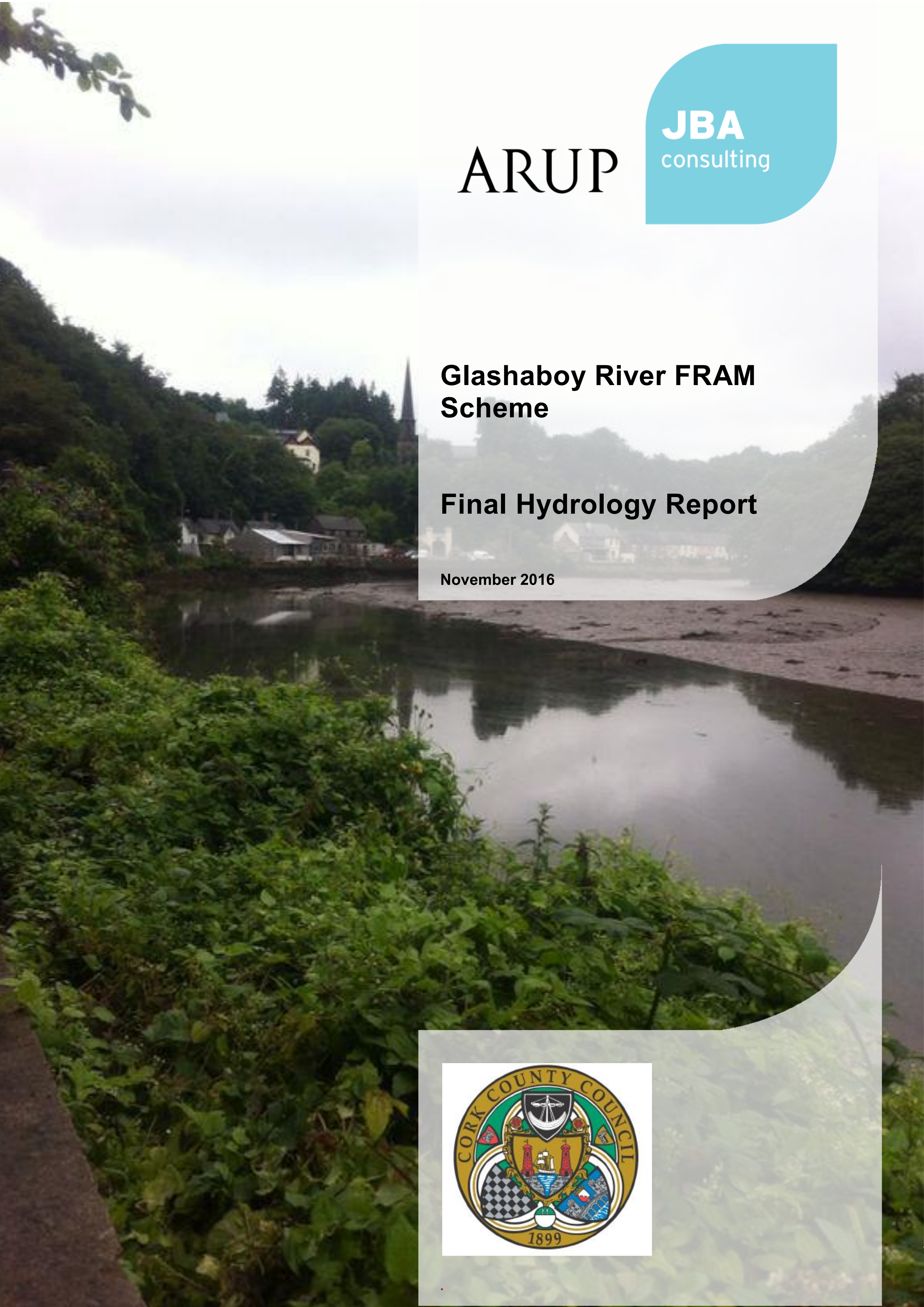

ARUP

JBA consulting

Glashaboy River FRAM Scheme

Final Hydrology Report

November 2016

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Revision History

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Issue V2 - 19 January 2015	Revision following OPW / CCC comments dated 24/09/2014	Cork County Council
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Issue V5 - 03 May 2016	Addition of Appendix C	Cork County Council and Steering Group
Issue V6 - 16 November 2016	Final amendments -	Cork County Council and Steering Group

Contract

This report describes work commissioned by the Cork County Council, under the Glashaboy River FRAM Scheme. CCC's representative for the contract was Colm Brennan. David Moran and Joanne Cullinane of JBA Consulting carried out this work.

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Purpose

This document has been prepared as a hydrology report for the Cork County Council. JBA Consulting accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared.

Acknowledgments

The EPA provided considerable data, including river flows and levels and the OPW provided accounts of historical flooding.

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Abbreviations

2D	Two Dimensional (modelling)
AEP	Annual Exceedance Probability
AMAX	Annual Maximum
APSR	Area of Potential Significant Risk
CFRAM	Catchment Flood Risk Assessment and Management
DoEHLG	Department of the Environment, Heritage and Local Government
DS	Downstream
DTM	Digital Terrain Model
EPA	Environmental Protection Agency
FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
FRMP	Flood Risk Management Plan
FSR	Flood Studies Report
FSU	Flood Studies Update
GEV	General Extreme Value Distribution
GL	General Logistic Distribution
GS	Gauging Station
HEP	Hydrological Estimation Point
ISIS	Hydrology and hydraulic modelling software

mOD	Meters above Ordnance Datum
MRFS	Medium Range Future Scenario
OPW	Office of Public Works
POT	Peaks Over a Threshold
QMED	Median Annual Flood (with return period 2 years)
SAAR	Standard Average Annual Rainfall (mm)
Tp	Time to Peak
TUFLOW	Two-dimensional Unsteady FLOW (a hydraulic model)
WINFAP-FEH	Windows Frequency Analysis Package - FEH version

1. Introduction

1.1 Context of the Study

Glanmire Town, in County Cork, has a long history of serious flooding, primarily due to high flows in the River Glashaboy exceeding the channel capacity. Surface water flooding associated with heavy rainfall and exceedance of the drainage system is also a problem. Glanmire and Sallybrook are at risk at both fluvial and tidal flooding. Tidal flooding results from tides and storm surges propagating up the Glashaboy River estuary and extends upstream of Glanmire Village in extreme tide events, and would be experienced as far upstream as the weir at the council water intake. River levels can be exacerbated by high tides in the River Lee estuary. The interaction of the tide and river flows will be investigated through the hydraulic modelling study. The most severe recorded flooding occurred in June 2012. Flooding has also occurred in November 2009, October 2004, November 2000 and December 2015.

Following recommendations contained within the Lee Catchment and Flood Risk Management (CFRAM) Study, and in particular the Flood Risk Management Plan (FRMP) and following the 2012 flood event, Arup and JBA Consulting were commissioned by the Cork County Council (CCoC) to assess the flood risk within the Glanmire Area and develop a flood relief scheme and other measures to manage this risk. The project will comprise five stages:

- Stage I - Feasibility study and preparation of a flood risk management plan
- Stage II - Public exhibition
- Stage III - Detailed design, confirmation and tender
- Stage IV - Construction
- Stage V - Handover of works

This hydrology report is one of a series being produced under Stage I of the project.

1.2 Scope of this Report

1.2.1 Project Brief

Key tasks identified in the project brief for the hydrological analysis are:

- Review and analysis of historic floods
- Delineation of catchment boundaries
- Analysis of hydrometric and meteorological data
- Estimation of design flood parameters
- Appraisal of future environmental and catchment changes with a view to determining the likely future operational capability of the scheme

This report details the work undertaken to complete these tasks and presents the results of the analysis.

1.2.2 Content and Key Tasks

This report provides an assessment of the flood hydrology of the Glashaboy river catchment, from its headwaters in the Nagle Mountains to its tidal limit at Lee Estuary. Details are provided regarding flow estimation locations, flow estimation methods and the flow estimates themselves.

1.2.3 Report Structure

This section provides an outline of the study and a description of the Glashaboy River catchment. The flood history of the town is explored in Section 2 and a discussion of the catchment boundaries and flow estimation points is provided in Section 3. The catchment hydrometric data is reviewed in Section 4, and in Section 5 the rating review for two gauges is detailed. Section 6 outlines various flow estimation methodologies and design flow estimates.

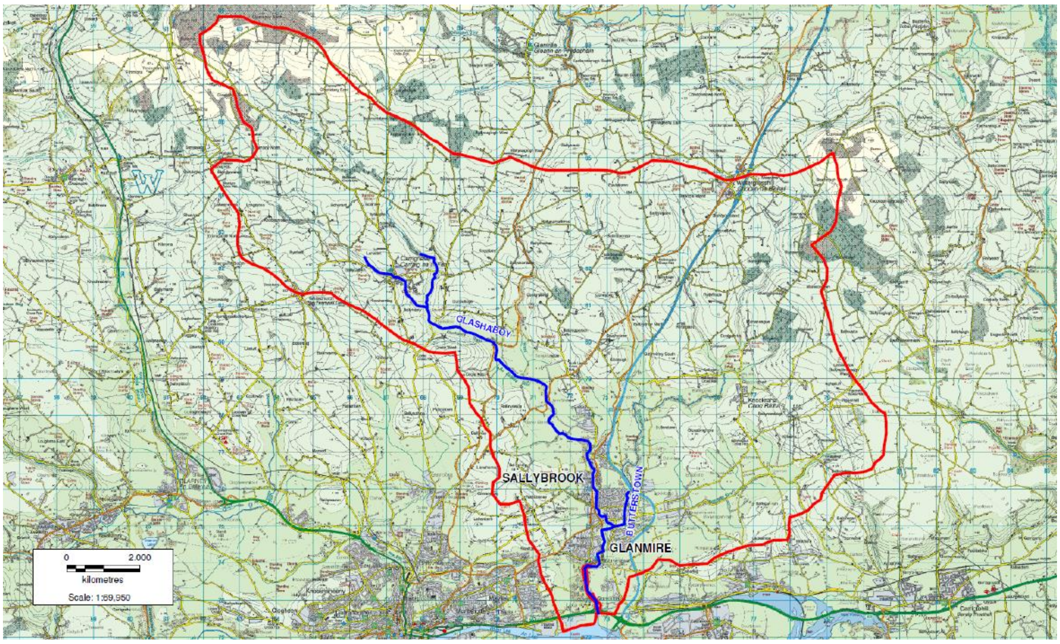
The hydraulic model and model requirements are not discussed within this report; this information will be provided in a separate report.

Since Version 3 of this report was issued, additional information in relation to flood levels experienced during the 2012 event was provided by local residents. This resulted in the development of a supplementary file note which discusses both the hydrology and hydraulic operation of the catchment. The file note has been included in Appendix B and should be read as a bridging document which links this report and the Glashaboy Hydraulics Report.

1.3 Study Area

The study area includes all areas within the Glashaboy and the Glanmire / Sallybrook Area of Potential Significant Risk (APSR)[1] as defined by the Lower Lee CFRAM and shown in Figure 1-1. All areas potentially prone to flooding from the Glashaboy River and Estuary, including all its tributaries, particularly the Butlerstown River.

Figure 1-1 - Study Area



1.4 Catchment Description

1.4.1 Overview

Digital mapping and catchment characteristics may be used to make an assessment of the likely response of rivers and tributaries during heavy rainfall events. Confidence in the assessment may be improved if hydrometric data is available for the catchment. River flow or level data, analysed in conjunction with rainfall data, can give a more accurate picture of the hydrological mechanisms operating within a catchment, and support the assessment made from catchment characteristics. The following sections of the report provide some background information on the Glashaboy catchment, including the main Glashaboy River and its tributaries, and the impact that different features may have on the response of the river to rainfall.

1.4.2 General Description

The River Glashaboy enters the River Lee Estuary to the East of Cork City. The river is 22km long, and has a catchment area of over 140km^2 at its tidal limit.

[1] Area of Potential for Significant Risk, APSR was a term used in the pilot CFRAM studies. It has since been replaced with the term Area for Further Assessment (AFA).

The Glashaboy River rises in the Nagles Mountains to the north of Cork and flows in a southerly direction, entering the Upper Cork Harbour downstream of Glanmire. The upper reaches are predominantly rural, however, the catchment becomes more urbanised in its lower reaches.

The geology of the catchment is predominantly sandstone till overlain by a cover of acid brown earth soils offering free drainage. The lower reaches are underlain by limestone. Low hills dominate the catchment with steeper sloping valleys located to the north.

The Glashaboy catchment is drained by a number of watercourses, the main one being the River Glashaboy which drains land to the west of the catchment. The Butlerstown River and Glenmore River join the Glashaboy at Glenmore and drain land to the east.

The lower reaches of the Glashaboy are tidally influenced (up to Glanmire). The fine sediment dynamics of the Cork estuary result in deposition of extensive mud flats through Lough Mahon. However, there is no significant deposition of tidally derived silts along the Glashaboy, suggesting that depositional processes are largely controlled by fluvial processes. This is discussed further in the hydromorphic audit of the catchment[2].

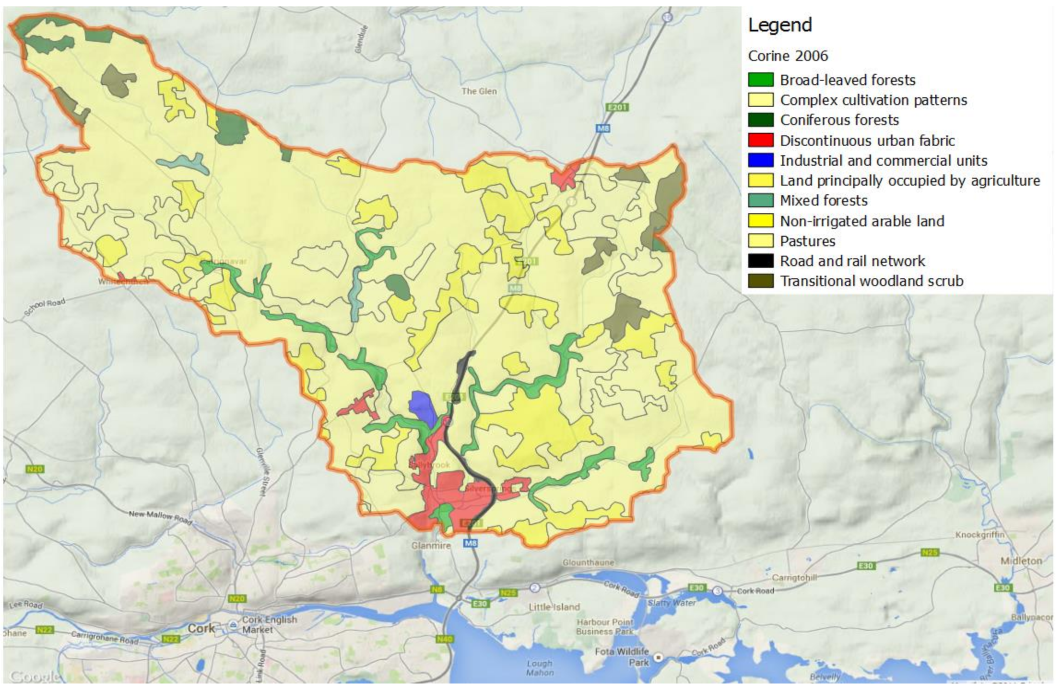
1.5 Topography and Rainfall

Average annual rainfall across the Glashaboy catchment is 1200mm. This compares with average annual rainfall in the west of Ireland of between 1000 and 1400mm, although in many mountainous districts rainfall exceeds 2000mm per year. The elevation of the catchment varies from in excess of 315mOD (Malin Head) in the northwest to approximately 2mOD near Glanmire. The valley of the River Glashaboy is well defined.

1.5.1 Land Use

An examination of the Corine 2006 Landcover data shows that majority of the catchment is agricultural land (80%). Of the remaining catchment area, approximately 16% of the catchment is forestry and 4% is classified as discontinuous urban fabric. The forested lands are predominantly found adjacent to the river as shown in Figure 1-2.

Figure 1-2 - Land Corine Map for Glashaboy Catchment



[2] JBA Consulting (2014), Hydromorphic audit of the River Glashaboy, Draft Report, Cork County Council

2. Review and Analysis of Historical Floods

2.1 Introduction

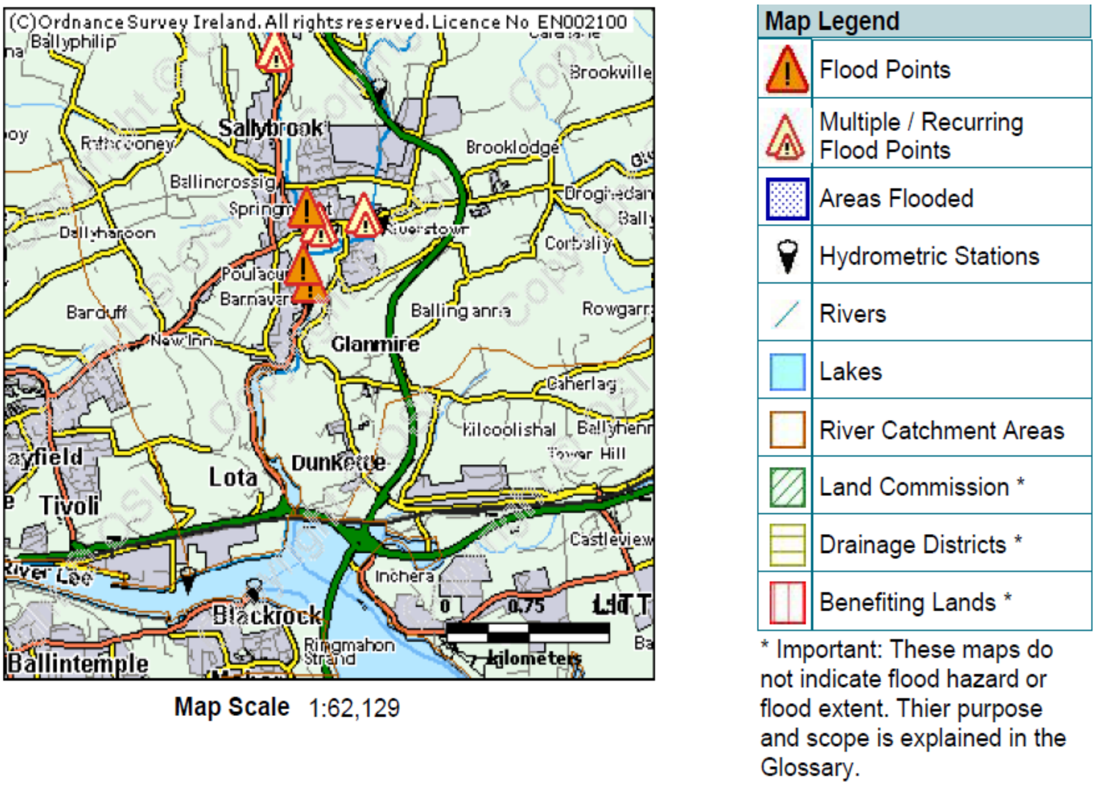
Records of past flooding are useful for looking at the sources, seasonality, frequency and intensity of flooding. Information may come from contemporary newspapers and journals, accounts of personal experiences, post-flood reports and surveys. Such historical records are mostly anecdotal and incomplete, but are useful for providing background information. A review of the flood history of the Glanmire area is detailed in this section.

More reliable information on flooding is provided by hydrometric gauges, which are examined through hydrological assessment, as detailed in Sections 4 and 5.

2.2 Notable Flood Events

The OPW provides a national flood hazard website (www.Floodmaps.ie) that makes available information on areas potentially at risk from flooding. This website shows numerous historical flood events that have affected Glanmire, as shown in Figure 2-1 below.

Figure 2-1 - Floodmaps.ie Extract



Through examination of the historic flood record, it is clear that there is a frequent and well documented history of flooding in Glanmire, as summarised in Table 2-1 During the 2012 flood event, a large area of Glanmire was inundated, causing significant flood damage. This event is the most severe on record, and in the memory of the residents of the town.

Table 2-1 - Historical Flood Chronology

Date of Flood	Comment
1968/1969?	Report of property flooding along the R369 in Riverstown
November 2000	N8 south of Watergrasshill and Annacartin Bridge closed along with flooding of Meadowbrook Estate
October 2004 (recorded) and recurring	House flooding occurred near Kearney's Cross Roads. This is reported to be a recurring event every 5 to 10 years. Flooding occurred on the Butlerstown River at Riverstown due to limited bridge capacity. Road flooding resulted. This is reported to flood infrequently. Flooding from the Glashaboy River affecting the park and Hotel recurs about every 2 years and is recorded in October 2004.
19 November 2009	Large Flows in the Glashaboy River caused by heavy rainfall resulted in overflows onto the adjoining R369 between Glanmire Bridge and Riverstown Cross. 300m of the R369 were flooded
28 June 2012	Significant flooding occurred. Flood waters flowed through Sallybrook, Hazelwood Cross, Hazelwood Shopping Centre, Meadowbrook Estate, Riverstown Park and Riverstown Cross to Glanmire Bridge road.
December 2015	Heavy rain resulted in pluvial and fluvual flooding in Glanmire. Area effected included Hazelwood, Meadowbrook, Copper Valley Vue and the R639 between Glanmire and Riverstown

Source: **www.floodmaps.ie**

2.2.1 June 2012 Event

Cork County experienced localised extreme rainfall events during the early hours of Thursday the 28th of June 2012. The rainfall event was described by Met Éireann as a 'Convective Storm' and caused widespread damage through Glanmire and left the community devastated. It is estimated that in excess of 50mm of rainfall fell in a period of three hours. Cork County Council activated its flood response plan in the early hours of June 28th.

The Glashaboy River which runs alongside the Meadowbrook Estate overflowed flooding the roads and most of the houses in the estate and in some areas to a depth of 4 feet. The Hazelwood Shopping Centre situated slightly upstream flooded to a similar depth. The flood extent included Sallybrook Industrial Estate, Grandon Car Sales, Glanmire GAA pitches and adjacent stretch of the R639, Hazelwood Shopping Centre, Meadowbrook Estate, John O'Callaghan Park and Glanmire Soccer pitches. Some sewers/combined sewers backed up and over flowed.

In the Glanmire Industrial Park in Sallybrook approximately 16 commercial premises and two residential properties were flooded. Approximately 45 houses were flooded in the Meadowbrook Estate and another 10 commercial units of the Hazelwood Shopping Centre, including the Council's Library. The source of the flooding appears to be a combination of significant fluvial storm flow in the Glashaboy River and pluvial run-off along the roads leading to the area. The flooding of the Hazelwood Shopping Centre arose from a flow path across the GAA pitches located to the north, and overtopping of the bridges in the Shopping Centre. The bridge on Hazelwood Avenue appeared to have been partially blocked with storm debris, which would have reduced its capacity[3]. Storm water flooded the area west of the bridge, including the Hazelwood Shopping Centre and a section of the R639 regional road. The basement of the Supervalu car park located to the east of the river flooded to a depth of 1.2m.

[3] *"CCC confirmed that a significant amount of debris was cleared from the bridges in Glanmire after the 2012 flood event. CCC stated that a large quantity of debris was cleared from the Hazelwood Bridge just upstream of the shopping centre."* Cork County Council, Steering Group Meeting 14/07, 11/08/2014

Figure 2-2 - Flow path to Hazelwood Shopping Centre

The Meadowbrook housing estate is low lying and there is an earthen flood protection embankment north of the estate and a flood protection wall at the east side of the estate. The flow entered the estate in two locations. At the upstream end, at the confluence of the Springmount Stream and Glashaboy, waters overtopped a low spot in the defence wall. Water also overtopped the embankment at the downstream end of the estate, immediately upstream of the Riverstown Bridge. Pluvial runoff from the R615, to the west, was also noted as a probable contributor

Figure 2-3 - Meadowbrook Estate under 2012 floodwaters

Partial Blockage of the Cois na Ghleann stream culvert under a local road west of the R369 regional road caused flooding of the R369/local road junction. The Glashaboy River flooded the R369 regional road and some road surface damage and potholing was widespread on roads in the Riverstown / Glanmire Area. However, by early afternoon on June 28th most of the floods had subsided.

Figure 2-4 - Flow path due to flood flow from Cois na Ghleann stream

2.2.2 December 2015 Event

December 2015 was the wettest month on records in many areas of Ireland, particularly in the Southwest where rainfall amounts were approximately 3 times the average. Storm Frank, the 6th major winter storm of 2015 brought high winds and significant rainfall between the 29 December 2015 and the 2 January 2016. This resulted in significant flooding across much of the country. County Cork was badly affected with major flood events on many rivers such as the Blackwater, Bandon, Glashaboy, Owenacurra and many others.

A number of locations in the Glanmire area were effected by fluvial and pluvial flooding. During the event, an Arup staff member from the locality observed the event taking useful photographs and providing useful observations. Arup subsequently visited the affected areas of Glashaboy catchment on 14 January 2016 to meet with residents and examine areas which had been affected by flooding in the recent event.

Appendix C details the finding of the post flood event study with further modelling of the event provide in the accompanying Glashaboy Hydraulics Report.

3. Catchment Boundaries

3.1 Hydraulic Model Extents

Levels of current and potential future flood risk, and various flood management options are being determined through hydraulic modelling. The details of the hydraulic model development will be provided in an accompanying report. When carrying out a hydrological assessment it is important to define the reaches of river that will be modelled. The extents of the hydraulic model are detailed in Table 3-1.

