

Western CFRAM Unit of Management 30 and 31 - Corrib and Owengowla

Final Hydraulic Modelling Report

September 2015

**Office of Public Works
Trim
Co. Meath**



**WESTERN
CFRAM
STUDY**
CATCHMENT FLOOD RISK
ASSESSMENT AND MANAGEMENT



JBA Consulting

24 Grove Island
Corbally
Limerick
Ireland

JBA Project Manager

Sam Willis BSc MSc CEnv CSci MCIWEM C.WEM

Revision History

Revision Ref / Date Issued	Amendments	Issued to
Revision 1 / 04/09/2015	Initial Issue	Richael Duffy, OPW
Revision 2 / 11/09/2015	Final Issue	Richael Duffy, OPW

Contract

This report describes work commissioned by The Office of Public Works, by a letter dated (28/07/11). The Office of Public Works' representative for the contract was Clare Butler. Sam Willis, Elizabeth Russell, Chris Smith and Tom Sampson of JBA Consulting carried out this work.

Prepared Elizabeth Russell BSc MSc CEnv MCIWEM
C.WEM

Reviewed by Sam Willis BSc MSc CEnv CSci MCIWEM C.WEM

Purpose

This document has been prepared as a draft report for The Office of Public Works. 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.

JBA Consulting has no liability regarding the use of this report except to the Office of Public Works.

Copyright

Copyright – Copyright is with Office of Public Works. All rights reserved. No part of this report may be copied or reproduced by any means without the prior written permission of the Office of Public works.

Legal Disclaimer

This report is subject to the limitations and warranties contained in the contract between the commissioning party (Office of Public Works) and JBA.

Carbon Footprint

A printed copy of the main text in this document will result in a carbon footprint of 206g if 100% post-consumer recycled paper is used and 262g if primary-source paper is used. These figures assume the report is printed in black and white on A4 paper and in duplex.

JBA is aiming to reduce its per capita carbon emissions.

Contents

1	Introduction.....	1
1.1	Scope of report	1
1.2	Report overview	2
1.3	Study background.....	3
2	Ballyhaunis.....	4
2.1	Watercourse and catchment overview	4
2.2	Flood history	4
2.3	Existing defences and walls	5
2.4	Model limitations	5
2.5	Key flood risk mechanisms	5
2.6	Sensitivity testing	7
2.7	Flood risk summary	9
3	Corrofin.....	10
3.1	Watercourse and catchment overview	10
3.2	Flood history	11
3.3	Existing defences and walls	11
3.4	Model limitations	12
3.5	Key flood risk mechanisms	12
3.6	Sensitivity testing	12
3.7	Flood risk summary	15
4	Galway City	16
4.1	Watercourse and catchment overview	16
4.2	Flood history	17
4.3	Existing defences and walls	18
4.4	Model limitations	18
4.5	Key fluvial flood risk mechanisms.....	19
4.6	Key tidal flood risk mechanisms	20
4.7	Sensitivity testing	20
4.8	Flood risk summary	23
5	Oughterard	25
5.1	Watercourse and catchment overview	25
5.2	Flood history	26
5.3	Existing defences and walls	26
5.4	Model limitations	27
5.5	Key flood risk mechanisms	27
5.6	Sensitivity testing	28
5.7	Flood risk summary	30
6	Tuam	31
6.1	Watercourse and catchment overview	31
6.2	Flood history	31
6.3	Existing defences and walls	31
6.4	Model limitations	32
6.5	Key flood risk mechanisms	32
6.6	Sensitivity testing	32
6.7	Flood risk summary	35
7	Roundstone.....	36
7.1	Watercourse and catchment overview	36
7.2	Flood history	36

7.3	Existing defences and walls	37
7.4	Model limitations	37
7.5	Key flood risk mechanisms	37
7.6	Sensitivity testing	37
7.7	Flood risk summary	39
8	UoM Summary.....	40

List of Figures

Figure 1-1: AFAs within UoM 30 and 31	1
Figure 2-1: Ballyhaunis AFA catchment overview	4
Figure 2-2: 1% AEP event uncertainty bounds - Ballyhaunis AFA.....	8
Figure 3-1: Overview of rivers in the Corrofin catchment	10
Figure 3-2: Overview of defences in Corrofin	11
Figure 3-3: 1% AEP event uncertainty bounds - Corrofin AFA	13
Figure 3-4: 1% AEP event uncertainty bounds - Clare River	14
Figure 4-1: Galway City AFA catchment overview	16
Figure 4-2: Galway coastal overview.....	17
Figure 4-3: Overview of defences in Galway City.....	18
Figure 4-4: 1% AEP fluvial event uncertainty bounds - Claddagh Area.....	21
Figure 4-5: 1% AEP fluvial event uncertainty bounds - Upper Corrib	21
Figure 4-6: 0.5% AEP tidal event uncertainty bounds - Salthill West.....	22
Figure 4-7: 0.5% AEP tidal event uncertainty bounds - Salthill East.....	22
Figure 5-1: Oughterard AFA catchment overview	25
Figure 5-2: Defences and walls locations	27
Figure 5-3: 1% AEP event uncertainty bounds - Oughterard	29
Figure 6-1: Tuam AFA catchment overview	31
Figure 6-2: 1% AEP fluvial uncertainty bound for the River Clare - Tuam AFA.....	33
Figure 6-3: 1% AEP fluvial uncertainty bound for the River Nanny - Tuam AFA	33
Figure 6-4: 1% AEP fluvial uncertainty bound for the River Suileen - Tuam AFA.....	34
Figure 7-1: Roundstone AFA catchment overview	36
Figure 7-2: Roundstone Quay Wall	37
Figure 7-3: 0.5% AEP tidal event uncertainty bounds - Roundstone AFA	38

List of Tables

Table 1-1: AFA report and model codes.....	2
Table 2-1: Flood history summary in Ballyhaunis.....	4
Table 2-2 - Wrack marks near Ballyhaunis gauge	6
Table 2-3 - Curries watercourse	6
Table 2-4: Flood risk to receptors in Ballyhaunis.....	9
Table 3-1: Flood history summary in Corrofin	11

Table 3-2: Corrofin flood mechanism	12
Table 3-3: Flood risk receptors in Corrofin	15
Table 4-1: Flood history summary in Galway City	17
Table 4-2: Fluvial flood risk to receptors in Galway city	23
Table 4-3: Tidal flood risk to receptors in Galway city	23
Table 5-1: Owenriff River gradient changes	26
Table 5-2 : Flood history summary in Oughterard.....	26
Table 5-3: Flood risk to receptors in Oughterard.....	30
Table 6-1: Flood risk to receptors in Tuam.....	35
Table 7-1: Flood history summary in Roundstone.....	36
Table 7-2: Flood risk to receptors in Roundstone.....	39
Table 8-1: Summary of flood risk to AFAs.....	40

Abbreviations

AEP	Annual exceedence probability
AFA	Area for further assessment
AMAX.....	Annual maximum
CFRAM	Catchment flood risk assessment and management
DAD	Defence asset database
DAS.....	Defence asset survey
DEM	Digital elevation model (Includes surfaces of structures, vegetation, etc)
DTM	Digital terrain model ('bare earth' model; does not include surfaces of structures, vegetation, etc
ESTRY	One-dimensional model from the TUFLOW suite
FRISM.....	Flood risk metrics (a flood risk tool developed by JBA)
FRMP	Flood risk management plan
FRR.....	Flood risk review
FSR	Flood studies report
FSU	Flood studies update
GIS.....	Geographical information system
HEFS	High-end future scenario
HEP.....	Hydrological estimation point
HPW.....	High priority watercourse
HWA.....	Hydrograph width analysis
IBIDEM.....	Interactive bridge invoking the design event method
ICPSS	Irish coastal protection strategy study
ISIS	One-dimensional hydraulic modelling software
LA.....	Local authority
LIDAR	Light detection and ranging
mOD.....	Metres above Ordnance datum (unless stated this refers to the Malin datum)
MPW	Medium priority watercourse
MRFS.....	Mid-range future scenario
NDHM	National digital height model (a DTM by Intermap)
OSi.....	Ordnance Survey Ireland
PFRA	Preliminary flood risk assessment
Q(T).....	Flow for a given return period
QMED	Median annual flood, used in FSU methods
SAAR	Standard annual average rainfall
SoP	Standard of protection (in relation to flood defences)
T	Return period, inverse of AEP
Tp.....	Time to peak

TUFLOW..... Two-dimensional hydraulic modelling software

UoM Unit of Management

* Asterisks at the end of a cross section label denotes interpolated
model cross sections

1 Introduction

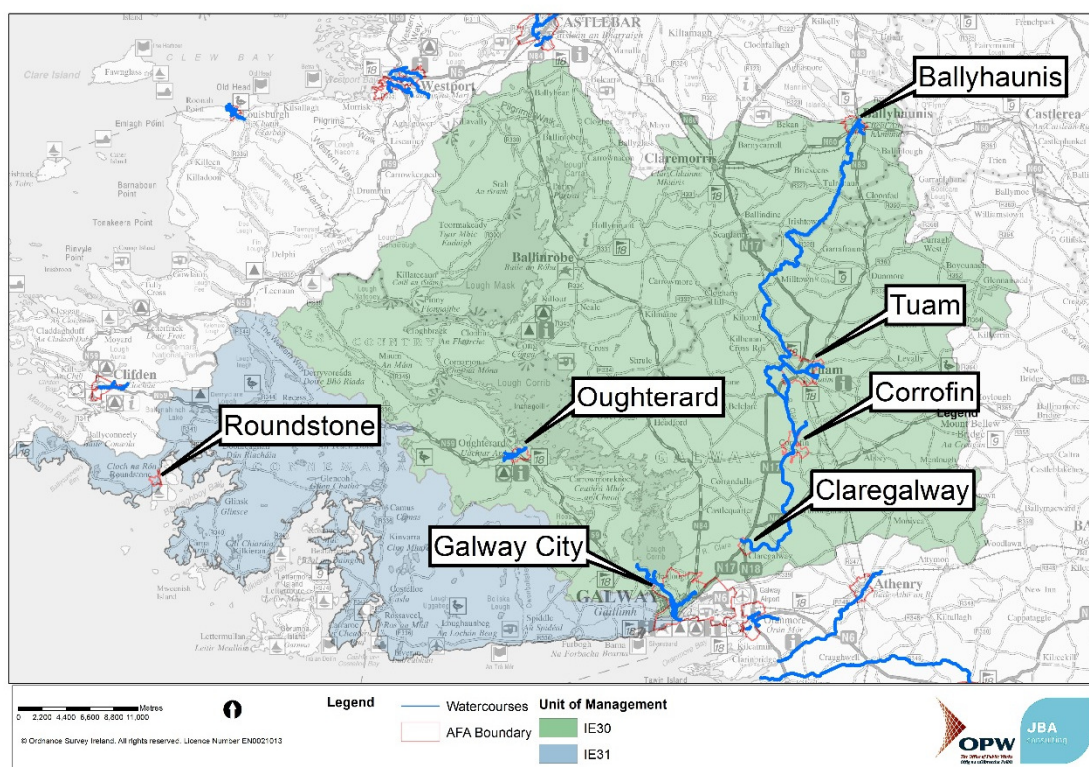
1.1 Scope of report

This report provides an overview of the findings of the modelling phase of the Western Catchment-Based Flood Risk Assessment and Management Study (WCFRAM). The report covers the Areas for Further Assessment (AFAs) within Unit of Management (UoM) 30 and 31, as shown in Figure 1-1:

- Ballyhaunis
- Claregalway
- Corrofin
- Galway City
- Oughterard
- Tuam
- Roundstone

This report is not intended to provide detail in relation to the hydrological assessment or modelling approaches used in any specific location, both of which are detailed in supporting technical reports, as detailed in Section 1.2.

Figure 1-1: AFAs within UoM 30 and 31



This report summarises the main sources of flood risk within each AFA, including details of the watercourses, historical flooding and flood defences. Where limitations in the modelling carried out have been identified they have also been summarised, with further detail provided in the relevant AFA report. An indication of the sensitivity to various parameters, such as increases in flow, changes in channel roughness and the representation of buildings and structures is also provided. For each AFA the main areas of flood risk, and the associated pathways to flooding, are discussed.

A summary of flood risk in each AFA has been included at the end of each section. This is in the form of a count of the number of receptors (for example, residential property, schools or lengths of motorway) which are at risk of flooding in 10%, 1%/0.5% and 0.1% AEP flood extents for fluvial

and coastal scenarios, for both the existing risk (present day), and medium range future scenario (MRFS).

Finally, a summary of risk to the whole Unit of Management is provided in Section 8.

This report does not include a summary of the medium priority watercourses, but each model is supported by its own Report, which forms part of Volume 2 of this series.

1.2 Report overview

This report is one of a series which describe the work undertaken as part of the CFRAM, and together they provide a description of the approach taken to identifying flood risk, and a discussion of the results of the analysis and potential flood management measures, where they are appropriate.

This report should be read in conjunction with the following supporting documents:

- Western CFRAM UoM30-31 Hydrology Report¹
- Western CFRAM UoM30-31 Inception Report²
- Western CFRAM Flood Risk Review Report³
- Western CFRAM SEA Scoping Report⁴
- Western CFRAM Defence Asset Database: Handover Report and accompanying database files⁵

The reports in the suite for the Hydraulic Modelling are:

- Western CFRAM UoM30-31 - Hydraulic Modelling Report (this report)
- Western CFRAM UoM30-31 - Hydraulic Modelling Report: Volume 1a – Hydraulic Modelling Method Statement
- Western CFRAM UoM30-31 - Hydraulic Modelling Report: Volume 1b – Hydromorphology and Coastal Erosion Assessment
- Western CFRAM UoM30-31- Hydraulic Modelling Report: Volume 2 – AFA Modelling Report (for example – 2a - Ballyhaunis AFA Modelling Report)
- Western CFRAM UoM30-31- Hydraulic Modelling Report: Volume 3 – Flood Risk Maps (for example - 3a Ballyhaunis Flood Risk Maps)
- Western CFRAM UoM30-31- Hydraulic Modelling Report: Volume 4a – Hydraulic Model and Check File (for example - 4a Ballyhaunis Hydraulic Model and Check File)

The letter code associated with the deliverables in Volumes 2, 3 and 4 will be consistent for a given AFA, so in the example above the letter 'a' applies to the Ballyhaunis AFA. Volume 4 is the technical output from the study and will only be available on request from the Office of Public Works.

The report and model codes for UoM 30 and 31 are provided in Table 1-1.

Table 1-1: AFA report and model codes

AFA	AFA / MPW code	Model code	Report code	Model type
Ballyhaunis	BLH	D1	a	Fluvial
Ballyhaunis to Tuam	MWB	92	h	MPW
Corrofin	CRF	L1	b	Fluvial
Galway City	GLW	N1	c	Fluvial
Galway City	GLW	C1	d	Coastal (Wave

¹ JBA Consulting (2014), Western CFRAM Unit of Management 30 and 31 – Corrib and Owengowla Hydrology Report, Final Report, Office of Public Works

² JBA Consulting (2012), Western CFRAM Unit of Management 30-31 – Corrib and Owengowla Inception Report, Final Report, Office of Public Works.

³ JBA Consulting (2012), Western CFRAM Flood Risk Review, Final Report, Office of Public Works.

⁴ JBA Consulting (2013), Western River Basin District Catchment-based Flood Risk Assessment and Management (CFRAM) Strategic Environmental Assessment, Scoping Report, Office of Public Works.

⁵ JBA Consulting (2013), Western CFRAM Defence Asset Database, Handover Report, Office of Public Works.

AFA	AFA / MPW code	Model code	Report code	Model type
Coastal				Overtopping)
Oughterard	OTD	U1	e	Fluvial
Tuam	TUM	Y1	g	Fluvial
Tuam to Lough Corrib	MWT	90	i	MPW
Roundstone Coastal	RSN	C4	f	Coastal

1.3 Study background

The Inception Report for UoM 30 and 31 was delivered in October 2012. This report consisted of a baseline review of available data and the development of the proposed methodology for the hydrological and hydraulic modelling investigations to be completed within this phase.

The method statement for the hydrological analysis detailed in the Inception Report has been developed and finalised in the UoM 30 and 31 Hydrology Report. This work has developed design flows at a series of Hydrological Estimation Points (HEPs) along all watercourses to be modelled. The detailed development of the hydrology has not been reiterated here and the reader is referred to the Hydrology Report for full details of the hydrological analysis. Design flows have been extracted directly from the Hydrology report and are summarised in the various editions of Volume 2, relating to the specific AFAs.

The Hydrology Report also provides guidance on the development of appropriate design storm hydrographs for each AFA for the purposes of the hydraulic modelling. These methods are summarised in this report to provide clarity on the application of the design event hydrology as this work has been undertaken in the hydraulic modelling phase.

The Inception Report identified all High Priority and Medium Priority Watercourses (HPWs and MPWs) to be modelled. HPWs are those watercourses that dictate flood risk within an AFA boundary as originally delineated within the Flood Risk Review (FRR) Report. HPWs therefore extend a short distance upstream and downstream of an AFA but do not include watercourses with catchments less than 1km². HPWs have been modelled to a greater level of detail than MPWs. MPWs are the watercourses which link two AFAs together and the watercourses that extend downstream of an AFA to the sea. Coastal AFAs do not have a downstream MPW associated with them.

In total, 56 km of HPW and 102 km of MPW have been modelled within UoM 30 and 31, along with the coastline in Roundstone and Galway City.

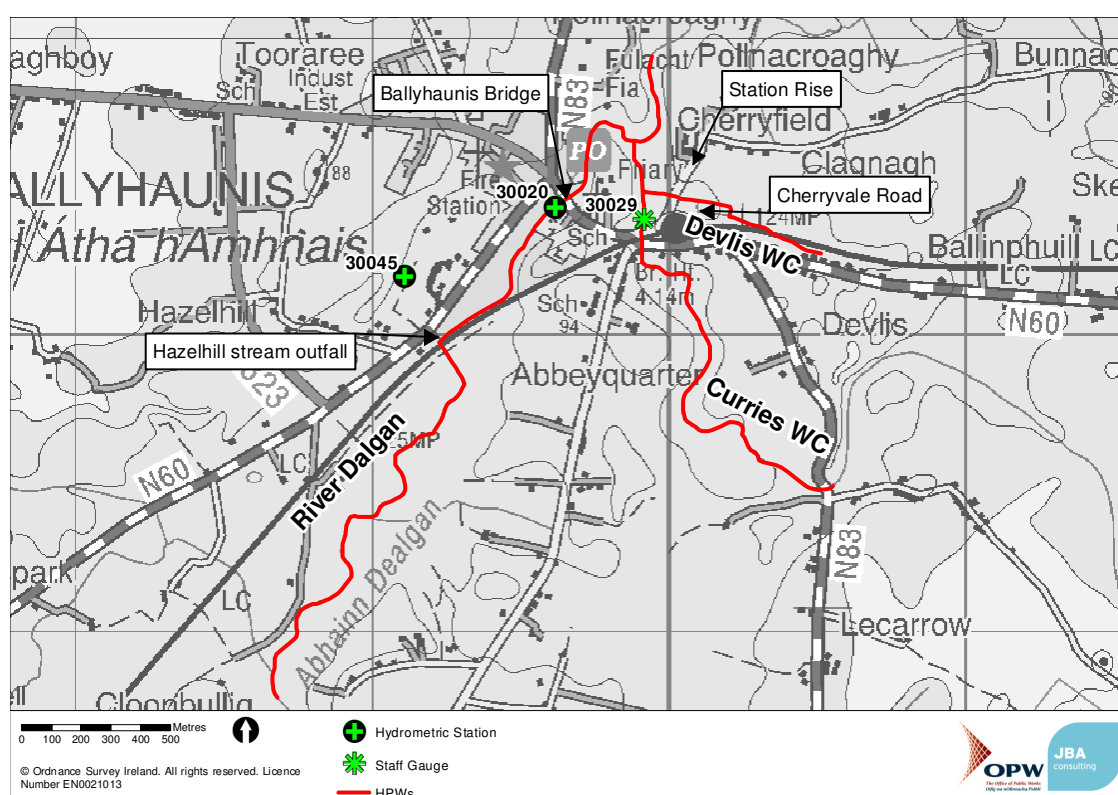
2 Ballyhaunis

2.1 Watercourse and catchment overview

The study area encompasses the Ballyhaunis AFA and includes the River Dalgan, which is the main river passing through Ballyhaunis town centre, Curries Watercourse, a tributary of the River Dalgan, and Devils Watercourse, a tributary of Curries Watercourse. The watercourses are all classed as High Priority Watercourses (HPWs) as they flow through the core of the AFA, and have been included in the model. The main hydraulic structure within the Ballyhaunis is the N60 Road Bridge, or Ballyhaunis Bridge. A gauging station is found shortly downstream of Ballyhaunis Bridge, where two weirs control river levels. Figure 2-1 provides an overview of the area.

There is an additional groundwater fed stream, called Hazelhill, discharging into the Dalgan downstream of the town centre. This stream has not been modelled.

Figure 2-1: Ballyhaunis AFA catchment overview



2.2 Flood history

Further details on the flood history of the town can be found in the AFA specific modelling report and the Hydrology and Inception Reports. A summary of known flood events is provided below.

Table 2-1: Flood history summary in Ballyhaunis

Area affected	Main flood mechanisms	Recorded flood event date	Use in model check
Some out of bank flow through the town centre and at the Dawn Meats Plant. No property flooded.	River Dalgan	Nov 2009	Limited verification using observed extents and flow record.
Right bank, downstream of Ballyhaunis bridge	River Dalgan	Nov 1999	Not used
Prolonged high water levels across the catchment	River Dalgan, but linked to pre-arterial drainage works conditions	1968-69	Not used

2.3 Existing defences and walls

No formal or informal effective defences were identified within the AFA. Six informal ineffective structures (i.e. walls or embankments with gaps in) were identified within Ballyhaunis along the banks of the River Dalgan and two along the banks of the Curries Watercourse. These structures are not assumed to function as flood defences and are either bypassed in the model or have been removed to allow flooding beyond them.

2.4 Model limitations

- Hazelhill has not been modelled. It is a groundwater fed stream and groundwater modelling is beyond the scope of the WCFRAM study. The additional inflow to the River Dalgan from Hazelhill Stream has not been included in the model. There was not enough data from the gauge located on this spring (30045) to allow any analysis of flows to be undertaken, and communication from the EPA indicates that the inflows were only significant at low flows.
- Channel blockage presents a higher level of risk, especially at section 30DEVL000111, below Station Rise - Detailed investigations of blockage and debris build-up have not been undertaken within the scope of the CFRAM. Although not investigated in more detail in this model, it is unlikely that culvert blockage in this location will increase flood risk to property.
- Geomorphological changes - Gravel and silt deposition on the Curries watercourse between the N60 and railway embankment crossing may affect the flood risk, particularly in the future, and could impact on the operation of potential flood management measures.

2.5 Key flood risk mechanisms

Further to the information presented in the flood risk maps, a brief description of the key flood risk sites and flooding mechanisms is provided below. In general, the flood extents produced are less than might be expected from a fully natural series of watercourses but there is evidence of man-made intervention on all three of the modelled watercourses so the natural regime is no longer fully in place. The result of these changes has been increased channel capacity, and a change from the natural flow regimes and resulting overtopping patterns. This fact, coupled with the records of two recent extreme events, give confidence that the under-prediction of flood extents is realistic.

2.5.1 Flooding upstream of Ballyhaunis Bridge on the River Dalgan.

Immediately upstream of Ballyhaunis Bridge, a small and confined amount of flooding is predicted to the rear of Delaney's Garden Centre, in the car park / yard area. This is predicted to occur from the 10% AEP event upwards, but no properties are at risk. Water levels in this section of river are dictated by the capacity of the channel, which is a reflection of the fact that even in large events floodplain flow is limited. The modelling has shown that Ballyhaunis Bridge is not a significant control structure in this location, with head losses associated with the structure less than 0.1m in the 1% AEP event.

The River Dalgan is predicted to flood the fields found a short distance upstream of Ballyhaunis Bridge from the 10% AEP event onwards. No properties are at risk as a result.

2.5.2 Flooding downstream of Ballyhaunis gauge

Model results show the River Dalgan exceeds bank top level upstream of the control weir of the Ballyhaunis gauge as a result of the limited channel capacity as frequently as the 10% AEP event (see Table 2-2). The floodplain is well confined around the gauging station itself and this results in no flooding of properties.

Approximately 80m downstream of the gauge, the 1% AEP event is predicted to cause flooding to Donnellan's Joinery on Clare Road and to the rear of neighbouring properties on Clare Road. This flooding can be attributed to a localised drop in the bank levels allowing flows to discharge onto the floodplain.

Table 2-2 - Wrack marks near Ballyhaunis gauge

Wrack marks clearly visible on the wire mesh fencing downstream of the Ballyhaunis gauge, on the right bank. The photograph was taken in June 2013, supporting the relatively high frequency of inundation of footpath.



2.5.3 Flooding at Dawn Meats Plant

Out of bank flow is predicted as frequently as the 10% AEP event upstream of the culvert adjacent to Dawn Meats Plant. However, it is not until the 0.1% AEP event that the river level upstream of the culvert is great enough to cause the river to bypass the culvert. Flood levels are shown to reach Dawn Meats Plant and also Keane Kitchens Ltd upstream in the 0.1% AEP event, but not to flood these properties.

2.5.4 Flooding downstream of railway bridge

The greatest extent of flooding within the Ballyhaunis AFA occurs in the fields downstream of the town; this is the area where drainage works are thought to have taken place. Under regular flow conditions the watercourse is extremely slow flowing, with a wide flat floodplain, and in extreme events it is unlikely water would discharge downstream very quickly; instead it is likely to spread across the floodplain. Downstream of the railway bridge on the River Dalgan, near Clare Road, flooding is predicted from the 10% AEP event onwards, also resulting in flooding to Hazelhill Road. No properties are at risk as a result of this flooding.

2.5.5 Curries Watercourse

The Curries watercourse is shown to present no risk of flooding to properties in Ballyhaunis up to the extreme 0.1% AEP event. Examination of the water level profile through the key culverts at the N60 and the railway bridge shows some head loss through both culverts. Despite this, the water remains in bank. In the Q1000 event, water levels upstream of the N60 are close to the top of the right bank, but if water were to overtop at this location it would be prevented from flowing onto the road by the field boundary wall.

Table 2-3 - Curries watercourse

Looking upstream from the N60. If flood waters were to overtop the left bank, they would be retained by the site boundary wall. However, current design events (to the 0.1%AEP) show water remains in bank.



View from the culvert over the Curries River, looking towards the dip below the railway line. The site shown in the above photo is to the left.



A potential risk of flooding to the N60 as it dips below the railway bridge has been identified. However, as discussed above, it has been shown that the Curries watercourse does not overtop the bank in the current scenario. If the capacity of the culverts were to be reduced or flows to increase (such as in a future scenario) overtopping may occur. However, property is unlikely to be impacted on, although passage through the railway tunnel would be obstructed. Surface water flooding at this location is more likely under the current situation. Water ponds in the dip, and is discharged through road gullies. It is assumed that this discharge is directly to the Curries watercourse. If the discharge through the outfall pipes was blocked, for example through high levels in the river, the surface water would not drain away. As with fluvial flooding though, this will block access through the tunnel, but will not impact on property.

2.5.6 Devils Watercourse

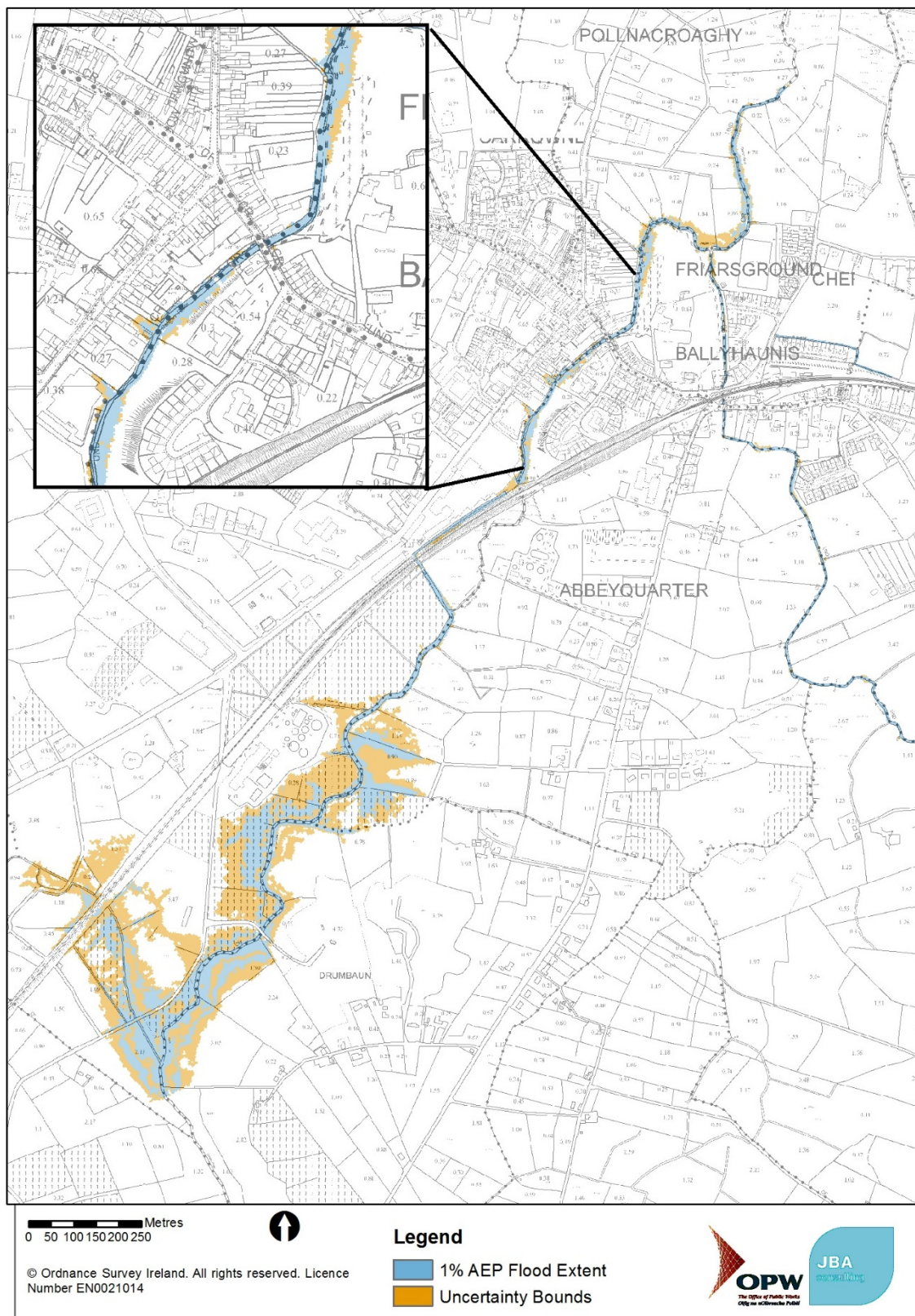
The Devils watercourse is shown to present no risk of flooding to properties in Ballyhaunis up to the extreme 0.1% AEP event, with all flows shown to remain within the drainage channel. This is a reflection of the over-capacity of the manmade drainage channel, coupled with the small catchment area draining into it.

Inspection during the site visit showed blockage of the culvert to be a likely occurrence.

2.6 Sensitivity testing

Sensitivity testing was conducted to determine which variables the model was sensitive to and their respective impacts. The model to the north of the railway line, and indeed for a short distance downstream of the railway crossing is not particularly sensitive to the parameters tested for either the 10% AEP or 1% AEP events, largely because the flooding is mainly in-bank, and the channel has sufficient capacity. The lower part of the model, where there is more out of bank flooding, shows a greater sensitivity to both flows and roughness changes. This is reflected in the increased flood extents, and also in flooding along the unmodelled tributary to the south of the domain, with water backing up under the railway line. Although inundating greater areas of agricultural land, there is no increase in the number of properties at risk. Overall, the hydraulic model was generally not shown to be sensitive with the exception of sensitivity to peak flow.

Figure 2-2: 1% AEP event uncertainty bounds - Ballyhaunis AFA



2.7 Flood risk summary

Table 2-4: Flood risk to receptors in Ballyhaunis

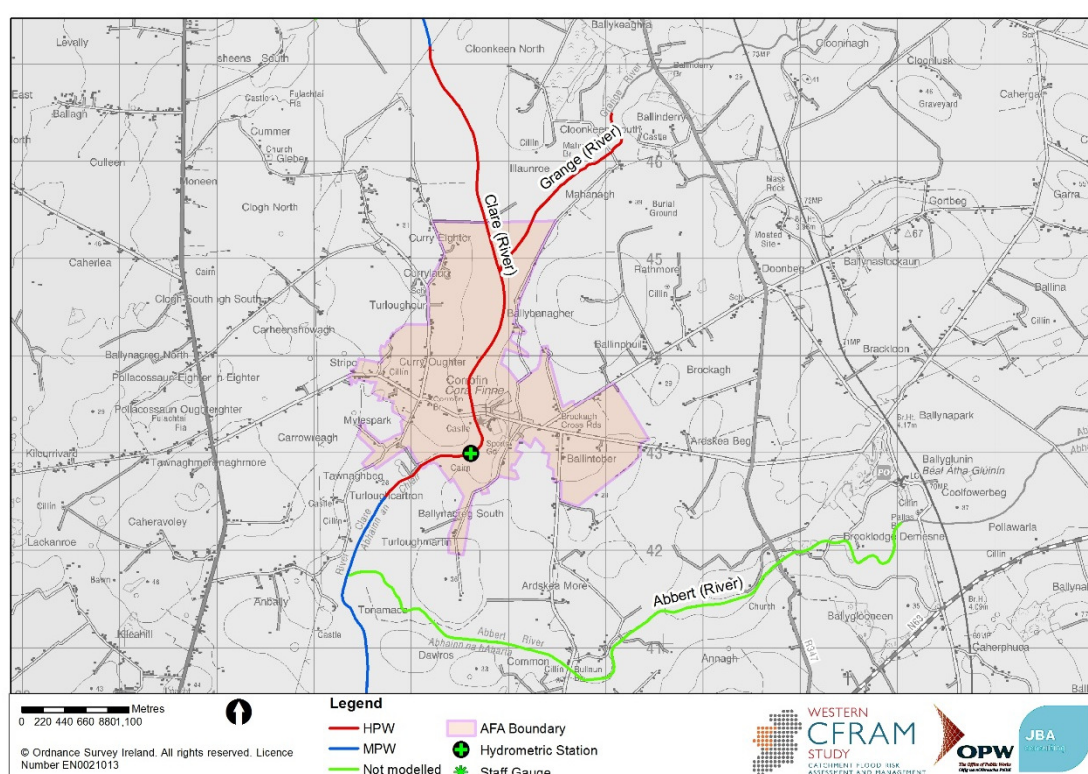
Risk Type	Receptor	Ballyhaunis				
		10% AEP	1% AEP	0.1% AEP	1% AEP MRFS	1% AEP HEFS
Social	Residential property	0	0	0	0	0
	School	0	0	0	0	0
	Health centre	0	0	0	0	0
	Nursing home	0	0	0	0	0
	Public residential care home	0	0	0	0	0
	Social infrastructure	0	0	0	0	0
	Hospital	0	0	0	0	0
	Gardai station	0	0	0	0	0
	Fire station	0	0	0	0	0
	Civil defence HQ	0	0	0	0	0
	Social amenity sites	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
Environment	IED / IPPC sites	0	0	0	0	0
	WFD Annex IV sites	At Risk	At Risk	At Risk	At Risk	At Risk
	NHAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
	pNHAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
	SACs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
	SPAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
Cultural heritage	National monument	0	0	0	0	0
	UNESCO heritage site	0	0	0	0	0
	Museum/ gallery	0	0	0	0	0
	NIAH building	0	0	0	0	0
Economy	Airport	0	0	0	0	0
	Train station	0	0	0	0	0
	Railway line (km)	0.00	0.00	0.00	0.00	0.00
	National roads (km)	0.00	0.00	0.00	0.00	0.00
	Water treatment plant	0	0	0	0	0
	Utilities	0	0	0	0	0
	Commercial building	0	0	0	0	0

3 Corrofin

3.1 Watercourse and catchment overview

The study area encompasses the Corrofin AFA and includes the Clare River, the main river passing through Corrofin village, and Grange River, a tributary of the Clare River. The watercourses are all classed as High Priority Watercourses (HPWs) as they flow through the AFA, and have been included in the model. Figure 3-1 provides an overview of the area. To the south of Corrofin is the Abbert River; this is outside the town boundary and has not been included in the CFRAM study. The area around Corrofin is heavily influenced by the karstic limestone bedrock, with turloughs, springs and swallow holes a common feature. Groundwater modelling and assessment has not been carried out as part of the CFRAM.

Figure 3-1: Overview of rivers in the Corrofin catchment



3.1.1 Clare River

The upstream modelled extent of the Clare is located approximately 1.5 km upstream of the confluence with the Grange River, and the downstream modelled extent is near Daly's Bridge, approximately 4.5km downstream of Corrofin Bridge, or 1.5 km downstream of the confluence with the River Abbert. The gradient of the Clare River through this reach is very shallow, at 0.7m/km.

The Clare River channel has been extensively worked over the centuries and is part of the Clare-Corrib OPW maintained arterial drainage scheme. This is evidenced by the extensive informal embankments along the river channel that appear to be made up of dredged material. Historic OSi mapping also suggests the river has been significantly altered, with changes to the permanence and location of loughs up and downstream of Corrofin and the alignment of the river through Corrofin. It also appears that Corrofin Bridge was changed from a bridge with multiple small arches to the one used today with a main span and remaining small side arches.

3.1.2 Grange River

The modelled length of the Grange River is 2.2 km. The gradient of this watercourse is approximately 1m/km. As with the River Clare, the Grange River has been subject to historical alteration, particularly downstream of Mahanagh Bridge. The Grange River would have flowed

into Cloonkeen Lough, upstream of the town before the improved drainage works were implemented in the 19th century.

3.2 Flood history

Further details on the flood history of the town can be found in the AFA specific modelling report and the Hydrology and Inception Reports. A summary of known flood events is provided below.

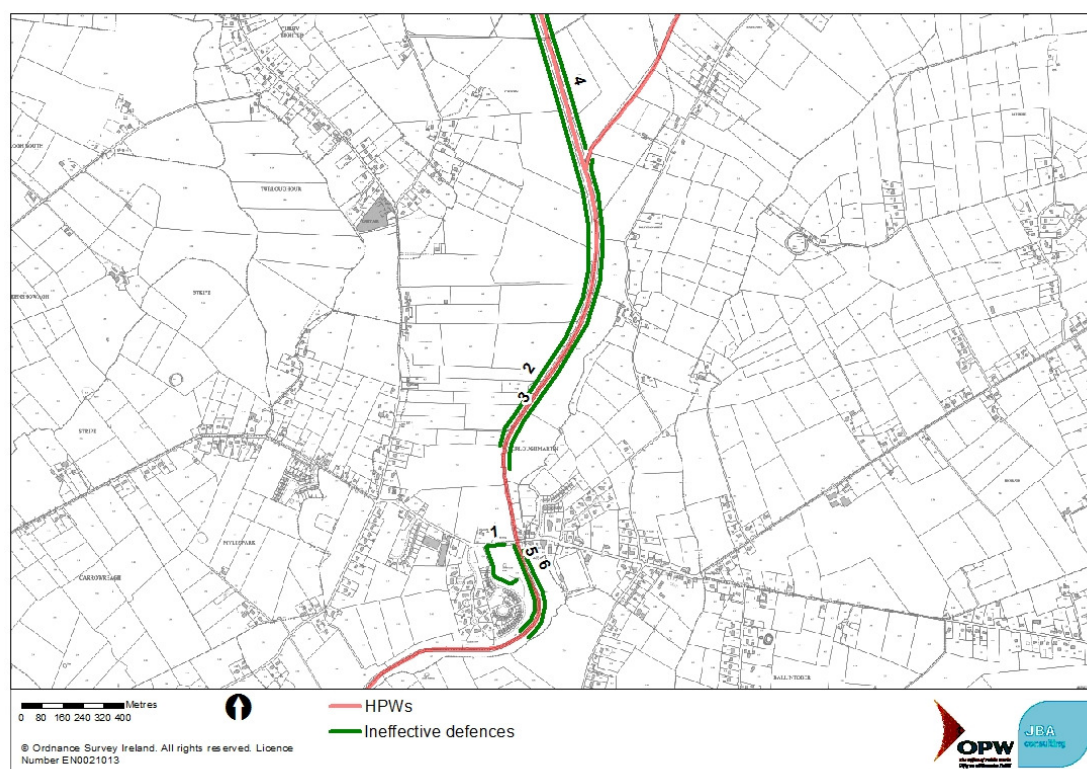
Table 3-1: Flood history summary in Corrofin

Area affected	Main flooding mechanisms	Recorded flood event data	Use in model check
Ballybanagher	Fluvial flooding from Clare and Grange rivers	November 2009	Verification run using aerial photography.
Unknown, but third highest stage recorded. Extensive floodplain inundation anticipated.	Fluvial	2006	Sensibility check
Unknown, but recorded stage is higher than 2009	Fluvial	1968	Not used - measurement is highly uncertain given a datum change since then and likely channel changes
Rural floodplain	Fluvial, surface water, drains and potentially groundwater	Recurring	Sensibility check

3.3 Existing defences and walls

No formal or informal effective defences were identified within the AFA. Six lengths of informal ineffective structures were identified within the AFA along the banks of the Clare River. These structures are not assumed to function as flood defences and are either bypassed in the model or have been removed to allow flooding beyond them.

Figure 3-2: Overview of defences in Corrofin



3.4 Model limitations

- Bankside embankments - The river banks along the Clare and Grange rivers are generally in the form of informal raised embankments that have gaps in them. As far as possible in the model these have been represented as they have been surveyed. The model is, however, a simplification of the actual situation and may not accurately model the flow paths onto the floodplain. Despite this, the overall effect looks realistic when compared with aerial photography of the 2009 flood, and local knowledge.
- Influence of tributaries and groundwater - There is a wide spread of gaugings at the Corrofin gauge and it is suggested that is because of a backwater effect from the Abbert confluence downstream and the influence of groundwater on the system. Further investigation could help understanding of the situation, but such detailed groundwater assessment is outside the scope of the CFRAM. Ideally, additional monitoring of water levels would be required downstream of the gauge location to understand the variation of water surface profile through that area; it is likely that this effect would only be seen during extreme events.

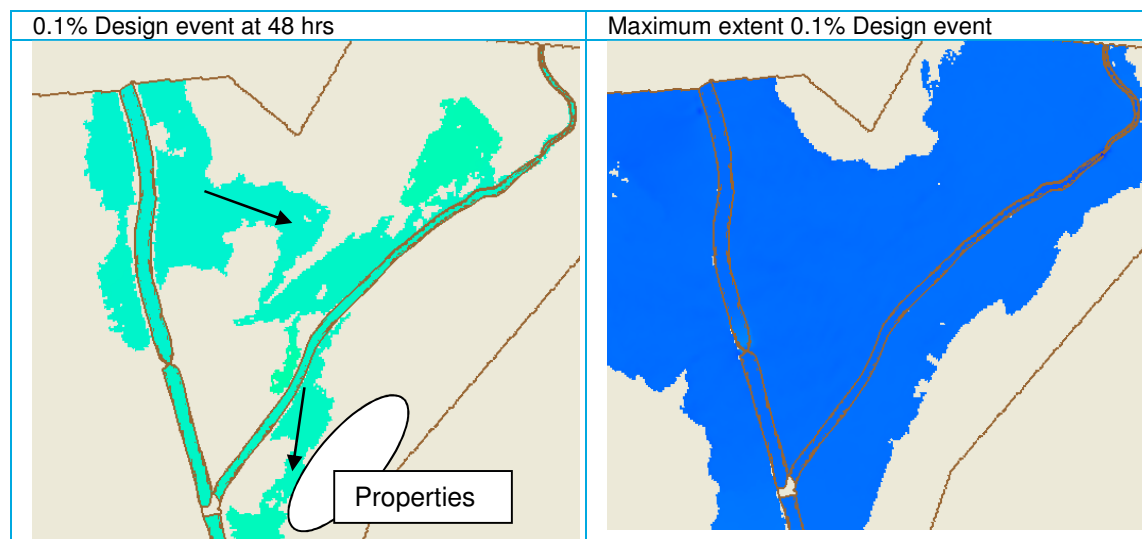
3.5 Key flood risk mechanisms

Further to the information presented in the flood risk maps, a brief description of the key flood risk sites and flooding mechanisms is provided below.

