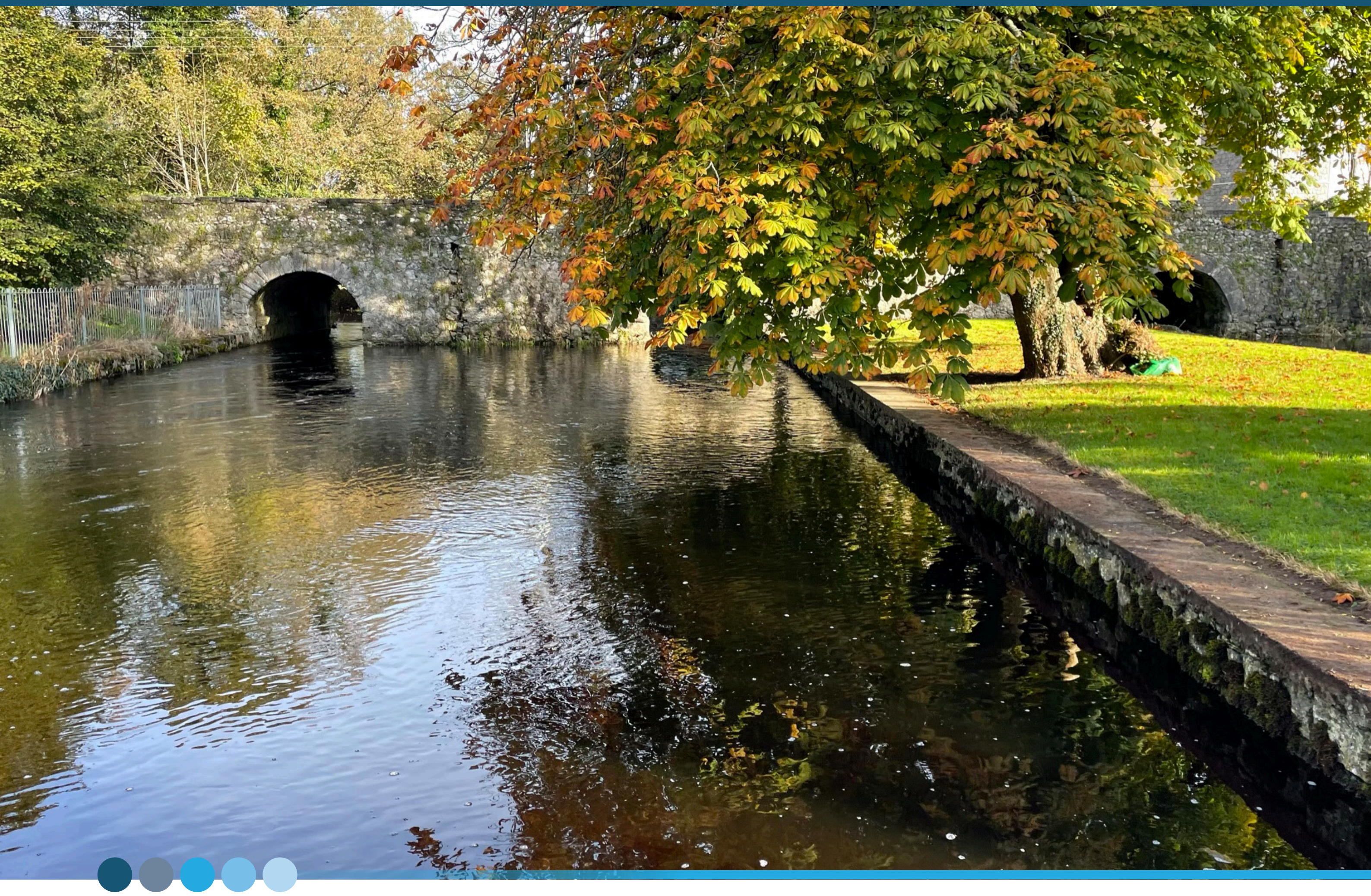
Oifig na nOibreacha Poiblí
Office of Public Works

Ballinasloe Flood Relief Scheme

Hydraulics Report

March 2022 | 271741-00



Comhairle Chontae na Gaillimhe
Galway County Council

ARUP

Office of Public Works

Ballinasloe Flood Relief Scheme

Hydraulics Report

271741-00

V1.1 | 1 March 2022

Job number 271741-00

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Document Verification

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Job title		Ballinasloe Flood Relief Scheme		**Job number** 271741-00	
Document title		Hydraulics Report		**File reference**	
Document ref		271741-00			
Revision	**Date**	**Filename**			
V0.1	25 Jun 2021	Description	First draft		
			Prepared by	Checked by	Approved by
		Name	Marco Maiozzi	Kevin Barry	Alan Leen
		Signature			
V0.2	2 Dec 2021	Filename	271741-00_Ballinasloe Hydraulics_Draft Final_MM.docx		
		Description	OPW comments on the draft report addressed		
			Prepared by	Checked by	Approved by
		Name	Marco Maiozzi	Kevin Barry	Alan Leen
		Signature			
V0.3	19 Jan 2022	Filename	271741-00_Ballinasloe Hydraulics_Draft 3_20220118		
		Description	OPW comments on the second draft report addressed		
			Prepared by	Checked by	Approved by
		Name	Marco Maiozzi	Kevin Barry	Alan Leen
		Signature			
V1.0	17 Feb 2022	Filename	271741-00_20220217_Ballinasloe FRS Hydraulics_v1.0_Final.docx		
		Description	Issue		
			Prepared by	Checked by	Approved by
		Name	Marco Maiozzi	Kevin Barry	Alan Leen
		Signature			
V1.1	01 Mar 2022	Filename	271741-00_20220301_Ballinasloe FRS Hydraulics_v1.1_Final.docx		
		Description	Issue		
			Prepared by	Checked by	Approved by
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		Signature	Marco Maiozzi	Kevin Barry	Alan Leen

Issue Document Verification with Document ✓

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Appendices

1 Introduction

1.1 Context

The Office of Public Works (OPW), in partnership with Galway County Council (GCC) and other Local Authorities, have completed a Catchment Flood Risk Assessment and Management Study (CFRAMS) for the Shannon Catchment, which includes the catchment of the River Suck. The Catchment Flood Risk Management Plan (CFRMP), which was published in 2018, concluded that a flood relief scheme for Ballinasloe would be viable and effective.

Arising from the CFRMP, Arup has been commissioned by the Office of Public Works (OPW) to develop a Flood Relief Scheme (FRS) for Ballinasloe. The overall scheme will consist of flood alleviation measures along the River Suck and its tributaries which offer the required standard of protection against fluvial flooding.

There are five stages to the project:

- Stage I: Identification and Development of a Preferred Scheme
- Stage II: Public Exhibition
- Stage III: Detailed Construction Design, Compilation of Work Packages and the Preparation of Tenders for Contracts and Confirmation Documents
- Stage IV: Construction
- Stage V: Handover of Works

This Hydraulics report is produced as part of Stage I of the project and details the hydraulic analysis undertaken for the existing baseline scenario. Hydraulic modelling undertaken as part of the optioneering phase of the project will be detailed in the Ballinasloe FRS Options report.

This report should be read in conjunction with the project Hydrology Report[1] that has also been produced as part of Stage I of the study.

1.2 Scope

The scope of the hydraulic analysis is to:

- Develop a dynamic 1D/2D hydraulic model of the River Suck and its main tributaries for the reaches within the study area;
- Derive QH ratings for the gauges at Bellagill and Derrycahill which informs on the rating curve reviews that have been undertaken at both gauges (please refer to the Hydrology report);

[1] Office of Public Works (2021), *Ballinasloe Flood Relief Scheme Hydrology Report*, consultants Arup and Hydro Environmental Ltd, December 2021

- Calibrate the hydraulic model against recorded water level timeseries from two hydrometric gauges in the centre of Ballinasloe for two minor flood events from February and November 2020;
- Calibrate the hydraulic model against various post-flood event data from the very significant November 2009 flood event;
- Simulate a range of fluvial design flood events with the hydraulic model for the current scenario. The Annual Exceedance Probability[2] (AEP) events to be considered are: 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1%.
- Climate change scenarios are also to be assessed with the model: 10%, 1% and 0.1% for both the Mid-Range Future Scenario (MRFS) and the High-End Future Scenario (HEFS);
- Produce flood maps in GIS format for the current scenario;
- Calculate flood depths at every property within the study area for a range of return period events for use in the economic damage's assessment;
- Produce a hydraulics report which details the findings of the study.

1.3 Study and Scheme Area

The study area is presented in Figure 1. The areas of the primary sub catchments are summarised in **Table 1**. The indicative scheme area is presented in Figure 2.

[2] Annual Exceedance Probability (AEP) is the probability, typically expressed as a percentage, of a flood event of a given magnitude being equalled or exceeded in any given year. For example, a 1% AEP flood event has a 1%, or 1 in a 100, chance of occurring or being exceeded in any given year.

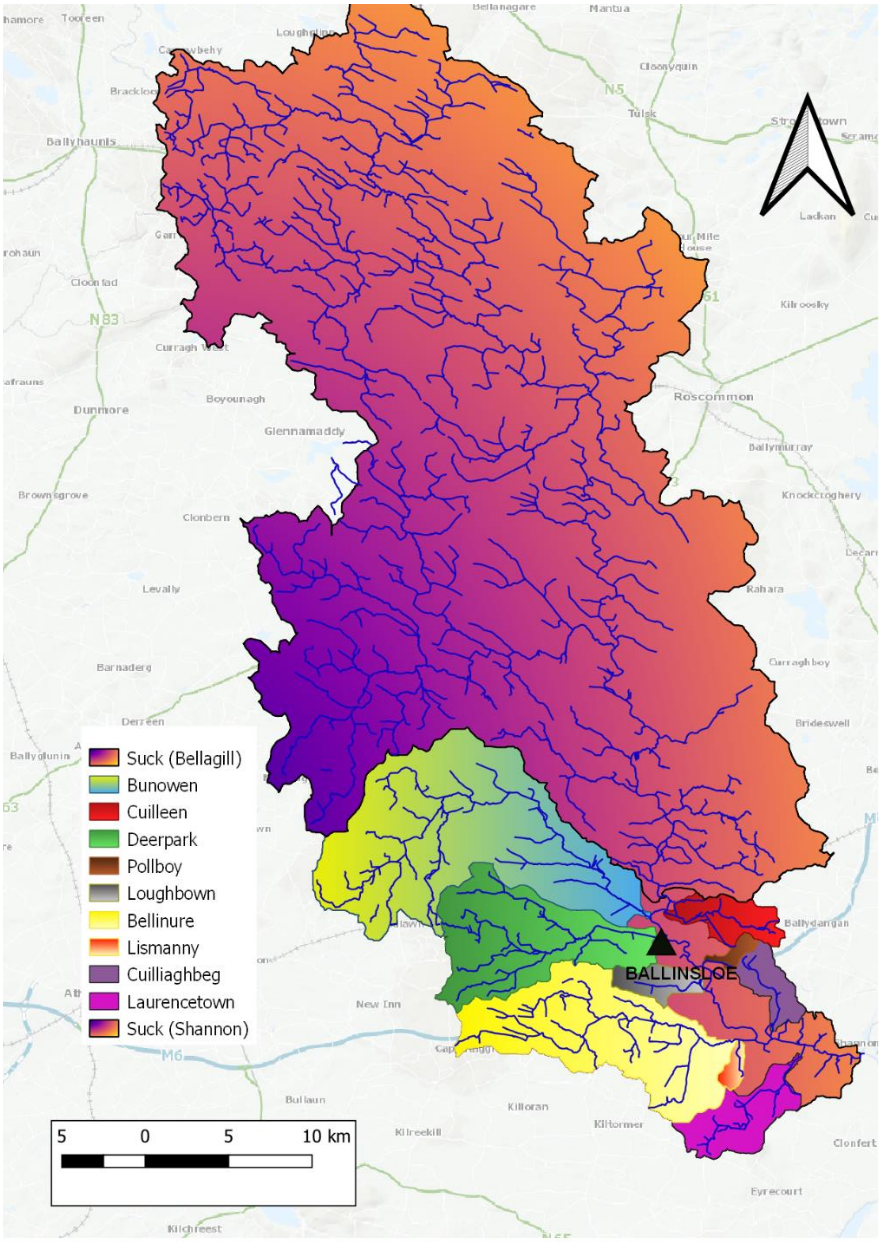

Figure 1: Study Area

Table 1: Primary Catchment areas

Catchment	Area (km^2)
River Suck (at Bellagill)	1207
Cuilleen	13.5
Bunowen	137
Deerpark	62
Loughbown	8.5
Ballynure	79

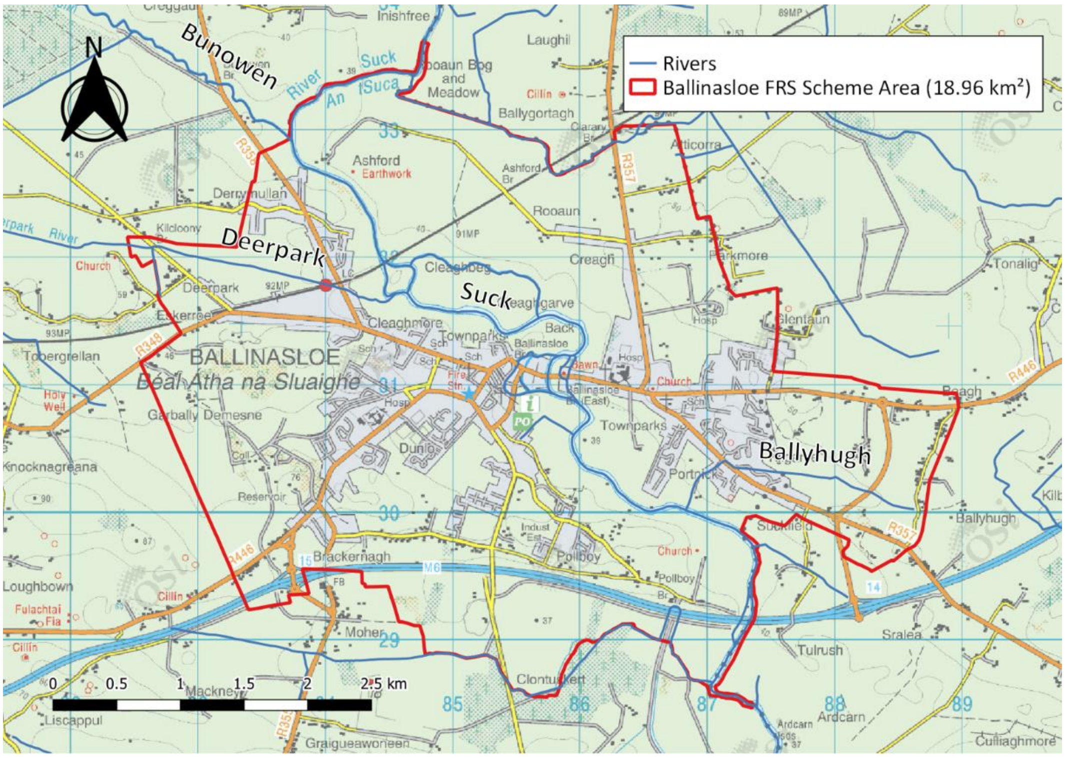

Figure 2: Indicative Scheme Area

The watercourses included as part of the existing scenario hydraulic modelling are listed in **Table 2**. The alignment of the watercourses are presented in **Figure 3**.

Table 2: Watercourses modelled for the existing scenario

Watercourse	Upstream extent (ING)		Downstream extent (ING)		EPA River ID
	Easting	Northing	Easting	Northing	
Suck	184776.57	233707.88	196323.39	224716.59	Suck
Bunowen	182845.76	233541.92	183716.17	232936.88	Ahascragh
Deerpark	182075.37	232077.44	184542.51	231712.43	Derrymullan (Stream)
Ballyhugh	188237.45	230162.81	187032.11	230326.86	Pollboy

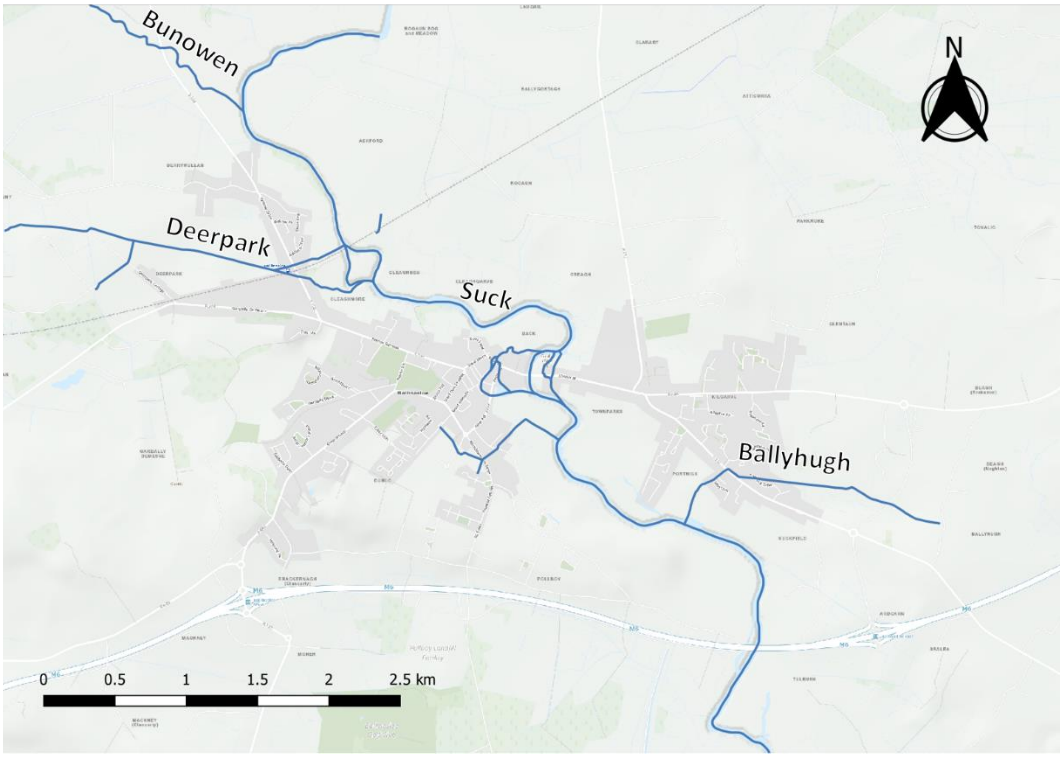

Figure 3: Alignment of the modelled watercourses

The River Suck splits into a number of separate branches upstream of the main town centre as indicated in **Figure 4**:

- The central branch of the River flows underneath a multi-arch bridge that is known as East Bridge (discussed in Section 4.4.5);
- A canal/diversion channel flows to the West and subsequently splits into a number of smaller channels that flow underneath West Bridge and a number of other local pedestrian bridges before re-joining the main River Suck circa 120m downstream of East Bridge;
- Two millstreams split from the River Suck upstream of the East Bridge and flow underneath the Eastern approach to the East Bridge, through the former Atlas Factory site before re-joining the River Suck 250m downstream of the Ballinasloe Marina. This network of watercourses is known locally as the Atlas channels.

  Each of these branches have been included within the hydraulic model developed as part of the study.

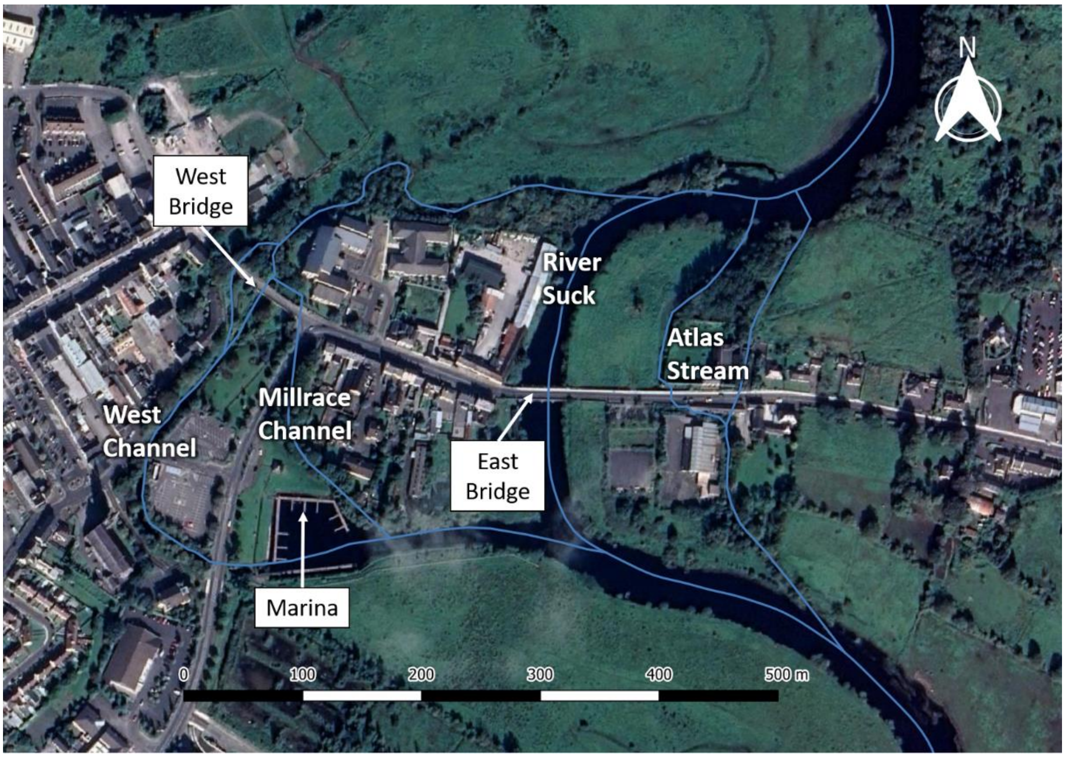

Figure 4: Detail of the channels and main structures in the town centre

1.4 Overview of the report

Section 1 presents an overview of the Ballinasloe Flood Relief Scheme Project and outlines the objectives of the hydraulic modelling element of the study.

Section 2 describes the various datasets utilised as part of the study. Section 3 outlines how the hydrological estimation has been used as part of the hydraulic modelling.

The development of the various elements of the model is described in Section 4 of the report while Section 5 presents the calibration. An overview of the existing scenario design model runs is presented in Section 6 which is to be read in conjunction with the flood maps produced as part of the report and are presented as digital deliverables.

Section 7 presents the finding of the Sensitivity Analysis runs (including climate change simulations). The overall conclusions of the hydraulic modelling are presented in Section 8.

2 Data Collection and Analysis

2.1 Overview

This chapter details the datasets that have been used in the development and running of the Ballinasloe 1D/2D hydraulic model.

2.2 Mapping

A suite of maps of varying resolutions (1:5000 and 1:50,000) have been used as part of the construction of the hydraulic models and in the presentation of model results. These maps are the most recent available and have been provided under licence from Ordnance Survey Ireland (OSi).

The OSi Prime2 dataset has also been used as part of the hydraulic modelling construction for identifying different surface types in the floodplain model and also for delineating the footprint of buildings. The Prime2 data was supplied to Arup under license by OPW.

2.3 River Survey Data

The 1D component of the 1D/2D Ballinasloe FRS hydraulic model has used channel and structure cross sectional survey data from two separate surveys:

- Shannon CFRAM survey (data taken in 2012);
- Ballinasloe FRS Infill and validation survey (data taken in 2020).

The data from both of these surveys is sufficient for the 1D component of the 1D/2D model be accurate and robust without any reliance on geometrically interpolated cross sections and/or interpolated units. Both of these survey datasets are now described.

2.3.1 Shannon CFRAM data

A detailed channel and structure survey of a number of the primary watercourses in the River Suck catchment was undertaken as part of the Shannon CFRAM study. The survey was undertaken by Murphy Surveys Ltd between November 2011 and July 2012.

