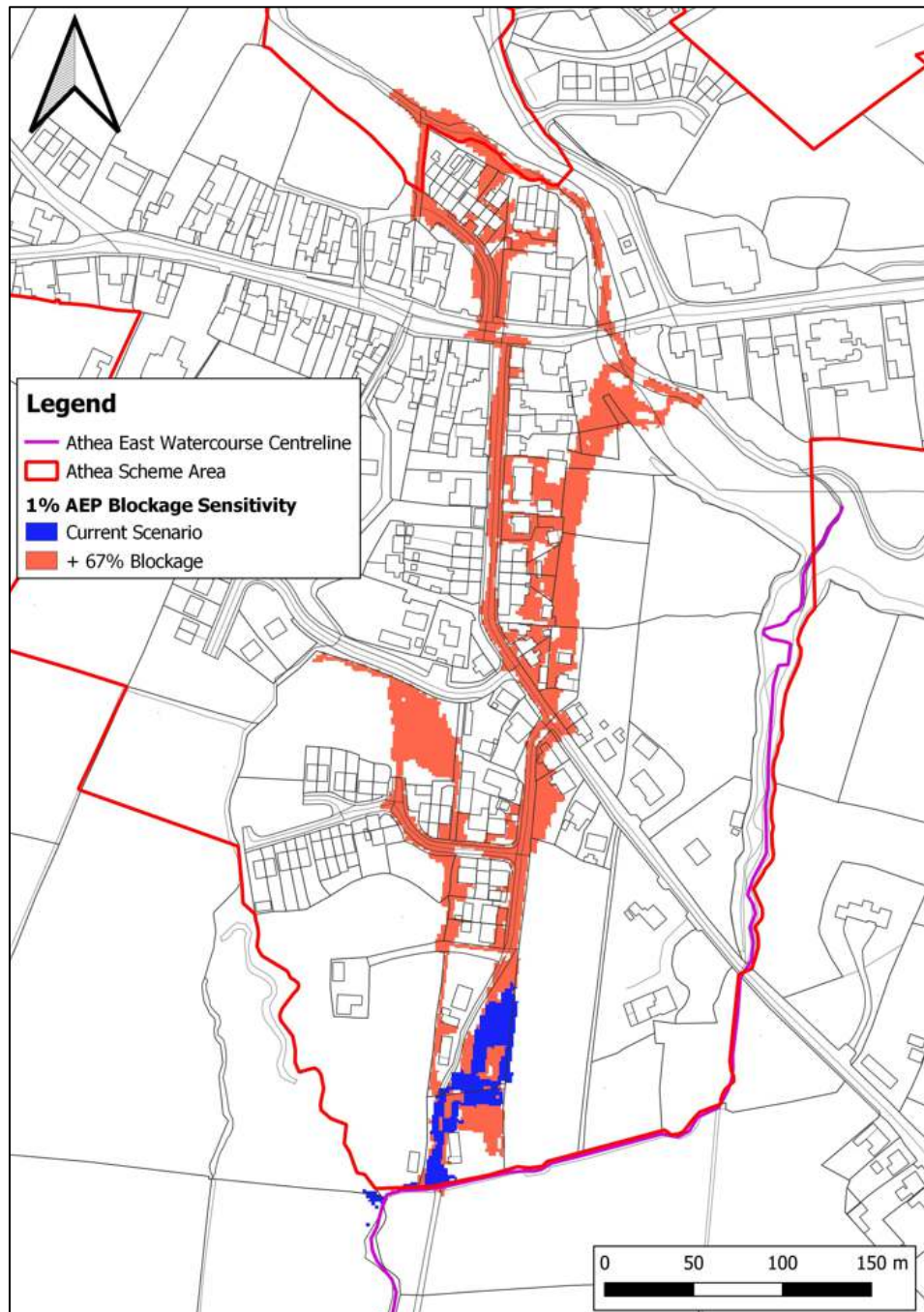


Figure 6-4: Sensitivity Test: Flood Extent (Q100) for 67% Blockage on Farm Access Culvert

6.2.6.3 Afflux

Further model runs have been completed to review the afflux sensitivity at Athea Bridge by assessing the bridge unit that has been applied in the model for the Athea Bridge with existing bed levels. For one scenario a “USBPR Unit” has replaced the “Arch Bridge Unit”, which was included in design runs, while for a second scenario, “Sprung Arch Conduit Units” have replaced the “Arch Bridge Unit”. The USBPR and Sprung Arch Conduits apply different head losses to that of the Arch Bridge Unit. The 1% AEP design event has been applied to assess the difference in water levels as a result of the afflux scenarios at Athea Bridge. Table 6-13 presents the results of these tests.

Table 6-13: Afflux at Athea Bridge Sensitivity Test

Model Node	Location	1% AEP Max. Stage (mOD)	1% AEP + Afflux - USBPR	Difference (m)	1% AEP + Afflux - Sprung Arch Conduits	Difference (m)
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			Max Stage (mOD)		Max Stage (mOD)	
Galey River						
04GAL02614	Upstream extent of model	84.00	84.00	0.000	84.00	0.000
04GAL01217d	Start of 2D domain	75.76	75.74	-0.019	75.74	-0.018
04GAL01117		75.36	75.33	-0.031	75.33	-0.031
04GAL01062		75.10	75.08	-0.024	75.08	-0.024
04GAL00979	23_Galey13 HEP location	74.20	74.19	-0.008	74.19	-0.008
04GAL00516		70.87	70.92	0.052	70.88	0.010
04GAL00417		70.44	70.59	0.152	70.49	0.056
04GAL00341		70.06	70.33	0.274	70.17	0.113
04GAL00341d	Athea East junction	70.06	70.33	0.274	70.17	0.113
04GAL00333	23_Galey12 HEP location	69.98	70.30	0.315	70.12	0.134
04GAL00323	Athea National School	70.02	70.33	0.306	70.15	0.130
04GAL00227		69.74	70.17	0.436	69.94	0.202
04GAL00200		69.67	70.14	0.467	69.89	0.219
04GAL00180u	Athea Bridge (US)	69.62	70.10	0.481	69.84	0.221
04GAL00180d	Athea Bridge (DS)	69.46	69.45	-0.015	69.47	0.006

The results from the sensitivity test for afflux at Athea Bridge shows a difference in maximum water level of 481mm directly upstream of the bridge for the USBPR unit and difference in maximum water level of 221mm directly upstream of the bridge for the Sprung Arch Conduit Units. These units are not representative of the Athea Bridge, but shows the result of increased head losses over the structure. This confirms that the Athea Bridge is sensitive to afflux/ head losses.

6.2.7 2D Model Domain Cell Size

For initial sensitivity testing, the 2D model domain cell size has been reduced to 2m from 6m for the sensitivity test. Figure 6-5 shows the difference in flood extent from this test. When a cell size of 6m is applied to the 2D domain, the model run time is less than 15 minutes, while the run time for the 2m cell size model is over 2 hours.

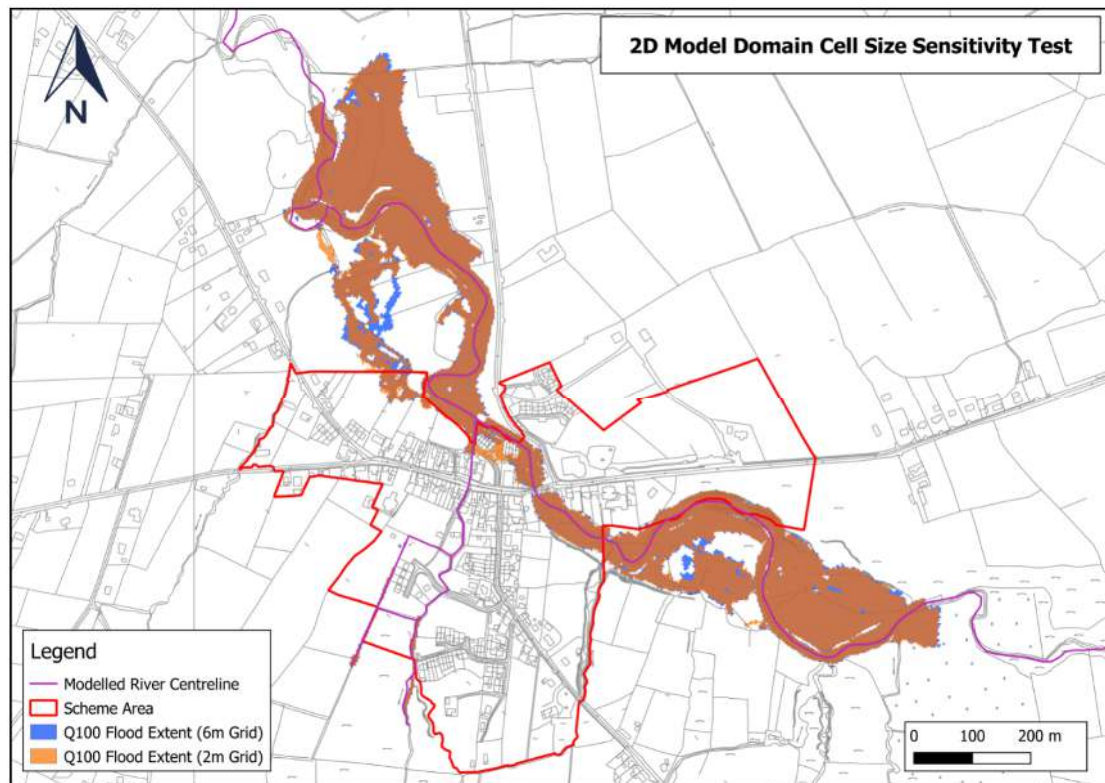


Figure 6-5: 2D Model Domain Cell Size Sensitivity Test (2m vs 6m)

There are slight differences in the flood extents from the 6m and 2m cell size, with the 6m cell size results showing a larger flood extent in some instances. This is due to part of the 6m cell being wet, thus the flood extent is applied to the whole cell. In addition, there are some flow routes that are present in the 2m cell size model and not in the 6m cell size model, namely a flow route from Cois na Gaile to Markievicz Park housing estates.