Table 3-1 - Modelled Watercourse Extents

Watercourse	Upstream Limit	Downstream Limits	Comments
Glashaboy	170860, 78946	172757, 72651	Main Glashaboy River Through Glanmire, downstream extent Lee Estuary
Bleach Hill	173126, 77665	172557, 77090	DS limit is confluence with Glashaboy
Cois na Ghleann	172366, 75633	172729, 75,598	DS limit is confluence with Glashaboy
Springmount	172448, 75267	172808, 75320	DS limit is confluence with Glashaboy
Butlerstown	173660, 75975	173216, 74976	DS limit is confluence with Glashaboy
Glenmore	174290, 75352	173479, 75140	DS limit is confluence with the Butlerstown

3.2 Hydrological Estimation Points

Hydrological Estimation Points (HEPs) have been developed along the River Glashaboy and its tributaries. These points are located at the upstream limits of the hydraulic model, at the junction of tributaries and at a number of other key points along the River Glashaboy. The location and a brief description of the HEPs are provided in Table 3-2, and illustrated in Figure 3-1. For each of the points, a catchment has been delineated based on the Flood Studies Update (FSU) programme digital data and has been cross checked using OPW's National Digital Height Model (NDHM), a 5m gridded digital terrain model (DTM). Catchment descriptors were obtained using the FSU datasets.

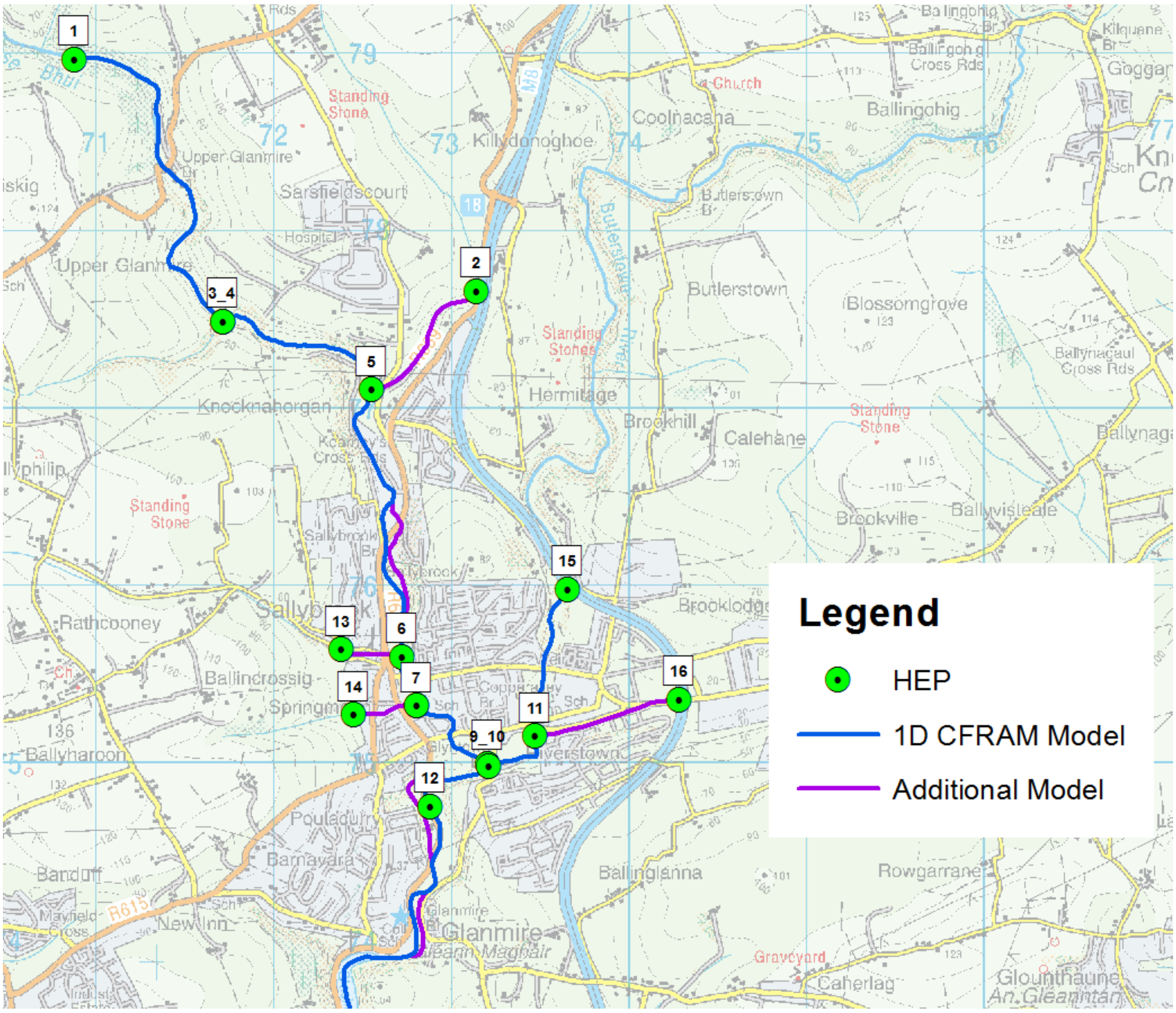
The HEPs at the upstream end of each watercourse will be modelled as inflows, and the others along the watercourses are check flow points. The study will aim to match the modelled flows to the calculated flows at each of the HEPs with the inclusion of lateral flows where necessary.

Table 3-2 - Hydrological Estimation Points

HEP	Coordinates		Watercourse	Description
1	171176	78916	Glashaboy	Upstream Modelled Limit
2	172540	79300	Bleach Hill	Upstream Modelled Limit
3	171713	77490	Unmodelled Trib (Upper Glanmire)	Point Inflow
4	171713	77490	Glashaboy	Upstream of Junction with unnamed Tributary
5	172556	77106	Glashaboy	Upstream of Junction with Bleach Hill
6	172723	75598	Glashaboy	Upstream of Junction with Cois na Ghleann
7	172806	75323	Glashaboy	Upstream of Junction of Springmount
8	172806	75323	Glashaboy	Meadowbrook Gauging Station

HEP	Coordinates		Watercourse	Description
9	173210	74982	Glashaboy	Upstream of Junction with Butlerstown
10	173210	74982	Butlerstown	Upstream of Junction with Glashaboy
11	173474	75152	Butlerstown	Upstream of Junction with Glenmore
12	172881	74756	Glashaboy	Glanmire Gauging Station
13	172212	75702	Cois ns Ghleann	Upstream Modelled Limit
14	172449	75287	Springmount	Upstream Modelled Limit
15	173571	75740	Butlerstown	Upstream Modelled Limit
16	174162	75347	Glenmore	Upstream Modelled Limit

Figure 3-1 - Hydrological Estimation Points



3.3 Lateral Catchments

Lateral catchments provide inflows to the hydraulic model from intervening areas between the flow estimation points. These inflows are from non-point sources such as overland flow, urban runoff or watercourses that are too small to be included as a sub-catchment. Inflows from lateral catchments tend to be adjusted during the modelling phase of mapping studies to ensure that they correspond with the hydrological estimates at the flow estimation point.

4. Analysis of Hydrometric Data

4.1 Overview

The estimation of design flows is arguably the most important part of a flood study, in that it can have the largest influence on the final flood outline. However, it can also be the greatest source of uncertainty, and it is widely accepted that flow estimates may be greatly improved with the use of local hydrometric data. This chapter details the availability of hydrometric data within the study catchment, and reviews the quality of the data sets likely to be used for flood estimation. All flood estimation is based, however indirectly, on measurements of river flow and/or rainfall. The quantity and quality of hydrometric data therefore is a major factor determining the quality of the flood estimates.

4.2 River Data

The Environmental Protection Agency (EPA) have a number of flow and level gauges within the River Glashaboy catchment. There are also a number of closed (obsolete) level gauges, which were used for water quality monitoring in the past. Summary information related to each of the gauges in the catchment is provided in Table 4-1 and the locations are shown in Figure 4-1.

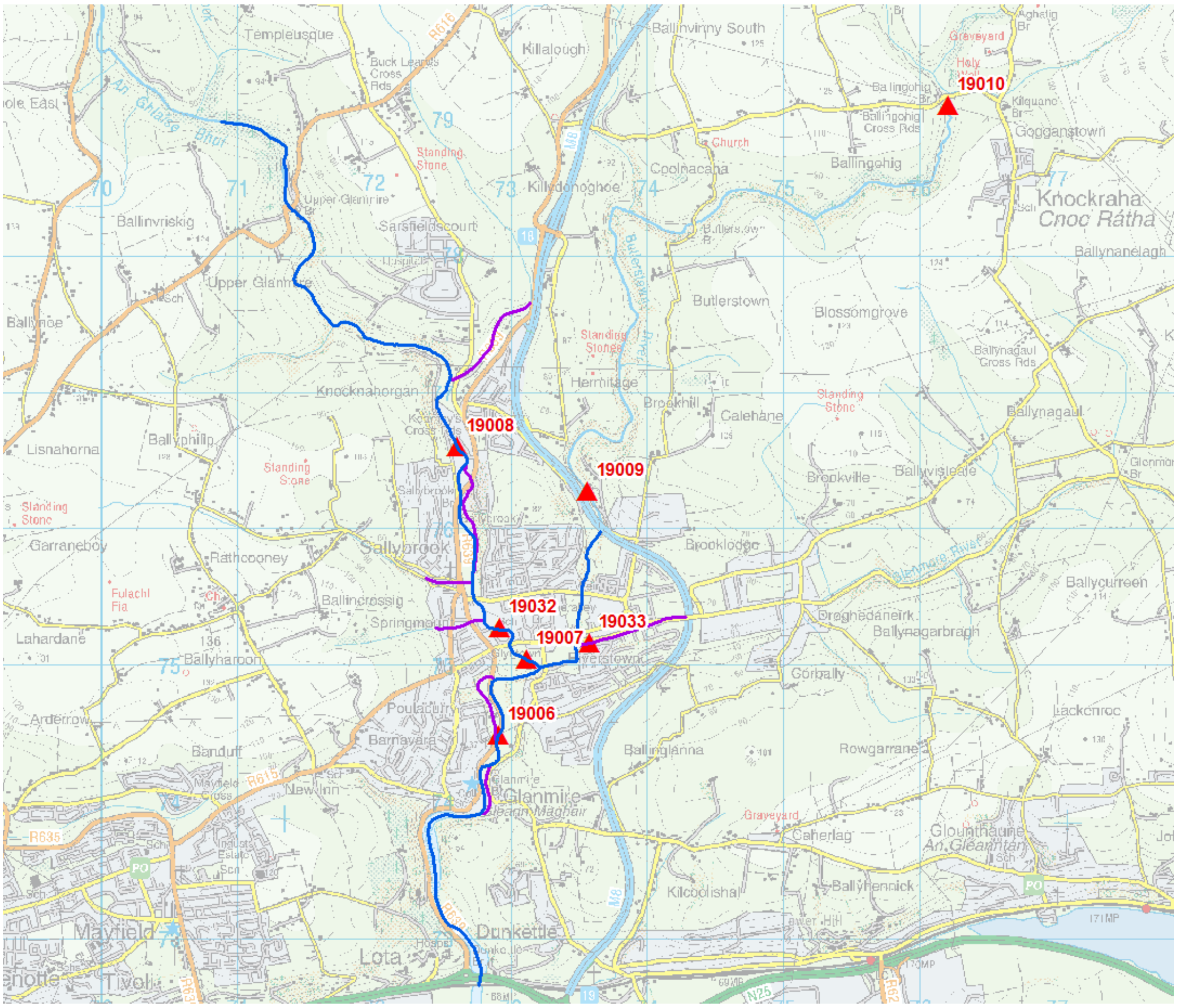
4.3 Stations for Review

Of the numerous gauging stations on the River Glashaboy, two stations have had detailed rating reviews carried out as part of this study, 19006 and 19032. The findings of the review are presented Section 5.

Table 4-1 - Hydrometric Gauges

Gauge Ref	Watercourse	Location	Grid Ref	Operator	Status	Record Period	Comments
19010	Butlerstown	Ballingohig Bridge	176206, 79092	EPA	Inactive staff gauge	1976 - 2003	The gauge is located in the upper portion of the catchment, and is upstream of the modelled reach within Glanmire.
19008	Glashaboy	Sallybrook	172608, 76600	EPA	Inactive recorder	1977-1982	No flow data available
19032	Glashaboy	Meadowbrook	172917, 75280	EPA	Active recorder	1986 - Present Day	Gauge has been subjected to a detailed rating review (See Section 5)
19007	Glashaboy	Riverstown	173113, 75045	EPA	Inactive recorder	1977-1979	No flow data available
19009	Butlerstown	Brookhill	173559, 76274	EPA	Inactive recorder	1977-1986	Record will be reviewed to establish flow splits / event coincidence with 19006.
19033	Glenmore	Brooklodge	173580, 75167	EPA	Inactive Staff Gauge	1982 - 2004	No flow data available
19006	Glashaboy	Glanmire	172913, 74488	EPA	Inactive recorder	1979-2009	Gauge has been subjected to a detailed rating review (See Section 5)

Figure 4-1 - Hydrometric Gauging Stations



5. Hydrometric Gauging Station Rating Review

5.1 Overview

All gauges within the study area were reviewed to determine their suitability for inclusion in this project. These included:

- 19032 - Meadowbrook - 1986 to current
- 19006 - Glanmire - 1979-2009
- 19007 - Riverstown - 1977-1979
- 19008 - Sallybrook - 1977-1982
- 19009 - Brookhill - 1977-1986

The following section details the review of these gauges, undertaken in parallel with the hydraulic modelling.

5.2 Gauges 19007 (Riverstown) and 19008 (Sallybrook)

The Riverstown (19007) and Sallybrook (19008) gauges were notionally operated for 2 years and 5 years respectively. However, in a communication received from EPA it was noted that *"there are no flow data available for 19007 Riverstown and 19008 Sallybrook as both these stations have no rating. The relationship between water level and flow could not be established at either location to derive a good enough rating curve to provide continuous flow data. At Riverstown, the site was vandalised and abandoned after one month. Sallybrook station was located immediately upstream of a set of sluices. The water levels were artificially* maintained." Although it is possible that construction of a hydraulic model would have allowed a better understanding of the relationship between flow and level to be developed, there is so little data on which to base any conclusions that no analysis of the data at these gauges has been carried out under this study.

5.3 19009 (Brookhill)

The Brookhill record covers the period 1977-1986 and includes an overlap with the Glanmire gauge of four years (the Glanmire gauge did not record in 1983 or 1984, and the 1986 record at Brookhill is incomplete). There is no overlap between the Brookhill and Meadowbrook gauge.

Of the four years of record, the AMAX values for each gauge have been examined for coincidence of flow. As shown in Table 5-1, the AMAX at the gauges only coincides in two years. Flows have been extracted from the Brookhill gauge record for the two remaining AMAX values at Glanmire. The Glanmire gauge was not recording when the AMAX flows were recorded in 1982 or 83 at the Brookhill gauge.

The difference in flow between the two gauges is also tabulated and shows there is not a simple relationship between flows recorded on the two catchments. This indicates there is a complex relationship between the Butlerstown and Glashaboy Rivers, whereby the rivers respond in a quite independent way to the same rainfall event.

Table 5-1 - Comparison between Brookhill and Glanmire gauges

Date	Amax at which gauge	Glanmire flow (m^3/s)	Brookhill flow (m^3/s)	Ratio between flow at the gauges
27/12/1979	Both	38.0	11.8	3.2
01/03/1981	Both	33.2	15.8	2.1
21/02/1982	Glanmire	45.4	26.4	1.7
21/02/1983	Glanmire	20.4	4.3	4.8

5.4 Gauge 19032 (Meadowbrook)

5.4.1 Gauge description

The Meadowbrook gauging station on the River Glashaboy is located approximately 270m upstream of Riverstown Bridge. The gauge record is 28 years long, and began in May 1986. The catchment area to the gauge is approximately 76km^2.

5.4.2 Gauge Datum

The height of gauge zero to national datum has changed a number of times since the gauge was established in 1980 (Figure 5-1).

The staff gauge datum is to a temporary benchmark, with no conversion to Malin or Poolbeg Datum provided. The conversion from staff gauge reading to Malin datum of +7.533m was established by comparing surveyed water levels and staff gauge readings for the time and date of the survey. This analysis has assumed the TBM has been constant since the gauge was established.

Figure 5-1 - Changes in Gauge Zero

Current value
Valid from: 23/09/2003 00:00
Gauge datum (GD): 98.617
Status: m (TBM) m (TBM)
Remark: SG zero = 1.383M below TBM
New...

Valid from:	Value	Status	Remark
06/05/1980 00:00	98.632	m (TBM) m (TBM	Taking TBM to be 100m. SG zero is 1.368m Below TBM.
15/07/1980 00:00	98.632	m (TBM) m (TBM	1.368m below TBM.
11/02/1982 00:00	98.606	m (TBM) m (TBM	1.394m below TBM.
23/11/1983 00:00	98.607	m (TBM) m (TBM	1.393m below TBM.
03/07/1984 00:00	98.608	m (TBM) m (TBM	New SG erected 1.392m below TBM.
22/05/1986 00:00	98.613	m (TBM) m (TBM	New SG erected 1.387m below TBM.
09/03/1994 00:00	98.615	m (TBM) m (TBM	1.385m below TBM.
19/06/1997 00:00	98.615	m (TBM) m (TBM	1.385 m below TBM.
31/01/2001 00:00	98.616	m (TBM) m (TBM	1.384 m below TBM.
07/06/2001 00:00	98.615	m (TBM) m (TBM	New SG erected 1.385m below TBM.

5.4.3 Stage – Flow Relationship

There have been two different ratings for the Meadowbrook gauge, both consisting of three limbs. The current EPA rating curve has an upper limit for the rating of 1.220m SGZ (8.753 mOD Malin); this is some 1.8m below top of bank.

Figure 5-2 - Changes in Rating Curve

Statistical evaluation (Continuation)

Q/C1.2 (relative to gauge datum)

Rating curve C1
Comment Rating curve revised August 2013 to incorporate high flow measurements taken in 2012
Version 2
Last change 14 March 2014
Comment

Validities for Q/C1.2

From	Transition since	Valid since	Valid to	Transition to	After
		15/05/1986 00:00:00			

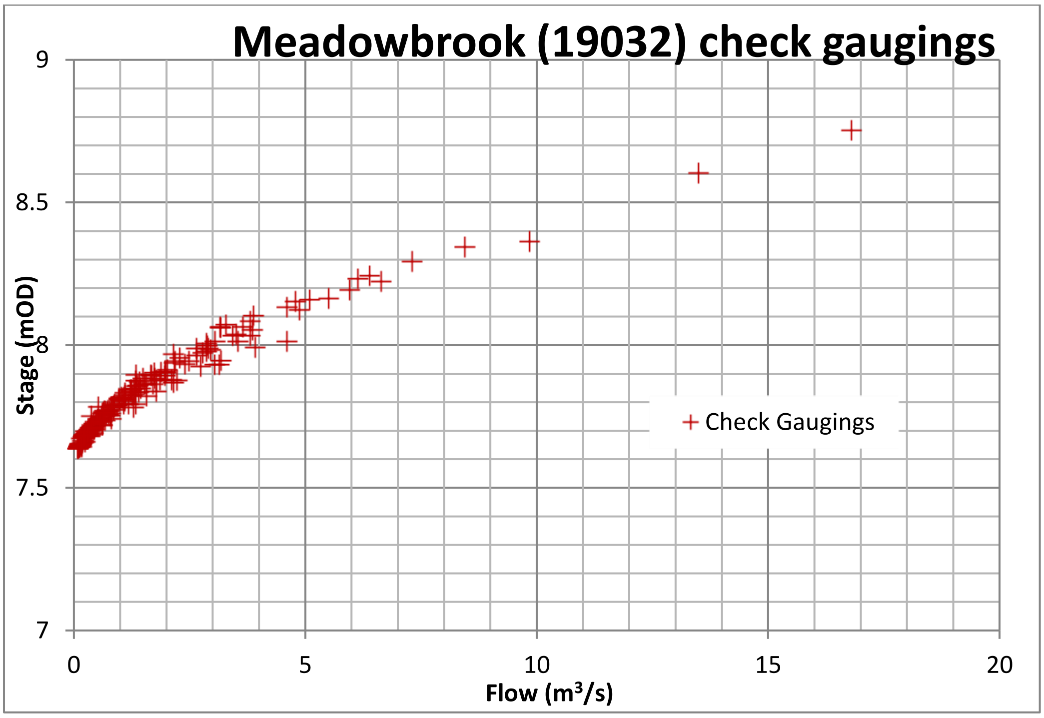
0.104 m < W < 0.199 m	Q(W) = 45.5499 * (W - 0)^2.74351 [m3/s]
0.199 m < W < 0.646 m	Q(W) = 13.5158 * (W - 0)^1.99036 [m3/s]
0.646 m < W < 1.220 m	Q(W) = 12.1373 * (W - 0)^1.74417 [m3/s]

The EPA improved their rating with the incorporation of a high flow measurement taken in 2012 (see Figure 5-3 - Check gaugings). Despite the inclusion of this measurement, the rating is only valid to a stage (8.753m OD) well below bank top and a flow (16.8m³/s) below Qmed (22.3m³/s).

The gauge is deemed to be in a very good location for rating due to its containment of high flow within bank. The extreme event in was noted to peak at 10.48mOD, which is 0.12m below bank top. The ability of the section to contain this extreme events is due to the defences walls already in place.

There are 192 check gaugings for the site, dating from 1980 to 2013. The maximum check gauging stage is 8.753mOD, recorded in October 2012. The maximum automatically recorded stage is 10.483mOD recorded in June 2012.

Figure 5-3 - Check gaugings



5.4.4 Section Change

The model section 4GLA3715, used for this rating review, underwent a section change due to the development of SuperValu in approximately 2010/early 2011[4]. This has changed the left bank of the section from a steep grassy slope, to a similarly stepped gabion bank.

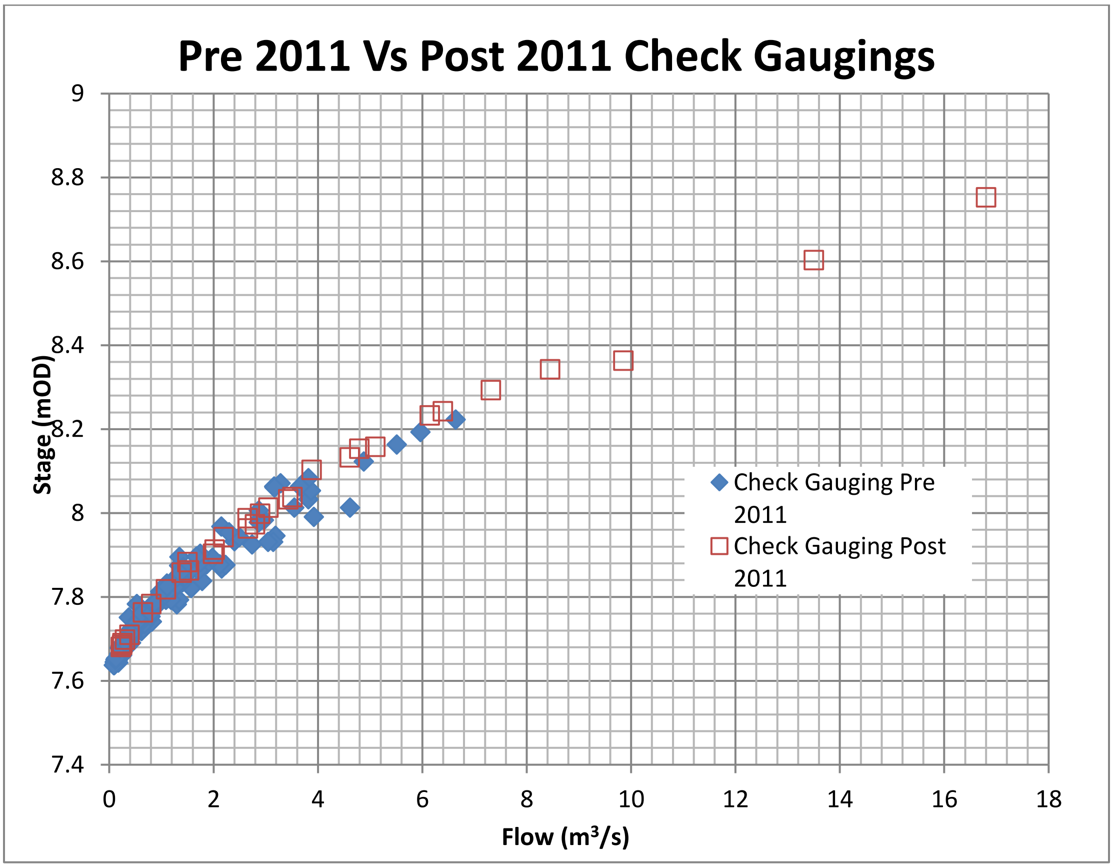
[4] Gerard O'Hara, Senior Executive Engineer, Roads Operations, Cork County Council; email (11/02/2014)

Figure 5-4 - Left Bank Post 2011 (top) and Pre 2011 (below)

	
Section profile prior to SuperValu development - looking upstream at the left bank.	Section profile following SuperValu development - looking down at the left bank.