Cross sections were surveyed at varying intervals along the various channels. Within the study area of this project the average spacing between the cross sections in the rural parts was circa 150m with the sections extending for approximately 20m into the floodplain on either side of the channel. In the urbanised area of Ballinasloe, the cross section spacing was reduced in order more accurately illustrate the water surface profile.

The Shannon CFRAMS Hydraulics report[3] was also reviewed in detail to understand the preceding work including any noted assumptions or shortcomings of the CFRAMS hydraulic model.

2.3.2 Ballinasloe FRS Infill and validation survey

As part of this project Arup undertook an extensive review and gap analysis of the Shannon CFRAM survey data. As part of this analysis a number of additional survey requirements were identified which were subsequently surveyed as part of the Infill Survey undertaken by McDonald Surveys between June and August 2020. Collating these additional cross sections ensures that the Ballinasloe FRS hydraulic model is sufficiently detailed and robust and meets the requirements of flood relief design project.

Spot levels along the banks of key reaches of the River Suck were also collected as part of the infill survey. This data allows for the accurate definition of the elevation at which water spills from the 1D to the 2D elements which is a critical component of the model.

The project brief specified that circa 19no minor watercourses were to be assessed at part of the project. Each of these watercourses were therefore surveyed as part of the infill survey and have been assessed by Arup as part of the project (refer to Section 4.8).

Figure 5 presents the 1D cross sectional data used for the model through the main area of the town. The plot is presented in order to illustrate how both the Shannon CFRAM data (red lines) and 2020 infill data (green lines) have been integrated together to form the 1D component of the hydraulic model. It can be seen from the plot that 1D model has a very high resolution through this critical area of the model.

[3] Office of Public Works (2016), *Shannon CFRAM Study – Hydraulics Report Unit of Management 25-26*, consultants Jacobs, June 2016

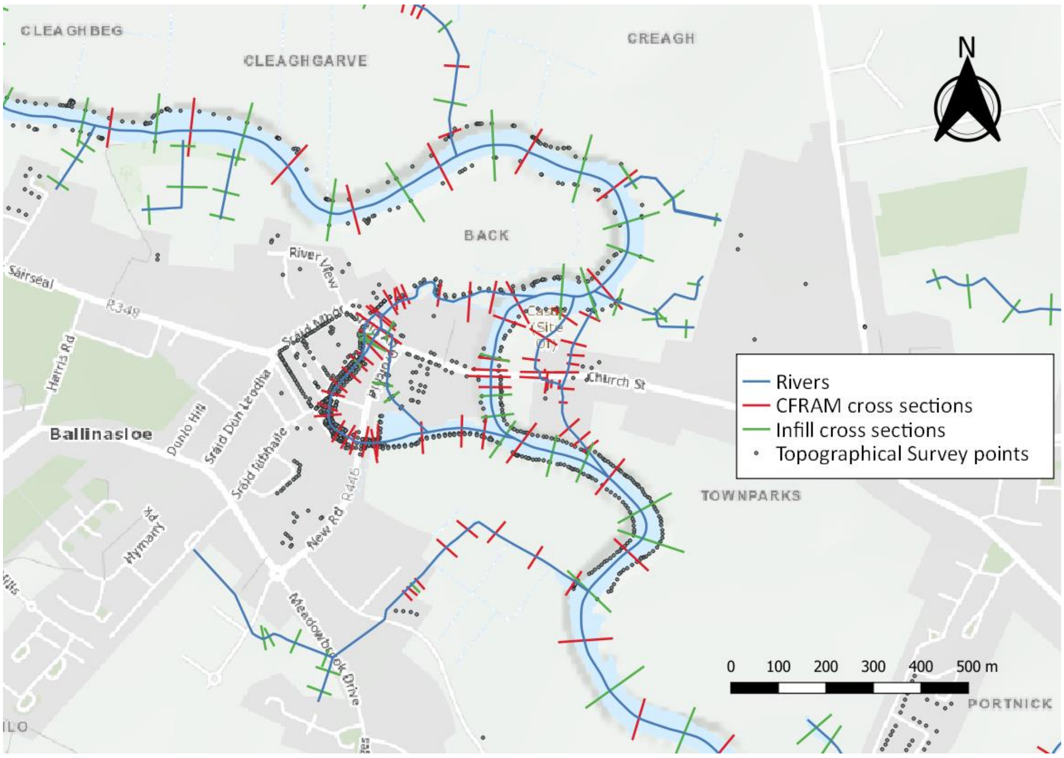

Figure 5: 1D river model cross sections – Town Centre

2.3.3 Culvert survey

A survey of a number of significant pipes and culverts was undertaken as part of the study. The survey included CCTV camera surveys, route tracing and geometric surveys. The internal dimensions, conditions, and constrictions within the culverts were obtained from the survey and have been used to inform the hydraulic analysis. The data will also be considered as part of the Optioneering. Figure 6 shows the location and alignment of each of the culverts. It is noted that all of the culverts are of circular shape.

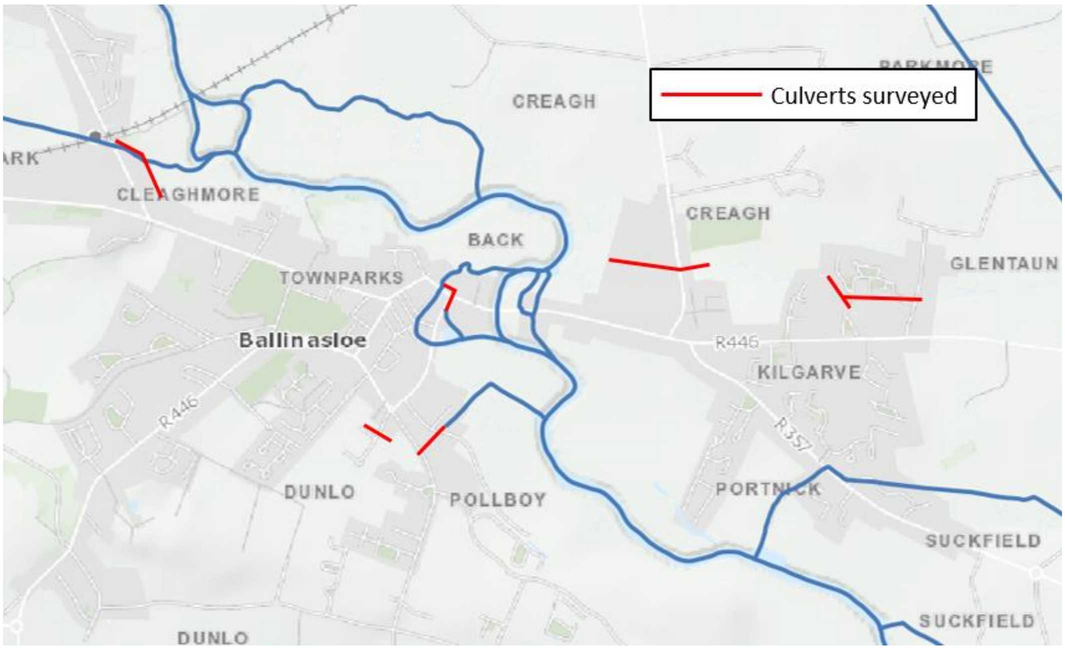

Figure 6: Location of the culverts surveyed

2.4 Digital Terrain Model

The Digital Terrain Model (DTM) is a bare earth representation of the floodplain topography in which all the buildings and vegetation have been removed. It is used in the model to define the ground elevations of the 2D model grid and represents a critical aspect of the model. The DTM used in the study is taken from the Shannon CFRAM Study. **Figure 7** presents a snapshot of the Lidar dataset of the study area superimposed over an aerial image of the town. It is noted that the DTM is up to date and reflects existing ground elevations across the study area.

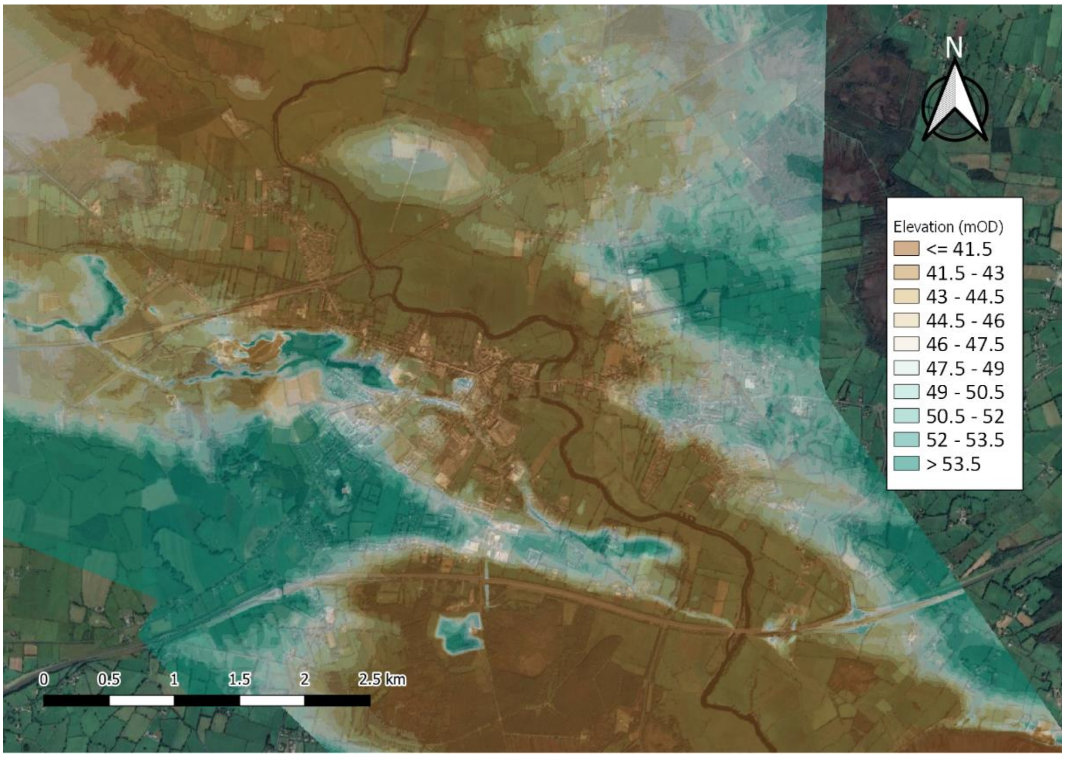

Figure 7: DTM in the Scheme area

2.5 Model Calibration Event Data and Assessment

The model has been calibrated to a number of events on the River Suck:

- Minor flow events in February 2020 and November 2020. These events are both in-bank within the town centre;
- The very significant flood event of November 2009, used to calibrate out-of-bank flow in the model.

The data used to inform the model calibrations is now described.

2.5.1 In-bank calibration data

Following the recommendations of the Shannon CFRAM study, the OPW installed two water level recording gauges in the centre of the town. The first gauge was installed on the Old Town Canal (**Figure 8**) in June 2019 and records water level at 15-minute intervals. The second gauge was installed downstream of the East Bridge on the River Suck (**Figure 9**) in July 2020 and also records water level at 15-minute intervals. Data from both gauges is available to view and download from waterlevel.ie.

Figure 8: Location of the Old Channel Gauge (26355)

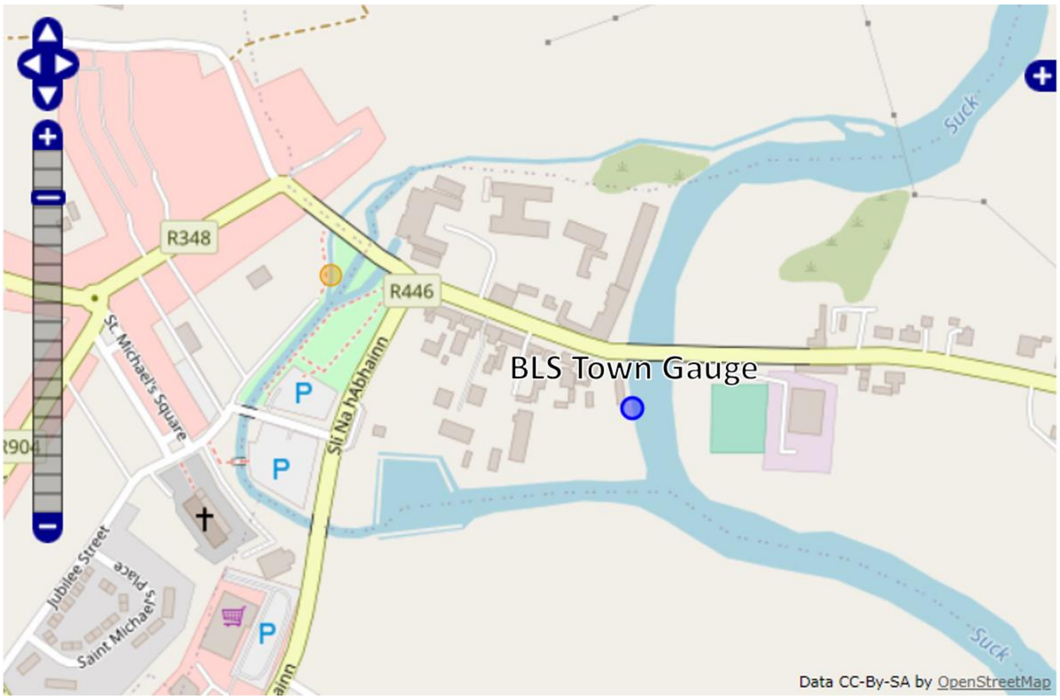

Figure 9: Location of the Town Gauge (26354)

The first in-bank model calibration event occurred in February 2020 and from our hydrological analysis have established that it approximates to a return period of circa 5 years on the River Suck. As the Town Gauge (ID 26354) was not operational at the time of the event, only data from the Old Channel Gauge (ID 26355) is available (**Figure 10**) for calibration purposes.

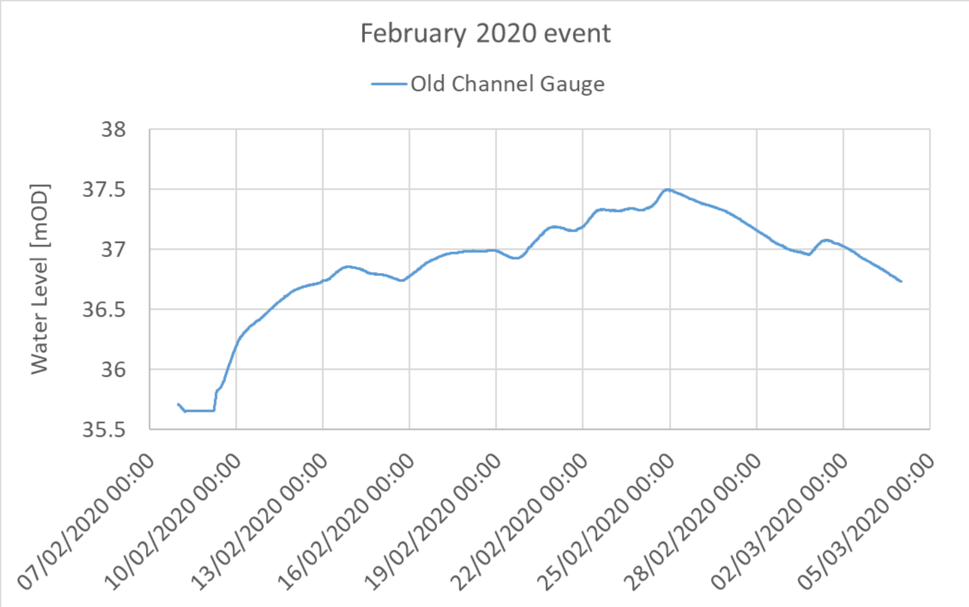

Figure 10: Recorded data for the February 2020 event

The second in-bank event (**Figure 11**) occurred in November 2020 and was recorded at both the Old Channel Gauge (ID 26355) and the Ballinasloe Town Gauge (ID 26354). The return period for this event was circa 2 years on the River Suck. It can be seen from **Figure 11** that the maximum water level at both gauges from the peak of the event is the same which suggests there is very little gradient between both of the gauges at the peak.

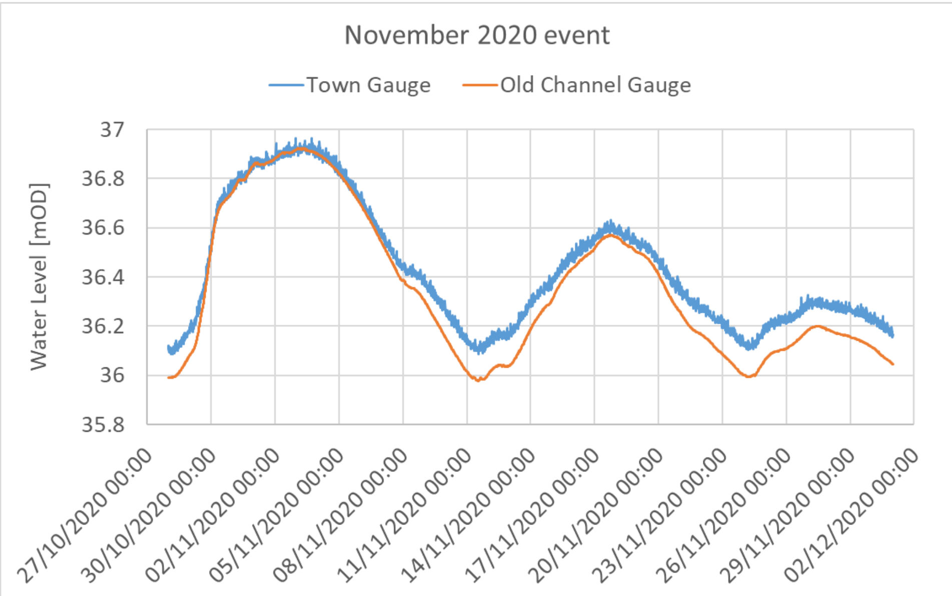

Figure 11: Gauged Water Levels for the November 2020 event

2.5.2 Additional gauges installed as part of the Ballinasloe FRS project

One of the recommendations arising from the hydrological analysis undertaken as part of this study was to install additional water level gauges on the Deerpark River and Bunowen river. Three separate gauges were installed[4]:

- Ballinasloe Rail Station (26402);
- Deerpark Bridge (26357);
- Bunowen Bridge (26358)

Data from these gauges has not been used as part of the hydraulic modelling presented in the study due to the short length of record at both of the gauges. It is noted however that data from these gauges will be used to inform any future hydraulic analysis undertaken as part of the study i.e. calibration of future flood events etc.

2.5.3 2009 Flood Event data

The November 2009 flood event is the most significant flood event in the 68-year record of the hydrological gauge at Bellagill (ID 26007).

We have estimated the recorded peak of the flood to be circa 212.5 m^3/s and from our at-site statistical analysis this represents a circa 50-year return period event. The reader is referred to the Hydrology Report for further information.

The impact of the event on Ballinasloe was severe as many houses and business throughout the greater Ballinasloe area were inundated by flood water. Approximately 94 houses were flooded at Ashfield Drive and Willow Park in Derrymullen when both the Deerpark River and River Suck got out of bank upstream of the railway culvert. **Figure 12** presents an aerial image of Derrymullen from the 2009 event. The blue line on the figure presents the approximate alignment of the Deerpark River.

[4] Data from these gauges is available to view at www.waterlevel.ie

Figure 12: Flooding of Derrymullen during the 2009 event.

Overland flow from the River Suck also inundated homes and businesses in the vicinity of Bridge Street, St. Michael’s Square and in the immediate vicinity of East Bridge (**Figure 13**). The marina car park bridge was overtopped and the Slí na hAbhainn area was also extensively flooded.

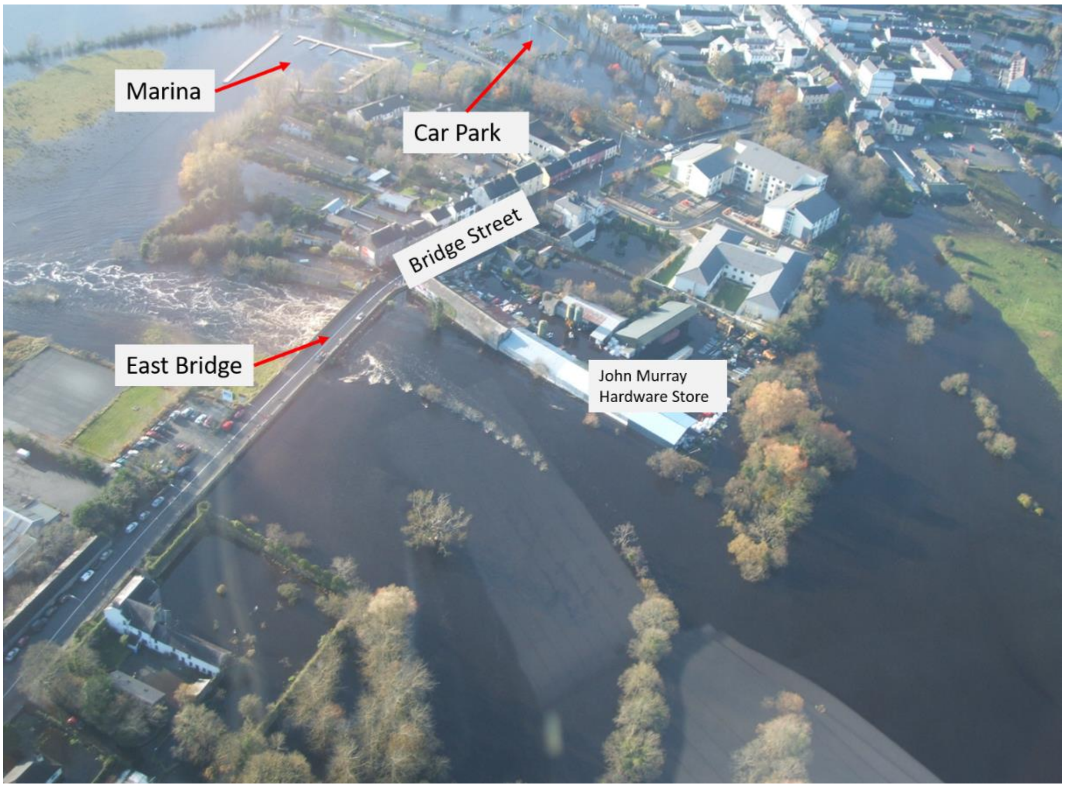

Figure 13: Flooding in the vicinity of East Bridge during the 2009 event

Other areas affected by the event include the fields surrounding Bunowen Bridge and hundreds of acres of land in Ashford. Pollboy Lock was also submerged during the event.

Following the 2009 event, Hydro Environmental Ltd. was commissioned by the Flood Alleviation Ballinasloe Community Group (FAB) to assess the 2009 flood event and to examine options for managing flood risk in the town[5]. As part of the study a survey of post flood event wrack marks was undertaken by Bronra Surveys in 2010. The survey relied on anecdotal information from residents and Galway County Council as well as photographs and videos of the event to identify high water marks. This information was used to define the maximum water level of the event (in mOD Malin) at a number of locations. The data was also used to produce a recorded extent of the event. The data from the event was sourced from Hydro Environmental Ltd and have used it as part of the model calibration which is detailed in Section 5 of this report.

Figure 14 presents the post flood event surveyed maximum water level data for Derrymullen. It can be seen from the image that there are inconsistencies in some of the peak water level data i.e., the peak level varying from 39.42mOD to 39.57 over a distance of circa 30m.