Following the initial sensitivity testing on the 2D model domain cell size, further tests were undertaken to compare a 4m cell size to a 2m. Figure 6-6 shows the difference in flood extent from this test. There is a slight difference in flood extent between the 2m and 4m cell size, but this is negligible and all properties that are within the 1% AEP flood extent for the 2m cell size are also within the 1% AEP flood extent for the 4m cell size.

As a result of this sensitivity test, the cell size for all model runs has been reduced from 6m to 4m.

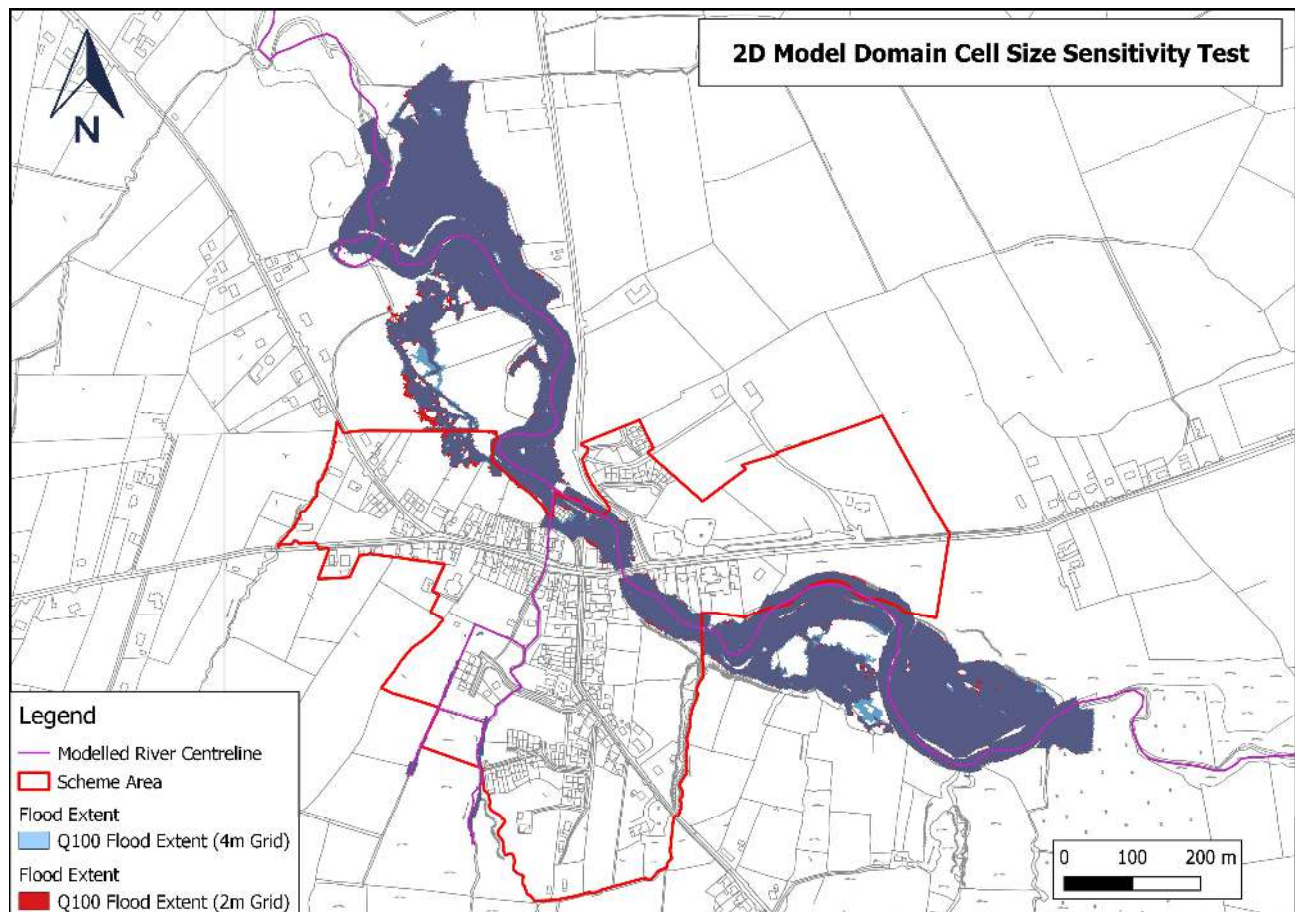


Figure 6-6: 2D Model Domain Cell Size Sensitivity Test (2m vs 4m)

6.2.8 Summary

6.2.8.1 Athea FRS Main Model

On review of the results from the sensitivity tests, the Athea FRS main model is most sensitive to increase in peak design flows. As discussed in the Athea FRS Hydrology Report (Ryan Hanley, 2021), a conservative approach has been taken in determining the design flows due to the presence of forestry in the upstream catchment and the presence of a hydrometric gauge downstream of Athea.

As a result of the sensitivity tests, the following amendments to the baseline current scenario Athea FRS main model have been made:

- Cell size for all model runs has been reduced from 6m to 4m.
- Further analysis on blockage scenarios and bed levels in the Galey River are required – see Section 7.

6.2.8.2 Athea East Stream Model

On review of the results from the sensitivity tests, the Athea East stream model is most sensitive to increase in peak design flows and blockage in the area of interest regarding flood risk. As discussed in the Athea FRS Hydrology Report (Ryan Hanley, 2021), a conservative approach has been taken in determining the design flows due to the presence of forestry in the upstream catchment and the presence of a hydrometric gauge downstream of Athea.

As a result of the sensitivity tests, the following amendments to the baseline current scenario Athea East stream model have been made:

- Blockage of 67% has been adopted to the baseline current scenario for the farmyard access culvert.
- Building representation has been amended. Buildings have been stamped on to the Lidar and elevations applied. This looks to be more representative than applying a high Mannings roughness value, due to the steep topography of the Scheme Area.

7 Additional Sensitivity Analysis – Blockage Scenarios [Athea FRS Main Model]

7.1 Introduction

This section of the report details additional blockage analysis and review of bed levels in the Galey River at Athea Bridge and of the Athea West stream culvert inlets.

Due to the nature of the Galey River channel in the vicinity of Athea Bridge with the constant movement and build-up of gravels, further blockage analysis and review of the bed conditions at Athea Bridge is required. There is also a risk of blockage at the Athea West stream culvert inlets due to the increase in vegetation and debris (e.g. timber, rubbish etc.) thus further blockage analysis is required. From the review of survey photographs from 2012 and 2021, it is clear that the two culvert inlets on the Athea West stream are overgrown and debris is prone to building up at the screens. The results of this analysis will be considered when determining baseline conditions for the design flood events and flood mapping for the Galey River and streams in Athea.

Potential blockage on the Athea East stream was reviewed as part of this study. The R524 Abbeyfeale Road culvert is a well-maintained masonry arch culvert is 2.38m wide, c2.17m high and 8m in length with a bed level in excess of 4m below the road level. The 1.1km² catchment has a steep gradient and the channel and culvert have appropriate capacity for the design flows determined in the Athea FRS Hydrology Report (Ryan Hanley, 2022). There is no evidence that the culvert has surcharged or flooded the R524 Road in the past. It was determined that blockage analysis was not required on this structure due to no records of flooding and assessment of the structure on site and through previous survey data. There is also 900mm diameter concrete culvert under a farm access road on private land on the Athea East stream. There is no evidence that the culvert has surcharged or flooded in the past and it was determined that blockage analysis was not required for this study. However, maintenance should be considered for this structure in the future.

7.2 Background

The blockage of structures (bridges/culverts or river sections) by debris (any material moved by a flowing stream including pebbles, cobbles, vegetation, sediment and man-made materials or refuse) has the potential to:

- Reduce channel and hydraulic structure flow capacity and raise water levels, which can result in increased flood risk, both upstream and downstream of a blockage;
- Lead to bank overtopping and erosion and damage to existing flood defences, such as earthen embankments,
- Cause new out of bank flood flow paths leading to further increases in flood risk;
- Lead to changes in flow patterns in the channel and at structures, resulting in scour, sedimentation or structural failure that can lead to further inundation of the floodplain.

Significant deposition of sediments, gravels and cobbles occurs in the channel at Athea Bridge and a vegetated gravel bar forms immediately up and downstream of the Athea Bridge. Historically, Athea Bridge and its associated channel reach are vulnerable to blockage from flood debris (i.e. branches, trees) and deposition upstream and downstream of the bridge. This is not unexpected considering the Galey River catchment and channel characteristics (i.e. unstable riverbanks, significant channel erosion, large sediment transport, wooded channel banks and extensive forestry (source for timber debris) in the upland areas of the catchment). Significant blockages were evident at Athea Bridge and the Galey River channel reach through Athea following the August 2008 extreme flood event.