The only area of property flooding within the AFA is upstream of Corrofin Bridge on the combined Clare and Grange floodplain. The area where property is at risk is close to the confluence of the two rivers on the eastern edge of the floodplain where development has encroached. The flood risk mechanism in this area is simply the large floodplain filling up to a level to cause flooding to the property.

Flood water on the left bank floodplain of the Clare River flows into the River Grange channel and the combined flow comes out of that channel into the area of the properties. Table 3-2, below shows early flood routes and then the full flood extent during the 0.1% AEP design run. Property flooding is experienced in as low as the 10% AEP event.

Table 3-2: Corrofin flood mechanism



3.6 Sensitivity testing

Sensitivity testing was conducted to determine which variables the model was sensitive to and their respective impacts.

Only the peak flow test was carried out for sensitivity testing in the 10% AEP event; consequently, any increase in flooding shown in the figure is as a direct result of this test. The greatest change in flood extent from sensitivity testing of this event is to the fields upstream of Corrofin Bridge, adjacent to Ballybanagher. One additional property is shown to be at risk of flooding in Ballybanagher. The increase in flooding as a result of the sensitivity testing is not dramatic for the

1% AEP event as shown in Figure 3-3 and is directly attributed to the sensitivity to peak flow. Flooding is shown to reach much nearer to properties in Corrofin itself, however this still does not result in the flooding of any properties in this location. This shows that the model was not sensitive to the other parameters tested. Figure 3-4 presents the extent of flooding where a storm event was run only on the Clare River and it demonstrates quite clearly that the flooding shown on the Grange River is almost completely attributable to the levels within the main river, the Clare River, particularly around the key flood risk area of Ballybanagher.

Figure 3-3: 1% AEP event uncertainty bounds - Corrofin AFA

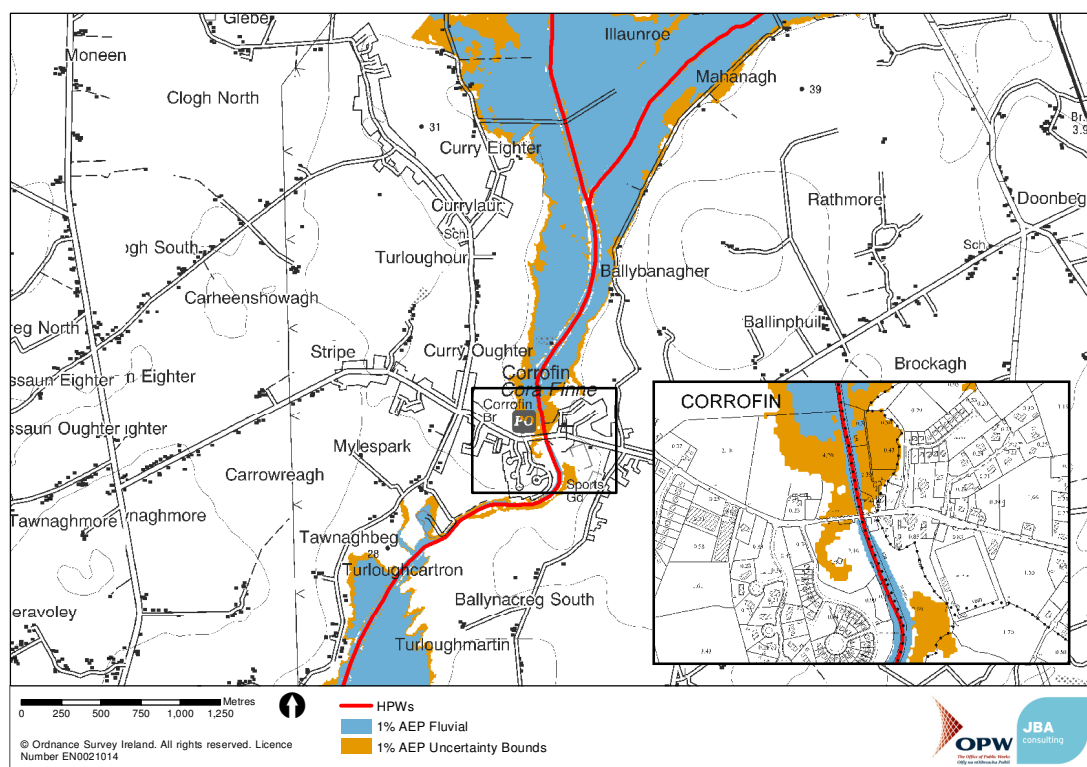
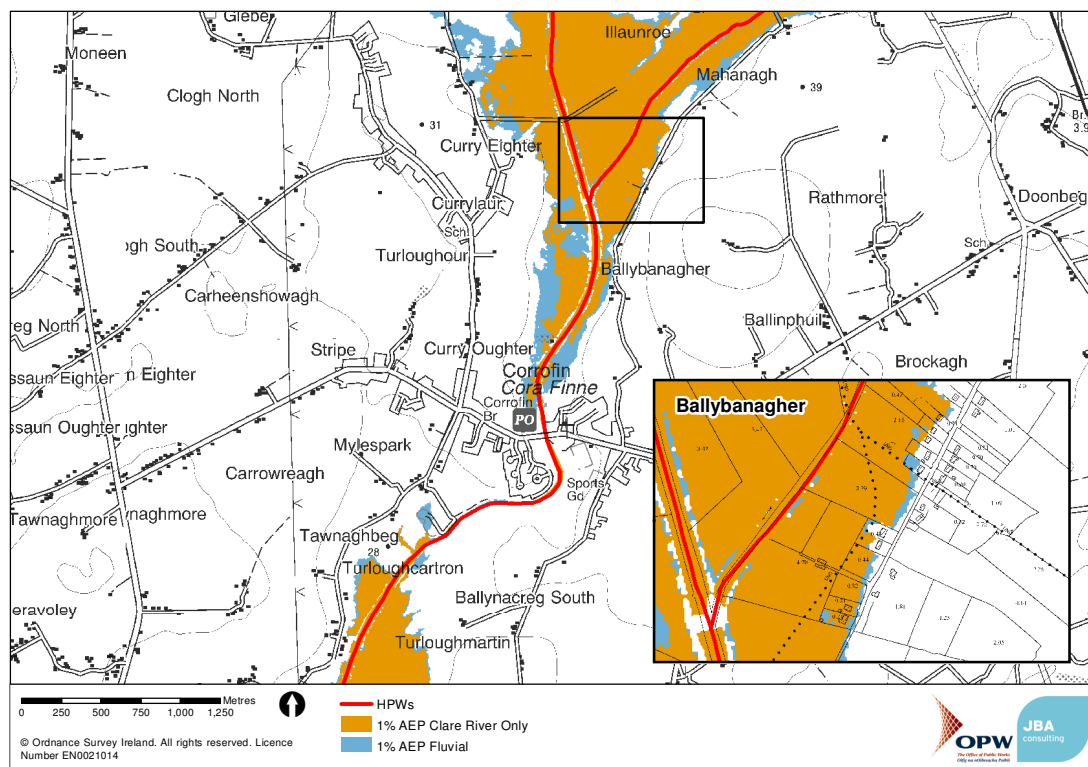


Figure 3-4: 1% AEP event uncertainty bounds - Clare River



3.7 Flood risk summary

Table 3-3: Flood risk receptors in Corrofin

Risk Type	Receptor	Corrofin				
		10% AEP	1% AEP	0.1% AEP	1% AEP MRFS	1% AEP HEFS
Social	Residential property	2	3	9	5	6
	School	0	0	0	0	0
	Health centre	0	0	0	0	0
	Nursing home	0	0	0	0	0
	Public residential care home	0	0	0	0	0
	Social infrastructure	0	0	0	0	0
	Hospital	0	0	0	0	0
	Gardai station	0	0	0	0	0
	Fire station	0	0	0	0	0
	Civil defence HQ	0	0	0	0	0
	Social amenity sites	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
Environment	IED / IPPC sites	0	0	0	0	0
	WFD Annex IV sites	At Risk	At Risk	At Risk	At Risk	At Risk
	NHAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
	pNHAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
	SACs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
	SPAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
Cultural heritage	National monument	0	0	0	0	0
	UNESCO heritage site	0	0	0	0	0
	Museum/ gallery	0	0	0	0	0
	NIAH building	0	0	0	0	0
Economy	Airport	0	0	0	0	0
	Train station	0	0	0	0	0
	Railway line (km)	0.00	0.00	0.00	0.00	0.00
	National roads (km)	0.00	0.00	0.00	0.00	0.00
	Water treatment plant	0	0	0	0	0
	Utilities	0	0	0	0	0
	Commercial building	0	0	0	0	0

4 Galway City

4.1 Watercourse and catchment overview

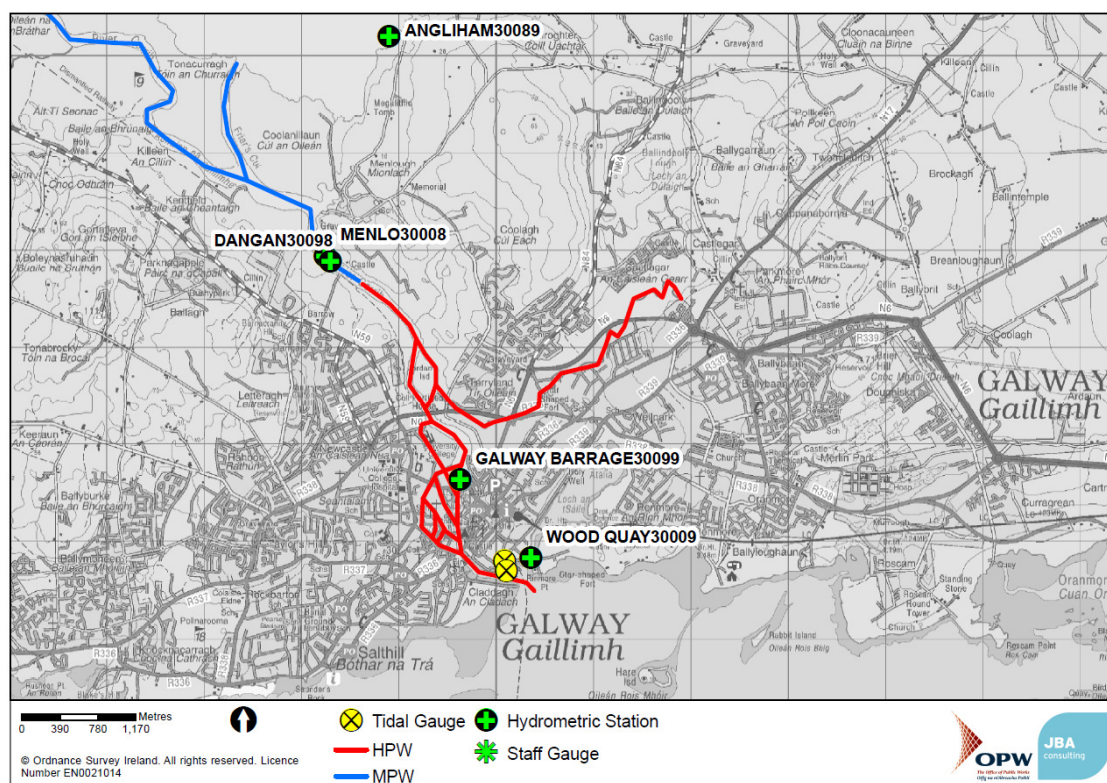
The Corrib flows along a short channel through Galway City which joins the outlet of Lough Corrib to the sea. Its catchment to the outfall is large (3,140km²). Loughs Corrib and Mask form a dividing line between two quite different portions of the catchment. To the east of the Loughs, where the bulk of the catchment lies, the land is low-lying with moderate rainfall and karst limestone geology. The smaller tributaries flowing into the Loughs from the west are much steeper, draining impermeable mountainous catchments with high rainfall.

Lough Corrib is the second largest lake in Ireland, with an area of 178km². It has a major influence on the nature of flood flows along the River Corrib through Galway. The management of Lough Corrib has changed over the years. In the 12th century, the Friars Cut was built to provide another outlet from the Lough into the River Corrib in an attempt to allow boats to access the Lough from the sea. Between 1846 and 1850 the lake was lowered to reduce flooding of surrounding farm land (Freeman, 1957). Between 1848 and 1857, the Eglinton canal was built, connecting the River Corrib to the sea. It allowed boats to access the Lough via a single lock and also made provision for improved operation of over 30 mills.

In 1959, a weir constructed in the 1850s was replaced with a sluice barrage (the Salmon Weir) consisting of 16 gates. The barrage is close to the centre of Galway, 800m upstream of Wolfe Tone Bridge, immediately downstream of the point where the Eglinton Canal leaves the river. This is 7.8km downstream of the main outlet from Lough Corrib. A small amount of flow can bypass this structure via various canals and mill races.

The barrage was intended to keep levels on the Lough between 5.84 and 6.44mAOD Malin (i.e. 28-30 feet above OD Poolbeg). The upper limit is intended to avoid flooding of shoreline and lower reaches of tributary rivers. The original design envisaged that this upper limit level would be reached at a flow of 311m³/s. This upper limit has been exceeded almost every year, apart from 1995 and 2005.

Figure 4-1: Galway City AFA catchment overview



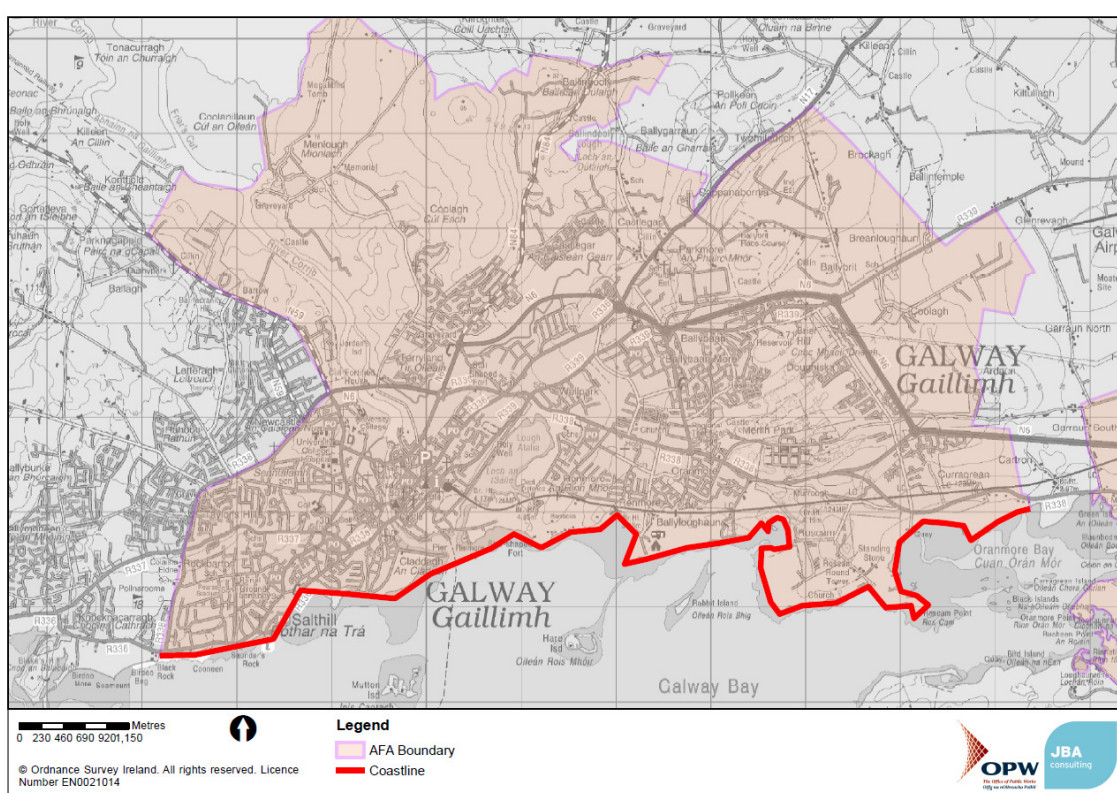
For the purpose of a catchment wide study the Lough Corrib to Galway Bay fluvial reach is divided into two models, the Medium Priority Watercourse (MPW) and the High Priority Watercourse

(HPW). The HPW model is a more detailed study of the flood risk mechanisms required for an urban area. It starts at the Dangan gauge and continues to Galway Bay.

The MPW outputs are to be used to investigate the key controlling elements of the watercourse system and support the AFA modelling decisions. Specifically, this model will be used to assess the impacts of the Salmon Weir Barrage on Lough Corrib and the River Clare. Figure 4-1 shows the overview of the HPW and MPW models.

A third model has been constructed to look at the impacts of direct coastal inundation and wave overtopping. Galway City has a coastline of approximately 13.5km that stretches from Black Rock in the west to Roscam Point to the east. Figure 4-2 shows the extent of the coastline and outline of the AFA area. There is substantial evidence that reclamation of lands from the sea occurred in Salthill during the last century, including White Strand and the land on which Toft Park, the Aquarium and car park are all located.

Figure 4-2: Galway coastal overview



4.2 Flood history

Further details on the flood history of the town can be found in the AFA specific modelling report and the Hydrology and Inception Reports. A summary of known flood events is provided below.

Table 4-1: Flood history summary in Galway City

Area affected	Main Flood Mechanisms	Recorded Flood Event
Spanish Arch, Quay Street, Flood Street and the Docks area, Lower Salthill	Due to high tide, low atmospheric pressure, wind direction, heavy rain.	Jan 1995, High tides in 2006, Jan & Feb 2014, recurring
Grattan Road	Overtopping, high tides and onshore winds.	Recurring
Seapoint Promenade	Overtopping, high tides and onshore winds.	Jan & Feb 2014, recurring
N17 at Two Mile Ditch	Heavy rain	Jan 1995, 1999, 2005, Nov 2009, recurring
Salthill, Fr. Griffin Road, Claddagh and Spanish Arch Areas	Heavy rain, gale force winds, high tide	Feb 2002 recurring
Headford rd/Ballindooley	Ballindooley lake margin	Feb 2002, prone to

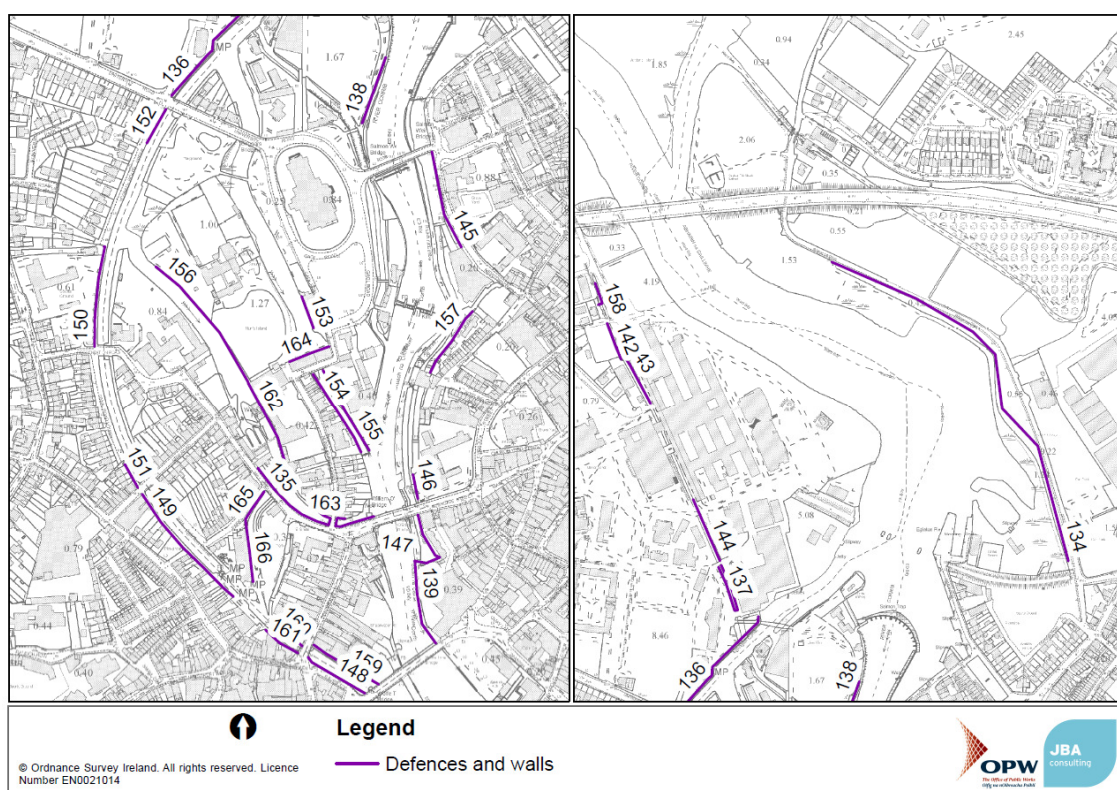
Area affected	Main Flood Mechanisms	Recorded Flood Event
	increased during heavy rain	flooding
Doughiska	Turlough	Recurring
Menlough	Turlough heavy rain	Nov 2009, recurring

4.3 Existing defences and walls

A number of formal (i.e. OPW, local authority or privately maintained defences) flood defences have been identified with the AFA, namely the dyke running in a north-northwest direction, a retaining wall on right bank of River Corrib and a short length of quay wall. The two effective structures have been modelled as surveyed and are assumed to retain flood waters to the crest of the structure. The ineffective quay wall is so called because it forms an incomplete run of defence. However, the full length of the quay has been included in the model as per the survey details.

Informal ineffective structures, identified with the AFA, are not assumed to function as flood defences and are either bypassed in the model or have been removed to allow flooding beyond them. All the identified defences, whether effective or ineffective, are shown in Figure 4-3.

Figure 4-3: Overview of defences in Galway City



4.4 Model limitations

Fluvial model

- Channel blockage - Blockage has not been investigated in more detail in this model as it is outside the scope of the CFRAM but there are high number of culverts, particularly on the canals, where blockage has been witnessed and if exacerbated could give rise to significant flood risk.
- Salmon Weir - Water level upstream of the Salmon Weir Barrage, and the flow to the canals is controlled by the operation of the 16 gates that form the structure. The operation rules are not known but as a conservative (i.e. higher flow) scenario, it has been assumed that the gates would be open for all the design events carried out in this study. This assumption is supported by operational evidence from the 2009 event and feedback that the gates are normally opened during the winter period.
- Structure representation - uncertainty in the modelling of structures where health and safety and technical issues meant there was limited survey data collected, particularly on

the Eglinton Canal, Nuns Island and Distillery River. Flow controls at the water treatments works on the Castlegar River are based on surveyed headloss, rather than knowledge of internal structures.

- Geomorphological change - The channel bed constantly shifts and may be easily eroded by high river flows. Although not examined through modelling, the likely impact on flood relief schemes has been appraised.
- Karst features - The Castlegar River flows into a sink hole, of which the operation and capacity is unknown. Analysis of the groundwater system is outside the scope of the CFRAM.
- Model calibration - There is limited fluvial calibration data available. A programme of water level monitoring across the canal system would to help calibrate the model.
- Inclusion of all the mill races and connections - A number of connections were not modelled due to there being no influence on flood risk.

Coastal model

- ESTRY Components - Width of structures were restricted to a minimum width of four metres due to the model so some structures were modelled with larger areas than their actual area.

4.5 Key fluvial flood risk mechanisms

Further to the information presented in the flood risk maps, a brief description of the key flood risk sites and flooding mechanisms is provided below. The downstream tidal boundary has a significant influence on a number of watercourses. The floodwaters from the tidal element are prevented from translating upstream by numerous weirs and sluices in Galway City.

4.5.1 Flooding of Upper Corrib

The flood extents arising from the MPW model on the Upper Corrib show much inundation in the 10% AEP event but this is mainly encroachment onto marsh bog land. Floodwaters enter the turloughs on the left bank, increasing the lake area and causing back watering to various streams that provide drainage to the area.

There are no properties at risk in this area as this land appears to have been liable to flooding in the past and development in this area has been avoided. This is indicated on the OSi historic 25" maps circa 1897-1913.

4.5.2 Flooding at Castlegar

The flooding on Castlegar is controlled by the amount of floodwater that can be conveyed through the sinkhole at the downstream and the inlet from the waterworks structure, both of which are uncertain. The 1% AEP extent shows the Dyke road embankment overtopped and allowing flow into the Castlegar area. This contributes mostly to the flooding in Castlegar. The backing up of drains at the downstream is evident. No properties are affected in this area.

4.5.3 Flooding of Distillery River

The Distillery River is a complex area of the Galway City AFA. The controlling structure of the watercourse is a siphon under the Eglinton canal in the middle of the watercourse. Floodwaters from the Eglinton canal can spill over its banks adding to floodwater in the Distillery River. No flooding occurs in the 10% AEP or 1% AEP event, however the 0.1% shows properties affected. The properties affected are mainly belonging to NUI Galway. There have been improvements to this channel since the CFRAM topographic survey was collected following recommendations in a report titled, NUI Galway Campus Flood Prevention⁶, the impact of which will be investigated in the next stages of the CFRAM.

4.5.4 Flooding of right bank canal system

The right bank canal system represents the canals whose flood waters are fed by the branch upstream of the Salmon Weir barrage. The Eglinton Canal feeds a number of old mill races

⁶ NUI Galway Campus Flood Prevention, University Road Galway

through the heavily urbanised area. Flooding occurs in the 1% AEP from the Galway Mill Run Area canal which overtops its right bank. Similar flooding is shown in the 0.1% AEP event, along with right bank flooding from the Madeira Court watercourse due to the culverts surcharging.

4.5.5 Flooding of downstream at Wolfe Tone Bridge

Flooding is evident in this area in the 1% and 0.1% AEP fluvial events that are run concurrently with a 50% AEP tidal events. In the 1% event the low lying area near the Claddagh basin floods from the downstream of the Eglinton (EGLI) canal and the basin itself over flowing. The area is greatly influenced by the tidal boundary and the fluvial event alone would not be expected to be sufficient to flood this area. The 0.1% event flooding shows further exacerbation on the right bank around Wolfe Tone Bridge. The area is a known area of flood risk from high tides.

4.6 Key tidal flood risk mechanisms

4.6.1 Flooding in the Salthill Area

The flood extent map for the Salthill area of Galway City shows much inundation in the 10% AEP event. Known areas of flooding such as Toft Park and along the promenade are shown flooded in the 10% AEP. The flooding is more extensive through Grattan Road in the 0.5% AEP and shows further properties affected.

4.6.2 Flooding at Spanish Arch and Dock Road

The area around Spanish Arch, Flood Street and Dock Road is a known area of flood risk from historical evidence and the more recent event of winter 2013/14. From the flood maps produced much of the flooding occurs in the 0.5% AEP event in comparison to the 10% AEP event which does not show extensive flooding. There is a marginal difference in flood extent between the 0.5% AEP and the 0.1% AEP.

4.6.3 Flooding at Claddagh Basin

There is no flooding shown at Claddagh Basin in the 10% AEP event but the 0.5% AEP extent shows expansive flooding down Father Burke road onto Father Griffin road. There are historical records of this flooding and the maps reinforce the flood risk potential present in this area.

4.6.4 Wave overtopping flood risk mechanisms

The wave overtopping results indicate that the Salthill area is susceptible to wave overtopping and experiences flooding from this mechanism at an AEP greater than 10%. This was to be expected and is evident from the flood history of the area.

The docklands area is not prone to wave overtopping. There is sufficient slope to return the wave volume breaking onto the ground to the sea.

4.7 Sensitivity testing

Sensitivity testing was conducted to determine which variables the model was sensitive to and their respective impacts.

4.7.1 Fluvial

There is a significant difference between the design 1% AEP model runs and the respective sensitivity runs as evident in Figure 4-4 and Figure 4-5. The most noticeable increase in flood extents along the Castlegar River is due to the increased flow sensitivity test. This causes the Dyke Road defence to overtop and exacerbate the flooding in this area. It was found that an increase in peak flow resulted in the greatest sensitivity. Adjusting roughness had a marginal affect. Adjusting building threshold has an impact of increasing flooding in areas while decreasing it at the same time in other areas.

Figure 4-4: 1% AEP fluvial event uncertainty bounds - Claddagh Area

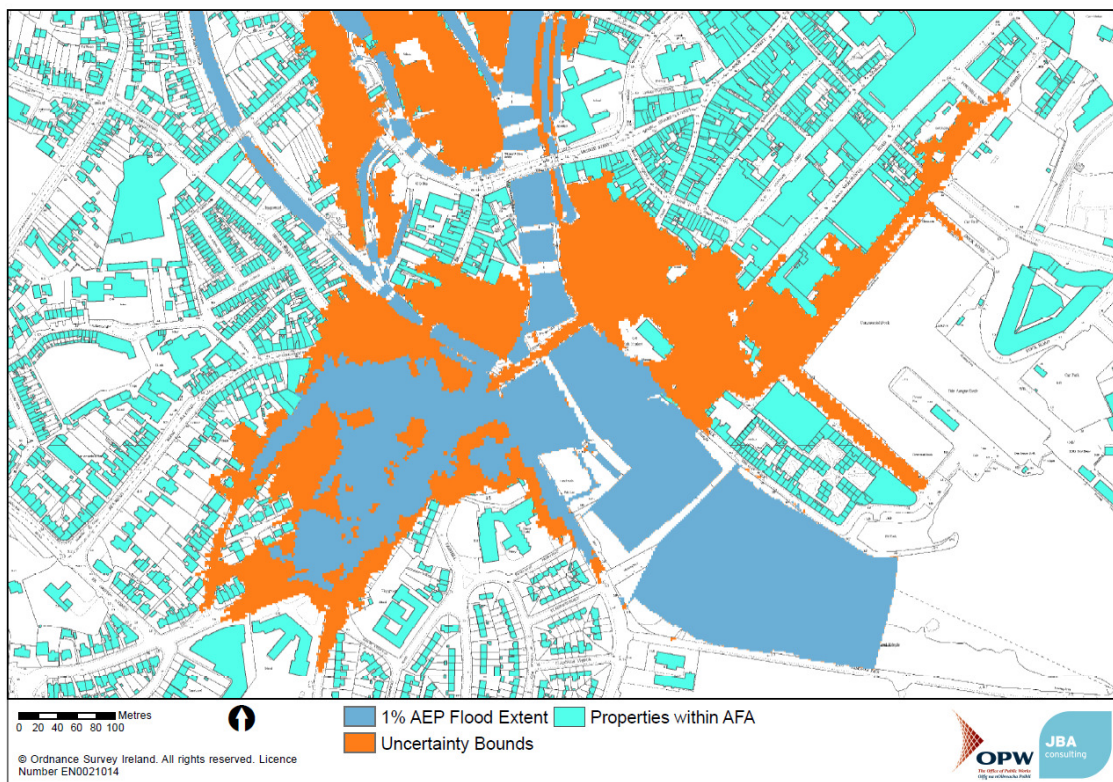
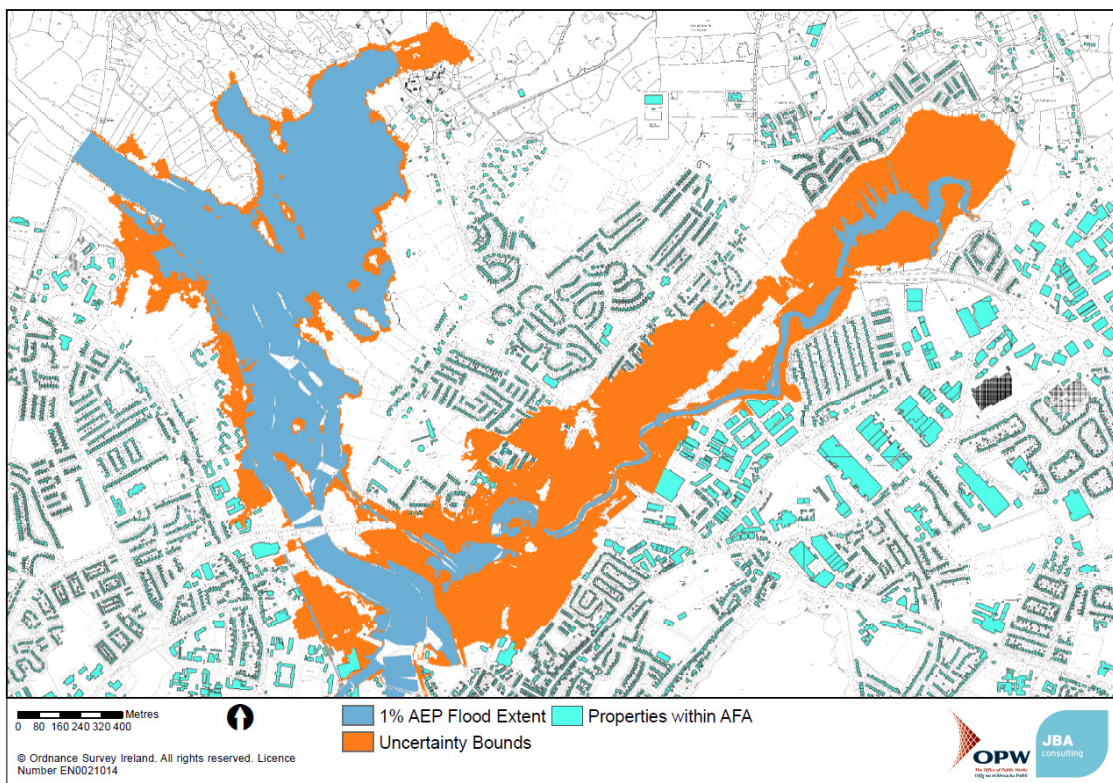


Figure 4-5: 1% AEP fluvial event uncertainty bounds - Upper Corrib



4.7.2 Coastal

The sensitivity of the Galway City coastal model to the tests are very marginal and indicate the model is insensitive to the parameters tested, as can be seen in Figure 4-6 and Figure 4-7.

Figure 4-6: 0.5% AEP tidal event uncertainty bounds - Salthill West

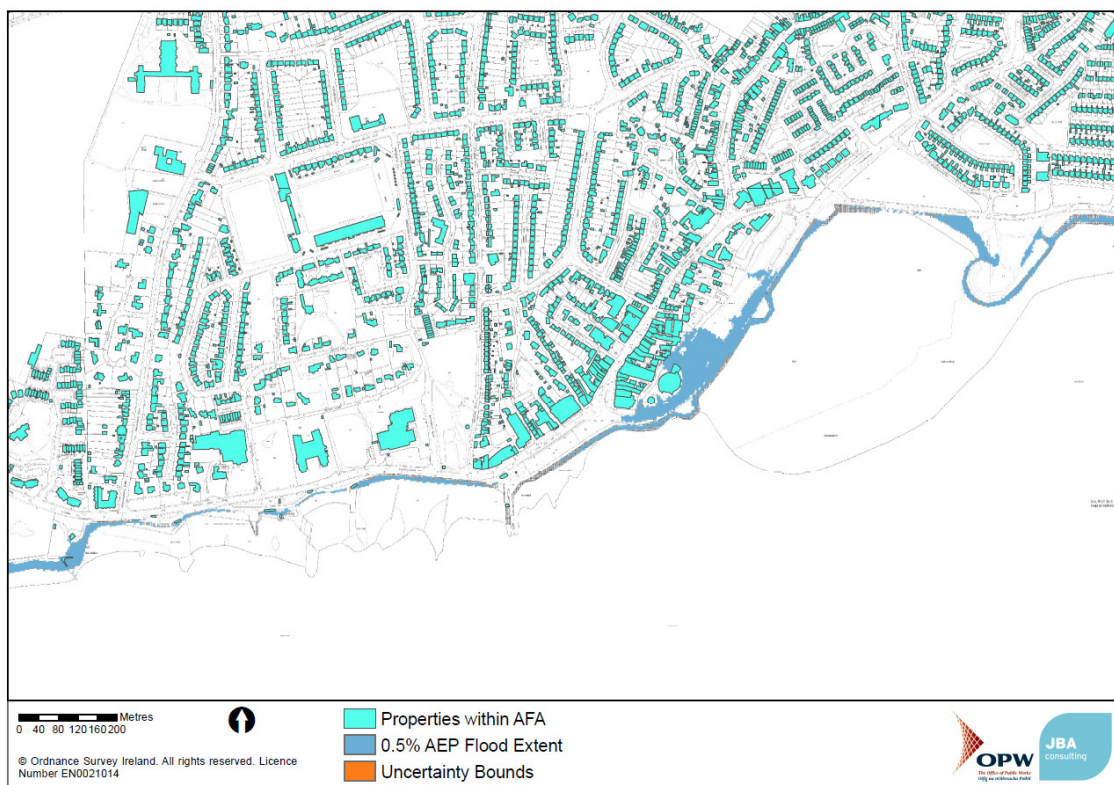
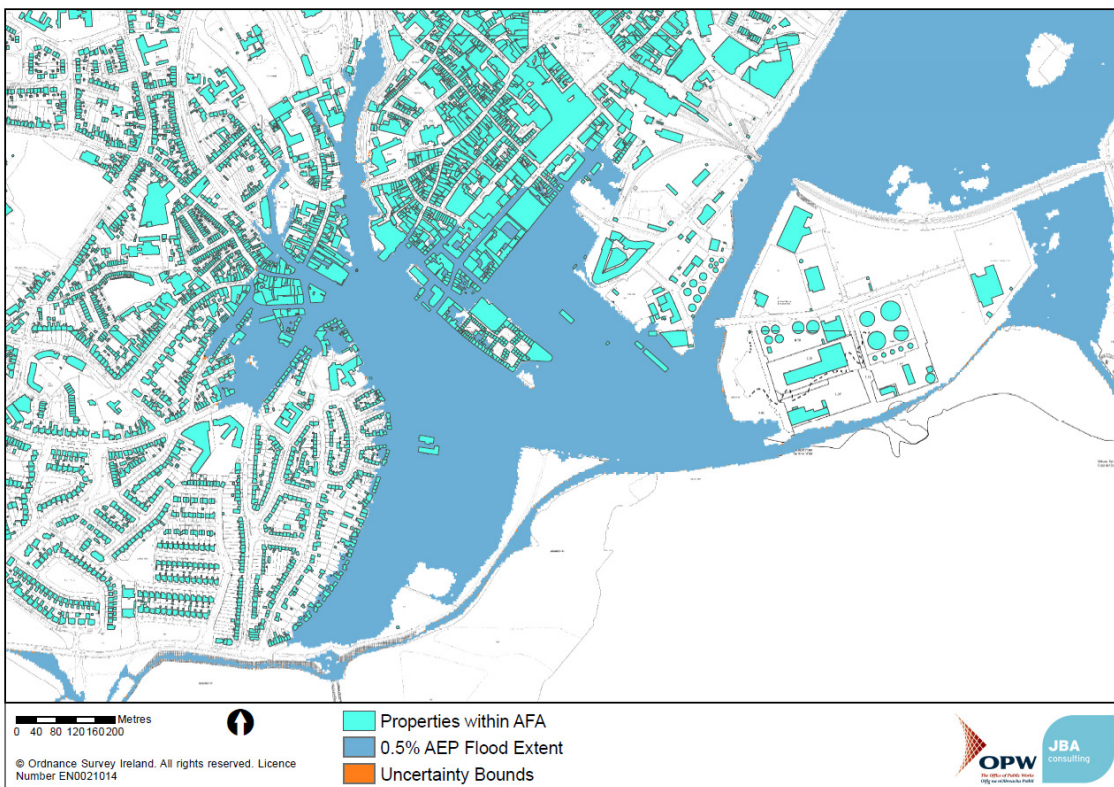


Figure 4-7: 0.5% AEP tidal event uncertainty bounds - Salthill East



4.8 Flood risk summary

Table 4-2: Fluvial flood risk to receptors in Galway city

Risk Type	Receptor	Galway city				
		10% AEP	1% AEP	0.1% AEP	1% AEP MRFS	1% AEP HEFS
Social	Residential property	16	99	895	504	648
	School	0	0	2	0	1
	Health centre	0	0	0	0	0
	Nursing home	0	0	0	0	0
	Public residential care home	0	0	0	0	0
	Social infrastructure	0	0	2	2	2
	Hospital	0	0	0	0	0
	Gardai station	0	0	0	0	0
	Fire station	0	0	1	1	1
	Civil defence HQ	0	0	1	1	1
	Social amenity sites	At Risk	At Risk	At Risk	At Risk	At Risk
Environment	IED / IPPC sites	0	0	0	0	0
	WFD Annex IV sites	At Risk	At Risk	At Risk	At Risk	At Risk
	NHAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
	pNHAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
	SACs	At Risk	At Risk	At Risk	At Risk	At Risk
	SPAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
Cultural heritage	National monument	1	1	5	3	7
	UNESCO heritage site	0	0	0	0	0
	Museum/ gallery	0	0	0	0	0
	NIAH building	0	0	0	0	0
Economy	Airport	0	0	0	0	0
	Train station	0	0	0	0	0
	Railway line (km)	0.00	0.00	0.00	0.00	0.00
	National roads (km)	0.00	0.00	3.91	0.00	0.26
	Water treatment plant	0	0	0	0	0
	Utilities	0	0	0	0	0
	Commercial building	16	81	627	350	489

Table 4-3: Tidal flood risk to receptors in Galway city

Risk Type	Receptor	Galway city				
		10% AEP	0.5% AEP	0.1% AEP	0.5% AEP MRFS	0.5% AEP HEFS
Social	Residential property	99	678	934	1266	2525
	School	0	0	0	0	0
	Health centre	0	0	0	0	0
	Nursing home	0	0	0	0	0
	Public residential care home	0	0	0	0	0
	Social infrastructure	0	2	2	2	2
	Hospital	0	0	0	0	0
	Gardai station	0	0	0	0	0
	Fire station	0	1	1	1	1
	Civil defence HQ	0	1	1	1	1
	Social amenity sites	At Risk	At Risk	At Risk	At Risk	At Risk
Environment	IED / IPPC sites	0	0	0	0	0
	WFD Annex IV sites	At Risk	At Risk	At Risk	At Risk	At Risk
	NHAs	Not at	Not at	Not at	Not at	Not at

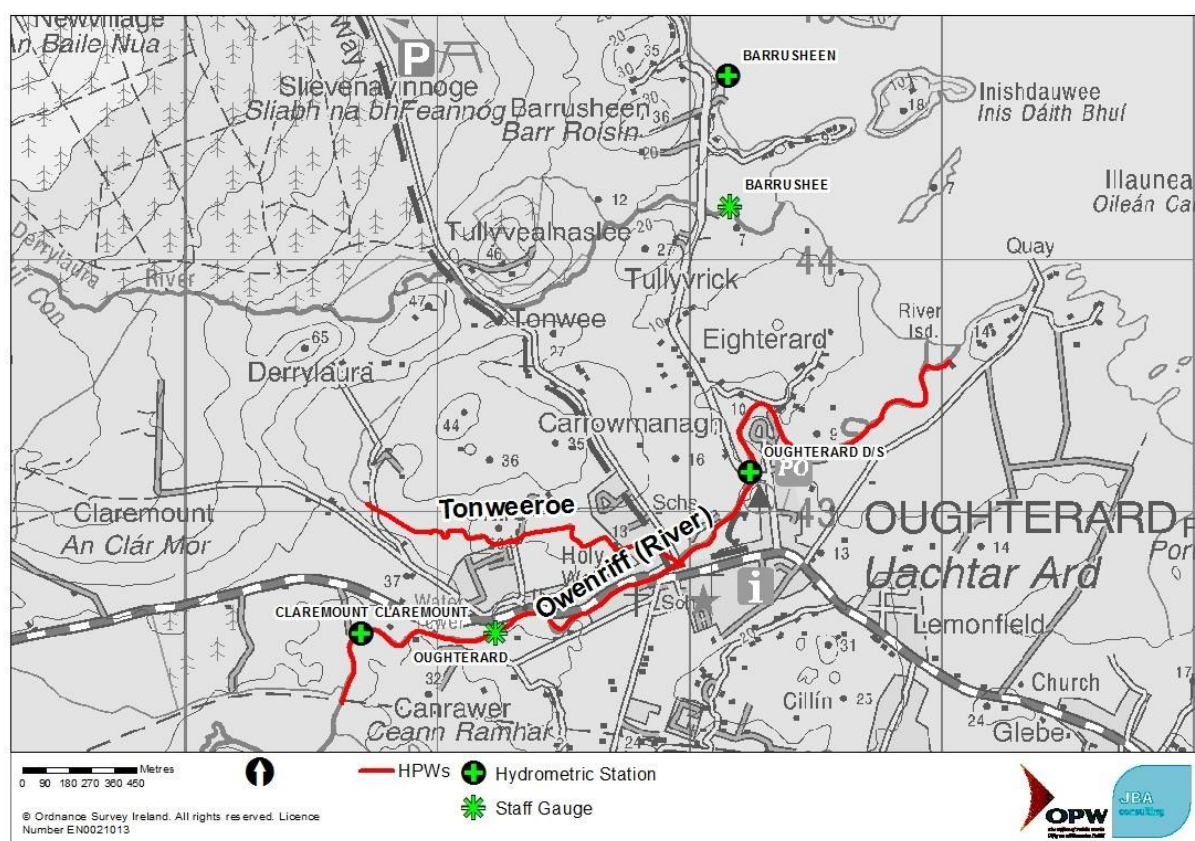
Risk Type	Receptor	Galway city				
		10% AEP	0.5% AEP	0.1% AEP	0.5% AEP MRFS	0.5% AEP HEFS
		Risk	Risk	Risk	Risk	Risk
	pNHAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
	SACs	At Risk	At Risk	At Risk	At Risk	At Risk
	SPAs	At Risk	At Risk	At Risk	At Risk	At Risk
Cultural heritage	National monument	3	4	6	10	13
	UNESCO heritage site	0	0	0	0	0
	Museum/ gallery	0	0	0	0	0
	NIAH building	0	0	0	0	0
Economy	Airport	0	0	0	0	0
	Train station	0	0	0	0	0
	Railway line (km)	0.08	0.08	0.09	0.09	0.10
	National roads (km)	0.00	0.00	0.00	0.00	0.00
	Water treatment plant	0	0	0	0	0
	Utilities	0	0	0	1	1
	Commercial building	70	508	626	724	1051

5 Oughterard

5.1 Watercourse and catchment overview

The study area encompasses the Oughterard AFA and includes the Owenriff River, which is the main river passing through Oughterard town centre, and Tonweeroe Watercourse, a tributary of Owenriff River. The watercourses are all classed as High Priority Watercourses (HPWs) as they flow through the centre of the AFA, and have been included in the model. Figure 5-1 provides an overview of the area. The Owenriff River discharges into Lough Corrib a short distance downstream of Oughterard.