[5] Flood Alleviation Ballinasloe Community Project (2010), *Ballinasloe Flood Relief Study*, consultant Hydro Environmental Ltd, October 2010

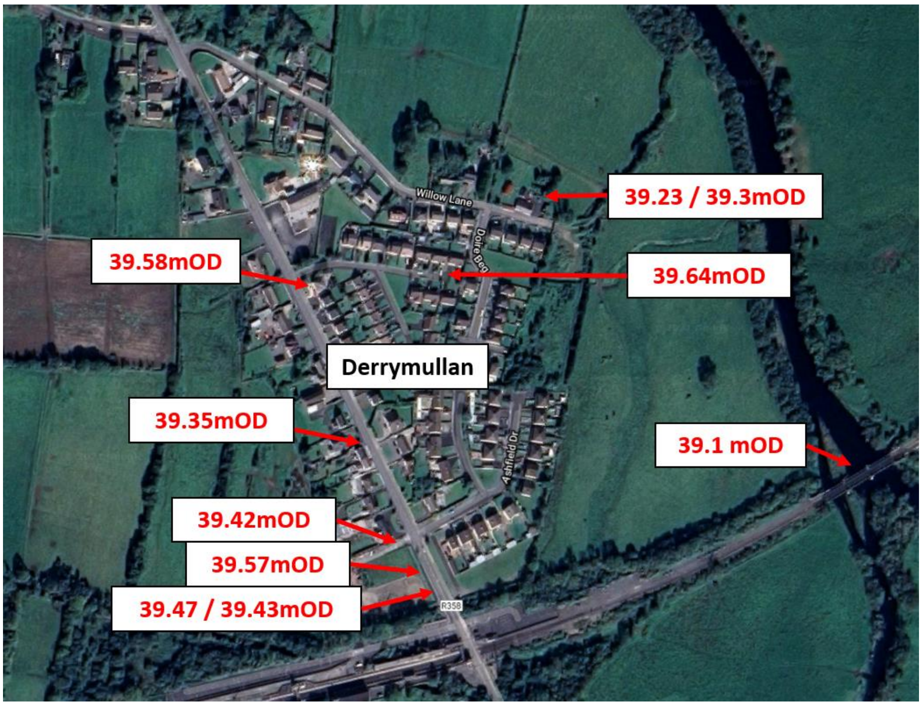

Figure 14: Maximum water levels in Derrymullen during the 2009 event – post flood event data

These inconsistences may result from:

- the original water levels may have been observed at different stages of the flood event (i.e. some at high water and others on either the rising or falling limb);
- the water levels may have been inaccurately recollected by residents hence the surveyed data is not representative of the maximum water level;
- Locally generated surface waves from passing vehicles may have artificially raised the maximum water level at a number of locations such that the original wrack marks may not be representative of the maximum flood levels but are instead representative of the total water level i.e. flood level plus local wave data. An example of this effect is illustrated in Figure 15 which shows a car driving along the R446 during the event. The surface wave generated by the car is evident from the photo.

Figure 15: Car driving through the flooded R446 during the 2009 event

As the wrack marks are based on anecdotal and not actual recorded data, it has not been possible to undertake a more detailed investigation into the data and to determine with precision the actual peak water level experienced during the event in Derrymullen. This uncertainly is addressed in Section 5.4 as part of the 2009 calibration event.

3 Hydrological Estimation

3.1 Overview

A detailed hydrological analysis of the various contributing catchments has been undertaken as part of the study and is reported on separately in the Hydrology Report. The objective is to provide reliable estimates of flood magnitudes and hydrograph shapes for various return period events for input as the inflow boundaries to the hydraulic flood model. The analysis utilised a number of hydrological estimation methods to establish a range of design flows at various Hydrological Estimation Points (HEPs) throughout the study area.

This chapter presents an overview of the work and discusses how the estimated flows were anchored in the hydraulic model. The reader is referred to the accompanying hydrology report for a detailed description of the work.

3.2 Hydrological Estimation Points

The primary HEPS are at (1) upstream model boundary nodes, (2) different confluence points, and (3) specific reference locations (i.e. at bridges, junctions, storm outfalls etc.). The HEPs for the study are presented in **Figure 16**. It can be seen from the figure that they are spaced at roughly 300m intervals along both the River Suck and on the tributaries.

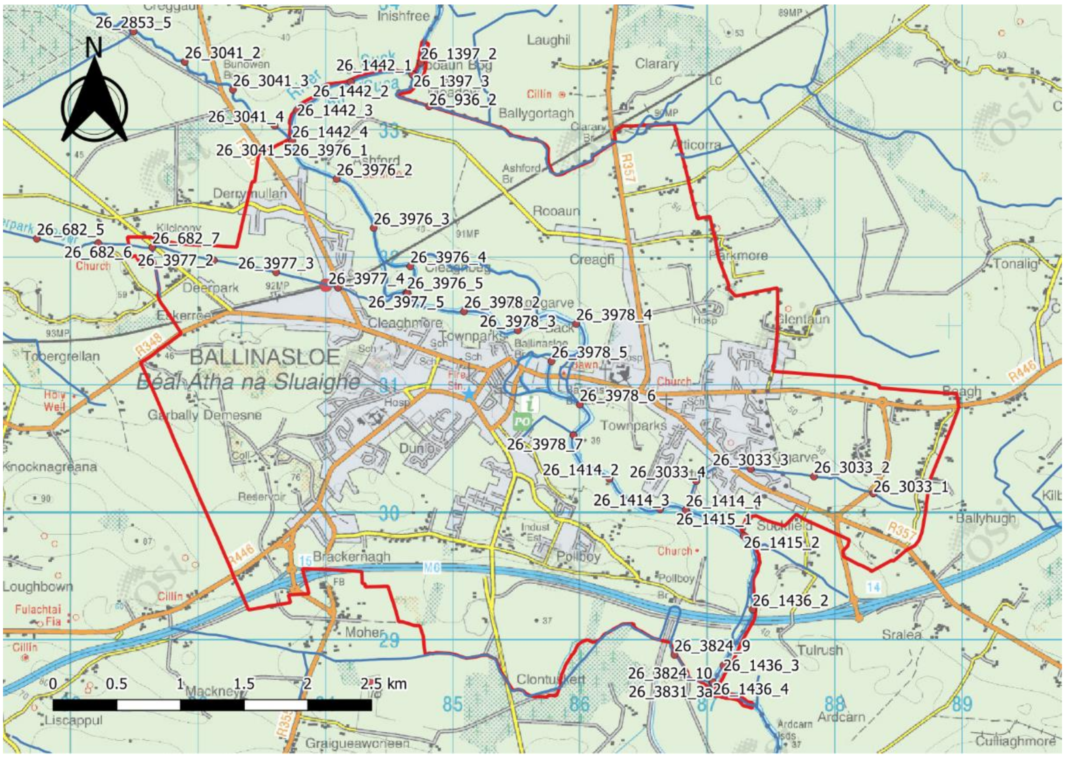

Figure 16: Location of primary Hydrological Estimation Points

3.3 Methodology

The hydrological assessment involved a number of related tasks which can be broadly summarised as:

- Collating and reviewing relevant topographical, meteorological and hydrometric data sets;
- Reviewing historical flood events at Ballinasloe (November 1968, November 2009 and December 2015);
- Undertaking a detailed rating review of the two gauges relevant to the study: Bellagill (26007) and Derrycahill (26005);
- Undertaking statistical flood frequency analysis on the gauged annual maximum data from the gauges;
- Undertaking trend analysis on the annual maximum flow series;
- Estimating likely catchment changes in a climate change scenario and the subsequent impact on fluvial flows;
- Uncertainty analysis on the design flows.

An overview of the key tasks is presented in the following sections.

3.3.1 Rating Review

The rating review analysis concluded that a slight adjustment to the Bellagill flood flow rating relationship was warranted. The new rating reduces the larger flood flow estimates by circa 5% such that the November 2009 flood event was reduced from 224m^3/s to 212.5m^3/s. The lower return period flood flows are also increased slightly based on the revised rating with the 2-year QMED estimate being increased from 89m^3/s to 93.6m^3/s. **Figure 17** shows the revised rating curve for Bellagill.

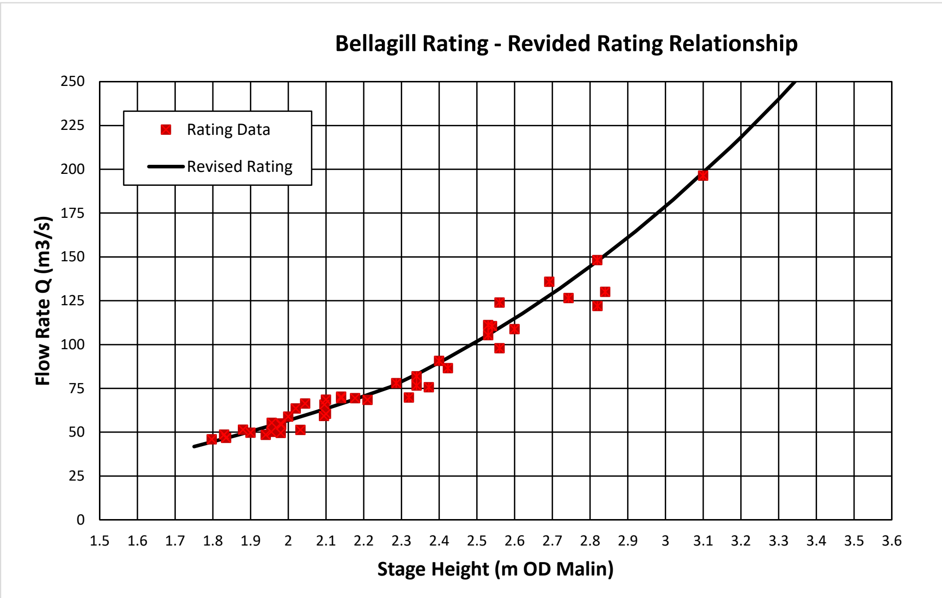

Figure 17: Revised rating curve for Bellagill

3.3.2 Design Flows and Hydrograph Shapes

The design flood flows and hydrographs for a range of return period events (2, 5, 10, 20, 50, 100, 200 and 1000 years) were estimated using the FSU PCD method for all catchments greater than 25km^2. The Bellagill gauged site was used as the pivotal adjustment factor in the QMED estimate. For the smaller catchments less than 25km^2 the IH124 flood estimation method was utilised.

A single flood growth curve was recommended for all tributaries and the River Suck. This flood growth curve was developed using a 3 parameter GLO statistical distribution and combined a regional based pooling group of Suck hydrometric gauges with the following weightings:

- 40% Bellagill;
- 20% Derrycahill;
- 20% Rockwood;
- 20% Willbrook.

The hydrograph shape was defined based on the average shape profile derived from the 2009 and 2015 extreme floods recorded at the Bellagill gauge (ID 26007). A modified FSR triangular hydrograph method was used on the Tributary streams and rivers.

3.3.3 Trend Analysis

The statistical trends analysis of the study concluded that there is a significant positive trend with time in flood magnitudes and frequency over the record period of almost 70 years which is associated to increased rainfall magnitude as no catchment changes. This trend significantly increased from the 1990's onwards with QMED increasing by 0.76 % per annum.

A precautionary approach was adopted as regards the definite increasing trend in QMED – for the pivotal adjustment the QMED estimate at Bellagill is based on the period from 1989 onwards (i.e. the recent 3 decades).

No definite trend was identified in the growth curve and given the requirement for a long record the flood growth curve is based on available full record length at the various pooled stations.

3.3.4 Climate Change Allowances

It is recommended that the climate change allowances of 20% and 30% increase at the Mid-Range Future Scenario (MRFS) and the High-End Future Scenario (HEFS) be included for both storm rainfall and flood runoff in assessing the adaptation of the proposed Flood relief scheme to future change.

3.3.5 Uncertainty Analysis

The uncertainty analysis undertaken as part of the study estimated a potential ±10% measurement error associated with the Bellagill flood rating relationship.

The flood frequency analysis quantified the statistical sampling error (SET) associated with the QT relationship of QMED as 4.3%. This increased to 22.8% for Q100 and 42.9% for the Q1000.

Other uncertainties have been identified as part of the study:

- catchment PCD data;
- the selected parent distribution;
- the potential increasing trend in flood magnitudes;
- the timing and shape of the design flood hydrograph.

These uncertainties have been reduced by undertaking a detailed review of the PCDs, selection of the best fit statistical model being a GLO and estimating the QMED based on the most recent 30years as opposed to the full record.

The factorial adjustments for uncertainty for the 100-year event are:

- 1.328 for the River Suck;
- 1.548 for the Deerpark and Bunowen tributaries;
- 1.828 for all of the smaller tributary inflows that are based on the IH124 estimation equation.

The reader is referred to the Hydrology report for further information.

3.4 Finalised peak design flows at the HEPs

The finalised set of design flows for the upstream boundaries are presented in **Table 3**.

Table 3: Peak flows at relevant HEPs, as applied to the model

River	HEP ID	Design event [m^3/s]							
		50%	20%	10%	5%	2%	1%	0.50%	0.10%
Suck	26_1442_4	111.11	138.88	163.33	187.77	234.43	278.87	332.21	524.42
Bunowen	26_3041_5	21.11	26.38	31.03	35.67	44.53	52.98	63.11	99.62
Deerpark	26_3977_5	11.12	13.90	16.35	18.79	23.46	27.91	33.25	52.49
Ballyhugh	26_3033_5	1.13	1.41	1.66	1.91	2.38	2.83	3.37	5.33
Deerpark Tributary 1	26_4178_1	0.13	0.16	0.18	0.21	0.24	0.28	0.31	0.43

3.5 Finalised hydrograph shapes

The finalised hydrograph shape for the 1% AEP event on the River Suck at Bellagill is presented in **Figure 18**.

The shape has been derived using the Shape Fitting method and is based on the actual recorded shape of the November 2009 and the December 2015 events. It was found that these hydrographs reasonably agreed with each other for the flow portion above the standardized flow of 0.5 (50% of the peak flow). This hydrograph can then be scaled up by multiplying it by the estimated return period flood at each of the HEPS. For more details, the reader is referred to the Hydrology Report.

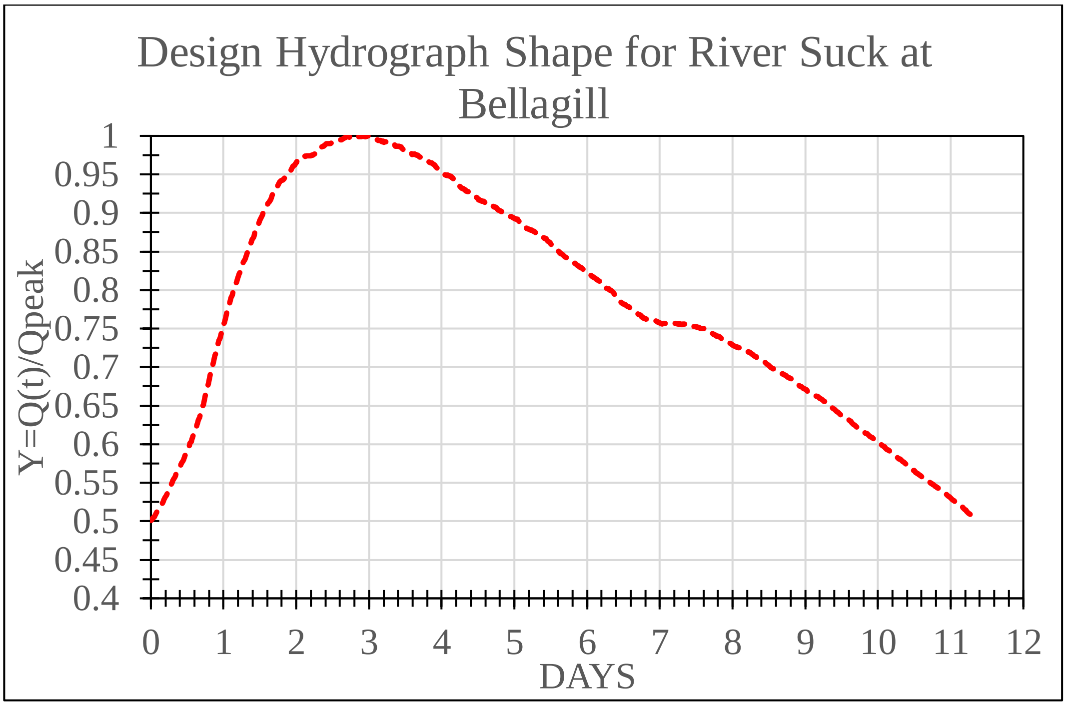

Figure 18: Design Hydrograph Shape

3.6 Integrating the design flows into the hydraulic model

3.6.1 Fluvial-Fluvial Joint Probability

In hydrological estimation, the sum of the design flows from two or more sub catchments can exceed the estimated design flow for the whole catchment due to differences in the catchment characteristics between various catchments. This can lead to an overestimation of flows downstream of confluences and consequently an overestimate of design water levels in a reach.

Table 4 presents the assessment of peak flows at three key junctions:

- The River Suck with the Bunowen;
- The River Suck with the Deerpark;
- The River Suck with the Ballyhugh.

As can be seen from the table, the hydrological derived design flow downstream of the confluences are generally within 3% of the sum of the design flows for the catchments upstream of the confluences.

Table 4: Peak flows for HEPs at various junctions for the 1% AEP event

	River Suck / Bunowen Junction		**River Suck / Deerpark Junction**		**River Suck / Ballyhugh Junction**	
	HEP ID	Peak flow [m3/s]	HEP ID	Peak flow [m3/s]	HEP ID	Peak flow [m3/s]
Upstream node on tributary	26_3041_5	52.98	26_3977_5	27.91	26_3033_5	2.83
Upstream node on River Suck	26_1442_4	278.87	26_3976_5	331.67	26_1414_4	347.86
Sum of flow at upstream nodes	-	331.85	-	359.58	-	350.69
Downstream of confluence	26_3976_1	330.68	26_3978_2	348.60	26_1415_1	348.48
Upstream / Downstream		1.00		1.03		1.01

We have adopted a conservative approach in our model set up by not making any adjustment to the design flows upstream of the confluences in order to set them exactly equal to the design flow downstream of the confluence. From **Table 4** it can be seen that our design flow will as a consequence be overestimated by circa 3% for the Deerpark and 1% for the Ballyhugh. There is no overestimation associated with the Bunowen.

We have also ensured that the model does not underestimate the design flow anywhere along a particular reach by using the design flow calculated for the downstream end of the reach as the upstream flow boundary of the reach. This process is illustrated for the Deerpark in the following figure.

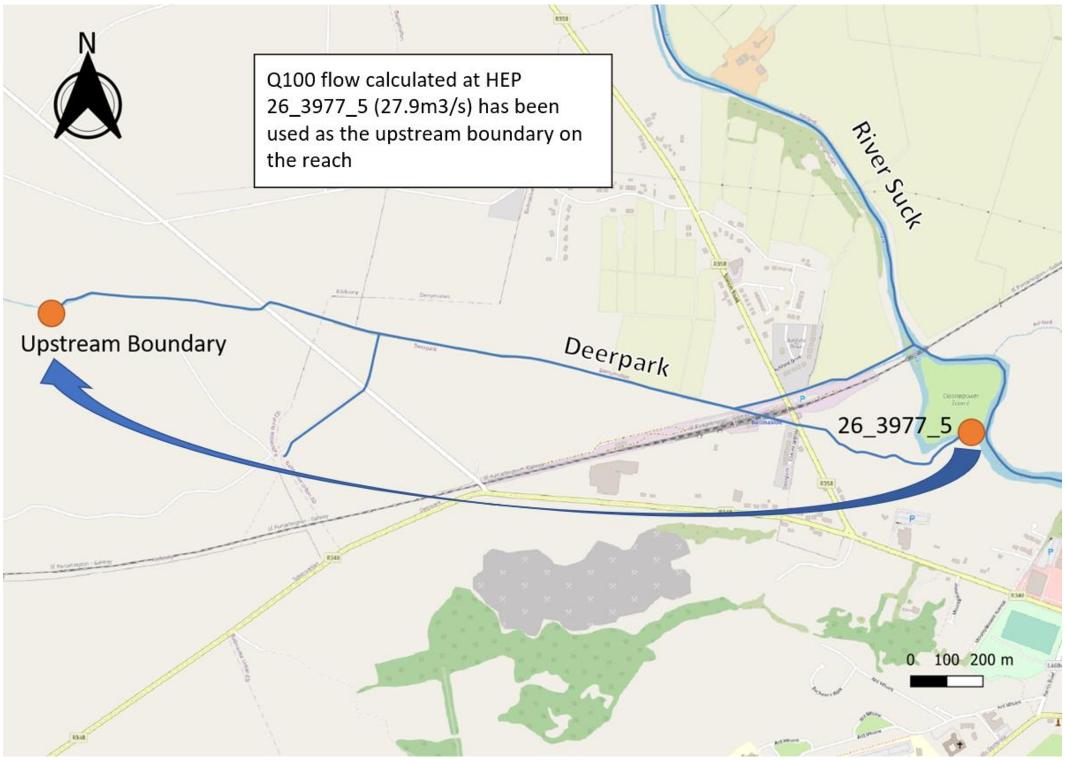

Figure 19: Setting the flow on the Deerpark Stream

3.6.2 Fluvial-Pluvial modelling

It is proposed to consider the risk of pluvial flooding and pluvial-fluvial joint probability as part of the Optioneering for the scheme when the defended areas will be correctly defined. This work will be presented as part of the Options report for the study.

3.6.3 Timing of the hydrographs

It has been assumed in the model that the peaks of the hydrographs from the various catchments occur at the same time. This represents a conservative approach as there will be some degree of offset given that the three sub catchments (Bunowen, Deerpark and Ballyhugh) will have a smaller time to peak that the main River Suck catchment due their steeper gradients and smaller catchment sizes.

This approach is justified on the basis that it ensures that flood risk on the smaller tributaries in the design runs is not at risk of being underestimated as the peaks on the tributaries will occur at the same time as the maximum backwatering from the River Suck.

This conservative approach will not lead to any significant overestimation of the flows on the main River Suck as the peak design flows from the sub catchments are small relative to the peak design flows on the Suck.

4 Model Development

4.1 Introduction

A one-dimensional (1D) and two-dimensional (2D) model of the River Suck and its main tributaries has been constructed as part of the study. The 1D model simulates the in-bank flows within all the watercourses and has been constructed in Flood Modeller Pro (v4.6) software. The 2D model simulates the out of bank floodplain flows and it has been developed in Tuflow software (v2018). The version of the software was the latest at the time of the creation of the model. Both the 1D and 2D models are dynamically linked and run together as a coupled hydraulic model – once the water level in the 1D model exceeds the bank level, it spills into the 2D grid and acts as a source discharge along the 1D/2D model interface.

This chapter described the development of the model.

4.2 Model Development

A coupled 1D/2D hydraulic model of the River Suck and some of its tributaries was developed as part of the Shannon CFRAM Study. The Ballinasloe FRS hydraulic model was developed from the Shannon CFRAM hydraulic model and represents a more refined and detailed version of it. The purpose of refining the model was to ensure that the level of detail and accuracy of the model is appropriate to the needs of flood relief scheme project.

The refinements and updates of the Ballinasloe model can be summarised as:

- Infill Survey – As detailed in Section 2.3.2, Arup identified a number of areas where additional river survey data would improve the performance and accuracy of the Ballinasloe FRS model over the Shannon CFRAM model. All of these areas were subsequently surveyed as part of the Infill Survey Management and incorporated into the model;
- Inclusion of additional tributaries – The Deerpark and one of its tributaries have been included as 1D watercourses and linked to the Tuflow grid in the 1D/2D model;
- Modification of 1D/2D interface – The 1D/2D interface has been modified across the scheme area in order to (1) accommodate tributaries that were not considered as part of the Shannon CFRAM, and (2) to provide a more accurate representation of the spilling from the river to the floodplain in a number of key urban areas;
- Updated structures – The East Bridge openings have been updated to reflect the current arrangement of the sluice gates;
- Model Parameters – A number of the model parameters used in the Shannon CFRAM model were altered in the Ballinasloe FRS model. These include channel roughness and structure coefficients which are described in Section 4.4 of this report.

- Defences – All effective defences in the town have been included in the model, while all ineffective defences (including informal ones) have not been included.