To determine the effect of the changed left bank the check gauged taken before and after 2011 were analysed. Figure 5-5 show the results and it is noted that no significant change occurs. Similarly, the rating for the gauge was not changed due to the development. The rating review, and hydraulic modelling was therefore based on the Lee CFRAM version of the river survey.

Figure 5-5 - Check gauging comparison



5.4.5 Hydraulic Modelling

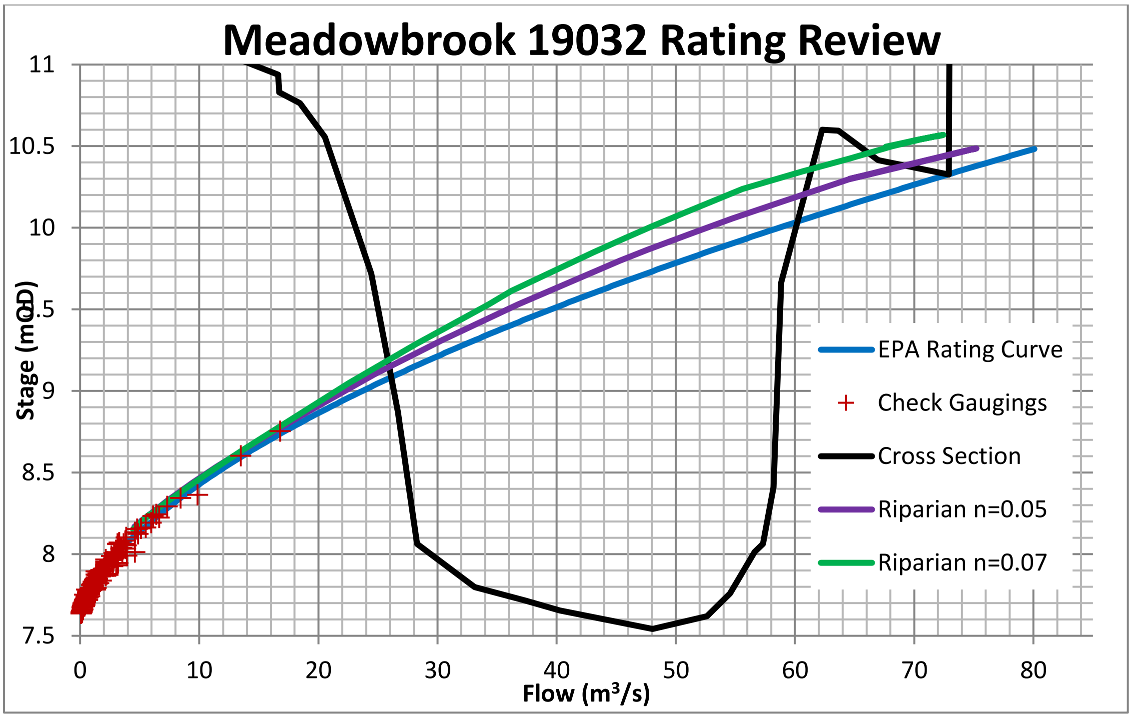
Detailed hydraulic modelling has been carried out for the Meadowbrook gauge using the ISIS-TUFLOW model of the River Glashaboy. The model was calibrated using the 2012 flood event along with gauge data, as presented here. Details of the modelling methods and results are presented in the accompanying Hydraulics report, but the model represents the event well when considering the level record at the gauge, observed flood extents and observed flood depths.

The rating curves derived using the model are plotted in Figure 5-6 along with the EPA existing rating curve and spot check gaugings. The model was calibrated using the check gaugings using a bed roughness of Manning's n=0.032 for low flow. Given the dominant nature of the overhanging trees and vegetation on the side banks of the Glashaboy two rating for higher water levels were used to represent the seasonality of the riparian strips. To account for this seasonality a roughness of Manning's *n*=0.05 was used for winter and *n*=0.07 for summer. These are defined by the equations below for the upper limb of the rating curve.

From 1.220m < W < 3.03m	Q(W) = 10.819 * (W - 0)^1.6926 [m3/s]	For Summer
From 1.220m < W < 2.95m	Q(W) = 10.688 * (W - 0)^1.7935 [m3/s]	For Winter

These equations were formed by calculating the power trendline for the model results. This is a mathematical line of best fit and therefore does not match the model line exactly. However it does have a high coefficient of determination (R^2=0.9948 & 0.9992 respectively) which indicates a very good fit.

Figure 5-6 - EPA and ISIS-TUFLOW Ratings and check gaugings for Meadowbrook



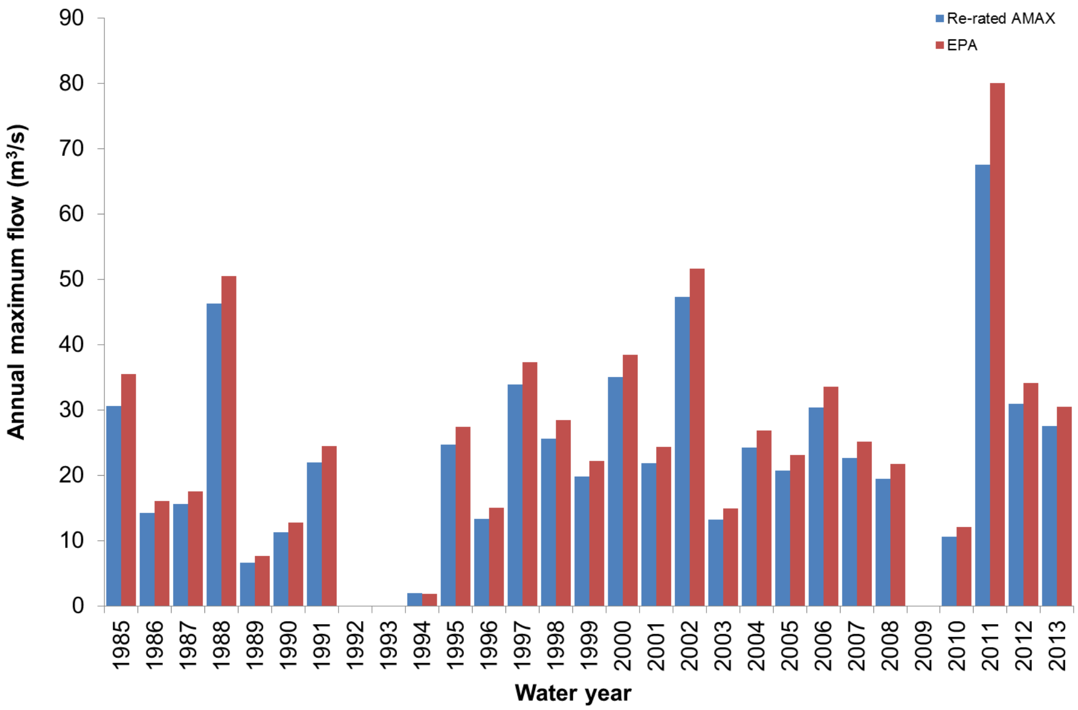
5.4.6 Summary for 19032

Detailed hydraulic modelling for gauge 19032 has confirmed that the current rating curve is accurate to its limit of 8.753m OD. The process had resulted in calibrating the model by modifying bed roughness along the affected river reach. Two upper limbs have been applied to the rating to account of the trees and vegetation on the banks, and their seasonal change. This has resulted in a slight reduction in AMAX overall (Figure 5-7), and a lowering of Qmed at the gauge from 24.8m^3/s to 22.3m^3/s.

Given the highest check gauging (16.8m^3/s) is below Qmed for the site, further higher flow check gauges would be required to increase confidence in the rating.

The change in section that occurred due to the development of SuperValu is deemed to be not significant and the same rating curve can be applied to level recorded pre and post 2011.

Figure 5-7 - Comparison of AMAX series



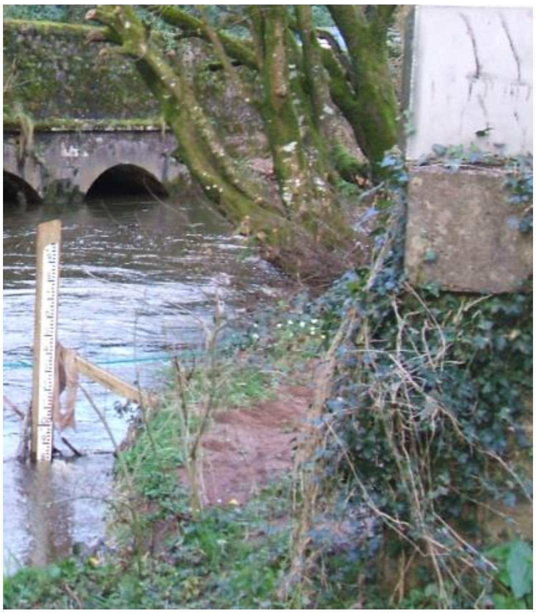
5.5 Gauge 19006 (Glanmire)

5.5.1 Gauge description

The gauging station on the River Glashaboy at Glanmire is located at grid reference 172913 74488. The catchment area at the gauge is approximately 140km^2, with the majority of the increase between here and Meadowbrook gauge arising from the Butlerstown River and its tributaries. The gauge is located approximately 450m upstream of Glanmire Bridge and approximately 450m downstream of a weir. The weir is for an old mill race which discharges just upstream of the gauge. The gauge record began in October 1974 and finishes in May 2008.

The cross-section profile is open channel, with the gauge located on the left bank as shown Figure 5-8.

Figure 5-8 - Gauge at Glanmire (19006) and downstream view



5.5.2 Gauge Datum

The height of gauge zero to Poolbeg datum has been amended several times since the gauge was established. The most significant change occurred in 1986 when a new staff gauge was erected. The gauge zero has been further converted to Malin Head for the purposes of this study. This was done by using the Lee CFRAM study which recorded the 2m level of the staff gauge to OD Malin in March 2007. The conversion for staff gauge readings to OD Malin is +1.38m.

The historical changes in gauge datum is illustrated in Figure 5-9.

Figure 5-9 - Changes in staff gauge zero

Current value

Valid from:	23/09/2003 00:00		New...
Gauge datum (GD):	4.359	Status:	m OD (Poolbeg) m
Remark:	SG zero 1.452m below TBM		

Valid from:	Value	Status	Remark
11/09/1975 00:00	4.181	m OD (Poolbeg)	SG erected. SG zero 8.335m relative to TBM
30/03/1982 00:00	4.186	m OD (Poolbeg)	
23/11/1983 00:00	4.195	m OD (Poolbeg)	Work at weir and millrace d/s affecting w/l during autum '83
27/05/1986 00:00	4.355	m OD (Poolbeg)	New SG erected new TBM on autogauge 5.811m OD(Poolbeg)
13/01/1992 00:00	4.355	m OD (Poolbeg)	SG zero 1.456m below TBM
09/03/1994 00:00	4.355	m OD (Poolbeg)	SG zero 1.456m below TBM
02/09/1994 00:00	4.355	m OD (Poolbeg)	
19/06/1997 00:00	4.357	m OD (Poolbeg)	SG zero 1.454m below TBM
23/01/2001 00:00	4.357	m OD (Poolbeg)	SG zero 1.454m below TBM

5.5.3 Stage – flow relationship

Figure 5-10 shows the last rating for the Glanmire gauge. There have been three different ratings for the Glanmire gauge, all consisting of three limbs. The current EPA rating curve has an upper limit for the rating of 1.065m above SG (2.445 mOD Malin); this is some 0.631m below top of bank.

Figure 5-10 - Changes in Rating Curve

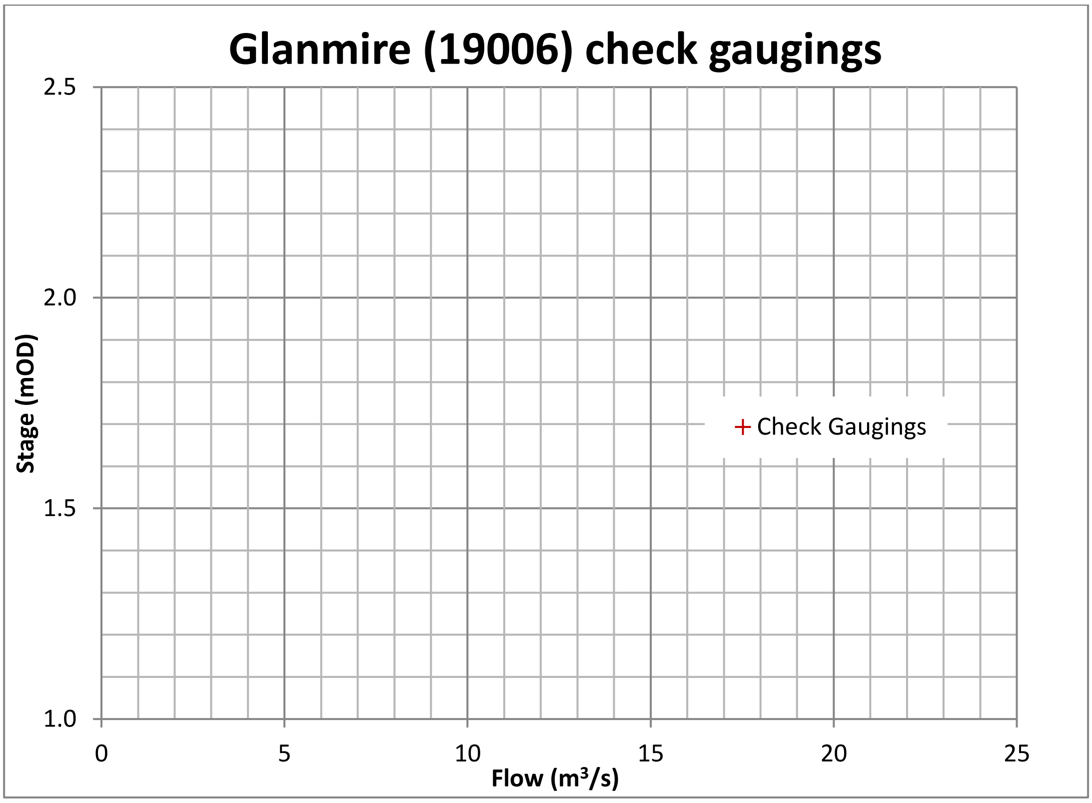
Validities for Q/C3.1

From	Transition since	Valid since	Valid to	Transition to	After
C2		01/06/1991 00:00:00			

0.020 m < W < 0.046 m	Q(W) = 3.14525 * (W - 0)^1.28102 [m3/s]
0.046 m < W < 0.428 m	Q(W) = 11.5945 * (W - 0)^1.70328 [m3/s]
0.428 m < W < 1.065 m	Q(W) = 18.78 * (W - 0)^2.27086 [m3/s]

There are 211 check gaugings for the site, dating from 1975 to 2008. The maximum check gauging stage is 2.445mOD Malin, recorded in February 1988. The maximum automatically recorded stage is 3.659mOD Malin recorded in November 2002. Note, the gauge had been taken out of service before the 2012 event occurred.

Figure 5-11 - Check gaugings for Glanmire (19006)



5.5.4 Hydraulic Modelling

As with the Meadowbrook gauge, detailed hydraulic modelling has been carried out for the Glanmire gauge using the ISIS-TUFLOW model of the River Glashaboy. The rating review was conducted in the same manner as the Meadowbrook gauge with the bed roughness being calibrated to the check gaugings (Manning's n=0.034) and two seasonal upper limbs applied for higher water levels.

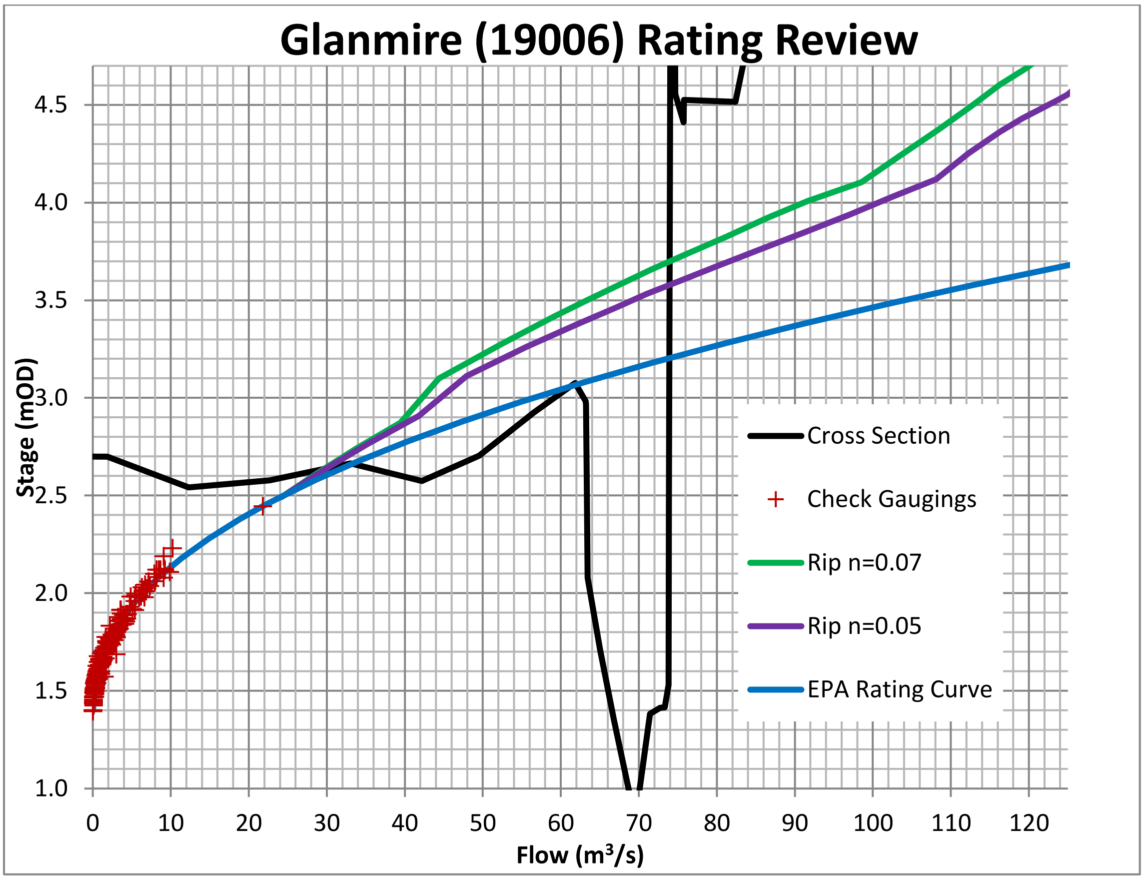
The rating curves derived using the model are plotted in Figure 5-12, along with the EPA existing rating curve. At higher flows there are significant flood plain flows on the left bank which is not accounted for in the current rating due to its highest check gauging being below bank crest, but is represented in the floodplain representation of the 2D element of the model. The inaccuracy in the current rating is suspected to be due to the check gauging at 21.8 m3/s skewing the extrapolated curve downward. The proposed updated curve includes an extra limb for high flows above this check gauging. This additional limb is defined in the same way as the other limbs (see Figure 5-10)) by:

From 1.065m < W < 2.723m Q(W) = 20.552 * (W - 0)^1.5259 [m3/s] For Summer

From 1.065m < W < 2.723m Q(W) = 20.234 * (W - 0)^1.6521 [m3/s] For Winter

These equation have a high coefficient of determination (R^2=0.9958 & 0.9981 respectively) which indicates a very good fit.

Figure 5-12 - Rating review for Glanmire (19006)



Further justification for the re-rating is demonstrated through the use of the flow series in Section 6, but it is worth noting that the Qmed adjustment using the EPA rating is 1.83. The re-rated value of Qmed results in an adjustment factor of 1.50. The lower adjustment factor is in line with other catchment analysis (see Section 6.2.2 for more details on this).

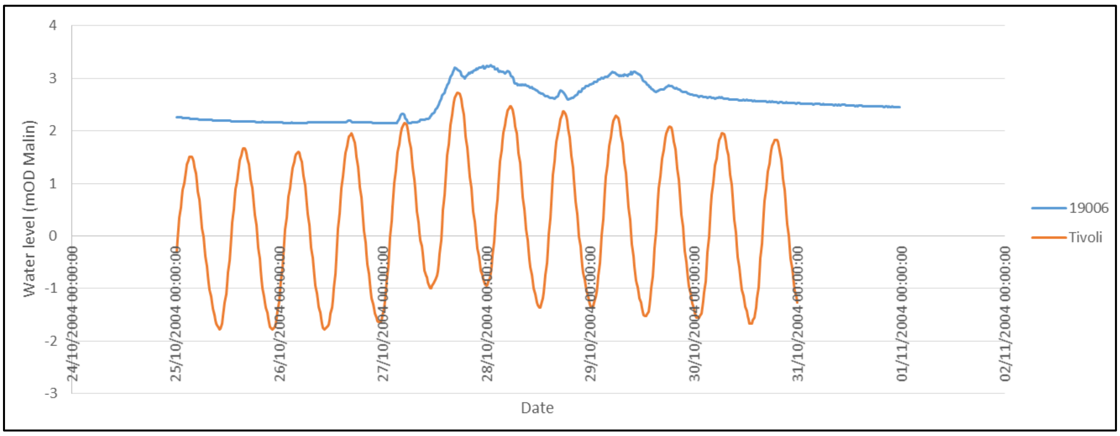
5.5.5 Tidal influence on 19006

The Glanmire gauge is located at the downstream end of the river reach, and is subject to a certain level of tidal influence. This is illustrated in Figure 5-13, which plots the recorded stage at both Tivoli dock, a tide gauge in the lower reaches of the Lower Lee, and at Glanmire gauge for the 2004 fluvial AMAX event. It is apparent from this plot that during very high tide events (over approximately 2mOD Malin), water levels at Glanmire are increased by approximately 20cm.

This indicates that the AMAX series at Glanmire may be influenced by tide levels when the event coincides with a high tide. However, there are insufficient coinciding stage data at the two gauges to fully assess this.

As will be shown in the analysis in the following sections, the Glanmire gauge is not central to the design flow estimates for the Glashaboy flood relief scheme, so the impact of the tide is not significant at this stage of the study. However, when designing the scheme and considering joint probability between fluvial and tidal events it will be important to take into account the coincidence of a fluvial event with a tidal surge, and to assess the impact this will have on flood risk at the downstream extents of the study area.

Figure 5-13 - Tivoli and 19006 gauges - 2004 Fluvial AMAX event



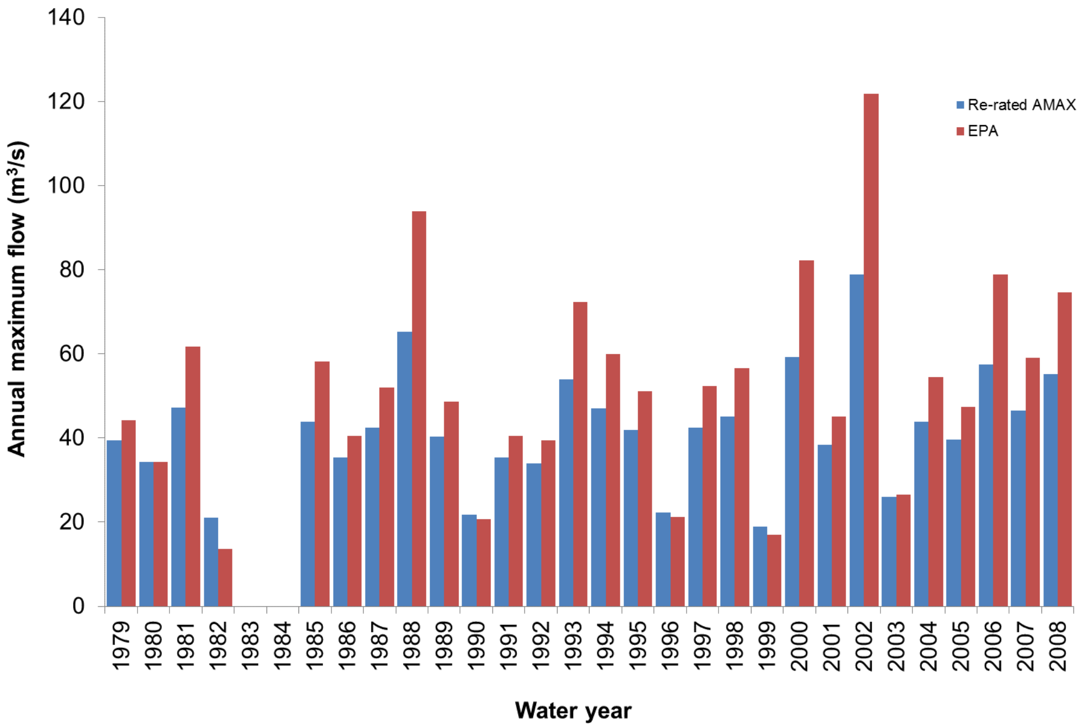
5.5.6 Summary for 19006

Detailed hydraulic modelling for gauge 19006 has produced an updated rating curve for winter and summer reading. The process had resulted in calibrating the model by modifying bed roughness along the affected river reach for recorded low flows. The updated rating curve has an altered upper limb to account for change in stage-flow relation due to out of bank flows, and high in bank flows. This has the impact of lowering Qmed by 9.4m³/s from 51.6m³/s to 42.2m³/s, as illustrated in Figure 5-14. The re-rating is supported by design flow analysis detailed in Section 6.