Figure 5-1: Oughterard AFA catchment overview



5.1.1 Owenriff River

The upstream modelled extent of the Owenriff is located at the old railway crossing approximately 1.5km upstream of the N59 Bridge, and the downstream modelled extent is at Lough Corrib; a distance of 3.7km. Across the modelled reaches the bed elevation drops 21.4m. The gradient of the Owenriff River through this reach is very variable, from extremely steep cascades towards the upstream end to very flat gradient as it flows into the lough.

The Owenriff River channel appears fairly natural and reference to historic maps shows very little change in course over the past nearly 200 years.

Table 5-1: Owenriff River gradient changes

	
<p>Owenriff River approaching Lough Corrib towards the downstream end of the model (30ORIF00064).</p>	<p>Owenriff River cascades towards the upstream end of the model (30ORIF00283).</p>

5.1.2 Tonweeroe Watercourse

The modelled length of the Tonweeroe watercourse is 1.5km. There are several small culverts along the length of the watercourse that can restrict extreme flows. The longest of these is located at the downstream end of the Tonweeroe watercourse beneath the houses of Abhainn Na Coille to the point of discharge into the Owenriff River. This culvert is around 130m long and has a screen on the inlet.

Inspection of the route of the Tonweeroe watercourse during site visits indicated that not all the flows reach this downstream culvert and it is often dry which suggests some water may be lost into the ground. At extreme flows this is likely to be less significant. Analysis of the historical mapping available through the OSi shows the downstream extent of this watercourse does not link to the Owenriff, but it is not clear where the channel does discharge to.

5.2 Flood history

Further details on the flood history of the town can be found in the AFA specific modelling report and the Hydrology and Inception Reports. A summary of known flood events is provided below.

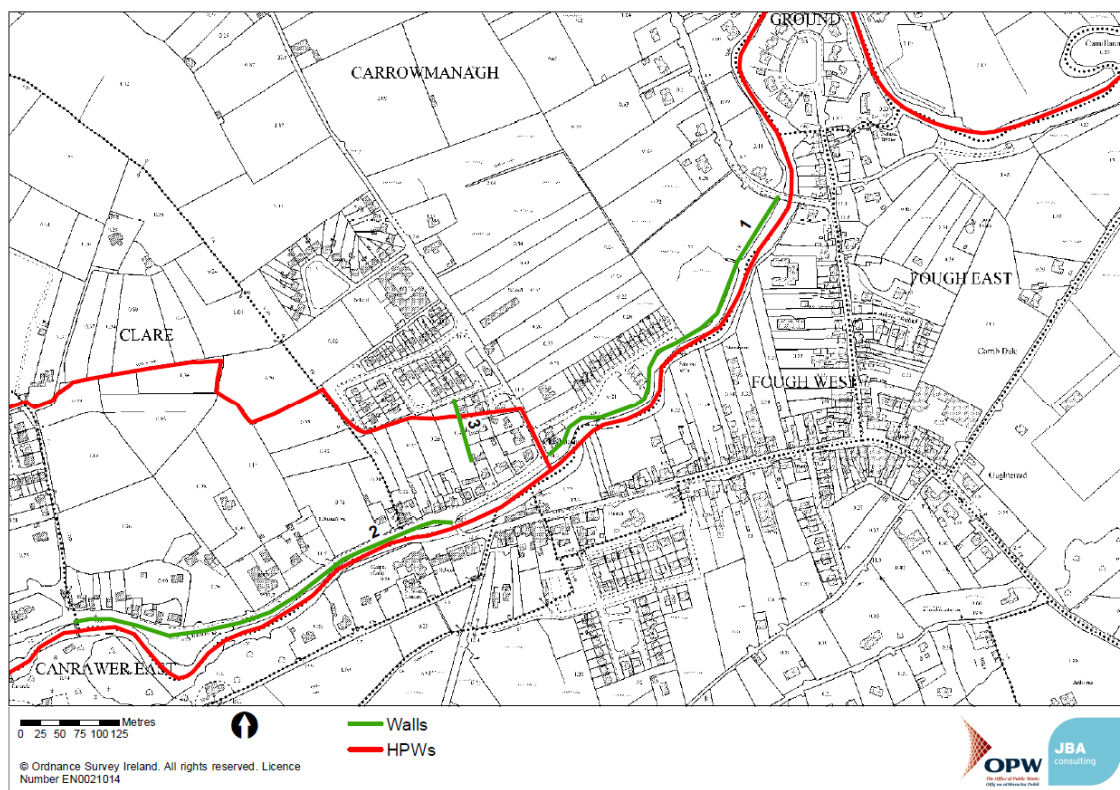
Table 5-2 : Flood history summary in Oughterard

Area affected	Main flood mechanisms	Recorded flood event date	Use in model check
Abhainn Na Coille	Fluvial	07/02/2000	Calibration run
Abhainn Na Coille	Fluvial	28/11/1999	Calibration run
Low lying field near Lough Corrib	Lake	5 year reoccurring	Sensibility check on design extents

5.3 Existing defences and walls

No formal or informal effective defences were identified within the AFA although three informal ineffective structures were identified along the banks of the Ballynageeha Watercourse. These structures are not assumed to function as flood defences and are either bypassed in the model or have been removed to allow flooding beyond them. The exception is the single skin block wall extending over the inlet to the downstream culvert on the Tonweeroe. This structure has been included as depths are shallow and it diverts flows to the south.

Figure 5-2: Defences and walls locations



5.4 Model limitations

- **Channel blockage** - In Oughterard the culverts on the Tonweeroe watercourse look particularly prone to blockage particularly at the screen. If the culvert blocked, water would back up in the channel, before overtopping onto the field into nearby properties. Although not investigated in more detail in this model, it is likely that culvert blockage will increase flood risk to property.
- **Cascades** - The cascades on the Owenriff River are extremely steep and have been simplified into a single drop in the ISIS model. This is considered acceptable to achieve model stability and because there is no flood risk in the immediate area.
- **Swallow hole** on the Tonweeroe watercourse - There appears to be swallow hole on the Tonweeroe watercourse as flow typically seems to be greater towards the upstream end, and almost dry under normal conditions at the downstream end. This has been ignored for design event models as it is assumed the swallow hole is overwhelmed and all the design flow peak will travel down the watercourse channel.

5.5 Key flood risk mechanisms

Further to the information presented in the flood risk maps, a brief description of the key flood risk sites and flooding mechanisms is provided below.

5.5.1 Flooding upstream of N59 Bridge on left bank

In events greater than 1% AEP, the water can rise over the left bank onto the N59 Clifden Road and flow along the road parallel to the river. The road is slightly elevated above the river level but there is no consistent raised wall along here. The N59 Bridge causes elevated upstream water levels due to it constricting the flow area. However, given the river's steepness and extent the road can flood, the bridge does not solely control this elevated water level.

5.5.2 Flooding at Oughterard gauging station (Glann Road) bridge

There is flooding on the left bank around the Glann Road Bridge for extreme events greater than 0.5% AEP. The calibration runs have suggested this is primarily from water from the Tonweeroe watercourse which flows overland to this area without entering the Owenriff. There is a connection

from the Owenriff to this area but capacity of the flow route is limited as it is flowing under the channel side wall (flow in 0.1% AEP event is modelled as 0.35 m³/s).

On the right bank is a care home that sits fairly close to the river. Flooding is not modelled as impacting the care home even in the 0.1% AEP event.

5.5.3 Flooding towards Lough Corrib

At the downstream extent of the Owenriff is a wide expanse of low lying land on the fringes of Lough Corrib. This area floods much more extensively from high lake levels than from the river but there is no property at risk here. Modelling the lake levels as peaking after the river means the risk from the lake levels is included for the same return period as the fluvial results.

5.5.4 Flooding from Tonweeroe watercourse

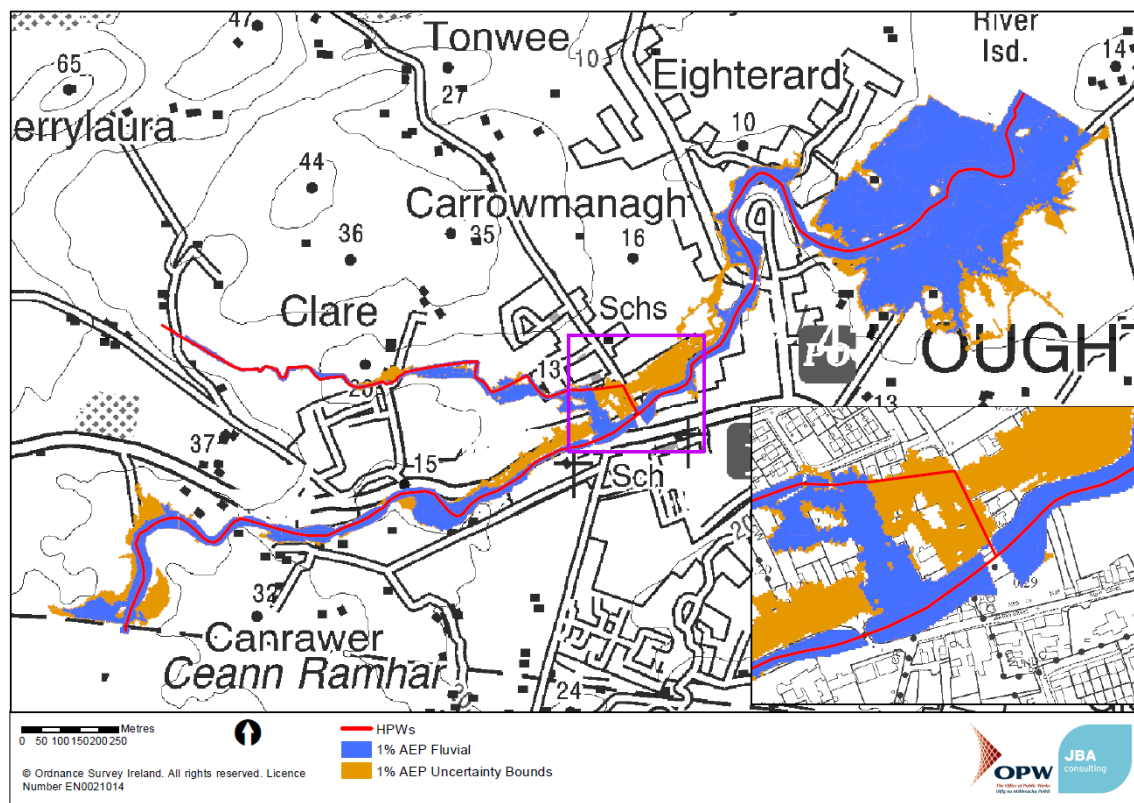
The most extensive property flooding modelled in Oughterard is associated with the Tonweeroe watercourse. The flooding appears primarily related to a small culvert along the lower reach of the watercourse, and particularly the final 130m culvert connecting to the Owenriff River that is undersized and cannot convey the design flows. Flood water flows out of the lower Tonweeroe channel towards property are initiated between the 10% and the 2% AEP event. This flooding has the potential to increase significantly in the event of culvert blockage which is fairly likely given the flat screen on the final (downstream) culvert. There is little evidence of geomorphological issues on this channel from the survey photos and no sign of siltation at the inlet of the final culvert.

The wall above the inlet to this culvert protects flooding to the properties to the west of the culvert entrance (Wall 3 in Figure 5-2). The performance of this wall as a flood defence is key in preventing flooding to properties in Abhainn na Coille and Carrowmanagh housing estates.

5.6 Sensitivity testing

Sensitivity testing was conducted to determine which variables the model was sensitive to and their respective impacts. The major increase in flood extent is seen in the magnified insert in Figure 5-3. This is primary due to the sensitivity result from the local Tonweeroe wall. This wall blocks a flow path that has the potential to flood a significant number of properties. The other increases in flood extent are as a result of the peak flow sensitivity, and the water level sensitivity at the downstream part of the Owenriff. This is an expected result due to the increase in flow and level for these tests. The building representation showed a minor increase, but was not deemed critical. The other tests showed no increase in flood extent.

Figure 5-3: 1% AEP event uncertainty bounds - Oughterard



5.7 Flood risk summary

Table 5-3: Flood risk to receptors in Oughterard

Risk Type	Receptor	Oughterard				
		10% AEP	1% / 0.5% AEP	0.1% AEP	1% AEP MRFS	1% AEP HEFS
Social	Residential property	0	4	21	4	7
	School	0	0	0	0	0
	Health centre	0	0	0	0	0
	Nursing home	0	0	0	0	0
	Public residential care home	0	0	0	0	0
	Social infrastructure	0	0	0	0	0
	Hospital	0	0	0	0	0
	Gardai station	0	0	0	0	0
	Fire station	0	0	0	0	0
	Civil defence HQ	0	0	0	0	0
	Social amenity sites	Not at Risk	Not at Risk	At Risk	Not at Risk	At Risk
Environment	IED / IPPC sites	0	0	0	0	0
	WFD Annex IV sites	At Risk	At Risk	At Risk	At Risk	At Risk
	NHAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
	pNHAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
	SACs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
	SPAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
Cultural heritage	National monument	0	0	0	0	0
	UNESCO heritage site	0	0	0	0	0
	Museum/ gallery	0	0	0	0	0
	NIAH building	0	0	0	0	0
Economy	Airport	0	0	0	0	0
	Train station	0	0	0	0	0
	Railway line (km)	0.00	0.00	0.00	0.00	0.00
	National roads (km)	0.00	0.00	0.00	0.00	0.00
	Water treatment plant	0	0	0	0	0
	Utilities	0	0	0	0	0
	Commercial building	0	0	2	0	1

6 Tuam

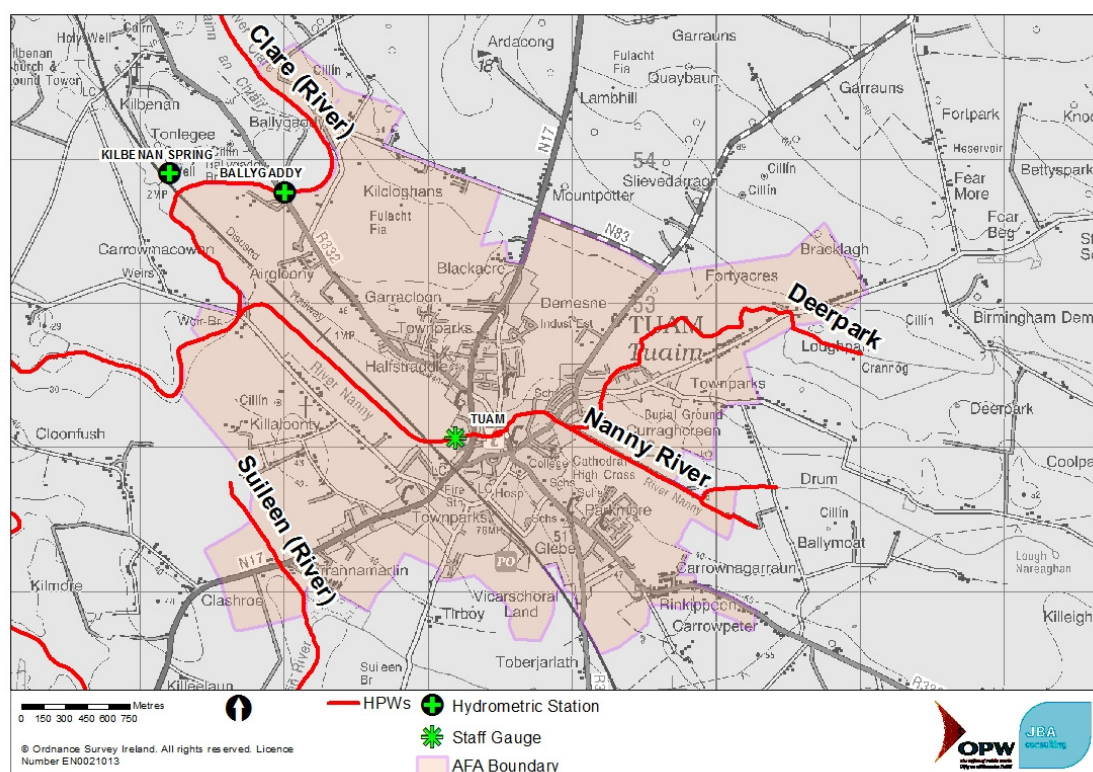
6.1 Watercourse and catchment overview

Three hydraulic models have been created for the Tuam AFA. One of these is of the River Clare which flows along the outskirts of the town. There is a gauge present at the upstream end of Clare River, Ballygaddy, with flood peak data from 1974. The River Clare is a large watercourse with extended floodplains. There has been historical flooding from the River Clare. Both upstream and downstream of the Clare HPW model at Tuam the River Clare is modelled as MPW.

The second model consists of the River Nanny and its tributaries; the Nanny Upper and Deerpark. These water courses flow through the AFA and Tuam town centre. There are many hydraulic structures in the centre of Tuam. These watercourses are much smaller than the River Clare and have no history of flooding. The River Nanny flows into the Clare River downstream of the Ballygaddy gauging station.

The last model is that of the Suilleen, a small watercourse to the South of the AFA. This watercourse flows into the River Clare downstream of the AFA. There is no evidence of historical flooding from this watercourse.

Figure 6-1: Tuam AFA catchment overview



6.2 Flood history

Further details on the flood history of the town can be found in the AFA specific modelling report and the Hydrology and Inception Reports. There have been reports of flooding within the Tuam AFA in 1950, 1991, 1995, 1999, 2002, 2005 and 2009. This flooding is mainly from the River Clare. There have also been some reports of flooding of the River Nanny along its downstream reach. This may be caused from the Clare River backing up into the Nanny floodplain.

6.3 Existing defences and walls

No formal or informal effective defences were identified within the AFA. Ten informal ineffective structures were identified within the AFA along the banks of the River Nanny, one along the banks its upper tributary and three along the banks of the Deerpark watercourse respectively. These

structures are not assumed to function as flood defences and are either bypassed in the model or have been removed to allow flooding beyond them.

6.4 Model limitations

- Hydrology - The Nanny and Suileen models are based on hydrology derived without direct gauge data in their respective catchments, compared with the River Clare which has a flow gauge on it. The combination of events on the different watercourses has not been directly modelled. The River Clare is a much larger river system than the Suileen or Nanny so we are not expecting joint events to occur.
- Channel blockage - In Tuam the culverts along the Nanny watercourse look particularly prone to blockage. If one of the culverts did block water would back up in the channel, before potentially causing flooding. However, detailed investigations of blockage and debris build-up have not been undertaken within the scope of the CFRAM.

6.5 Key flood risk mechanisms

Further to the information presented in the flood risk maps a brief description of the key flood risk sites and flooding mechanisms is provided below.

6.5.1 River Nanny and its tributaries

During the 0.1% AEP event properties on the right bank downstream of Shop Street are at risk of flooding from the River Nanny. Downstream of the Garda station on Abbey Trinity Road there is flooding on the right bank during the 1% and 0.1% AEP events. The extent of flooding in this area is constrained by the right bank of the land drain.

There is limited flooding on the downstream reach of the River Nanny from the River Nanny itself. Historically there has been flooding in this area but it is modelled as arising from the River Clare.

There is a large area of flooding on left bank of the Deerpark watercourse just upstream of its confluence with the River Nanny. The majority of this flooding is a result of a low point on the left bank between cross sections 30DEER00031 and 30DEER00025. In the 1% AEP event, flow from the Deerpark River is diverted to the River Nanny via this floodplain. No properties are affected from flooding in this area.

Further upstream where the Deerpark watercourse flows under Bothar na Greanna, properties are predicted to be at risk of flooding in the 0.1% AEP event.

6.5.2 Clare River

The Clare River is low lying and flooding is predicted along the majority of its reach on the left and right bank for flows as low as the 50% AEP event. In the 0.1% AEP event 18 properties are predicted at risk of flooding, on the left bank upstream of the Ballygaddy gauging station. In the 0.5% AEP event only one of these 18 properties is predicted at risk of flooding.

Flow from the Clare River inundates the flood plains of the Kilbenan river and the Nanny river during the Q2 event and greater. Although no properties within the AFA are predicted to be a risk of flooding along these flood plains up to the 0.5% AEP event, approximately 58 properties on the left bank of the river Nanny are predicted to be a risk of flooding in the 0.1% AEP event.

6.5.3 Suileen River

There is some flooding on the right and left bank of the Suileen water course in the Tuam AFA. There are not properties in the areas predicted to flood.

6.6 Sensitivity testing

Sensitivity testing was conducted to determine which variables the model was sensitive to and their respective impacts.

On the River Clare, Nanny, the results of the sensitivity testing show the peak flow is the greatest uncertainty associated with this model and the test produces the largest extent in all locations. The River Suileen also shows some sensitivity to peak flow, particularly in the 1% AEP event, and is also sensitive to the water level boundary at the downstream end.

Figure 6-2: 1% AEP fluvial uncertainty bound for the River Clare - Tuam AFA

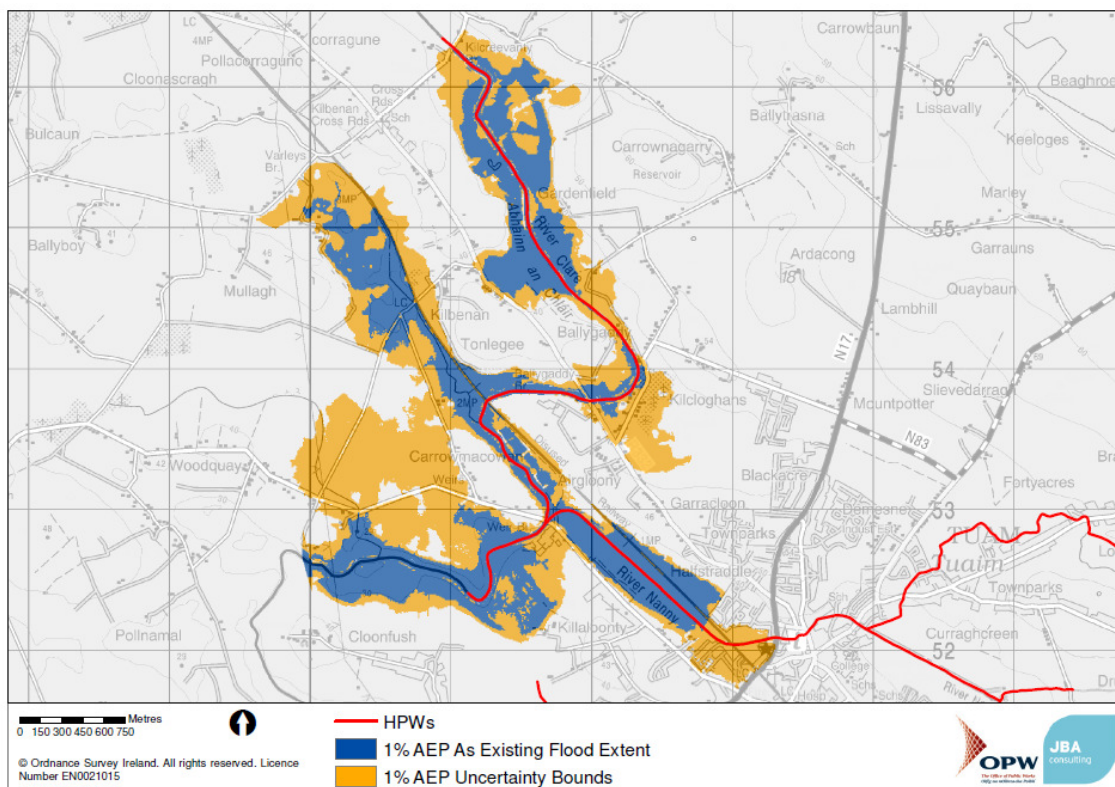


Figure 6-3: 1% AEP fluvial uncertainty bound for the River Nanny - Tuam AFA

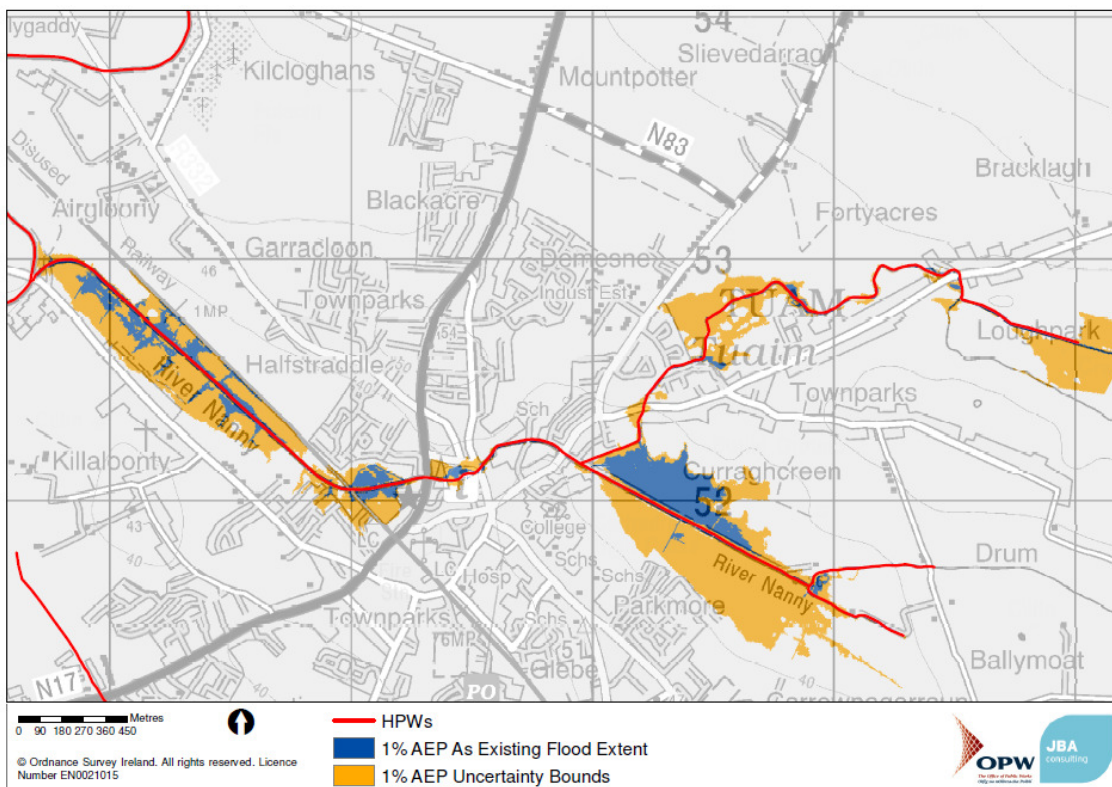
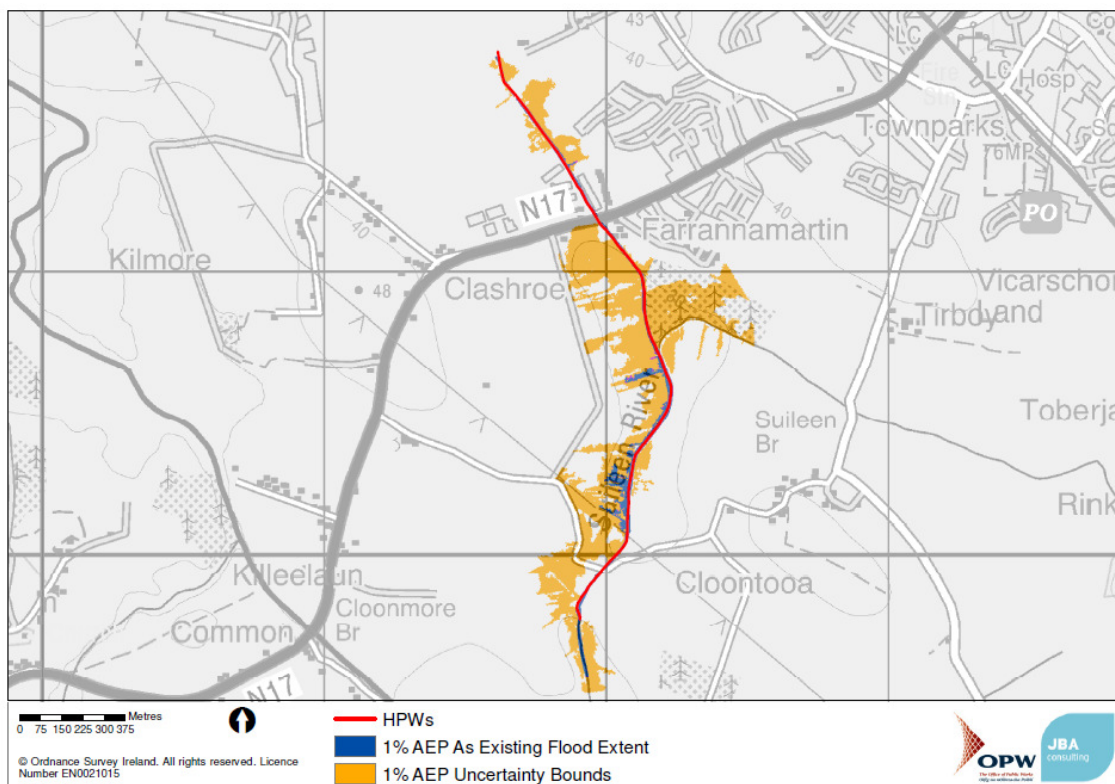


Figure 6-4: 1% AEP fluvial uncertainty bound for the River Suileen - Tuam AFA



6.7 Flood risk summary

Table 6-1: Flood risk to receptors in Tuam

Risk Type	Receptor	Tuam				
		10% AEP	1% / 0.5% AEP	0.1% AEP	1% AEP MRFS	1% AEP HEFS
Social	Residential property	0	0	92	4	38
	School	0	0	0	0	0
	Health centre	0	0	0	0	0
	Nursing home	0	0	0	0	0
	Public residential care home	0	0	0	0	0
	Social infrastructure	0	0	0	0	0
	Hospital	0	0	0	0	0
	Gardai station	0	0	0	0	0
	Fire station	0	0	0	0	0
	Civil defence HQ	0	0	0	0	0
	Social amenity sites	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
Environment	IED / IPPC sites	0	0	0	0	0
	WFD Annex IV sites	At Risk	At Risk	At Risk	At Risk	At Risk
	NHAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
	pNHAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
	SACs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
	SPAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
Cultural heritage	National monument	1	1	1	1	1
	UNESCO heritage site	0	0	0	0	0
	Museum/ gallery	0	0	0	0	0
	NIAH building	0	0	0	0	0
Economy	Airport	0	0	0	0	0
	Train station	0	0	0	0	0
	Railway line (km)	0.00	0.69	1.61	1.03	1.19
	National roads (km)	0.00	0.00	0.00	0.00	0.00
	Water treatment plant	0	0	0	0	0
	Utilities	0	0	1	1	1
	Commercial building	0	1	9	3	3

7 Roundstone

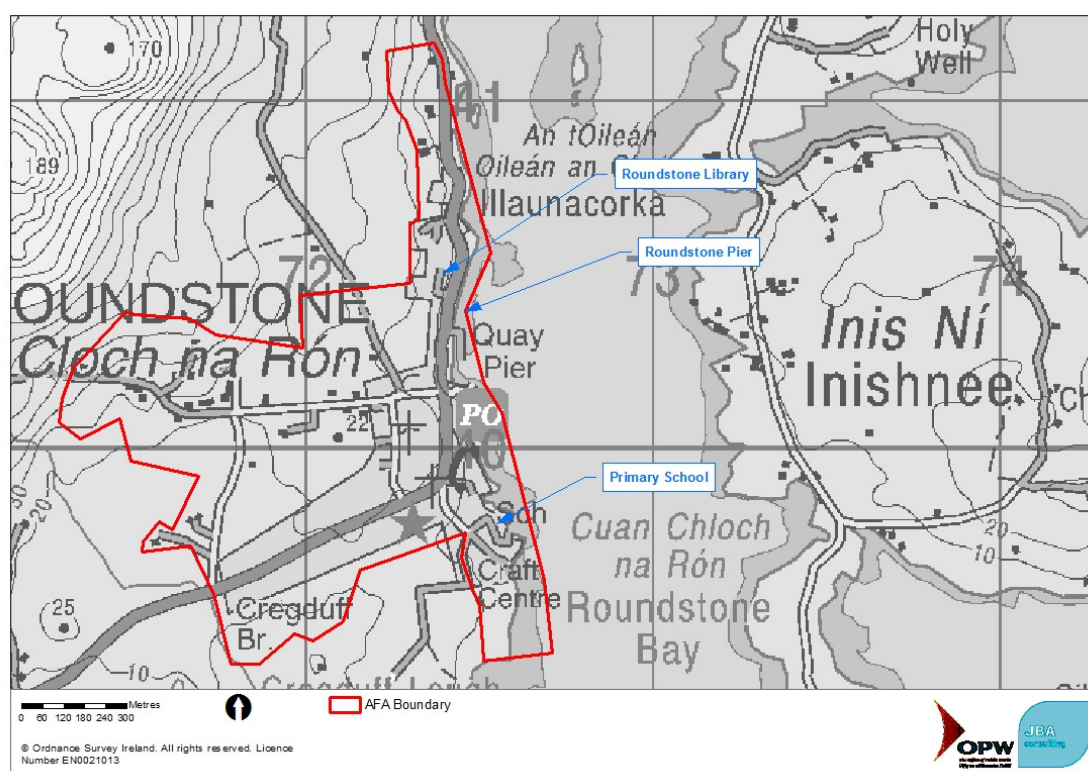
7.1 Watercourse and catchment overview

Roundstone has a coastline of approximately 1.8km within the boundaries of the AFA. The key areas of flood risk within the AFA are properties in the centre of the village, particularly adjacent to the pier.

There is a quay wall that extends north from the pier along the R341 to the outskirts of the village. The ground elevation along the pier is approximately 3.00mOD Malin. The elevation increases to approximately 5.00mOD on the R341 behind the quay wall. The quay wall provides some protection to seaward properties. However, the wall is of old, masonry construction and has some gaps in it. Its structural integrity could be compromised if subjected to extreme water levels. The wall's maximum crest level is 5.04mOD Malin, at the corner of the pier, before falling to a minimum of 3.19mOD Malin approximately 100m to the north. There are no bridges or culverts within the AFA that will impact upon the tidal flooding extents.

The frequency of flooding is relatively high within Roundstone. It can be as frequent as once or twice a year for the R341 road. Flooding within the village is due to a combination of high tides and storm surge, exacerbated by wave action. Floor levels have been raised in properties adjacent to the southern jetty in the centre of the village. Critically, the same cannot be said of the properties directly behind the quay wall in the north of the village.

Figure 7-1: Roundstone AFA catchment overview



7.2 Flood history

Further details on the flood history of the town can be found in the AFA specific modelling report and the Hydrology and Inception Reports. A summary of known flood events is provided below.

Table 7-1: Flood history summary in Roundstone

Area affected	Main flood mechanisms	Recorded flood event date	Use in model check
Roundstone Quay	High tides	January 2014	Sensibility checking of model
Roundstone Quay	High tides	2012	Background information

Area affected	Main flood mechanisms	Recorded flood event date	Use in model check
Roundstone Quay	High tides	Recurring	Corroborates 2014 validation run
R341 (North AFA)	High tides	Recurring	Corroborates 2014 validation run
Monastery Road	High tides	Recurring	Corroborates 2014 validation run

7.3 Existing defences and walls

No formal effective defences were identified within the AFA. However the quay wall present in the village was identified as being an informal effective defence, despite being of low structural integrity. No informal ineffective structures were identified within the AFA.

Figure 7-2: Roundstone Quay Wall



7.4 Model limitations

- Gap in quay wall - Due to model stability and limitations of the grid resolution, the gap has been modelled as a 2m wide opening but is approximately 1m wide in reality. Given the small area that fills behind the wall, the water level across the wall will equalise at the event peak making the size of gap less significant. The impact of this change was also investigated and documented through the sensitivity testing.

7.5 Key flood risk mechanisms

Further to the information presented in the flood risk maps, a brief description of the key flood risk sites and flooding mechanisms is provided below.

7.5.1 Flooding at Roundstone pier and quay wall

The model shows that flooding within the village begins with flow coming up through the gap in the quay wall onto the R341 road. The northern extent of the village is at particular risk and this has been confirmed by the flooding on the 3rd of January 2014. In the 0.1% AEP event, there are approximately 11 different properties at risk. The wall in front of these properties is also bypassed from the north.

7.5.2 Flooding at Roundstone National School

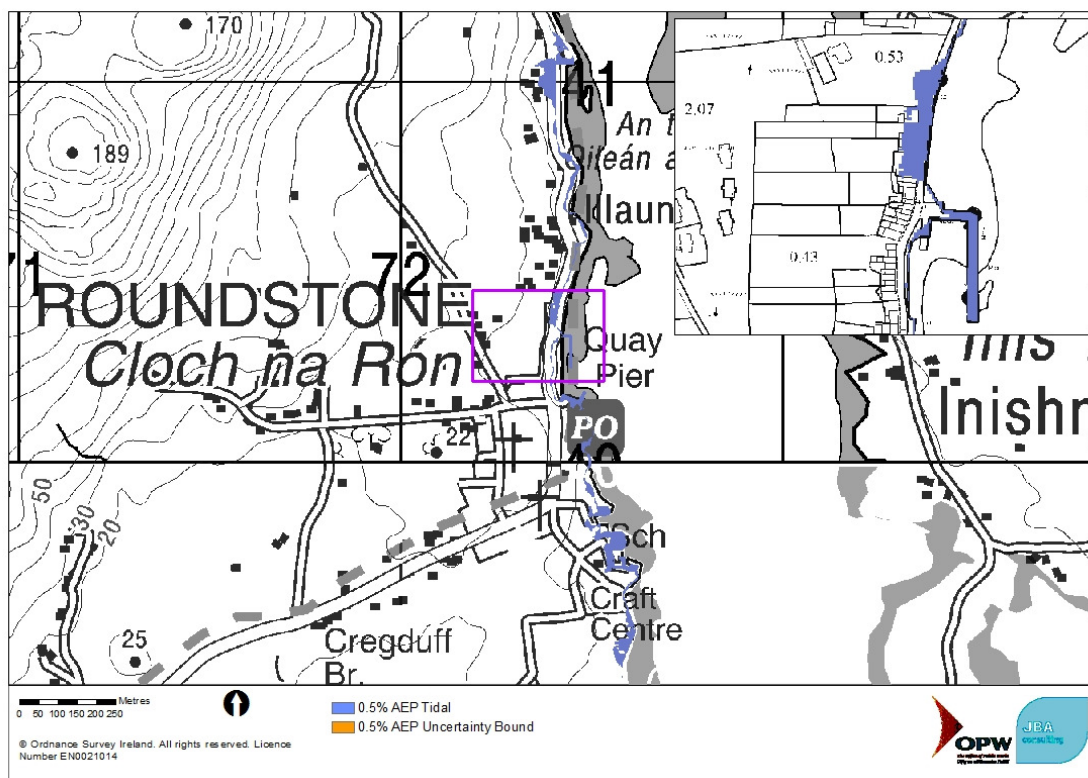
Although the Roundstone National School was not seriously affected in January 2014, risk is likely to be more significant in larger events and particularly in the MRFS and HEFS scenarios. Risk in this location is solely dictated by elevated water levels.

7.6 Sensitivity testing

Sensitivity testing was conducted to determine which variables the model was sensitive to and their respective impacts. Upon conducting these tests it was determined that the model was not sensitive to the adjustment of the various parameters. The reason is that the model simply runs

the design water level to a particular contour on the DTM. This process is not affecting by changing the parameters as they are not variables. Closing of the gap in the quay wall transfers the point at which flow makes land further north along the R341.

Figure 7-3: 0.5% AEP tidal event uncertainty bounds - Roundstone AFA



7.7 Flood risk summary







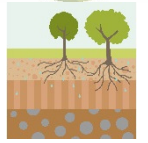
























Table 7-2: Flood risk to receptors in Roundstone





































Risk Type	Receptor	Roundstone				
		10% AEP	0.5% AEP	0.1% AEP	0.5% AEP MRFS	0.5% AEP HEFS
Social	Residential property	0	2	9	24	31
	School	0	0	0	1	1
	Health centre	0	0	0	0	0
	Nursing home	0	0	0	0	0
	Public residential care home	0	0	0	0	0
	Social infrastructure	0	0	0	0	0
	Hospital	0	0	0	0	0
	Gardai station	0	0	0	0	0
	Fire station	0	0	0	0	0
	Civil defence HQ	0	0	0	0	0
	Social amenity sites	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
Environment	IED / IPPC sites	0	0	0	0	0
	WFD Annex IV sites	At Risk	At Risk	At Risk	At Risk	At Risk
	NHAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
	pNHAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
	SACs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
	SPAs	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Not at Risk
Cultural heritage	National monument	0	0	0	0	0
	UNESCO heritage site	0	0	0	0	0
	Museum/ gallery	0	0	0	0	0
	NIAH building	0	0	0	0	0
Economy	Airport	0	0	0	0	0
	Train station	0	0	0	0	0
	Railway line (km)	0.00	0.00	0.00	0.00	0.00
	National roads (km)	0.00	0.00	0.00	0.00	0.00
	Water treatment plant	0	0	0	0	0
	Utilities	0	0	0	0	0
	Commercial building	0	0	2	5	5

8 UoM Summary

The table below summarises flood risk to the AFAs within UoM30-31.