The deposition is impacting on the conveyance capacity at the bridge and potentially increasing flood risk locally. It is believed that historically, these deposits were removed from the channel, as necessary, by local landowners. However, since the river was designated as part of the Lower River Shannon SAC, this no longer happens. Following extreme weather events in 2008, high river levels along the Galey River resulted in the major accumulation of trees, vegetation and debris at Athea Bridge, which significantly reduced the available flow conveyance of the structure and represented a flood risk to the immediate locality. During the 2008 flood event, 21 No. properties in Athea were flooded due to high water levels in the Galey River, most of which are in the vicinity of Athea Bridge. In addition, on completion of sensitivity analysis on the Athea West stream culvert inlets, it was noted that if the inlets were blocked, water levels increased significantly in the locality. On review of previous survey photos and from recent site walkovers, it was noted that there had been significant vegetation growth and debris accumulation at the inlets. Hence, it is essential to understand the effects of blockage on the Galey River and Athea West stream on the flood extents and flood depth through detailed modelling of plausible blockage scenarios.

7.3 Blockage at Athea Bridge during the 2008 Flood Event

Based on a review of the JBA Flood Severity Report and topographical surveys that were carried out for this study and for previous studies (See Section 4.2.2 of this report), it is concluded that for the flood event that occurred between 31st of July and 1st of August 2008, flow conveyance in the river channel was reduced due to flood debris and gravel accumulations at Athea Bridge. In addition to gravel build-up in the river channel upstream and downstream of Athea Bridge, flood debris, overgrowth and vegetation along the channel banks downstream of the bridge and accumulation of gravels directly downstream of Athea Bridge added to the flood risk in Athea.

For the 2008 flood event, the peak flood level was observed to be approximately 0.3m below the soffit of the central arch of Athea Bridge (the bridge soffit is 70.54mOD), which equates to a peak level of **70.24mOD**).

Figure 7-1 and Figure 7-2 show the accumulation of gravel upstream of downstream of Athea Bridge, observed during site visits in 2020 and 2021. Figure 7-3 is a photo from the JBA Flood Severity Report of gravel accumulations at Athea Bridge taken following the 2008 flood event.



Figure 7-1: Gravel Deposition Upstream of Athea Bridge (Cross Section 04GAL00180u) (Taken on 05/03/2021)



Figure 7-2: Gravel Deposition Downstream of Athea Bridge (Cross Section 04GAL00163) (Taken on 18/06/2020)



Figure 7-3: Gravel Accumulation at Athea Bridge following the 2008 Flood Event (JBA Flood Severity Report)

7.4 Blockage on the Athea West Stream

Blockage analysis is being undertaken on the Athea West stream culvert inlets due to the increase in vegetation in the locality of the culvert inlets recorded on site (between 2012 and 2021/2022). From comparison of previous topographical survey of the structure and the current condition of the inlets, it was determined that further blockage analysis would be required due to vegetation overgrowth, receptors at flood risk in the vicinity of the inlets, upstream land-use and the results of sensitivity analysis in Section 6.2 of this report. Figure 7-4 compares the condition of culvert inlets from 2012 to 2021 and 2022. The 2012 CFRAM survey photos were recorded in April of 2012. The comparison photos were taken during a site visit on 24th November 2021. It was noted to be a moderately wet day with a yellow rainfall warning in place and the catchment was saturated. There is an additional photo of the Western Branch culvert inlet, recorded by a surveyor in November 2022, which shows the vegetation overgrowth on the trash screen.



**Athea West Stream – Eastern Branch Culvert Inlet
(01GGR00393u) 2012**



**Athea West
Stream –
Eastern Branch
Culvert Inlet
2021**



Figure 7-4: Comparison of Athea West Stream Inlet Conditions

7.5 Modelling of Blockage Scenarios

In order to assess the blockage risk at Athea Bridge and Athea West stream culverts, a range of scenarios have been determined and set up to perform the required additional sensitivity analysis. These scenarios were determined to ensure that a comprehensive investigation of the potential effects of blockage on flood extent, flood inundation depth and local flooding mechanisms during flood events are analysed. The 1% AEP design flood events have been run for each blockage scenario, whereas 2% and 0.5% AEP design event flows have been used to assess the sensitivity of the model for optimised blockage scenarios.

7.5.1 Galey River at Athea Bridge

Historically, Athea Bridge is susceptible to blockage due to cobbles/ gravels and vegetation/ trees being carried by the river from its upstream catchment and deposited at Athea Bridge and its vicinity. Table 7-1 shows the list of blockage scenarios to be modelled for Athea Bridge (at cross section 04GAL00180u). These include a number of variations of full and partial blockages of the three bridge arches to represent the varying levels of accumulation of gravel and vegetation build up at the bridge. The scenarios were determined by reviewing what has occurred previously, as well as including scenarios to test sensitivity.

There are a number of blockage/ riverbed raising scenarios to be applied directly downstream of Athea Bridge in the Galey River (at cross section 04GAL00163) - see Table 7-2 for the list of these scenarios. These represent the varying accumulations of gravel/ vegetation build up downstream of the bridge that have been observed on site. The scenarios were determined by reviewing what has occurred previously, as well as including scenarios to test sensitivity.

Figure 7-5 shows the location of where the blockage scenarios are applied on the Galey River – i.e. at Athea Bridge and directly downstream of Athea Bridge. Figure 7-6 shows the three arches of Athea Bridge, named Arch A, B and C for this analysis.

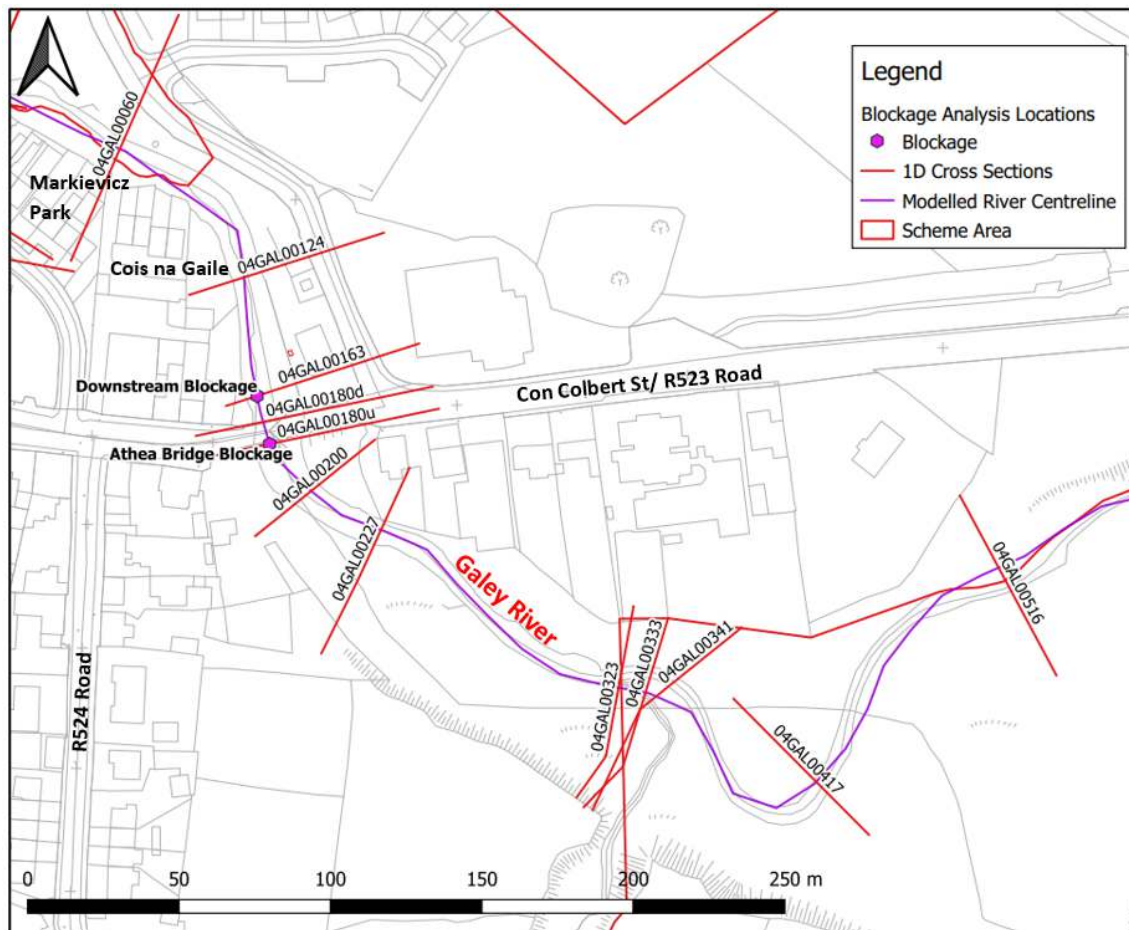


Figure 7-5: Location of Blockage Scenario Runs on the Galey River

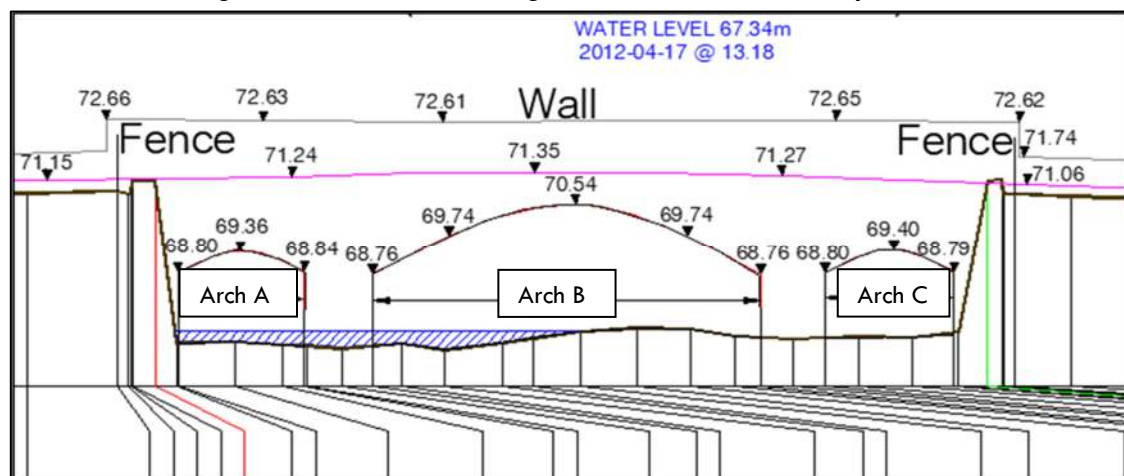


Figure 7-6: Cross Section Details for Athea Bridge (Upstream Face, looking Downstream) [04GAL00180u]