Summary details of the model build process are included in Appendix C.

4.3 Model Extents

4.3.1 Ballinasloe FRS Model

The Irish National Grid (ING) coordinates of the extent of the Ballinasloe FRS model is presented in **Table 5**. The extent is presented graphically in **Figure 20**.

Table 5: Extents of the Ballinasloe FRS model. All coordinates are in ING

Watercourse	Model Upstream Extent		Model Downstream Extent	
	Easting	Northing	Easting	Northing
Suck	184776.57	233707.88	196323.39	224716.59
Bunowen	182845.76	233541.92	183716.17	232936.88
Deerpark	182075.37	232077.44	184542.51	231712.43
Ballyhugh	188237.45	230162.81	187032.11	230326.86

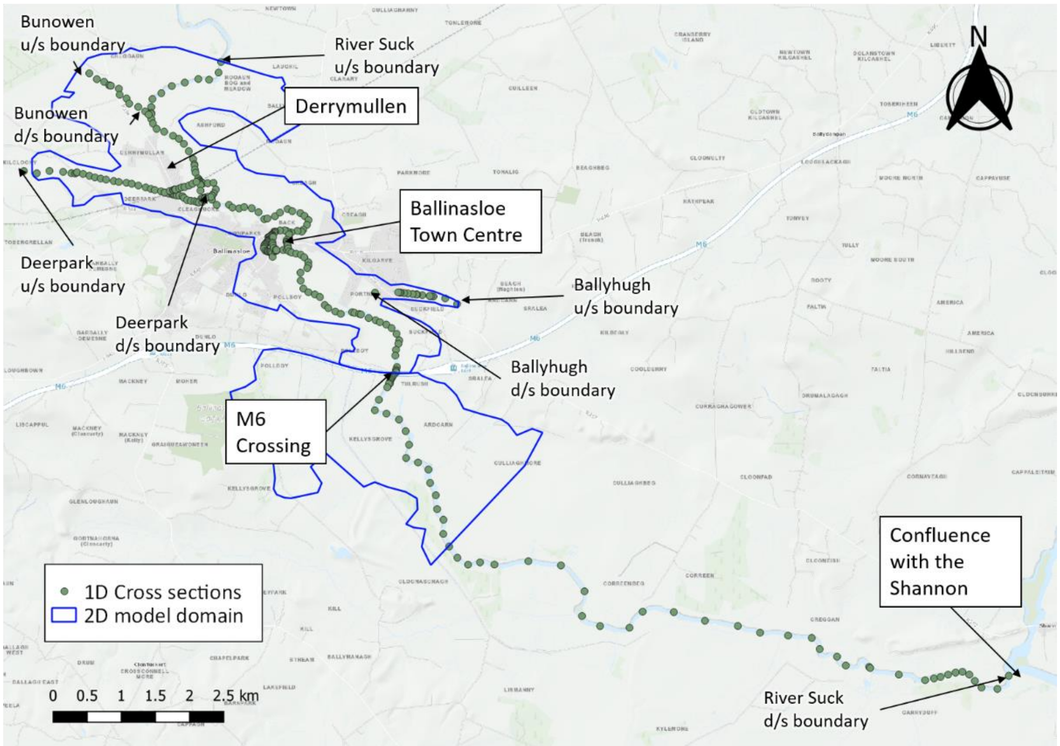

Figure 20: Ballinasloe FRS model - 2D model domain (blue polyline) and 1D model cross sections (green nodes)

Sensitivity testing of the model demonstrated that water levels along the River Suck up as far as the M6 bridge are sensitive to backwatering from the River Shannon – water levels in the vicinity of the M6 Bridge increase by circa 170mm when a normal depth boundary at the downstream end of the River Suck is substituted with 100 year flood event water level from the River Shannon. Water levels upstream of the M6 are not however sensitive to this mechanism.

In order to ensure water levels at the M6 bridge and downstream of it are not underestimated, the downstream boundary of the hydraulic model was set at the confluence of the River Suck with the River Shannon. Water levels from the River Shannon are therefore used as the downstream boundary data.

4.4 Model Parameters

4.4.1 Labelling System

The model nodes derived from the infill and validation survey followed the same labelling format as used for the Shannon CFRAM survey (e.g. The River Suck labels are provided in the form of 26SUCK00000, with chainage starting from 0 at the junction with the Shannon).

The CFRAM model however adopted a different convention to the CFRAM survey data as it split the River Suck into five separate reaches with chainages in each reach starting from 0 (i.e. river sections adopt the form 02SUC00000, 03SUC00000, 04SUC00000, 05SUC00000, 06SUC00000).

The Ballinasloe FRS model has adopted utilised both labelling system conventions:

- the infill sections (as described in Section 2.3.2) follow the survey convention system;
- the CFRAM sections utilised within the Ballinasloe FRS model have retained their original CFRAM model labelling system.

This approach was adopted to ensure that a direct comparison can be made between the results of both the CFRAM and Ballinasloe FRS (Arup) models.

4.4.2 Model Resolution

The 1D model resolution is determined by the distance between adjacent cross sections which changes throughout the model domain. For the key urban area this distance is on average between 40-50m which is deemed sufficiently accurate to assess water levels for both the existing scenario and the optioneering. A finer cross section spacing has been used along the Old Channel and within the main area of the town in order to account for the change in channel geometry and to accommodate the various hydraulic structures all of which require cross sections both upstream and downstream.

The 2D model resolution is defined by the spacing of the 2D grid. Defining this parameter involves a trade-off between accurately resolving the two-dimensional flow in an urban environment using a high-resolution grid and the computational run time of the model which is reduced with the lower resolution grids.

A 10m grid resolution has been selected for the Ballinasloe FRS 2D model domain. This is deemed to provide sufficient accuracy in the model given that the topography of Ballinasloe is relatively bowl-shaped and fills up in a flood event without involving complex urban flow patterns. It is noted that a 5m grid resolution was also tested as part of the model build and it was found that the modelled water levels are not sensitive to the finer grid.

If deemed necessary as part of the optioning, the 2D model grid resolution can be refined.

4.4.3 Manning’s n for the 1D and 2D Models

The roughness values of the 1D model have been defined for three separate sections of each cross section: (1) The left bank, (2) The main channel, and (3) The right bank. These sections of each cross section in the model are defined through the use of panel markers.

Some cross sections located in the 2D domain of the model have no left or right bank as they link to the 2D model domain at the point where the left/right bank begins.

The spatially-varying Manning’s n roughness values of the 1D model were selected based on a detailed analysis of a number of datasets:

- The values previously used in the Shannon CFRAM study[6];
- Survey photographs;
- Site visits undertaken by Arup;
- Relevant literature[7] and
- Model calibration.

An overview of the values used in the study are presented in Table 6. A photograph of a typical reach of the River Suck is presented in **Figure 21** in order to demonstrates the suitability of applying the manning’s value for reach (n=0.04).

Table 6: 1D Manning's n values used in the study

Channel Characteristics	Manning’s n values
Main Channel	0.04
Banks	0.06
Heavily vegetated banks	0.096

[6] Office of Public Works (2016), *Shannon CFRAM Study – Hydraulics Report Unit of Management 25-26*, consultants Jacobs, June 2016
[7] Chow, V.T., 1959, *Open-channel hydraulics*: New York, McGraw-Hill, 680 p.

Figure 21: Photograph of the River Suck showing a long straight channel (n = 0.04)

The Manning's n floodplain values were selected based on an analysis of datasets:

- Land use derived from OSi Prime2 mapping;
- Site visits undertaken by Arup;
- The calibration of the model against the 2009 flood event
- Relevant literature[8];
- The values used as part of the Shannon CFRAM[9].

Typical values used in the study are presented in **Table 7**. A photograph of a typical area of the floodplain is presented in **Figure 22** in order to demonstrate the suitability of applying the chosen manning's value (n=0.05/0.06). As the model was calibrated to Winter flood events, the selected model parameters represent Winter conditions.

Table 7: 2D Manning's values used in the study

Floodplain	Manning's n values
Land use	
Rural floodplain (with heavy grass)	0.054
Urbanised area (with boundary walls, footpaths etc)	0.072
Thick dense vegetation	0.1
Short Grass	0.040 – 0.060
Water Bodies	0.035
Road surfaces	0.02
Railway lines	0.06
Buildings footprint	0.1

[8] Chow, V.T., 1959, *Open-channel hydraulics*: New York, McGraw-Hill, 680 p.
[9] Office of Public Works (2016), *Shannon CFRAM Study – Hydraulics Report Unit of Management 25-26*, consultants Jacobs, June 2016

Figure 22: Vegetation with a high roughness value on the floodplain (n=0.05/0.06)

4.4.4 Representation of the River Structures

The majority of bridges in the model have been modelled using the Bridge ARCH unit as this is the most suitable bridge unit within Flood Modeller Pro for modelling the size of bridges in study area given the size of their openings relative to the channel geometry. The Railway Bridge and the M6 Bridge have been modelled using the USBPR unit as their openings are relatively larger when compared with the channel geometry. The Atlas channels were represented in the model using Tuflow culvert units.

The East Bridge is a key hydraulic structure and is discussed in detail in the following section.

Overtopping of the bridges has been accounted for through the use of a spill unit in the 1D domain of the model. In-line weirs have been modelled using the weir unit in Flood Modeller Pro. Culverts have been modelled through use of the culvert units (conduits) in Flood Modeller Pro.

The dimensions of all the hydraulic structures have been taken from the surveyed data. The reader is referred to Appendix C which presents a datasheet for all the key structures included in the Ballinasloe FRS model.

4.4.5 East Bridge

The East Bridge is a multi-arch bridge that spans the River Suck on the Eastern side of the town and is a key hydraulic structure in Ballinasloe. The bridge was modelled as an ARCH bridge in the Ballinasloe FRS model.

The bridge comprises four large masonry arches and abutments (approximate spans and overall heights of 7.5m and 4.5m respectively and a typical invert of 33.8mOD) and one smaller arch along the right bank (2m span, 3.9m high). The bridge is circa 9.7m wide. The dimensions of the overall structure have been based on the survey that was part of the CFRAM Shannon Study.

Following review of the CFRAM study, it was found that the CFRAM survey did not correctly measure the bed levels on the left hand side of the river channel downstream of the East Bridge. This issue was corrected by supplementing the CFRAM survey data with additional bed level data provided by GCC.

The bridge was originally constructed with four sluice gates on the upstream face of the bridge in order to regulate flow through the structure and feed the western channel through the town centre, where a number of corn mills and associated waterwheels were once in operation.

During the 2009 event, the westernmost sluice gate of the bridge was completely lowered which effectively blocked the opening. The other three sluice gates were partially closed with sill levels of circa 36.34mOD, which further limited the discharge through the bridge in during the event. **Figure 23** presents a schematic of the bridge opening for the event which has been used as part of our 2009 calibration model. We note that the total cross-sectional area of the openings in this configuration of the bridge openings is 55m^2.

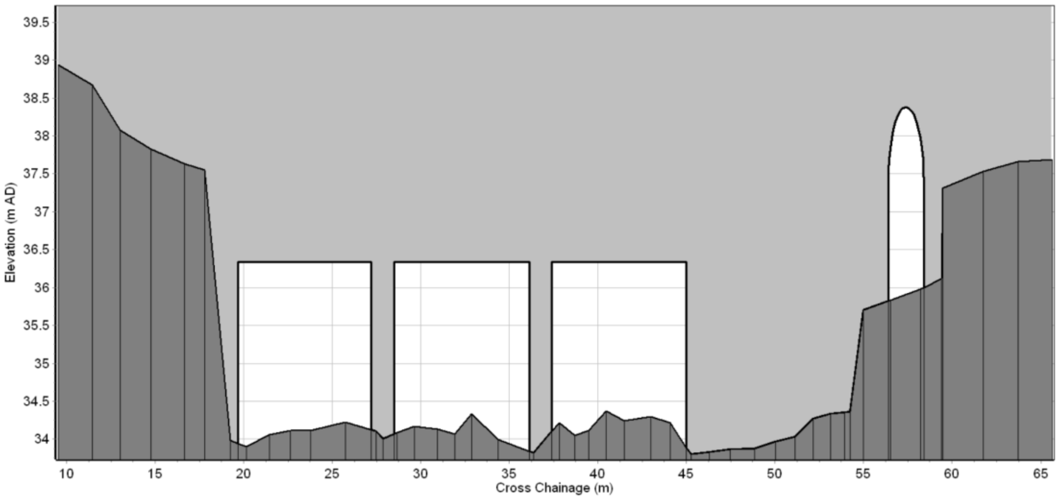

Figure 23: Configuration of the East Bridge's sluice gates during the 2009 event

A photograph of the bridge is presented in **Figure 24** which shows the sluice gates in the position that they were in during the 2009 event.

Figure 24: Sluice Gates on the upstream face (non‐flood conditions)

After the 2009 event the sluice gates were opened and set at various heights until circa 2012. **Figure 25** presents a schematic of the bridge opening for this configuration of the sluice gates which we note was adopted as part of the Shannon CFRAM hydraulic modelling. The total cross-sectional area of the openings in this configuration is 70m^2.

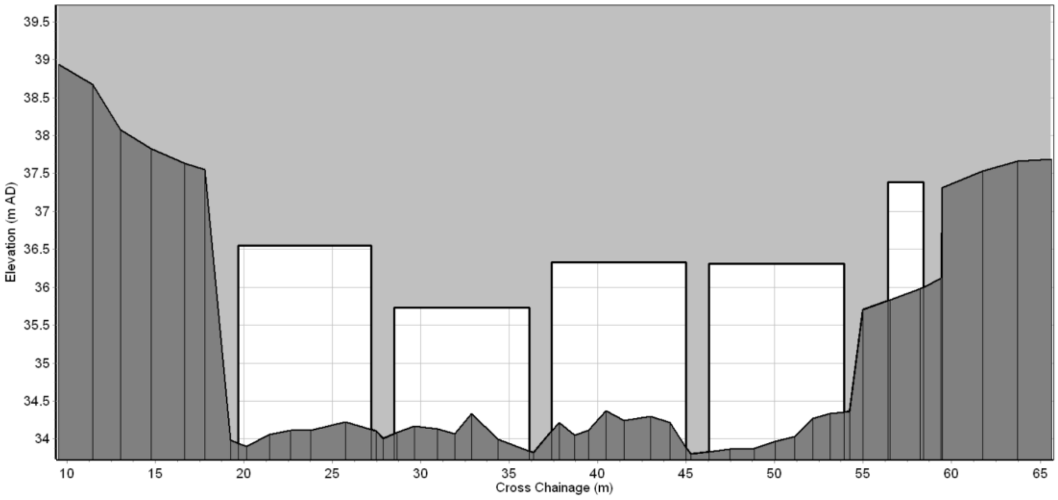

Figure 25: Configuration of East Bridge's sluice gates up to 2012

After 2012, works were undertaken by Galway County Council to permanently raise the sluice gates. The gate sills are now permanently set at a level of 37.89mOD as indicated in **Figure 26**. We note that this is the configuration used in our hydraulic model for the existing scenario. We note that the total cross-sectional area of the openings in this configuration is 120m^2. The available cross section area for the existing scenario runs is therefore more than double the area that was available for the 2009 flood event.

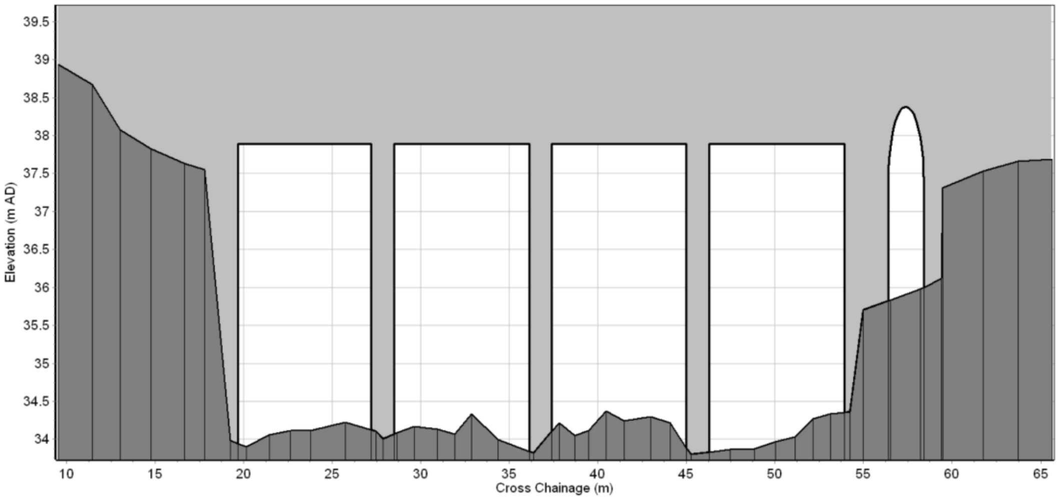

Figure 26: Configuration of East Bridge's sluice gates currently in place

Figure 27 shows a visual comparison of the changes made to the openings of the East Bridge, as discussed in this Section.

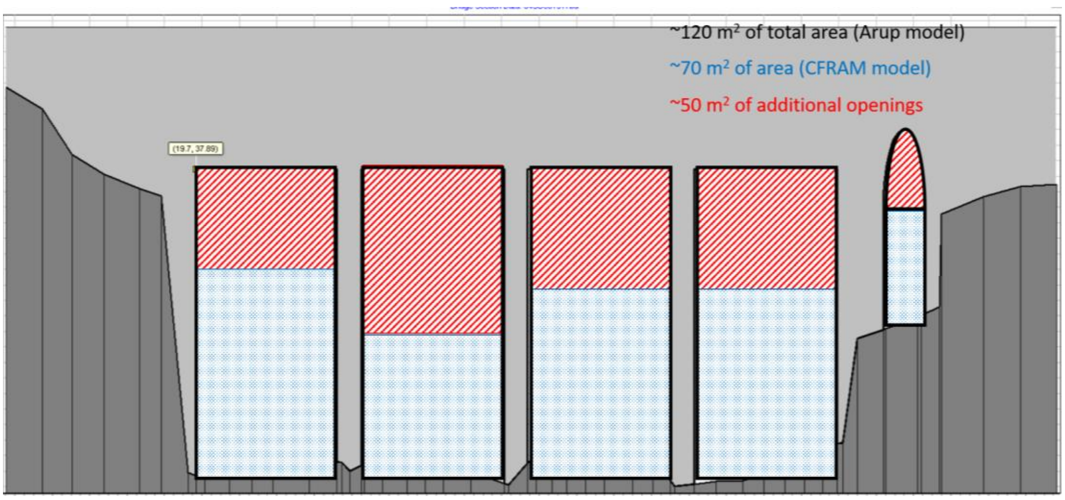

Figure 27: Comparison of East Bridge sluice gates configurations

4.4.6 Representation of the Atlas Channels

The Atlas Channels are two separate channels that run North-South in the vicinity of the East Bridge (see **Figure 28**). The channels remain dry in times of low flow on the River Suck and only convey water when levels on the Suck are greater than the bed levels of the channel at their confluence with the Suck.

The channels have been modelled within Tuflow - the alignment and bed of the channels have been defined through the use of Z lines while the structures have been modelled using individual culvert units.

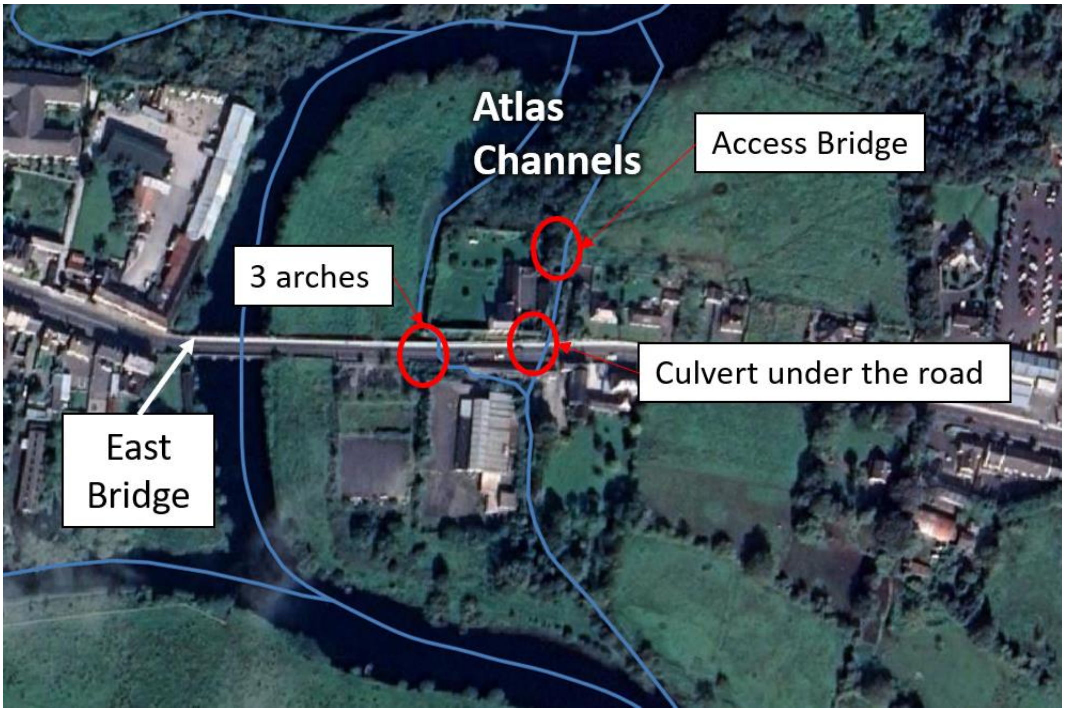

Figure 28: Atlas channels and modelled structures

The dimensions of the structures along the Atlas channels are presented in the following table.

Table 8: Atlas channels structure dimensions

Structure	Shape of opening(s)	Width (m)	Height (m)
Access Bridge	Arch	2.2	1.3
Culvert under the road	Rectangular	3.73	0.9
3 Arches bridge	Arch	3.3	2.3

4.4.7 Representation of Buildings and other Structures in the 2D grid

The buildings in the model were represented by specifying a high manning's value (0.1) across the footprints of all the buildings which were identified from the OSi Prime2 dataset.

Other structures such as walls, roads and railway embankments can influence the movement of water in the floodplain and must be correctly represented in the model. This can be achieved in two separate ways:

- Utilising the existing Lidar data where the relevant structure geometries can be accurately represented by both the Lidar data and the 10m grid;
- Through the use of Z lines shapefiles in the model;

The M6 motorway embankment is sufficiently large for its geometry to be accurately defined by the Lidar and represented by the 10m grid.

A number of walls and embankments have however been represented in the model through the use of specific Z lines (see **Figure 29**). It has been assumed that these walls will not fail during a flood event. This assumption is based on our appreciation of the structural integrity of the wall. The heights of each wall have been taken from site surveys.

It is noted that the defences at Derrymullen (Section 4.5) are classified as formal effective flood defences. The other structures represented in the model and highlighted in **Figure 29** are informal effective flood defences.