Table 8-1: Summary of flood risk to AFAs

Parameter	Ballyhaunis	Corrofin	Galway City	Oughterard	Tuam	Roundstone
Primary source of risk:  Fluvial,  Coastal,  Wave overtopping  Groundwater (note, groundwater has not been assessed through the CFRAM).		 	  			
Receptors at risk in the 1% AEP fluvial or the 0.5% AEP coastal event.  Property  Infrastructure  Rural Land Use  Economic Risk  Activity At Risk  Activity Not At Risk						
Effective defences						

Parameter		AFA					
		Ballyhaunis	Corrofin	Galway City	Oughterard	Tuam	Roundstone
Current flood risk:	10% AEP						
	1%/0.5% AEP						
	0.1% AEP						
Future MRFS flood risk:	10% AEP						
	1%/0.5% AEP						
	0.1% AEP						



Registered Office

**24 Grove Island
Corbally
Limerick
Ireland**

t: +353 (0) 61 345463
e: info@jbaconsulting.ie

**JBA Consulting Engineers
and Scientists Limited**

Registration number 444752



Visit our website
www.jbaconsulting.ie

Western CFRAM Unit of Management 30 and 31

**Final Hydraulic Model Report:
Volume 1a: Hydraulic Modelling Method
Statement**

September 2016

**Office of Public Works
Trim
Co. Meath**



**WESTERN
CFRAM
STUDY**
CATCHMENT FLOOD RISK
ASSESSMENT AND MANAGEMENT

JBA Consulting

24 Grove Island
Corbally
Limerick
Ireland

JBA Project Manager

Sam Willis BSc MSc CEnv CSci MCIWEM C.WEM

Revision History

Revision Ref / Date Issued	Amendments	Issued to
Version 1.0 26/01/2014	Initial Issue	Rosemarie Lawlor
Version 2.0 12/09/2014	Responding to OPW comments	Rosemarie Lawlor
Version 3.0 11/09/2016	Final Issue	Clare Butler

Contract

This report describes work commissioned by The Office of Public Works, by a letter dated (28/07/11). The Office of Public Works' representative for the contract was Rosemarie Lawlor. Sam Willis, Elizabeth Russell, Chris Smith and Tom Sampson of JBA Consulting carried out this work.

Prepared Sam Willis BSc MSc CEnv CSci MCIWEM C.WEM
 Elizabeth Russell BSc MSc CEnv MCIWEM C.WEM
 Reviewed by Chris Smith BSc PhD CEnv MCIWEM C.WEM MCI
 Jonathan Cooper BEng MSc DipCD CEng MICE MCIWEM C.WEM MIO

Purpose

This document has been prepared as a draft report for The Office of Public Works. 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.

JBA Consulting has no liability regarding the use of this report except to the Office of Public Works.

Copyright

Copyright – Copyright is with Office of Public Works. All rights reserved. No part of this report may be copied or reproduced by any means without the prior written permission of the Office of Public works.

Legal Disclaimer

This report is subject to the limitations and warranties contained in the contract between the commissioning party (Office of Public Works) and JBA.

Carbon Footprint

A printed copy of the main text in this document will result in a carbon footprint of 140g if 100% post-consumer recycled paper is used and 178g if primary-source paper is used. These figures assume the report is printed in black and white on A4 paper and in duplex.

JBA is aiming to achieve carbon neutrality.

Contents

Legal Disclaimer	ii
1 Introduction	1
1.1 Scope of report	1
1.2 Report overview	1
1.3 Study background	2
1.4 Geometric data	3
2 Fluvial hydraulic modelling	5
2.1 Modelling approaches	5
2.2 1D model development	6
2.3 2D model development	10
3 Coastal hydraulic modelling	14
3.1 Modelling Approach	14
3.2 Coastal model development	14
3.3 Wave overtopping	14
4 Defence modelling	17
4.1 Classification and modelling of raised structures adjacent to watercourses	17
4.2 Undefined modelling	18
4.3 Breach analysis	19
5 Model calibration and sensibility checking	20
5.1 Objectives and categorisation	20
6 Application of hydrology	21
6.1 Hydrological estimation points	21
6.2 Application of design flow estimates	21
7 Sensitivity testing	24
7.1 Screening	24
7.2 Sensitivity analyses	25
7.3 Joint probability analysis	29
7.4 Sensitivity testing results	29
8 Model outputs and mapping	30
8.1 Model run scenarios and design events	30
8.2 Flood hazard mapping	30
8.3 Long section plots	31
8.4 Presentation of uncertainty	31
8.5 Flood risk maps	32

List of Figures

Figure 1-1: HPW and MPW modelled watercourses within UoM 30 and 31	3
Figure 2-1: Schematisation of cross sections in a typical MPW model	5
Figure 2-2: Schematisation of a typical HPW model	6
Figure 2-3: Typical section of a weir within bank	9
Figure 8-1: Sensitivity run example outputs	32

List of Tables

Table 1-1: AFAs within the UoM	2
Table 1-2: Shortlist of culverts for CCTV survey	4
Table 2-1: Cross section survey label structure suffix codes	7
Table 2-2: Typical roughness values for river channels	8
Table 2-3: Typical roughness values for river banks	8
Table 2-4: 2D model floodplain roughness values	12
Table 2-5: Overtopping spill coefficients	13
Table 4-1: Ineffective structure classifications	17
Table 4-2: Breach analysis screening results	19
Table 7-1: Sensitivity tests	24
Table 7-2: Flow sensitivity test scoring mechanism	25
Table 7-3: Flow sensitivity scaling factors	25
Table 7-4: Roughness bounds for river channels	26
Table 7-5: Roughness bounds for river banks	26
Table 7-6: Roughness bounds for floodplain surfaces	26
Table 7-7: Flood duration multipliers for flow volume sensitivity test	27
Table 7-8: Coefficients for contraction and expansion head losses	28
Table 7-9: Roughness bounds for culverts	28
Table 8-1: Allowances for future scenarios	30
Table 8-2: Flood mapping requirements	30
Table 8-3: Risk map receptors	32

Abbreviations

AEP	Annual exceedence probability
AFA	Area for further assessment
AMAX	Annual maximum
CFRAM	Catchment flood risk assessment and management
DAD	Defence asset database
DAS	Defence asset survey
DEM	Digital elevation model (Includes surfaces of structures, vegetation, etc)
DTM	Digital terrain model ('bare earth' model; does not include surfaces of structures, vegetation, etc
ESTRY	One-dimensional model from the TUFLOW suite
FRISM	Flood risk metrics (a flood risk tool developed by JBA)
FRMP	Flood risk management plan
FRR	Flood risk review
FSR	Flood studies report
FSU	Flood studies update
GIS	Geographical information system
HEFS	High-end future scenario
HEP	Hydrological estimation point
HPW	High priority watercourse
HWA	Hydrograph width analysis
IBIDEM	Interactive bridge invoking the design event method
ICPSS	Irish coastal protection strategy study
ISIS	One-dimensional hydraulic modelling software
LA	Local authority
LIDAR	Light detection and ranging
mOD	Metres above Ordnance datum (unless stated this refers to the Malin datum)
MPW	Medium priority watercourse
MRFS	Mid-range future scenario
NDHM	National digital height model (a DTM by Intermap)
OSi	Ordnance Survey Ireland
PFRA	Preliminary flood risk assessment
Q(T)	Flow for a given return period
QMED	Median annual flood, used in FSU methods
SAAR	Standard annual average rainfall
SoP	Standard of protection (in relation to flood defences)
T	Return period, inverse of AEP
Tp	Time to peak
TUFLOW	Two-dimensional hydraulic modelling software

UoM Unit of Management

* Asterisks at the end of a cross section label denotes interpolated model cross sections

1 Introduction

1.1 Scope of report

This report details the generic hydraulic modelling methodologies applied in the modelling phase of the Western Catchment-Based Flood Risk Assessment and Management Study (WCFRAM). The report is therefore applicable for all Areas for Further Assessment (AFAs) within Unit of Management (UoM) 30-31, Corrib and Owengowla, but in general does not go into detail regarding the specifics associated with a given AFA. Modelling assumptions specific to an AFA are discussed in the relevant AFA modelling reports.

The report covers the overall hydraulic modelling processes from model build through to the development of design runs.

Whilst it has been necessary to develop a general methodology for the hydraulic models across the WCFRAM to ensure consistency, it is not possible to pre-empt the approach required at all locations. This document does therefore not preclude changes to the approaches, which are applied at an AFA level where appropriate. Where local knowledge justifies an alternative approach, this will be reported in the AFA modelling report. However, the AFA reports do not duplicate the generic methodology detailed in this report.

1.2 Report overview

This report is one of a series which describe the work undertaken as part of the CFRAM, and together they provide a description of the approach taken to identifying flood risk, and a discussion of the results of the analysis and potential flood management measures, where they are appropriate.

This report should be read in conjunction with the following supporting documents:

- Western CFRAM UoM30-31 Hydrology Report¹
- Western CFRAM UoM30-31 Inception Report²
- Western CFRAM Flood Risk Review Report³
- Western CFRAM SEA Scoping Report⁴
- Western CFRAM Defence Asset Database: Handover Report and accompanying database files⁵

The reports in the suite for the Hydraulic Modelling are:

- Western CFRAM UoM30-31 - Hydraulic Modelling Report
- Western CFRAM UoM30-31 - Hydraulic Modelling Report: Volume 1a – Hydraulic Modelling Method Statement (this report)
- Western CFRAM UoM30-31 - Hydraulic Modelling Report: Volume 1b – Hydromorphology and Coastal Erosion Assessment
- Western CFRAM UoM30-31- Hydraulic Modelling Report: Volume 2 – AFA Modelling Report (for example – 2a - Ballyhaunis AFA Modelling Report)
- Western CFRAM UoM30-31- Hydraulic Modelling Report: Volume 3 – Flood Risk Maps (for example - 3a Ballyhaunis Flood Risk Maps)
- Western CFRAM UoM30-31- Hydraulic Modelling Report: Volume 4a – Hydraulic Model and Check File (for example - 4a Ballyhaunis Hydraulic Model and Check File)

The letter code associated with the deliverables in Volumes 2, 3 and 4 will be consistent for a given AFA, so in the example above the letter 'a' applies to the Ballyhaunis AFA. Volume 4 is

¹ JBA Consulting (2014), Western CFRAM Unit of Management 30 and 31 – Corrib and Owengowla Hydrology Report, Final Report, Office of Public Works

² JBA Consulting (2012), Western CFRAM Unit of Management 30-31 – Corrib and Owengowla Inception Report, Final Report, Office of Public Works.

³ JBA Consulting (2012), Western CFRAM Flood Risk Review, Final Report, Office of Public Works.

⁴ JBA Consulting (2013), Western River Basin District Catchment-based Flood Risk Assessment and Management (CFRAM) Strategic Environmental Assessment, Scoping Report, Office of Public Works.

⁵ JBA Consulting (2013), Western CFRAM Defence Asset Database, Handover Report, Office of Public Works.

the technical output from the study and will only be available on request from the Office of Public Works.

The AFAs covered by this report, and the corresponding models, are listed in Table 1-1

Table 1-1: AFAs within the UoM

UoM	Model type: Fluvial, Coastal (with Wave Overtopping), MPW, Undefended, Breach	AFA / MPW code	AFA / MPW name	Model codes within AFA / MPW
30	F	BLH	Ballyhaunis	D1
30	MPW	MWB	Ballyhaunis to Tuam	92
30	F	CRF	Corrofin	L1
30	F, U	GLW	Galway City	N1
30	C (WO), U	GLW	Galway City Coastal	C1
30	F	OTD	Oughterard	U1
30	F	TUM	Tuam	Y1-3
30	MPW	MWT	Tuam to Lough Corrib	90
31	C	RSN	Roundstone Coastal	C4

1.3 Study background

The Inception Report for UoM 30 and 31 was delivered in October 2012. This report consisted of a baseline review of available data and the development of the proposed methodology for the hydrological and hydraulic modelling investigations to be completed within this phase.

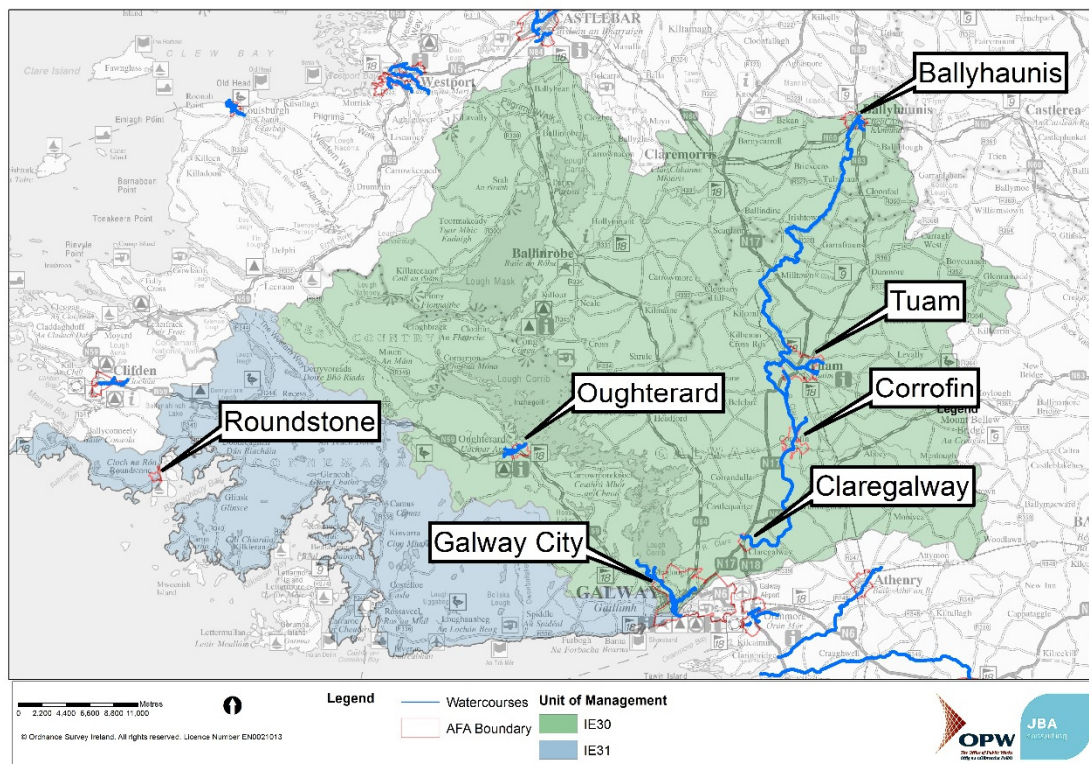
The method statement for the hydrological analysis detailed in the Inception Report has been developed and finalised in the UoM 30 and 31 Hydrology Report. This work has developed design flows at a series of Hydrological Estimation Points (HEPs) along all watercourses to be modelled. The detailed development of the hydrology has not been reiterated here and the reader is referred to the Hydrology Report for full details of the hydrological analysis. Design flows have been extracted directly from the Hydrology report and are summarised in the various editions of Volume 2, relating to the specific AFAs.

The Hydrology Report also provides guidance on the development of appropriate design storm hydrographs for each AFA for the purposes of the hydraulic modelling. These methods are summarised in this report to provide clarity on the application of the design event hydrology as this work has been undertaken in the hydraulic modelling phase.

The Inception Report identified all High Priority and Medium Priority Watercourses (HPWs and MPWs) to be modelled. HPWs are those watercourses that dictate flood risk within an AFA boundary as originally delineated within the Flood Risk Review (FRR) Report. HPWs therefore extend a short distance upstream and downstream of an AFA but do not include watercourses with catchments less than 1km². HPWs have been modelled to a greater level of detail than MPWs. MPWs are the watercourses which link two AFAs together and the watercourses that extend downstream of an AFA to the sea. Coastal AFAs do not have a downstream MPW associated with them.

In total, 56 km of HPW and 102 km of MPW have been modelled within UoM 30 and 31, along with the coastline in Roundstone and Galway City, Figure 1-1.

Figure 1-1: HPW and MPW modelled watercourses within UoM 30 and 31



1.4 Geometric data

1.4.1 Topographic Survey data

The hydraulic models have been constructed from topographic survey of the river channels and ground level survey of the floodplain.

Topographic survey has been collected as cross sections perpendicular to the direction of flow at regular intervals along watercourses and along the faces of key structures, and as spot level survey along the bank tops between cross sections. Cross sections have been surveyed at 50-100m intervals along HPWs and 500m-1,000m intervals along MPWs. The spacing of the bank top survey was 10m, with additional points collected where elevations changed by 250mm or more. No bank top survey has been collected along MPWs.

The survey data was reviewed as part the QA process for the relevant survey contract, and the review certificates were included as part of the survey report deliverables. Additional checks were undertaken as part of the model development. These included checking all structures had been surveyed, the full length of reaches had been covered and sufficient detail was surveyed on sluices and other complex structures. A comparison between surveyed levels and LIDAR has also been carried out, and is reported on in the relevant AFA modelling reports.

The main topographic survey was collected over three survey contracts and data delivered between December 2012 and June 2013. Further infill survey contracts were commissioned to collect additional survey data where it was required to supplement the three major survey contracts, as follows.

- National Survey Contract No. 6, by CCS - July 2012 - February 2013
- Western Survey Contract 1 - Maltby Land Surveys - June 2012 - October 2012
- Western Survey Contract 2 - Murphy Surveys Limited - November 2012 - July 2013
- Infill Survey Contract 4 - CCS Surveys - August 2013
- Infill Survey Contract 6 - Blom 6West - December 2013
- Infill Survey Contract 7 - Murphy Surveys - January 2014
- Infill Survey Contract 9 - 6West - May 2015

The cross section survey key plan for each model reach is included in the maps contained in Volume 3 of this report.

1.4.2 Digital terrain model

Ground level survey is available from LIDAR data for AFAs only, so covers HPWs and associated floodplains. Data has been provided in both filtered and unfiltered formats in a 2m grid resolution. The LIDAR was flown between November 2011 and August 2012. For MPWs, floodplain data has been extracted from a coarse Informar Digital Terrain Model (DTM). This is the Office of Public Work's National Digital Height Model (NDHM), flown between 2007 and 2009. This 5m resolution DTM was supplied by the Office of Public Works in 2013.

A comparison between surveyed levels and LIDAR has also been carried out, and is reported on in the relevant AFA modelling reports. In all cases, the LIDAR and survey matched to an acceptable level and no AFA scale changes were required.

1.4.3 CCTV survey

Where long and non-uniform culverts were identified along river systems, the need for CCTV survey was considered as follows:

- Is further information needed to model the culvert?
- Is this information available from other sources (design drawings or previous CCTV survey for example)?
- If a blockage occurred, would properties be at risk of flooding?
- Is connectivity between the upstream and downstream faces confirmed?
- Can sufficient additional information be gathered through a detailed engineering site visit?

Table 1-2 lists the culverts which were considered on the basis detailed above. In all cases it was determined that sufficient data was available to allow the culvert to be modelled appropriately without requiring CCTV survey.

Table 1-2: Shortlist of culverts for CCTV survey

AFA Name	Upstream Culvert XS_ID	CCTV survey commissioned
Ballyhaunis	30DEVL00011I	No
Oughterard	30TONW00016I	No
Oughterard	30TONW00019I	No
Oughterard	30TONW00037I	No
Oughterard	30TONW00040I	No

2 Fluvial hydraulic modelling

2.1 Modelling approaches

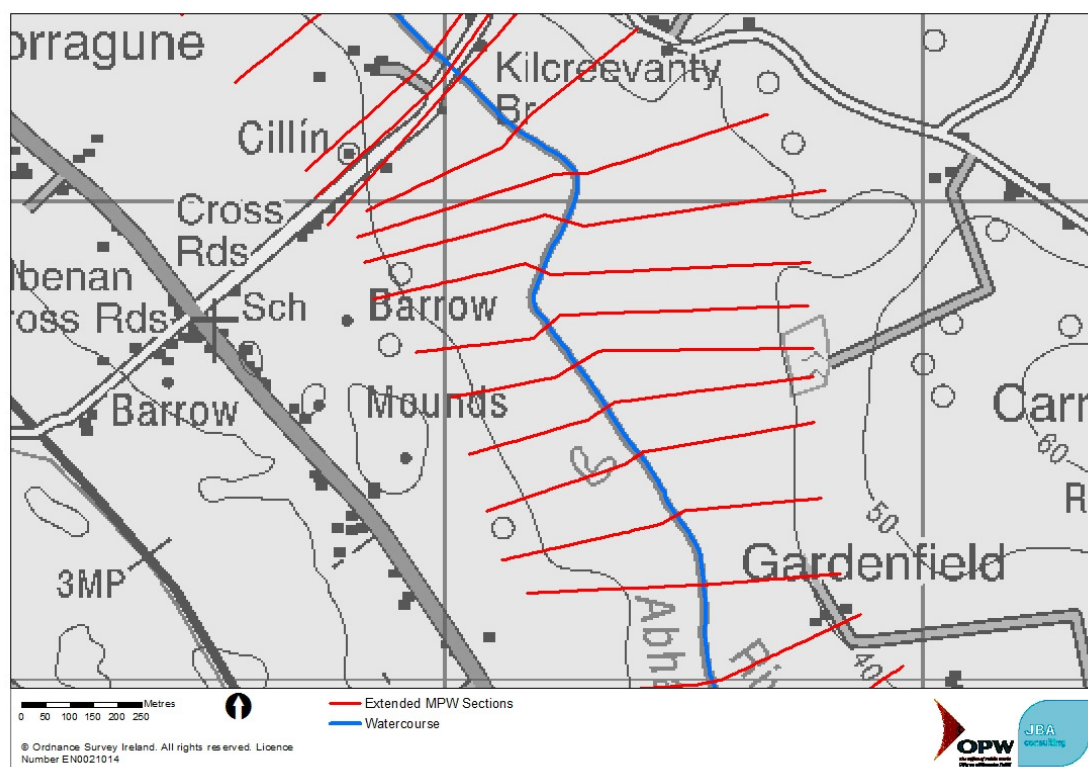
Different modelling approaches have been adopted for HPWs and MPWs. The outputs from the HPW models are to a greater level of detail and accuracy than those from MPW models, reflecting the focus of the WCFRAM study on those areas where the greatest numbers of receptors are located. This increased level of detail is reflected in the quality and quantity of the survey data collected for each watercourse and also in the modelling methodologies described below.

2.1.1 MPW models

MPW models have been constructed using only cross section survey data in the software package ISIS; this is referred to as 1 dimensional or 1D modelling. Cross sections for these models are located at 500m-1000m intervals and at key hydraulic structures, such as bridges, embankments and significant weirs. To represent inundation of the floodplain, the surveyed cross sections have been extended using data from the Infomar 5m grid.

Figure 2-1 provides an example of the combined cross sections, the surveyed sections are the elements spanning the channel, and are perpendicular to the watercourse. The extended sections are aligned so that they are perpendicular to the flow in the floodplain. This approach results in the dog leg effect along the banks of the watercourse for each cross section shown in the figure below.

Figure 2-1: Schematisation of cross sections in a typical MPW model



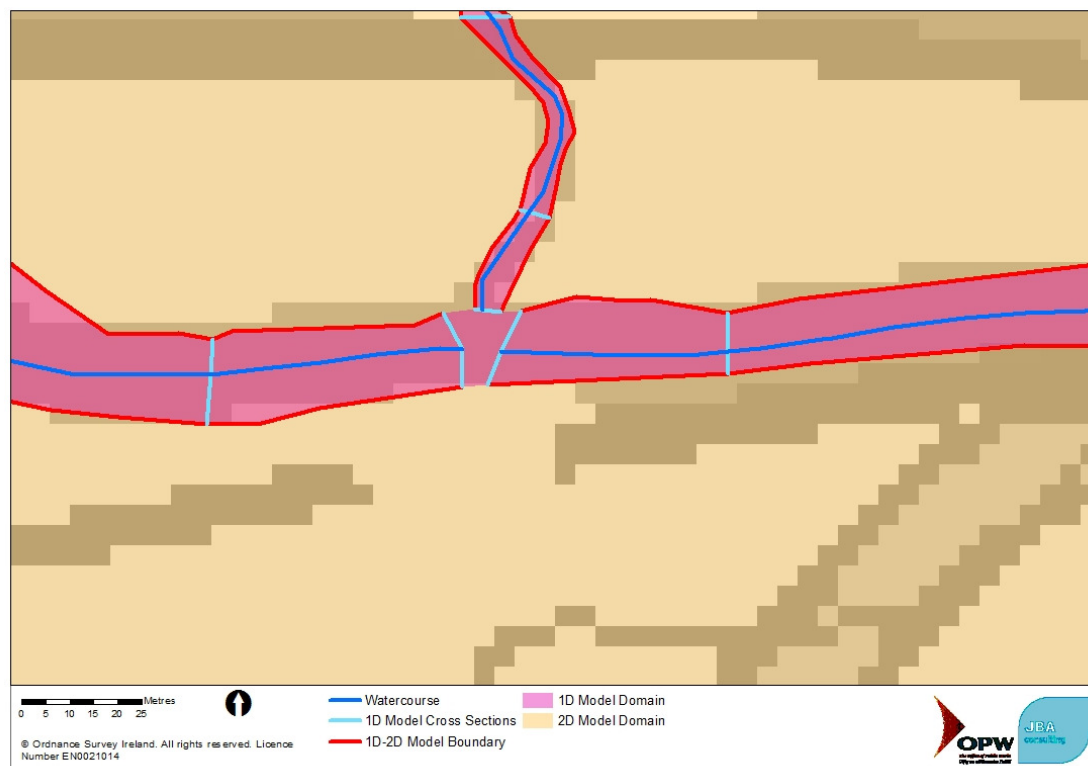
The low frequency of model cross sections and the coarse resolution of the NDHM grid result in a higher level of uncertainty associated with the MPW model outputs when compared with HPW models.

2.1.2 HPW models

HPW models have been constructed using both the cross section survey to represent the channel and the LIDAR data to represent the floodplain, rather than extended cross sections. This approach uses two software packages, ISIS and TUFLOW, and is referred to as a linked 1

dimensional and 2 dimensional (or 1D-2D) model, where 2D refers to the modelling of flow in the floodplain. Cross sections are located at approximately 50-100m intervals and at all structures; as with the MPWs, these form the basis of the 1D model. The 1D model consists of the river channel itself and generally extends to the top of the river bank. The 2D model consists of the floodplain beyond the river channel (as represented in the 1D model) and has been developed from the LIDAR data, which forms a grid of floodplain levels rather than the cross section levels used in the MPW models. Bank top survey collected along HPWs provides greater detail at the interface of the 1D and 2D models (or the river channel and floodplain flow regimes). Figure 2-2 provides an example of schematisation of a linked 1D-2D model.

Figure 2-2: Schematisation of a typical HPW model



Flood maps from the HPW models are derived from the 2D model and so the level of detail in these outputs is directly related to the accuracy of the underlying LIDAR data. The resolution and accuracy of the data in the HPW models provides significantly greater certainty in the model results compared to the MPW models. More details relating to the flood mapping methodology are provided in Section 8.

2.2 1D model development

2.2.1 Labelling system

Nodes within the model have been labelled using a 12 digit code. This is compiled from a 2 digit code detailing the UoM, a 4 letter code representing the watercourse name, a 5 digit figure representing the chainage along the watercourse from its downstream end, in units of 10m, and a single letter code representing the structure and face the section is representing. If the node is not associated with a structure the last letter code is omitted. For example 30CLAR02888 is in UoM 30 on the Clare River, is 28880m upstream from the downstream limit of the watercourse and is not representing a structure. The codes for the structure suffix are detailed in Table 2-1.

Table 2-1: Cross section survey label structure suffix codes

Identifier	Description
A	Upstream node at JUNCTION
B	Downstream node at JUNCTION
C	CONDUIT section
D	Upstream node at BRIDGE
E	Downstream node at BRIDGE
F	Upstream node at FLOODPLAIN section
G	Downstream node at FLOODPLAIN section
H	Upstream node at CULVERT BEND
K	Downstream node at CULVERT BEND
I	Upstream of CULVERT INLET
J	Downstream of CULVERT OUTLET
L	Lateral SPILL on left bank
O	Upstream node at ORIFICE
P	Downstream node at ORIFICE
R	Lateral SPILL on right bank
S	Upstream node at a SPILL
T	Downstream node at a SPILL
W	Upstream node at a WEIR
X	Downstream node at a WEIR

In general as part of the modelling process, identifier labels from the survey which are associated with the channel cross section at a structure have been moved to the structure unit itself within the ISIS model, and the open channel has lost the structure suffix code. For consistency, a junction unit has been included in the model between all river units and structures. The river unit adjacent to a structure in the model will therefore have a junction identifier rather than the structure identifier. For example, at the upstream face of a bridge the surveyed cross section was supplied with a D suffix; within the model, the D suffix is associated with the bridge unit, a junction inserted and an A suffix added to the cross section.

For interpolates, due to limited space in the software for labels, the UoM code has been removed, the correct chainage detailed, and an asterisk (*) appended. This allows for situations with more than one interpolate section in a 10m reach. An example of where this would occur is at culverts of less than 10m length: these require an upstream and downstream conduit unit, which without the proposed changes would have the same label. Conduit units that have the same chainage in the survey have had the UoM code removed, the correct chainage detailed and a C identifier added (BRUS002304C).

2.2.2 Hydraulic Roughness

In both HPW and MPW models, the hydraulic roughness within the 1D model has been appraised over three panels across the channel as follows:

- Left bank – from left bank top (or end of model left bank section) to a typical water level
- Channel bed – typically inundated part of cross section
- Right bank – from right bank top (or end of model right bank section) to a typical water level

For MPW models, the roughness applied for left and right bank panels typically includes the full width of the floodplain. This approach is considered suitable given the low resolution nature of the MPW models.

The determination of initial suitable hydraulic roughness values for each watercourse was based upon a combination of survey photographs, notes on survey drawings and observations from site visits. Reaches of similar roughness were identified and values reflective of these reaches extracted from published tables, summarised in Table 2-2 and Table 2-3. The majority of critical storms are expected to be winter storm and high roughness values based on summer vegetation in these instances are not considered to be appropriate. The assessment has therefore focused on the more permanent vegetation on banks, e.g. bushes and trees, when determining values.

Further adjustments to hydraulic roughness have been made where calibration data is sufficient to justify variations away from the quoted values.

Table 2-2: Typical roughness values for river channels⁶

Channel substrate	Typical value (Manning's n)
Bedrock	0.025
Cobbles (64-256mm)	0.055
Coarse Gravel	0.035
Gravel (2-64mm)	0.03
Sands	0.025
Silt	0.022
Clay	0.02
Concrete	0.02

Table 2-3: Typical roughness values for river banks⁷

Bank material	Typical value (Manning's n)
Scrub/Long Grass	0.04
Bushes	0.06
Trees – flood level not reaching branches	0.07
Trees – flood level reaching branches	0.15

2.2.3 Hydraulic structures

The representation of hydraulic structures in all instances should be case specific and reflect the hydraulic controls at the local site. The following sections outline general principles for the representation of hydraulic structures that have been recommended to deliver consistency across all WCFRAM models. However, these are not prescribed approaches and modelling judgement has been used where these principles do not appropriately capture the key controls at a given site.

2.2.3.1 Bridges

In general, bridges have been modelled using the Bridge (Arch) unit, with the USPBR unit reserved for larger sized bridges. Head loss at surcharged bridges has been calculated using the orifice equation and so will be consistent for either bridge type.

Bridge skew has been represented by entering the angle in the unit and not by adjusting local cross section chainages manually. This is consistent with the format the survey has been delivered in, which surveyed the full face of the bridge and recorded the skew angle.

Overtopping of bridge (and culvert) structures has been modelled in a number of ways. For HPW models, out of bank bypassing of structures has been represented in the 2D model. Overtopping of structures between banks has either been represented in the 1D domain, where the structure is relatively short and flows are expected to return to the channel on the downstream face, or in the 2D domain, where the structure is larger and flows spilling over the deck may not return directly to the channel. In the latter case either no spill over the structure has been included in the 1D model, or the spill has been included but deactivated to allow sensitivity testing to be carried out.

For MPW models, the full width of the bypass route (i.e. the width of the floodplain) is included in the 1D spill over the structure.

2.2.3.2 Culverts

Culverts have generally been modelled with culvert inlets and outlets to represent head losses at the upstream and downstream limits of the structure. This reflects the methodology outlined in the Culvert Design and Operation Guide⁸. Where these units have been found to be unstable or

⁶ Simplified version of Table 10 from Reducing Uncertainty in River Flood Conveyance. Roughness Review. By Karen Fisher and Hugh Dawson. DEFRA / Environment Agency Flood and Coastal Defence R&D Programme, Project W5A-057. July 2003.

⁷ Simplified version of Table 16 and 23 from Reducing Uncertainty in River Flood Conveyance. Roughness Review. By Karen Fisher and Hugh Dawson. DEFRA / Environment Agency Flood and Coastal Defence R&D Programme, Project W5A-057. July 2003.

⁸ Culvert Design and Operation Guide, CIRIA C689, 2010.

water levels are consistently exceeding the culvert soffit then the orifice unit and equation has been considered as an alternative.

Overtopping of culverts has been modelled using the approach detailed for bridges in Section 2.2.3.1.

2.2.3.3 Weirs

Weirs have been modelled using two parallel flow routes in HPW models. The first of these represents the weir structure itself within the stream bed and the second represents the banks either side of the weir but within bank top (Figure 2-3). The purpose of this is to allow the different hydraulic efficiencies of the weir and channel sides to be appropriately represented. Out of bank flows have been modelled in the 2D domain.

The weir itself has been modelled using the relevant equation for the structure, for example broad crested, sharp or jagged weir.

Figure 2-3: Typical section of a weir within bank



Typical coefficients for a jagged spill unit used are 1.7 for a well-constructed weir, dropping to 1.3 where the weir is in a poorer state of repair. The bank side coefficients may range from 0.8 to 1.3, depending on condition and vegetation growth. The out of bank portions of the weirs through AFAs are represented in the 2d domain.

2.2.4 Model boundaries

Hydrological inflows have been located at the upstream limits of the watercourses, at un-modelled tributaries along the watercourse length and over intervening reaches where the catchment is sufficiently large for lateral inflows to contribute to the peak flow observed in the watercourse. The methodology for the application of the hydrology is specific to each hydraulic model. However, a general approach was devised and reported in the Hydrology Report; this is discussed in further detail in Section 6.2. The detailed application of the hydrology to a particular model is provided in the Volume 2 AFA Modelling Report.

Where the downstream boundary of one model forms the upstream boundary of another model, the rating relationship from the downstream model has been applied to the upstream model.

This ensures the relationship between the two models is maintained, and provides confidence that the downstream boundary is responding correctly to flood flows.

In cases where a watercourse outfalls into a lake, the boundary was developed from gauge data where available. Tidal boundaries were developed for all required sites around the WCFRAM coastline based on the ICPSS, and are reported on in the UoM30-31 Hydrology Report.

2.2.5 Siltation

The presence and impact of silt in a channel is a function of the flow velocities experienced, both under normal and extreme conditions. High flow velocities could be expected to clear the temporary build-up of sediments, but lower flow velocities allow deposition and suggest sediments are a long term issue. This understanding is supported by the hydro-geomorphological assessment which has assessed the sediment regime within the modelled watercourses. In conjunction with this information and preliminary modelling results, a screening assessment of structures where sediment build up is apparent has been completed. The approach to the hydro-morphological assessment is provided in the UoM30-31 Volume 1b Method Statement, and specific details of the impact of sedimentation and gravel movements is provided in the relevant Volume 2 Hydraulic Modelling Report.

The representation of siltation within channels has generally been modelled as surveyed. The preferential output from the survey was for hard bed levels, which excludes siltation. Where the surveyors had observed a depth of silt on the open channel bed it was noted on the survey drawing as a second bed level. This information was used in the hydro-geomorphological assessment but did not impact on the model. The exception to the use of hard bed was where bed profiles were surveyed using remote techniques, such as an echosounder. In this case, the first return was used to represent the bed profile, which may have been the surface of the silt. This was the case in deep rivers where wading was not possible. For bridges and culverts, inclusion of siltation has been approached on a case by case basis. The modeller has made a judgement on the level of siltation observed in the survey, photographs and through site visit, and has included an appropriate level of accumulation. The decisions were influenced by the type of material and level of permanence, and the likely distance the deposits extended into the culvert.

2.2.6 Blockage

The assessment and modelling of the impact of blockage of bridges and culverts, whether through natural or manmade causes was not part of the CFRAM specification. However, where the potential for blockage was noted (evidence of accumulations of debris or fly tipping for example), and where there was the potential for such blockage to be a source of flood risk to neighbouring receptors this has been noted in the Volume 2 Hydraulic Modelling Reports.

A screening assessment has also been undertaken to identify locations where historical flooding has been attributed to culvert or bridge blockage and recommendations for modelling and development of remedial measures have been made. The method for undertaking this screening is detailed in Volume 1b: Hydromorphology Method Statement.

2.3 2D model development

2.3.1 1D-2D model boundary

The hydraulic boundary between the 1D and 2D models has been situated along the crest of the river banks. Crest levels, and hence the point at which water transfers from the 1D to the 2D domain have been determined in one of three ways. In order of accuracy (and therefore preference) these are:

- Directly extracted from bank top survey - this means any low spots between sections is represented in the spill between model domains
- Interpolated between surveyed cross sections - where detailed crest survey has not been collected it is likely the crest level is relatively consistent so interpolation is appropriate

- Extraction of bank heights from LIDAR data - where there are data gaps and the LIDAR data gives sufficient detail to be incorporated, or where the modeller has determined the crest top to be in a different position than that captured in the survey.

The AFA report indicates which of the above approaches has been taken for each watercourse within the model domain.

Along HPW reaches, the surveyed cross sections extended approximately 20m from top of bank. This was to allow comparison with LIDAR and to ensure the full requirements of the modeller were met, but was longer than was required to develop the 1D model. There are two methods for 'removing' the out of bank sections of the cross section:

- Deactivation markers can be assigned in ISIS, normally in the same place as the bank marker. This means ISIS ignores the portion of the section outside the marker. However, in some versions of ISIS (pre-3.7) the out of bank elements are still displayed on the cross section plots even though they are not accounted for in the hydraulic calculations.
- Rather than using deactivation markers, the cross section can be truncated at the end of the 1D domain. This means the visualisation of the cross section in ISIS relates directly to the length over which hydraulic calculations are carried out. This approach is required in spill and structure units, where deactivation markers cannot be used.

On open channel sections, neither approach is right or wrong so the modeller has used their judgement in each case. The main advantage of the first approach is that the cross section can easily be made wider by relocating the deactivation markers and the full extent of the cross section survey data is readily available for inspection.

A number of the watercourses being modelled as part of the WCFRAM are small and narrow. In these instances it has occasionally been necessary to situate the hydraulic boundary beyond the crest of the river bank. The reason for this is that low volume channels can cause model instability or significant fluctuations in water levels when proportionately large volumes, compared to the capacity of the channel, discharge into the 2D domain; this is particularly likely to occur where these small watercourses are tidally influenced or are situated within the floodplain of much larger watercourses. In these instances the capacity of the channel has been increased in the following ways;

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

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

2.3.2 Cell size

The 2D model floodplain is represented as a ground level grid and has been constructed from the filtered LIDAR data. An appropriate grid resolution has been determined considering the size of the watercourse, floodplain complexity and model run times. The floodplains of narrow channels, or areas where complex overland flow paths may develop (such as around buildings and alleyways) are better represented with a small grid resolution, for example 2m, but model run times will increase accordingly.

The selected model cell sizes are specific to the waterbody being modelled and the resulting flood extent. Where possible, one model has been constructed per AFA but in some cases it has been necessary to construct separate models. The main reason for this is because of the requirement for different cell sizes for each watercourse. In AFAs where fluvial and coastal models have been built, cell size may also vary between domains.

Where a larger than 2m cell size has been used, this is reflective of a wide, uncomplicated floodplain and large model domain which would otherwise take a long time to run (in nearly all cases, the models developed can be run overnight). Where cell sizes greater than 2m have

been used, and there is the potential for complex flow paths to develop, the implications have been considered as part of the sensitivity testing (see Section 7.2).

2.3.3 Floodplain roughness

The complexity of the floodplain itself has been represented using a varying hydraulic roughness to represent the different surfaces apparent within the floodplain, Table 2-4. The different surface types have been derived from OSi NTF data. The data has been incorporated into the 2D model in the order listed so that coarse, wide ranging surfaces, such as woodland, do not overwrite more complex surfaces, such as roads.

Table 2-4: 2D model floodplain roughness values

2D model order	Land use type	Manning's n roughness value
1	Inland Water	0.035
2	General Natural Surfaces	0.04
3	Coniferous Trees	0.1
4	Mixed Vegetation	0.08
5	Non-coniferous Woodland	0.07
6	Rock	0.05
7	Roads and Tracks and Paths	0.015
8	General Manmade Surfaces	0.017
9	Glass Houses	0.2
10	Buildings	0.3
99	Stability patch	0.5

There are a number of different ways to represent buildings within 2D models, ranging from removing them from the floodplain entirely to allowing flow to pass through the building with reduced hydraulic efficiency, represented through Manning's n, and as described above. The baseline approach has been to represent the buildings using Manning's n, but the implications of the approach to building representation have been reviewed as part of the sensitivity analysis in Section 7.2.

2.3.4 Stability patches

Instabilities in TUFLOW are generally a result of irregularities in the underlying LIDAR ground model resulting in the transfer of large volumes of water between cells with each time step. This can result in rapidly fluctuating water levels and hence instability in the model results. There are a number of methods for overcoming TUFLOW model instabilities. One of these is to use stability patches, which are polygons that have been assigned a high (0.5) Manning's n value. The patches slow the flow of water across the local surface, thus reducing the volume of water transferred between cells with each time step. Use of these patches should be used with caution as they can potentially constrain flow and result in an under prediction of flood risk, however they may be appropriate where there are low lying dips in the topography or where elevations in the LIDAR DTM vary greatly between adjacent cells (this may be a reflection of the natural topography or processing relics). The specific use of the stability patches is explained and justified in the relevant Volume 3 Hydraulic Model Report.

2.3.5 Overtopping of structures in the main channel

Section 2.2.3.1 details those instances where overtopping of hydraulic structures will have been represented in the 2D domain. In these instances, the crest levels of the structures have been incorporated into the 2D model by modifying the floodplain grid. This is a two stage process whereby the surveyed deck level is first applied across the width of the channel over the length of the structure and then the surveyed parapet levels applied along the upstream and downstream face of the structure. The modelling of parapets at specific structures is detailed in the individual AFA hydraulic modelling reports, but in general the spill is positioned at the top of a solid parapet, but if there are railings / open parapet face the spill is at deck level. Including the top of the parapet level in the model does not indicate the structure functions as a flood defence, as they are often bypassed. Instead, this method of representing the structure ensures that the flow routes around the bridge are included. This is particularly important if the overtopping water flows away from the channel, rather than re-entering the watercourse immediately downstream of the structure. Although all bridges have been assessed structurally in the Defence Asset

Database, where the parapet has been included in the model, it has been assumed the structure is capable of withstanding the water build up.

As part of the initial model construction, all bridges and culverts were included in the model with an overtopping spill unit. This allowed water to overtop the structure and return to the 1D channel downstream where deck levels were low enough. When the 1D model was linked to the 2D domain, this bypass route could either be retained in the 1D element of the model, or represented in the 2D domain. In the case of short structures where flows would simply flow over the deck and back into the channel, the structure remained in the 1D domain, and an appropriate spill coefficient applied (Table 2-5). These coefficients are indicative only and the actual selected coefficient will represent the conditions at the site and be site specific.

If the flow paths over the structure are more complex the bridge deck has been included in the 2D domain. In this case, the ISIS spill unit is not required. In some cases the spill will have been deleted from the model, and in other cases will have been deactivated by setting the coefficient to 0.

Table 2-5: Overtopping spill coefficients

Structure description	Overtopping spill coefficient
Spill deactivated	0
Structure deck is a road/foot path less than 20m in width	Within the range 1.5 to 1.7
Structure deck is a road/foot path greater than 20m in width	Within the range 1.2 to 1.5

2.3.6 Representation of structures in the floodplain

Raised structures such as motorways and railway embankments often bisect floodplains and so dictate the extent of flooding. The exclusion of drains or bypass routes beneath these structures can result in the underestimation of flood risk on the side furthest from a watercourse and can potentially overestimate flood risk on the side nearest to the watercourse. Two alternative approaches to including such structures have been used in this modelling study.