It is important to note that this update is based on modelled flows only. If the gauge was still in operation it would be recommended that an effort to obtain check gaugings at higher water levels is made. As the gauge is not currently in operation, it is unlikely that this will occur. The changes to the flow record due to the new rating are illustrated in Figure 5-14, which highlights to change to the AMAX series due to the re-rating.

The gauge has been shown to be impacted by tidal events in excess of approximately 2mOD, when recorded at Tivoli dock. However the impact of this on the design events for the scheme are limited as the Glanmire gauge is not central to the flow calculations, and is located downstream of the core area of flood risk. However, consideration of joint probability fluvial and tidal events will be important when developing the scheme design.

Figure 5-14 - EPA AMAX Vs. Re-rated Amax



6. Estimation of Design Flood Flows

6.1 Overview

The UK Natural Environmental Research Council carried out a comprehensive flood study across a large number of catchments throughout Britain and Ireland. This investigation involved extensive data analysis and resulted in the publication of the Flood Studies Report (FSR)[5] which has been widely used for design flow estimation in Ireland and the UK. Since its publication in 1975, significant advancement has been gained in analytical techniques and many more years of data have become available.

The Irish Flood Policy Review Group judged that a programme of study to develop new methods, and following similar principles to the Flood Estimation Handbook (FEH)[6], will significantly improve the quality and facility of flood estimation for flood risk management in Ireland (OPW, 2004)[7]. This programme of study, the Flood Studies Update (FSU) consists of a number of Work Packages containing extensive research ranging from analysis of meteorological data to flood attenuation analysis and flood estimation for urbanised catchments. The work package most relevant to this study is the Index Flood Estimation (FSU - WP2.3)[8] and is described in the following sections.

6.2 Calculation of Qmed

6.2.1 FSU - Index Flood Estimation (WP 2.3)

At ungauged sites, the value of Qmed can be obtained from catchment descriptor data through the application of a regression model. As part of the FSU, a multivariate regression equation was developed on the basis of data from 199 gauged catchments, linking Qmed to a set of catchment descriptors.

$$Qmed_{rural}=1.237\text{x}10^{-5}AREA^{0.937}BFIsoils^{-0.922}SAAR^{1.306}FARL^{2.21}DRAIND^{0.341}\text{x}S1085^{0.185}(1+ARTDRAIN2)^{0.408}$$

Where: AREA is the catchment area (km^2).
BFIsoils is the base flow index derived from soils data
SAAR is long-term mean annual rainfall amount in mm
FARL is the flood attenuation by reservoir and lake
DRAIND is the drainage density
S1085 is the slope of the main channel between 10% and 85% of its length measured from the catchment outlet (m/km).
ARTDRAIN2 is the percentage of the catchment river network included in the Drainage Schemes
The Factorial Standard Error (FSE) of $Qmed_{rural}$ in the above equation is 1.36.

The Qmed estimate is multiplied by a growth factor derived either from the national, regional or pooled growth curve to arrive at the T – year flood estimate.

Table 6-1 provides flow estimates for Qmed as derived from the FSU catchment characteristic method at the HEP sites.

Table 6-1 - Qmed at the HEPs

HEP Reference	Watercourse	Description	Qmed (m^3/sec) from FSU
1	Glashaboy	Upstream Modelled Limit	13.40
2	Bleach Hill	Upstream Modelled Limit	1.14
3	Unmodelled Trib (Upper Glanmire)	Point Inflow	0.58
4	Glashaboy	Upstream of Junction with unnamed Tributary	13.74

[5] The Flood Studies Report (1975) Natural Environment Research Council
[6] The Flood Estimation Handbook (1999) Institute of Hydrology
[7] OPW 2004. Report of the Flood Policy Review Group. Office of Public Works, Dublin, 235pp.
[8] Flood Studies Update Programme Work -Package WP-2.3 "Index Flood Estimate", Final Report NUI Galway, OPW 2009

HEP Reference	Watercourse	Description	Qmed (m^3/sec) from FSU
5	Glashaboy	Upstream of Junction with Bleach Hill	15.51
6	Glashaboy	Upstream of Junction with Cois na Ghleann	15.54
7	Glashaboy	Upstream of Junction of Springmount	16.09
8	Glashaboy	Meadowbrook Gauging Station (19032)	16.36
9	Glashaboy	Upstream of Junction with Butlerstown	16.29
10	Butlerstown	Upstream of Junction with Glashaboy	13.62
11	Butlerstown	Upstream of Junction with Glenmore	9.41
12	Glashaboy	Glanmire Gauging Station (19006)	28.13
13	Cois ns Ghleann	Upstream Modelled Limit	0.72
14	Springmount	Upstream Modelled Limit	0.39
15	Butlerstown	Upstream Modelled Limit and approximate location of gauge 19009	9.20
16	Glenmore	Upstream Modelled Limit	4.78

6.2.2 Data transfer from gauged catchments to estimate Qmed at ungauged sites (Donor Catchment Analysis)

The FSU recommends that use is made of donor catchments to improve estimates of the index flood at ungauged sites. Based on the methodology of the FSU the catchment characteristics-based estimate of Qmed at each subject site is scaled by the ratio of observed and estimated Qmed values at the donor site, so that;

$$Qmed_A = Qmed(estimated)_A * Qmed(measured)_B / Qmed(estimated)_B$$

Where subscript A refers to the subject site and subscript B refers to the donor site.

A donor catchment assessment was undertaken using the Meadowbrook Gauge (19032), Brookhill (19009), Glanmire gauge (19006) and Healy's Bridge (19015), which is outside the Glashaboy catchment but is geographically close and hydrologically similar. An average Qmed adjustment factor was found which could be applied to ungauged estimates of flow.

Table 6-2 presents the estimated, gauged Qmed and Qmed adjustment factor for all the gauged sites. A Qmed adjustment factor of 1.36 at Meadowbrook and 1.50 at Glanmire was found. In addition, the Qmed adjustment factor for the Brookhill (19009) gauge of 1.7 was determined based on analysis of Qmed from Peak over Threshold analysis, and is shown in Table 6-2. A weighted average based on record length of the four stations was found to be 1.47 and this will be applied throughout the catchment. This compares well with the ongoing Douglas Flood Relief Scheme which uses an adjustment factor of approximately 1.5.

Table 6-3 details the adjusted Qmed at all the HEPs.

These values can also be compared with analysis undertaken for the Lower Lee Flood Relief Scheme. For the Lower Lee, an average adjustment factor of 1.73 was estimated; although this figure is higher (and therefore more conservative) it covers catchments stretching from the wetter headwaters of the Lee catchment in the west, to the relatively drier catchments to the east.

Table 6-2 - Comparison of estimated and adjusted Qmed

Gauging Station	Record Length	Qmed gauged (m^3/s)	Qmed FSU (m^3/s)	Qmed Adjustment Factor
19032 - Meadowbrook	27	22.30	16.36	1.36
19006 - Glanmire	26	42.21	28.13	1.50
19009 - Brookhill (from POT)	10	15.76	9.20	1.70
	Weighted Catchment adjustment factor based on Record length			**1.47**

Table 6-3 - Adjusted HEP Qmed

HEP Number	Qmed FSU	Qmed adjusted
1	13.40	19.70
2	1.14	1.68
3	0.58	0.85
4	13.74	20.20
5	15.52	22.81
6	15.54	22.84
7	16.10	23.67
8	16.36	24.05
9	16.29	23.95
10	13.62	20.02
11	9.42	13.85
12	28.137	41.36
13	0.72	1.06
14	0.40	0.59
15	9.20	13.52
16	4.79	7.04

6.3 Flood Frequency Analysis

The method for estimation of peak flows using an index flood method involves two stages. The first stage of the method involves estimating Qmed as calculated in Section 6.2 and having completed this the second stage involves estimating a flood growth curve. The growth curve is a dimensionless version of the flood frequency curve which defines how the flood magnitude grows as the probability reduces, i.e. for more extreme design floods. The design flood for a particular exceedance probability is then simply calculated as the product of Qmed and the value of the growth curve for that probability (known as the growth rate).

Flood growth curves can be derived from analysis of annual maximum flows either at the site of interest (single-site analysis) or at a group of gauging stations chosen from a wide area (pooled analysis).

6.3.1 Single Site Analysis

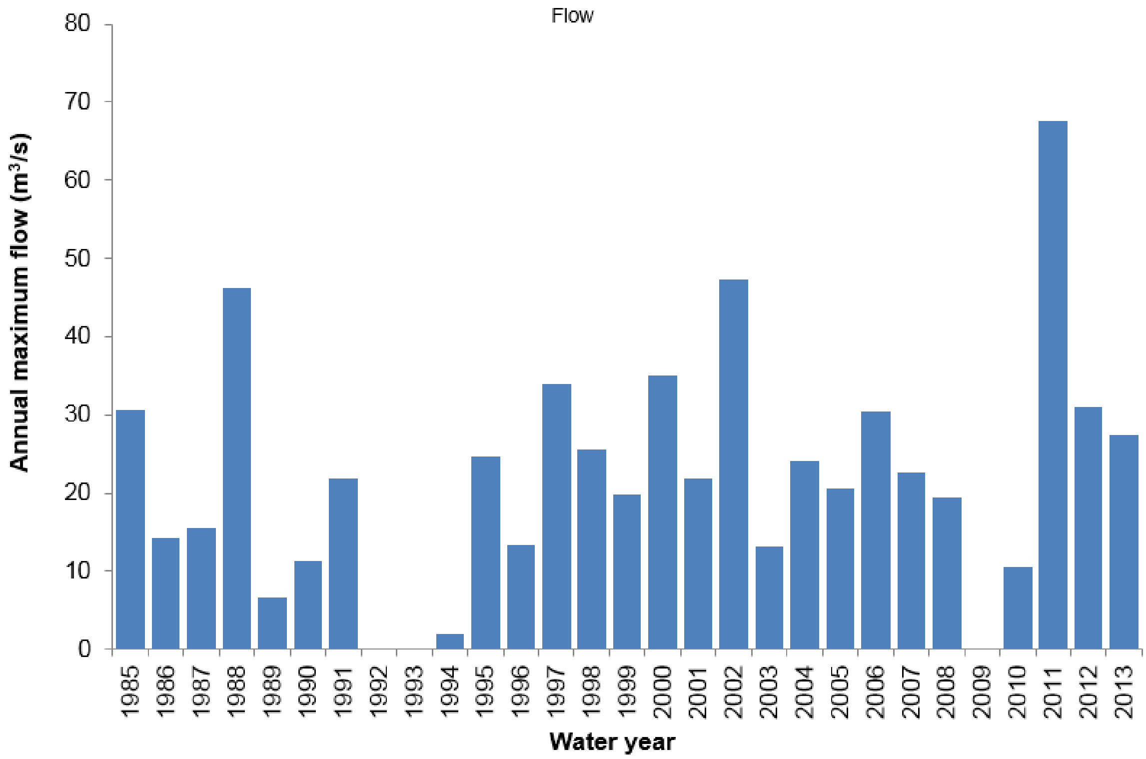
The statistical analysis of the annual maximum series at each of the gauging stations may provide a valuable check on the performance of other methods of flood estimation, and can be used to the determination of appropriate growth curves.

FSU WP 2.2 recommends considering two parameter distributions for single-site growth curves, either the extreme value type 1 (EV1, known as the Gumbel) or the 2-parameter log-normal distribution (LN2). Restricting the number of parameters to two helps reduce the standard error of the fitted distribution, albeit at a cost of a potential greater bias compared with 3-parameter distributions. In this assessment, both distributions have been fitted, and the goodness-of-fit assessed visually. For Meadowbrook gauge the data did not plot sufficiently well to two parameter distributions and it was necessary to consider 3- parameter distribution. Generalised extreme value (GEV), generalised logistic (GL) and the 3 parameter log -normal distributions were applied. The most suitable distribution was chosen based on a visual assessment.

Single Site Analysis 19032

A Single Site analysis was undertaken for gauging station Meadowbrook (19032), which provides the most centralised location to the study area and also the second longest data record of the gauging stations in the Glashaboy River catchment, after the Glanmire gauge. Figure 6-1 presents the annual maximum series for this station. The data presented in the table, and used in the single site analysis. A rating review was completed as discussed in Section 5 and an updated rating curve was produced. Figure 6-1 shows the Amax series based on the EPA rating as confirmed by the rating review completed.

Figure 6-1 - Annual Maximum Series at Station 19032



The software package WINFAP-FEH was used to apply a number of typical statistical distribution methods and findings are presented in Figure 6-2 and Table 6-4.

Figure 6-2 shows that the majority of the AMAX data are well represented by both the GL distribution and the GEV distribution. It can also be seen that the most extreme event (June 2012) results in an upwards trend of the distribution curve.

Results from the Single Site analysis show that the GL distribution provides the steepest growth curve. The GEV distribution provides similar results for up to the 100 year return period with a slightly lower growth curve for the more extreme return periods and has been chosen as the best fit.

Figure 6-2 - Growth Curve Fitting Single Site Analysis - 19032

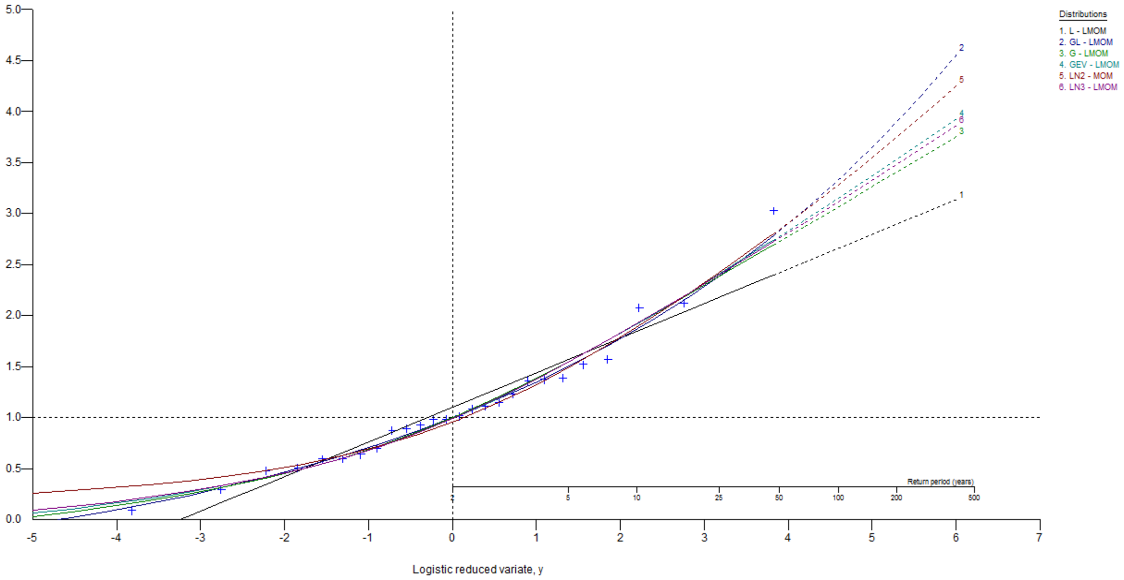


Table 6-4 - Growth Curve Fitting Single Site Analysis - 19032

Return Period	Logistic	Gen. Logistic	Gumbel	Gen. Extreme Value	Lognormal (2P)	Lognormal (3P)
	No 1	No 2	No 3	**No 4**	No 5	No 6
2	1.00	1.00	1.00	**1.00**	0.96	0.99
5	1.57	1.50	1.55	**1.54**	1.49	1.55
10	1.85	1.87	1.92	**1.92**	1.89	1.92
25	2.18	2.39	2.38	**2.41**	2.42	2.40
50*	2.42	2.83	2.73	**2.77**	2.84	2.76
100*	2.66	3.33	3.07	**3.15**	3.28	3.12
200*	2.89	3.89	3.41	**3.53**	3.75	3.48
500*	3.21	4.76	3.86	**4.04**	4.40	3.97
* Return Period exceeds record lengths and results should be treated with caution						

Single Site Analysis 19006

A Single Site analysis was undertaken for gauging station 19006, which has the longest record length, at 27 years and is located downstream of the confluence with the Butlerstown river so is representative of the whole catchment. The AMAX series is shown in Figure 5-14. The values presented in Figure 5-14 and used in the analysis, are the flows derived through the rating review (see Section 5.5).

WINFAP-FEH was used to apply a number of typical statistical distribution methods and findings are presented in Figure 6-3 and Table 6-5.

Figure 6-3 and Table 6-5 show that there is little difference between the distributions, with the AMAX data being well represented by all. It is should be noted that the most severe flood event to be experienced in Glanmire (June 2012) was not recorded at this station as the gauge was not in operation at that time. Results from the Single Site analysis can be seen in Figure 6-3 and Table 6-5 and the 2 parameter log normal has been chosen as the best fitting distribution.

Figure 6-3 - Growth Curve Fitting Single Site Analysis - 19006

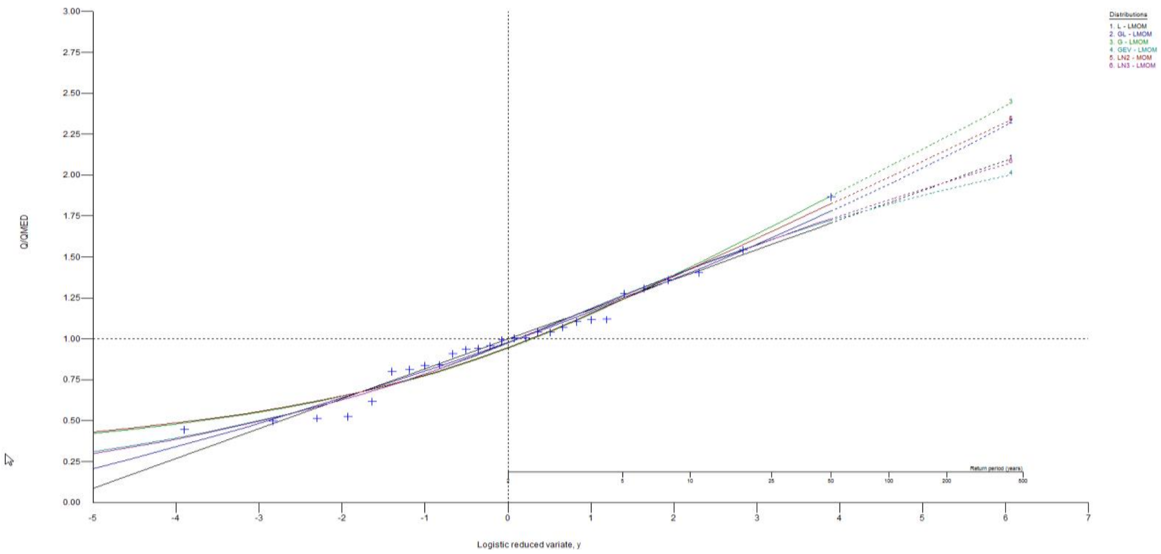


Table 6-5 - Growth Curve Fitting Single Site Analysis - 19006

Return Period	Logistic	Gen. Logistic	Gumbel	Gen. Extreme Value	Lognormal (2P)	Lognormal (3P)
	No 1	No 2		No 4	**No 5**	No 6
2	1.00	0.98	0.94	0.97	**0.95**	0.98
5	1.25	1.24	1.24	1.27	**1.24**	1.26
10	1.40	1.41	1.44	1.43	**1.43**	1.42
25	1.58	1.62	1.69	1.61	**1.66**	1.61
50*	1.71	1.78	1.87	1.72	**1.82**	1.73
100*	1.83	1.95	2.05	1.83	**1.99**	1.85
200*	1.96	2.12	2.24	1.92	**2.15**	1.96
500*	2.13	2.36	2.48	2.02	**2.37**	2.10
* Return Period exceeds record lengths and results should be treated with caution						

6.3.2 FSR Rainfall Runoff Growth Factors

The unit hydrograph method most widely used in Ireland and the UK for ungauged catchments is the FSR triangular unit hydrograph and design storm method. This method estimates the design flood hydrograph, describing the timing and magnitude of flood peak and flood volume (area beneath hydrograph). This method requires the catchment response characteristics (time to peak, tp), design rainstorm characteristics (return period, storm duration, rainfall depth and profile) and runoff / loss characteristics (percentage runoff and baseflow).

The UK Natural Environmental Research Council (1975) carried out a comprehensive flood study involving a large number of catchments from throughout Britain including many Irish catchments. The unit hydrograph prediction equation was derived from 1,631 events from 143 gauged catchments (the hydrograph method only included one Irish catchment) ranging in size from 3.5 to 500km^2. The result was a triangular Unit Hydrograph described by the time to peak Tp of the catchment derived from catchment characteristics. The instantaneous triangular unit hydrograph is defined by a time to peak Tp, a peak flow in cumecs/100km^2 Qp = 220/Tp and a base length TB = 2.52Tp.

Subsequent FSSR reports and in particular report No. 16 (1985) and IH 124 (1994) slightly modified the (Tp) equation and the calculation of percentage runoff (PR).

$Tp = 283\ S_{1085}^{-0.33}\ SAAR^{-0.54}\ MSL^{0.23}$ *(eqn 1)*

and $PR = SPR + DPR_{CWI} + DPR_{RAIN}$ *(eqn 2)* where

S_{1085} is the mainstream channel slope

MSL is the mainstream length

SAAR is the standard annual average rainfall depth

SPR = 10S1 + 30S2 + 37S3 + 47S4 + 53S5

S_1 to S_5 are the catchment fractions covered by the five winter rainfall acceptance potential (WRAP) classes and Su is the unclassified fraction which is covered either by standing water or a paved area.

DPR_{CWI} = 0.25(CWI – 125) and CWI = catchment wetness Index which is a function of SAAR.

DPR_{RAIN} = 0.45(R – 40)$^{0.7}$ for storm depth R > 40mm and = 0 for R < 40mm.

The FSSR 16 has been applied in this study. The design rainstorm duration is obtained from the FSR formula D = (1 + 0.001SAAR) Tp. Using the prescribed FSR rules for computing the storm duration, profile and percentage runoff a 140year return period design storm is required to produce the 100year design flood. The corresponding design rain storm in Table 6-6 were used in order to generate the FSR rainfall runoff growth curve.

Table 6-6 - FSR Design Rain Storms

Design Flood Event (years)	Design Rain Event required to produce the flood event (years)
2.33	2
5	8
10	17
20	35
30	50
50	81
100	140
250	300
500	520
1000	1000

Applying FSR using JBA Flood Estimation Software (JFes) at Meadowbrook and Glanmire gauging stations gives a FSR Flood Frequency curves as shown in Table 6-7

Table 6-7 - FSR Flood Frequency Curves

Return Period	Meadowbrook (19032)	Glanmire (19006)
2	1	1
5	1.45	1.44
10	1.70	1.69
25	2.03	2.03
50	2.33	2.32
100	2.63	2.63
1000	3.91	3.94

6.3.3 Composite Flood Frequency Curves

The FEH suggests that single site analysis is likely to offer the best estimate of flows up to a return period of 0.5N, where N equals the number of years in the record, therefore, at Glanmire with a 27 year record should provide robust estimates up to the 13-year event. FSU methodology suggests single site analysis can provide accurate estimates up to 2N. For this study single site analysis will be applied up to N years and the FSR rainfall runoff growth curve was applied above the record length, as shown in Table 6-8, ie. Glanmire has 27 years of record so the single site growth curve is applied up to 27 years from where the slope of the FSR rainfall runoff is applied to return periods greater than 27 years. This is in line with the methodology developed for the Lower Lee Flood Relief Study, and sensible given the limited record length of the gauge and the lack of high flow ratings.