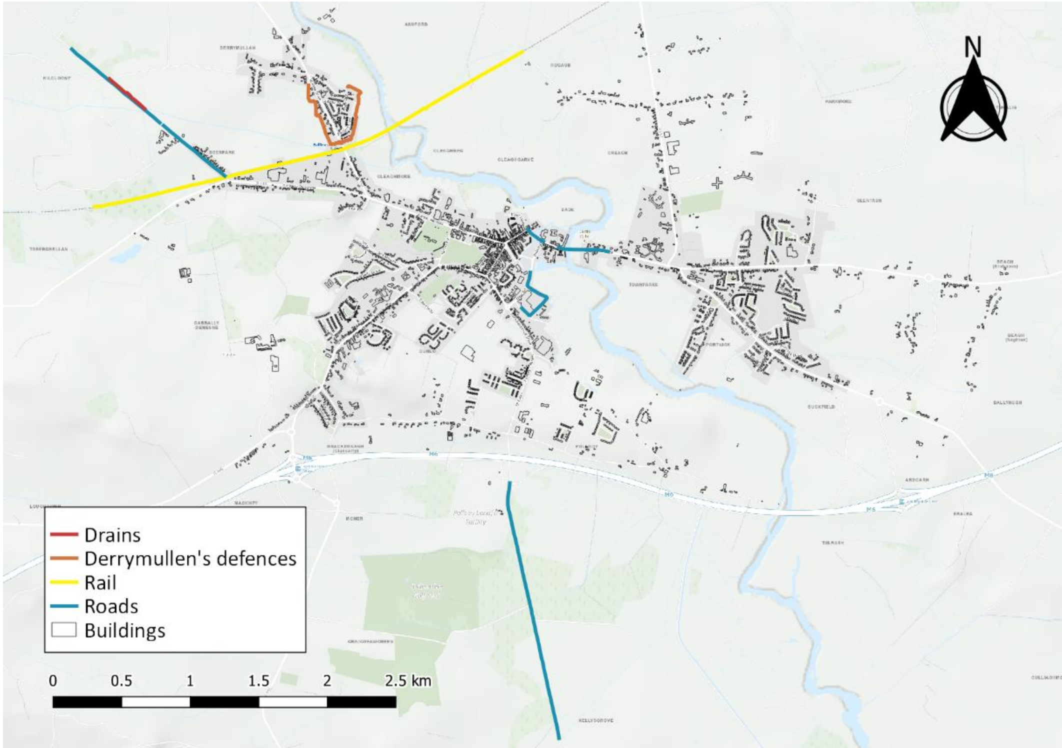

Figure 29: Structures included in the model

4.5 Derrymullen Flood Defence Scheme

4.5.1 Overview

A flood defence scheme for the area of Derrymullen was constructed in 2010 / 2011 in response to the very significant 2009 flood event which inundated the area.

The engineering works consist of circa 1.2km of flood defences (including both walls and embankments) around the Eastern, Southern and Western sides of the estate. The minor watercourse that flows through the estate from west to east had penstock controls constructed at either end in order to isolate the estate from all watercourses during a flood event. A bypass drain was constructed on the outside of the flood defences to facilitate the diversion of the minor watercourse when the penstocks are closed.

Surface water and foul services are managed via a series of sluice valves and pumps. An overview of the direct defences of the scheme is presented in **Figure 30**.

Figure 30: Simplified schematic of the Derrymullen Flood defence scheme

The operation of the Derrymullen Flood Defence Scheme requires a number of actions to be undertaken in advance of a flood e.g. closure of penstocks, closure of a flood gate, pumping etc. The baseline scenario model has assumed that the operational protocol of the Derrymullen flood defence scheme is fully enacted. The culvert underneath the estate (dashed line in **Figure 30**) has therefore not been added to the model and the direct defences (including the flood gate) form a complete barrier around the Western, Southern and Eastern sides of the estate. It has also been assumed that surface water does not collect within the estate due to the correct operation of the various surface water pumps.

The direct defences have been included in the model through the use of Z lines. Both the alignment and height of the defences have been taken from the recent Survey by McDonald Surveys.

It is noted that as per the requirements detailed in the Ballinasloe FRS brief, a defence asset condition assessment of the Derrymullen scheme has been undertaken. It is intended that the scheme will be incorporated as part of the overall scheme for Ballinasloe.

The full operational protocol for the Derrymullen scheme can be found in Appendix F.

4.5.2 Defended and undefended hydraulic model runs

While the baseline hydraulic model runs consider the Derrymullen flood defence scheme, the undefended scenario has also been assessed as part of a sensitivity analysis. The reader is referred to Section 7 of this report.

4.6 Flood mitigation measures at Sli na hAbhann along the Old Town Channel

In recent years, Galway County Council implemented the following temporary flood defence measures along the old town channel of the Suck near the town centre:

- Circa 60m long blockwork flood defence wall at Sli na hAbhainn;
- Slot-in demountable barrier at town park pedestrian bridge;
- Circa 160m long water-filled “Aquadam” barrier from Sli na hAbhainn to St Michael’s Square. A photograph of the Aquadam is presented in **Figure 31**. The alignment of the dam is presented in **Figure 32**.

Figure 31: Temporary flood barrier at Sli na hAbhann

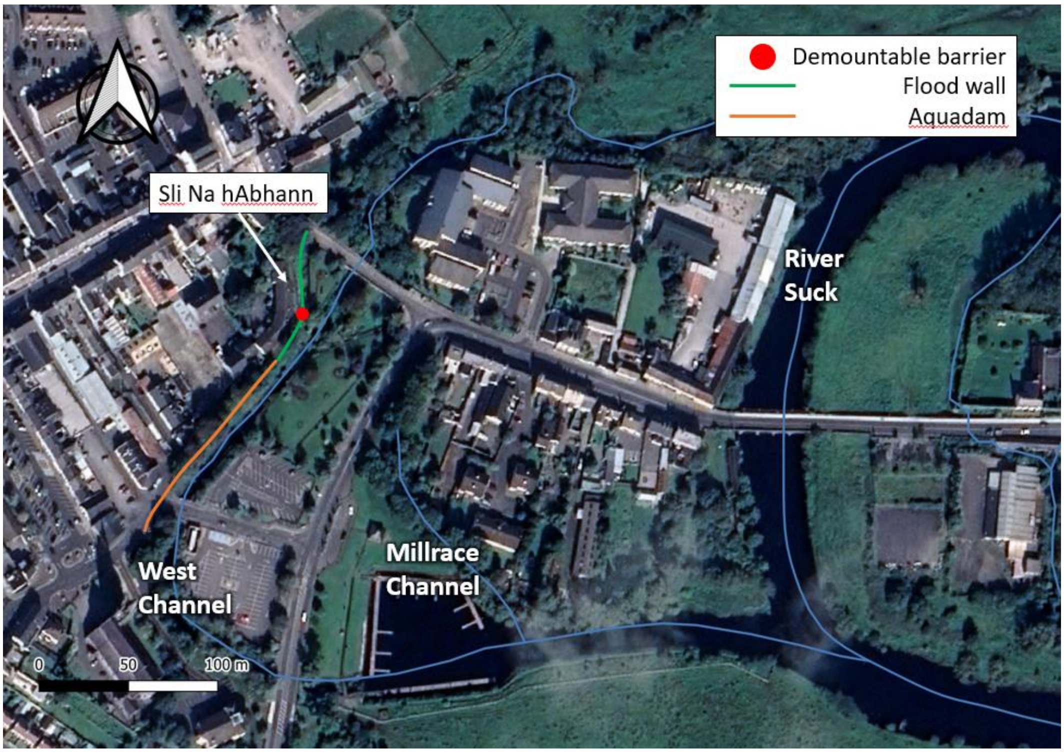

Figure 32: Indicative alignment of temporary flood defence measures

These temporary measures have not been included in the baseline hydraulic model. The modelled flood extents therefore present the undefended scenario.

4.7 1D and 2D Model Linkage

There are two parameters which control the volume of water that spills onto the floodplain (the 2D model domain) from the river channel (the 1D model domain):

- The water level in the river channel;
- The elevation of the bank of the channel i.e. the elevation at which water spills from the river to the floodplain.

The water level in the river channel is calculated by the 1D model. The elevation of the bank however is defined in the model by the user using the topographic survey data. It is a very important dataset in the model as it controls the volume of water that spills into the 2D domain of the model. Its correct specification is essential in ensuring an accurate and credible hydraulic model.

The elevation of the left and right banks throughout the 2D model domain of the model were defined from actual surveyed elevations from the river channel survey and were accounted for in the model through the use of Z lines in Tuflow. These Z lines were defined for the entire 1D-2D reach of the model and ensured an accurate representation of the volume of water spilling from the 1D to the 2D domain.

4.8 Minor Tributary Watercourses

Section 3.1.2 of the project brief lists circa 19 minor watercourses/drainage channels within the scheme area that were to be considered as part of the study. The alignment of these water courses is presented in **Figure 33**. It is noted that the number of watercourse shown on the figure is greater than 19 as we have considered a number of them as consisting of smaller individual reaches.

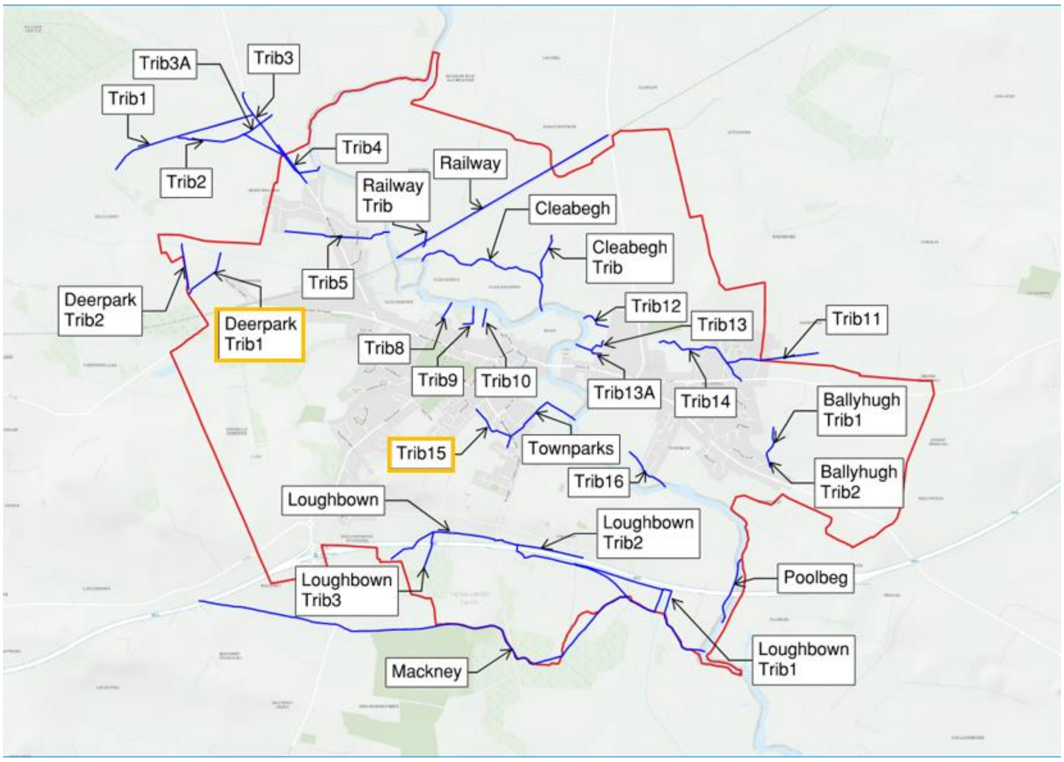

Figure 33: Assessed minor watercourses

An initial hydraulic assessment of the flood risk associated with each of the watercourses was therefore undertaken as part of the study and is presented in Appendix E. The key recommendation from the initial assessment was to explicitly model the existing scenario flood risk associated with three of the minor watercourses:

- Deerpark Trib 1;
- Townparks Stream culvert;
- Culvert downstream of the M6.

Figure 34 presents the alignment of the Deerpark Tributary in the hydraulic model and **Figure 35** presents the alignment of the Townparks Stream culvert.

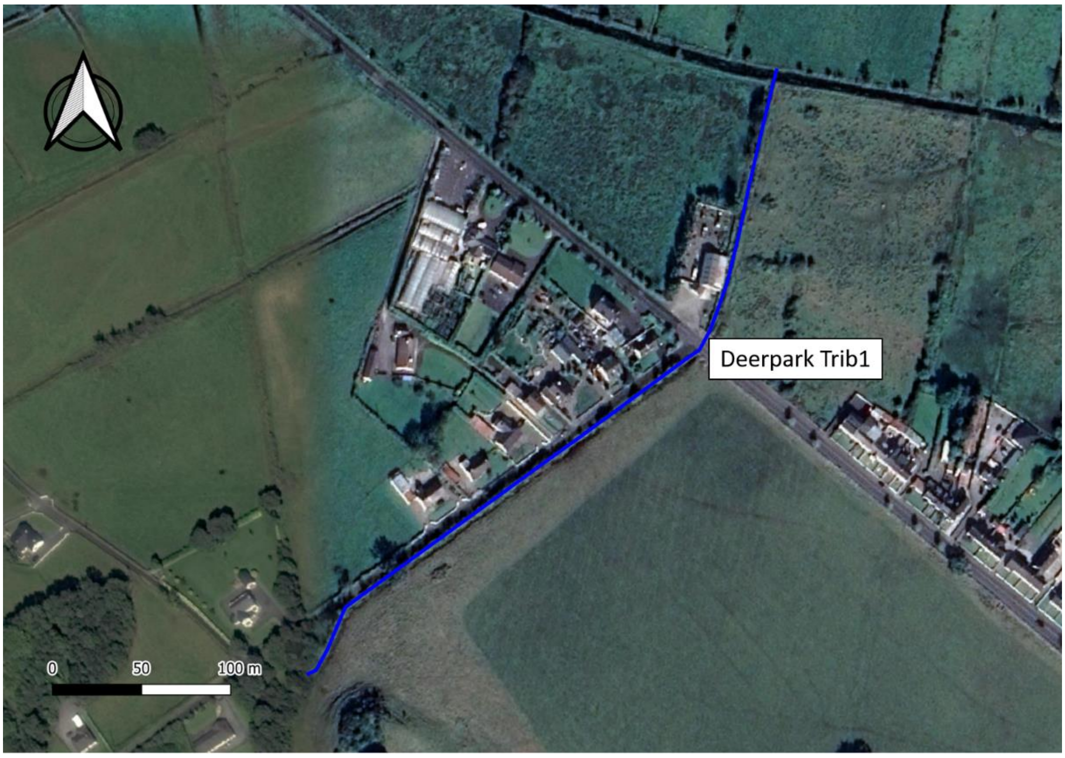

Figure 34: Deerpark Trib 1

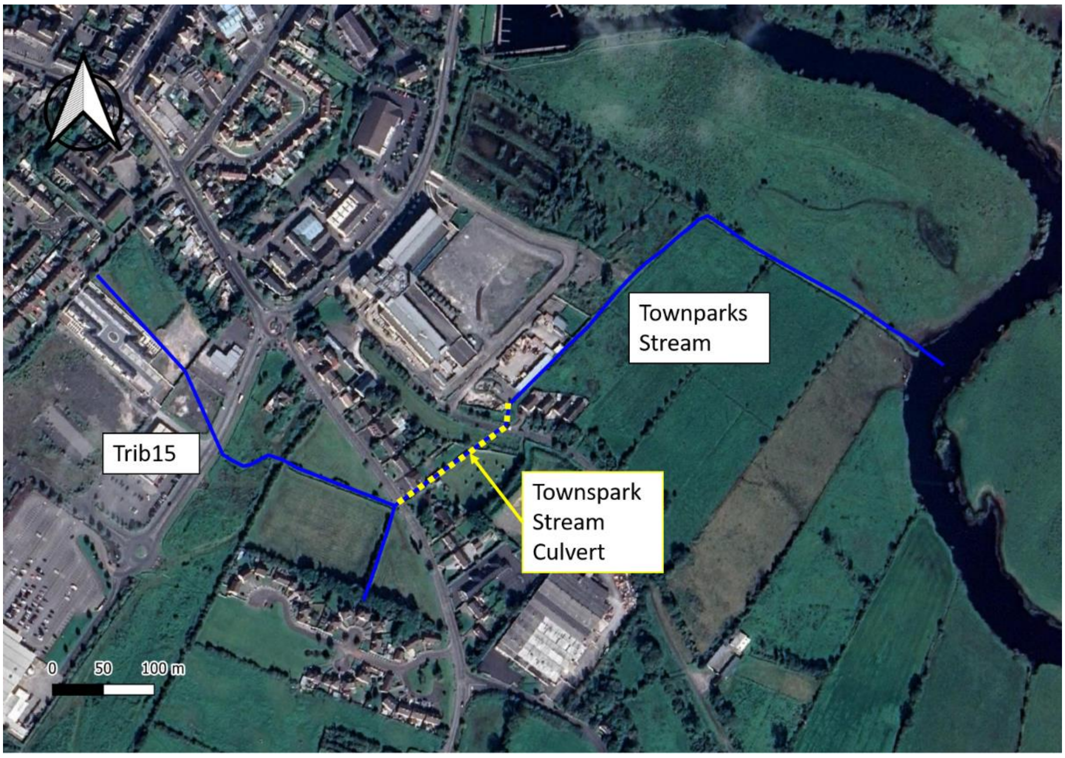

Figure 35: Culvert that connects the Townpark Stream and Trib 15

4.9 Blockage Risk

A blockage risk assessment of all the key hydraulic structures in the scheme area has been undertaken as part of the study and is detailed in Appendix G.

The key conclusion from this analysis is that a number of structures are at risk of blockage and that needs to be assessed as part of the study.

This work will be undertaken as part of the optioneering of the study.

4.10 Hydraulic Modelling of the Options

The Ballinasloe FRS model will be modified to model the various flood relief options considered as part of the development of the scheme. This work will be reported in a seperate options development report.

5 Model Calibration

5.1 Introduction

The first step of the calibration process is to calibrate the model to an in-bank event in order to demonstrate the ability of the 1D component of the model to reproduce water levels in the main River Suck. This gives confidence that the 1D schematisation, structure representation, head losses and Manning's parameters in the 1D model are correctly represented. The second step of the process is to calibrate the model to an out-of-bank event in order to demonstrate the ability of both components of the model (and their interface) to reproduce water levels across the entire floodplain. When a good calibration is achieved against both in-bank and out-of-bank events it gives confidence that the model is able to reproduce the mechanisms of flooding in the town.

The model was calibrated by adjusting the following set of parameters:

- Manning's number within the river channel and across the floodplain;
- Bridge/Culvert entrance head loss coefficients;
- 1D/2D boundary alignment and set-up;
- Bridge unit set up;

Two separate in-bank events have been chosen from the gauge record in the town: February 2020 and November 2020. Both of these 2020 events would have caused out-of-bank flow in the low-lying flood plain upstream of Ballinasloe. Within the town itself however neither of these events got out-of-bank and did not inundate any property. Hence, they are referred to as "in-bank" events in this report.

The very significant flood event of 2009 has been selected as the out-of-bank calibration event. This has been selected over the 2015 event as it was more significant – calibrating the model to this event therefore gives us greater confidence of the ability of the model to simulate large event. There is also a greater amount of calibration data being available for the 2009 event than there is for the 2015 event.

5.2 Calibration model boundary conditions

5.2.1 Upstream boundaries – calibration inflows

Data recorded at Bellagill gauge during all three calibration events has been used as the upstream flow boundary for the River Suck in the calibration modelling. Inflows for the other watercourses have been scaled from the Bellagill data based on catchment sizes. This introduces uncertainly into the calibration boundaries on account of the differences in the timing and magnitude of the inflow hydrographs which results from the variance in catchment sizes.
This uncertainty needs to be considered when evaluating the calibration plots and is discussed later in the chapter.

5.2.2 Downstream boundary – River Shannon water levels

Data recorded at the Shannonbridge gauge during each of the calibration events has been used as the downstream water level boundary of the calibration model. Data from this gauge is deemed suitable for use given its close proximity to the confluence of the River Suck with the River Shannon.

5.3 In bank calibration

5.3.1 February 2020 event

The first in-bank model calibration event occurred in February 2020 and approximates to a return period of circa 5 years on the River Suck. As the Town Gauge was not operational during the event, only data from the Old Channel Gauge has been used in the calibration.

Figure 36 presents the modelled and recorded water level at the Old Channel gauge for the event as well as the differences between them. It can be seen from the figure that the model is very well matched to the recorded data across the full duration of the hydrograph. The shape of both the rising and falling limbs are well captured by the model and the modelled peak of the event (37.35mOD) is within circa 40mm of the recorded peak (37.49mOD).

The model is therefore able to reproduce the water levels across the full hydrograph in the Old Channel for the event.

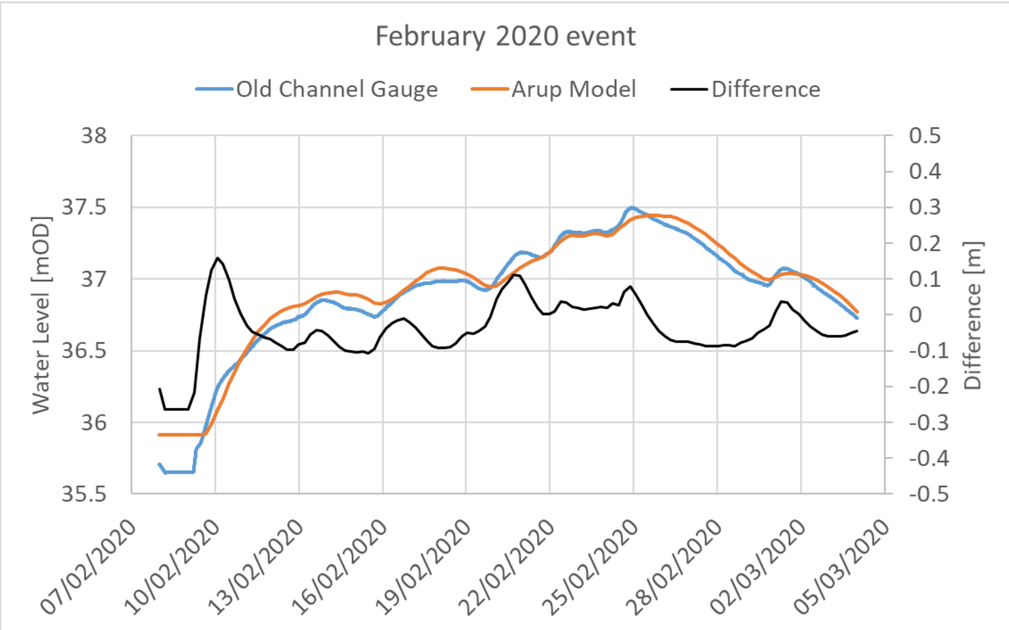

Figure 36: February 2020 event - Old Channel Gauge

5.3.2 November 2020 event

The second in-bank event is November 2020. Data from both the Old Channel Gauge and the Ballinasloe Town Gauge have been used as part of the calibration. The return period for this event was circa 2 years on the River Suck.

Figure 37 presents the modelled and recorded water level at the Town gauge for the event. It can be seen from the plot that the recorded data is somewhat noisy as minor oscillations in water level are evident from the time series. These are likely caused by localised turbulence within the water column at the location of the gauge. It is however clear from the figure that the model is well matched to the recorded data across the full double peaked event. Both the rising and falling limbs of both peaks are well captured by the model and the modelled peak of the first and more significant event (36.88mOD) is within circa 80mm of the recorded peak (36.96mOD).

The model is therefore able to reproduce the water levels at the Town gauge across the full hydrograph.