Table 7-1: List of Blockage Scenarios for Athea Bridge

Scenarios	Description	Justification
1	Arch 'A' fully blocked	The flow area for arch A and arch C are relatively small (width of each arch is ~3.0m) when compared with the Arch B (width ~10.2m). These two arches are more vulnerable to blockage due to debris (trees) getting trapped at their entrances, subsequently leading to complete blockage of flow area.
2	Arch 'C' fully blocked	
3	Arch A and C fully blocked and Arch B is blocked by 25%	A review of the blockage mechanisms and risk during historical flood events has concluded that the flow area for arch B would most likely only start to reduce significantly once near complete blockage of arch A and B has occurred. To simulate this series of blockage scenarios at arch B have been modelled comprising reducing the available flow area by 10%, 25%, 50% and 75%, while arch A and C are fully blocked. The maximum blockage scenario at arch B is set at 75%.
3A	Arch A and C fully blocked and Arch B is blocked by 10%	
4	Arch A and C fully blocked and Arch B is blocked by 50%	
5	Arch A and C fully blocked and Arch B is blocked by 75%	
1A	Arch A, B and C blocked by 10%	A further feasible blockage regime at Athea Bridge is that the flow area at each arch reduces by the same equivalent amount at the same time. To represent this condition, the total flow area for all three arches have been reduced uniformly by 10%, 25% and 30%. These percentages are determined based on historically reported blockages at the bridge.
1B	Arch A, B and C blocked by 25%	
1C	Arch A, B and C blocked by 30%	

Table 7-2: List of Blockage Scenarios for Cross Section Downstream of Athea Bridge

Scenarios	Description	Justification
6	Blockage of cross section by 20%	For this simulation the blocked flow area for the cross section downstream of the Athea Bridge has been increased in increments from 10% to 75% to assess its impact on water level upstream of Athea Bridge for wide range of blockage scenarios. Based on a review of the historic channel blockage regime downstream of Athea Bridge, there is potential for the flood debris and vegetation which passes through the Arches to accumulate and deposit downstream of the bridge. The maximum flow area reduction simulated is set at 75%.
6A	Blockage of cross section by 10%	
7	Blockage of cross section by 30%	
8	Blockage of cross section by 40%	
9	Blockage of cross section by 50%	
10	Blockage of cross section by 75%	
13	(Scenario 1C+ Scenario 7)	Based on historical reports of blockages at Athea, it is feasible for blockages to occur both in the channel downstream of the bridge and at the. This scenario has been simulation to access the in-combination effects of the channel and bridge blockage scenarios.

The blockage scenarios associated with Athea Bridge and with the downstream river cross section (increase in bed levels due to debris and gravel deposition) have been modelled using a 'Blockage Unit' in Flood Modeller. Hydraulically, Flood Modeller uses contraction (inlet loss) and expansion (outlet loss) co-efficient for the calculation of blockages in bridges/culverts/cross sections.

7.5.2 Athea West Stream Culvert Inlets

A number of blockage scenarios have been modelled for the culvert blockage for Athea West stream as presented in Table 7-3. The location of the Athea West stream culvert inlets on the eastern branch (01GGR00393u) and on the western branch (01GGR00044u) are shown in Figure 7-7. During a site visit in November 2021, it was observed that the screens on eastern and western branch culvert inlets were 75% blocked - there was timber, plastic, footballs, rubbish in addition to dense briars covering the screens. Given the catchment land use (mainly agriculture), it is possible that debris could be washed off the catchment during a rainstorm event resulting in vegetation and debris getting lodged in the screens. It was also evident that the screens are not maintained on a regular basis.

After review of the previous survey data on these structures and comparing with the observed condition of and vegetation growth at the culvert inlets, it was proposed to test each inlet with a 90% blockage.

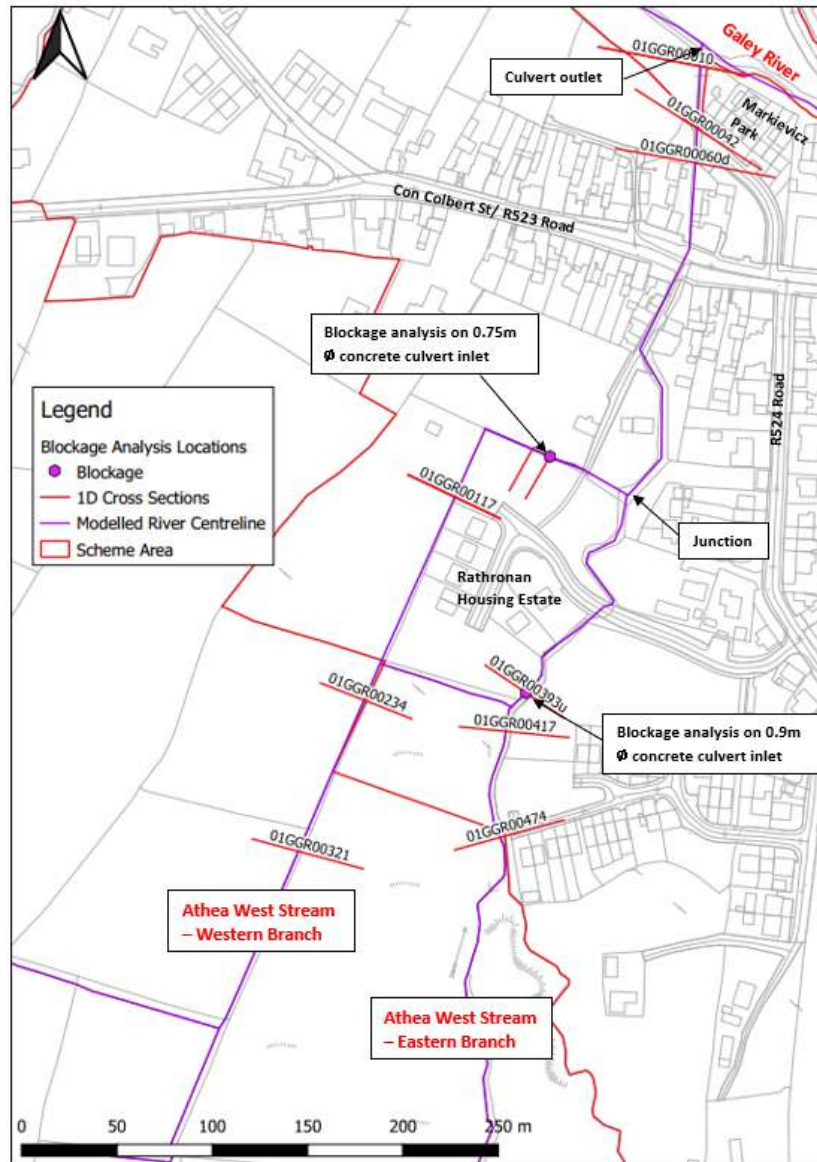


Figure 7-7: Location of Blockage Scenario Runs on the Athea West Stream Culvert Inlets

Table 7-3: List of Blockage Scenarios for Athea West Stream Culvert Inlets

Scenarios	Description	Justification
14	Blockage of culvert by 90% for Athea West stream – Western branch	Review of culvert inlet conditions in 2012 versus 2021/2022.
15	Blockage of culvert by 90% for Athea West stream – Eastern branch	

7.6 Modelling Results – Galey River

7.6.1 Blockage of Athea Bridge

Table 7-4 shows the 1% AEP maximum water levels at the modelled nodes for Athea Bridge blockage scenarios. For the baseline model, the maximum water level at the upstream face of Athea Bridge is 69.48mOD, with scenario 5 resulting in a maximum water level at the upstream face of Athea Bridge of 71.31mOD (See Table 7-4). The model is more sensitive to the blockage of Athea Bridge in comparison with the blockage of downstream river section (with reference to the water levels in the Table 7-5).