Table 6-8 - Flood Frequency Curves

Return Period	Meadowbrook (19032)	Glanmire (19006)
2	1	1
5	1.54	1.24
10	1.91	1.43
25	2.41	1.66
50	2.71	1.95
100	3.05	2.26
1000	4.29	3.57

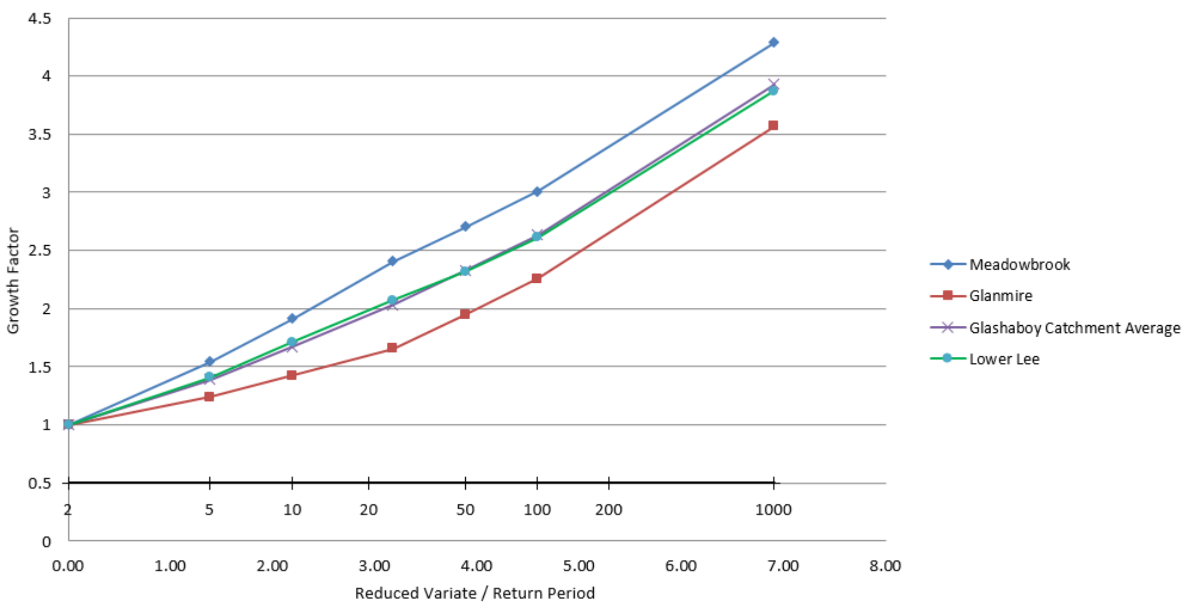
6.3.4 Comparison of Flood Frequency Curves

A comparison of the growth curves at Meadowbrook (19032) and Glanmire (19006) was undertaken. It should be noted that the majority of annual maximum flow records are extrapolated above the reliable limit of the gauging records (see Section 5) and each of the rating curves has a degree of uncertainty arising from both flow and water level recordings. Figure 6-9 shows the growth curves for both stations along with an average for the two. The Lower Lee catchment flood frequency curve is also plotted for comparison purposes. Table 6-9 shows the corresponding growth factors.

Table 6-9 - Comparison of flood frequency curves

Return Period	Meadowbrook (19032)	Glanmire (19006)	Average	Lee Average
2	1	1	**1.00**	1
5	1.54	1.24	**1.39**	1.41
10	1.91	1.43	**1.67**	1.71
25	2.41	1.66	**2.03**	2.07
50	2.71	1.95	**2.33**	2.32
100	3.05	2.26	**2.65**	2.61
1000	4.29	3.57	**3.53**	3.87

Figure 6-4 - Comparison of flood frequency curves based on the full record lengths



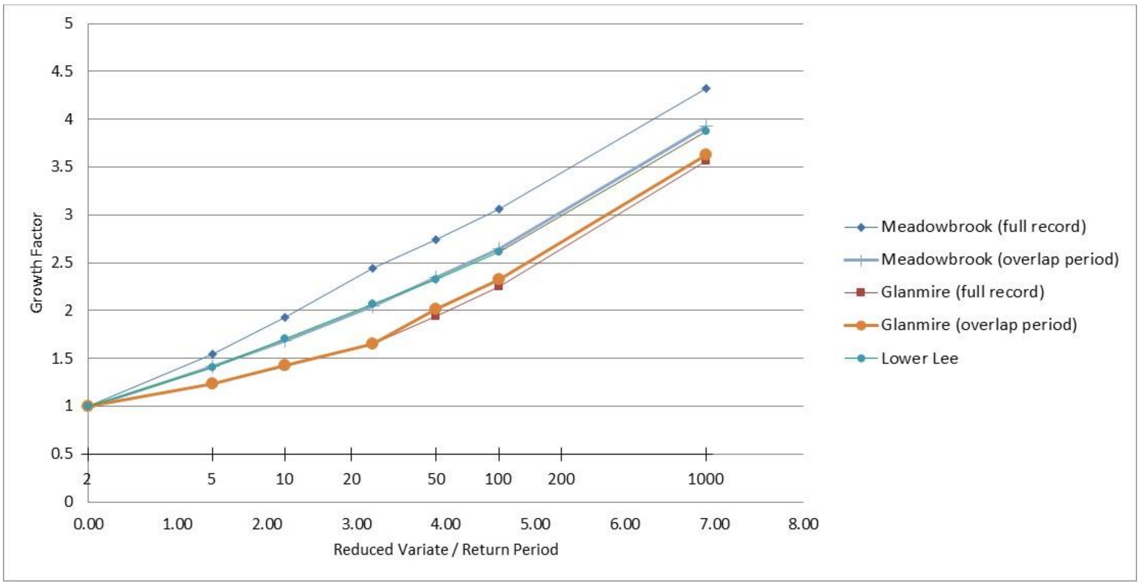
The Meadowbrook growth curve is steeper than the curve for Glanmire, which is expected as the upper catchment will be flashier. Glanmire will be also be influenced by the differing responses of the upper catchment and the significant Butlerstown sub-catchment. However, this Meadowbrook growth curve is considerably steeper than average, with a growth factor for 100 year event of 3.00. This demonstrates the impact of the extreme 2012 event in pulling the curve up, which is further investigated by analysing the period of overlapping gauge record, which excluded the 2012 event.

The Glanmire and Meadowbrook growth curves have also been compared to the Lower Lee average growth curve, which is found to lie between the two gauge curves, as shown by its coincidence with the curve representing the average of the two gauges.

6.3.5 Analysis of Overlapping Record Periods

One of the reasons for difference in growth curve between the Glanmire and Meadowbrook gauges could be the difference in the record period of the gauge, and the inclusion of the 2012 event in the Glanmire record. This was further investigated by carrying out single site analysis as described in the previous sections using only the annual maximum flows for the overlapping record period. The results are shown in Figure 6-5.

Figure 6-5 - Comparison of flood frequency curves based on the period 1986-2008



The graph shows there is little difference in the curve for the Glanmire gauge whether based on the whole or partial record. This indicates the partial record is representative of the whole series, with no outliers having occurred in the record period. In contrast, there is a substantial drop in the curve for Meadowbrook when the 2012 event is excluded, bringing it down to match the Lower Lee growth curve.

The response of the catchments to the same events has also been considered to determine how applicable the growth curves are to neighbouring catchments. This is illustrated in Figure 6-6 and Figure 6-7 for the Brookhill (19009) and Glanmire (19006) gauges, and Figure 6-8 for the Meadowbrook (19032) and Glanmire gauges, which all show area based specific unit runoff for various events. The Brookhill and Meadowbrook gauges did not overlap so a three-way comparison is not possible. Analysing the four plots shows the independence of response on the Brookhill and Meadowbrook catchments. For example, Figure 6-6 shows a marked increase in the unit flow at Brookhill when compared with Glanmire, indicating a lack of response from the rest of the catchment to the rain event. Figure 6-7 clearly shows additional inflows in the rising limb of the Glanmire hydrograph, although it is not possible to determine how much of this is from the Glashaboy upstream of the confluence, and how much is from the Glenmore River. The spikes in the Glanmire gauge plot in Figure 6-8 indicate the contribution of flow arising from the Butlerstown catchment. There are few instances when AMAX at the overlapping gauges coincide with each other, adding to the conclusion that the Glashaboy catchment as a whole is not homogenous, although in some events responses are similar.

Figure 6-6 - 1981 event at the Glanmire and Brookhill gauges

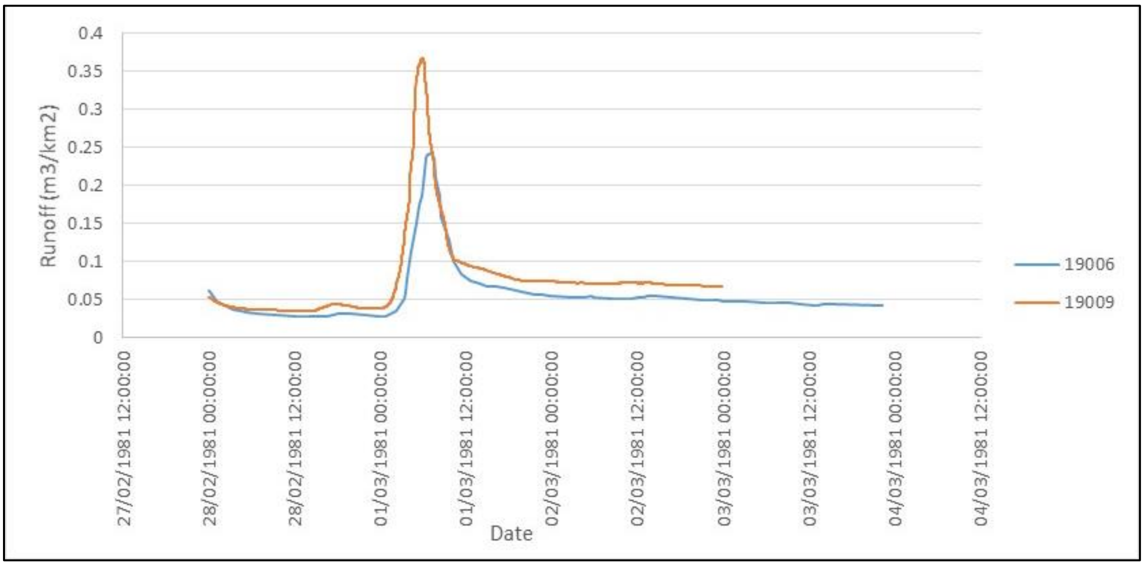


Figure 6-7 - 1979 event at the Glanmire and Brookhill gauges

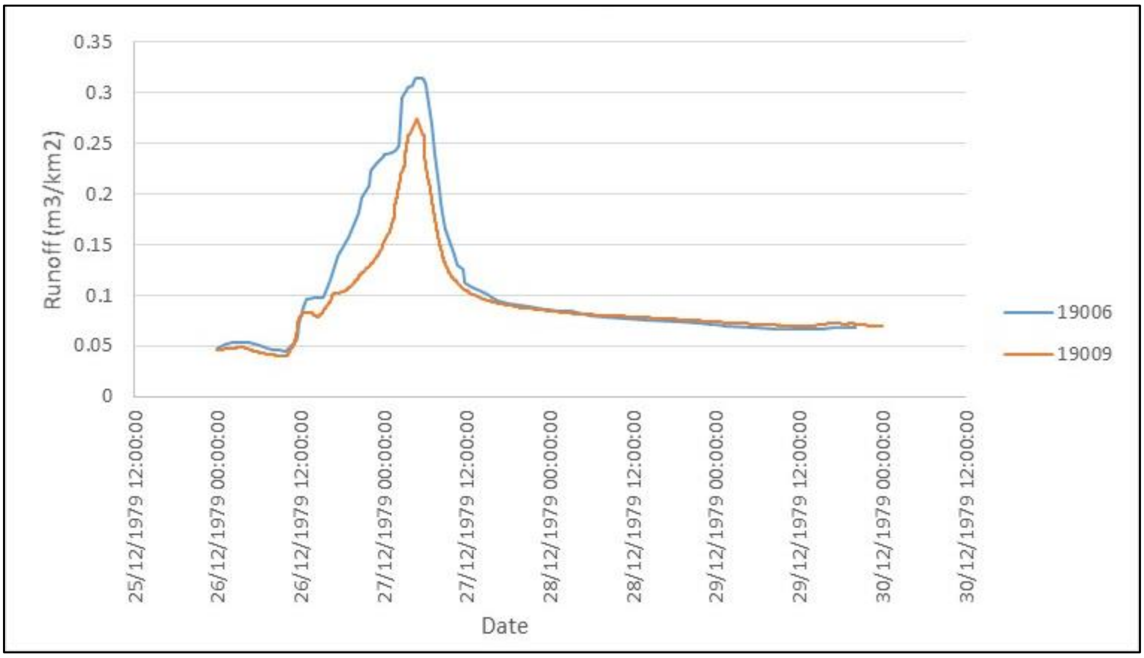
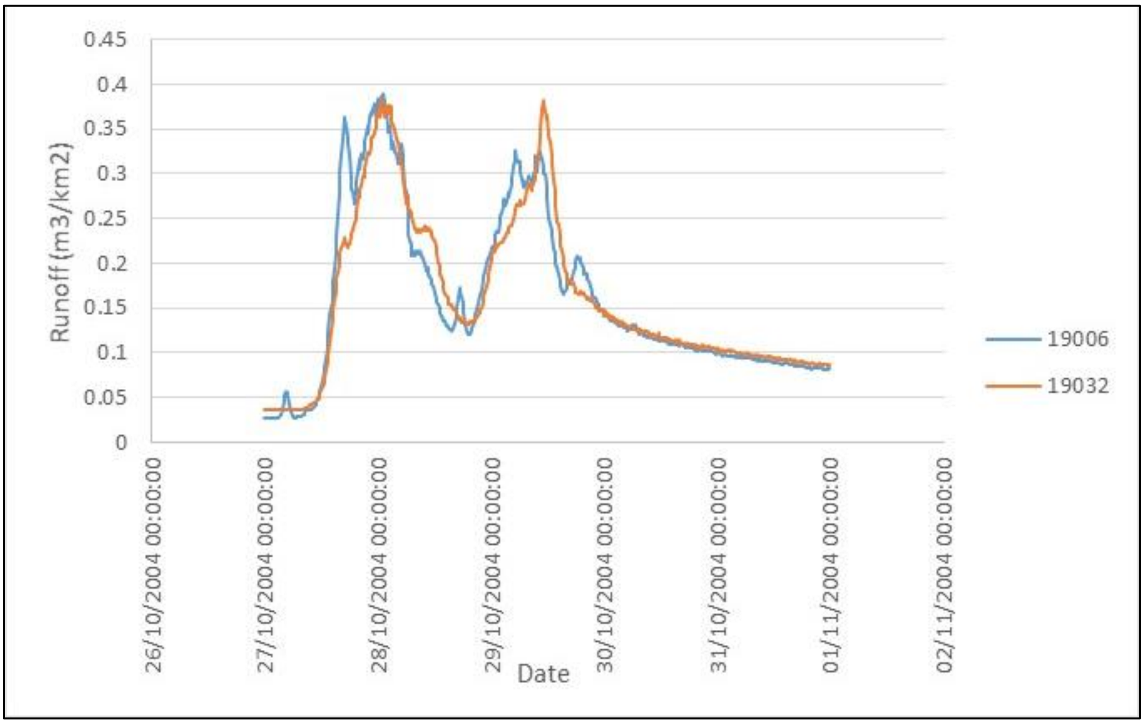


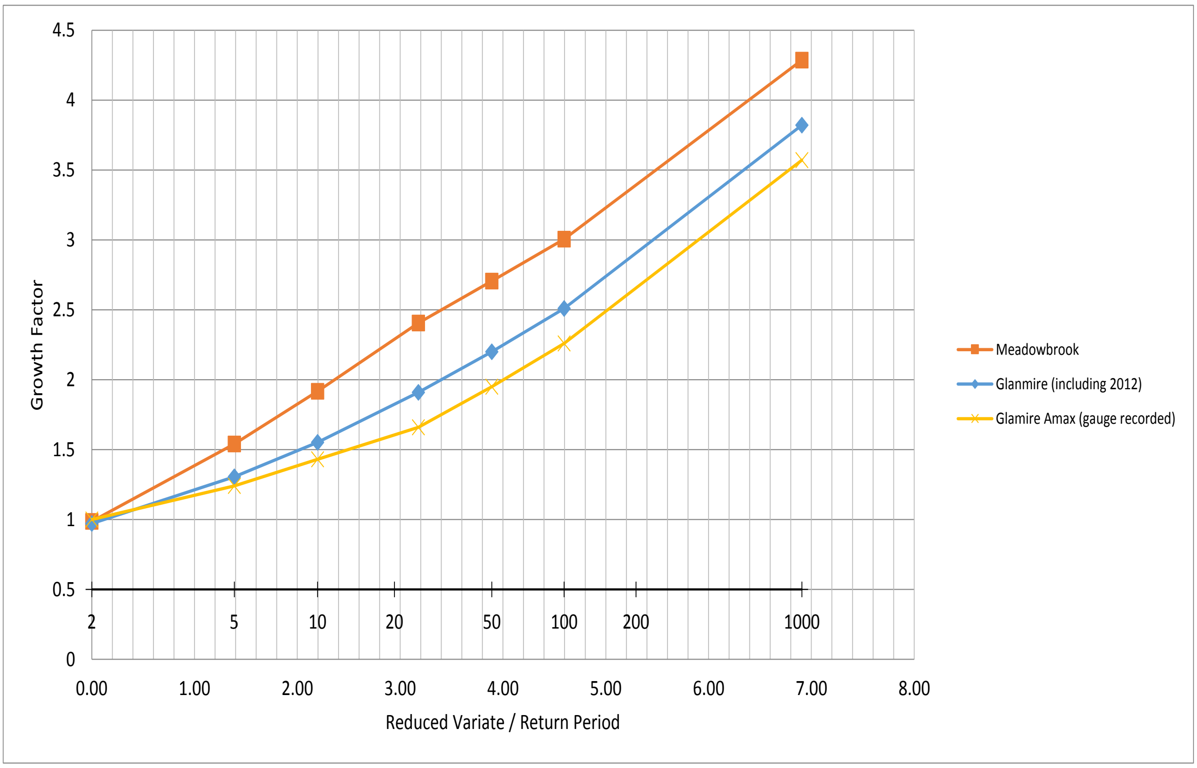
Figure 6-8 - 2004 event at the Glanmire and Meadowbrook gauges



6.3.6 The effect of the Inclusion of 2012 event at Glanmire

Recording of data at Glanmire ceased in 2009, however it was possible to estimate a flow value for the event based on trash marks taken during the event using the hydraulic model. This estimated a flow of 110m^3/s during the event. This flow value was added to the Amax series and with its inclusion a composite flood frequency curve was calculated as shown in Figure 6-9. It can be seen with the inclusion of 2012 growth curve (Blue) the original frequency curve (Yellow) shifts towards the frequency curve for Meadowbrook (Orange). This would lead to the conclusion that the flood frequency curve based on gauged data is too shallow. Based on the frequency curves the growth factors for the Q100 would be 3 (Meadowbrook), 2.5 (Glanmire including 2012) and 2.26 (Glanmire Amax based on gauged record).

Figure 6-9: Effect of 2012 inclusion at Glanmire



6.3.7 Choice of flood frequency curve

As the catchments are hydrologically similar the flood frequency curve developed from the full period record at Meadowbrook will be applied to all inflow points above the confluence of the Glashaboy and Butlerstown Rivers. This growth curve is shown in Table 6-10.

This growth curve gives a return period of approximately 90 years for the 2012 event at Meadowbrook.

Table 6-10 - Design flood frequency curve upstream of the Glashaboy / Butlerstown confluence

Return Period	Meadowbrook (19032)
2	1.00
5	1.54
10	1.91
25	2.41
50	2.71
100	3.05
1000	4.29

Analysis of the Q100 event was used to determine the most appropriate frequency curve to be applied at Glanmire is shown in Table 6-11. The design flow at Meadowbrook is 74m^3/s in the Q100 event. If the shallowest of the above frequency curves (based on Glanmire gauged data) is applied this would lead to a design flow of 95 m^3/s at Glanmire, which would only result in Butlerstown and Glenmore contributing a flow of 21 m^3/s. During the 2012 event, the extent of the flooding was lesser on the Butlerstown and Glenmore catchments and though Section 6.3.5 found the Glashaboy and Butlerstown catchments can be distinct from each other, it would be impractical to suggest that only a 2 year event occurs on this catchments when a 100 year occurs in the Glashaboy catchment.

Likewise, applying the flood frequency curve calculated based on the Amax for Glanmire gauge including the estimated 2012 would only lead to 32m^3/s been contributed from the eastern catchments, equivalent to 1 in 5 year events in the those catchments. For this reason the Meadowbrook frequency curve will be applied throughout. This would lead to a return period of 1 in 50 years for the 2012 in Glanmire, and based on flood accounts on the Butlerstown catchment during the event this is deemed appropriate.

Table 6-11: Choice of Glanmire Frequency Curve

	Q100 GF (Figure 6-9)	Design Flow Glanmire (m^3/s)	Required Contributing flow from Butlerstown (m^3/s)	Design Flow Butlerstown/ Glenmore
Meadowbrook	3	123	49	25 Year Event
Glanmire (2012)	2.5	106	32	5 Year Event
Glanmire (gauged)	2.26	95	21	2 Year Event

However, as shown in the assessment of independence of the Glashaboy and Butlerstown catchments, applying a 100 year event simultaneously on both catchments would overestimate the flow at Glanmire (i.e. the combined probability of a 1 in 100 year event occurring on both rivers would be greater than 1 in 100 at Glanmire).

It is therefore proposed that the model will be run in two hydrologically independent set ups. In the first, the Meadowbrook catchment inflows will be the 1% AEP event based on the FSR adjusted single site analysis for the Meadowbrook gauge. The inflows from the Butlerstown River will be scaled so the 1% AEP flow value is matched at the Glanmire gauge HEP (as derived from the Meadowbrook flood frequency curve). It is this model which will be used to design the flood relief scheme for the Glashaboy River.

The second model set up will be the reverse of the Glashaboy scheme, in that the Butlerstown inflows will be fixed a 1% AEP, and the Glashaboy flows will be scaled to match the Glanmire HEP 1% AEP.

6.4 Inflow Hydrographs

The FSR Rainfall Runoff hydrograph shape was adopted as the basis of the hydrograph shape on all watercourses, with the hydrograph being scaled to match the relevant peak flow estimates. Additional lateral inflows were added along the Glashaboy River and tributaries in order to match the peak flow estimates to provide consistency between the hydrological assessment and the hydraulic analysis, as described above.

6.5 Final Choice of Scheme Design Flows

Design Flows for each HEP have been calculated by multiplying the estimates of Qmed listed in Table 6-3 by the flood frequency curve shown in Table 6-10 and are outlined in Table 6-12.

Table 6-12 - Final Scheme Design Flows

Retrun Period	Growth Factor	HEP01	HEP02	HEP03	HEP04	HEP05	HEP06	HEP07	HEP08 (Meadowbrook)	HEP09	HEP 10	HEP11	HEP12 (Glamire)	HEP13	HEP14	HEP15	HEP16
2	1.00	19.7	1.7	0.9	20.2	22.8	22.8	23.7	24.0	23.9	20.0	13.8	41.4	1.1	0.6	13.5	7.0
5	1.54	30.3	2.6	1.3	31.1	35.1	35.2	36.4	37.0	36.9	30.8	21.3	63.7	1.6	0.9	20.8	10.8
10	1.91	37.6	3.2	1.6	38.6	43.6	43.6	45.2	45.9	45.7	38.2	26.4	79.0	2.0	1.1	25.8	13.4
25	2.41	47.4	4.0	2.1	48.6	54.9	54.9	56.9	57.8	57.6	48.1	33.3	99.5	2.5	1.4	32.5	16.9
*50	2.71	53.3	4.5	2.3	54.6	61.7	61.8	64.0	65.1	64.8	54.2	37.4	111.9	2.9	1.6	36.6	19.0
*100	3.01	60.2	5.1	2.6	61.7	69.7	69.8	72.3	73.5	73.2	65.1	42.3	126.4	3.4	1.8	41.3	21.5
*1000	4.29	84.4	7.2	3.7	86.6	97.8	97.9	101.4	103.1	102.6	85.8	59.3	177.2	4.5	2.5	58.0	30.2

The flood event of June 28th was recorded at Meadowbrook and is estimated at 67.5m^3/s, which, based on the design flow (HEP08) is estimated to be around the 1 in 90 year return period event.

6.6 Climate Change

The DoEHLG and OPW guidelines, The Planning System and Flood Risk Management, recommend that a precautionary approach is adopted due to the level of uncertainty regarding the potential effects of climate change. A significant amount of research into climate change has been undertaken both nationally and internationally.

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 and its first report in 1990 justified concern about the effects of climate change on a scientific basis. The more recent IPCC Fourth Assessment Report 2007 concludes that climate change is unequivocal. It projects a global average sea level rise of between 0.18m and 0.59m for different SRES emissions scenarios, up to the end of the century.

More specific advice on the expected impacts of climate change and the allowances to be provided for future flood risk management in Ireland is given in the OPW draft guidance. For this study the Mid-Range Future Scenario (MRFS) will be considered. The MRFS is intended to represent a "likely" future scenario based on the wide range of future predictions available. The guidance states that flood flows shall be increased by 20% for the MRFS scenario. This change has been implemented by scaling up the flood hydrograph for each HEP and for each probability by the specified percentage. The design of the scheme will be tested for robustness against MRFS flows of +20% as outlined in Table 6-13. Sensitivity will also be included to analyse the effect of a higher downstream boundary due to the predicted rise in tide levels.