- If the bypass routes exert no real vertical constraint on flow, for example in the case of a large underpass which will provide a flow route but will not become surcharged, then modifying the DTM with a cut line through the embankment is sufficient to simulate the flow path.
- For smaller culverts where capacity may limit flow, or where the culvert is smaller than the cell size, the structure has been incorporated into the 2D domain as a 1D ESTRY element. In such cases culvert is specified in a similar manner to the culverts described in Section 2.2.3.2.

The choice of approach in specific situations is detailed in the relevant AFA reports.

2.3.7 2D model boundaries

The 2D model domain has been extended to incorporate the full width of the active floodplain (as determined by draft model runs for extreme flood extents, and through examination of the topography). This means water generally only flows into the 2D domain from the 1D domain, across the boundary discussed in Section 2.3.1.

However, there are a number of instances where modelled flows reach the edge of the 2D domain and a standalone 2D model boundary is required; the extent of the floodplain in these areas will be dictated by this boundary, for example, where the floodplain discharges directly to the sea. In these cases, the tidal curve was applied along the length of the coastline where the floodplain is active and water discharged into the sea only when tidal levels fell below the water level in the floodplain.

3 Coastal hydraulic modelling

3.1 Modelling Approach

Coastal models have been constructed as 2D only models using TUFLOW. The model consists of the floodplain beyond the coastline and has been developed from the LIDAR data, which forms a grid of floodplain levels. Where coastal defences and walls were identified, crest level survey provided greater detail at the 2D boundary and was incorporated into the model.

3.2 Coastal model development

3.2.1 2D model boundaries

EWLs have been taken from the ICPSS Phase IV - West Coast, Predicted Extreme Water Levels Associated with Combined Tide and Surge and were used to develop design tide curves; the details of which are provided in the UoM 30-31 Hydrology Report.

The water levels were determined at intervals around the coastline, generally some distance offshore, however, in accordance with the project specification these were deemed suitable for application at the foreshore. These water levels were generally applied along the coastline as shown in the OSi 1:5,000 mapping. Exceptions to this occurred where there was a complex headland which was not fully represented in the LIDAR. In these cases, the boundary was moved out to sea by a short distance, smoothing the transition of flows across the 2D domain.

There are a number of uncertainties inherent in the translation of the offshore tide curves to the near shore, particularly where this naturally involves the propagation of the tide along an estuary, around islands or through headlands; such limitations are discussed in the relevant Hydraulic Modelling Reports, but it was outside the scope of the CFRAM to attempt to address these issues.

3.2.2 Cell size

As with the fluvial 2D model domains, the coastal floodplain is represented as a ground level grid and has been constructed from the filtered LIDAR data. An appropriate grid resolution has been determined considering the floodplain complexity and model run times; complex overland flow paths (such as around buildings and alleyways) are better represented with a small grid resolution, for example 2m, but model run times will increase accordingly.

Sensitivity testing has been carried out where cell sizes greater than 2m have been used, and there is the potential for complex flow paths to develop, (see Section 7.2).

3.2.3 Floodplain roughness

The same approach to defining Manning's n values has been applied as in the fluvial models. See Section 2.2.2 for more details.

3.2.4 Representation of structures

Flood defences and walls which occur on the coastal boundary (such as quay walls) have been included in the models as a single raised line of cells along the alignment of the defence. Where crest level survey was not available an allowance for the structure has been estimated from site photos. This is of particular importance for the wave overtopping analysis where the presence of a raised structure may prevent flows from returning to the sea, see Section 3.3. Structures in the floodplain - As with the fluvial models, floodplain structures, such as culverts below embankments, can play a significant role in causing or preventing inundation of land. Such features have been represented as ESTRUCT units in the models.

3.3 Wave overtopping

In certain locations, the coastal flooding models were developed further such that they were able to simulate flooding from wave overtopping of defences as well as from tide and surge events.

The locations were driven by the availability of wave data, which in turn was a function of the assessment undertaken through the ICWWS. Of relevance to this UoM is Galway City, which has a history of flooding caused by overtopping in the city⁹. It should be noted that other locations may be vulnerable to wave overtopping, but they were screened out of the ICWWS and have therefore not been included in the CFRAM.

Wave overtopping is a complex process controlled by the state of the sea (depth, wave properties) and the geometry of local flood defences. Wave overtopping has been calculated using EurOtop¹⁰ methods. The EurOtop manual includes different methods and associated guidelines for the prediction of wave overtopping for different structure types. For this study the Neural Network methodology was utilised, requiring the following input parameters for the calculations: still water level at the toe of the structure (coastal defence), the incident wave conditions at the toe of the defences to be overtopped, and the defence profile shape. There are some uncertainties inherent in this process such as the manual schematisation of flood defences, the initial wave heights, the storm duration and the output results being estimates of the mean overtopping discharge rather than the exact values.

The methodology for assessing wave overtopping risks followed the steps laid out below:

- Receipt of still water and wave data from the ICPSS and ICWWS
- Compilation of environmental and topographic data available
- Generate schematisations of the coastal defences
- Estimate overtopping potential for the 2, 5, 10, 20, 50, 100, 200 and 1000-year wave return period events
- Estimate overtopping potential for the present day, MRFS and HEFS
- Provide the mean overtopping discharge for a matrix of scenarios
- Apply the overtopping volumes to the coastal hydraulic model.

3.3.1 Schematisations

Each site was individually investigated for the availability of appropriate environmental and topographic data. Wave, tide, LIDAR and flood defence survey data was collated for the AFA. The suitability of these data was assessed and where necessary additional site survey was procured through the infill contracts.

Due to the history of flooding due to wave overtopping, in order to accurately perform overtopping analysis on the structures in Galway a topographic survey was conducted to determine the changes in structure types. The profiles from this survey provided greater accuracy compared to the available LIDAR data and allowed the changes in roughness and berm level to be accurately represented.

3.3.2 Wave data

Wave data was provided by OPW from the Irish Coastal Wave and Water Level Modelling Study (ICWWS). The wave data was calculated at specific depths using both wind and swell waves. For the analysis these wave heights are used in a depth limited calculation relative to the individual profiles of the coastal defences. For each return period the wave data was provided with six joint probability combinations of water level and wave height for both the wind wave and swell wave components. To find the worst case wave overtopping at each location the wave overtopping calculations were performed for all joint probability scenarios for each return period.

Overtopping calculations were performed for the following scenarios;

- 2 x Sea states: wind and swell waves;
- 6 x Joint probability combinations of water level and wave height;
- 3 x Climate change scenarios (as defined by the ICWWS): Current, Mid-range Future Scenario (MRFS) and High End Future Scenario (HEFS);
- 8 x Return periods: 2, 5, 10, 20, 50, 100, 200 and 1000-year wave events, and

⁹ Galway City Council (2012) "SEA Environmental Report of Galway City Development Plan," 2011- 2017

¹⁰ EurOtop (2010) "Wave Overtopping of Sea Defence and Related Structures: Assessment Manual", Overtopping Course Edition, November 2010. HR Wallingford.

- A design storm surge shape.

3.3.3 Worse case overtopping scenario

Overtopping calculations were performed for all joint probability combinations of water level and wave height. This combined the scenarios described in Section 3.3.2 (i.e. $8 \times 3 \times 6 \times 2 = 288$ scenarios), and the worst case i.e. the highest overtopping volume was selected for each return period at each of the schematised overtopping profiles, was extracted. For input into the flood inundation models the wave overtopping was therefore a composite of the worst case overtopping at each individual defence which may be made up of a number of different combinations of water level and wave height within each return period. Overtopping volumes of less than 0.03l/s/m were considered negligible and so were not included in the flood inundation models.

For each profile through the defence overtopping volumes were generated for the present day, MRFS and HEFS. The wave overtopping conditions were provided every 15 minutes for the duration of overtopping over the peak of one tidal cycle, for each of the different return periods.

3.3.4 Modelling overtopping

Flood risk in the wave overtopping models is driven by both the still water level and the wave overtopping volume associated with the worst case joint probability scenario. These scenarios are represented in the model using two boundary lines, the existing boundary line from the coastal models, which is located a short distance off shore, is used for the still water level, and an additional series of boundary lines, located on the landward side of the coastal defences, are used to add the wave overtopping volumes for each defence profile assessed.

For most return periods in Galway City and Roundstone, the still water level from the joint probability scenario is lower than the typical crest level of the coastal defences. Where this is the case, no tidal boundary has been applied in the model as no overtopping due to the still water levels would occur, and the modelled flood risk extents are attributable to wave overtopping only. In the limited number of scenarios where the still water levels do exceed the defence crest it has generally been possible to apply a single tidal profile as the still water level and wave height combination resulting in the worst case scenario has been the same.

It is important to note that the still water level in these model runs is not equivalent to the extreme sea water levels calculated as part of the ICPSS. Therefore the 0.5% AEP wave overtopping extent will not inherently incorporate the 0.5% AEP tidal flood risk extent.

4 Defence modelling

4.1 Classification and modelling of raised structures adjacent to watercourses

Raised structures adjacent to watercourses and coastlines will play a significant part in determining if the land behind these structures is shown as at flood risk in the final flood maps. Removing these structures when, in reality, they prevent flooding would overestimate flood risk and reduce public confidence in the quality of the flood maps produced. Conversely, including structures when they are not constructed to a sufficient standard to withstand elevated water levels would result in a false sense of security amongst residents, and result in them being underprepared and at greater risk should the structure fail.

All raised structures identified adjacent to watercourses and coastlines, whether OPW defences or other structures identified on site, have been reviewed in some detail and classified as effective or ineffective depending on their ability to provide a flood defence function. The classification is based on visual inspections carried out as part of work on the defence asset database. This classification then dictates how the structure has been represented in the hydraulic model.

Some defences are classed as 'formal' flood defences; these are engineered schemes which have been constructed specifically to provide a flood defence function, but may be effective or ineffective depending on the specific maintenance regime. They are usually the responsibility of the OPW, but may fall under Local Authority or private control. Informal defences are those structures which are not designed specifically for flood defence purposes, but serve to provide such benefits. These may include railway and road embankments and other walls and embankments which would be effective in flood conditions.

The classifications are recorded in the Defence Asset Database, which includes a condition assessment of each structure.

4.1.1 Effective

'Effective' structures are continuous and tie into high ground or other defences. Failure of these structures occurs via overtopping or in the event of a breach. Within the hydraulic model these structures have been represented as surveyed, i.e. the crest level of the defence has been included in the model.

These structures have been considered for the breach scenarios and have been removed for the purposes of the defended area and flood zone mapping.

4.1.2 Ineffective

Ineffective structures can be assumed to fail in a number of different ways, and the way they are likely to fail has dictated the way in which they have been represented in the hydraulic models. To help explain the different modes of failure a further three sub-classifications have been developed.

Table 4-1: Ineffective structure classifications

Ineffective structure	Description	Treatment for modelling purposes
Type 1a - structures with gaps	In their existing condition there is a route for the structure to be bypassed, either through gaps or low points in the structure or because the structure does not tie in to high ground at one or both ends. Such features are included in the topographic survey. The structure may be adequate in its design and materials to resist flood water causing it to overturn or breach.	Modelled as surveyed
Type 1b - walls less than 0.6m	These will not normally have been designed as flood defences but, due to the limited depth of water able to pond against them before overtopping occurs, they are expected to remain intact during a flood event. The effect of these structures would be expected to quickly become negligible in larger flood events as they become drowned out or bypassed.	Modelled as surveyed

Ineffective structure	Description	Treatment for modelling purposes
	They are important in low order events as they push flood waters in particular directions.	
Type 2	Form coherent barriers adjacent to the watercourse and most probably tie into high ground at either end. However the structures themselves were not designed as flood defences and would be expected to fail in the event of a flood. The depth at which the hydraulic pressure on these structures will result in failure has been modelled at 0.6m. This is the height that results in the load that can be withstood by a single skin brick wall where the failure mode is through tensile cracking of mortar bond in brick. Structures where this depth is not exceeded in the 1% AEP event have been classified as Type 1a.	Excluded from the model
Type 3	Structures which could in the future form part of a flood defence but are either currently bypassed, as described in the Type 1 classification, or the base is above the current 1% AEP flood level. They are considered to be structurally sound and capable of retaining flood waters, should the gaps (often walkways) be filled.	Modelled as surveyed

4.1.3 Defences in UoM30-31

Following the classification of defences detailed above, formal defences were identified in Galway, and Gort AFAs. Formal defences, in the form of embankments, were identified by OPW in Corrib Clare, Corrib Mask and Cregadare. No informal effective defences were identified. All the defences protect against fluvial flooding, and in Galway City also protect against coastal flooding.

4.2 Undefended modelling

4.2.1 Defended areas

A suite of undefended flood outlines have been produced. These defended area polygons show areas benefiting from the effective defences identified within AFAs. For each defence the model results have been reviewed and the most severe (lowest AEP) of the 8 predefined AEP events that does NOT overtop the defence / defence group along its length has been identified and termed the effective standard of protection (SOP). For example, if the 10% AEP is fully contained within the defence, but the 5% AEP overtops the defence at any point, then the effective standard of protection of the defence can be considered to be the 10% AEP event.

To generate the defended area polygons, the defences were removed from the model and an undefended run at the effective SOP was completed. The difference between the defended and undefended outline for this SOP is the defended area.

In Galway, where there were multiple defence lines within an AFA, all defences were first removed from the model and the effective SOP event corresponding to each defence line was run in turn, thereby producing a defended area polygon specific to each defence line.

4.2.2 Flood Zones

In addition to modelling the effective SOP of the defences, Flood Zone maps have been produced, meeting the requirements of the Planning System and Flood Risk Management¹¹. Flood Zone A is the 1% AEP fluvial or 0.5% AEP tidal (1 in 100 year fluvial / 1 in 200 year tidal) extent and Flood Zone B is the 0.1%AEP (1 in 1000 year) event; both scenarios are undefended. In order to generate these maps, the 1% and 0.1% AEP flows were run through the undefended models, regardless of the effective SOP of the defences. It should be noted that where there are no defences, the flood extents and flood zone maps are the same.

¹¹ OPW (2009), The Planning System and Flood Risk Management: Guidelines for Planning Authorities 2011s5232 WCFRAM UoM 30-31 Volume 1a Hydraulic Modelling Method Statement v3.0.docx

4.3 Breach analysis

4.3.1 Screening

In the event of a failure of flood defence assets (such as the collapse of a section of wall or breach of an embankment), areas that would otherwise be defended against flooding during a given event severity might become subject to flooding.

The modelling of the defence failure scenarios was required where the defence provided protection to receptors within an AFA and the depth of water retained by the defence exceeds 1.0m during a flood event of a probability equal to the standard of protection provided by the defence.. Where these conditions are met, two failure scenarios were assessed.

A screening was carried out to determine which defences were greater than 1m from crest to toe, and therefore capable of retaining more than 1m of water. If the defences were in excess of this height, the depth of water retained behind the defences in the existing risk scenarios was reviewed. The results of this screening is provided in Table 4-2.

In addition, the requirement for breach analysis where there was a risk from coastal erosion under a current or future scenario was assessed, but was not identified. There are no coastal defences in Galway City, where the only coastal model was developed, and there is in general little risk associated with coastal erosion.

Table 4-2: Breach analysis screening results

AFA	Defence ID	Defence height greater than 1m	Retained depth of water greater than 1m
Galway	A30GLW_146	Yes	No
Galway	A30GLW_150	Yes	No

4.3.2 Breach modelling

The screening assessment did not identify any defences, either formal or informal effective which required breach modelling within UoM 30-31.

5 Model calibration and sensibility checking

5.1 Objectives and categorisation

The objective of the calibration process is to provide confidence in the outputs from the hydraulic model (either fluvial or coastal) by demonstrating that the models produce a suitable representation of past events, and are therefore likely to predict the output of design events well. This process is heavily dependent on the availability of data from past events, both from gauge records and evidence of historical events. Three levels of checking have been identified for use in this study:

- Calibration - where gauge data and evidence of one or more events is available
- Partial calibration - where there is gauge data but limited / no evidence of flooding, or no gauge data but evidence of flooding
- Sensibility check - where there is no gauge and no evidence of flooding.

The availability of gauge data is discussed in the UoM Hydrology Report, and in the specific AFA report, where the historical events are also summarised. Data relating to historical events are likely to be evidence or anecdotal records from a given flood collected by local authorities or residents. A large data collection exercise was completed at the start of the WCFRAM project and historical flood evidence collected is presented in the Flood Risk Review (FRR) Reports and summarised in the AFA modelling reports. Where additional flood records have come to light since the FRR stage, they are discussed in the relevant AFA model report.

In the absence of flow data, it is also theoretically possible to calibrate the model using recorded rainfall data and a rainfall run-off model. However, there are very few sub-daily rainfall gauges across the catchment which has prevented the development of hydrological models to represent the response to catchment wide rainfall events. This issue was identified within the Inception Reports and recommendations were made for the installation of additional rainfall gauges to support the calibration process. As a result, rainfall runoff models have not been used for model calibration exercises.

5.1.1 Calibration

Where flood records, including recorded flows or levels and records of the impacts of flooding at a number of locations (either flood extents, or spot levels) are available, it is possible to calibrate the model. This process would involve running the recorded flows through the model and changing model parameters, such as Manning's n , to match the flood extents or levels that were observed. Where possible a second (or more) event is then run through the amended model and the outputs compared with flood records to confirm the validation work.

5.1.2 Partial calibration

If there is only limited information available, either gauge data but no accompanying historical flood records or vice versa, an informed sensibility check, or partial calibration, has been carried out. This involved checking that the model is producing an expected outcome (such as matching a wrack mark at a suitable return period or producing a reasonable flood extent for the largest recorded event), but without a high degree of confidence in the overall outputs. This level of checking is unlikely to have resulted in changes to the model parameters being made but will flag up where there are obvious inconsistencies between the model and reality. For example if a site has flooded twice in the last 10 years then the site would be expected to be shown as inundated in the 10% AEP design flood extent and dry in the 50% AEP flood extent. Conversely if a site has only flooded once in the last 50 years it would not be expected to be shown as inundated in the 10% AEP design flood extent.

5.1.3 Sensibility check

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

6 Application of hydrology

6.1 Hydrological estimation points

Design flows have been provided at a series of HEPs along the length of all watercourses to be modelled. These HEPs are located at the upstream limits of models, upstream and downstream of tributaries, at gauging stations and also at sufficient frequency between these locations to pick up the progressive increases in the catchment drainage area moving downstream.

The hydrology for all catchments has been calculated and reported within the Hydrology Report for UoM 30 and 31. No further details are provided on the development of the design flows and the reader is referred to the Hydrology Report for further information. The design flows for each model have been reported in the relevant AFA modelling report.

6.2 Application of design flow estimates

The approach to applying the design hydrology to the hydraulic models has been set out in the Hydrology Report. It has been reiterated and summarised here as it forms an integral part of the development of the hydraulic models and the approach adopted for each model has been reported on in the specific AFA modelling reports.

As part of the work completed for the Hydrology Report a detailed review of the best way to develop design hydrographs was completed. The findings were that hydrographs developed from catchment descriptors using the Flood Studies Report (FSR) rainfall runoff method for hydrograph generation provided the best fit against a suite of observed data.

The objective of the application of hydrology process is to match the design flows at each of the HEPs within the model. For the purposes of the study a modelled flow within 5% of the design flow is considered to have adequately achieved this aim. It is noted that due to the changing data sets and methodologies when calculating design flows across a large catchment, HEPs along the length of a watercourse are not always consistent, for example where a donor site changes from an upstream gauging station to a downstream gauging station. In these instances a generally conservative approach has been adopted and the HEPs with the higher flows used as the basis for the design events.

6.2.1 Hydrograph shapes

Inflow hydrograph shapes for each watercourse have been developed from the Flood Studies Report (FSR) rainfall runoff method. This approach has been tested (with results detailed in the Hydrology Report) and with the exception of a few gauges, which are detailed in Section 6.2.3, this found the FSR approach to provide the best fit against gauge data. Model inflow hydrographs are located at the upstream limit of each watercourse.

6.2.2 Standard methodology

The specific approach taken in developing the hydrology to match HEPs within the model is detailed in each of the AFA modelling reports, but included the following steps:

1. Production of FSR hydrographs from catchment descriptors for all HEPs within the AFA. FSR hydrographs at the upstream limit of the modelled watercourses or at tributaries have been used directly. FSR hydrographs at intermediate sites along the watercourse have been used to develop lateral inflows.
2. Identification of a suitable critical storm duration (based on catchment descriptors) for the main watercourse. The critical storm duration is assumed to be representative of the whole reach of the AFA but the focus is on the main area of interest, i.e. between the critical duration of the upstream and downstream limits of the reach of interest. The storm duration for all FSR boundary units has been set equal to this to represent a consistent event across the AFA.

Applying the FSR method with a uniform design storm for all sub-catchments within a model imposes a structure on the model inflows with realistic relative timings of the hydrographs. This avoids the need to apply the FSU regression model for relative timings of hydrographs at a confluence, which is associated with a large standard error.

Because the FSR method is being used only to control the shape of the hydrographs rather than the magnitude of the peak flows (which are based on the HEPs), there is no benefit to identifying a critical storm duration, i.e. one that results in the highest peak flow or water level. However, in order to ensure a realistic flood duration, the duration of the design storm has been related to the time to peak for the principal watercourse in the model, using the FSR formula that evaluates storm duration from time to peak and SAAR. The potential impact of the critical storm duration on tributary flood extents has been reviewed and is discussed in Section 7.2.8.

3. Adjustment of time to peak (Tp(0)) values if required. Tp(0) values have been adjusted where a lag analysis has been completed as part of the hydrological analysis and included in the Hydrology Report. Sites where this has been done and the associated Tp(0) adjustment are Ballyhaunis (2.0) and Corrofin (2.49). The Tp coefficient in the FSR units have been set to the relevant values for the gauged watercourse only, unless a tributary is of a sufficient scale to be considered comparable to the gauged watercourse, in which case the same scaling factor has been applied.
4. Scaling of the peak for all FSR units to reflect the design event peaks provided in the HEP file and application of upstream inflows. Where the difference in flows between the upstream and downstream limits of a watercourse, or between confluences, is within 10% then an intermediate value has been selected as representative of the whole reach and applied at the upstream of the model. Where this is not the case, the upstream inflow, as indicated in the HEP, has been used and additional inflows added using lateral inflow units, as detailed in step 5.
5. Application of lateral inflows where required. Lateral inflows have been developed from the FSR units at the upstream and downstream limit of the reach of interest, which will likely include the intermediate HEPs. The lateral inflow hydrograph shape is the upstream hydrograph subtracted from the downstream hydrograph, typically for the 1% AEP event. These have then been scaled to match the flows at the HEPs as required, and input as a lateral inflow over the reach of interest. Where the upstream and downstream hydrographs do not overlap, and so prevent the development of a lateral hydrograph, a suitable hydrograph for the watercourse has been selected from the available HEPs.
6. Confirmation that flows at confluences are consistent. Flows upstream and downstream of tributaries have been reviewed to confirm if HEPs are providing a reasonable estimation.

Whilst the above approach is also appropriate for most MPW models, the Clare River has been split as the catchment changes along its length and the critical storm duration changes significantly between upstream and downstream limits.

6.2.3 Hydrograph width analysis methodology

Rather than applying the FSR method detailed above, inflow hydrographs for Galway City have been developed from observed events; this is due to the availability of suitable gauges in proximity to the AFA. The application of the hydrology in these instances has included the following steps:

1. Setting up the HWA hydrograph for the AFA. The hydrographs from the HWA have been scaled to reflect the design event peaks detailed in the HEPs.
2. Identification of all FSR boundaries required along tributaries for the hydraulic model. Hydrographs on the main watercourse have been based on the HWA hydrograph.
3. Identification of the critical storm duration for tributaries and set the storm duration for all FSR boundary units on tributaries equal to this. Each tributary has been treated separately and the identified critical duration set for all intermediate points on the tributary.
4. Scaling of the peak for all inflow units to reflect the design event peaks at the upstream HEPs.
5. Determination of the timing of the events on the tributaries. The difference between the timing of the peak flow on the main watercourse and the tributary has been determined using the following regression equation from the FSU report Work Package 3.4:

$$\text{time.diff} = 32.1 \times \text{BFI.diff} - 103 \times \text{FARL.diff} + 1.62 \times \text{SQRT.AREA.diff} - 1.94 \times \text{TAYSL0.diff} - 46.4 \times \text{ARTDRAIN.diff} - 0.0272 \times \text{NETLEN.diff}$$

where:

- time.diff is the time difference (hours) between the inflow and the modelled reach. A positive value of time difference means that the inflow peaks before the modelled reach (which it normally will).
- BFI.diff is the BFI of the modelled reach (upstream of the confluence) minus that of the tributary.
- FARL.diff is the FARL of the modelled reach (upstream of the confluence) minus that of the tributary.
- SQRT.AREA.diff is the square root of the AREA (km²) of the modelled reach (upstream of the confluence) minus that of the tributary.
- TAYSLO.diff is the Taylor-Schwartz slope of the modelled reach (upstream of the confluence) minus that of the tributary.
- ARTDRAIN.diff is the arterial drainage index of the modelled reach (upstream of the confluence) minus that of the tributary.
- NETLEN.diff is the network length (km) of the modelled reach (upstream of the confluence) minus that of the tributary.

Timings should be relative to the time of the event peak on the main watercourse at the confluence with the tributary.

1. Application of inflows at the upstream limit of each watercourse
2. Application of lateral inflows where required to match HEPs. Lateral inflows have been developed from the inflow hydrographs, i.e. scaled HWA hydrographs if required. The method used to match design flows at HEPs is as described in Section 6.2.2, except that the HWA hydrographs have been used instead of FSR hydrographs.
3. Confirmation that flows at confluences are consistent

7 Sensitivity testing

7.1 Screening

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

The nature of the sensitivity analysis and the model parameters assessed means that any analysis has been based on engineering judgement only, however by maximising the hydraulic modellers' knowledge of the site, sensitivity assessments are representative of the limitations of the data availability for the site.

Rather than adopting a generic approach to the sensitivity analysis, a screening judgement has been made as to those tests that are applicable and required for each AFA.

The following sections discuss the range of the sensitivity tests required and provide examples of how parameters have been adjusted to reflect known uncertainties. The sensitivity tests and the situations in which they apply are laid out in Table 7-1.

Table 7-1: Sensitivity tests

Sensitivity test	HPW/ MPW applicable	Other watercourse characteristics
Peak flow	HPW and MPW	In all watercourses
Roughness	HPW and MPW	In all watercourses
Water level boundaries	HPW and MPW	Watercourses which discharge into the sea or a lake
Building representation	HPW	Where buildings are within the flood extents
Flow volume	HPW and MPW	Where the hydrograph is generated from catchment descriptors
Afflux / headloss at key structures	HPW and MPW	Where headloss has been noted in the long section, and the structure may cause flood risk
Timing of tributaries	HPW	Where tributary is in the same model as the main river
Timing of fluvial and tidal peaks	HPW and MPW	Where the river has a tidal boundary
Critical storm duration	HPW	Where tributary is in the same model as the main river
Cell size	HPW	Where cell size is greater than 2m and there are complex flow routes across the floodplain.

Where site specific assumptions are identified within the AFA modelling report, further sensitivity tests may be completed to examine these, and may include testing specific control structures.

Sensitivity tests to flow, roughness and water level boundaries have been carried out on all models for the 1% AEP event. Sensitivity tests to building representation, flow volume, afflux at key structures and timing of tributaries for the 1% AEP event, and for all tests related to the 10% AEP event have only been carried out where a screening exercise has identified that there remains significant uncertainty and models may be underestimating flood risk. Details and results of this screening exercise have been provided in the individual AFA modelling reports. Sensitivity testing of the 0.1% AEP events has not occurred.

In all cases it is important to consider the sensitivity tests as a sensible shift within the bounds of reasonableness. Therefore, if through the calibration process, parameters have been increased towards the upper limits of reasonableness for a given parameter then the additional shift for a review of sensitivity will be less than if no calibration/validation process has been carried out and default parameters have been applied.

The mapping of uncertainty bounds is described in Section 0.

7.2 Sensitivity analyses

7.2.1 Flow

Table 7-2 provides a scoring mechanism through which each watercourse has been attributed a score from each row of the table reflecting the level of confidence in the hydrology. The resulting scores have been summed to provide an overall indication of uncertainty and used to look up in Table 7-3 the uncertainty weighting to apply for the sensitivity test.

The uncertainty in QMED was assessed using the equations for SE and FSE provided in the FSU WP2.2 report. These were applied to estimates derived from catchment descriptors, which will give a scaling factor of 1.37, or at gauge sites which will typically give a lower scaling factor. This reflects the uncertainty in the index flood but does not reflect the uncertainty in the growth curve, for this reason an additional multiplication factor is included for the 1% AEP event.

Table 7-2: Flow sensitivity test scoring mechanism

Scoring parameter	Score of 1	Score of 3	Score of 5	Score of 7
Is there a local recording gauge that has been used as a donor for the hydrology?	Within 5km of the AFA and on the same watercourse with no significant other inflows between the gauge and the AFA OR Upstream and downstream of the AFA with no significant other inflows between and routing of flows supports the hydrology	Within 5km of the AFA but not on the same watercourse or with significant other inflows between the gauge and the AFA	Beyond 5km or with significant other inflows between the gauge and the AFA	No useable gauge
What is the length of record of the local gauge?	Greater than 40 years	Between 20 and 40 years	Between 2 and 20 years.	No useable gauge
What quality is the record from the gauge?	Rating review carried out, high confidence	Rating review carried out, moderate confidence or no rating review carried out but gauge is FSU class A	All other sites.	N/A.
What unusual features are there in the catchment hydrology?	None – a rural catchment typical of many in the gauged datasets	Some lakes ($0.99 > \text{FARL} > 0.9$) or urbanisation ($0.05 < \text{URBEXT} < 0.15$)	Some karst or extensive lakes ($\text{FARL} < 0.9$) or urbanisation ($\text{URBEXT} > 0.15$) or arterial drainage	N/A
What is the size of the catchment?	N/A	N/A	<25km	N/A

Table 7-3: Flow sensitivity scaling factors

Return period of event	Score up to 6	Score of between 7 and 14	Score of between 15 and 22	Score above 23
10%	No sensitivity test required.	Use QMED uncertainty	Use QMED uncertainty	Use QMED uncertainty
1%*	Use QMED uncertainty then apply adjustment factor of 1.1	Use QMED uncertainty then apply adjustment factor of 1.2	Use QMED uncertainty then apply adjustment factor of 1.3	Use QMED uncertainty then apply adjustment factor of 1.5.
* Where extensive areas of karst with connections to the surface water system is present then use QMED uncertainty then multiply flows by 2.0 to reflect the uncertainty in the 1% event flow.				

7.2.2 Roughness

Based on the assessment of typical vegetation cover completed as part of the hydraulic modelling, and an understanding of the maintenance regime carried out by the local authorities and OPW, high and low end roughness values have been determined for each channel.

If one or more large events have been observed and sufficient data is available with which to calibrate the roughness within the channel then the uncertainty in channel roughness is assumed to be reduced and a variation of Manning's n to the full extent suggested has not been applied. It is also noted that in large events with greater depths the influence of channel roughness is often reduced; in these instances a variation to the maximum upper bound may not have been applied.

Floodplain Manning's n values have also been adjusted for the 1% AEP roughness sensitivity test only.

Table 7-4 to Table 7-6 build on the quoted values detailed in Section 2.2.2 and 3.2.3 and provide upper and lower bound values for a variety of surfaces. These have been used as a guide; actual values used for the sensitivity analysis are presented in the individual AFA modelling reports and take into consideration local factors as described above.

Table 7-4: Roughness bounds for river channels

Channel substrate	Roughness values (Manning's n)		
	Lower Bound Value	Typical Value	Upper Bound Value
Bedrock	0.023	0.025	0.028
Cobbles (64-256mm)	0.04	0.055	0.07
Coarse Gravel	0.022	0.035	0.04
Gravel (2-64mm)	0.028	0.03	0.035
Sands	0.023	0.025	0.032
Silt	0.02	0.022	0.025
Clay	0.018	0.02	0.023
Concrete	0.018	0.02	0.022

Table 7-5: Roughness bounds for river banks

Bank material	Roughness values (Manning's n)		
	Lower Bound Value	Typical Value	Upper Bound Value
Scrub/Long Grass	0.03*	0.04	0.06*
Bushes	0.04*	0.06	0.08*
Trees – flood level not reaching branches	0.05	0.07	0.13
Trees – flood level reaching branches	0.1	0.15	0.2
* these values are not from published literature, but represent a reasonable uncertainty bound to guide the modeller.			

Table 7-6: Roughness bounds for floodplain surfaces

Floodplain material	Roughness values (Manning's n)		
	Lower Bound Value	Typical Value	Upper Bound Value
General Natural Surfaces	0.030	0.040	0.050
Buildings	0.100	0.300	1.000
Inland Water	0.025	0.035	0.045
Roads, Tracks and Paths	0.013	0.015	0.017
Non-coniferous Woodland	0.060	0.070	0.100
Coniferous Trees	0.080	0.100	0.120
General Manmade Surfaces	0.015	0.017	0.020
Glasshouses	0.100	0.200	0.300
Rock	0.040	0.050	0.070
Mixed Vegetation	0.060	0.080	0.110

7.2.3 Building representation

Buildings in the floodplain can dictate flow paths, and some consideration of how the chosen representation of buildings influences the flood extent is required.

The preferred method for floodplain and building representation has been to apply an increased roughness for building footprints.

The sensitivity test has identified whether the selected approach is appropriate by increasing the threshold level of buildings by 300mm, or an appropriate (higher) level based on local site information.

The results of the sensitivity test have determined if the alternate approach needs to be adopted for all model runs for the AFA or if it can remain as a demonstration of sensitivity only.

This sensitivity test has only been applied where properties are shown to be located within the flood extents.

7.2.4 Water level boundaries

In cases where the downstream boundary of the model has been linked to a model downstream, there is no requirement to test the boundary, which will be based on a rating relationship rather than a water level boundary.

The effect of rising sea levels has been investigated through the future event scenarios detailed in Section 8.1. The increases in levels highlighted for the MRFS have been applied for this sensitivity test.

Further consideration has been given to the initial conditions in lakes within hydraulic models. Where long term level data is available this has been reviewed to determine levels in a typical year and in an extreme year during winter months to determine a suitable shift. Where no long term data is available, an estimate of appropriate changes in water levels is required and an increase in water levels of 1m has generally been adopted.

7.2.5 Flow volume

The sensitivity to the hydrograph duration has been assessed where design storm hydrographs have been developed from limited data. Where observed data from significant flood events is available, it is considered a reasonable approximation of the flood duration has been made and no sensitivity test has been required. Table 7-7 details a range of flood duration multipliers reflecting the basis for the development of the design event hydrographs.

Where the 1% AEP flow remains in bank, sensitivity to flow volume will not be investigated because the peak flow, and therefore corresponding peak water level would remain unchanged, and would stay within bank.

Table 7-7: Flood duration multipliers for flow volume sensitivity test

Description of site	Sensitivity multiplier applied to flood duration
Flood duration has been developed from a single observed event data or multiple events below the 10% AEP.	1.2
Flood duration has been developed from catchment descriptors and there are few or no lakes in the upstream catchment (FARL>0.9)	2
Flood duration has been developed from catchment descriptors and there are extensive lakes in the upstream catchment (FARL<0.9)	9

7.2.6 Afflux/head loss at key structures

General modelling parameters often fail to fully represent the head loss that can occur at complex structures. Whilst it is not realistic to model these structures exactly as observed on site, it is feasible to investigate the effect of greater head losses resulting from this known complexity.

In some cases, such as where pipe crossings exist which have the potential to alter the flow regime within or upstream of a culvert, or there is unusual skew apparent on the approaches or exits, then specific modelling approaches to reflect these observed constriction, such as partially blocking the culvert, have been adopted.

Where there is complexity that is less easily quantified, such as changes in culvert shape through the length, sensitivity tests incorporating additional contraction and expansion losses to account for these complexities have been completed to determine the effect of incorporating these in the model. These losses are relative to the velocity head and can be applied simply through a general head loss unit and the multiplier K, Table 7-8.

Table 7-8: Coefficients for contraction and expansion head losses

K Value	
Calculated expansion loss	$K = \left(1 - \frac{W_1}{W_2}\right)$ where W1 and W2 are the upstream and downstream widths
Typical bridge expansion	K = 0.5
Abrupt expansion	K = 0.8
Square edged contraction	K = 0.3 (lower bound 0.23, upper bound 0.35)
Round edged contraction	K = 0.15 (lower bound 0.1, upper bound 0.2)
Typical bridge contraction	K = 0.3
Abrupt contraction	K = 0.6

Based on Table 5-2 in the HEC-RAS manual

This analysis has been completed for hydraulically significant structures only, i.e. those that are likely to have an impact on either scale of flood risk or future flood risk management measures.

Hydraulically significant structures have been identified in the AFA modelling report. They are those structures that show a hydraulic jump in the long section plot, and are also situated near a receptor that could be at risk of flooding. If the structure is in a low risk area it is not deemed to be hydraulically significant.

Table 7-9: Roughness bounds for culverts

Culvert material	Roughness values (Manning's n)		
	Lower Bound Value	Typical Value	Upper Bound Value
Precast concrete	0.009	0.008	0.013
Monolithic concrete construction	0.011	0.012	0.014
Brickwork (well pointed)	0.014	0.016	0.017
Brickwork (in need of pointing)	0.018	0.021	0.023

7.2.7 Timing of tributaries

Coincidence of flood peaks on tributaries needs to be considered in the context of the catchment and the potential impact. A shift in the timing of tributaries to coincide the peaks will give higher peak flows downstream of the confluences. Therefore, this test was only required if the resulting increase in flows was greater than those tested in the flow sensitivity (as detailed in Section 7.2.1). To be truly useful, this test would also require good confidence in the model hydrology.

A simple alignment of flood peaks on tributaries is considered too conservative, and instead a shift in the timing of flood event hydrographs has been limited to a maximum of +/-10% of the tributary event duration.

7.2.8 Critical storm duration

The critical storm duration used in model was based on timing for the main watercourse. As the peak flow is matched to the HEPs on the watercourse, the impact of changing the storm duration is to increase or decrease the volume of the hydrograph. This is unlike the standard approach to varying storm duration where a longer storm tends to result in a longer, but lower hydrograph than a shorter duration storm. In cases where tributaries drain considerably smaller catchments than the main river, it is likely the storm duration has been overestimated, and therefore flood volumes are too large. This may result in over estimation of flood extents.

In each case where a main river and a tributary share a common storm duration the flood extent for the tributary was examined. If the extent was limited (i.e. largely in-bank) testing alternative storm durations was not required as the only adjustment would be to reduce the volume of the hydrograph, thereby giving even less out of bank flooding. However, if there was considerable floodplain inundation arising from the tributary, an additional model run was carried out using the critical storm duration for the tributary, matched to the 1% AEP flows at the HEPs. If this run resulted in smaller flood event, the base model was adjusted accordingly.

7.2.9 Cell size

Where a cell size greater than 2m has been used, and there are complex flow routes (such as around buildings), the model will be run with a 2m grid resolution. This will allow the potential for development of additional flow paths to be identified. It is not proposed to test sensitivity to cell size at a resolution less than 2m, or where flood extents are limited, or are simple (i.e. across open floodplain).

7.3 Joint probability analysis

7.3.1 Fluvial and tidal

The potential for a joint probability event has been considered in relation to the impact of a fluvial event in conjunction with extreme still water tidal levels only, for example the joint probability of waves and tidal levels in conjunction with fluvial flows has not been investigated.

A staged approach has been adopted to determine those locations where a detailed joint probability analysis is required. This has consisted of using the hydraulic models to screen out those sites where the flood risk associated with a joint probability event in excess of the 1% AEP event is limited or of no significant consequence. This scoping event has combined the 2% AEP fluvial event with the 2% AEP tidal event. This has been compared against the extents produced by a 1% AEP fluvial event in conjunction with a 50% AEP tidal event, and a 1% AEP tidal event in conjunction with a 50% AEP fluvial event.

Should flood risk from the screening event have been found to impact receptors beyond the fluvial only or tidal only flood risk extents, a more detailed joint probability analysis would have been carried out. However, in all cases there was little, if any, increase in the extent of flooding and no new receptors at risk.

The results of the joint probability sensitivity testing are detailed in the water level boundary section of the relevant AFA hydraulic modelling report.

7.3.2 Main river and tributaries

No joint probability testing has been carried out at the confluence of tributaries and the main river. This is because the CFRAM approach is intended to model the same design event on all watercourses at the same time. As the flows are scaled to the HEPs it is not possible to run alternative combinations; the default position is to match the 1% AEP on the main river with the 1% AEP event on the tributary. In addition, as the flows have all been calculated using FSU catchment descriptor methodology at HEPs along the watercourse, the contribution of tributaries is automatically taken into account at the downstream HEPs.

7.4 Sensitivity testing results

As discussed in the introduction to this section, a screening assessment was undertaken in each AFA to determine which sensitivity tests would be undertaken. The result of the screening assessment is detailed in the relevant AFA hydraulics report, and is summarised in the UoM30-31 Hydraulic Report.

8 Model outputs and mapping

8.1 Model run scenarios and design events

There are a suite of model scenarios and associated design events for which the hydraulic models have been run to fulfil the requirements for the WCFRAM study.

The full suite of design events include the 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1% AEP events.

The three scenarios represent different time periods; a present day scenario, a Mid-Range Future Scenario (MRFS) and a High End Future Scenario (HEFS). The objective of the future scenarios is to understand the implications of climate change and land use change on flood risk over the period to 2100. The MRFS is intended to represent a 'likely' future scenario, whereas the HEFS is intended to represent a more extreme, but still possible, future scenario. Full details of the development of the hydrology for the future scenarios are recorded in the Hydrology Report but the general changes are summarised in Table 8-1. The future scenarios have been run for the 10%, 1% and 0.1% AEP design events.

Table 8-1: Allowances for future scenarios

	MRFS	HEFS
Flood Flows	+20%	+30%
Mean Sea Level Rise	+500mm	+1000mm
Urbanisation	+20% to URBEXT	+30% to URBEXT
Land movement	-0.5mm/year for Kinvarra. Nothing elsewhere	-0.5mm/year for Kinvarra. Nothing elsewhere

8.2 Flood hazard mapping

The flood mapping deliverables include flood extent maps, Flood Zone maps, flood depth maps, flood velocity maps and risk to life maps. The Flood Zone maps are primarily used for development planning and management, and represent an undefended situation as discussed in Section 4.2.2. The maps have been produced for all modelled watercourses.

For each of these mapping deliverables there are different combinations of scenario and design event model runs required. Table 8-2 details the flood mapping requirements for the WCFRAM.

Table 8-2: Flood mapping requirements

Map type	Flood event probabilities to be mapped for each scenario		
	Present day	MRFS	HEFS
Flood extent	All probabilities	All probabilities	10%, 1%, 0.1%
Flood Zone	1%, 0.1%	1%, 0.1%	Not required
Flood depth	All probabilities	10%, 1%, 0.1%	Not required
Flood velocity	All probabilities	Not required	Not required
Risk to life	10%, 1%, 0.1%	Not required	Not required
Wave overtopping	10%, 1%, 0.1%	Not required	Not required

8.2.1 HPWs

One of the advantages of using a 2d modelling package, such as TufLOW, is that the outputs from the model can be used directly to generate hazard maps, with little or no post-processing required. The only exceptions are the flood extent and Flood Zone maps, which are polygons generated from the outer extents of the depth grid. The main advantage of this approach to generating maps is that the outputs are consistent. However, the resulting grid (depth, hazard etc.) is linked to the resolution of the DTM used in the model. This means the resolution of the maps may vary from AFA to AFA and between models within an AFA. This is particularly true where varying cell sizes have been used in the models.

Where an HPW flows to or from an MPW, this is indicated on the map with a note directing the viewer to the appropriate adjacent map.

8.2.2 MPWs

The maps for the MPWs have been produced by interpolation of water levels between cross sections, and projection of those levels across the DTM. Owing to the coarse resolution of the section spacing this means the accuracy of the outlines is lower than for the HPW maps. A relic of this process is wet and dry islands; these are disconnected areas of floodplain which are shown to have flooded, or areas within the floodplain which are raised above water levels and are shown to be dry. In general, wet islands have been removed where there is not obvious link to the watercourse network, however in some instances where there are turloughs present these have been left in as they are representative of likely flood risk. Dry islands have been removed where they are less than 750m² in area, islands larger than this have been left in the maps.