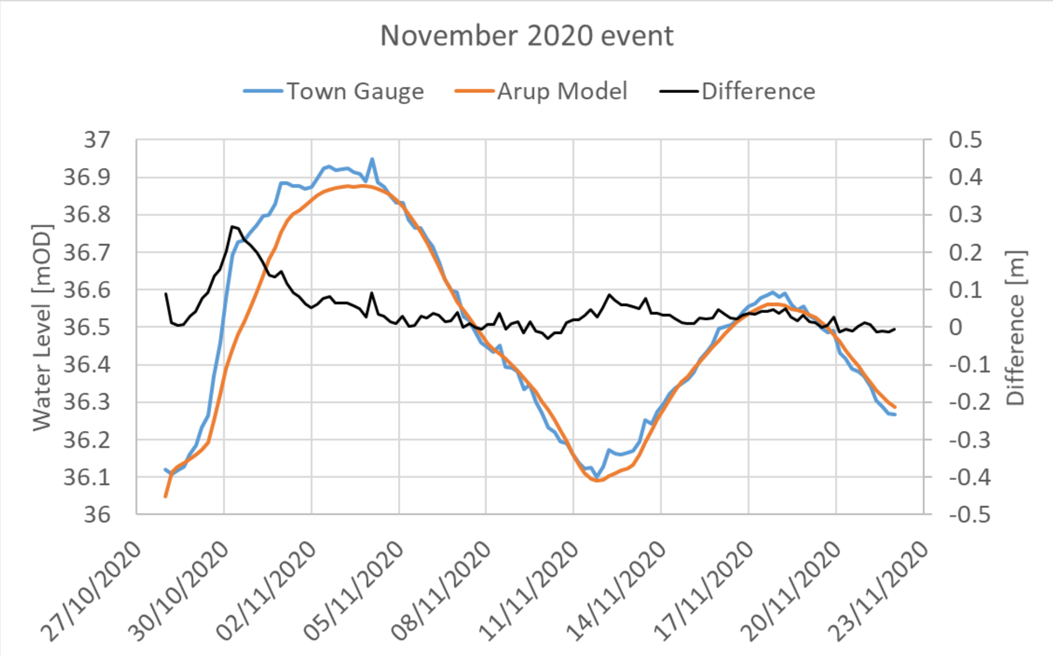

Figure 37: November 2020 Event. Recorded at the Town Gauge

Figure 38 presents the modelled and recorded water level at the Old Channel gauge for the same event. It can be seen from the figure that the model is overestimating water levels across the event – at the peak the overestimation is circa 130mm.

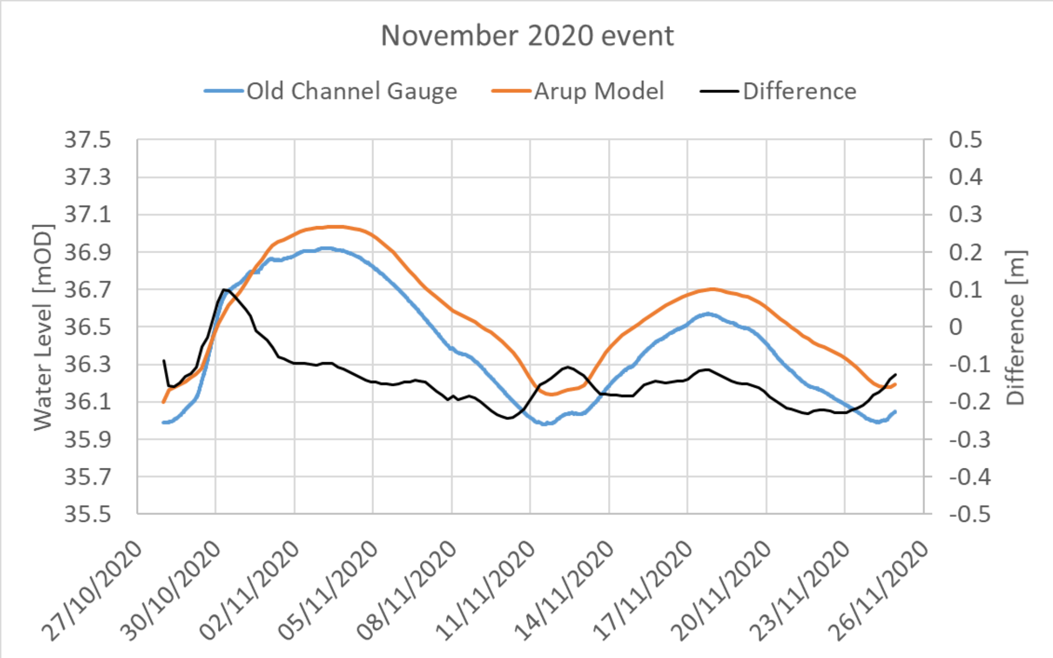

Figure 38: November 2020 event. Recorded at the Old Channel Gauge

Given that the model was well calibrated to the Old Channel gauge for the February 2020 event, the overestimation of water levels for the November 2020 event is somewhat unexpected. A number of factors however need to be considered when assessing this calibration:

- At the location of the gauge, the Old Town canal consists of three individual channels which have been schematised as a single channel in the FMP model. A constant water level is therefore simulated across the each of the three individual channels;
- The soffit of the first and second openings of the pedestrian bridge located immediately upstream of the gauge are both set at 36.45mOD (refer to **Figure 39** and **Figure 40**). The soffit level of the third opening is set at a higher elevation of 37.1mOD. When the water level is greater than the soffit level of the first and second openings, but less than the soffit level of the third opening, the head loss associated with flow going through the first two openings will cause the water in the third channel to be overestimated due to the schematisation of the three channels as a single cross section. As evident from **Figure 38**, this scenario applies to the peak of the November 2020 event;
- When the water level is greater that the soffit of the third opening the head loss at the bridge will be experienced across each of the three channel and the schematisation of the model allows for this mechanism to be captured, such that water levels will not be overestimated. This scenario applies to the November 2020 event as evident from **Figure 36**.

The hydraulic model of the Old Channel is therefore more accurate in representing water levels that exceed circa 37.1m than it is in representing water levels below this level. This is not deemed to be a limitation on the performance of the model given that the objective of the study is to assess flood flows conditions in Ballinasloe and not low conditions.

The model schematisation along this reach is therefore deemed suitable for use in the study as is clearly able to represent flood flow conditions along the channel.

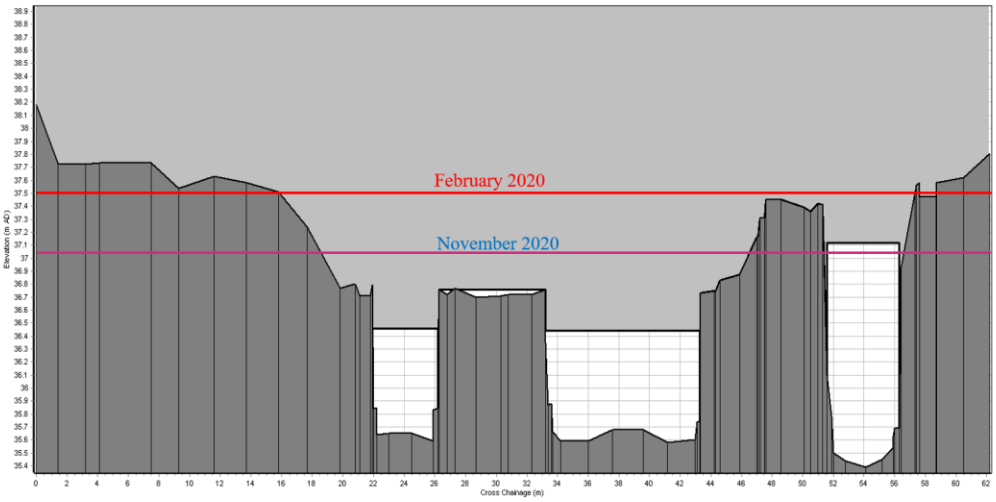

Figure 39: Pedestrian bridge geometry with maximum water levels for both 2020 events superimposed

Figure 40: Town Park Pedestrian bridge (looking upstream)

5.4 Out of bank Calibration (2009 event)

5.4.1 Overview

Once a very good in-bank calibration was achieved, the very significant November 2009 event was simulated with the 1D/2D hydraulic model.

The model simulation covered a 310.50-hour period and ran from 17/11/2009 17:15 to 27/11/2009 17:45.

5.4.2 Maximum Flood extents

The modelled and recorded maximum flood extents for the event is presented in **Figure 41**. It can be seen from the figure that the model is very well matched to the data as the modelled extent closely follows the recorded extent across the full study area. There are only a small number of areas where there is a very slight divergence between the model and recorded extents which are due to minor differences in the maximum water level between the two datasets. As the recorded extent was developed from the wrack mark data, the uncertainly associated with that dataset (discussed in the following sections) needs to be considered when assessing the minor divergences in the flood extent.

It can therefore be concluded that the model is well able to reproduce the flood extents associated with large fluvial events.

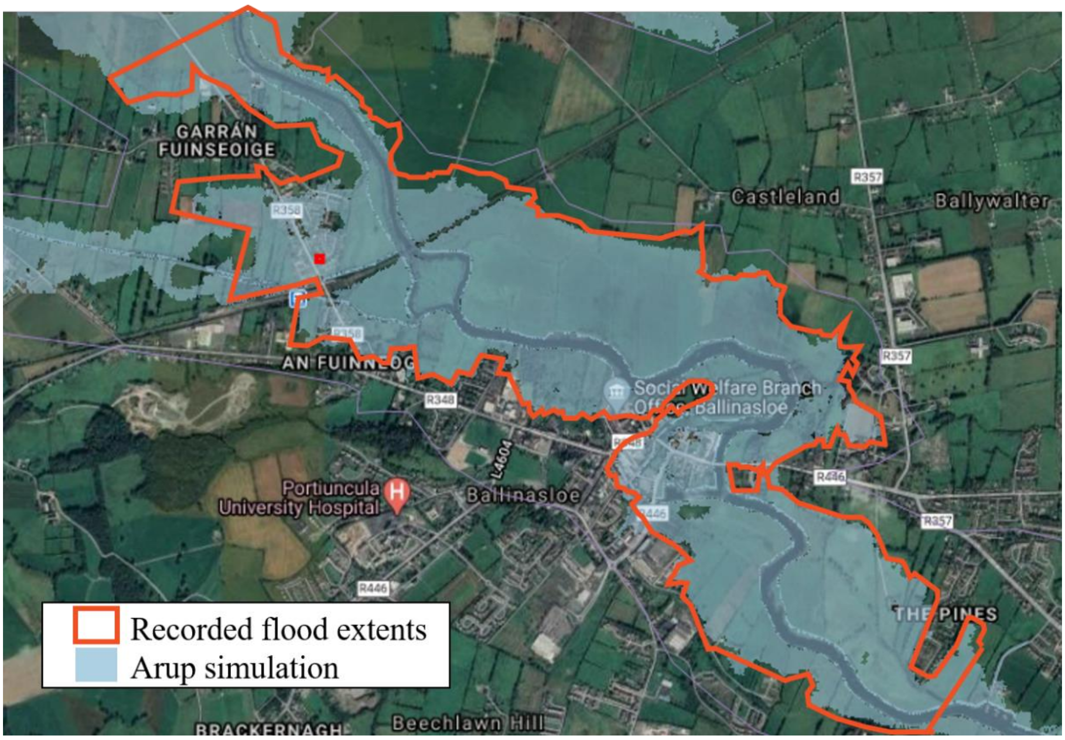

Figure 41: Comparison between the recorded flood extents and Arup's simulation result.

5.4.3 Maximum Water Levels - Derrymullen

Peak flood levels from the event have been estimated from post flood event wrack marks and surveyed to mOD. These wrack mark levels have been compared with modelled data in order to assess the ability of the model to reproduce peak water levels across the study area. As noted earlier in the report however the surveyed wrack marks in a few areas are inconsistent. The calibration therefore needs to be considered in light of this uncertainty.

Figure 42 presents the peak water level comparison in Derrymullen. Within the channel of the River Suck, it can be seen that the model is well calibrated to the observed maximum level at the Railway Bridge as the difference between the model and the data is circa 40mm. This gives us confidence that the model is representing peak water levels at this key hydraulic structure for the event.

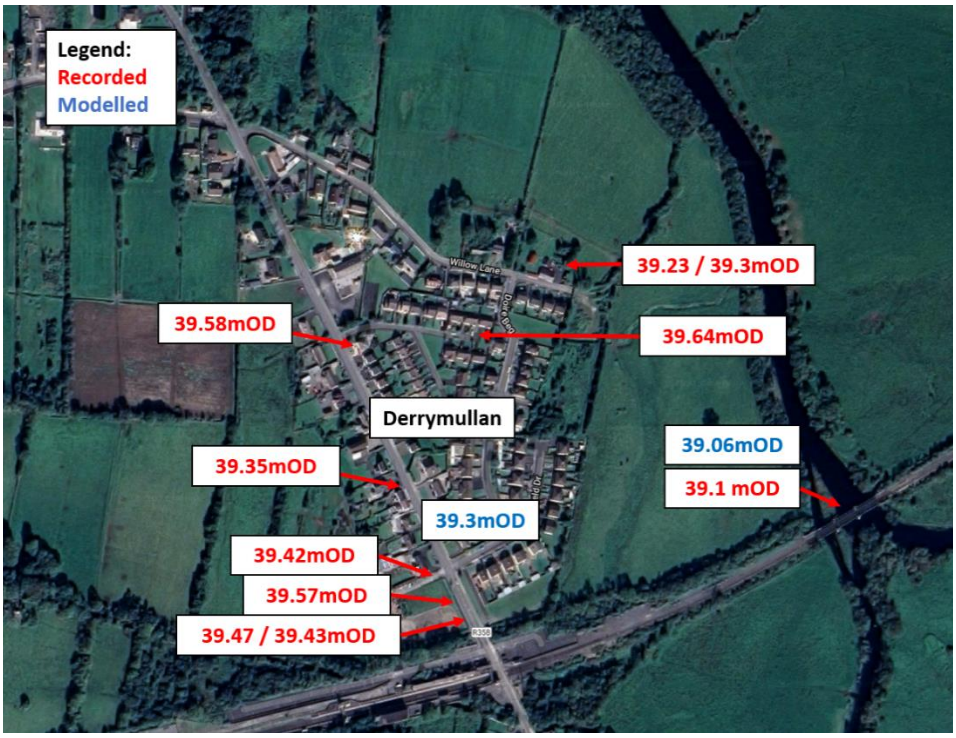

Figure 42: Maximum water levels at Derrymullen

We can see from **Figure 42** that the wrack marks are inconsistent within Derrymullen – the peak water levels immediately upstream of the railway crossing vary from 39.57mOD to 39.43mOD over a distance of 15m along the road. Over a longer distance of 150m the levels vary from 39.57mOD to 39.35mOD. Peak water level differences over these relatively short distances is deemed unrealistic for a major event on the River Suck given that the slow and prolonged nature of its flood hydrograph will generally result in a flat hydraulic gradient. The inconsistency in the data is therefore likely to be the result of errors in how the wrack marks were originally observed as outlined in Section 2.5.2.

When the complete set of wrack marks are considered, there is generally a lower bound estimate of circa 39.35mOD and an upper bound estimate of 39.6mOD. The modelled peak water level is a near constant circa 39.3mOD (i.e. the water level gradient is flat). Should the lower bound estimate of water level be representative of actual levels during the event it is clear that the model is well calibrated to the data. If, however the upper bound estimate is more representative then the model would be underestimating.

As part of the calibration process, numerous runs of the model with difference configurations of the mannings number and structure coefficients were undertaken to investigate if the model could produce water levels closer to the higher bound estimate.

It was found from these runs that the model cannot reproduce the higher bound estimate of peak water level in this area.

In assessing the performance of the model at this location we must first consider that the model is well calibrated to the observed level at the Railway Bridge and that the only differences are between the model and the upper bound estimate of water levels on the floodplain.

It is very unlikely that an error of circa 300mm (i.e. the difference between the model and the upper bound estimate) would develop in the 2D component of the model given that it is correctly schematised and utilises accurate input data. The results of the calibration therefore indicate that the lower bound estimate of peak water levels from the event (i.e. 39.35mOD) is more representative of actual water levels than the higher bound estimate (i.e. 39.6mOD). We can therefore state with confidence that the model is well calibrated to be the observed levels in both the channel and also on the floodplain.

5.4.4 Maximum Water Levels – Cleaghmore

Figure 43 presents the calibration downstream of the Railway line at Cleaghmore. It can be seen from the plot that the model is well calibrated to the recorded data as the difference in peak water level is circa 50mm.

Figure 43: Max Water Levels at Cleaghmore

5.4.5 Blockage of the Atlas channels during the 2009 event

The Atlas channels have been blocked out in the 2009 calibration model and are therefore not conveying any flow during the simulation.

This assumption is based on our knowledge of two separate blockages which were present in the channel during the event (**Figure 44**):

- The eastern channel was blocked underneath the local access bridge upstream of the R446 as indicated on **Figure 44**. The blockage caused flooding upstream of the access bridge and water flowed onto the entrance road into the castle grounds and also onto the R446 (Church Street);
- The channel downstream of East Bridge was also blocked during the event by a stone and clay embankment located adjacent to Atlas Industries. Water collected upstream of the blockage in the industrial yard until a machine was used to remove the blockage which allowed water to flow back into the channel. It is our understanding that this blockage was removed on the 22/11/2009 which is after the peak of the event.

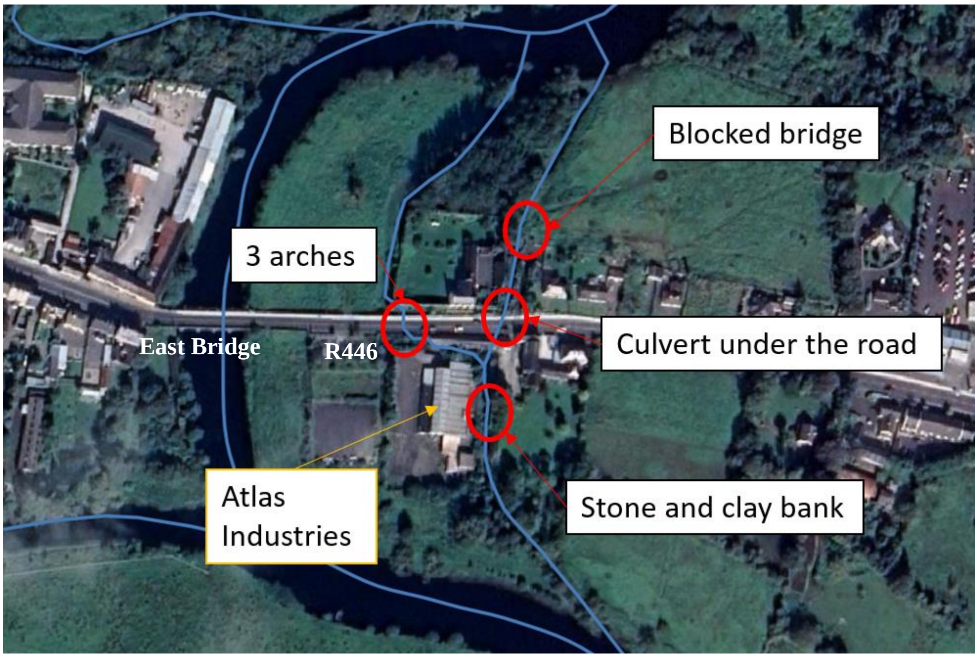

Figure 44: Situation at the Atlas channels during the 2009 event

Figure 45: Removal of the obstruction at the Atlas channels

Despite the presence of these blockages, it is possible that some water was able to flow downstream within the Atlas channel due to bypassing and/or overtopping of the blockages. Our assumption that the Atlas channels were fully blocked during the event may therefore be conservative i.e. the modelled water levels upstream of the East Bridge may be marginally overestimated.

5.4.6 Maximum Water Levels – Town Centre

Figure 46 presents the peak water level calibration for the main town centre. Anecdotal evidence suggests that the peak water level downstream of the bridge indicated on the plot (37.64mOD) was not taken at high water and is therefore not considered as part of the calibration.

It can be seen from the plot that the model is overestimating peak water levels by between 130mm and 210mm at different points upstream of the bridge. Given the uncertainty inherent in wrack mark data and the influence of the blockage on the flow through the Atlas channel during the event, this peak water level calibration is deemed to be good.

Figure 46: Maximum Water Levels in the Town Centre area

5.5 Conclusion of the hydraulic model calibration

The model has been calibrated against recorded water level data for two separate in-bank events from 2020. The model has also been calibrated against the very significant and out-of-bank flood event from November 2009.

In assessed the overall performance of the model we note that the project brief states that the project “shall aim for the calibrated models to have vertical accuracies of +0.1m, but not greater +0.2m, when compared to recorded flood event point data”.

The model is able to reproduce the water levels across the full hydrograph in the Old Channel for the February 2020 in-bank event. The difference between the recorded and modelled data for the event (40mm) is well within the 100mm tolerance specified by the brief. The modelled water levels at the same gauge for the November 2020 event are overestimated on account of the schematisation of the three individual channels through the reach as a single cross section in the model. The difference between the model and measured data for the peak of the event (130mm) is within the higher 200mm tolerance specified by the brief. For this same event the model is however well matched to the recorded data at the main Town Gauge (difference of 80mm) and is within the 100mm tolerance specified by the brief. It is therefore evident that the model is able to reproduce water levels within the tolerances specified by the brief at both gauges for low return period events. This gives us confidence in the accuracy and overall performance of the model.

The model is very well calibrated to the recorded flood extent of the 2009 event as the model closely matches the recorded extent of the flood. The model is also well calibrated to the lower bound estimate of maximum water level in Derrymullen and falls within the 100mm tolerance. The model is however underestimating when compared to the upper bound estimate of water levels and falls outside of the 200mm tolerance. We have concluded however that the upper bound estimate is highly unlikely to be representative of the actual water levels during the event due to errors in how the anecdotal data was observed and surveyed.

The model is well calibrated to the observed water level downstream of the Railway line at Cleaghmore where the difference between the model and data (50mm) is well within the 100mm tolerance.

The model appears to overestimate the peak water level upstream of East Bridge by between 130mm and 210mm at different locations. These differences are however all generally within the 200mm tolerance as specified by the brief. It is noted that flow through the Atlas channels was totally blocked out in the model due to the presence of two blockages which occurred along the stream during the event. If some flood water was able to flow past the blockages then the model may too conservative such that water levels upstream of the bridge may be overestimated. Due to the absence of data on the movement of water through the Atlas channels from the event it is not possible to investigate this issue further.

When all of the calibration runs are considered, it is evident that the model is able to reproduce maximum flood extents and maximum water levels within the specified tolerances across the study area for large flood events. The model is therefore deemed suitable to simulate design model runs as part of the study.

6 Design Runs

6.1 Design Model Runs

The calibrated model was used to simulate the design model runs for the study. In total eight design model runs have been simulated for the current scenario as listed in **Table 9**. Additional runs were also undertaken as part of the sensitivity analysis and in the assessment of the impact of climate change. These are described in Section 7 of the report.

It can be seen from **Table 9** that a downstream water level boundary condition of the 10% AEP on the River Shannon has been used for the design runs. This was selected in order to provide a conservative estimate of the downstream boundary in the model.

Table 9: Design model runs

Model Run No.	Scenario	Design Event	Upstream Boundary	Downstream WL boundary on the River Shannon
1	Fluvial	50% AEP	50% AEP	10% AEP
2	Fluvial	20% AEP	20% AEP	10% AEP
3	Fluvial	10% AEP	10% AEP	10% AEP
4	Fluvial	5% AEP	5% AEP	10% AEP
5	Fluvial	2% AEP	2% AEP	10% AEP
6	Fluvial	1% AEP	1% AEP	10% AEP
7	Fluvial	0.5% AEP	0.5% AEP	10% AEP
8	Fluvial	0.1% AEP	0.1% AEP	10% AEP

6.2 Flood Extents and Nodes

Appendix A presents an image of the current scenario 10%, 1% and 0.1% AEP flood extents. Fluvial flood depths are also presented for the 1% AEP event.

Flood extents are presented in shapefile format as a digital deliverable accompanying this report. The shapefiles are in compliance with Appendix G (I) of the OPW FRS Engineering Spatial Data Specification[10] as per the instruction in the project brief. Defended and undefended runs are presented.

Maximum water levels at each of the nodes in the 1D model for the full range of return periods events are presented in Appendix B. Maximum water levels are also presented in longitudinal plot form, as well as in GIS format. GIS outputs of the maximum flows at each node are provided in both table and GIS format.

[10] Office of Public Works (September 2021), *Flood Relief Scheme Engineering Spatial Data Specification*, online gov.ie - Technical Specifications and Guidance Notes (www.gov.ie)

These model outputs reflect the results of the hydrological assessment, whose focus being the Design of the Scheme. The results are discussed in the following sections of the report.