Table 6-13 - Design Flows with an allowance for Climate Change (+20%)

Retrun Period	Growth Factor	HEP01	HEP02	HEP03	HEP04	HEP05	HEP06	HEP07	HEP08 (Meadowbrook)	HEP09	HEP 10	HEP11	HEP12 (Glamire)	HEP13	HEP14	HEP15	HEP16
2	1.00	23.6	2.0	1.0	24.2	27.4	27.4	28.4	28.9	28.7	24.0	16.6	49.6	1.3	0.7	16.2	8.4
5	1.54	36.4	3.1	1.6	37.3	42.2	42.2	43.7	44.4	44.3	37.0	25.6	76.4	2.0	1.1	25.0	13.0
10	1.91	45.2	3.9	2.0	46.3	52.3	52.4	54.2	55.1	54.9	45.9	31.7	94.8	2.4	1.3	31.0	16.1
25	2.41	56.9	4.8	2.5	58.3	65.8	65.9	68.3	69.4	69.1	57.8	40.0	119.4	3.1	1.7	39.0	20.3
*50	2.71	64.0	5.5	2.8	65.6	74.1	74.2	76.8	78.1	77.7	65.0	44.9	134.3	3.4	1.9	43.9	22.8
*100	3.01	72.2	6.2	3.1	74.1	83.6	83.8	86.8	88.2	87.8	78.1	50.8	151.6	4.1	2.1	49.6	25.8
*1000	4.29	101.3	8.6	4.4	103.9	117.3	117.5	121.7	123.7	123.1	102.9	71.2	212.7	5.5	3.0	69.6	36.2

Appendices

A. HEP Catchment Characteristics

HEP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
AREA	62.57	3.49	1.95	65.18	68.04	73.10	75.27	76.35	76.49	63.83	43.69	140.50	2.07	1.08	43.42	19.97
SAAR	1196.9	1154.9	1108.4	1195.2	1192.0	1187.8	1184.5	1182.9	1182.7	1161.1	1189.3	1172.8	1074.5	1184.5	1190.0	1100.3
FARL	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
URBEXT	0.00	0.05	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.00	0.04
ALLUV	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00
FLATWET	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.65	0.64	0.64	0.64
BFISOIL	0.697	0.703	0.661	0.696	0.695	0.696	0.695	0.695	0.695	0.686	0.697	0.694	0.687	0.687	0.697	0.681
STMFRQ	63	1	1	63	65	67	69	71	71	57	35	129	1	1	35	21
MSL	15.95	4.00	1.46	17.74	18.78	20.45	20.75	20.75	21.37	14.43	14.04	21.87	2.94	1.12	13.43	8.37
S1085	10.26	26.13	42.62	9.81	10.33	9.67	9.89	9.89	9.40	10.95	10.94	9.17	38.58	38.58	10.49	14.82
ARTDRAIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARTDRAIN2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Qmed FSU	13.40	1.14	0.58	13.74	15.52	15.54	16.10	16.36	16.29	13.62	9.42	28.14	0.72	0.40	9.20	4.79

B. Supplementary Hydrology and Hydraulic analysis

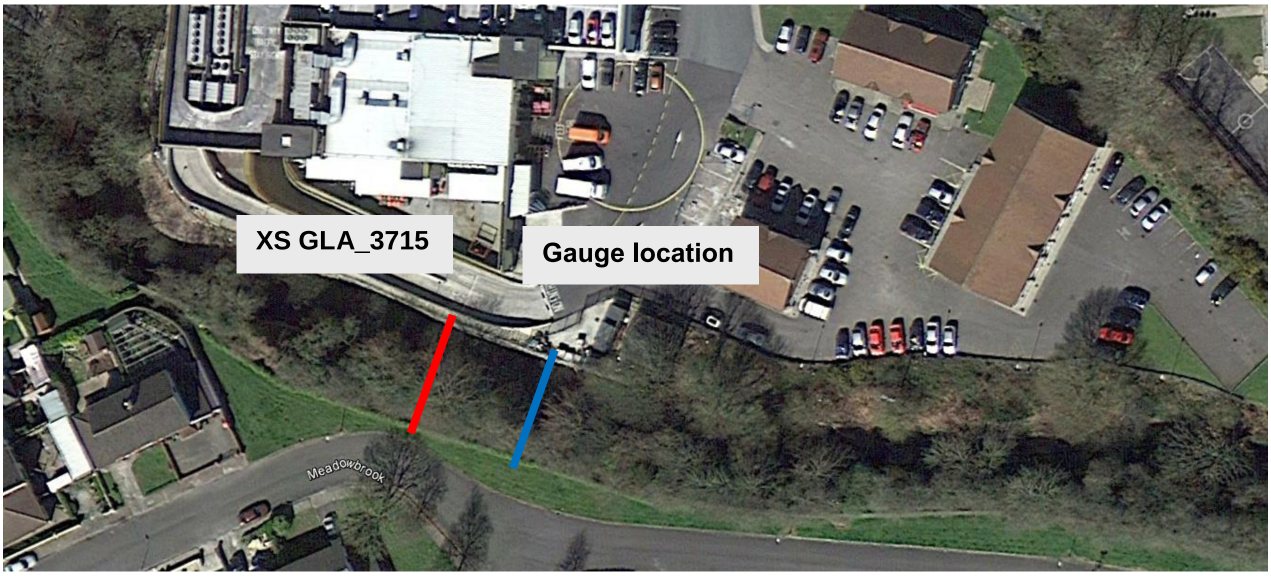
Meadowbrook Rating Review

B.1 Cross-sectional change

The development of SuperValu created a change of the left bank of the river bordering the site. The effect of this change was to the left bank, where it changed from a steep earth bank to a gabion basket wall. An aerial view of the change is presented below. It should be noted that the channel downstream of the gauge section has not changed.

Figure 6-10: Glashaboy at Meadowbrook 2007

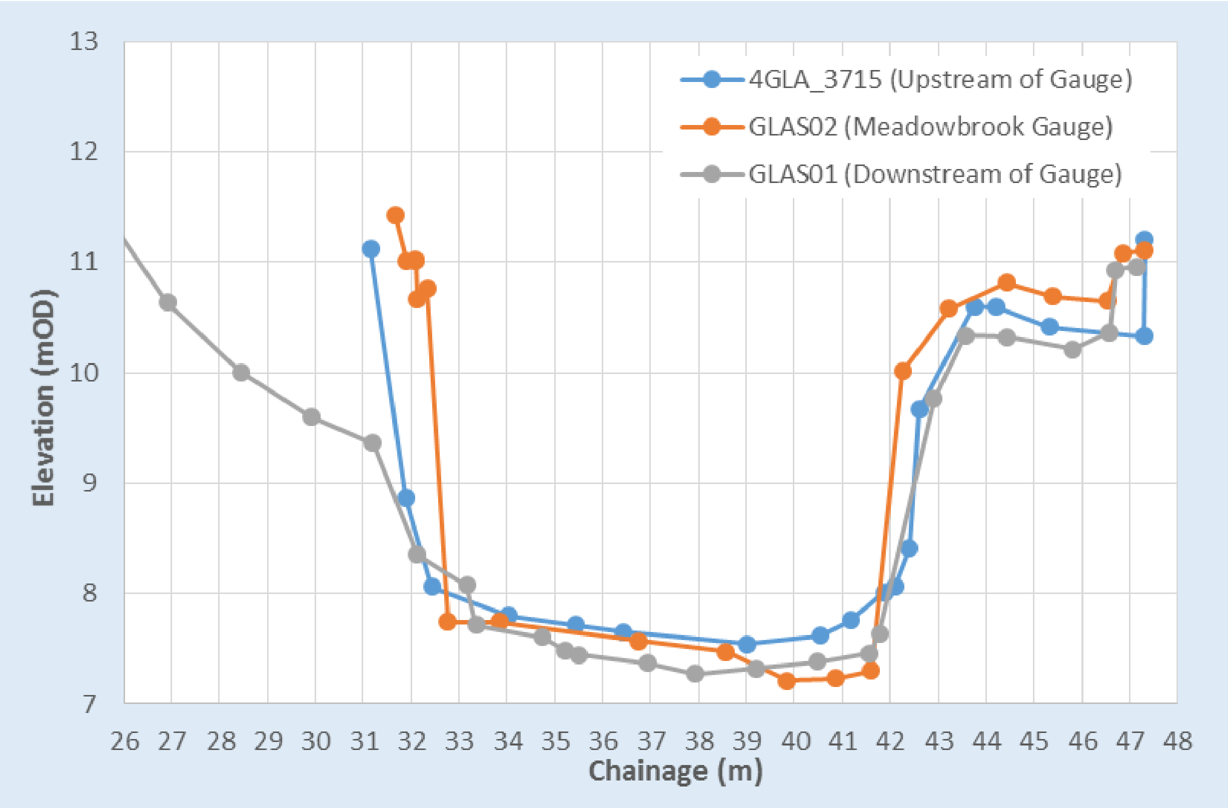
Figure 6-11: Glashaboy at Meadowbrook 2013



The rating for the gauge was only available from the original survey point taken at XS GLA_3715 15m upstream of the gauge. Following the calibration exercise and the levels observed in this section of channel it was decided to sensitivity check the validity of this approach and additional infill survey was taken of the gauge section (GLAS02) and a section 30m downstream (GLAS01). Figure 6-12 depicts the new sections and the GLA_3715 section which has been updated on the left to represent the SuperValu development. These sections represent the river post the SuperValu

The section at the GS was found to be very similar to that previously adopted. However, the section downstream reflected the previously wider channel, but only occurred over a relatively short section of the watercourse.

Figure 6-12: Cross-sections upstream and downstream of Meadowbrook gauge



B.2 Staff Gauge Datum

Staff gauge zero has been resurveyed to have a definitive figure. Received gauge datum zero recording from EPA were to a TBM and corrected to Malin OD from surveyed water levels in order to convert staff gauge readings. The difference between SGZ as used in the assessment and as surveyed is 0.015m.

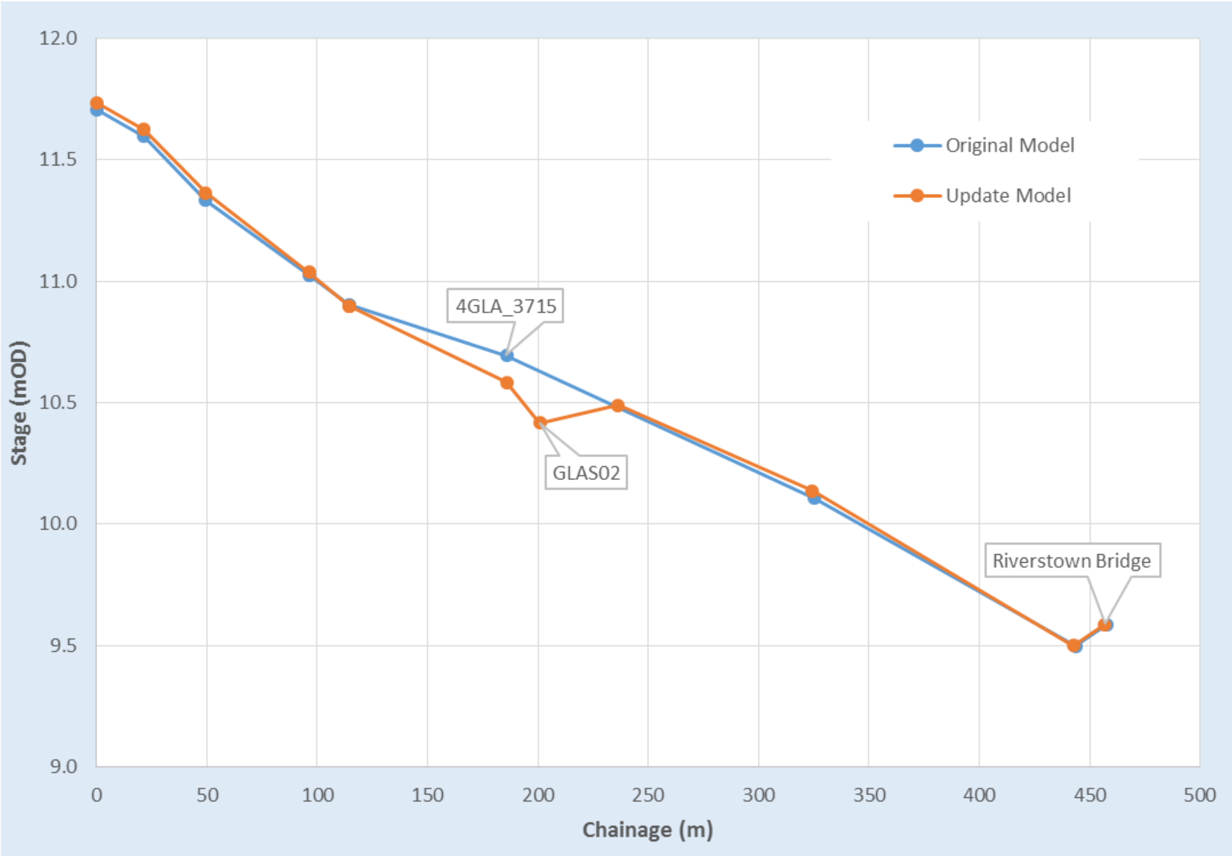
Used SGZ	=	7.533mOD
Survey SGZ	=	7.548mOD
Difference	=	0.015m

This change would increase flows by ~0.5m3/s for a given stage. This is within the errors of the rating and the models application of the hydrology so no change is proposed.

B.3 Hydraulic

The inclusion of the new sections has an unexpected effect on the hydraulic gradient through Meadowbrook. As demonstrated in Figure 6-13 the long section dips at the gauge section (GLAS02) relative to the more consistent hydraulic profile of the original model. This has an effect on the higher stage-flow relationship at the modelled gauge section, which is discussed in the next section

Figure 6-13: Hydraulic long section comparison (1% AEP)

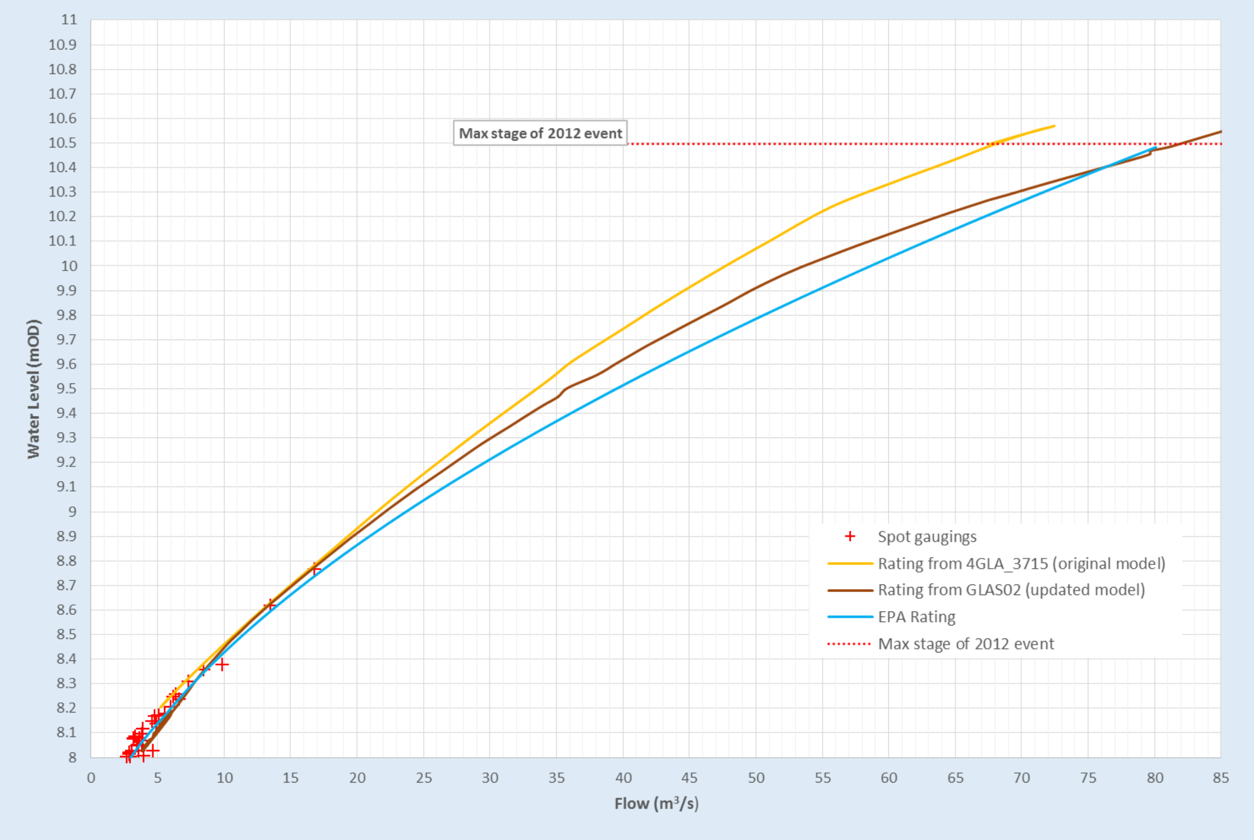


Hydraulically this may be a phenomena of the ISIS model and is very local. No observations have been reported of an acceleration zone around the GS.

B.4 Rating Review

A new rating curve was produced for GLAS02 in the updated model and compared to the curve for 4GLA_3715 in the original model. Figure 6-14 demonstrates the flatter curve for the GLAS02 cross-section. This rating curve for GLAS02 describes higher flows for river stages compared to that of the original model, with high stages (above the value of the spot ratings) most affected. The flood events affected by this change, in terms of revisions to AMAX values, are those which occurred after the SuperValu development was carried out. The flood event most affected is that of June 2012, which increases from 67.5m3/s to 81.0m3/s. Incorporating this into the calculation of the design flows accounts for an increase of Q100 from 73.4m3/s to 78.2m3/s.

Figure 6-14: Meadowbrook rating comparison



B.5 Conclusion

The new cross sections have been incorporated into the hydraulic model and a new rating has been produced to sensitivity check the rating from the original model. This new rating has the effect of increasing the Q100 by 4.8m3/s. Qmed was increased by 3%. More critically the flood level recorded at the GS during the 2012 event, would generate a higher flow using this revised rating.

Care should be taken in using this updated hydraulic modelling to automatically update the hydrology. The hydraulics in this section of watercourse have been altered by the recent construction of the Supervalu store, and also we know from observations that this reach of watercourse is downstream of a 90° bend and superelevation effects are present. The calibration of the model with this new section in place did not alter the goodness of fit along this reach. As a result of the behaviour of the hydraulic profile and ability to observe that phenomena on site a lower weight should be given to this revised rating. However, it does assist in improving the calibration of the 2012 event in the upper reaches, particularly at Grandon's garage. This improvement will be depicted in a revised hydraulics report.

Overall the revised rating is not deemed sufficient to alter the design hydrology for the project particularly given the uncertainty associated with the localised hydraulics of the channel and the apparent dip / jump in water levels when the new section is incorporated. However, it will be incorporated into the design of all proposed flood defences by including it into the sensitivity analysis. An additional 6.5% will be added to the sensitivity flows in assessing freeboard. This 6.5% combined with Qmed uncertainty of 7% and growth curve uncertainty of 8% gives a total in the flow sensitivity of 23.5%.

C. December 2015 Flood Report

Cork County Council

Glashaboy Flood Relief Scheme

Glanmire December 2015 Flood Report

REP/4-04-03

Issue 3 | 18 November 2016

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1 Introduction and background

December 2015 was the wettest month on records in many areas of Ireland, particularly in the Southwest where rainfall amounts were approximately 3 times the average.

By the end of December, many areas were entirely saturated and even normal rainfall events resulted in very significant flooding.

Storm Frank, the 6^{th} major winter storm of 2015 brought high winds and significant rainfall between the 29 December 2015 and the 2 January 2016.

Significant flooding resulted across much of the country. County Cork was badly affected with major flood events on many rivers such as the Blackwater, Bandon, Glashaboy, Owenacurra and many others.

During the event, an Arup staff member from the locality observed the event taking useful photographs and providing useful observations.

Arup subsequently visited the affected areas of Glashaboy catchment on 14 January 2016 to meet with residents and examine areas which had been affected by flooding in the recent event.

This report details the findings of a desk study of the event including observations and anecdotal evidence collected while visiting the catchment and meeting with local residents, and a high level analysis of the event is discussed in the context of Arup's on-going work on the Glashaboy Flood Relief Scheme (FRS).

2 Data collection

The following sources were used to inform this report:

- Glashaboy FRS Existing Reports & Hydraulic Model
- Met Éireann Rainfall Data
- Tidal Gauge Data from www.waterlevel.ie
- A Site visit on the 14 January 2016
- Feedback and anecdotal evidence from local residents
- Surveyed wrack marks
- Social Media

3 Antecedent catchment conditions, rainfall and tidal recordings

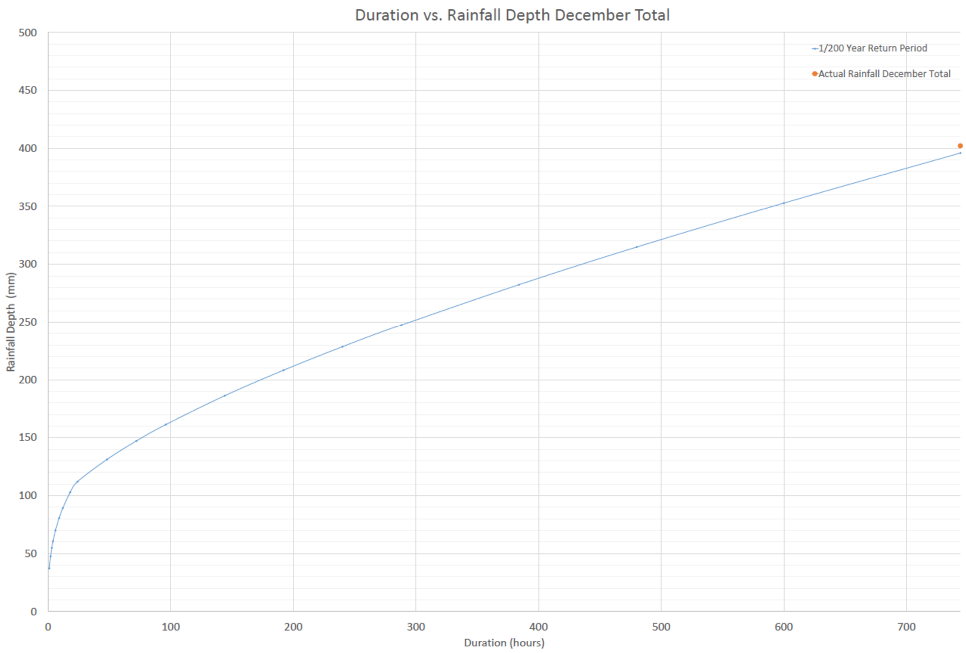
December 2015 was the wettest month on records in many areas of Ireland, particularly in the southwest where rainfall amounts were approximately 3 times the average.

Met Éireann's December 2015 Weather Summary notes that '*All stations reported well above Long-Term Average rainfall with most stations across the country reporting double or triple their normal rainfall for December. Wettest conditions (compared to LTA) were in county. Cork where nearly all stations reported over 300% of LTA. Roche's Point reported the highest percentage of LTA with 342% (340.6 mm of rain) it's highest for December since 1955.*

It further noted that the highest rainfall total for the month of December was recorded at Cork Airport where some 402.2mm of rainfall fell, approximately 3 times the long term average. 324mm of rainfall, 312% of the LTA rainfall was also recorded at Fermoy, Moore Park.

Figure 1 below provides the depth duration curve for 1 in 200year rainfall event at Cork Airport. It is extrapolated from 25 days to 31 days as met Éireann's Depth Duration Frequency (DDF) data only extends to 25 days. It can be seen that the monthly calendar rainfall total for December of 402mm has a return period of more than 1 in 200years.

Figure 1 Depth Duration Graph for 1 in 200year rainfall event



Clearly, December's rainfall was exceptional. By the end of December, many areas were entirely saturated and even normal rainfall events resulted in very significant flooding. Groundwater levels were therefore also extremely elevated.

Storm Frank, the 6th major winter storm of 2015, brought high winds and significant rainfall between the 29 December 2015 and the 2 January 2016.

Prior to the 28 December 2015, approximately 312mm of rainfall had already fallen in the month at Cork Airport, with 248mm having fallen at Moore Park for the month to that date.

A further 16mm of rain fell at both locations on the 28 December in the run-up to Storm Frank.

The largest rainfall amounts fell in a 21 hour window between about noon on the 29 Dec 2015 and 7am on the morning of the 30 Dec 2015 with 61mm being recorded at Cork Airport, 46mm at Moore Park, Fermoy.

Whilst there is no synoptic rainfall gauge in the Glashaboy catchment, the nature of Storm Desmond is such that the rainfall in the catchment was likely to have been of this order of magnitude.

A further 13mm of rainfall fell over the remainder of the 30th and through the 31 December 2015.

The second major rainfall occurred through the 1 January 2016 and the early hours of the 2 January 2016. On these dates, approximately 40mm of rain fell in a 30 hour window at both Moore Park and Cork Airport. Again, this would have been representative of rainfall at Glashaboy.

A further 12mm to 15mm of rainfall fell on the 3 January 2016. Table 1 below shows the cumulative rainfall totals for various durations that occurred during Storm Frank and outlines the equivalent return periods for these events by comparison against the relevant DDF data for the relevant locations.

Table 1 Rainfall Totals during Storm Frank

Duration (hours)	Rainfall Cork Airport (mm)	Return Period Cork Airport (Years)	Rainfall Moorepark Fermoy (mm)	Return Period Moorepark Fermoy	Estimated Rainfall at Glanmire (mm) (taken as average of Cork Airport and Moore Park)	Return Period Glanmire (Years)
1	7.1	1	5.1	0.8	6.1	1
2	12.3	1.4	9.3	1.12	10.8	1.2
3	16.4	1.6	13.5	1.4	14.95	1.4
4	20.6	1.8	17.4	1.6	19	1.6
6	26	1.9	22.9	1.8	24.45	1.7
9	30.9	1.9	28.3	1.9	29.6	1.8
12	48.8	6	33.9	2	41.35	3
24	61	5	46.5	3.5	53.75	2.5
48	72.8	4	62.8	4	67.8	3.5
72	88.6	6	69.8	4	79.2	3.5
96	111.4	12	90.7	7.5	101.05	5
144	139.8	22	126.1	25	132.95	10

A number of things are noteworthy as follows:

The return period increases for increasing duration meaning that the duration/volume rather than the intensity was the most significant aspect of these rainfall events. The maximum 1 hour rainfall had a return period of 1 in 1 year. However, the 24hr event had a return period of about 1 in 5 years.