Table 7-4: Maximum Water Levels for Blockage at Athea Bridge

Node ID	Location	Maximum Water Levels (mOD) for 1% AEP Design Event									
		Blockage Scenarios									
		Baseline	1	2	3	3A	4	5	1A	1B	1C
04GAL02614	US model extent	84.00	84.00	84.00	84.00	84.00	84.00	84.00	84.00	84.00	84.00
04GAL01217d	Start of 2D domain	75.68	75.68	75.68	75.68	75.68	75.68	75.68	75.68	75.68	75.68
04GAL00341d	Athea East junction	69.97	70.11	70.10	71.03	70.94	71.20	71.37	70.16	70.34	70.43
04GAL00227		69.71	69.94	69.93	71.00	70.90	71.18	71.28	70.02	70.25	70.35
04GAL00200		69.62	69.89	69.87	70.99	70.90	71.18	71.20	69.97	70.22	70.33
04GAL00180u ¹	Athea Bridge US	69.48	69.77	69.75	70.97	70.87	71.18	71.31	69.86	70.13	70.24
04GAL00180d ²	Athea Bridge DS	69.30	69.30	69.30	69.42	69.41	69.44	69.45	69.30	69.30	69.31
04GAL00163		69.34	69.34	69.34	69.42	69.42	69.42	69.42	69.34	69.34	69.36
04GAL00124	Cois na Gaile	69.14	69.14	69.14	69.09	69.10	69.06	69.06	69.14	69.14	69.13
04GAL00060	Markievicz Park	68.44	68.44	68.44	68.45	68.44	68.45	68.45	68.44	68.44	68.44
04GAL00011		68.28	68.28	68.28	68.29	68.29	68.30	68.29	68.28	68.28	68.28

1- Upstream Athea Bridge cross section, 2- Downstream Athea Bridge cross section

7.6.2 Blockage of River Cross Section Downstream of Athea Bridge

Table 7-5 shows the 1% AEP maximum water levels at modelled nodes for the downstream river cross section blockage scenarios. The modelled cross section is located directly downstream of Athea Bridge and has been used to represent the accumulation of debris in model using a Blockage Unit. The modelled results show that there is a small to moderate impact on the water level in comparison with the baseline results. The modelled maximum water level is 70.61mOD (US of the Athea Bridge) when the flow area for downstream cross section (04GAL00163) is blocked by 75% (scenario 10).

Table 7-5: Maximum Water Levels for Blockage of River Cross Section Downstream of Athea Bridge

Node ID	Location	Maximum Water Levels (mOD) for 1% AEP Design Event						
		Blockage Scenarios						
		Baseline	6	6A	7	8	9	10
04GAL02614	US model extent	84.00	84.00	84.00	84.00	84.00	84.00	84.00
04GAL01217d	Start of 2D domain	75.68	75.68	75.68	75.68	75.68	75.68	75.68
04GAL00341d	Athea East junction	69.97	70.01	69.99	70.06	70.12	70.22	70.72
04GAL00227		69.71	69.80	69.75	69.87	69.96	70.09	70.68
04GAL00200		69.62	69.72	69.66	69.80	69.91	70.05	70.67
04GAL00180u ¹	Athea Bridge US	69.48	69.60	69.53	69.68	69.80	69.95	70.61
04GAL00180d ²	Athea Bridge DS	69.30	69.42	69.35	69.51	69.62	69.78	70.38
04GAL00163 ³		69.34	69.47	69.40	69.56	69.68	69.83	70.38
04GAL00163d ⁴	Cois na Gaile	69.34	69.35	69.35	69.35	69.36	69.36	70.43
04GAL00124	Markievicz Park	69.14	69.14	69.14	69.14	69.14	69.14	69.46
04GAL00060		68.44	68.44	68.44	68.44	68.44	68.44	69.12
04GAL00011		68.28	68.28	68.28	68.28	68.28	68.28	68.28

1- Upstream Athea Bridge cross section, 2- Downstream Athea Bridge cross section 3- Upstream of the blocked cross section, 4- Downstream of the blocked cross section.

7.6.3 Combination of Blockage Scenarios – Athea Bridge and DS of Athea Bridge

In order to assess the effect on flood extents, the model has been tested for the combination of blockage scenarios i.e. blockage of Athea Bridge (scenario 1C) and blockage of river cross section downstream of the Athea Bridge (scenario 7) together. Table 7-6 shows the maximum water levels at modelled nodes upstream and downstream of Athea Bridge for the 1% AEP design event with the combined blockage scenario.

Table 7-6: Maximum Water Levels for Combination of Blockage Scenarios

Node ID	Location	Maximum Water Levels (mOD) for 1% AEP		
		Blockage Scenarios		
		Baseline	1C	13 (1C+7)
04GAL02614	US model extent	84.00	84.00	84.00
04GAL01217d	Start of 2D domain	75.68	75.68	75.68
04GAL00341d	Athea East junction	69.97	70.43	70.56
04GAL00227		69.71	70.35	70.50
04GAL00200		69.62	70.33	70.48
04GAL00180u ¹	Athea Bridge US	69.48	70.24	70.41
04GAL00180d ²	Athea Bridge DS	69.30	69.31	69.54
04GAL00163		69.34	69.36	69.58
04GAL00163d	Cois na Gaile	69.34	69.36	69.58
04GAL00124	Markievicz Park	69.14	69.13	69.12
04GAL00060		68.44	68.44	68.43
04GAL00011		68.28	68.28	68.28

The modelling results for blockage scenario 1C and scenario 13 (1C+7) for 1% AEP shows that the maximum water level variation is in the range of 200mm to 250mm, indicating that the blockage of the river cross section downstream of Athea Bridge has a relatively lower impact on the water levels than a blockage at Athea Bridge.

7.6.4 Sensitivity of Blockage Scenarios for Design Events

The 2% and 0.5% AEP design event flows have been used to test the Athea Bridge blockage scenario (scenario 1C). Table 7-7 shows the maximum water levels for 2%, 1% and 0.5% design events. Figure 7-8 shows a comparison of maximum stage and total energy through the Athea Bridge for the 1% AEP baseline scenario and scenario c for the 1% AEP and 0.5% AEP design events.

Table 7-7: Sensitivity Test of Blockage Scenarios on Galey River

Maximum Water Levels (mOD) for Scenario 1C				
Node ID	Location	Design Events		
		2%	1%	0.5%
04GAL02614	US model extent	83.93	84.00	84.04
04GAL01217d	Start of 2D domain	75.62	75.68	75.73
04GAL00341d	Athea East junction	70.24	70.43	70.60
04GAL00227		70.15	70.35	70.53
04GAL00200		70.12	70.33	70.50
04GAL00180u ¹	Athea Bridge US	70.04	70.24	70.42
04GAL00180d ²	Athea Bridge DS	69.23	69.31	69.40
04GAL00163		69.27	69.36	69.44
04GAL00124	Cois na Gaile	68.99	69.13	69.23
04GAL00060	Markievicz Park	68.39	68.44	68.48
04GAL00011		68.25	68.28	68.31

¹ - Upstream Athea Bridge cross section, ² - Downstream Athea Bridge cross section

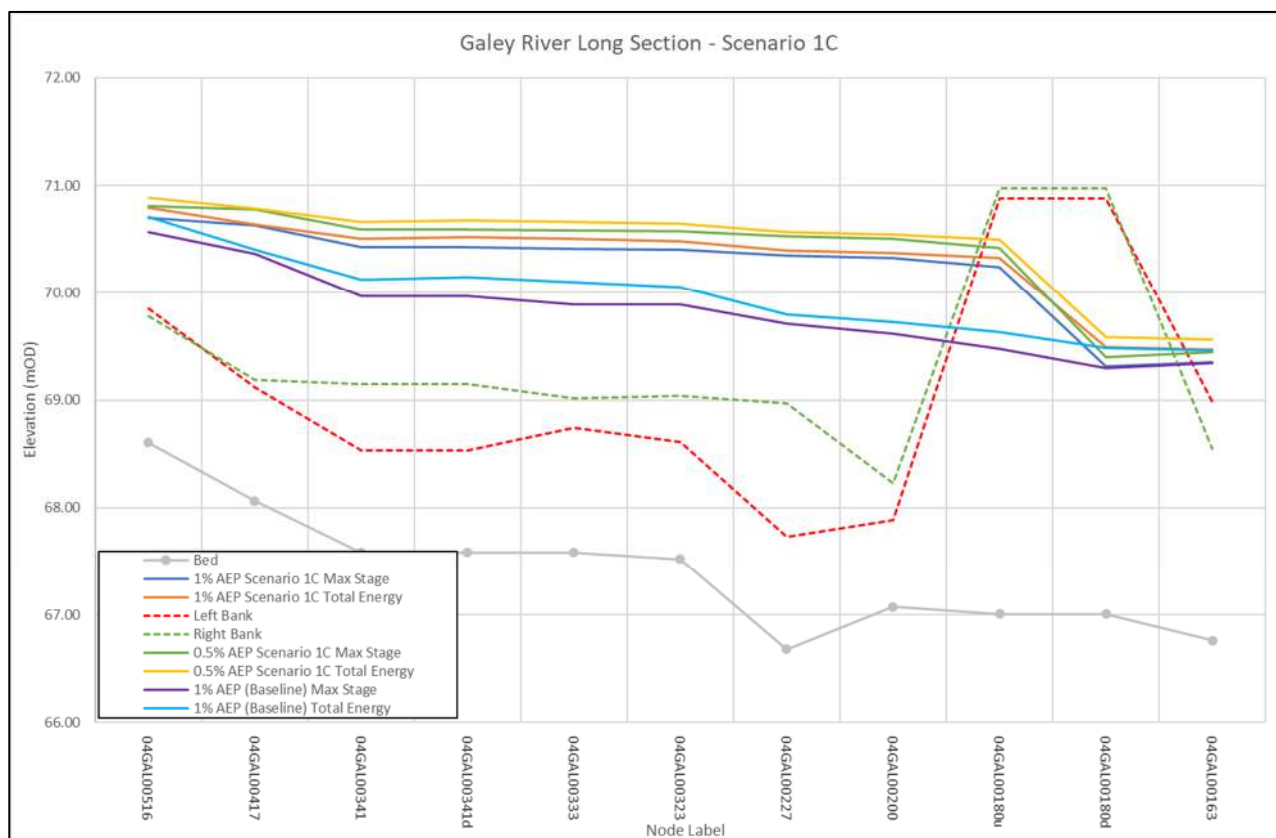


Figure 7-8: Comparison of Max Stage and Total Energy through Athea Bridge

The modelling results for 2%, 1% and 0.5% AEP design event has shown that the maximum water level variation is in the range of 150mm to 200mm. This clearly indicates that the blockage of Athea Bridge has a low sensitivity to the design flow. The flood extent and water levels upstream of Athea Bridge depend more on the percentage of the blockage than the design flows.