6.3 Discussion of the Fluvial Flood Risk - Current Scenario

The baseline design model runs assume that blockages do not occur at any of the culverts or bridges in the model. A blockage sensitivity and their impact on flood risk will however be assessed as part of the optioneering and be discussed in the Options report.

The baseline model also assumes that the flood defence scheme at Derrymullen is operating as designed.

The following sections of the report present a discussion on the baseline design runs. The reader is referred to the accompanying GIS files for the modelled flood extents.

6.4 50% AEP (Q2) event

Significant parts of the study area immediately adjacent to the River Suck are low lying and at risk of flooding from low return period events, due to the main channel having insufficient capacity to accommodate the peak flow of the event. As these areas are predominately grass land, there are no properties at risk of inundation. Flood water does however encroach on the curtilage of a number of the properties for these low return period events.

In Derrymullen, both the Deerpark and River Suck get out of bank for the Q2 event, due to insufficient channel capacity. Backwatering from the reach downstream of the railway embankment also contributes to the flood risk. Large areas of the floodplain both to the west of Derrymullen and immediately adjacent to the River Suck are inundated. While no properties are inundated by the event in Derrymullen, flood waters do encroach on a number of commercial properties along the R358.

Large areas of the floodplain downstream of the railway line are also inundated by the Q2 event and the flood extent encroaches on a number of residential properties at Sarsfield Crescent, as well the Oliver Colohan commercial property closer to the town.

Within the town centre, the Q2 event is kept largely in bank and no properties are inundated. For this event, the East Bridge is sufficiently large to be able to accommodate the flow i.e. there is no significant head loss across the bridge.

Downstream of the town centre, low-lying areas are also inundated but this does not lead to any flooding of properties. The Ballyhugh get outs of bank in the Q2 event and inundates a number of properties on Portnick Drive.

Across the whole scheme area, 9no residential properties and no commercial properties are inundated by this event.

6.5 20% AEP (Q5) event

The Q5 maximum modelled extent is very similar to the Q2 event. The additional volume of water added by the Q5 event increases flood depths, but it does not lead to any significant increase in the flooded extent due to the bowl-shaped topography of the study area.

A number of commercial properties in Derrymullen (along the R258) are inundated by the Q5 event. The Oliver Colohan commercial property upstream of the town centre is also inundated. No properties in the main part of the town or in the vicinity of the Old Town Channel are flooded in this event.

There are some increases in the flood extent downstream of the town centre and flood waters encroach on the residential properties at Riverside View, but they are not inundated by the event.

The Q5 flood extent on the Ballyhugh is marginally greater than the Q2 event on Portnick Drive but no new additional properties are inundated.

Across the whole scheme area, 12no residential properties and no commercial properties are inundated by this event.

6.6 10% AEP (Q10) event

The Q10 flood extent in Derrymullen is only marginally greater than the Q5 flood extent and the same commercial properties inundated by the Q5 event along the R358 are also inundated by the Q10 event.

A number of properties within the town centre are inundated by the Q10 event. Two separate area are impacted: (1) the right bank of the River Suck downstream of East Bridge, and (2) the right bank of the Old Town Canal along Bolger's Lane. The Atlas Industries commercial property immediately adjacent to the Atlas channel is also inundated by the event. The Q10 event therefore represents the threshold of flooding within the centre of the Town.

The Q10 flood extents downstream of the town centre are largely the same as the Q5 extent and no additional properties are brought into the floodplain for this higher event.

Across the whole scheme area, 21no residential properties and 3no commercial properties are inundated by this event.

It is noted that an additional 8no residential properties are inundated in Derrymullen for this event in the Derrymullen undefended scenario.

6.7 5% AEP (Q20) event

The commercial properties along the R358 in Derrymullen are flooded to greater depths in the Q20 event when compared with the Q10 event. The number of properties impacted however remains the same.

A number of residential properties along the R358 downstream of the Railway line are inundated from behind by overland flow from the River Suck. The Q20 event therefore represents the threshold of flooding for the properties in this area of the town.

Within the town centre all of Bolger's Lane and its adjacent side streets (Woodslip Lane, Hopsons Lane) are inundated by the Q20 event. St Michael's Square is also flooded.

A number of buildings upstream of East Bridge on the right bank of the River Suck are also inundated by the Q20 event including John Murray hardware stores.

The Q20 flood extents downstream of the town centre are largely the same as the Q10 extent and no additional properties are brought into the floodplain.

Across the whole scheme area, 42no residential properties and 10no commercial properties are inundated by this event.

6.8 2% AEP (Q50) event

A number of additional commercial and residential properties along the R358 are inundated by the Q50 event in Derrymullen when compared against the Q20 event. A greater number of residential properties are also inundated along the R358 downstream of the Railway line by the River Suck which also crosses the road at two separate points at this location. A number of residential properties are also inundated in Sarsfield Crescent for this event.

There is significant flooding of the town centre in the Q50 event with large areas of Bolger's Lane, its adjacent side streets and St Michael's square inundated. The Lidl store to the South of the Square is also flooded.

There is significant flooding of properties both upstream and downstream of East Bridge and also along the Atlas channel by the same mechanisms of flooding which occurred in the Q20 event. In the Q50 event the flooded extent extends across the road and inundates residential properties.

A number of both commercial and residential properties are also inundated in the vicinity of the Atlas channels and along Church Street.

The Q50 event leads to the inundation of a number of properties downstream of the town centre. A small number of commercial properties are inundated along Canal Drive. The culvert underneath Canal Drive and the L4602 is surcharged by the River Suck and causes water from the Suck to flow out its entrance into farmland adjacent to the L4602.

The biggest impact of this event downstream of the town is in Riverside View where the River Suck overtops the road along the Eastern side of the estate and floods a number of residential properties. The Q50 event is therefore the threshold of flooding for this estate.

The Moycarn Lodge at the confluence of the River Suck and the Ballyhugh is also inundated by the River Suck in the Q50 event.

Across the whole scheme area, 94no residential properties and 28no commercial properties are inundated by this event.

6.9 1% AEP (Q100) event

The Q100 event is the design event of the proposed scheme. Upstream of the railway line the Derrymullen flood defence scheme protects all the properties in the Derrymullen estate from both the River Suck and the Deerpark. The scheme is therefore offering the required standard of protection to the various properties. There are no additional properties flooded in this area beyond what was inundated during the Q50 event.

Flooding downstream of the railway line is more extensive in the Q100 event when compared against the Q50 event and a greater number of properties are inundated at a number of locations including along the R358, at Sarsfield Close and River View.

There is very significant flooding of the town centre in the Q100 with all of the area around Bolger's Lane inundated up as far as Main Street. The Church is also inundated due to the extensive flooding of St Michael's square.

All of the properties along Church road in the vicinity of East Bridge and the Atlas channel are inundated during the Q100 event from overland flow that originates from the right bank of the River Suck upstream of the East Bridge.

A number of both commercial and residential properties are also inundated in the vicinity of the Atlas channel and along Church Street.

Downstream of the town centre the entire Riverside View estate is inundated in the Q100 event, and a greater number of properties are also inundated by the Ballyhugh in this event when compared with the Q50 event.

Across the whole scheme area, 162no residential properties and 55no commercial properties are inundated by this event.

It is noted that an additional 89no residential properties and 3no commercial properties are inundated in Derrymullen for this event in the Derrymullen undefended scenario.

6.10 0.5% AEP (Q200) event

The most notable difference between the Q200 and Q100 flood extents across the study area relates to Derrymullen. The area defended by the existing Derrymullen scheme is fully inundated in the Q200 event due to overland flow from the River Suck which enters the estate from the north. Once water enters the estate it is contained by the flood walls and collects there.

In the main area of the town the entire area upstream of the East Bridge is inundated by the Q200 event. The Shearwater hotel is also inundated by overland flow from the River Suck from the north.

Across the whole scheme area, 291no residential properties and 69no commercial properties are inundated by this event.

6.11 0.1% AEP (Q1000) event

The Q1000 event leads to very extensive flooding right across Ballinasloe. Upstream of the Railway bridge a large number of residential properties in the vicinity of Oakmill Drive that are not at risk from the Q100 event are inundated by this event. Likewise, immediately downstream of the railway, a number of properties along the R348 that are not at risk in the Q100 event are inundated by the Q1000 event.

The surcharging of the culvert underneath Canal Drive and the L4602 is very significant in this event and leads to a number of residential properties in Meadowbrook Close to be inundated. A number of commercial properties adjacent to the Shearwater Hotel are also flooded by this event.

The town centre is very extensively flooded by the Q1000 event with flood water reaching the edge of Main Street. The Q1000 event introduces a number of additional flow paths along the Ballyhugh which inundates a number of properties along the reach.

Across the whole scheme area, 411no residential properties and 96no commercial properties are inundated by this event. This includes all of the properties in the area defended by the existing Derrymullen flood defences.

6.12 Summary of results

There is a significant risk of flooding throughout Ballinasloe from both the River Suck and its principal tributaries. Large areas of the town are inundated for the design event.

The principal mechanism of flooding is insufficient channel capacity coupled with backwatering from two key structures: the railway embankment and the East Bridge.

When the operational protocol of the Derrymullen Flood defence scheme is followed the results of the model confirm that the scheme protects the defended area up to and including the Q100 event as defined by the Ballinasloe FRS.

The findings of the study will be brought forward to optioneering stage of the project where additional hydraulic analysis of the options will be undertaken. This work will be reported on in the Options report.

7 Sensitivity Analysis

7.1 List of Sensitivity Runs

A number of sensitivity analysis runs were undertaken to assess how the 1% AEP design water levels for the existing scenario may vary under different modelling assumptions. A complete list of the sensitivity runs is presented in the **Table 10**. The results of the sensitivity model runs are presented in Section 7.2.

Table 10: List of sensitivity model runs

Sensitivity Parameter	SA model no.	Model runs
Manning's Value	1a and 1b	1a) +20% increase in the Manning's number across both the 1D and 2D model 1b) -20% increase in the Manning's number across both the 1D and 2D model
Bridge Head Loss Coefficients	2	Specification of a higher head loss coefficient parameter at critical hydraulic structures: East Bridge Railway Bridge
Bridge unit type	3	Specification of an alternative bridge unit at key hydraulic structures. The following bridge was considered: East Bridge changed from an ARCH to an USBPR bridge unit
Atlas channels – conveyance sensitivity	4	Cross sectional area of the Atlas channels were reduced in order to test the sensitivity of the model to the dimensions of the channels
Derrymullen Flood Defence Scheme – Undefended	5	The Derrymullen Flood Defence scheme was removed from the model.

7.2 Sensitivity Analysis Results

7.2.1 Changes to the Manning's number

Both a 20% increase and a 20% decrease was applied to the Manning's number for both the 1D and 2D model domains to test the sensitivity of the model to changes in roughness values.

Figure 47 presents a longitudinal plot of the maximum water levels reached along the River Suck for the +20% Manning's n scenario.

It can be seen that the increased roughness increases the maximum water levels along the reach by circa 200 – 250mm.

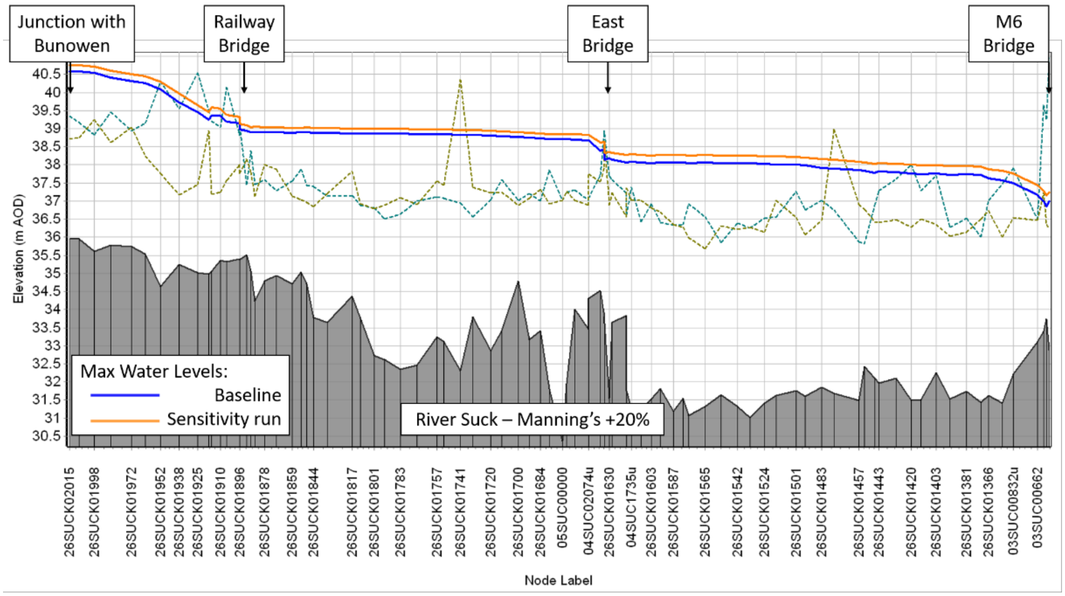

Figure 47: Longitudinal plot of the Maximum WLs along the River Suck - baseline Q100 model with 20% increase in Manning's n

The most significant difference arising from the manning's sensitivity is experienced in Derrymullen as indicated in **Figure 48**. It can be seen from the figure that the estate is inundated by overland flow from the North in this scenario.

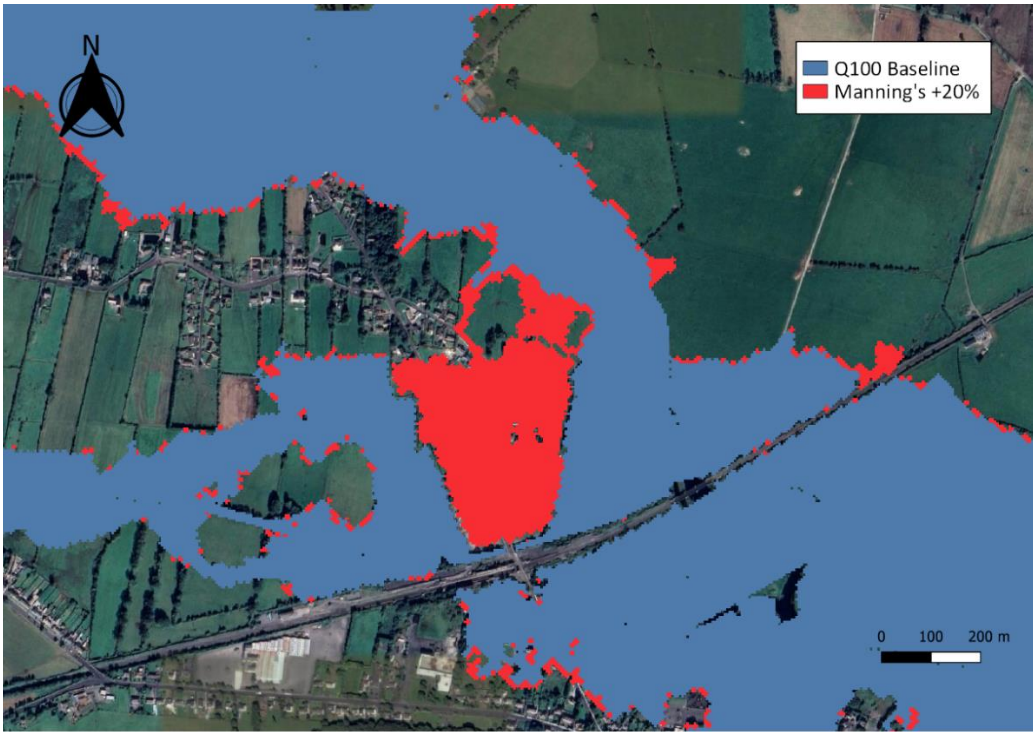

Figure 48: Manning's number sensitivity – impact in Derrymullen for the Q100 event

Figure 49 presents a longitudinal plot of the maximum water levels reached along the River Suck for the -20% Manning's n scenario.

It can be seen that the reduced roughness reduces the maximum water levels along the reach by circa 500 – 600mm.

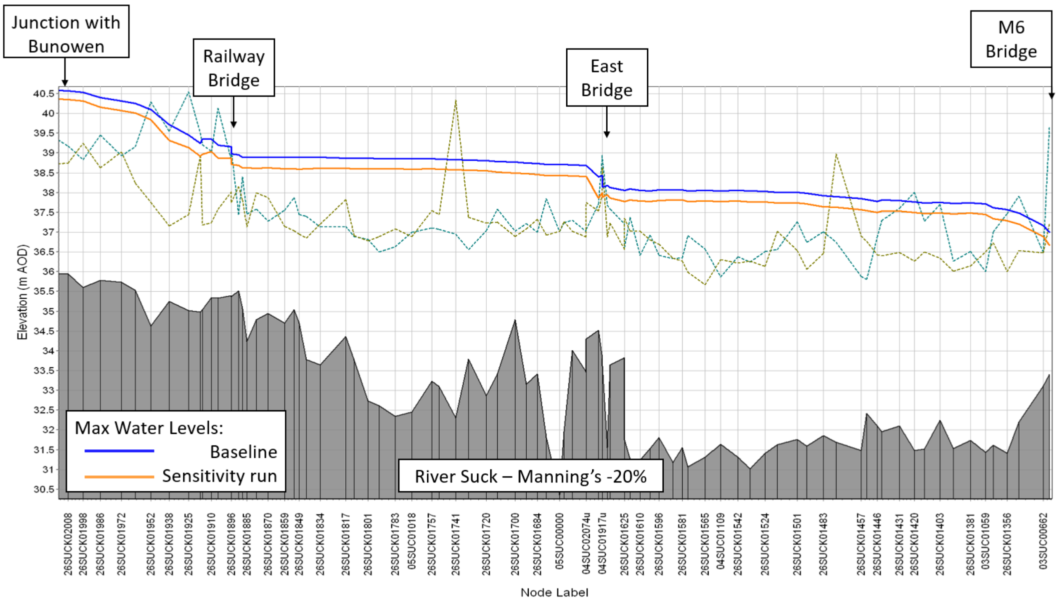

Figure 49: Longitudinal plot of the Maximum WLs along the River Suck - baseline Q100 model with 20% decrease in Manning's n

7.2.2 Bridge Head Loss

The effects of increasing the entrance head-loss coefficient have been investigated for the two key structures in the study area:

- the East Bridge;
- Railway Bridge south of Derrymullen.

These bridges were selected for the sensitivity as they exert a significant influence on the design flood levels.

As can be seen from Appendix C, more structures are present in the model, but these two are the most important and were considered the most likely to have an influence on the water levels.

In both cases the head-loss coefficient was increased from 1 to 2 as part of the sensitivity. **Figure 50** presents the maximum water levels reached for the River Suck, while **Figure 51** presents a zoomed-in detail in the immediate vicinity of the East Bridge. It can be seen from the figures that the maximum water level upstream of the bridge is increased by circa 30mm.

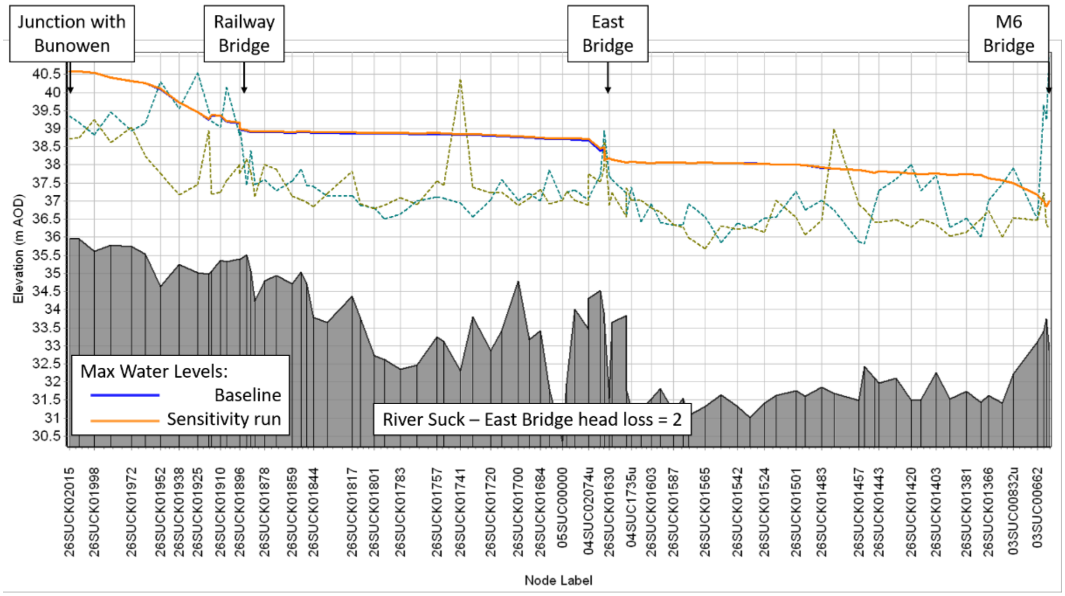

Figure 50: Longitudinal plot of the Max WLs along the River Suck - baseline Q100 model with East Bridge head-loss coefficient sensitivity analysis

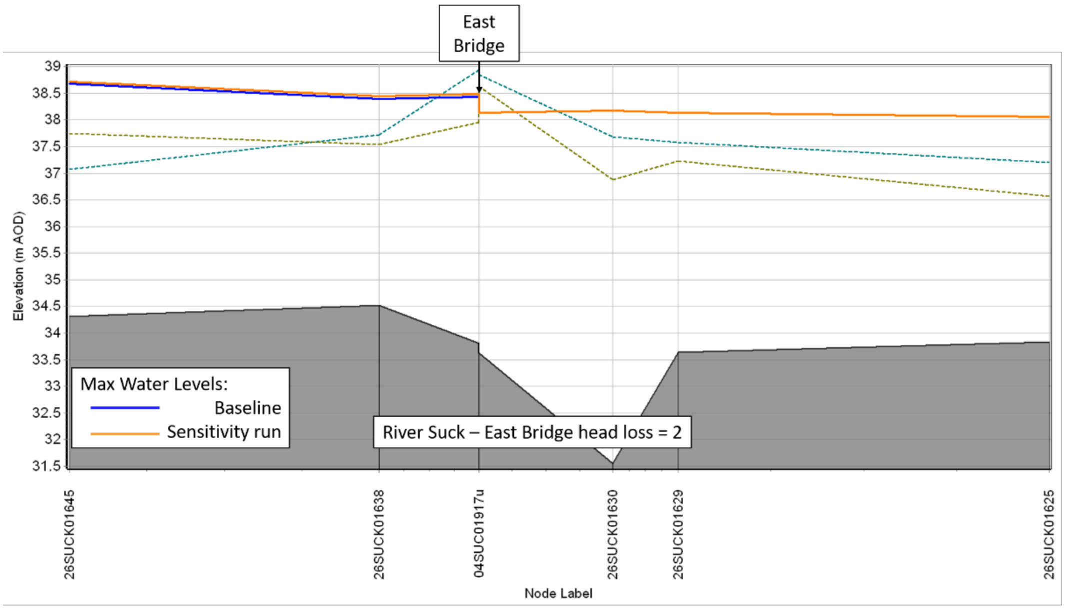

Figure 51: Zoomed in longitudinal plot of the Max WLs along the River Suck - baseline Q100 model with East Bridge head-loss coefficient sensitivity analysis

Figure 52 and **Figure 53** present the results of the sensitivity for Railway Bridge. Upstream of the bridge the increase in water level is circa 60mm with the increased head loss coefficient.