This means that the rainfall events would have been most significant on medium to large catchments rather than smaller catchments. This is evident from the locations where flooding did occur, i.e. Blackwater, Glashaboy, Bandon etc., all medium to large catchments.

The main rainfall event on the 29/30 December lasted about 21 hours and the subsequent event lasted approximately 30hours.

It is noteworthy that the Lee CFRAM Study established that the critical storm duration for the Glashaboy catchment was 21-25hours. It is clear that the two events that occurred were very close in duration to the critical duration for the catchment and having a return period of approx. 1 in 5 years were significant.

4 Tide analysis during the Dec 2015/Jan 2016 flood events

Tidal influence extends to just above the confluence of the Glashaboy River and the Mill Race at the Weir, upstream of Glanmire Bridge. Tidal flooding has previously occurred in Glanmire, most notably in 2012.

Therefore, it is important to establish if tidal influence played a part in the Dec 2015/Jan 2016 event.

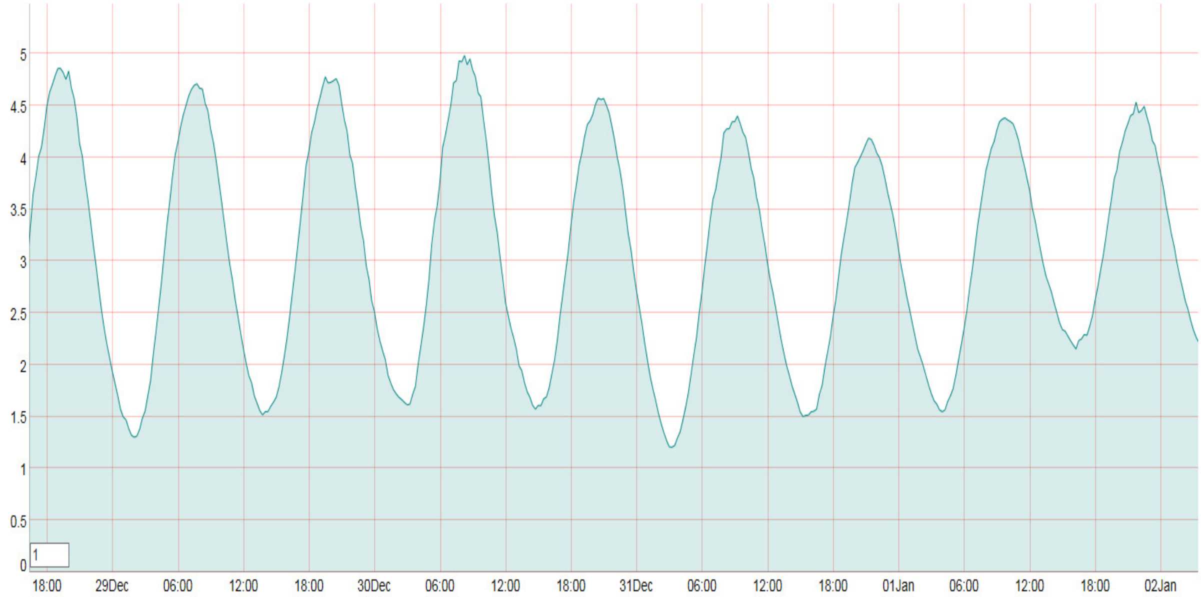
Tidal information was established by reference to the Ringaskiddy Gauge data from waterlevels.ie. The gauge is located as shown in Figure 2 below.

Figure 2 Ringaskiddy Tidal Gauge

Figure 3 below illustrates the tidal cycle for the critical period from the 29th December 2015 to 2 January 2016.

The gauge record must be corrected to OD Malin Head by subtracting the Staff Gauge Zero reading of -2.897m OD.

Figure 3 Ringaskiddy Tidal Gauge record – 29 Dec 2015 to 2 Jan 2016.



Data for 19069 Ringaskiddy NMCI

Sensor no. 0001 Parameter Water level

Latest data: Jan. 8, 2016, 4:30 p.m. (UTC / GMT) staff gauge level 4.518m. Staff gauge zero is -2.897m above Malin Head datum (from 02 Jun 1900).

Disclaimer

Use of this site is subject to the disclaimer on the Home page.

View on OPW Hydro-Data website (new tab).

Water level readings for 19069 Ringaskiddy NMCI

Only data for the past 35 days are shown.

Times are always shown in UTC (GMT). Stage is in meters relative to the bottom of the staff gauge at the station.

Table 2 below sets out the time and magnitude (in mOD) of the high and low tides during the critical period.

Table 2: High and Low Tide Levels

Date & time	Gauge Reading	Tide Level
		mOD
29/12/2015 02:00	1.303	-1.59
29/12/2015 07:45	4.712	1.82
29/12/2015 13:45	1.518	-1.38
29/12/2015 19:30	4.78	1.88
30/12/2015 03:00	1.616	-1.28
30/12/2015 08:15	4.986	2.09
30/12/2015 14:45	1.573	-1.32
30/12/2015 20:30	4.575	1.68
31/12/2015 03:15	1.207	-1.69
31/12/2015 09:15	4.403	1.51
31/12/2015 15:15	1.502	-1.40

Date & time	Gauge Reading	Tide Level
		mOD
31/12/2015 21:15	4.187	1.29
01/01/2016 04:00	1.549	-1.35
01/01/2016 09:45	4.383	1.49
01/01/2016 16:15	2.154	-0.74
01/01/2016 21:45	4.535	1.64
02/01/2016 05:00	1.977	-0.92
02/01/2016 10:30	3.921	1.02
02/01/2016 17:00	1.708	-1.19
02/01/2016 22:45	3.867	0.97

As can be seen above, the highest tide that occurred during the relevant period was on the morning of the 30 December 2015 and was in the order of 2.1mOD. This is significantly less than a 1 in 1 year tide.

Anecdotal evidence from the occupier of the Grove suggests that the peak on the Glashaboy occurred at around 2am to 3am on the morning of the 30 December 2015 (which coincided with low tide) and had significantly dropped by the time the tide peaked later that morning at circa 8.15am.

High Tide levels were very low during the subsequent flooding on the 1st/2nd January 2016 and was not a significant factor at that stage.

It is clear from the evidence of flooding and the above discussion, that fluvial flooding was the dominant cause with tidal influences having little if any impact on the flooding which arose in the tidally influenced area adjacent to the Grove.

5 Site visit

On 14 January 2016, Arup walked the sites of flooding in the Glashaboy Catchment, with residents who were able to provide first-hand accounts and valuable information on the approximate flood depths, extents, mechanisms and chronology of the flood events.

This information is very important in the absence of any available gauge data for the event.

Arup liaised with EPA to gather hydrometric data for the event from the Meadowbrook gauge. Unfortunately, the EPA advised that the gauge is currently suspended and therefore no gauge date was available for this event.

As a result, no accurate flow or level recordings of the Dec 2015/Jan 2016 event are available which would have been useful in calibrating the hydraulic model, and quantitatively assessing the flood event. However, following the event, Arup liaised with Cork County Council to acquire surveyed levels of wrack marks and a number of finished floor levels. This report is therefore limited to an assessment of the anecdotal evidence collected during the site visit and surveyed wrack marks gathered following the flood event.

5.1 Meadowbrook Estate

A number of members of the Meadowbrook Residents Association met with Arup on site and provided their account of the Dec 2015/Jan 2016 flood event.

By every account, without the two pumps provided by the council, the assistance of a local farmer's slurry tank, sandbags and the tireless efforts of residents, the emergency services and all flood responders, many properties in the Meadowbrook Estate would likely have been flooded. Thankfully, it appears that no dwellings were flooded.

The Dec 2015/Jan 2016 flooding in the Meadowbrook Estate was primarily a pluvial-fluvial event. The high levels in the Glashaboy River caused the drainage systems within the Estate to become surcharged with flood waters flowing at modest depths along the roads and through gardens. Residents reported that on this occasion, the Glashaboy River remained in channel throughout the event, i.e. did not overtop the existing boundary wall.

Cork County Council provided two pumps to operate in Meadowbrook Estate which arrived at approximately 10pm on the 29 December 2015.

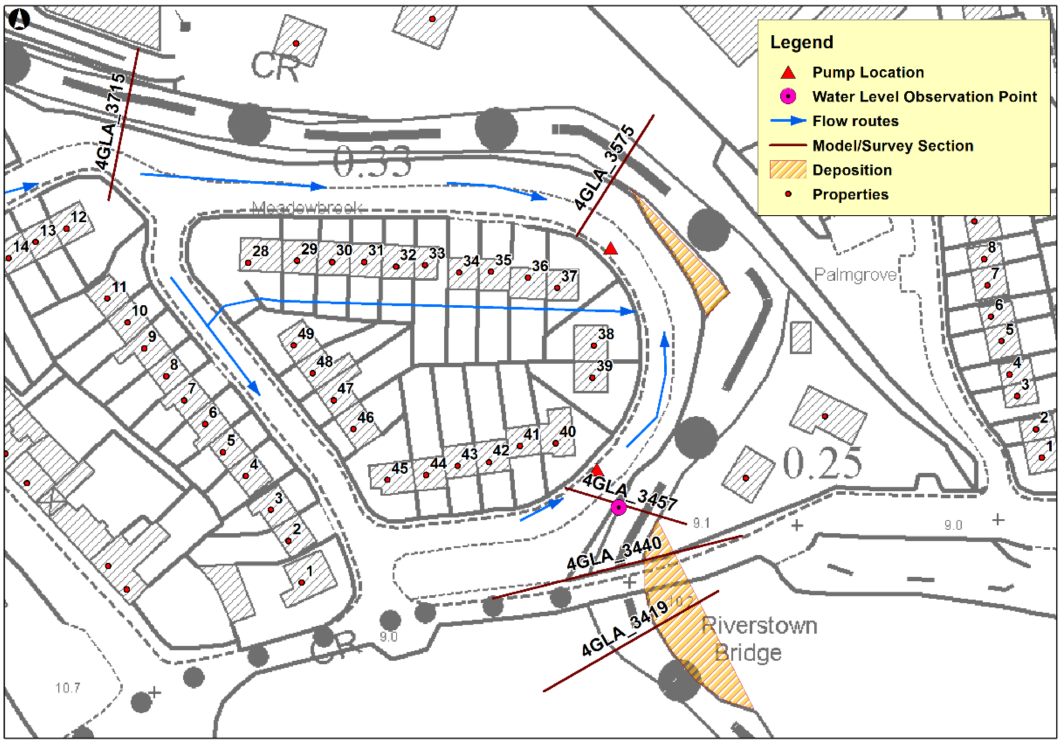
Figure 4 below show the location of the council pumps which discharged pumped floodwaters back into the river. The residents noted that as soon as the pumps stopped, the water level in the manholes began to rise immediately.

During the early hours of the 30 December 2015 residents operated in shifts manning pumps and overseeing that the flood waters did not flow into houses.

The residents also noted that the primary flow route for water emerging from the drainage system (manhole in front of house No. 8), was along the back (southern) gardens of houses No.28 to No.37.

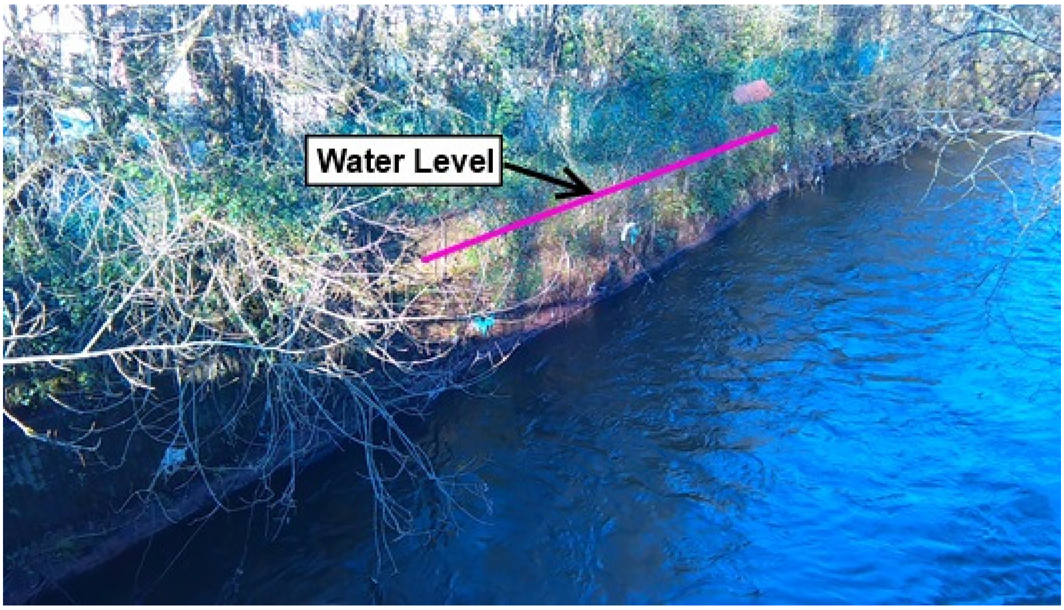
The approximate routes of flooding is shown in Figure 4.

Figure 4 Meadowbrook Estate



During the Dec 2015/Jan 2016 event, residents noted that water in the river reached the second block of the second stage of the wall, as shown in Figure 5 below.

Figure 5 Water Level in the Glashaboy



The location of this water level marker as observed by local residents is indicated in Figure 5above. Based on survey cross sections it is estimated that the water level at this location reached approximately 7.9m – 8.0m OD.

Residents had noted that during the event the arches of Riverstown Bridge remained relatively free flowing.

Residents were also keen to point out the deposition of silt which has accumulated over the years (see Figure 6) and have requested that Cork County Council remove the deposition from the river banks as an interim measure, in advance of the Glashaboy FRS works.

The residents believe that the removal of the silt accumulation upstream of the bridge on the right bank would soften the bend in the river, while clearing of the deposition and vegetation on the left bank in the vicinity of the bridge would realign the centreline of the river. They feel that the bridge abutments would then be at a lesser skew angle to the direction of flow and the four large arches of the bridge would be utilised, increasing the bridges conveyance capacity.

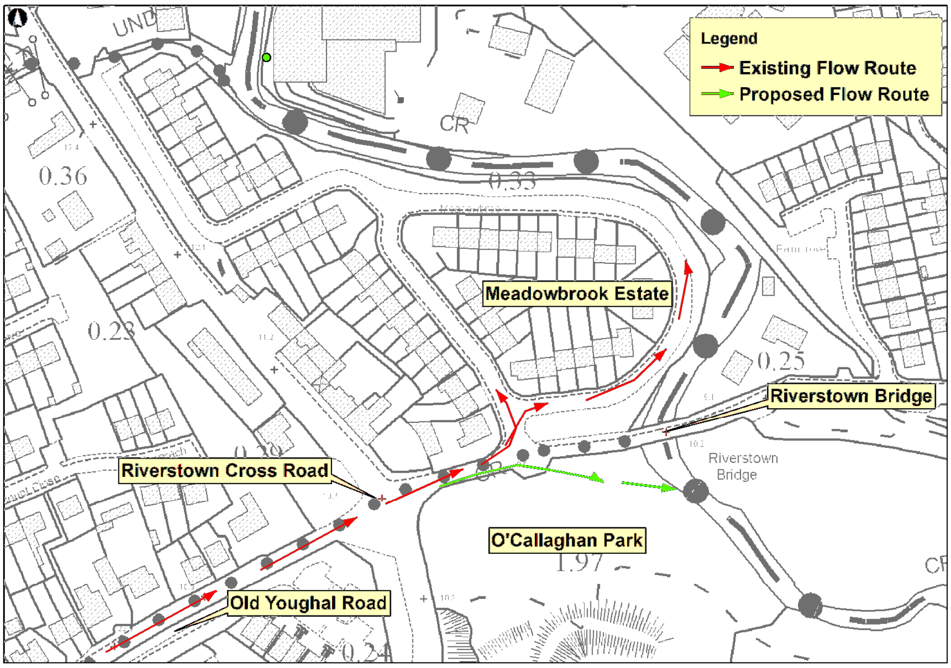
Figure 7 below shows the downstream face of Riverstown Bridge, and highlights the area of deposition, vegetation and soil which the residents would like to see cleared.

Figure 6 The downstream face of Riverstown Bridge

The residents of Meadowbook are very anxious to see interim measures executed which will contribute to improving the conveyance capacity of the channel at their estate and therefore lower water levels in the event of a possible high flow event occurring prior to the completion of the Glashaboy FRS works.

Another flooding mechanism which the residents are concerned about, is the surface water flowing down the Old Youghal Road, through Riverstown junction and into Meadowbrook Estate. While this mechanism was not critical in the Dec2015/Jan2016 event, interim road re-grading & drainage measures would contribute to the alleviation of flood levels in Meadowbrook Estate.

Figure 7 Overland Flow from the Old Youghal Road

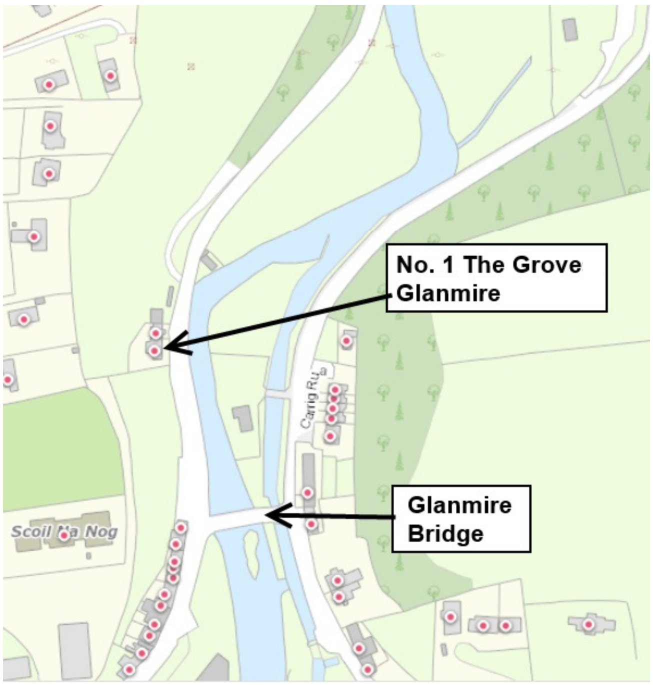


5.2 The Grove at Glanmire

The occupier of No1 The Grove contacted the Glashaboy FRS project team through the project website. The resident is concerned that the scheme outlined at the previous Public Information Day (PID) did not appear to include measures to protect his and his neighbour's isolated houses, despite having flooded during the 2012 event and now again in Dec2015/Jan 2016.

Figure 8 below shows the location of No1 The Grove, Glanmire.

Figure 8 Location Map of No.1 The Grove



The resident outlined the flood mechanism at his property as follows:

- Flooding began in the downstairs bathroom around the base of the toilet.
- Soon after water was observed rising up through the manhole and gully outside on the road.
- Water then began to flow down the road through the gaps in the wall further upstream.

Figure 9 below shows the level to which the flood water reached its peak at approximately 2am or 3am on the 30 of December 2015 according to the resident of No.1 The Grove.

Figure 9 Water Level reached outside The Grove, Glanmire.

Figure 10 below shows the interior of his ground floor living room flooded to the top of the skirting board, an approximate depth of 150mm. The resident has commented that the water depth in his house would have been deeper only that he had a demountable flood gate installed on the hall door. The photo was not taken at the peak of the flooding either, so it is only an indication of how deep the flooding was.

Figure 10 Interior of the No1. The Grove

Another point which the resident noted, was that water level on the morning of the 30 December 2015 was 4 to 5 foot higher on the upstream side of Glanmire Bridge than the water level on the downstream side. This suggests that during the event, Glanmire Bridge was surcharged with an afflux greater than 1m across the bridge and therefore may have been partially or even significantly blocked.

The resident also noted that he parked his car at Monkey Maze (downstream of Glanmire Bridge), where it remained safe from flood waters for the duration of the event.

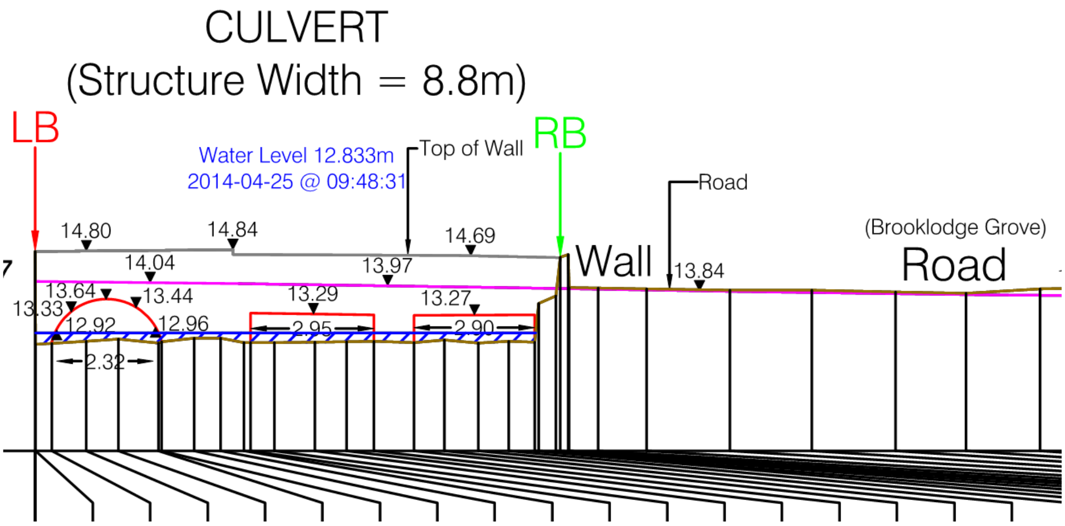
The resident also express concern that the development of raised sports pitches between O'Callaghan Park and Glanmire Bridge may have exacerbated the flooding during the Dec2015/Jan 2016 event.

5.3 Copper Valley Vue

Eight properties in Copper Valley Vue suffered significant flooding on the evening of the 29 December 2015, commencing at approximately 8pm, when the Glenmore stream overflowed its bank on the northern side of Brooklodge Grove Road. The stream directly overtopped Brooklodge Grove culvert parapet due to a lack of conveyance in the culvert under the road. Anecdotal evidence suggests that the culvert capacity was likely compromised due to partial blockage.

Figure 11 below shows a surveyed section of the Brooklodge Grove Road culvert. It can be seen in the section that blockage of one of the arches would significantly reduce the conveyance capacity of the culvert.

Figure 11 Section of Brooklodge Grove Road Culvert



The flood water having crossed the road, could not enter the open channel on the southern side of Brooklodge Grove road, as there is a wall/kerbing along the front of Copper Valley Vue estate which guided the water along the road, and in the main entrance of Copper Valley Vue, as shown in Figure 13.

Figure 12 Glenmore Stream overland flow routes

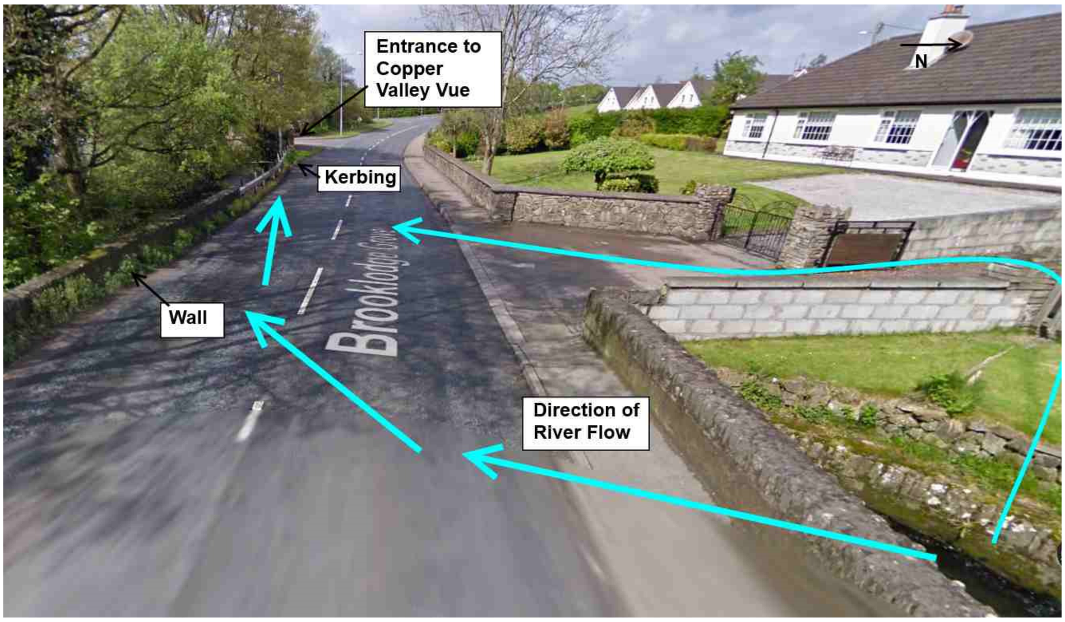


Figure 13 below shows the initial flow route of the Glenmore stream (Flow Route 1) at the entrance of Copper Valley Vue which flooded house numbers 28 to 34.