8.3 Long section plots

For each modelled watercourse a long section plot has been produced. These plots show the design water levels against a corresponding area of mapping. The plots have been produced to show water flowing downstream across the page from left to right. To ensure consistency across the images it has, in some cases, been necessary to rotate the mapping orientation to align with the long section plot. This is indicated by the north arrow on the mapping.

In some cases it is possible that the long section plot indicates water levels are lower than the bank crests while the plan indicates out of bank flooding. The reason for this anomaly is that at a particular cross section the bank is raised, or includes a wall, but flows have bypasses the structure from upstream. It does not indicate an error in the modelling.

The long section plots are useful for indicating where bridges and culverts cause constrictions and result in afflux (headloss) which may result in flood risk locally.

8.4 Presentation of uncertainty

Uncertainty bounds have been developed by extracting the largest flood extents produced by the sensitivity tests discussed in Section 7 in all locations along a river or coastal reach. The final uncertainty bound is therefore the result of all sensitivity tests overlain using a GIS package to produce a final merged uncertainty bound.

In general, the hydrology sensitivity test has produced the greatest uncertainty extents, reflecting the fact that hydrology is usually the greatest source of uncertainty in modelling. However, in the particular locations where multiple sensitivity tests produce equivalent extents, a review has been undertaken, and where necessary additional model runs completed, to incorporate a greater worst case scenario by modelling a combination of uncertainties for that specific location.

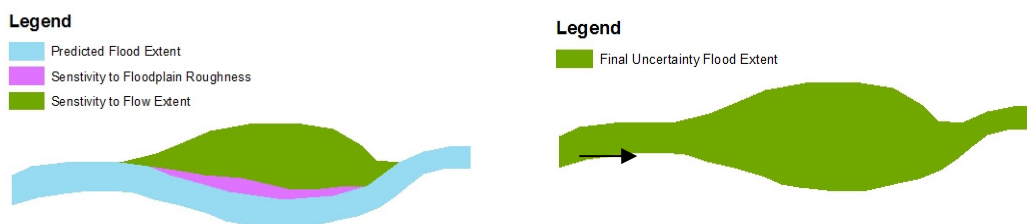
In summary, the approach is as follows:

1. Complete hydraulic modeller led sensitivity assessments and document findings
2. Map 2D model results and review extents to identify where multiple sensitivity tests produce similarly extreme outlines.
3. Run extreme sensitivity model run if required.
4. Overlay and merge in GIS to develop a final uncertainty bound.

Examples of the output of this process is shown in Figure 8-1 which illustrates sensitivity to one or a number of parameters. It also provides an example of one model location which may be sensitive to a number of different parameters. In such a case, an additional, worst case sensitivity run will be carried out.

Figure 8-1: Sensitivity run example outputs

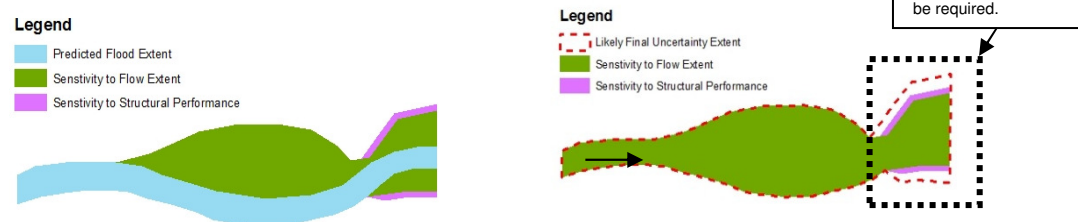
Example 1 – A single sensitivity test produces the greatest bound



Example 2 – Different locations are sensitive to different sensitivity tests



Example 3 – Different sensitivity tests produce similarly large extents in critical areas



8.5 Flood risk maps

Maps have been produced showing flood risk to a number of receptors within AFAs. These maps are based on a GIS interrogation of the receptor data against the 10%, 1%/0.5% and 0.1% flood extents for fluvial and coastal scenarios. All the risk maps have been produced for the existing risk (present day), and MRFS. A summary of the receptor data examined in each case is provided in Table 8-3.

Table 8-3: Risk map receptors

Map type	Receptors mapped
Specific risk - No. inhabitants	Gridded density of inhabitants at flood risk
Specific risk - Type of activity	Presence or absence of property, infrastructure, rural activities or economic activities at flood risk within the AFA.
Specific risk - Risk density	Annual average damages (AAD (€))
General risk - Social	Residential Properties
	Residential Homes - Children
	Residential Homes - Disabled
	Residential Homes - Elderly
	Primary Schools
	Post-primary Schools
	Third Level Education
	Health Centres
	Prisons
	Fire Stations

Map type	Receptors mapped
	Garda Stations
	Civil Defence
	Ambulance Stations
	Hospitals
	OPW Buildings
	Government Buildings
	Local Authority Buildings
General Risk - Environmental	Pollution Sources
	Groundwater abstraction for Drinking water
	Recreational water including Bathing water
	Special Area of Conservation
	Special Protected Area
	S4 and S16 licences
	Shellfish waters including fresh water pearl mussel areas, surface drinking water, and nutrient sensitive areas.
General risk - Cultural heritage	Architectural Heritage
	National Monuments
	National Heritage Area
	Proposed National Heritage Area
General risk - Economic	Commercial Properties
	Airports
	Road Networks
	Rail networks & Stations
	Ports & Harbours
	Infrastructure: ESB Power Stations, ESB HV Substations, Bord Gais Assets, Eircom Assets
	Water Supply
	Oil infrastructure



Registered Office

**24 Grove Island
Corbally
Limerick
Ireland**

T: +353 (0) 61 345463
e: **info@jbaconsulting.com**

**JBA Consulting Engineers and
Scientists Limited**

Registration number 444752

Visit our website
www.jbaconsulting.com


Western CFRAM Unit of Management 30 and 31 - Corrib and Owengowla

**Final Hydraulic Model Report
Volume 1b: Hydromorphology and Coastal
Erosion Assessment**

September 2016

**Office of Public Works
Trim
Co. Meath**



 **WESTERN
CFRAM
STUDY**
CATCHMENT FLOOD RISK
ASSESSMENT AND MANAGEMENT

JBA Consulting

24 Grove Island
Corbally
Limerick
Ireland

JBA Project Manager

Sam Willis BSc MSc CEnv CSci MCIWEM C.WEM

Revision History

Revision ref / Date issued	Amendments	Issued to
April 2015 version 1.0	First Issue	Rosemarie Lawlor
July 2016 version 2.0	Minor typos/format	Clare Butler
September 2016 version 3.0	Final issue including coastal erosion	Clare Butler

Contract

This report describes work commissioned by The Office of Public Works, by a letter dated (28/07/11). The Office of Public Works' representative for the contract was Rosemarie Lawlor. Clare Bithell and Sam Willis of JBA Consulting carried out this work.

Prepared by Claire Bithell BSc
..... Sam Willis BSc MSc CEnv CSci MCIWEM C.WEM

Reviewed by Jonathan Cooper BEng MSc DipCD CEng MICE
MCIWEM C.WEM MIOd

Purpose

This document has been prepared as a draft report for The Office of Public Works. 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.

JBA Consulting has no liability regarding the use of this report except to the Office of Public Works.

Copyright

Copyright – Copyright is with Office of Public Works. All rights reserved. No part of this report may be copied or reproduced by any means without the prior written permission of the Office of Public works.

Legal Disclaimer

This report is subject to the limitations and warranties contained in the contract between the commissioning party (Office of Public Works) and JBA.

Carbon Footprint

A printed copy of the main text in this document will result in a carbon footprint of 157g if 100% post-consumer recycled paper is used and 157g if primary-source paper is used. These figures assume the report is printed in black and white on A4 paper and in duplex.

JBA is aiming to reduce its per capita carbon emissions.

Contents

1	Introduction.....	1
1.1	Background and project scope	1
1.2	Report overview.....	1
1.3	Study background.....	2
2	Hydromorphology assessment methodology	3
2.1	Overview	3
3	Hydromorphology results.....	7
3.1	Mapping Outputs	7
3.2	Structures identified from hydromorphology appraisal	8
4	Hydromorphology summary	14
5	Coastal erosion assessment background	17
5.1	Scope.....	17
5.2	Available Data.....	17
6	Coastal erosion assessment analysis.....	18
6.1	Review of existing ICPSS data.....	18
6.2	Methodology	19
6.3	Findings	19
6.4	Recommendations	20
7	Coastal erosion assessment summary	21
	Appendices.....	22
A	Hydromorphology maps	23
B	Coastal erosion maps	24

List of Figures

Figure 1-1: AFAs within UoM 30 and 31	1
Figure 2-1: Flow chart of hydromorphology appraisal process	4

List of Tables

Table 3-1: Mapping output legend and explanation	8
Table 3-2: Structures at risk of sedimentation from reach scale sedimentation processes	9
Table 3-3: Structures at risk of sedimentation from local scale sedimentation processes.....	11
Table 3-4: Structures to be monitored for sedimentation from reach scale sedimentation processes	13
Table 4-1: Summary of findings and recommendations for each AFA.....	15
Table 6-1: Review of ICPSS outputs against latest aerial imagery	18
Table 6-2: Summary of coastal erosion risk categorisation.....	19

Abbreviations

AEP	Annual exceedence probability
AFA	Area for further assessment
AP	Aerial photography
CFRAM	Catchment flood risk assessment and management
HEFS	High end future scenario
HPW	High priority watercourse
ICPSS	Irish Coastal Protection Strategy Study
MIKE21	Hydraulic modelling software package
MPW	Medium priority watercourse
MRFS	Medium range future scenario
NHA	National Heritage Area
pNHA	proposed National Heritage Area
SAC	Special Area of Conservation
SPA	Special Protection Area
UoM	Unit of management
WCFRAM	Western Catchment flood risk assessment and management

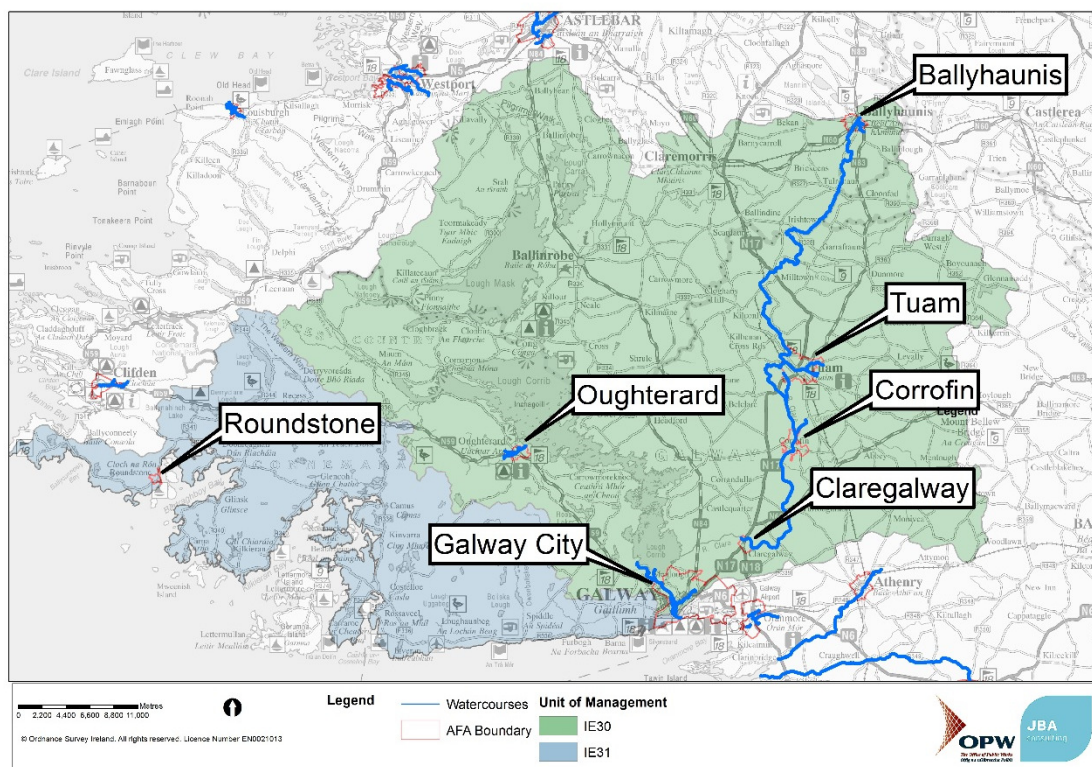
1 Introduction

1.1 Background and project scope

This report describes the investigations into hydromorphology and sediment transport issues, and coastal erosion across the Western Catchment-based Flood Risk Assessment and Management (WCFRAM) study area. The report covers the Areas for Further Assessment (AFAs) within Unit of Management (UoM) 30 and 31, Corrib and Owengowla, as shown in Figure 1-1:

- Ballyhaunis
- Claregalway
- Corrofin
- Galway City
- Oughterard
- Tuam
- Roundstone

Figure 1-1: AFAs within UoM 30 and 31



The focus of the study is on channel hydromorphology and coastal erosion in so far as it may affect flood risk within the AFAs being investigated within the CFRAM. This report is one element of the hydraulic modelling investigations and presented within this suite of reports provides valuable context for understanding the implications of the historical management of watercourses across the WCFRAM and the best approaches for continued management into the future. Results reported in the hydraulic modelling investigations can therefore be considered in light of the findings from this study.

This work will also feed into the Preliminary Options Investigation Phase of the study supporting the discussion within the Strategic Environmental Appraisal on the implications of proposed measures and options.

1.2 Report overview

This report is one of a series which describe the work undertaken as part of the CFRAM, and together they provide a description of the approach taken to identifying flood risk, and a discussion

of the results of the analysis and potential flood management measures, where they are appropriate.

This report should be read in conjunction with the following supporting documents:

- Western CFRAM UoM30-31 Hydrology Report¹
- Western CFRAM UoM30-31 Inception Report²
- Western CFRAM Flood Risk Review Report³
- Western CFRAM SEA Scoping Report⁴
- Western CFRAM Defence Asset Database: Handover Report and accompanying database files⁵

The reports in the suite for the Hydraulic Modelling are:

- Western CFRAM UoM30-31 - Hydraulic Modelling Report
- Western CFRAM UoM30-31 - Hydraulic Modelling Report: Volume 1a – Hydraulic Modelling Method Statement
- Western CFRAM UoM30-31 - Hydraulic Modelling Report: Volume 1b – Hydromorphology and Coastal Erosion Assessment (this report)
- Western CFRAM UoM30-31- Hydraulic Modelling Report: Volume 2 – AFA Modelling Reports
- Western CFRAM UoM30-31- Hydraulic Modelling Report: Volume 3 – Flood Risk Maps
- Western CFRAM UoM30-31- Hydraulic Modelling Report: Volume 4a – Hydraulic Model and Check Files

1.3 Study background

The Inception Report for UoM 30 and 31 was delivered in October 2012. This report consisted of a baseline review of available data and the development of the proposed methodology for the hydrological and hydraulic modelling investigations to be completed within this phase.

The method statement for the hydrological analysis detailed in the Inception Report has been developed and finalised in the UoM 30 and 31 Hydrology Report. This work has developed design flows at a series of Hydrological Estimation Points (HEPs) along all watercourses to be modelled. The detailed development of the hydrology has not been reiterated here and the reader is referred to the Hydrology Report for full details of the hydrological analysis. Design flows have been extracted directly from the Hydrology report and are summarised in the AFA modelling reports.

The Hydrology Report also provides guidance on the development of appropriate design storm hydrographs for each AFA for the purposes of the hydraulic modelling. These methods are summarised in this report to provide clarity on the application of the design event hydrology as this work has been undertaken in the hydraulic modelling phase.

The Inception Report identified all High Priority and Medium Priority Watercourses (HPWs and MPWs) to be modelled. HPWs are those watercourses that dictate flood risk within an AFA boundary as originally delineated within the Flood Risk Review (FRR) Report. HPWs therefore extend a short distance upstream and downstream of an AFA but do not include watercourses with catchments less than 1km². HPWs have been modelled to a greater level of detail than MPWs. MPWs are the watercourses which link two AFAs together and the watercourses that extend downstream of an AFA to the sea. Coastal AFAs do not have a downstream MPW associated with them.

In total, 56 km of HPW and 102 km of MPW have been modelled within UoM 30 and 31, along with the coastline in Roundstone and Galway City.

¹ JBA Consulting (2014), Western CFRAM Unit of Management 30 and 31 - Corrib and Owengowla Hydrology Report, Final Report, Office of Public Works

² JBA Consulting (2012), Western CFRAM Unit of Management 30 and 31 - Corrib and Owengowla Inception Report, Final Report, Office of Public Works.

³ JBA Consulting (2012), Western CFRAM Flood Risk Review, Final Report, Office of Public Works.

⁴ JBA Consulting (2013), Western River Basin District Catchment-based Flood Risk Assessment and Management (CFRAM) Strategic Environmental Assessment, Scoping Report, Office of Public Works.

⁵ JBA Consulting (2013), Western CFRAM Defence Asset Database, Handover Report, Office of Public Works.
WCFRAM UoM 30-31 Volume 1b Hydromorphology and Coastal Erosion Assessment_v3.0.docx

2 Hydromorphology assessment methodology

2.1 Overview

The study has approached the investigation in two stages:

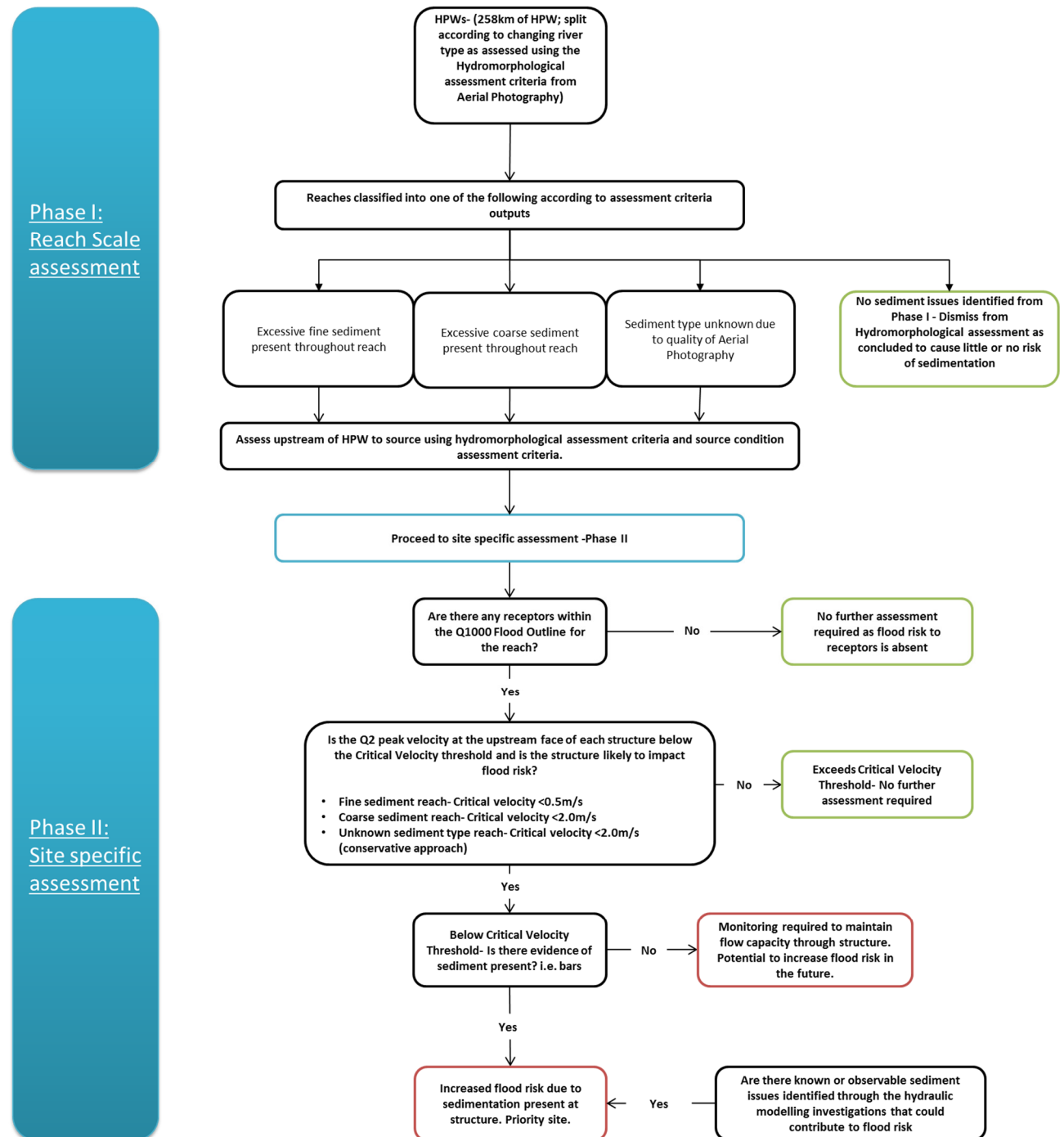
1. A catchment based hydromorphology audit which has identified key watercourses susceptible to sedimentation at a catchment scale.
2. A site specific assessment using the outputs from the hydromorphology audit along with the knowledge of the sites developed as part of the hydraulic modelling investigations to identify key structures along these watercourses where sedimentation could be relevant to flood risk.

This information has been supplemented by the finding of the asset inspection work, which highlighted where scour was present beneath structures.

The aim of this process therefore is to produce a hydromorphological assessment of the key watercourses informed by both available catchment data and local knowledge from across the project team.

The flow chart in Figure 2-1 summarises the stages of the hydromorphology appraisal and each stage is discussed in further detail in the following sections.

Figure 2-1: Flow chart of hydromorphology appraisal process



2.1.1 Phase I: Reach Scale assessment

All HPWs throughout Western CFRAM have been assessed using a Hydromorphological Assessment Criteria developed for this study allowing for categorisation of river types and sediment behaviour to be made about the rivers throughout WCFRAM. The assessment utilises readily available information including Aerial Photography (APs), soils maps and site photos. The Western River Basin Management Plan was reviewed for suitable information to support the analysis.

The Hydromorphological Assessment Criteria included the River Type, the activity of the channel, the vegetation in the floodplain and along the banks, the sediments in and outside of the channel and the evidence of historical activity.

HPWs have been taken forward to Phase II where the catchment assessment indicated the presence of excessive fine or coarse sediment. Where no sediment issues were determined by the desk based assessment no further analysis of the HPW has taken place. Where it was not possible to identify the sediment type due to poor quality data, a conservative approach has been adopted and the HPWs have been taken forward to the Phase II part of the assessment.

All watercourses, with the exception of those where no sediment issues were observed, have then been traced to their source to determine the source condition and to provide a wider understanding of system processes.

The Phase I assessment has identified 41 HPWs to take forward to the Phase II assessment.

2.1.2 Phase II: Site specific assessments

All HPWs identified from Phase I have been taken forward to Phase II in order to provide a deeper understanding of local issues associated with the watercourses susceptible to sedimentation. This identified those structures or channels where sedimentation could lead to increased flood risk to surrounding receptors with flood risk being the primary driver.

Initially the 0.1% AEP flood extent developed as part of the hydraulic modelling work has been used as a screening tool to identify sites where there are local flood risk receptors. Whilst high levels of blockage at a structure from sedimentation could result in a larger flood risk extent, a detailed blockage analysis is outside the scope of the study and so has not been undertaken as part of the hydraulic modelling investigations. The 0.1% AEP extent is therefore considered to be a reasonable proxy for the implications of increased sedimentation in lower order events and allows the study to focus only on those sites where sedimentation is most likely to affect flood risk.

Where there are receptors within the 0.1% AEP flood extent along the watercourse, then the peak velocity from the 50% AEP event (seen as a typical 'bankful' or geomorphologically effective flow) has been extracted from the hydraulic modelling results at the upstream face of key structures. This has been compared against the critical velocities extracted from the Hjulström curve for the dominant sediment type on each watercourse. Where the modelled velocities do not exceed the critical velocity, deposition of sediment is assumed to be likely to occur leading to a reduction in the capacity of the structure over time and hence an increase in flood risk.

A final stage has reviewed photos of the key structures identified to confirm if sedimentation is apparent at the site at the date taken. Where there is visible evidence at the identified structure the structures have been flagged as priority sites, (and are shown on the associated maps in red) where there is not visible evidence at the identified structure, it has been flagged for monitoring only (these sites are shown on the associated maps in green).

This review of the catchment audit HPWs has been supplemented using the local knowledge available within the project team developed through the study to date and in particular as part of the hydraulic modelling investigations, or from other sources such as Local Authorities. This allows for problems that may not have been picked up in the catchment scale approach to be identified. For example, sedimentation may have been observed at key structures from survey data or site photographs which is causing flooding or concerns may have been raised by local authorities which were screened out in the broad catchment scale approach.

In each case, the structures identified have been assessed using the same Phase II assessment criteria to determine if they are likely to increase flood risk to surrounding receptors. That is if a

structure has been observed with sedimentation issues in an entirely rural area, based on the 0.1% AEP flood extent, then it will not have been flagged as a priority structure in the associated maps.

3 Hydromorphology results

3.1 Mapping Outputs

The results of the hydromorphology assessment, including the findings of the Phase 1 assessment are presented in the AFA specific maps presented in Appendix A at the end of this report.

The findings of Phase 1 are presented in the line colour and line style of each watercourse assessed. The line colour dictates the sediment characteristic of the reach of interest, i.e. the reach within the AFA boundary. The line style dictates the source condition of the reach of interest, i.e. the likelihood of the upstream watercourse to carry sediments to the AFA.

The OPW arterial drainage schemes are also presented on these maps. This information can be important to understand where, despite the hydromorphology audit highlighting a watercourse with high risk of sedimentation, there are no observed sedimentation effects or high priority structures identified. Such watercourses could have had problems historically which are now resolved as a result of the maintenance regime. Examples of such findings are Swinford and Athenry.

The findings of the assessment are presented on the accompanying maps as "high priority" or "for monitoring only". High priority structures are those where there are known and observed sedimentation issues. Structures for monitoring are those where there are no observed problems but the catchment audits and flow velocities suggest sediment build up is likely to be a problem in the long term.

Furthermore receptors that are likely to be susceptible to high levels of sediments in the water have been overlain on the maps. These include Special Areas of Conservation (SACs), Special Protection Areas (SPAs), existing and proposed National Heritage Areas (NHAs and pNHAs) and relevant Annex IV sites. The Annex IV sites have excluded groundwater zones but include shellfish and salmonid watercourses.

Table 3-1 below shows the legend used in the mapping outputs and provides an explanation of how the results of the hydromorphology assessment have been translated into a graphical format.

Table 3-1: Mapping output legend and explanation




Map Legend	Explanation
<p>Legend</p> <p>Phase 1 Findings User Note: Phase 1 findings include both the Sediment Characteristic and the Source Condition and as such are presented through both the line colour and style.</p> <p>Sediment characteristic</p> <ul style="list-style-type: none"> Coarse sediment reach Fine sediment reach Sediment type unknown- Proceed to Phase II No sediment issues identified from Phase I <p>Source Condition</p> <ul style="list-style-type: none"> Stable or no upstream watercourse Incised but stable Incised valley bottom with reworking Extensive valley side inputs <p>Phase 2 Findings</p> <ul style="list-style-type: none"> High Priority Structures Structures for Monitoring Only <p>Supporting Information</p> <ul style="list-style-type: none"> Structures with Scour AFA Boundary WFD Annex IV Sites WFD Annex IV Sites WFD Annex IV Sites National Heritage Areas Proposed Natural Heritage Areas Special Area of Conservation Special Protection Areas Arterial drainage schemes 0.1% AEP Fluvial Extent 	<p>Phase 1 Findings The findings of Phase 1 are presented in the dashed box and are presented in the map itself as a single line of varying colour and style. The sediment characteristic of the watercourse within the AFA boundary is represented by the colour of the line. The source condition, associated with the relevant watercourse upstream of the AFA boundary, is represented by the style of the line. Therefore a fine sediment reach with an incised but stable source condition will be represented on the map as a yellow dashed line.</p> <p>Phase 2 Findings The findings of Phase 2 of the assessment are represented in the coloured points (red or light orange) situated at relevant structures. The red points are high priority structures and have been identified as having observable sedimentation issues. The light orange structures are for monitoring only; these have been identified through the hydromorphology assessment as being susceptible to sedimentation but for various reasons, such as arterial drainage schemes, no sedimentation issues have been observed at the site.</p> <p>Supporting Information Further data to support the analysis is shown in the supporting information. This includes details of OPW's arterial drainage schemes, the findings of the asset condition assessment and a range of environmental receptors.</p>

3.2 Structures identified from hydromorphology appraisal

The results of the overall assessment have led to individual structures being identified as being high risk of sedimentation which increase flood risk to receptors. The results and node locations of individual structures from the hydromorphology assessment are presented in Table 3-2 and Table 3-3.

Table 3-2 details those high priority structures identified from the catchment based hydromorphology audit. Table 3-3 details those high priority structures where sedimentation is not associated with reach scale deposition but is rather a local risk associated with the channel in the vicinity of the structure. Table 3-4 shows those structures along the reaches identified from the catchment based hydromorphology audit where velocities suggested sedimentation may be an issue but no evidence of sedimentation was observed at the structures.

Table 3-2: Structures at risk of sedimentation from reach scale sedimentation processes

Location	Comments from site specific assessment	Photo
Galway, Castlegar watercourse, 30CAST00397	Fine sediment reach supported by extracted velocity data and local evidence of sedimentation.	
Galway, Castlegar watercourse, 30CAST00302	Fine sediment reach supported by extracted velocity data and local evidence of sedimentation.	
Galway, Castlegar watercourse, 30CAST00115	Fine sediment reach supported by extracted velocity data and local evidence of sedimentation.	








Location	Comments from site specific assessment	Photo
Galway, Castlegar watercourse, 30CAST00085	Fine sediment reach supported by extracted velocity data and local evidence of sedimentation and vegetation	
Galway, Castlegar watercourse, 30CAST00034	Fine sediment reach supported by extracted velocity data and local evidence of sedimentation.	
Galway, Castlegar watercourse, 30CAST00017	Fine sediment reach supported by extracted velocity data and local evidence of sedimentation and vegetation.	

Table 3-3: Structures at risk of sedimentation from local scale sedimentation processes

Location	Comments from site specific assessment	Photo
Ballyhaunis, Curraghfore watercourse, 30CURR00033	Vegetated bar in channel. Channel through this reach has been artificially straightened and over-widened. Shallower depths resulting in build-up of sediment in centre of channel.	
Ballyhaunis, Dalgan, 30DALG02200	Heavily vegetated channel. Channel downstream of this reach has been artificially straightened and over-widened. Lower velocities resulting in build-up of sediment encouraging plant and weed growth in the channel.	
Ballyhaunis, Devils, 30DEVL00011	Heavily vegetated channel. Channel upstream of this reach has been artificially straightened and over-widened. Lower velocities upstream resulting in build-up of sediment encouraging plant and weed growth in the channel.	
Galway, Nun's Island, 30NUNS00043	Vegetated bar on right bank of channel. The whole channel is heavily modified and over-widened. Lower velocities downstream of Bergers Bridge have resulted in build-up of sediment encouraging plant and weed growth in the channel.	


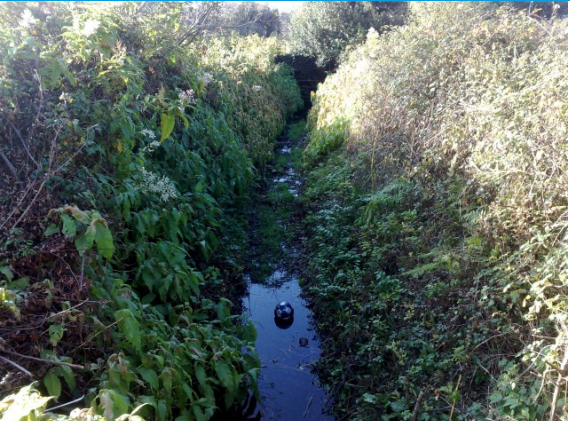
Location	Comments from site specific assessment	Photo
Oughterard, Owenriff, 30ORIF00203	Gravel bar on right bank. Widened channel upstream of bridge resulting in reduced flows. Downstream structure appears reasonably clear so minor issue only.	
Oughterard, Tonweeroe, 30TONW00016	Heavily vegetated channel. Channel upstream of this reach has been artificially straightened and is heavily incised. Structure at downstream of this reach likely reducing flows resulting in sediment deposition and plant growth in the channel.	

Table 3-4: Structures to be monitored for sedimentation from reach scale sedimentation processes

Location	Comments from site specific assessment	Photo
No structures identified in UoM 30 and 31		

4 Hydromorphology summary

This study has completed a preliminary assessment of the hydromorphological issues with respect to flood risk only.

A catchment wide analysis using geomorphic auditing principles, analysing the watercourses for sediment loading, has identified sources and pathways of sedimentation. The findings of this analysis, presented in the accompanying maps, are river systems susceptible to sedimentation. In addition to supporting the identification of key structures where sedimentation is critical to flood risk, this work has also been beneficial to flag those sites where there may be a problem in the future but for reasons, such as the OPW arterial drainage programme, there is currently no risk of flooding resulting from sedimentation.

Using the knowledge from the catchment wide analysis and built up through the hydraulic modelling work completed as part of the WCFRAM, all AFAs have been ground truthed. The findings of the ground truthing have identified those structures where flood risk from sedimentation is a current issue, either as a result of catchment wide sedimentation processes or as a result of local conditions in the vicinity of the structure. Sites where, based on velocity data and the reach scale assessment, there may be a problem in the future have also been flagged for monitoring.

The approach to the assessment reflects the different causes of sediment build up. The hydromorphology audit has identified sensitive watercourses, such as the Castlegar in Galway. The ground truthing builds on the hydromorphology audit but also allows local reach processes, such as straightening and widening, to be flagged.

Table 4-1 summarises the findings of the assessment for each AFA and provides recommendations for the incorporation of the findings into future analysis, within and without the WCFRAM, based on an understanding of the broader flood risk management issues.

Table 4-1: Summary of findings and recommendations for each AFA

AFA	Reach in potential deposition from audit	Historic issues with sediments and erosion	Arterial Drainage active in this AFA	Sites where modelling and site surveys have identified sediment and erosion	Conclusion	Recommendations for further consideration		
						Structures where modelling of long term impacts of sedimentation should be considered in the FRMP	Watercourses /sites to include in maintenance regime	Watercourses where scheme works may be required and would need to seek hydromorphic support in SEA
Ballyhaunis	Yes	No known issues.	Yes	30CURR00033, 30DALG02200, 30DEVL00011.	Sediment is a reach level issue but is generally managed through the arterial drainage schemes. Flood risk is exacerbated by sedimentation at a limited number of key structures.	30CURR00033, 30DALG02200, 30DEVL00011.	Curries, Devlis and Dalgan.	Curries, Devlis and Dalgan in the vicinity of the structures identified.
Corrofin	Yes	No known issues.	No	No key structures identified with current sediment issues.	No evidence of sediment issues associated with flood risk.	None	None	None
Galway City	Yes	Canals in Galway, especially in the Western Canal System, are heavily silted. The Castlegar is silted to some degree. The Upper Corrib has some evidence of shoaling. The loop around Jordans Island is thought to have deteriorated over recent years.	Yes	30NUNS00043, 30CAST00397, 30CAST00302, 30CAST00115, 30CAST00085, 30CAST00034, 30CAST00017.	Sediment is a reach level issue within the AFA with flood risk particularly a concern along the Castlegar watercourse. The canals do not show significant flood risk at the moment but the current situation could worsen.	None	Castlegar River	Upper Corrib, Castlegar River, Canal systems.
Oughterard	No	The Owenriff was reported to be heavily modified in the 1970s by blasting of the bedrock deepening the river	Yes	30ORIF00203, 30TOWN00016.	Sediment is a local issue only with flood risk exacerbated by local channel modifications encouraging deposition.	30TOWN00016	Tonwee	Locally around structures only.

AFA	Reach in potential deposition from audit	Historic issues with sediments and erosion	Arterial Drainage active in this AFA	Sites where modelling and site surveys have identified sediment and erosion	Conclusion	Recommendations for further consideration		
						Structures where modelling of long term impacts of sedimentation should be considered in the FRMP	Watercourses /sites to include in maintenance regime	Watercourses where scheme works may be required and would need to seek hydromorphic support in SEA
		channel.						
Tuam	No	No known issues.	Yes	No key structures identified with current sediment issues.	Sediment is a reach level issue but is generally managed through the arterial drainage schemes. Flood risk is potentially exacerbated by sediment at multiple locations along the watercourse but risk has been managed so will need to be monitored over time.	None	Suileen	None
Roundstone	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

5 Coastal erosion assessment background

5.1 Scope

The project brief requires the assessment to build on the work completed as part of the Irish Coastal Protection Strategy Study (ICPSS) and develop erosion prediction lines within AFAs at risk from coastal flooding for the Medium Range Future Scenario (MRFS) and High End Future Scenario (HEFS) for 2050 and 2100.

5.2 Available Data

5.2.1 ICPSS

The coastline of the WCFRAM is covered by Phase 4⁶, the West Coast, and Phase 5⁷, the North West Coast, of the ICPSS. The hazard maps for these areas were completed in January 2014.

The ICPSS presents two predictive erosion maps representing the future location of the coastline in 2030 and 2050. These maps have been generated from observed erosion rates extracted from historical mapping and aerial photography. The position of the coastline was compared in two time periods reflecting the data available, the starting point for the analysis was aerial photography from between 1973 and 1975 and the end point for the analysis was aerial photography from 2000 for the west of Ireland. The calculated erosion rates therefore represent the change over a period of approximately 25 years.

A baseline for the existing coastline has been derived from data for the year 2000. Predictive erosion lines have then been extrapolated from the baseline inland using the historically observed erosion rates with no additional allowance for climatic factors such as sea level rise.

Historic erosion rates have been developed typically for reaches of approximately 25m in length for the entire WCFRAM coastline. This dataset has been supplied for use in the development of future scenario erosion lines.

The ICPSS maps were produced at a strategic level only and the report recommends that these lines should not be used in place of detailed local erosion hazard and risk assessment. Furthermore, the study assumes that defences currently in situ will continue to be maintained into the future.

5.2.2 Climate Change Scenarios

The climate change scenarios, the MRFS and HEFS, have been specified in the project brief and are considered to be applicable for future changes to 2100.

- The MRFS is intended to represent a 'likely' future scenario, based on the wide range of predictions available with the allowances for sea level rise etc. within the bounds of widely accepted projections.
- The HEFS is intended to represent a more extreme potential future scenario, but one that is nonetheless not significantly outside the range of accepted predictions available, and with the allowances for sea level rise, etc. at the upper bounds of widely accepted projections.

Two elements of the climate change scenarios are applicable to the analysis of coastal erosion, sea level rise and land movement. The sea level rise climate change scenarios are an increase in levels of 0.5m and 1m in the MRFS and HEFS respectively. Land movement changes are only applicable for coastal sites south of the Galway to Dublin line; therefore, this does not apply to any AFAs within UoM 30-31.

Increases in sea levels of 0.5m and 1.0m will be applied for the MRFS and HEFS respectively.

⁶ Irish Coastal Protection Strategy Study, Phase 5 – North West Coast, Work Packages 2, 3 & 4A – Appendix 4 – Erosion Mapping, The Office of Public Works, January 2014.

⁷ Irish Coastal Protection Strategy Study, Phase 4 – West Coast, Work Packages 2, 3 & 4A – Appendix 4 – Erosion Mapping, The Office of Public Works, January 2014.

6 Coastal erosion assessment analysis


6.1 Review of existing ICPSS data

The coastal erosion hazard analysis for the WCFRAM is limited to within the boundary of the AFAs only. The coastal AFAs within the UoM 30-31 consist of Galway City and Roundstone.

The baseline date for the ICPSS existing coastline is set to the year 2000 and appears to have been based on data from that period. Digital aerial photography is now available online from as late as 2012 for the West of Ireland. A review of the ICPSS existing coastline was made against this latest dataset, paying particular attention to those sites where historical erosion had been observed, Table 6-1.

Without the aerial imagery from 2000 it has been difficult to validate the observed changes in locations. The following table summarises the findings of this review. The findings indicate confirmed observable erosion risk since the year 2000 is present in the rural areas around Galway only.

Table 6-1: Review of ICPSS outputs against latest aerial imagery

Site	Description of change
Galway City	<p>The two sites highlighted to the west coincide with predicted sites of erosion in the ICPSS study. The changes are relatively minor and it is possible coastal protection works have been undertaken on the eastern of the two sites. Minor erosion is shown in the eastern location although this could be a result of image quality in this location. It is also noted that the coastline of the harbour area has changed as a result of recent development, this is not shown on the map below.</p> 
Roundstone	No change.

The hazard prediction lines for 2030 and 2050 from the ICPSS have been extracted and plotted in the maps at the end of the report.

The outputs from the ICPSS study show Galway City has seen some coastal retreat over this period.

UK Climate Projections⁸ reports that average sea levels around the UK are rising on average approximately 1mm/yr although this rate has increased since 1990. This suggests the observed changes already incorporate a degree of sea level rise.

⁸ Jenkins, G.J., Perry, M.C., and Prior, M.J. (2008). The climate of the United Kingdom and recent trends. Met Office Hadley Centre, Exeter, UK.

6.2 Methodology

It is accepted that coastal erosion into the future will be impacted by rising sea levels. The increase in water depth offshore will support increased wave heights which, in conjunction with increasing storm frequency will increase erosion rates at any given site. Erosion rates at a given site however will not be dictated by sea level rise alone. Of equal or greater importance are the sediment transport processes in action along the shoreline both on a local and on a regional basis. It is quite possible that along with sea level rise, the shoreline continues to progress seawards where sediment deposition is sufficient. Furthermore the existing sediment transport processes cannot be assumed to continue to operate as understood currently; the effect of the local topography as well as changes in storminess and hence wave heights and wave direction resulting from climate change will also contribute to the equation. In this context therefore the coastline in any given location must be understood as a site specific dynamic system that will redistribute sediments in response to its own range of influences. A search undertaken to identify literary sources for sediment transport in coastal waters, and thereby the influence of sediments at the sites of interest, across the west of Ireland found no available information. This would appear to be an area where further research is required.

The level of data required to determine coastal erosion lines into the future with any degree of confidence is not available. Simplified approaches as proposed in the project brief, such as the Bruun Rule, are also considered to be unreliable for the reasons stated above and so have not been taken forward.

Instead to fulfil the requirements of the brief the study has focussed on discussion of local landform and its likely influence on coastal erosion. A risk based approach has been applied to determine the likelihood of future erosion based on the historical erosion rates available, the prevalence of the wave climate and the observed shoreline material in each case. As with the ICPSS study it has been assumed that where existing coastal protection works are in place, these will continue to be maintained. Similarly, where there are existing structures which would need to be abandoned or moved for further coastal erosion to occur, it has been assumed that these will continue to be protected.

Four risk categories have been defined for the analysis as follows:

- Low Risk – Active management of the shoreline is likely to protect key assets.
- Moderate Low Risk – Tide dominated environment. No observed erosion over the last 30 years, however no active management of the shoreline is likely.
- Moderate High Risk - Wave dominated environment. No observed erosion over the last 30 years, however no active management of the shoreline is likely.
- High Risk – Erosion has been observed over the last 30 years and there is no active management of the shoreline expected in this location to prevent further erosion.

It is noted that because of the approach adopted there can be no differentiation between the risk associated with the MRFS and the HEFS and the risk boundaries are considered to be applicable to both.

6.3 Findings

Table 6-2 provides a summary of the findings of the analysis and this is also presented in the attached maps in Appendix B.

Table 6-2: Summary of coastal erosion risk categorisation

AFA	Brief Description of Site	Risk Categorisation
Galway City	Manmade coastal frontage to the west of the Corrib and mix of manmade coastal and limestone till shoreline to the east. Some observed erosion has occurred to the east of the Corrib. Erosion protection works are now in place in some of these areas.	Low Risk for manmade reaches, high risk for remaining sites.
Roundstone	Granite till and rock shoreline to the south, manmade coastal frontage to the north. No observed erosion.	Low Risk for manmade reaches, moderate low risk for remaining sites.