7.7 Modelling Results – Athea West Stream Culvert Inlets

7.7.1 Blockage of Athea West Stream Culvert Inlets

The modelled results for Athea West Culvert inlets (western branch and eastern branch), which have been blocked by 90% to assess the flood risk due blockage, are shown both in tabular format and using flood extent mapping. Mapping for these scenarios are presented in Appendix F – Additional Blockage Scenario Mapping. The mapping shows that there is a significant local impact due to the blockage of both culvert inlets. Table 7-8 and Table 7-9 show the maximum water levels at modelled nodes upstream and downstream of the Athea West stream culvert inlets, on the western and eastern branches of the stream, for the blockage scenarios and for the baseline scenario.

Table 7-8: Maximum Water Levels for Blockage of Culvert Inlet on Athea Western Stream – Western Branch

Node ID		Maximum Water Levels (mOD) for 1% AEP Design Event	
		Blockage Scenarios	
		Baseline	14
01GGR00321	Upstream extent of stream	88.42	88.42
01GGR00158	Rathronan housing estate	80.70	80.70
01GGR00117	Rathronan housing estate	78.81	78.81
01GGR00097		78.23	78.24
01GGR00067		77.14	77.26
01GGR00054		76.76	77.21
01GGR00049	Upstream of Athea West	76.70	77.21

	culvert inlet (Western branch)		
01GGR00060d	Downstream of Athea West culvert	68.36	68.34
01GGR00042		68.24	68.24
01GGR00010		68.26	68.26
01GGR00000u	Junction with Galey River	68.22	68.22

Table 7-9: Maximum Water Levels for Blockage of Culvert Inlet on Athea Western Stream – Eastern Branch

Maximum Water Levels (mOD) for 1% AEP Design Event			
Node ID		Blockage Scenarios	
		Baseline	15
01GGR00593	Upstream extent of stream	89.57	90.42
01GGR00534		86.51	87.29
01GGR00474		83.40	84.14
01GGR00417	Upstream of Athea West culvert	80.64	81.35
01GGR00060d	Downstream of Athea West culvert	68.36	68.32
01GGR00042		68.24	68.24
01GGR00010		68.26	68.25
01GGR00000u	Junction with Galey River	68.22	68.22

The modelling results for blockage scenarios 14 and 15 for 1% AEP shows that the maximum water level variation on the Western Branch is 850mm and 450mm for the eastern branch. This increase in water levels due to the blockage scenario is very localised to the upstream inlets. There is no impact on water levels at the outlet of the culvert.

For the baseline scenario, there are no properties flooding due to the 1% AEP flood event on the Athea West stream, while for scenario 14 and 15, there are 10 no. properties flooding due to the 1% AEP event on the Athea West stream.

7.8 Conclusions from Additional Blockage Scenarios

From the simulation of the blockage scenarios described above it has been concluded that the following key conclusions can be drawn out of the modelling results:

1. Historically, Athea Bridge is vulnerable to blockage due to vegetation/ tree debris and deposition of the cobbles/pebbles at the entry of the Athea Bridge arches, as observed during the 2008 flood event and from ongoing build-up of gravel/ vegetation over time.
2. The modelled results for the Athea Bridge blockage scenarios show significant change in water levels and that the bridge is highly sensitive to arch blockage. The overall blockage of all three arches of Athea Bridge by 10%, 25% and 30% resulted in the water level increasing by 380mm, 650mm and 760mm respectively at upstream cross section of the bridge for the 1% AEP design event.
3. The simulation of the 1% AEP design flood flow and the extreme blockage scenario, whereby arches A and C are fully blocked and arch B is 75% blocked calculated, resulted in a 1.8m increase in upstream flood levels compared to the no blockage (2020 survey) scenario. Such an increase is shown to significantly increase flood risk at Athea.
4. The simulation of the 1% AEP design flood flow and the 1C blockage scenario (comprising 30% blockage of all three arches) resulted in an equivalent upstream flood level to the maximum levels observed during the August 2008 flood event (approximately 70.24mOD).
5. The simulation of the 1% AEP design flood flow and the blockage of the river cross section downstream of Athea Bridge was shown to have had much less of an impact on flood levels then the bridge blockage scenarios, with

resultant water level increases of 5mm, 120mm and 200mm for blockages of 10%, 20% and 30% at the river cross section respectively.

6. The simulation of the 1% AEP design flood flow and in-combination blockage scenario (all bridge arches 30% blockage and downstream river cross section 30% blockage (scenario 13 [1C+7])) resulted in only a 150mm to 200mm water level rise upstream of the bridge in comparison with Scenario 1C, which confirms the majority of the increase in flood levels, in the in-combination scenario, is associated with bridge blockage.
7. The modelled results for 2%, 1% and 0.5% AEP design events for scenario 1C have shown little variation in water level (in the range of 200mm), concluding that the hydraulic model is more sensitive to the blockage of Athea Bridge than the design peak flows in the Galey River.
8. For Athea West stream, 90% blockage of both culvert inlets, which was determined to be a feasible scenario based on observed conditions during site inspections, demonstrated the potential for significant overland flood flow paths to establish downhill into Athea (i.e. similar to the impact of the flow paths observed during the September 2009 flood event).

7.9 Recommendations

7.9.1 Galey River

Based on the catchment and channel characteristics and the historical records of flood debris and gravel-sediment deposits at Athea Bridge and the Galey River channel reach through Athea following flood events (i.e. August 2008 flood event), and the outputs from the additional blockage scenario simulations and sensitivity analysis for design flood event flows, it is recommended that Scenario 1C (30% of the Athea Bridge arches) is adopted as the baseline condition for assessment of the current flood risk at Athea, on comparison with previous flood events. This best represents the changeable conditions that have been observed in the Galey River at Athea Bridge during an extreme flood event, that has caused extensive damage to properties and infrastructure in Athea in the recent past.

To mitigate against blockage in the future on the Galey River, gravel should be removed from the Galey River in the vicinity of Athea Bridge at set time intervals. In order to avoid debris build up in the Galey River, it is recommended that a debris catcher is installed upstream of Athea.

7.9.2 Athea West Stream

For the Athea West stream, it is recommended that 67% blockage of the culvert inlets is adopted as the baseline condition for assessment of the current flood risk at Athea. Following consultation with LCCC and OPW, it was determined that this best represents current conditions at the inlets of the Athea West stream culvert and shows the potential flood risk in the area. To mitigate against blockage in the future at the Athea West culvert inlets, channel maintenance should be undertaken at set time intervals and debris should be removed from the inlet screens.

8 Model Results

Following completion of the additional blockage scenario runs for the Athea FRS main model, it was determined that a 30% blockage at Athea Bridge, a 67% blockage at the Athea West stream culvert inlets and a 67% blockage of the Athea East stream farm access culvert would be included in the baseline current scenario design events for the Athea FRS main model.

8.1 Model Run Scenarios and Design Events

The following sections show the design flows for each of the HEPs within the Athea FRS hydraulic models (main model and Athea East stream model), which include the current scenario and climate change scenarios – Mid-Range Future Scenario (MRFS) and Higher End Future Scenario (HEFS). The flows associated with the climate change scenarios are discussed in more detail in the Athea FRS Hydrology Report (Ryan Hanley, 2021).

8.1.1 Current Scenario

Table 8-1: Ryan Hanley Current Scenario Design Inflows

HEP	Predicted Peak Flows (m ³ /s): Current Scenario							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
23_Galey13	32.00	40.80	46.80	52.50	60.00	65.60	71.20	84.20
23_Galey12	32.90	42.00	48.10	54.10	61.80	67.60	73.30	86.70
23_Galey11	33.90	43.30	49.60	55.70	63.60	69.60	75.50	89.30
23_Galey10	34.70	44.20	50.70	56.90	65.00	71.10	77.20	91.30
23_Galey09	34.70	44.20	50.70	57.00	65.10	71.20	77.20	91.30
23_Galey08	35.10	44.70	51.30	57.60	65.80	72.00	78.10	92.40
23_Galey07	36.60	46.60	53.50	60.10	68.60	75.00	81.40	96.30
23_AtheaWest01	0.81	1.03	1.18	1.33	1.52	1.66	1.80	2.13
23_AtheaWest02	0.27	0.34	0.39	0.44	0.50	0.55	0.60	0.70
23_AtheaWest03	0.34	0.43	0.50	0.56	0.64	0.70	0.76	0.90
23_AtheaEast01	1.64	2.09	2.40	2.69	3.08	3.36	3.65	4.32
23_AtheaEast02	1.30	1.66	1.90	2.14	2.44	2.67	2.90	3.43

8.1.2 Future Scenarios

Table 8-2: Ryan Hanley MRFS Design Flows

HEP	Predicted Peak Flows (m ³ /s): MRFS							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
23_Galey13	38.40	48.96	56.16	63.00	72.00	78.72	85.44	101.04
23_Galey12	39.48	50.40	57.72	64.92	74.16	81.12	87.96	104.04
23_Galey11	40.68	51.96	59.52	66.84	76.32	83.52	90.60	107.16
23_Galey10	41.64	53.04	60.84	68.28	78.00	85.32	92.64	109.56
23_Galey09	41.64	53.04	60.84	68.40	78.12	85.44	92.64	109.56
23_Galey08	42.12	53.64	61.56	69.12	78.96	86.40	93.72	110.88
23_Galey07	43.92	55.92	64.20	72.12	82.32	90.00	97.68	115.56
23_AtheaWest01	0.97	1.24	1.42	1.60	1.82	1.99	2.16	2.56
23_AtheaWest02	0.32	0.41	0.47	0.53	0.60	0.66	0.72	0.84
23_AtheaWest03	0.41	0.52	0.60	0.67	0.77	0.84	0.91	1.08
23_AtheaEast01	1.97	2.51	2.88	3.23	3.70	4.03	4.38	5.18
23_AtheaEast02	1.56	1.99	2.28	2.57	2.93	3.20	3.48	4.12