The wall and kerbing along Brook Lodge Grove Road (See Figure 13) prevented flow entering the open channel on the southern side of the road and instead diverted it into the houses of Copper Valley Vue.

Flow Route 2 was later established by local residents by demolishing the downstream bridge parapet over the culvert at the entrance to Copper Valley Vue and blocking off Flow Route 1 with sandbags across the internal road. The location of the demolished parapet is visible in Figure 13 and Figure 14 (see traffic cones).

Once the bridge parapet was demolished, and Flow Route 1 blocked with sandbags and later tarmacadam (Figure 14 below), the water followed Flow Route 2.

Figure 13 Flood flow route of the Glenmore Stream

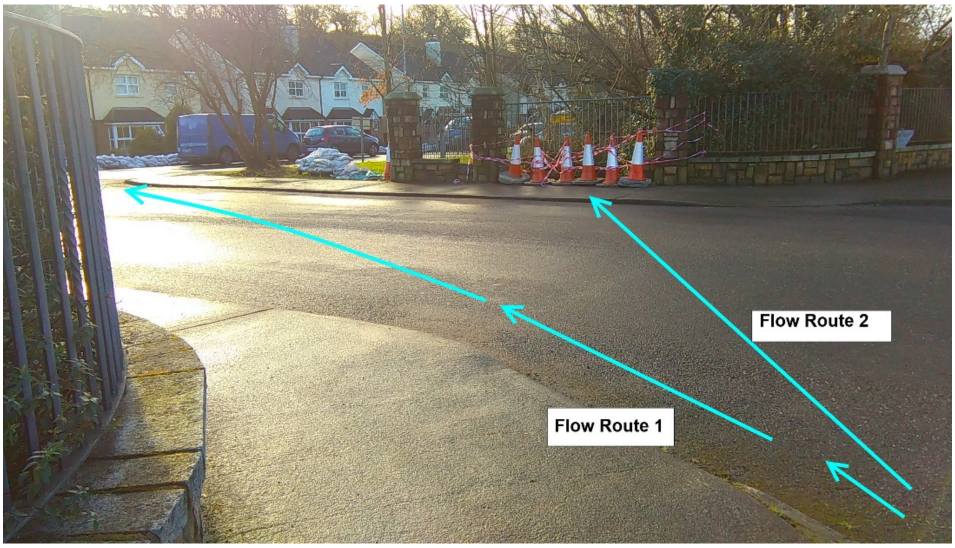
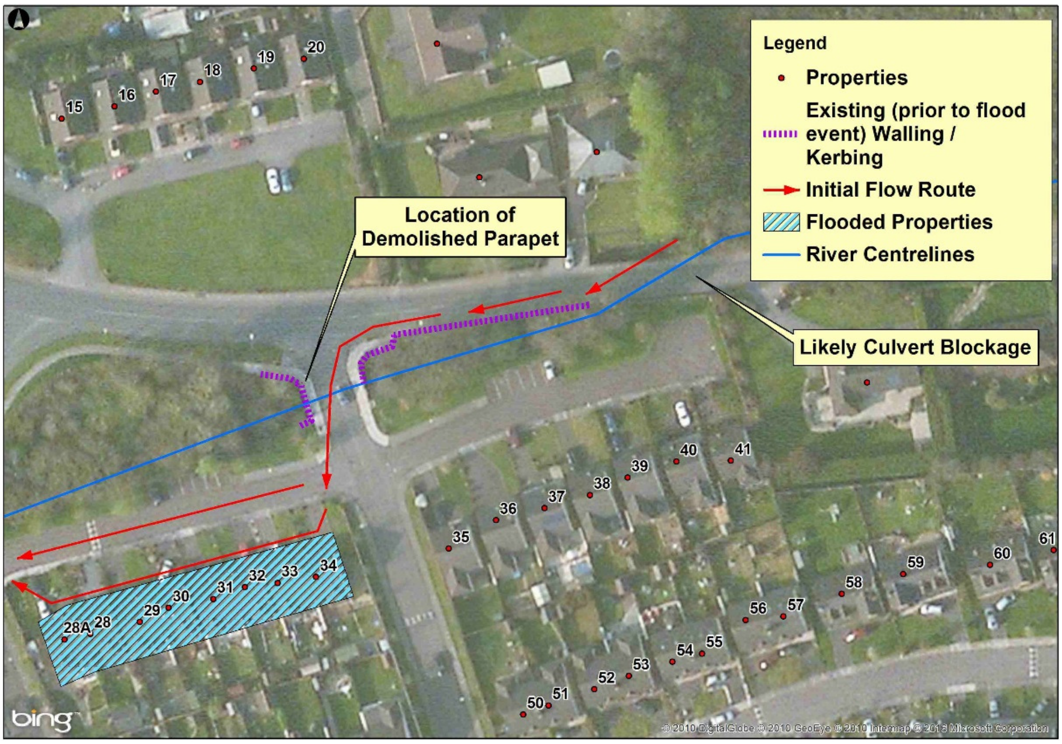


Figure 14 Flow Route 1 ramp blockage and demolished bridge parapet wall

Figure 15 below identifies the flooded properties and the initial flood flow routes.

Figure 15 Flood Flow Route at Copper Valley Vue



A local, present on the night of the flooding stated that water reached the bottom of the bay windows as shown in Figure 16.

Figure 16 Level reached by flood waters

Internally, the water in No.34 & No.33, the first and second house in the row was at the 3rd stair step (approximately 600mm deep). The water in No. 32, the third house in the row was approximately 250mm deep. Figure 17 below, shows that water in the rear garden of the house reached the bottom of the swing seat. In No. 31, the fourth house, water was 50mm to 60mm deep.

Water in No.30 & No.29 (the fifth and sixth house) was approximately 30mm. Water in the seventh and eighth house was shallow.

The row of houses which flooded are located in a hollow with their front and back gardens sloping up away from the houses themselves.

Figure 17 Rear Garden water level reach the bottom of the swing

5.4 Hazelwood Centre and regional road R639

Anecdotal evidence from residence of Glanmire and social media report that the R639, the main road between Riverstown and Glanmire junction was flooded and impassable during this event as show in Figure 18 Flooding on the R639 (see Figure 19 for location)below.

Reports in the media also include that of drivers and passengers rescued from cars when they became stranded by floodwaters on the R639 Glanmire and a fallen tree on the R639, However the impact and location of this fallen tree is unconfirmed.

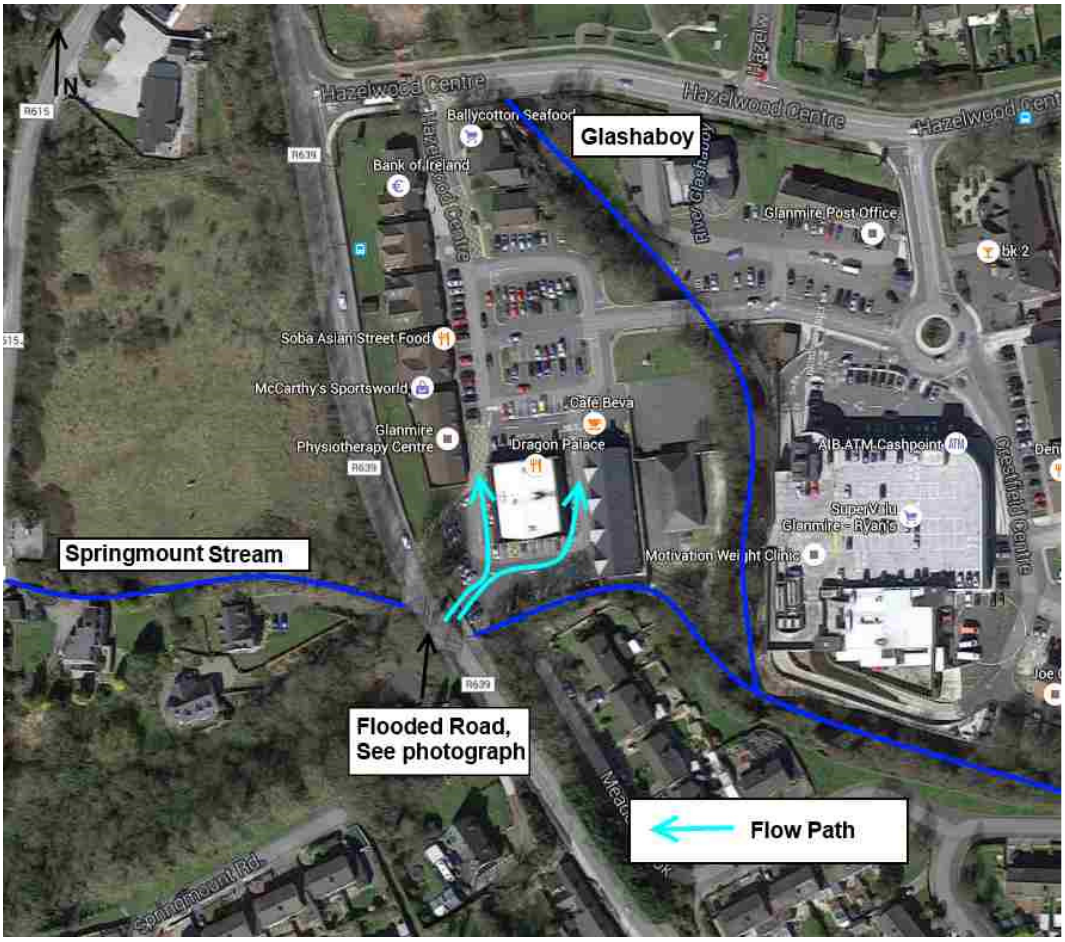
Figure 18 Flooding on the R639 (see Figure 19 for location)

Water was also reported to have inundated some of the businesses in the Hazelwood centre to a depth of approximately 25mm, including Café Beva. The flow route of this flood water as suggested by a resident is show in Figure 19 below.

Both the flood water on the R639 and the reported flooding in the Hazelwood Centre is likely to be the result of a combination of the following:

- Pluvial flooding along the road which came about as a consequence of the heavy rainfall in the catchment on the 28th/29th of December 2015, as the location of flooding corresponds to a low point in the road.
- Fluvial flooding from Springmount stream as the flooding occurred at the point where the stream is culverted under the R639.

Figure 19 Reported flood flow route at the Hazelwood centre



6 Return period estimation

6.1 Meadowbrook Estate

Based on anecdotal evidence reported by residents, the Glashaboy River levels adjacent to Meadowbrook Estate reached circa 7.9m – 8.0mOD. This level equates to a flood event with a return period of approximately 2 years, which would not result in out of bank flooding at Meadowbrook Estate.

However, wrack marks surveyed following the event in the vicinity of the Meadowbrook gauge suggest that a water level of 9.58mOD was reached and this is higher than the levels reported by residents, as it would suggest a return period of up to the 1 in 5 year flood event.

The main flood mechanism which affected Meadowbrook Estate during the Dec 2015/Jan 2016 event was the higher than normal level in the Glashaboy River which resulted in the drainage network backing up and over flowing onto the road.

The water level suggested by wrack marks illustrates that the water level was slightly higher than that of the road. This elevated water level, hydraulic losses in the surface water drainage system and possible ineffective non-return flap valves, resulted in road flooding at Meadowbrook Estate. Further information on the model calibration is provided in Section 3.3.3 of the Final Hydraulics Report (November 2016).

6.2 The Grove at Glanmire

Anecdotal evidence suggests that the water level along the road reached circa 4.0mOD. This level is derived from the average of two water level approximations of 4.05m OD and 3.97mOD detailed below:

1. The road gully outside the Grove properties was surveyed at a level of 3.15mOD. Residents noted a water depth at this location of approximately 0.9m, suggesting a flood level of 4.05mOD.
2. The Finished Floor level of No.1 The Grove was surveyed at 3.77mOD. Allowing for an estimated water depth of approximately 200mm (based on photograph (Figure 10) of water level reaching the top of living room skirting board) suggests a flood level of circa 3.97mOD.

Following the anecdotal evidence outlined above, the hydraulic model was adjusted to represent the food characteristics and extents experienced, suggesting a return period of circa 1 in 5 years. Please refer to Section 3.3.5 of the Final Hydraulics Report (November 2016) for further information.

6.3 Copper Valley Vue

Based on anecdotal evidence flood waters reached a level between circa 13.94mOD – and 13.98mOD in the properties which flooded. A survey of the property threshold levels varied between 13.41mOD and 13.51mOD, which puts water depth in the houses at approximately 0.5m, which matches the anecdotal evidence collected during the site visit.

These level cannot be linked to the water level/return period in the river channel, as this level is predominantly dictated by the threshold at which water (which ponded at the low point of the terrain, and flooded the properties) could escape back into the channel within the estate. The flood mechanisms and flood extents are therefore more relevant in establishing an approximate return period for the event. Figure 21 shows the wrack marks that were surveyed and used as part of the model calibration for the Glenmore Stream, suggesting a return period of circa 1 in 10 years for the Glenmore Stream. Please refer to Section 3.3.4 of the Hydraulics Report (November 2016) for further information.

Figure 20 Selection of wrack marks on the Glenmore stream

	**Wrack marks on the Glenmore stream, Between Brooklodge Grove Culvert, and Copper Valley Vue entrance culvert.**
	**Wrack marks on the Glenmore stream, immediately downstream of the Copper Valley Vue entrance culvert.**
	**Wrack marks on the Glenmore stream, Downstream of the Copper Valley Vue entrance culvert.**
	**Wrack marks on the Glenmore stream, upstream of the Marwood Bridges**
	**Collapsed masonry arch in rover Downstream of entrance to Marwood.**

7 Commentary on proposed flood relief scheme in light of recent flooding

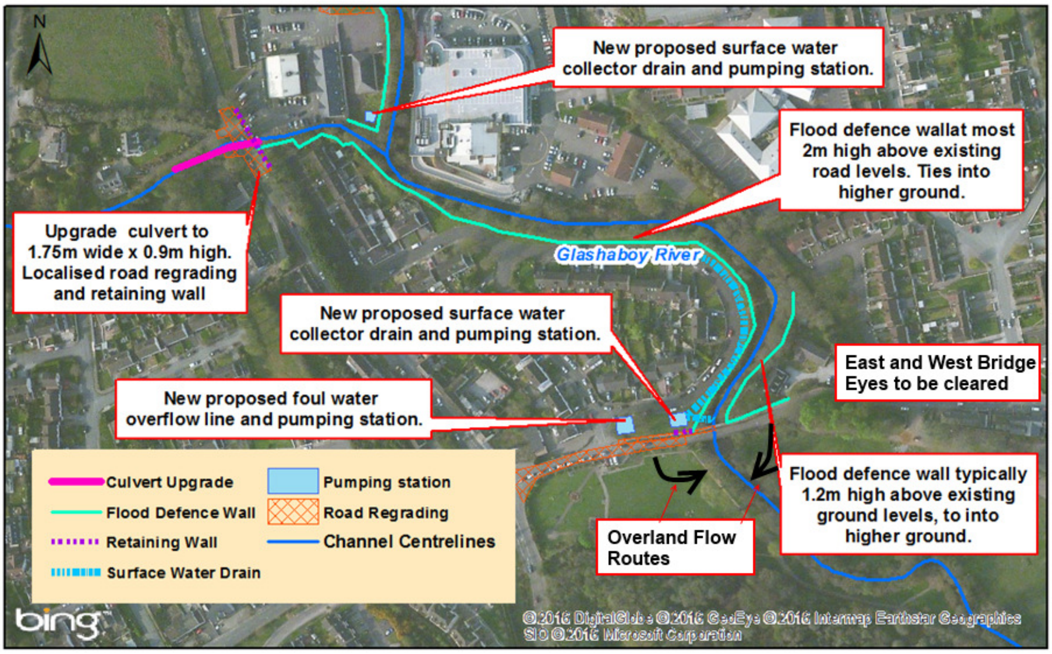
This section provides a brief commentary on the proposed measures in light of the recent December 2015 flood event. For further information on the proposed measures, please refer to the Final Options Report (November 2016) and also the Exhibition Drawings (November 2016).

7.1 Meadowbrook Estate

The preferred option for Meadowbrook Estate comprises a new flood defence wall on the right bank and a new surface water collector drain and pump system (see Figure 21). In addition, works are proposed to direct surface runoff from the Old Youghal Road away from Meadowbrook and into O'Callaghan Park.

A CCTV was been carried as part of the site investigation and to aid in the understanding of the drainage system at Meadowbrook. As part of the preferred option ineffective drainage lines will be removed and replaced where necessary, and non-return flap valves placed on all drainage outfalls. A new proposed foul water overflow line and pumping station is also proposed to address sewerage flooding.

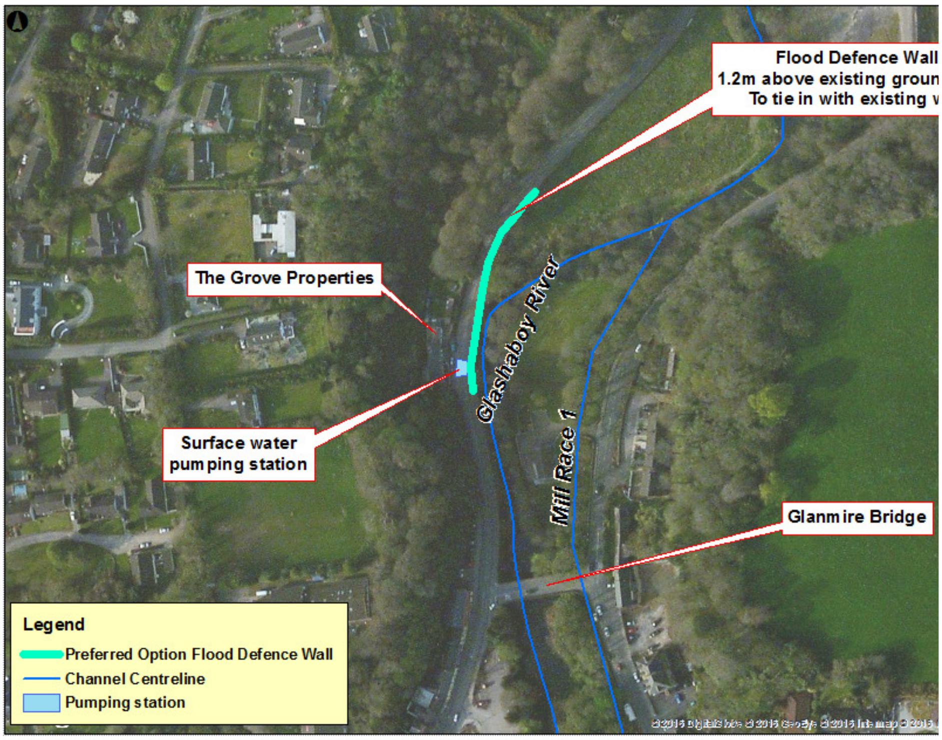
Figure 21 Meadowbrook Estate Preferred Option



7.2 The Grove, Glanmire

The area of the Grove was not included during the initial stages of the scheme. As part of the scheme development and following review of the recent flood, the hydraulic model was refined and calibrated, confirming flood risk to properties at The Grove. As a result a new flood defence wall of 1.2m high and approximately 100m in length is proposed in addition to a local stormwater pumping station and collector drain to alleviate pluvial flooding. Figure 30 presents the proposed measures.

Figure 22 Proposed measures at– The Grove

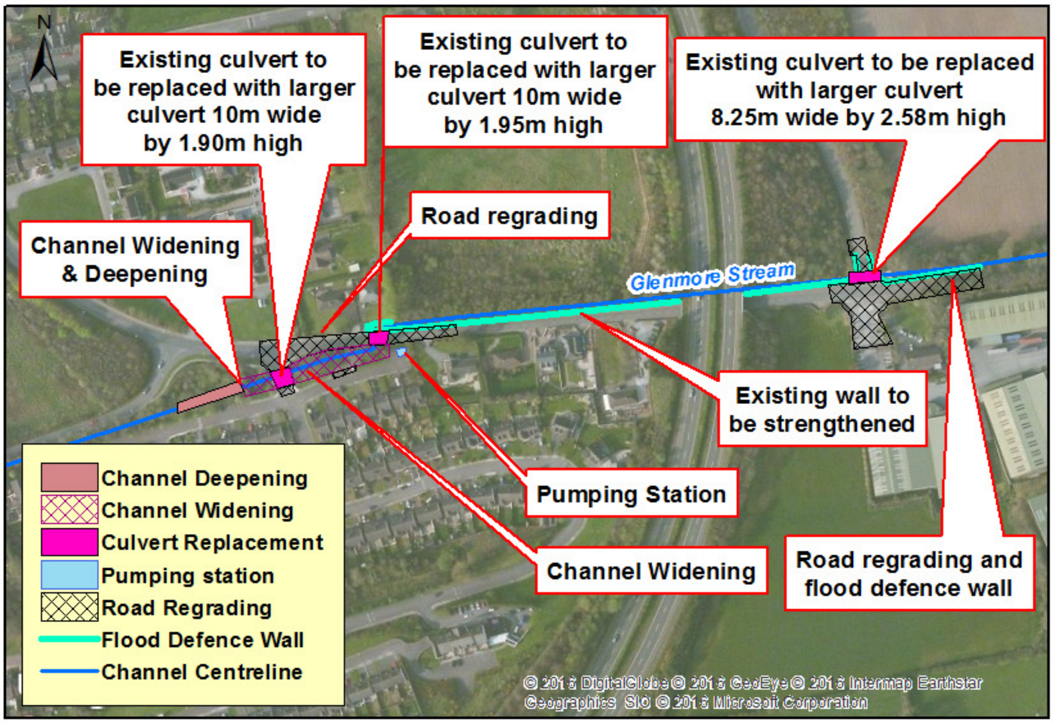


7.3 Glenmore Stream (Copper Valley Vue)

Overland flow management was the preferred option during the initial stages of the study. This option was reviewed in light of the 2015 flood event. This review concluded that while the option of overland flow management would still be viable, it could not cater for the significant risk of blockage in this area and it could not alleviate the relatively frequent road flooding at Brooklodge Grove, which is estimated to occur during the 1 in 5 year event.

Further hydraulic analysis was carried out and modelling results show that the existing culverts would need to be replaced. This option would also significantly reduce the risk of blockage in this area and thereby significantly reduce the residual risk. Figure 24 presents the proposed measures at Glenmore Stream.

Figure 23 Proposed Measures at Glenmore Stream



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8 Conclusions and Recommendations

The cumulative rainfall that fell in the Cork area in December 2015 was unprecedented, being circa 3 times the long term average and having an estimated return period of circa 1 in 200years. This meant that the catchment was extremely saturated in advance of the flood event of the 29 December 2015. This lead to extremely high groundwater levels and a high rate of runoff from the surrounding lands.

The periods of rainfall in the events of 29/30 December 2015 and 1/2 January were both of the critical duration for the Glashaboy Catchment. The return period for the rainfall event of the 29/30 December was circa 1 in 5 years. The impact of course would have been greater given the antecedent conditions.

An analysis has been completed of the possible return periods for the river flow at various flooded locations by comparison of the actual flood levels and extents with the output of the Glashaboy Drainage Scheme. This analysis is limited by the level of inaccuracy in estimating flood levels during the event and also by the limitations of the modelling undertaken to replicate the antecedent catchment conditions for this particular event. It can therefore only be used as a guide.

The analysis suggests that the return period for river flows in the Glashaboy Rivers was likely to be circa a 1 in 2 year to 1 in 5 year event, (although there is evidence of potential higher return period in some areas, but local affects are considered to be the major factor at these locations.

The primary cause of flooding at The Grove was fluvial flooding from the Glashaboy River. The high water level upstream of Glanmire Bridge resulted in flooding along the road and into the properties at The Grove. The properties' drainage systems were also affected.

Flooding at Meadowbrook was primarily caused by inundation of the drainage system, from high levels in the Glashaboy River.

Flooding at Copper Valley Vue was likely from restricted conveyance capacity and potential partial blockage of the Brooklodge Grove Road culvert, which diverted fluvial flow from the Glenmore Stream into the low point in Copper Valley Vue where a number of houses are located.

The pumping undertaken by CCC had a beneficial effect in Meadowbrook Estate and resulted in prevention of properties being flooded. The measures taken by local residents at Copper Valley Vue, knocking the downstream the bridge parapet of the entrance bridge to allow diverted fluvial water re-entre the Glenmore Stream was also beneficial in reducing the number of properties flooded and the depth to which they were flooded at Copper Valley Vue.

Each of the affected areas has undergone a detailed review in light of the recent December 2015 flood and it is concluded that the mechanisms that occurred during that event would be catered for by the proposed scheme.

The absence of detailed survey data of flood levels from the event and the absence of recordings from the Meadowbrook gauge meant that a more quantified assessment could not be undertaken.

To address this and to avoid missing future data collection opportunities, it is recommended that measures to get the Meadowbrook Hydrometric Gauge operational are undertaken. The gauge will be useful to inform any future hydrological analysis and provide a baseline for future flood risk management in the catchment.