6.4 Recommendations

Taking the findings of the screening assessment forward focus for further investigations should be on those areas where there is moderate high or high risk of coastal erosion. Within UoM 30-31 this consists of Galway only. It is noted there is no immediate risk of coastal erosion impacts on property in Galway.

High level methodologies are not appropriate for these further investigations. A more detailed approach is required, which is beyond the scope of the WCFRAM study. It is recommended the modelling undertaken for the ICPSS be used as a base dataset to extend the assessment of coastal erosion potential.

The ICPSS used the MIKE21 SW package and outputs include wave conditions and the associated radiation stresses in the surf zone, from which the wave-induced currents can be derived. The long shore currents and the sediment transport can then be calculated using the MIKE21 flow and sediment transport modules. This approach may not give a direct indication of shoreline regression but will at least provide an indication of changes in shoreline vulnerability, through changes in radiation stresses, during the climate change scenarios; particularly when matched against the previously identified high risk coastal erosion sites.

The ICPSS results include wave conditions at 3 of the 7 moderately high or high risk coastal erosion sites that have been identified in the Western CFRAM study area. The ICPSS also assumed the coastline remains constant and the existing sea defences will be maintained. Further work should be undertaken to extend beyond these assumptions, such as calibration of the wave model against recorded/observed wave data, and concurrent wind data, for an extended period (at minimum including a winter period). This would give some confidence in the models capability to reproduce current conditions, and therefore it's probable capability at predicting future conditions. Without calibration data the best that can be achieved is a reality check on the propagation of the waves applied at the boundaries. It is therefore a priority that the availability of calibration data be reviewed and additional data collection be undertaken if required.

Where there is the potential erosion to impact on an AFA it is recommended that a bespoke model is produced, not tied into the ICPSS licencing restrictions, and a local assessment of nearshore currents and sediment processes undertaken. For example, the model could be developed using the suite of modules such as the Deltares Delft3D software package, namely FLOW⁹ (hydrodynamics and sediment) and SWAN¹⁰ (Waves). Delft3D is a leading computer package that is used to numerically simulate tides, storm surges, currents, waves, transport, morphology, water quality, ecology and biology in natural waters such as harbours, rivers, lakes, reservoirs and coastal seas. It has been developed, calibrated and validated for a large number of applications for marine waters, estuaries and rivers and combinations of these.

⁹ FLOW is a multi-dimensional (2D or 3D) hydrodynamic (and transport) simulation program which calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing on a rectilinear or a curvilinear, boundary fitted grid.

¹⁰ SWAN computes the evolution of random, short-crested waves in coastal regions with deep, intermediate and shallow water and ambient currents. The model accounts for propagation due to current and depth and represents the processes of wave generation by wind, dissipation due to whitecapping, bottom friction and depth-induced wave breaking and non-linear wave-wave interactions. Wave blocking by currents is also explicitly represented in the model.

7 Coastal erosion assessment summary

The Irish Coastal Protection Strategy Study (ICPSS) includes an assessment of predicted coastal erosion rates, which is based on observed shorelines, from either mapping or anecdotal sources. A suite of maps have been prepared and they can be referenced from <http://www.opw.ie/en/floodriskmanagement/floodanderosionmapping/icpss/>

A generic methodology to assess the potential for future coastal erosion was considered for the Western CFRAM study. Extending the observed rates as was undertaken for the ICPSS does not consider underlying geology and coastal processes. The Bruun Rule is typically applied in these situations, which is the first and best known model relating shoreline retreat to an increase in local sea level is that proposed by Per Bruun (1962). The Intergovernmental Panel on Climate Change reports that 1 cm rise in sea level erodes beaches about 1 m horizontally. This becomes a large issue for developed beaches that are less than 5 m from the ocean (IPCC, 1998).

There are acknowledged limitations in the application of the Bruun Rule, and it is considered applicable to small scale local sites. Over long stretches of coast, the Bruun rule and associated cross-shore transport models become complex. There has been a number of critiques e.g. Cooper and Pilkey (2004). It is limited to a sediment based cross shore process. For the coastal AFAs included in the Western CFRAM study area the Bruun rule is not applicable.

Instead a risk based approach has been applied to determine the likelihood of future erosion based on the historical erosion rates available, the prevalence of the wave climate and the observed shoreline material in each case.

Four risk categories have been defined for the analysis as follows:

- Low Risk – Active management of the shoreline is likely to protect key assets.
- Moderate Low Risk – Tide dominated environment. No observed erosion over the last 30 years, however no active management of the shoreline is likely.
- Moderate High Risk - Wave dominated environment. No observed erosion over the last 30 years, however no active management of the shoreline is likely.
- High Risk – Erosion has been observed over the last 30 years and there is no active management of the shoreline expected in this location to prevent further erosion.

Within UoM 30-31 Galway was classified as low risk for manmade reaches and, high risk for remaining sites and Roundstone was classified as low risk for manmade reaches and moderate low risk for remaining sites..

The findings of the screening assessment should be used to inform further investigations, with the focus on those AFAs where there is moderate high or high risk of coastal erosion. Within UoM 30-31 this consists of Galway only. It is noted there is no immediate risk of coastal erosion impacts on property in Galway.

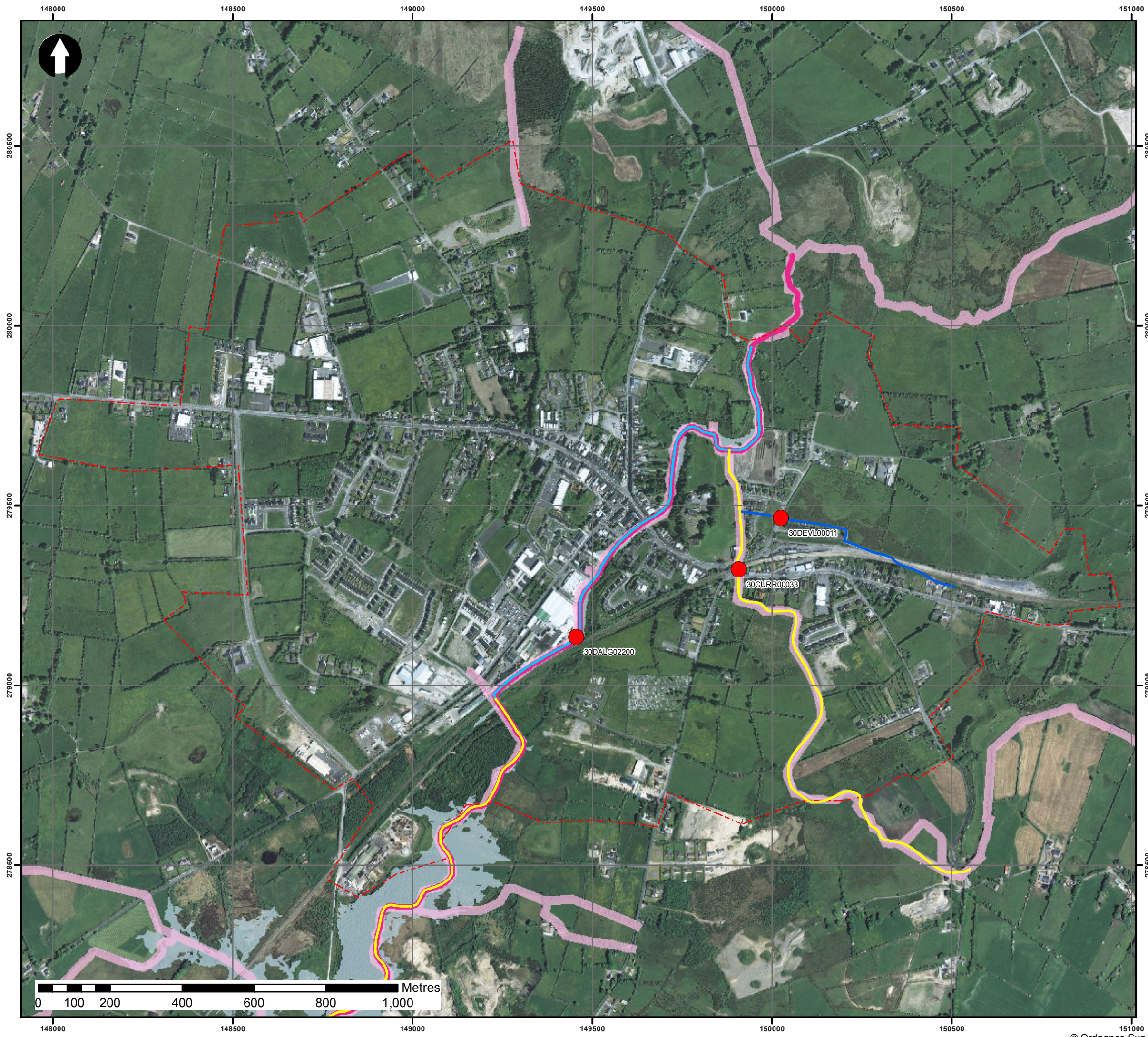
The level of detail required in these further investigations is beyond the scope of the WCFRAM study. It is recommended the modelling undertaken for the ICPSS be used as a base dataset to extend the assessment of coastal erosion potential. The long shore currents and the sediment transport can be calculated using the ICPSS flow and sediment transport modules. This will provide an indication of changes in shoreline vulnerability, through changes in radiation stresses, during the climate change scenarios; particularly when matched against the previously identified high risk coastal erosion sites.

Further work should be undertaken to extend beyond the ICPSS assumptions, such as calibration of the wave model against recorded/observed wave data, and concurrent wind data, for an extended period (at minimum including a winter period). Without calibration data the best that can be achieved is a reality check on the propagation of the waves applied at the boundaries. It is therefore a priority that the availability of calibration data be reviewed and additional data collection be undertaken if required.

Where there is the potential erosion to impact on an AFA it is recommended that a bespoke model is produced, not tied into the ICPSS licencing restrictions, and a local assessment of nearshore currents and sediment processes undertaken.

Appendices

A Hydromorphology maps



Legend
Phase 1 Findings
User Note: Phase 1 findings include both the Sediment Characteristic and the Source Condition and as such are presented through both the line colour and style.
Sediment characteristic
Coarse sediment reach
Fine sediment reach
Sediment type unknown- Proceed to Phase II
No sediment issues identified from Phase I
Source Condition
Stable or no upstream watercourse
Incised but stable
Incised valley bottom with reworking
Extensive valley side inputs
Phase 2 Findings
High Priority Structures
Structures for Monitoring Only
Supporting Information
Structures with Scour
AFA Boundary
WFD Annex IV Sites
WFD Annex IV Sites
WFD Annex IV Sites
National Heritage Areas
Proposed Natural Heritage Areas
Special Area of Conservation
Special Protection Areas
Arterial drainage schemes
0.1% AEP Fluvial Extent

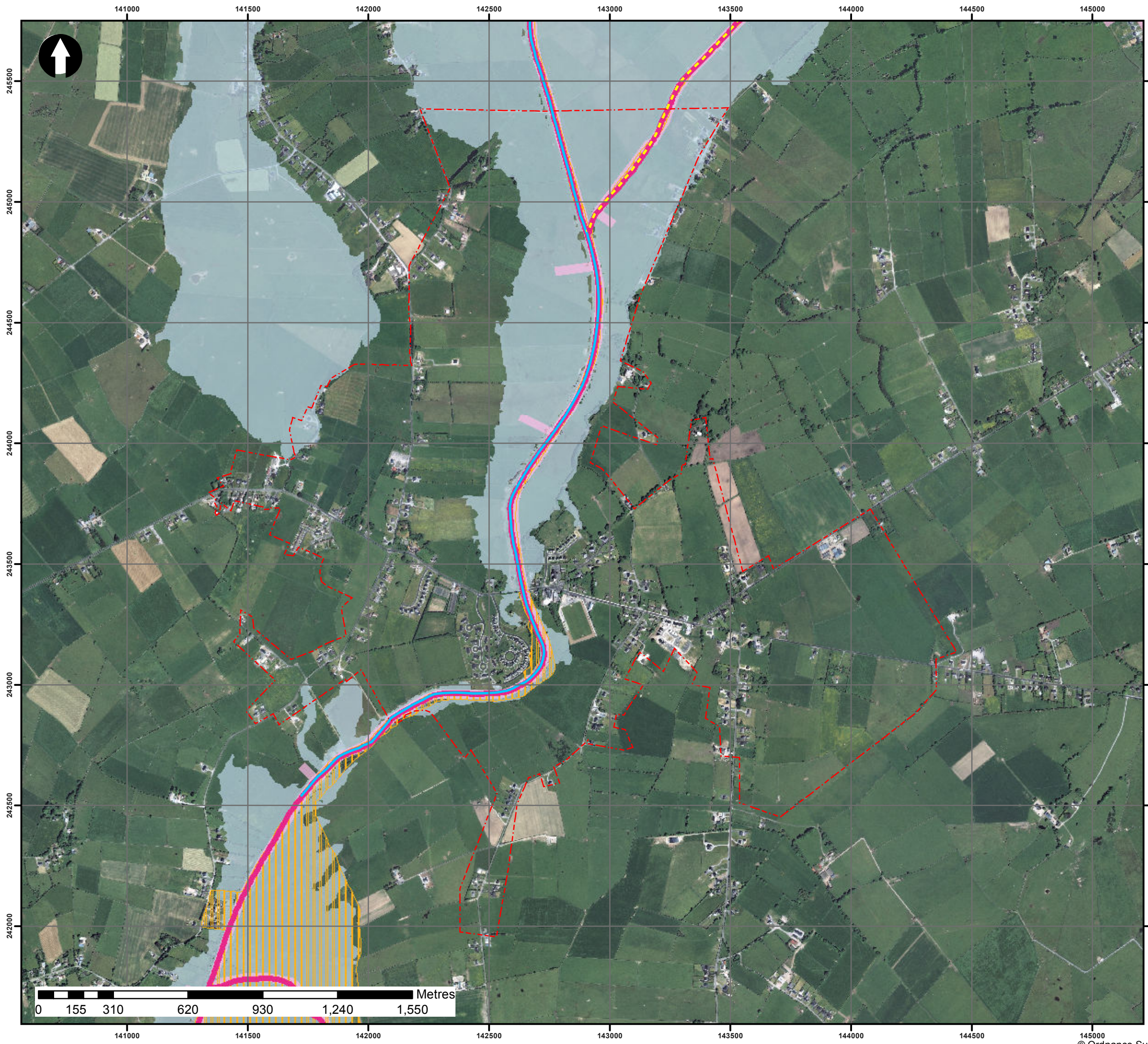
Important user note:
The viewer of this map should refer to the disclaimer guidance notes and conditions of use that accompany this map.
This draft map is for consultation purpose only and should not be used for any other purpose.

OPW
The Office of Public Works
Oifig na nOibreacha Poiblí
The Office of Public Works
Jonathan Swift Street
Trim
Co. Meath

JBA consulting
JBA Consulting
24 Grove Island
Corbally
Limerick, Ireland

WESTERN CFram STUDY
CATCHMENT FLOOD RISK ASSESSMENT AND MANAGEMENT

Map: Ballyhaunis	
Map Type: Hydromorphology Assement Results	
Map Area: HPW	
Drawn by: SW Date: Apr 2015	Scale: 1:10,000
Checked by: JNC Date: Apr 2015	
Approved by: SW Date: Apr 2015	Original @ A3
Map No: W30BLH_Hydromorphology_D_001	



Legend
Phase 1 Findings
User Note: Phase 1 findings include both the Sediment Characteristic and the Source Condition and as such are presented through both the line colour and style.
Sediment characteristic
Coarse sediment reach
Fine sediment reach
Sediment type unknown- Proceed to Phase II
No sediment issues identified from Phase I
Source Condition
Stable or no upstream watercourse
Incised but stable
Incised valley bottom with reworking
Extensive valley side inputs
Phase 2 Findings
High Priority Structures
Structures for Monitoring Only
Supporting Information
Structures with Scour
AFA Boundary
WFD Annex IV Sites
WFD Annex IV Sites
WFD Annex IV Sites
National Heritage Areas
Proposed Natural Heritage Areas
Special Area of Conservation
Special Protection Areas
Arterial drainage schemes
0.1% AEP Fluvial Extent

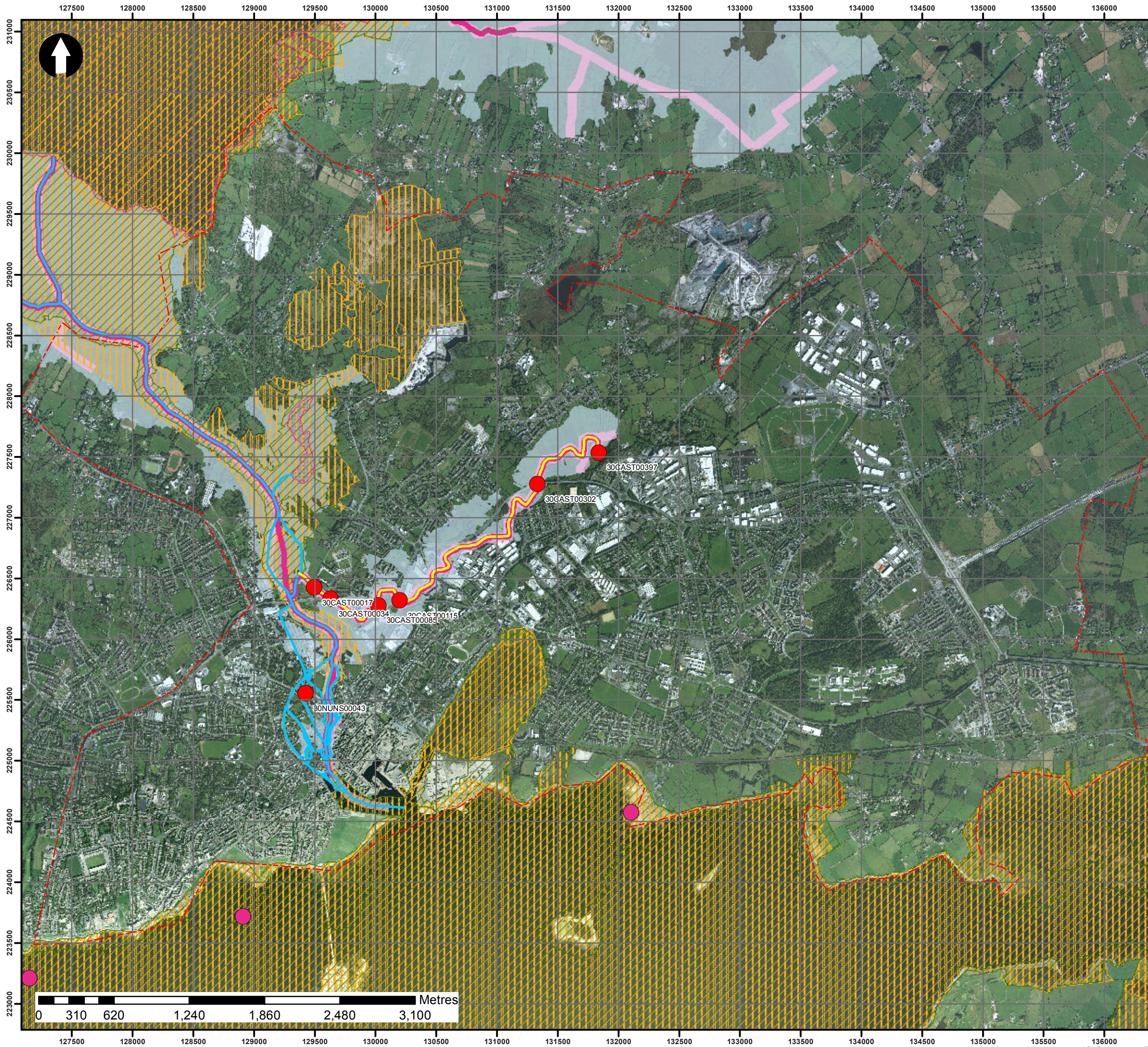
Important user note:
The viewer of this map should refer to the disclaimer guidance notes and conditions of use that accompany this map.
This draft map is for consultation purpose only and should not be used for any other purpose.

OPW
The Office of Public Works
Oifig na nOibreacha Poiblí
The Office of Public Works
Jonathan Swift Street
Trim
Co. Meath

JBA
consulting
JBA Consulting
24 Grove Island
Corbally
Limerick, Ireland

WESTERN
CFRAM
STUDY
CATCHMENT FLOOD RISK
ASSESSMENT AND MANAGEMENT

Map: Corrofin	
Map Type: Hydromorphology Assement Results	
Map Area: HPW	
Drawn by: SW Date: Apr 2015	Scale: 1:15,000 <small>Original @ A3</small>
Checked by: JNC Date: Apr 2015	
Approved by: SW Date: Apr 2015	
Map No: W30CRF_Hydromorphology_D_001	



Legend
Phase 1 Findings
User Note: Phase 1 findings include both the Sediment Characteristic and the Source Condition and as such are presented through both the line colour and style.
Sediment characteristic
Coarse sediment reach
Fine sediment reach
Sediment type unknown- Proceed to Phase II
No sediment issues identified from Phase I
Source Condition
Stable or no upstream watercourse
Incised but stable
Incised valley bottom with reworking
Extensive valley side inputs
Phase 2 Findings
High Priority Structures
Structures for Monitoring Only
Supporting Information
Structures with Scour
AFA Boundary
WFD Annex IV Sites
WFD Annex IV Sites
WFD Annex IV Sites
National Heritage Areas
Proposed Natural Heritage Areas
Special Area of Conservation
Special Protection Areas
Arterial drainage schemes
0.1% AEP Fluvial Extent

Important user note:
The viewer of this map should refer to the disclaimer guidance notes and conditions of use that accompany this map.
This draft map is for consultation purpose only and should not be used for any other purpose.

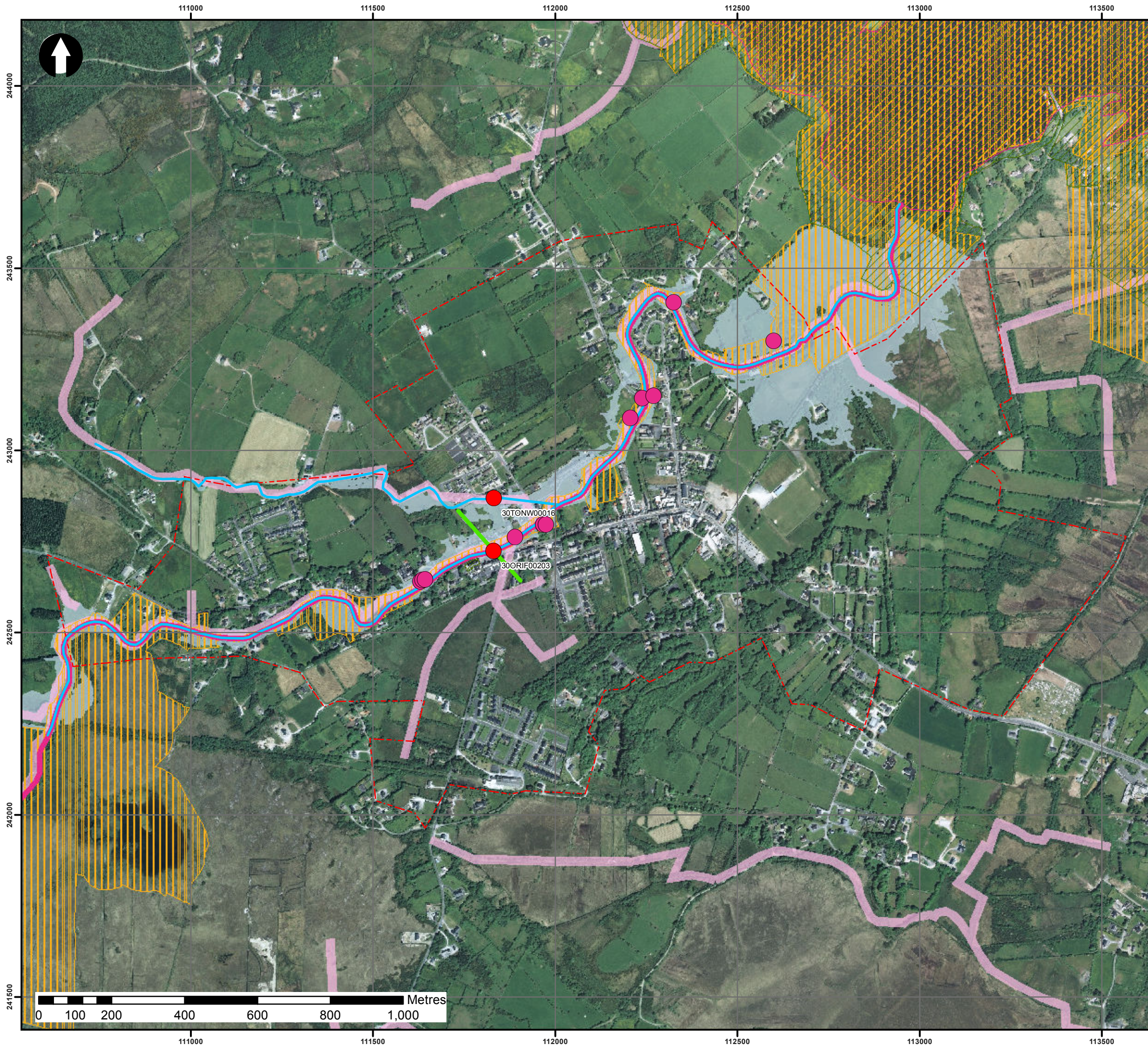
OPW
The Office of Public Works
Oifig na nOibreacha Poiblí
The Office of Public Works
Jonathan Swift Street
Trim
Co. Meath

JBA
consulting
JBA Consulting
24 Grove Island
Corbally
Limerick, Ireland

WESTERN
CFRAM
STUDY
CATCHMENT FLOOD RISK
ASSESSMENT AND MANAGEMENT


Map: Galway City
Map Type: Hydromorphology Assement Results

Map Area: HPW	Scale: 1:30,000 Original @ A3
Drawn by: SW Date: Apr 2015	
Checked by: JNC Date: Apr 2015	
Approved by: SW Date: Apr 2015	
Map No: W30GLW_Hydromorphology_D_001	




Legend
Phase 1 Findings
User Note: Phase 1 findings include both the Sediment Characteristic and the Source Condition and as such are presented through both the line colour and style.
Sediment characteristic
Coarse sediment reach
Fine sediment reach
Sediment type unknown- Proceed to Phase II
No sediment issues identified from Phase I
Source Condition
Stable or no upstream watercourse
Incised but stable
Incised valley bottom with reworking
Extensive valley side inputs
Phase 2 Findings
High Priority Structures
Structures for Monitoring Only
Supporting Information
Structures with Scour
AFA Boundary
WFD Annex IV Sites
WFD Annex IV Sites
WFD Annex IV Sites
National Heritage Areas
Proposed Natural Heritage Areas
Special Area of Conservation
Special Protection Areas
Arterial drainage schemes
0.1% AEP Fluvial Extent


Important user note:
The viewer of this map should refer to the disclaimer guidance notes and conditions of use that accompany this map.
This draft map is for consultation purpose only and should not be used for any other purpose.



The Office of Public Works
Jonathan Swift Street
Trim
Co. Meath

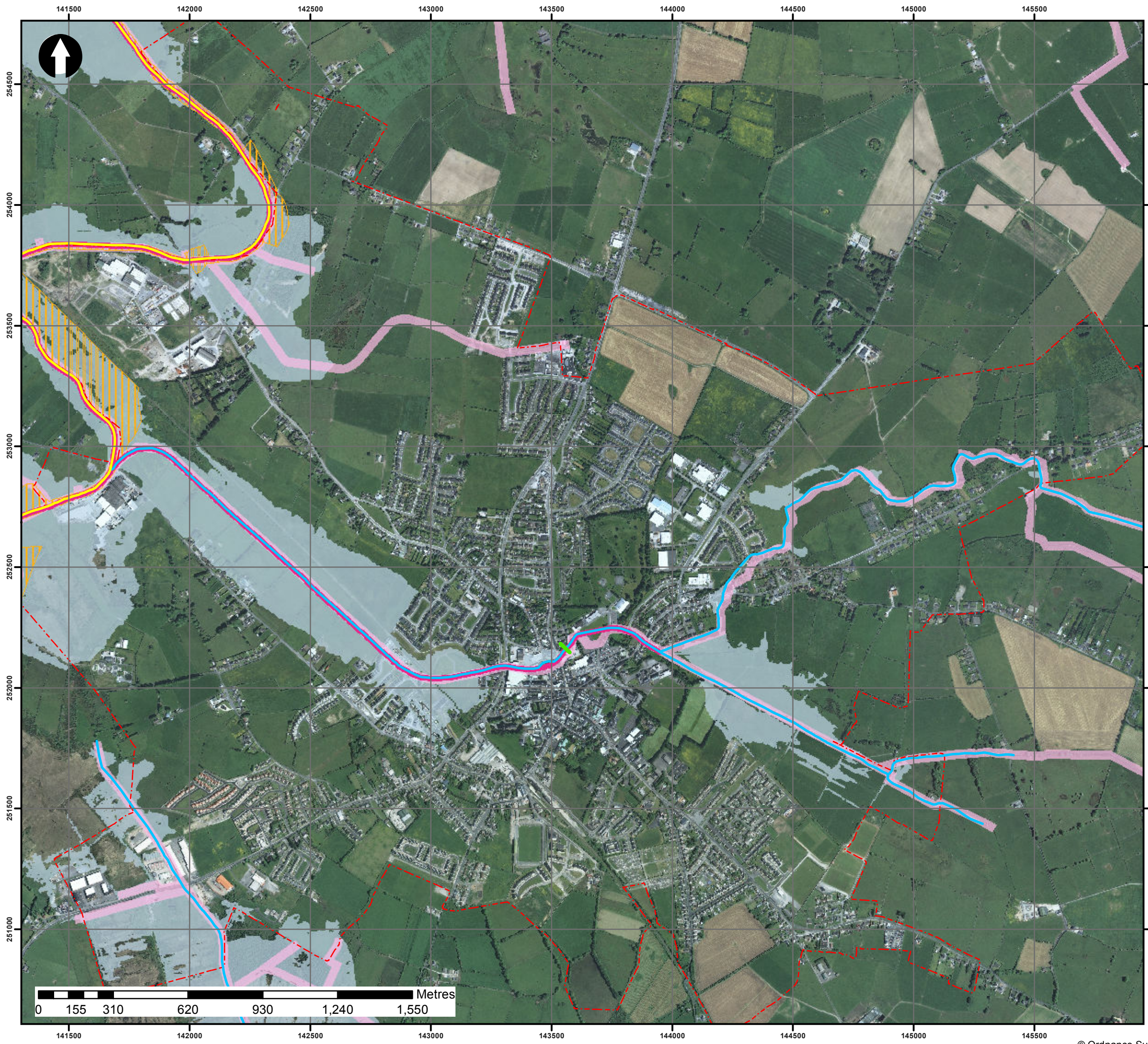


JBA Consulting
24 Grove Island
Corbally
Limerick, Ireland



WESTERN
CFRAM
STUDY
CATCHMENT FLOOD RISK
ASSESSMENT AND MANAGEMENT

Map: Oughterard	
Map Type: Hydromorphology Assement Results	
Map Area: HPW	
Drawn by: SW Date: Apr 2015	Scale: 1:10,000 Original @ A3
Checked by: JNC Date: Apr 2015	
Approved by: SW Date: Apr 2015	
Map No: W30OTD_Hydromorphology_D_001	



Legend
Phase 1 Findings
User Note: Phase 1 findings include both the Sediment Characteristic and the Source Condition and as such are presented through both the line colour and style.
Sediment characteristic
Coarse sediment reach
Fine sediment reach
Sediment type unknown- Proceed to Phase II
No sediment issues identified from Phase I
Source Condition
Stable or no upstream watercourse
Incised but stable
Incised valley bottom with reworking
Extensive valley side inputs
Phase 2 Findings
High Priority Structures
Structures for Monitoring Only
Supporting Information
Structures with Scour
AFA Boundary
WFD Annex IV Sites
WFD Annex IV Sites
WFD Annex IV Sites
National Heritage Areas
Proposed Natural Heritage Areas
Special Area of Conservation
Special Protection Areas
Arterial drainage schemes
0.1% AEP Fluvial Extent

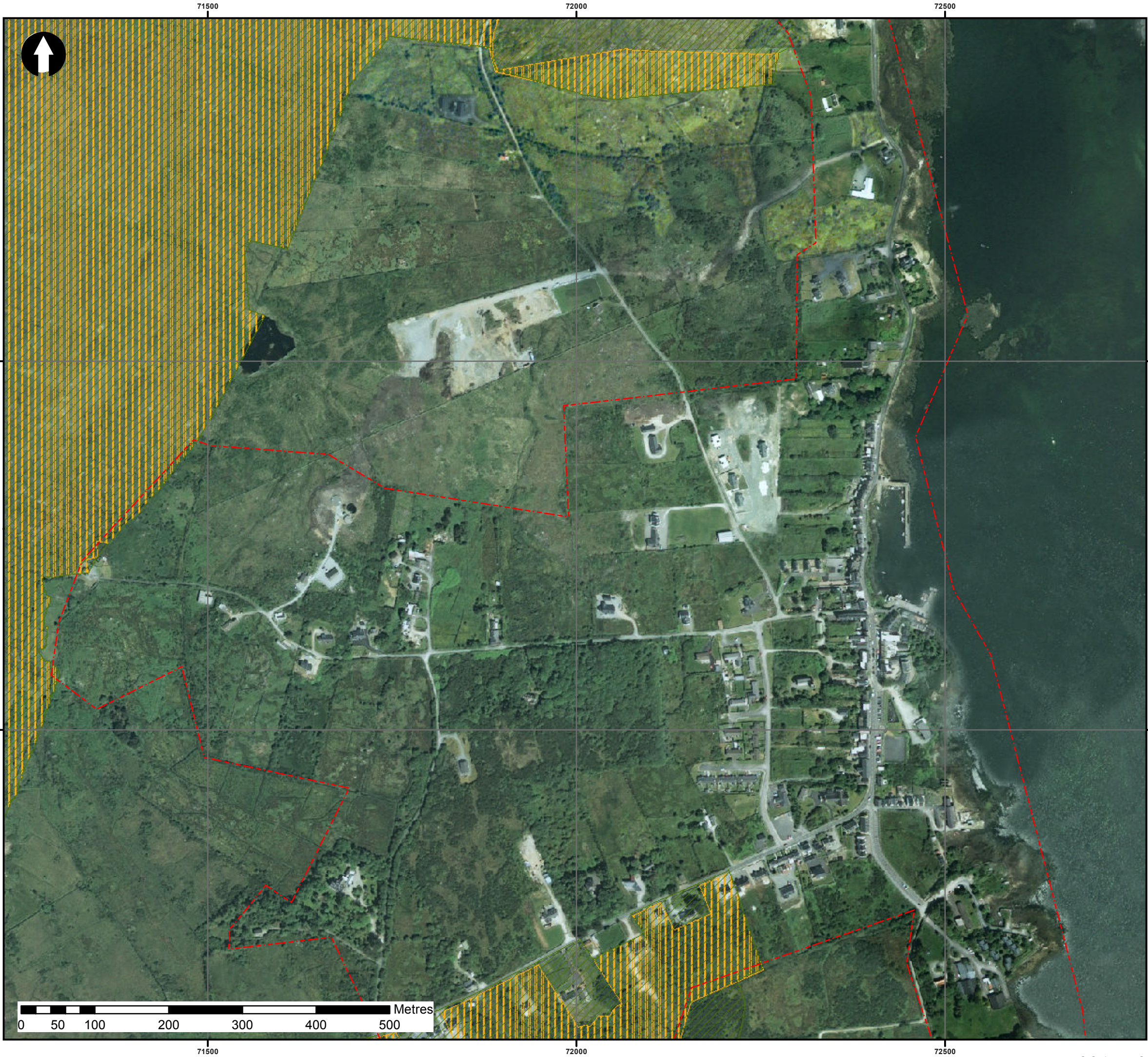
Important user note:
The viewer of this map should refer to the disclaimer guidance notes and conditions of use that accompany this map.
This draft map is for consultation purpose only and should not be used for any other purpose.

OPW
The Office of Public Works
Oifig na nOibreacha Poiblí
The Office of Public Works
Jonathan Swift Street
Trim
Co. Meath

JBA
consulting
JBA Consulting
24 Grove Island
Corbally
Limerick, Ireland

WESTERN
CFRAM
STUDY
CATCHMENT FLOOD RISK
ASSESSMENT AND MANAGEMENT

Map: Tuam	
Map Type: Hydromorphology Assement Results	
Map Area: HPW	
Drawn by: SW Date: Apr 2015	Scale: 1:15,000 Original @ A3
Checked by: JNC Date: Apr 2015	
Approved by: SW Date: Apr 2015	
Map No: W30TUM_Hydromorphology_D_001	



Legend
Phase 1 Findings
User Note: Phase 1 findings include both the Sediment Characteristic and the Source Condition and as such are presented through both the line colour and style.


Sediment characteristic
Coarse sediment reach
Fine sediment reach
Sediment type unknown- Proceed to Phase II
No sediment issues identified from Phase I

Source Condition
Stable or no upstream watercourse
Incised but stable
Incised valley bottom with reworking
Extensive valley side inputs


Phase 2 Findings
High Priority Structures
Structures for Monitoring Only

Supporting Information
Structures with Scour
AFA Boundary
WFD Annex IV Sites
WFD Annex IV Sites
WFD Annex IV Sites
National Heritage Areas
Proposed Natural Heritage Areas
Special Area of Conservation
Special Protection Areas
Arterial drainage schemes
0.1% AEP Fluvial Extent


Important user note:
The viewer of this map should refer to the disclaimer guidance notes and conditions of use that accompany this map.
This draft map is for consultation purpose only and should not be used for any other purpose.



The Office of Public Works
Jonathan Swift Street
Trim
Co. Meath



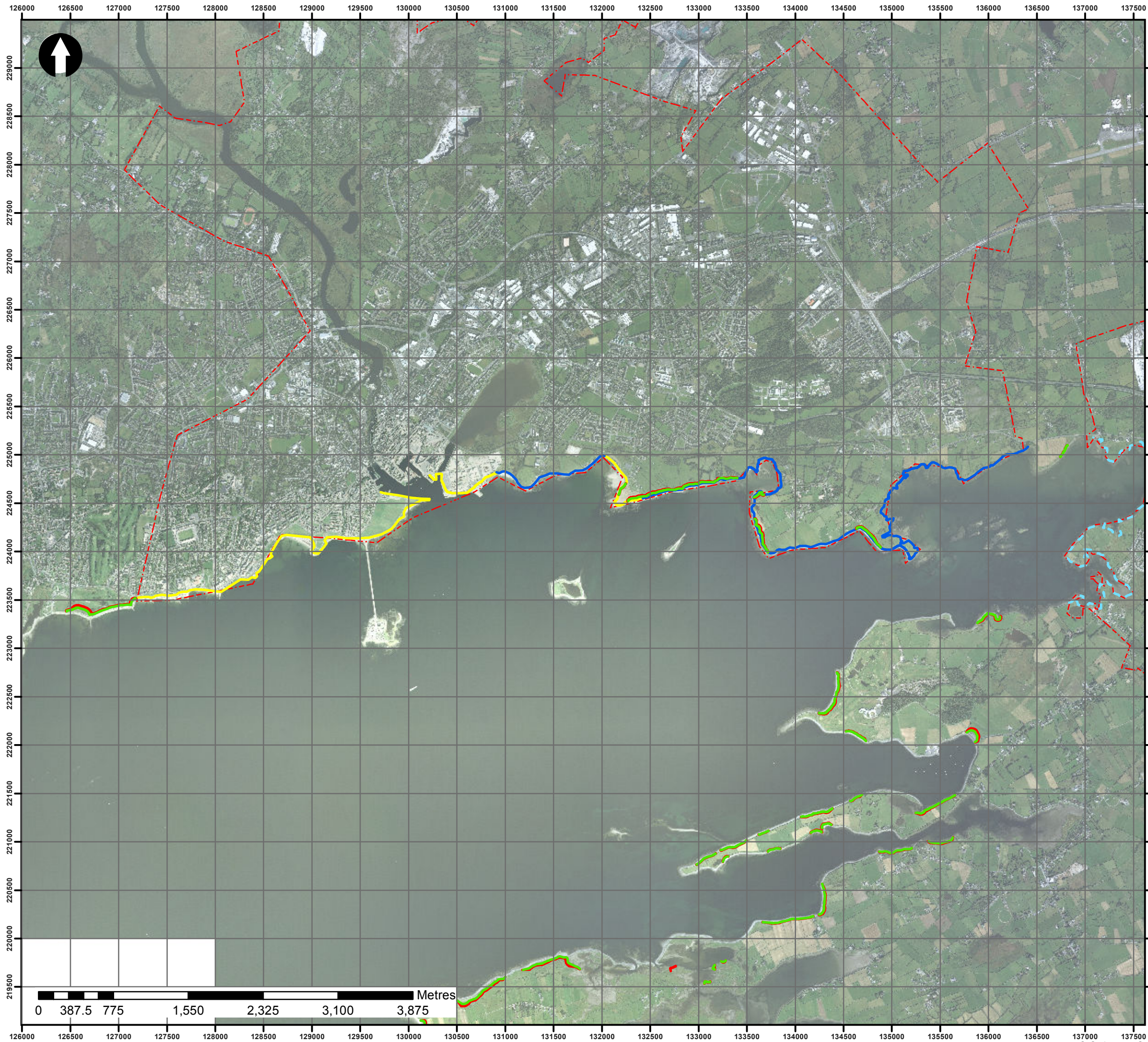
JBA consulting
24 Grove Island
Corbally
Limerick, Ireland



WESTERN
CFRAM
STUDY
CATCHMENT FLOOD RISK
ASSESSMENT AND MANAGEMENT

Map: Roundstone	
Map Type: Hydromorphology Assement Results	
Map Area: HPW	
Drawn by: SW Date: Apr 2015	Scale: 1:5,000 <small>Original @ A3</small>
Checked by: JNC Date: Apr 2015	
Approved by: SW Date: Apr 2015	
Map No: W31RSN_Hydromorphology_D_001	

B Coastal erosion maps



Legend

- ICPSS Erosion Line Yr 2030
- ICPSS Erosion Line Yr 2050

Coastal Erosion Risk Classification

- Low Risk
- Moderate Low Risk
- Moderate High Risk
- High Risk
- AFA_Boundary

Important user note:

The viewer of this map should refer to the disclaimer guidance notes and conditions of use that accompany this map.
This draft map is for consultation purpose only and should not be used for any other purpose.