Table 8-3: Ryan Hanley HEFS Design Flows

HEP	Predicted Peak Flows (m³/s): HEFS							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
23_Galey13	41.60	53.04	60.84	68.25	78.00	85.28	92.56	109.46
23_Galey12	42.77	54.60	62.53	70.33	80.34	87.88	95.29	112.71
23_Galey11	44.07	56.29	64.48	72.41	82.68	90.48	98.15	116.09
23_Galey10	45.11	57.46	65.91	73.97	84.50	92.43	100.36	118.69
23_Galey09	45.11	57.46	65.91	74.10	84.63	92.56	100.36	118.69
23_Galey08	45.63	58.11	66.69	74.88	85.54	93.60	101.53	120.12
23_Galey07	47.58	60.58	69.55	78.13	89.18	97.50	105.82	125.19
23_AtheaWest01	1.05	1.34	1.53	1.73	1.98	2.16	2.34	2.77
23_AtheaWest02	0.35	0.44	0.51	0.57	0.65	0.72	0.78	0.91
23_AtheaWest03	0.44	0.56	0.65	0.73	0.83	0.91	0.99	1.17
23_AtheaEast01	2.13	2.72	3.12	3.50	4.00	4.37	4.75	5.62
23_AtheaEast02	1.69	2.16	2.47	2.78	3.17	3.47	3.77	4.46

8.2 Flood Risk Mapping

Appendix A presents the flood risk mapping associated with the Athea FRS hydraulic model design runs (main model and Athea East stream model). The mapping includes flood extent, flood zone, flood depth and flood velocity.

8.3 Tabulated Water Levels from Design Runs

Appendix B presents the resulting water levels and flows from the design events for each cross section in the Athea FRS hydraulic models (main model and Athea East stream model). These include the results from the current scenario, MRFS and HEFS model runs.

8.4 Long Section Plots

Appendix C provides long section and cross section plots of the peak water levels for the Athea FRS main model and Athea East stream model design events.

8.5 Key Flood Risk Mechanisms

Further to the information presented in the flood risk maps, a brief description of key flood risk sites and flooding mechanisms is provided below. A breakdown of the properties that are within the 10%, 1% and 0.1% AEP design event flood extents are presented in Table 8-4.

8.5.1 Flooding from the Galey River

A blockage sensitivity test was completed for the Athea Bridge on the Galey River (See Section 7.5.1). This blockage scenario was adopted as the existing baseline scenario.

There is property flooding from the Galey River both upstream and downstream of the Athea Bridge from the 10%, 1% and 0.1% AEP design events. On the right bank upstream of Athea Bridge, 1 no. property is within the 10% AEP flood extent; 5 no. properties are within the 1% AEP flood extent; and 7 no. properties are within the 0.1% AEP, including the school. 2 properties, as well as some residential gardens and part of the school site are within the flood extent. Flooding occurs due to overtopping of the right bank.

Downstream of Athea Bridge, the residential property on the right bank (ground floor and basement), as well as the Irish Water pumping station site are within the 10% AEP flood extent; while the community centre and R523 regional road are within the 1% and 0.1% AEP flood extents. On the left bank downstream of Athea Bridge, there is 1 residential property and some gardens/ sheds on Main Street within the 10% AEP flood extent. For the 1% AEP, there are 2 no. properties on Main Street; 4 no. properties in Cois na Gaile; and 4 no. properties in Markievicz Park within the flood extent. For the 0.1% AEP, there is a further 7 no. properties on Main Street and 2 no. properties in Markievicz Park within the flood extent. The maximum flood water levels directly downstream of Athea Bridge for the 1% AEP event is 69.36mOD, while

the threshold levels of properties range from 68.96 to 69.08mOD. This flood risk is due to the Galey River overtopping its banks.

8.5.2 Flooding from the Athea West Stream

A blockage sensitivity test was completed for the culvert inlets on the Athea West stream (See Section 7.5.2). This blockage scenario was adopted as the existing baseline scenario.

For the Athea West stream, there are 9 no. properties within the 10% and 1% AEP flood extents; a further 1 no. property within the 0.1% AEP flood extent. Flooding occurs from the Athea West stream due to blockage of 2 no. culvert inlets, which result in an overland flow route to Main Street due to the steep topography of the land.

8.5.3 Flooding from the Athea East Stream

A blockage sensitivity test was completed for the farm access culvert on the Athea East stream (See Section 6.1.7.2). This blockage scenario was adopted as the existing baseline scenario.

For the no-blockage scenario, there are no properties flooding from the Athea East stream due to the 1% AEP design event. The farm access culvert overtops and some flood water flows around the culvert, on the left bank, and re-enters the watercourse. There is a short overland flow route through the farmyard to the north and into farmland. The depths of flooding are very shallow. For the 0.1% AEP design event, there is property and road flooding, which is very shallow in nature – on average less than 0.075m. The farm access culvert overtops and some flood water flows around the culvert, on the left bank, and re-enters the watercourse. The remainder of the flood water flows to the north through the farmyard, down Hillside Drive, on to the R524 Regional Road and crosses Con Colbert Street into Markievicz Park. Circa. 15 no. properties are flooded along this route due the Athea East stream only. The flood duration is very short (circa 1.5 hours) and the flow volumes are very low.

For the blockage scenario (existing baseline scenario), there are 17 no. properties flooding from the Athea East stream due to the 10% AEP design event. 18 properties are within the 1% AEP design event flood extent and 27 no. properties are within the 0.1% AEP design event flood extent. The overland flow path that occurs for the 0.1% AEP non-blockage design event occurs for the blockage 10%, 1% and 0.1% AEP design events. [Note that there is an overlap of the number of properties flooding and areas flooding from the Athea East stream and Athea FRS Main models and the combined number of properties and areas at flood risk have been included in Table 8-4.]

Table 8-4: Properties at Flood Risk in Athea

Risk Type	Receptor	10% AEP	1% AEP	0.1% AEP
Social	Residential property	24	38	50
	School	0	0	1
	Health centre/pharmacy	0	0	1
	Nursing home	0	0	0
	Public residential care home	0	0	0
	Community hall	0	1	1
	Hospital	0	0	0
	Gardai station	1	1	1
	Fire station	0	0	0
	Civil defence HQ	0	0	0
	National/Regional roads (km)	0.076	0.175	0.278
	IW pumping station	1	1	1
	Butcher	1	1	1
	Petrol station	1	1	1
	Grocery shop	1	1	1
	Bar/restaurants	2	2	5
	Retail	0	0	1
	Social amenity sites	0	0	0

9 Model Limitations

9.1 Channel Blockage and Maintenance

9.1.1 Athea FRS Main Model

Blockage of culverts and bridges has the potential to increase flood risk on any watercourse. In Athea, the multiple openings in the Athea West culvert have a history of blockage and flood risk and thus, look likely to block due to the small size of each of the openings. If the western branch of the Athea West culvert becomes blocked, then the left bank of the stream can overtop and flood waters could flow to the south and downhill towards Main Street in Athea, where flooding of multiple residential and commercial properties is probable – see Section 6.2 of this report. There is an earthen embankment on the left bank of the stream, but there is topographical data on this, however there is limited information on the effectiveness of the embankment. In addition, roughness values have been applied to the 2D domain using NTF data. This is the best available information for floodplain roughness. However, this may not take into account local areas of increased roughness, associated with dense vegetation.

The Galey River channel in the vicinity of Athea Bridge is prone to gravel deposition. This used to be maintained, but has not been for some time. In 2021, there was a large gravel shoal extending upstream and downstream of Athea Bridge, which was vegetated. This reduced the capacity of the bridge and thus, increases flood risk. LCCC, in conjunction with the OPW cleared the gravel and vegetation from the Galey River in September 2022, thus improving the capacity of the Athea Bridge.

For the above-mentioned reasons, blockage was adopted into the baseline current scenario for the Athea Bridge (30% blockage) and Athea West stream culvert inlets (67% blockage), based on historic issues and risk associated with the catchment areas for each structure.

The model does not take into account the condition of the river channels and channel maintenance, other than through Manning's n values.

9.1.2 Athea East Stream Model

Roughness values have been applied to the 2D domain using Prime2 and NTF data. This is the best available information for floodplain roughness. However, this may not take into account local areas of increased roughness, associated with dense vegetation, that is not being regularly maintained.

For consistency, a 67% blockage has been applied to the farm access culvert on the Athea East stream for the baseline current scenario.

9.2 Building and Floodplain Features

9.2.1 Athea FRS Main Model

The Athea FRS main model is sensitive to the representation of buildings and other structures within the floodplain – i.e. informal ineffective defences such as walls and embankments. General assumptions have been made on which building and structures obstruct and convey the flow of flood water. There is no representation of the surface water drainage network, which may in some cases allow water to return to the river. Consideration for the surface water drainage scheme will be included in the detailed design of Athea FRS.