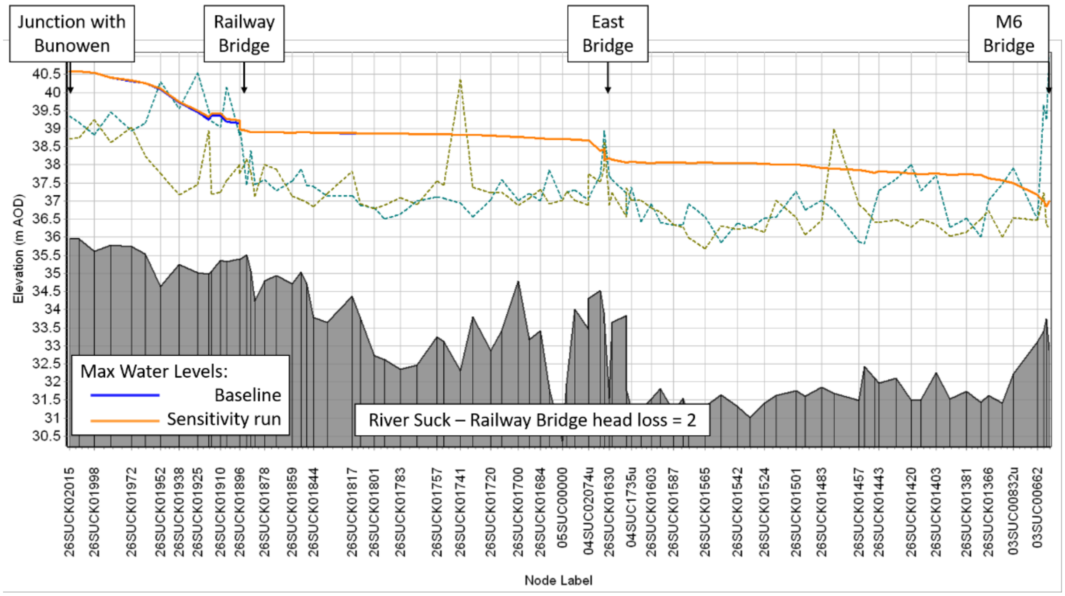

Figure 52: Longitudinal plot of the Max WLs along the River Suck - baseline Q100 model with Railway Bridge head-loss coefficient sensitivity analysis

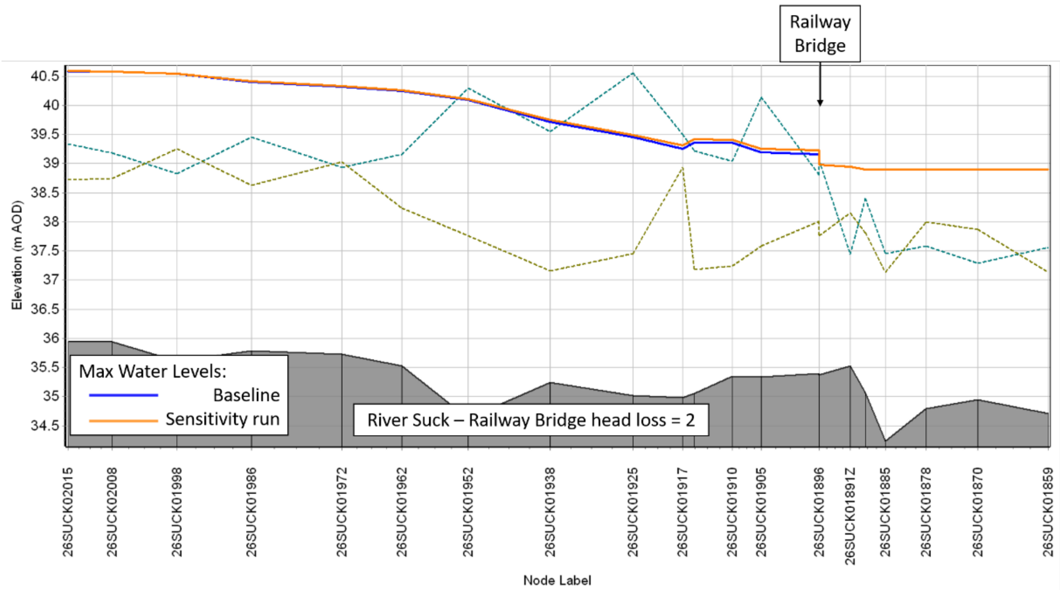

Figure 53: Zoomed in longitudinal plot of the Max WLs along the River Suck - baseline Q100 model with Railway Bridge head-loss coefficient sensitivity analysis

The sensitivity demonstrates that the peak water levels upstream of the bridge are sensitive to increases in head loss coefficient. This will be further considered as part of the optioneering for the scheme.

7.2.3 Bridge Unit Type

The East Bridge was changed from an ARCH to an USBPR bridge type unit, while maintaining all other parameter exactly the same. **Figure 54** and **Figure 55** present the results of the sensitivity run.

It can be seen that the water levels are sensitive to the representation of the bridge as a USBRP unit as they are increased by circa 80mm upstream of the bridge. This will be further considered as part of the optioneering of the scheme.

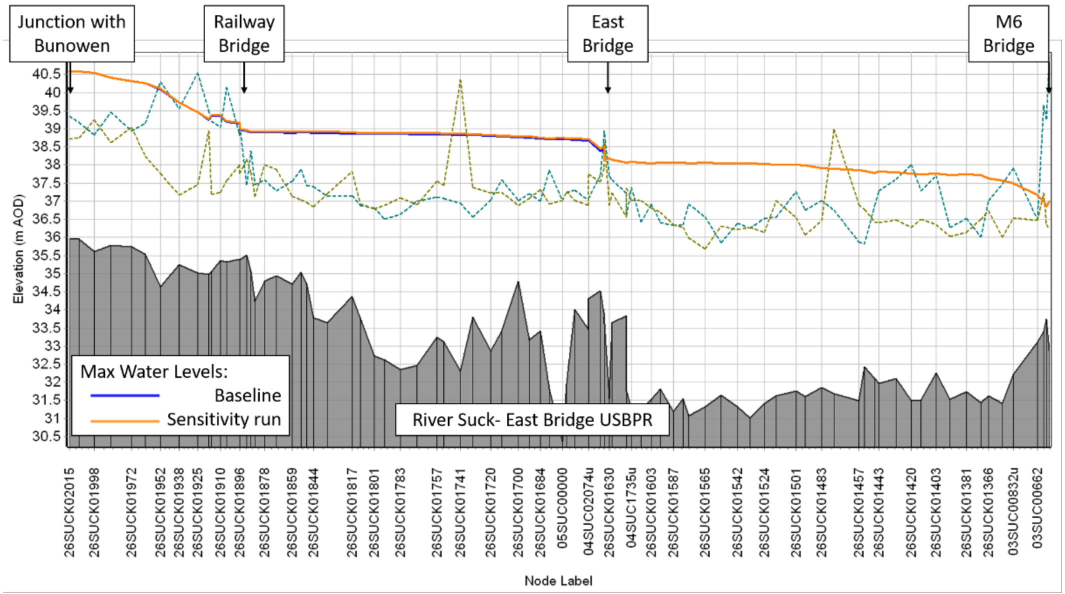

Figure 54: Longitudinal plot of the Max WLs along the River Suck - baseline Q100 model with East Bridge defined as a USBPR

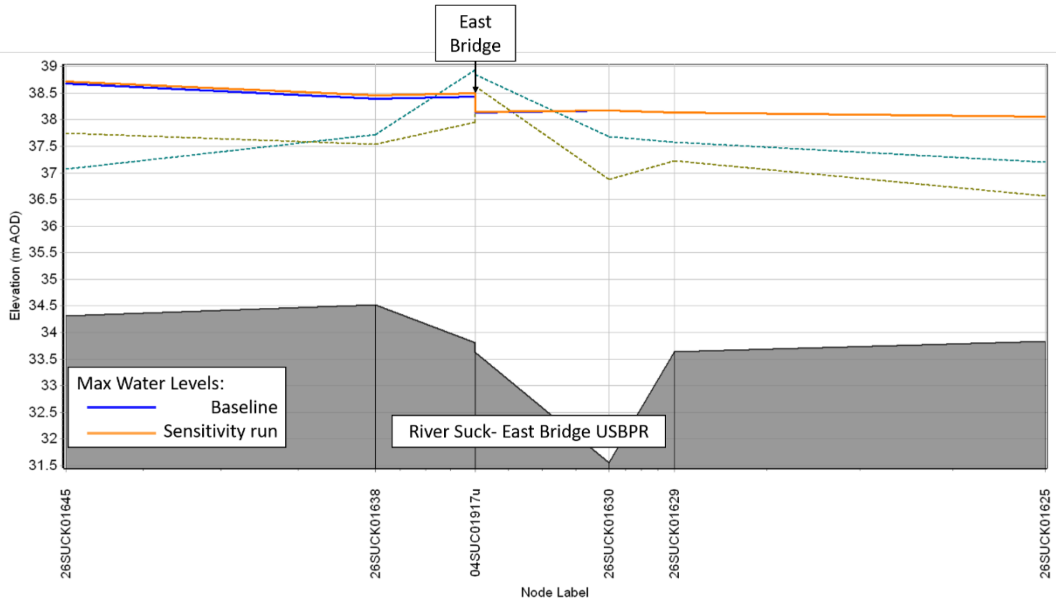

Figure 55: Zoomed in longitudinal plot of the Max WLs along the River Suck - baseline Q100 model with East Bridge defined as a USBPR

7.2.4 Atlas channels cross sectional area sensitivity

Conveyance through the Atlas channels is curtailed by the presence of ineffective flows areas which will occur due to the irregular shaped alignment of the channel. The impact of these ineffective flow areas has been assessed by reducing the cross-sectional area of the bridge opening by 50%.

Figure 56 presents the results of the sensitivity run. It is evident from the plot that the model is not sensitive to the reduction in cross sectional area as the main bridge opening on the River Suck conveys the far greater percentage of the flow when compared with the flow being conveyed along the Atlas channel.

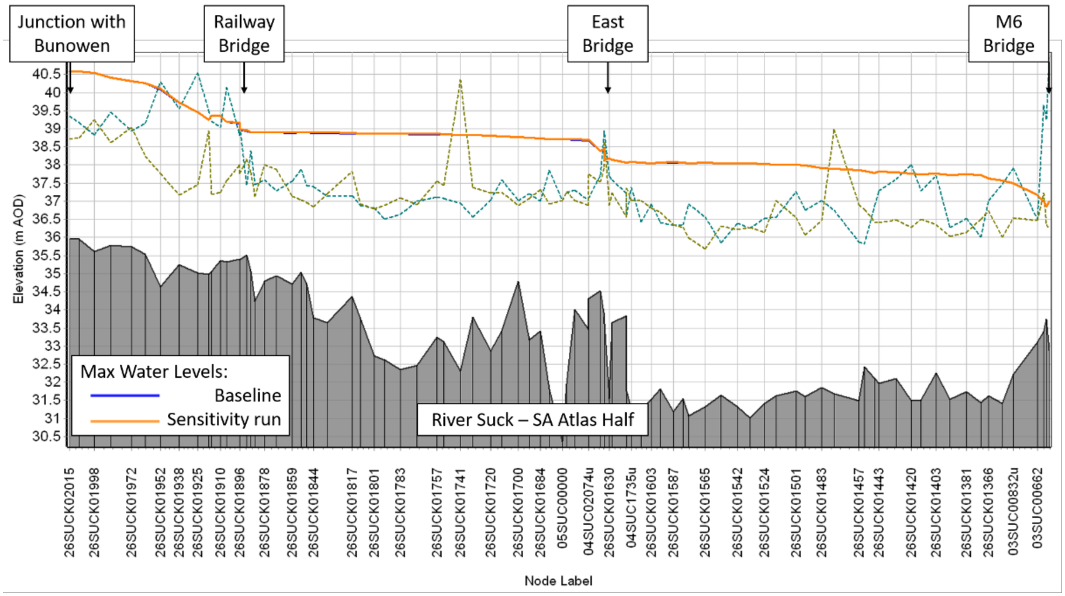

Figure 56: Longitudinal plot of the Max WLs along the River Suck - baseline Q100 model with Atlas channels sensitivity run

A more detailed discussion on Blockage Design can be found in the accompanying Options Report blockage modelling.

7.2.5 Derrymullen Undefended Sensitivity Analysis

The hydraulic model was run with the Derrymullen defences on the South, East and West side of the development removed (see **Figure 30** and Section 4.5 for a description of the defences).

Figure 57 presents the findings of the sensitivity for the 10% AEP scenario. It can be seen that the Westend end of the development is inundated in the undefended 10% AEP event.

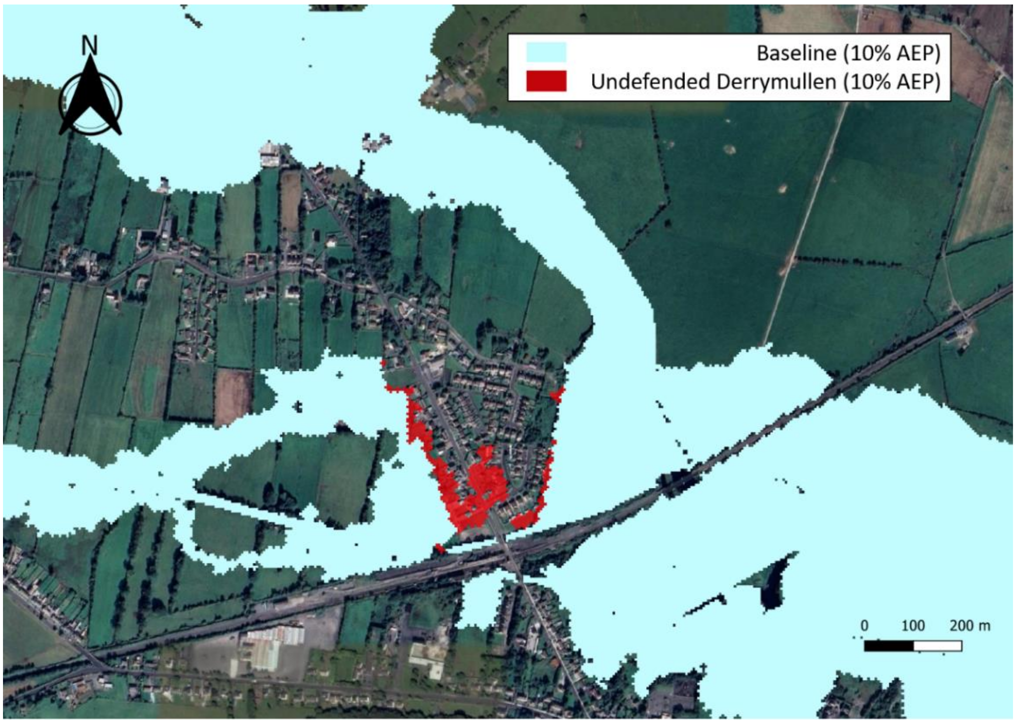

Figure 57: Comparison of flood extents for the Derrymullen Undefended scenario (10% AEP)

Figure 58 presents the flood extents for the 1% AEP scenario. It is evident from the plot that most of Derrymullen is flooded in the undefended scenario for this AEP event.

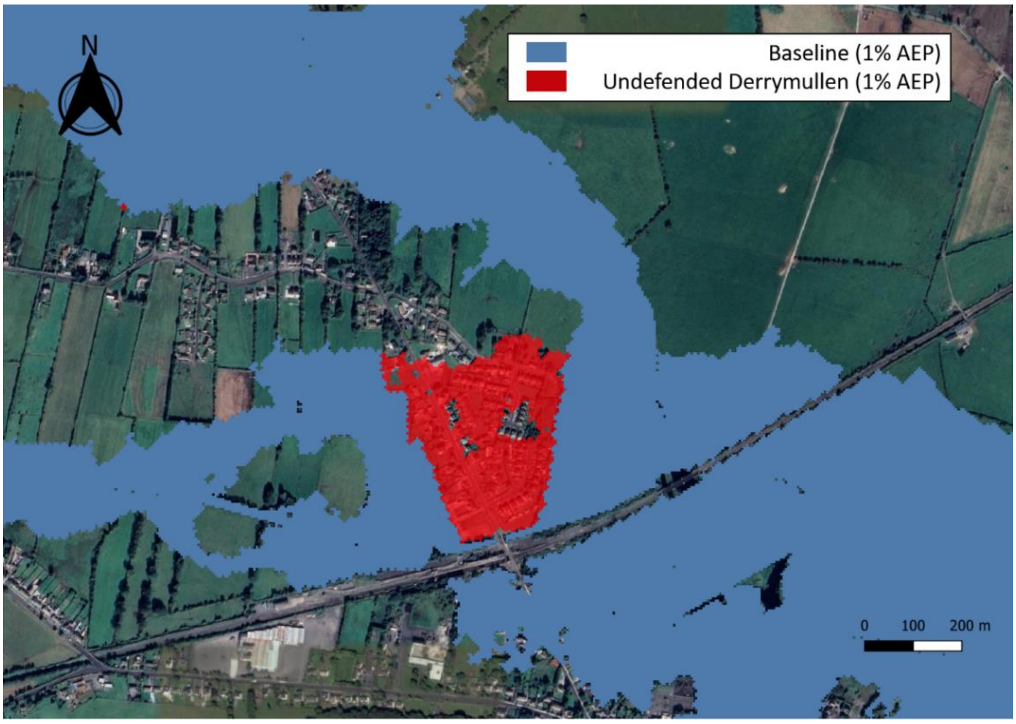

Figure 58: Comparison of flood extents for the Derrymullen Undefended scenario (1% AEP)

Figure 59 presents the flood extents in the Derrymullen area for the 0.1% AEP scenario. This scenario results in the whole estate being inundated for both the defended and undefended scenario.

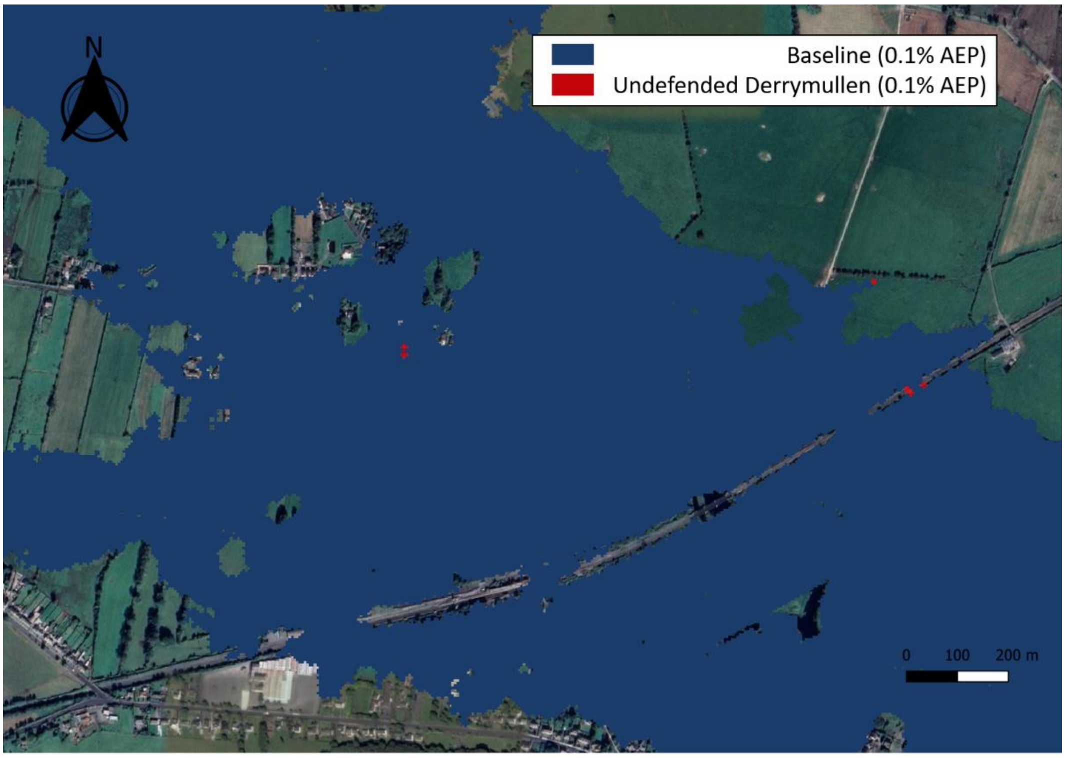

Figure 59: Comparison of flood extents for the Derrymullen Undefended scenario (0.1% AEP)

7.3 Climate Change Design runs

The hydraulic model was simulated with uplifts in the design flow to account for the potential impact of climate change. A 20% uplift for the Mid-Range Future Scenario and a 30% uplift for the High-End Future Scenario have been applied. **Figure 60** presents the findings of the sensitivity run. It can be seen from the plot that the average increase in WL across the study area is 300mm for the MFRS, and 440mm for the HEFS, when compared to the baseline case.

The increase in flood risk associated with climate change will therefore be significant and will result in a greater number of properties being inundated.

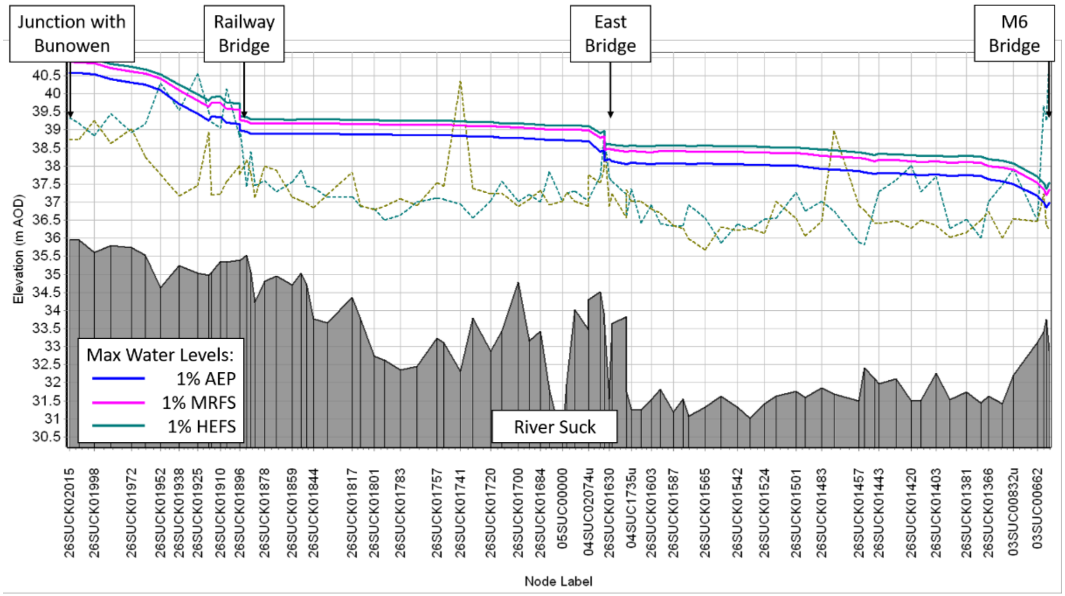

Figure 60: Longitudinal plot for the Q100 Climate Change runs

8 Conclusions

A dynamic 1D/2D hydraulic model of all the relevant watercourses in Ballinasloe and associated floodplain areas was developed as part of the study in order to assess flood risk across the study area. The model simulated a range of fluvial design flood events for the current scenario.

The findings of the hydrological assessment undertaken as part of the study were used to define the fluvial inflows into the models. Fluvial water levels on the River Shannon were used to define the downstream boundary of the model and are based on peak water levels estimated as part of the Shannon CFRAM study.

The 1D/2D hydraulic model was calibrated against a number of different events: two minor in-bank events which occurred 2020 and also against the very significant out-of-bank event from November 2009.

Overall a very good match was achieved between the modelled and measured results across Ballinasloe. It is therefore evident that the model is able to reproduce maximum flood extents and maximum water levels within the specified tolerances across the study area for large flood events. The model is therefore deemed suitable to simulate design model runs as part of the study. The model is also deemed suitable to assess various engineering options to mitigate flood risk in the town.

Fluvial flood extent maps were produced from the result files of the model and highlight all the flood risk areas in the town. It was seen from the results that a large area of Ballinasloe is at risk of flooding.

The findings of the study will be brought forward to optioneering stage of the project where additional hydraulic analysis of the options will be undertaken. This work will be reported on in the Options report.