There is an embankment on the left bank of Athea East stream, upstream of the 900mm diameter farm access culvert, which prevents the stream from flowing towards the Athea West stream (eastern branch), should the Athea East stream break its banks. If this embankment was to overtop, it was determined that additional flow volumes could potentially flow into the Athea West stream or else towards the Abbeyfeale Road. Through the sensitivity tests of this study, additional flows have been applied to the Athea West stream (see Section 6.1.4 and 6.2.4), which would take this risk into account sufficiently, should the embankment on the Athea East stream overtop. However, it was confirmed by further hydraulic modelling that any additional flow volumes would flow towards the Abbeyfeale Road. Some of the additional flow would be captured by the proposed pluvial flood risk management on the Abbeyfeale Road and furthermore, flood relief solutions in the vicinity of the farm access culvert will be investigated – more detail on this to be included in the Options Development Report. It should be noted that there are no records of flood risk on the Athea East stream and future maintenance of the 900mm diameter concrete culvert should be considered.

Deposition has occurred on the Galey River at Athea Bridge in the past and increases flood risk in Athea. Therefore, it is difficult to accurately model the river channel bed in the vicinity of Athea Bridge, due to the changeable bed conditions.

A topographical survey of the gravel build up was undertaken in September 2020. To improve the channel conveyance at Athea Bridge, a planning application was lodged to An Bord Pleanála to remove gravel build up in the channel. Gravel removal works were completed in September 2022, with approximately 240m³ of material being removed from the channel, which should improve channel conveyance at Athea Bridge. A further topographical survey of the river channel at Athea Bridge was completed in October 2022, on completion of the gravel removal works.

9.2.2 Athea East Stream Model

The Athea East stream model is very sensitive to the representation of buildings and other structures within the floodplain – i.e. informal ineffective defences such as boundary walls, embankments and kerbs. Non-standard modelling approaches have been applied to the model to better represent building and other structures in the floodplain. Boundary walls, stream banks, road banks and land boundary embankments have been included in the 2D model domain.

Buildings are usually represented in the 2d domain by applying a high value for Mannings n – usually 0.300 – to stop or slow the flow through the building. Due to the steepness of the Scheme Area and the very shallow depths of flow, this method was not effective at obstructing the flow. Buildings from the Prime2 dataset were stamped on to the Lidar and their elevations were increased so that the flow paths would be “blocked”. This is a non-standard approach to modelling but is the best way to represent buildings in the Scheme Area for this model.

Kerbs and drop kerbs have not been represented in the model, but these could easily influence any of the flow paths within the 2d domain. With a 2m cell size, it is not practical to include such intricacies in the model – as due to the 2m cell size, the level of detail that the modeller inputs into the model would not be fully represented in the model.

There is no representation of the surface water drainage network, which may in some cases allow water to return to the river. Consideration for the surface water drainage scheme will be included in the detailed design of Athea FRS.

10 Conclusions

2 no. 1D-2D hydraulic models were developed for Athea FRS, including the Athea FRS main model which comprises the Galey River and the Athea West stream and the Athea East stream model. The model builds were focused on the Athea FRS Scheme Area, where the 1D models extends upstream and downstream of Athea to represent the watercourse channels and the 2D domain simulates the floodplain areas in Athea in order to capture all flood mechanisms in the Scheme Area. The models have simulated a range of fluvial design flood events for the current and climate change scenarios. The findings of the hydrological assessments carried out for the Athea FRS were used to set the fluvial inflows into the model and produce design scenario results.

Partial calibration of the 1D-2D Athe FRS main hydraulic model was carried out against the most severe flood event on record, which occurred in July/ August 2008 for the Galey River only. The closest hydrometric gauge was Inch Bridge gauge, located 26.6km downstream of Athea. The inflow for the flood event was determined based upon the relationship between the Galey River from Athea and Inch Bridge gauge. Observed water levels located throughout Athea on the Galey River were compared against model results. Bed levels in the vicinity of Athea Bridge constantly change due to deposition and the model representation for the 2008 flood event is the best estimate, from information gathered. In general, a good quality match was achieved in most locations, taking into account low confidence for some observed levels and the varying bed conditions. Calibration was not completed for the Athea East and Athea West streams, due to lack of gauged data and observed flood levels. Note that there is no record of historic flood risk

The 2 no. model's sensitivity was investigated using a suite of parameters to assess the implications of the assumptions made in the development of the hydraulic model and production of design flood mapping. The findings of these tests indicated that the model sensitivity to the tested model parameters was not outside typical sensitivity bounds and that the model was representative of on-site conditions for 2020 for the Athea FRS main model (with additional infill surveys completed after this) and 2023 for the Athea East stream, when the topographical surveys were completed. Non-standard modelling approaches were applied for the Athea East stream model, as detailed in Section 9 of this report. The models were deemed suitable to simulate design model runs as part of the study, using bed conditions for 2020 only. It was determined that due to the changeable bed conditions and flood risk in the vicinity of Athea Bridge on the Galey River and at the culvert inlets on the Athea West stream, that further sensitivity analysis would be required.

Additional sensitivity analysis was undertaken, in the form of blockage analysis on the Galey River at Athea Bridge due to the constant movement and build-up of gravels in the vicinity of Athea Bridge, as well as the observed gravel build up during the August 2008 flood event. There was also a risk of blockage at the Athea West stream culvert inlets due to the increase in vegetation and debris (e.g. timber, rubbish etc.) in recent years. A number of blockage model scenarios were undertaken on the Galey River and Athea West stream, to determine how best to represent the blockage risk associated with these watercourses. Tabulated model results and flood mapping were produced for this assessment. From the additional blockage analysis, it was recommended that the baseline conditions for the riverbed at Athea Bridge (scenario 1C) and at the Athea West stream culvert inlets (scenario 14 and 15) be updated for the design scenarios, due to the changeable conditions and its associated risk. This would allow for the best representation of possible channel conditions during a flood event. Frequent maintenance was recommended for the Galey River and Athea West stream, following the review of additional blockage analysis.

On completion of the sensitivity assessment, including additional blockage analysis, it was determined that the model was deemed suitable to simulate design model runs as part of the study and suitable to be utilised to assess the various flood risk management options as part of optioneering and determination of the final scheme design in Athea. It was agreed to apply a 30% blockage on Athea Bridge and 67% blockage on the Athea West stream culvert inlets and Athea East stream farm access culvert as part of the currently scenario baseline design runs. As part of the options assessment, further testing of parameters may be required with various options in place to inform design of defences and to determine freeboard allowances.

Design event model results were produced in the form of flood maps, tabulated model results and long section profiles, which highlight the primary areas of flood risk in the village and the relative flood levels in key areas throughout the Scheme Area.

Appendix A – Hydraulic Model Results: Flood Risk Maps

The flood risk maps provided include flood extent, flood zone, flood depth and flood velocity.

Athea FRS Combined Model Results

- A1 – Flood Mapping: Extent
- A2 – Flood Mapping: Depth 10% AEP
- A3 – Flood Mapping: Depth 1% AEP
- A4 – Flood Mapping: Depth 0.1% AEP
- A5 – Flood Mapping: Velocity 10% AEP
- A6 – Flood Mapping: Velocity 1% AEP
- A7 – Flood Mapping: Velocity 0.1% AEP
- A8 – Flood Mapping: Zones

Appendix B – Hydraulic Model Results: Tabulated Results from Design Runs

Tabulated maximum water levels, flows and velocities from the current scenario, MRFS and HEFS model runs are provided.

Athea FRS Main Model

- B1 – Current Scenario Max Flow
- B2 – Current Scenario Max Stage
- B3 – Current Scenario Max Velocity
- B4 – MRFS Scenario Max Flow
- B5 – MRFS Scenario Max Stage
- B6 – MRFS Scenario Max Velocity
- B7 – HEFS Scenario Max Flow
- B8 – HEFS Scenario Max Stage
- B9 – HEFS Scenario Max Velocity

Athea East Stream Model

- B10 – Current Scenario Max Flow
- B11 – Current Scenario Max Stage
- B12 – Current Scenario Max Velocity
- B13 – MRFS Scenario Max Flow
- B14 – MRFS Scenario Max Stage
- B15 – MRFS Scenario Max Velocity
- B16 – HEFS Scenario Max Flow
- B17 – HEFS Scenario Max Stage
- B18 – HEFS Scenario Max Velocity

Appendix C – Hydraulic Model Results: Long Section Plots

Long section plots from the 10%, 1% and 0.1% AEP events are provided for locations on the Galey River, Athea West stream and Athea East stream.

Appendix D – GIS Data

- Flood extent
- Flood depth
- Modelled river centreline
- Model nodes
- Hydrological flows at the HEPs.

Appendix E – Model Check Files

The Model Check Files includes specific build details relating to the Athea FRS main hydraulic model and the Athea East stream hydraulic model.

Appendix F – Additional Blockage Scenario Mapping (Galey & Athea West)*

Galey River Blockage Scenarios

- Flood Extent Map: 1% AEP for Existing Scenario and Scenario 1C
- Flood Extent Map: 1% AEP for Existing Scenario and Scenarios 1A, 1B and 1C
- Flood Extent Map: 2%, 1% and 0.5% AEP for Scenario 1C

Athea West Stream Blockage Scenarios

- Flood Extent Map: 1% AEP for Scenario 14 (90% Blockage at Athea West culvert inlet (Western Branch))
- Flood Extent Map: 1% AEP for Scenario 15 (90% Blockage at Athea West culvert inlet (Eastern Branch))

Note: The Additional Blockage Scenario Mapping was produced solely to assess blockage analysis on the Athea Bridge and Athea West stream culverts. For Athea FRS Flood Risk Mapping for the Athea FRS Scheme Area, which includes the Galey River, Athea East stream and Athea West stream, refer to **Appendix A.*