The Office of Public Works
Jonathan Swift Street
Trim
Co. Meath

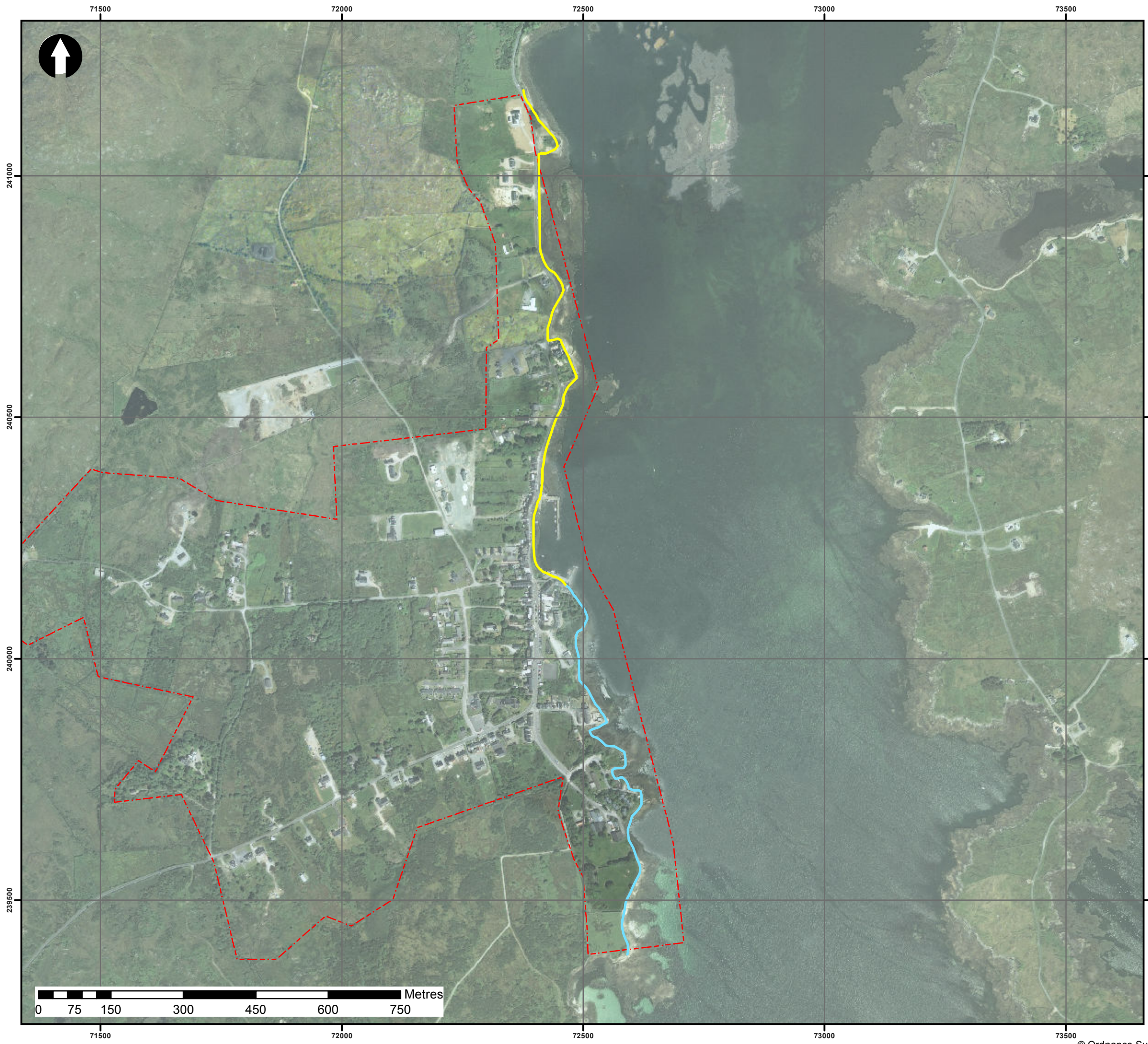


JBA Consulting
24 Grove Island
Corbally
Limerick, Ireland



WESTERN
CFRAM
STUDY
CATCHMENT FLOOD RISK
ASSESSMENT AND MANAGEMENT

Map: Galway City	
Map Type: ICPSS Coastal Erosion Results	
Map Area: HPW	
Drawn by: SW Date: Mar 2015	Scale: 1:37,500 Original @
Checked by: ER Date: Mar 2015	
Approved by: JNC Date: Mar 2015	
Map No: W30GLY_Coastal_Erosion_D_001	



Legend

- ICPSS Erosion Line Yr 2030
- ICPSS Erosion Line Yr 2050


Coastal Erosion Risk Classification

- Low Risk
- Moderate Low Risk
- Moderate High Risk
- High Risk
- AFA_Boundary


Important user note:

The viewer of this map should refer to the disclaimer guidance notes and conditions of use that accompany this map.


This draft map is for consultation purpose only and should not be used for any other purpose.



The Office of Public Works
Jonathan Swift Street
Trim
Co. Meath



JBA consulting
JBA Consulting
24 Grove Island
Corbally
Limerick, Ireland



WESTERN
CFRAM
STUDY
CATCHMENT FLOOD RISK
ASSESSMENT AND MANAGEMENT

Map: Roundstone	
Map Type: ICPSS Coastal Erosion Results	
Map Area: HPW	
Drawn by: SW Date: Mar 2015	Scale: 1:7,500 <small>Original @ A3</small>
Checked by: ER Date: Mar 2015	
Approved by: JNC Date: Mar 2015	
Map No: W31RSN_Coastal_Erosion_D_001	



Registered Office

**24 Grove Island
Corbally
Limerick
Ireland**

T: +353 (0) 61 345463
e: info@jbaconsulting.com

**JBA Consulting Engineers and
Scientists Limited**

Registration number 444752

Visit our website
www.jbaconsulting.com

Western CFRAM UoM 30 - Corrib Hydraulic Modelling Report: Volume 2a

Final

September 2016

**Office of Public Works
Trim
Co. Meath**



**WESTERN
CFRAM
STUDY**
CATCHMENT FLOOD RISK
ASSESSMENT AND MANAGEMENT

JBA Consulting

24 Grove Island
Corbally
Limerick
Ireland

JBA Project Manager

Sam Willis BSc MSc CEnv CSci MCIWEM C.WEM

Revision History

Revision ref / Date issued	Amendments	Issued to
Version 1.0	Initial issue	Rosemarie Lawlor, OPW
V1.5 / July 2014 (intermediate draft)	TAS model review comments addressed	Rosemarie Lawlor, OPW
V2.0 / January 2015	Report updated to reflect client and TAS review.	Rosemarie Lawlor, OPW
V3.0 / September 2016	Final updates	Clare Butler, OPW

Contract

This report describes work commissioned by the Office of Public Works, by a letter dated (28/07/11). The Office of Public Works' representative for the contract was Rosemarie Lawlor. Tim Diesner, Sam Willis, Chris Smith and Elizabeth Russell of JBA Consulting carried out this work.

Prepared by Tim Diesner BEng

Reviewed by Sam Willis BSc MSc CEnv CSci MCIWEM C.WEM

Elizabeth Russell BSc MSc CEnv MCIWEM
C.WEM

Purpose

This document has been prepared as a draft report for the Office of Public Works. 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.

JBA Consulting has no liability regarding the use of this report except to the Office of Public Works.

Copyright

Copyright – Copyright is with the Office of Public Works. All rights reserved. No part of this report may be copied or reproduced by any means without the prior written permission of the Office of Public works.

Legal Disclaimer

This report is subject to the limitations and warranties contained in the contract between the commissioning party (the Office of Public Works) and JBA.

Carbon Footprint

A printed copy of the main text in this document will result in a carbon footprint of 181g if 100% post-consumer recycled paper is used and 231g if primary-source paper is used. These figures assume the report is printed in black and white on A4 paper and in duplex.

JBA is aiming to achieve carbon neutrality.

Contents

1	Introduction.....	1
1.1	Scope of report	1
1.2	Model and report overview	1
1.3	Watercourse and catchment overview	2
1.4	Available data	8
2	Hydraulic modelling	10
2.1	Key hydraulic structures	10
2.2	Hydraulic roughness	12
2.3	1D-2D boundary	14
2.4	Defences and walls.....	14
2.5	Floodplain	16
3	Flood history, model calibration and sensibility checking	17
3.1	Calibration versus sensibility checking	17
3.2	Flood history	17
3.3	Calibration outcomes	18
3.4	Stakeholder Engagement	20
4	Application of hydrology	21
4.1	Hydrological estimation points	21
4.2	Application of design flow estimates.....	22
4.3	Downstream boundary.....	23
5	Model results.....	25
5.1	Model runs	25
5.2	Flood risk mapping	25
5.3	Key flood risk mechanisms	25
6	Sensitivity testing	28
6.1	Screening of sensitivity tests	28
6.2	Sensitivity testing results	30
7	Model limitations	33
7.1	Hazelhill - Groundwater stream	33
7.2	Channel blockage	34
7.3	Geomorphological changes	34
A	Hydraulic model results	35

List of Figures

Figure 1-1: Ballyhaunis AFA catchment overview	2
Figure 1-2: Downstream River Dalgan	3
Figure 1-3: Historical mapping showing the River Dalgan circa 1900.....	4
Figure 1-4: Development of the Devlis Watercourse.....	5
Figure 3-1: November 2009 modelled flood extent (overall)	19
Figure 3-2: November 2009 modelled flood extent (detail)	19
Figure 4-1: Ballyhaunis AFA HEP locations	21
Figure 5-1: Wrack marks near Ballyhaunis gauge	26
Figure 5-2: Curries watercourse	27
Figure 6-1: 10% AEP event uncertainty bounds.....	31
Figure 6-2: 1% AEP event uncertainty bounds.....	32

List of Tables

Table 1-1: Abbreviated watercourse names.....	9
Table 1-2: Hydrometric gauging stations in the vicinity of the AFA.....	9
Table 2-1: Key hydraulic structures	10
Table 2-2: Reach hydraulic roughness values	12
Table 2-3: Key hydraulic structures	14
Table 3-1: Summary of flood history.....	17
Table 3-2: PCD Feedback	20
Table 4-1: Summary of hydraulic model design inflows	24
Table 5-1: Peak flows for the Mid-Range Future Scenario	25
Table 5-2: Peak flows for the High-End Future Scenario	25
Table 6-1: Sensitivity test summary.....	28
Table 6-2: Flow sensitivity scaling factors	28
Table 6-3: Sensitivity to roughness scenarios	29
Table 7-1: Hazelhill Stream	33
Table 7-2: Station Rise culvert.....	34
Table A-1: 1D model peak current flows	35
Table A-2: 1D model peak MRFS flows	37
Table A-3: Current peak flows at HEPs.....	39
Table A-4: MRFS peak flows at HEPs.....	40

Abbreviations

AEP	Annual exceedence probability
AFA	Area for further assessment
AMAX	Annual maximum
CFRAM	Catchment flood risk assessment and management
DAD	Defence asset database
DAS	Defence asset survey
DEM	Digital elevation model (Includes surfaces of structures, vegetation, etc)
DTM	Digital terrain model ('bare earth' model; does not include surfaces of structures, vegetation, etc)
ESTRY	One-dimensional model from the TUFLOW suite
FRISM	Flood risk metrics (a flood risk tool developed by JBA)
FRMP	Flood risk management plan
FRR	Flood risk review
FSR	Flood studies report
FSU	Flood studies update
GIS	Geographical information system
HEFS	High-end future scenario
HEP	Hydrological estimation point
HPW	High priority watercourse
HWA	Hydrograph width analysis
IBIDEM	Interactive bridge invoking the design event method
ICPSS	Irish coastal protection strategy study
ICWWS	Irish Coastal Wave and Water Level Modelling Study
ISIS	One-dimensional hydraulic modelling software
LA	Local authority
LIDAR	Light detection and ranging
mOD	Metres above Ordnance datum (unless stated this refers to the Malin datum)
MPW	Medium priority watercourse
MRFS	Mid-range future scenario
NDHM	National digital height model (a DTM by Intermap)
OSi	Ordnance Survey Ireland
PFRA	Preliminary flood risk assessment
Q(T)	Flow for a given return period
QMED	Median annual flood, used in FSU methods
SAAR	Standard annual average rainfall
SoP	Standard of protection (in relation to flood defences)
T	Return period, inverse of AEP
Tp	Time to peak

TUFLOW	Two-dimensional hydraulic modelling software
UoM	Unit of Management
*	Asterisks at the end of a cross section label denotes interpolated model cross sections

1 Introduction

1.1 Scope of report

This report summarises the hydraulic modelling work for the Ballyhaunis AFA HPW hydraulic model. This document is specific to the AFA itself and should be read in conjunction with the various reports detailed below for details on the modelling approaches and wider context of the study.

The report covers the overall hydraulic modelling process from model build through to the development of design runs, with the aim of providing a detailed understanding of the hydraulic controls and flood mechanisms identified throughout the study.

The report is not a user manual for the hydraulic model itself, full details of which are provided in the model handover check files accompanying the hydraulic model.

The hydraulic modelling work summarised in this and the UoM 35 Hydraulic Modelling Report, of which this report is an Annex, forms one element of the Western Catchment-based Flood Risk Assessment and Management (WCFRAM) study process. The process to date has included amongst other tasks a Flood Risk Review (FRR)¹, a project inception stage², a Strategic Environmental Assessment (SEA)³ and the development of the catchment hydrology⁴. Where the work completed in these tasks contains information relevant to the analysis discussed in this document, references have been included directing the reader to the relevant report for further background information.

1.2 Model and report overview

There is one model for the Ballyhaunis AFA, which starts a short distance upstream of the AFA boundary. It includes the River Dalgan, and the Curries watercourse and Devils watercourses.

The Ballyhaunis AFA is situated in the upstream catchment of the River Clare and as such feeds into the upstream limit of the Clare MPW model. The River Dalgan watercourse changes from a HPW model to an MPW model approximately 2km downstream of town centre, and changes to the River Clare approximately 2km upstream of Dalgin town.

The model code relevant to the rivers in the Ballyhaunis AFA is D1, and the MPW watercourse downstream is 92. The details of the assessment of the MPW are in a separate report.

Reports which are relevant to this AFA are:

- Western CFRAM Flood Risk Review Report
- Western CFRAM UoM30 and 31 Inception Report
- Western CFRAM UoM30 and 31 Hydrology Report
- Western CFRAM UoM30 and 31 Hydraulic Modelling Report: Volume 1 - Hydraulic Modelling Method Statement
- Western CFRAM UoM30 and 31 Hydraulic Modelling Report: Volume 3 - Flood Risk Maps (which includes long section and cross section plans)
- Ballyhaunis AFA Hydraulic Model Check File
- Western CFRAM UoM30 and 31 Hydraulic Modelling Report: Volume 2g - Ballyhaunis to Tuam MPW -

¹ JBA Consulting (2012), Western CFRAM Flood Risk Review, Final Report, Office of Public Works

² JBA Consulting (2012), Western CFRAM Unit of Management 35 – Sligo Bay/Drowes Inception Report, Final Report, Office of Public Works

³ JBA Consulting (2013), Western River Basin District Catchment-based Flood Risk Assessment and Management (CFRAM) Strategic Environmental Assessment, Scoping Report, Office of Public Works.

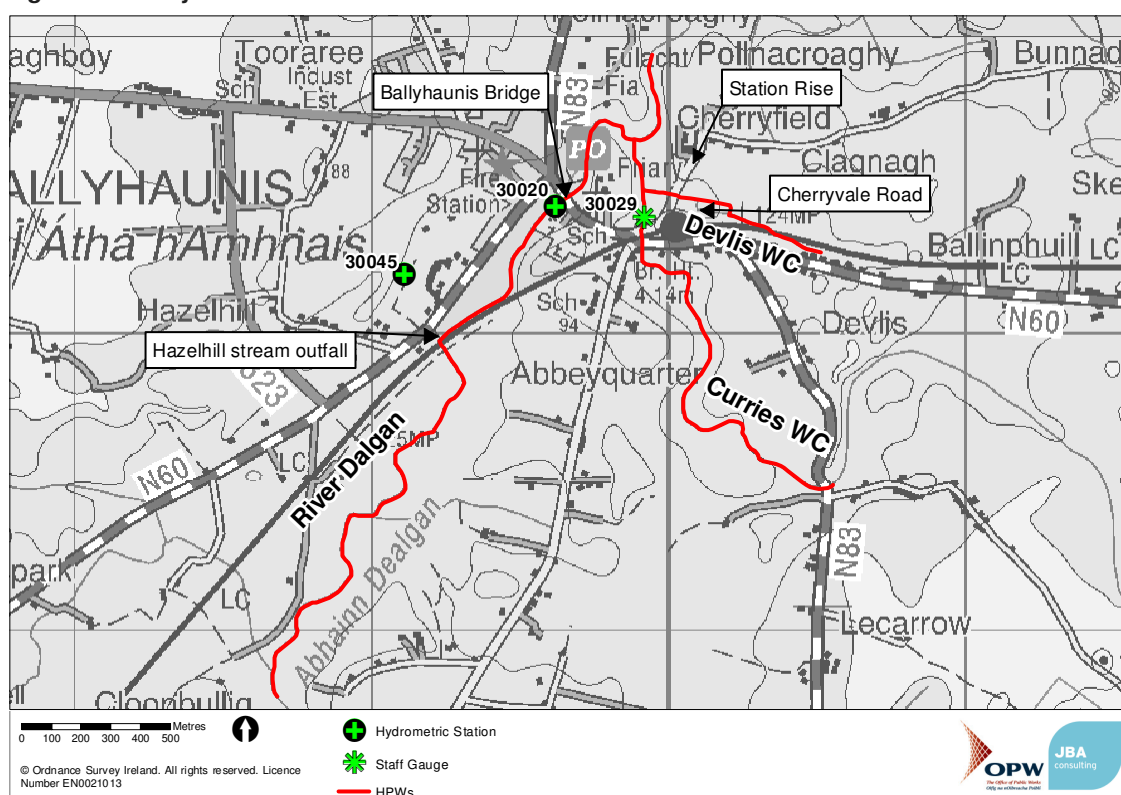
⁴ JBA Consulting (2014), Western CFRAM Unit of Management 35 – Sligo Bay/Drowes Hydrology Report, Final Report, Office of Public Works

1.3 Watercourse and catchment overview

The study area encompasses the Ballyhaunis AFA and includes the River Dalgan, which is the main river passing through Ballyhaunis town centre, Curries Watercourse, a tributary of the River Dalgan, and Devils Watercourse, a tributary of Curries Watercourse. The watercourses are all classed as High Priority Watercourses (HPWs) as they flow through the core of the AFA, and have been included in the model. The main hydraulic structure within the Ballyhaunis is the N60 Road Bridge, or Ballyhaunis Bridge. A gauging station is found shortly downstream of Ballyhaunis Bridge, where two weirs control river levels. Figure 1-1 provides an overview of the area and the cross section plans in Volume 3 of this suite of maps provide more detailed of the same extents.

There is an additional, unmodelled groundwater fed stream, called Hazelhill, discharging into the Dalgan downstream of the town centre. Further details of this watercourse, and the reasons for omitting it from the modelling assessment, are provided in Section 7.1.

Figure 1-1: Ballyhaunis AFA catchment overview



1.3.1 Dalgan River

The upstream modelled extent of the River Dalgan is located approximately 900m upstream of Ballyhaunis Bridge, and the downstream modelled extent is 2km past the town centre. The River Dalgan through this reach has a gradient of around 0.003m/km as it passes through Ballyhaunis town before flattening out in the open fields downstream.

An information board near the gauging station notes that 'the river channel is straight and lacks the form of a natural river that gives the impression that it may have been impacted by an arterial drainage programme in the past'. This is particularly true in the reach of watercourse immediately downstream of the Ballyhaunis Bridge (see photographs letter in the report), although examination of historical mapping for this area shows the route of the watercourse is largely unchanged; it is the dimensions and profile that seem to have been altered. Similarly, the channel downstream of Ballyhaunis is also part of the OPW's Corrib-Clare Arterial Drainage Works Scheme and has been subject to drainage works, with an over-wide and sluggish watercourse now following the original route of the river (Figure 1-2).

Figure 1-2: Downstream River Dalgan

The River Dalgan, downstream of Ballyhaunis town (approximately cross section 30DALG02042). Channel shows evidence of drainage works, being sluggish, shallow and wide.

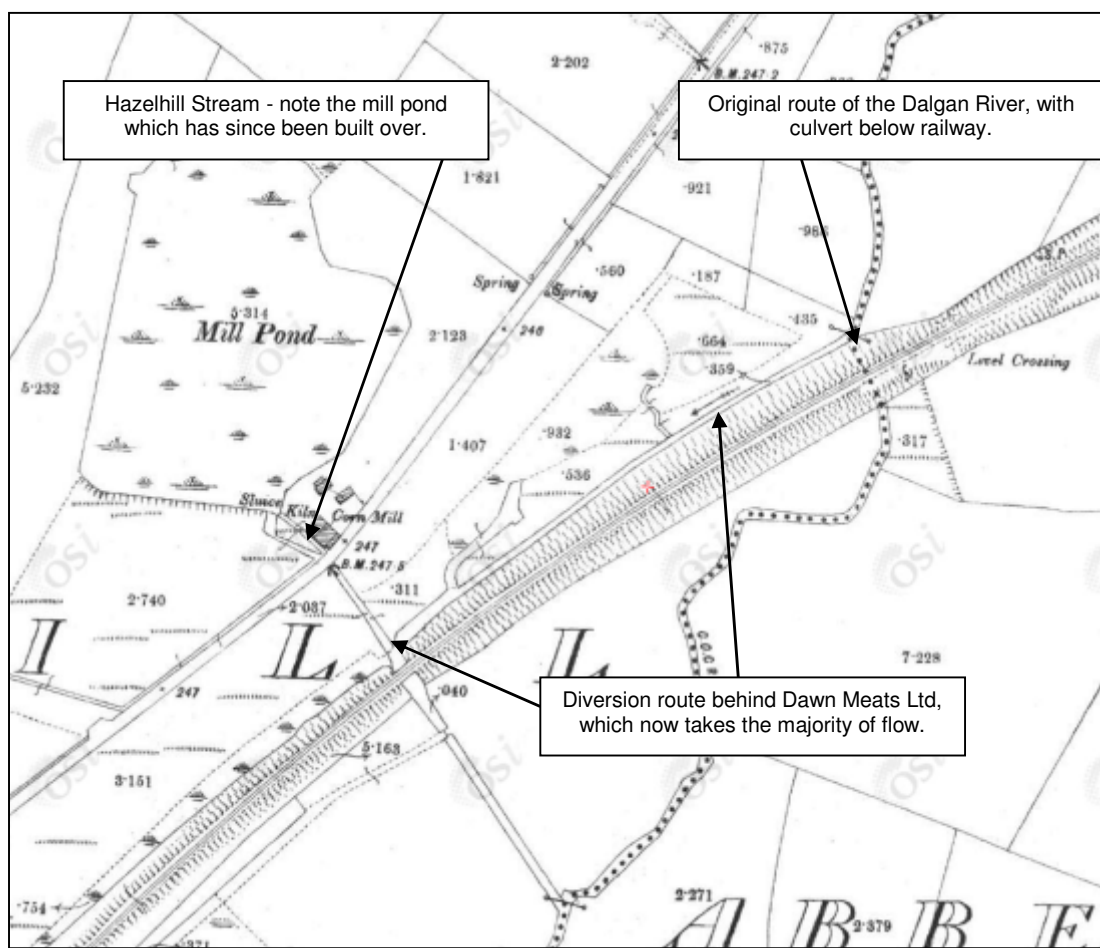


The route of the Dalgan River a short distance downstream of the gauge has been modified over time, most substantially linked to the construction of the railway line which runs on a raised embankment through the town. Figure 1-3 shows the original route of the river, which was culverted below the railway line when the embankment was constructed. The map also shows the diversion route, which runs along the north side of the railway embankment, behind the Dawn Meats Ltd plant, before passing in culvert below the railway line. The diversion route and the original course meet approximately 100m to the south of the railway, and continue along the natural course of the Dalgan. Site inspection and information from Mayo County Council has confirmed that the diversion route is now the primary flow path, and although there is culvert at the original crossing location below the railway, through-flow is relatively minor and modelling indicates water levels do not get high enough to activate this as a significant flow route. The modelling has focused on the main river route.

Examination of the historical mapping shows the area had a series of ponds and linking streams, which have since been built upon. The large mill pond and Hazelhill Stream are discussed further in Sections 1.4.2 and 7.1.

Although unconfirmed, it is possible that the Arterial Drainage Works and changes to the route have resulted in an increased channel capacity, which gives a lower risk of flooding than would be expected from a natural regime.

Figure 1-3: Historical mapping showing the River Dalgan circa 1900⁵



1.3.2 Curries Watercourse

The Curries Watercourse upstream modelled extent is located at the N83 Bridge. It flows in a northerly direction, through open fields and towards Ballyhaunis town. It passes beneath the N60 and the confluence of the Curries Watercourse and the River Dalgan is located 300m downstream of this point.

The most significant changes to the geometry of the watercourse occur at the crossing point with the railway bridge, where two culverts are located in close proximity to each other. This is discussed further in Section 2.1.

1.3.3 Devils Watercourse

The modelled length of the Devils Watercourse is 600m. From its upstream limit it flows adjacent to the railway embankment before flowing through a dog-leg series of bends and continuing in the same broadly west direction behind properties on Cherryvale Road. At the end of these properties it enters a culverted section beneath Station Rise road. This culvert extends the remaining distance to its downstream limit at the confluence with Curries Watercourse.

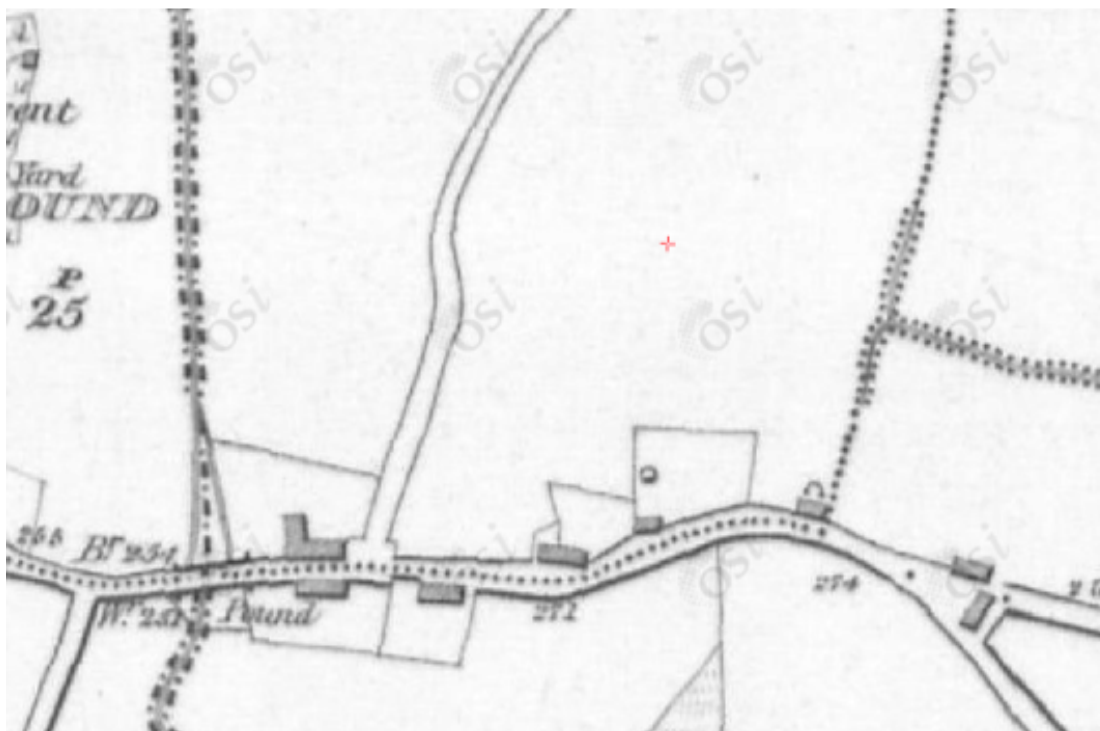
Initial inspection of the route of the Devils watercourse during the site visit indicated that the route of the channel had been substantially altered as a result of construction of the properties on Cherryvale. However, further analysis of the historical mapping available through the OSi shows this is not the case. Rather, the development of the watercourse seems to have been as an agricultural drainage channel, with possible extension linked to the development of the railway and

⁵ Mapping © 2014 Ordnance Survey Ireland and sourced from <http://maps.osi.ie/publicviewer/#V1,549991,779522,7,3>

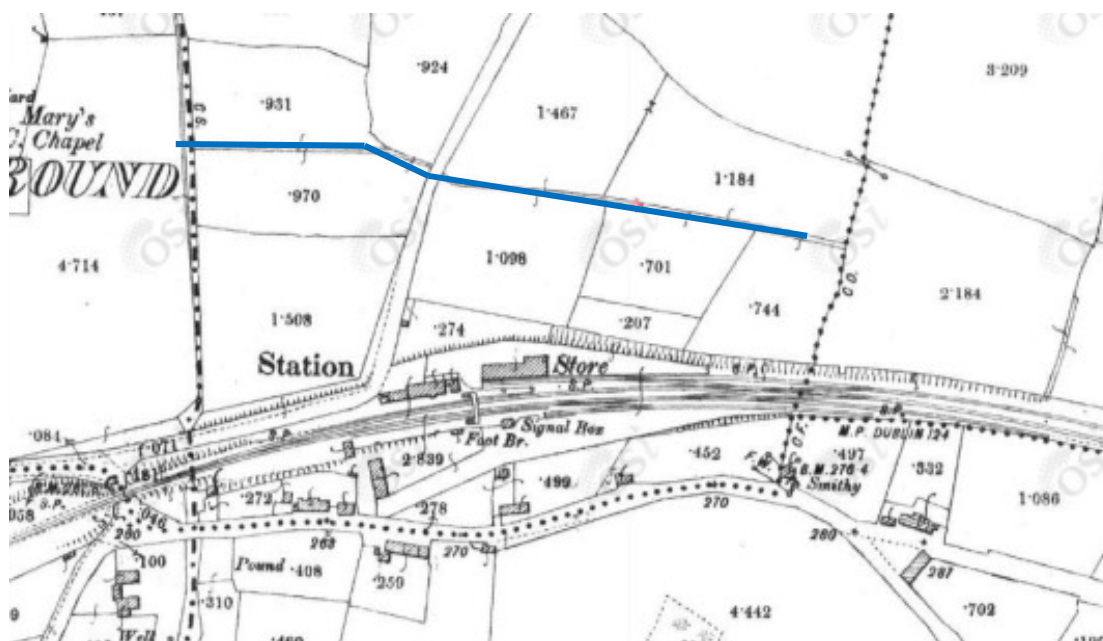
management of runoff from the line to the south of Cherryvale; hence the 'manmade' route with 90° bends. Commentary on the development of the watercourse is provided in Figure 1-4.

If the watercourse had been diverted it would indicate that there may be flow routes following the route of the original channel. However, as this watercourse appears to be constructed drainage channel with limited catchment area flood risks are more likely to be linked to generally poor ground conditions, evident through marsh vegetation observed when on site. This may lead to frequent surface water ponding in the fields to the north of the railway line.

Figure 1-4: Development of the Devils Watercourse⁶

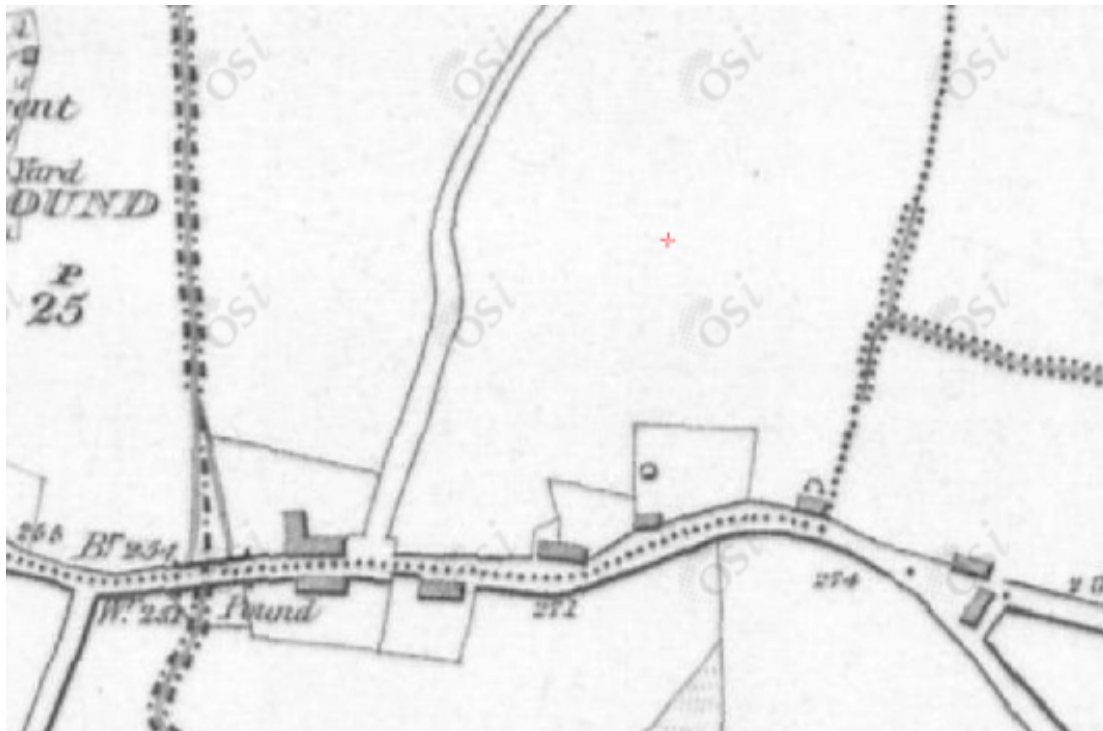


Ballyhaunis in the area of the Devils Watercourse circa 1830s. Limited development along the modern N60, and no railway line or watercourse present.



Map circa 1900. More substantial development along the modern N60, with railway and station established. Watercourse parallel and to the north of the railway, but no sign of a link between the channel and the railway line.

⁶ Mapping © 2014 Ordnance Survey Ireland and sourced from <http://maps.osi.ie/publicviewer/#V1,549991,779522,7,3>



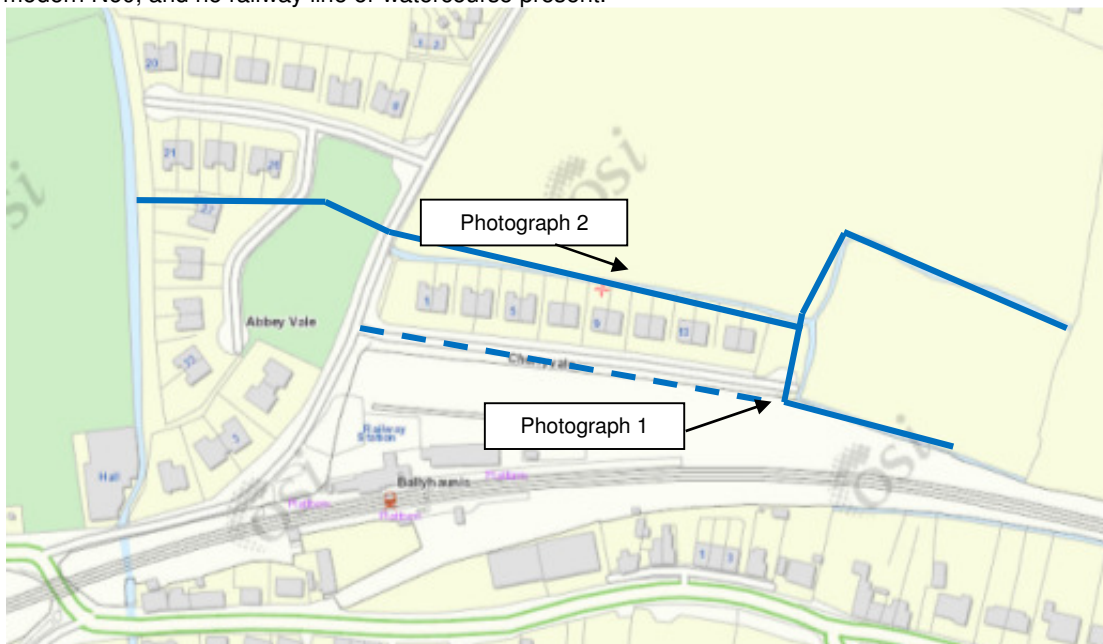
Ballyhaunis in the area of the Devils Watercourse circa 1830s. Limited development along the modern N60, and no railway line or watercourse present.



2005 aerial photography showing the field drain has been extended with a 'dogleg' to the north. The Abbeyvale estate has been developed to the west of Station Rise, resulting in culverting of the downstream section of the Devils watercourse which was undertaken in a 1999 planning application. Route of the watercourse upstream of Station Rise is unchanged.



Ballyhaunis in the area of the Devilis Watercourse circa 1830s. Limited development along the modern N60, and no railway line or watercourse present.



Present day streetview mapping, showing the Cherryvale development running parallel to the railway. The watercourse has been extended at the upstream end, with a southerly 'dogleg' providing what would appear to be a drainage channel for the railway line and embankment. There was also evidence of a largely unconnected drain running to the south of Cherryvale, as shown as a dashed line on the mapping above, and in the photographs below.



Ballyhaunis in the area of the Devilis Watercourse circa 1830s. Limited development along the modern N60, and no railway line or watercourse present.

Photograph 1 - Drainage channel running parallel to the railway line.



Photograph 2 - Channel on the right of the photograph, running behind Cherryvale houses. Note evidence of marsh grass and other water-loving species in the field to the north of the properties.



1.4 Available data

1.4.1 Survey data

Cross sectional survey was collected by CCS Surveying in Work Package 1 and 2 as part of the National Survey Contract No. 6 and delivered in December 2012 and February 2013 respectively.

The abbreviated versions of each watercourse name as represented in the hydraulic models are detailed in Table 1-1.

Table 1-1: Abbreviated watercourse names

Reference	Description	Corresponding Model Code
DALG	River Dalgan	D1
CURR	Curries Watercourse	D1
DEVL	Devlis Watercourse	D1

LIDAR survey was commissioned by OPW for use in the model. Data was provided in both filtered and unfiltered formats in a 2m grid resolution. The LIDAR was flown between Nov 2011 and August 2012. A comparison of LIDAR levels against the surveyed cross sections was completed as part of the survey review process. This compared spot levels collected on roads or in open spaces and found an average difference between the two of 95mm, with the survey generally being higher than the LIDAR.

1.4.2 Hydrometric data

A summary of hydrometric data within the AFA is provided in Table 1-2 and an overview of gauge locations is provided in Figure 1-1.

Table 1-2: Hydrometric gauging stations in the vicinity of the AFA

Gauge	Type	Use in calibration
30020 - Ballyhaunis	Active flow site with record from 1975 to date	Rating review calibrated to gaugings. Primary calibration location.
30029 - Ballyhaunis Rly	Inactive staff gauge	Limited number of gaugings 1976 - 1987. No potential use for calibration.
30045 - Hazelhill	Inactive water level	Limited record, no datum. No potential use for calibration.

As part of the study a review of the rating curve at the Ballyhaunis active flow gauge 30020, hereafter referred to as the Ballyhaunis gauge, has been completed. Full details of this review are detailed in the WCFRAM Hydrology Report for UoM 30.

The largest recorded event occurred in November 2009 and had a peak flow of 9.2 m³/s; this is between the 1% AEP and 0.5% AEP calculated design event flows, Section 4.1.


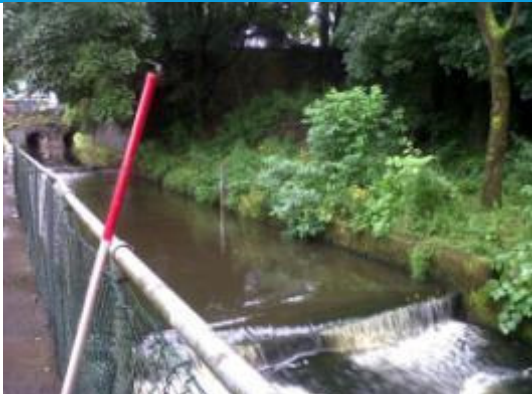
Gauge 30045, known as the Hazelhill station, is found on the groundwater stream on the River Dalgan. The EPA, who operated the gauge on behalf of Mayo County Council, confirmed that the data available from this gauge is limited and of poor quality. A site inspection by EPA hydrometric staff (carried out in May 2013) revealed the staff gauge is missing (the wall that the gauge was attached to has been demolished). The channel control has also changed and the boards that formed the weir have been removed. Also, the spring is no longer contained and a second (bypass) spring enters the channel just downstream of the weir. As a result, the gauge has not been used within this study.




2 Hydraulic modelling


2.1 Key hydraulic structures

The key hydraulic structures that dictate water levels and flows routes in the vicinity of key flood risk areas are summarised in Table 2-1. The location of the structures is also shown on the cross section plan in Volume 3 Volume 3 of the UoM 30 and 31 Hydraulic Modelling Report.

Table 2-1: Key hydraulic structures

Structure Name	Description	Photograph
Ballyhaunis Bridge - section 30DALG02240D [River Dalgan]	<p>The structure has been modelled as a twin arch bridge.</p> <p>The height of the road and associated bridge parapet means bypassing of the structure is unlikely and the capacity of the twin arches will dictate the pass forward flow in this location.</p>	 <p>Looking downstream at upstream face of structure.</p>
Weirs - sections 30DALG02236 and 30DALG02233 [River Dalgan]	<p>Downstream of Ballyhaunis Bridge there are two weirs. The downstream weir is used as a control structure for the Ballyhaunis gauge. Both structures have been modelled as parallel weirs allowing reduced hydraulic efficiency for out of bank flows</p> <p>The weirs are situated in a constrained channel with raised banks on either side. Whilst the structures are small, model results do not show the weirs becoming completely drowned out in larger events and they will continue to have a limited impact on flood risk.</p>	 <p>Looking upstream at structures.</p>

Structure Name	Description	Photograph
Culvert at 30DALG02200A [River Dalgan]	This culvert is located where the River Dalgan runs adjacent to the railway line. The Dawn Meats Factory is located on the right bank. The culvert is rectangular, is approximately 35m in length and reduces in capacity part way down its length (as determined by survey of the up and downstream faces). The change in capacity has been assumed to occur at the midway point of the culvert. The railway embankment on the left bank minimises bypassing on this side. In large events flows may overtop and bypass the structure on the right bank.	 <p>Looking downstream at upstream face of structure.</p>
Culverts at 30CURR00036I (below the N60) and 30CURR00033I (below the railway line) [Curries Watercourse]	These two culverts are in close proximity, with approximately 10m open channel between the two. Although the capacities of both culverts are of reasonable capacity, the gradient of the watercourse shallows out at this location and significant deposits were noted in the channel. This has the potential to restrict the capacity of both culverts.	 <p>Looking downstream to 30CURR00036I</p>  <p>Looking downstream from the N60 road bridge (30CURR00036I) to 30CURR00031I - sedimentation in the open channel reach is clear.</p>

Structure Name	Description	Photograph
Culvert at 30DEVL00011A [Devlis Watercourse]	This is the long culvert at the downstream end of the Devlis watercourse which discharges into the Curries watercourse. The structure is approximately 115m in length and is a single 700mm diameter pipe. The crest level of the road at its upstream face is 1.25m above the soffit of the culvert and once this is exceeded the natural flow path will discharge towards the Curries Watercourse.	 <p>Looking at outlet of culvert.</p>


2.2 Hydraulic roughness

Reaches of similar hydraulic roughness have been identified from survey photos and drawings. Manning's n values for both the river bed and banks to bank top within each of these reaches are summarised in Table 2-2.

Table 2-2: Reach hydraulic roughness values

Upstream and Downstream Cross Section	Roughness Values (Manning's n) and materials	Photograph
30DALG02240A to 30DALG02335	Bed - 0.035 Rocks Banks - 0.050 Mainly bushes with some trees	 <p>Looking upstream from 30DALG02335.</p>
30DALG02240B to 30DALG02231	Bed - 0.035 Concrete Channel sides - 0.020 Banks - 0.070 Bushes and Trees	 <p>Looking downstream from 30DALG02237.</p>

Upstream and Downstream Cross Section	Roughness Values (Manning's n) and materials	Photograph
30DALG02231 to 30DALG02120	Bed - 0.035 Rocks Banks - 0.050 Mainly bushes with some trees	 <p>Looking upstream from 30DALG02130</p>
30DALG02110 to 30DALG01964	Bed - 0.035 Rocks Banks - 0.040 Long Grass/ Scrub	 <p>Looking upstream from 30DALG01964.</p>
30CURR00174 to CURR00000*	Bed - 0.030 Gravel Banks - 0.040 Long Grass/ Scrub	 <p>Looking downstream from 30DALG00003.</p>

Upstream and Downstream Cross Section	Roughness Values (Manning's n) and materials	Photograph
30DEVL00057 to 30DEVL00011A	Bed - 0.030 Gravel / Stones and Silt Banks - 0.040 Grass / Scrub	 Looking upstream from 30DEVL00011A.

2.3 1D-2D boundary

Bank top survey provides the crest levels between cross sections along the River Dalgan and Curries Watercourse and has been used to develop the 1D-2D boundary along these watercourses.

On the Devlis Watercourse bank top levels for the 1D-2D boundary have been interpolated between the crests surveyed on the individual cross sections.

2.4 Defences and walls


2.4.1 Defences





No formal or informal effective defences were identified with the Ballyhaunis AFA.



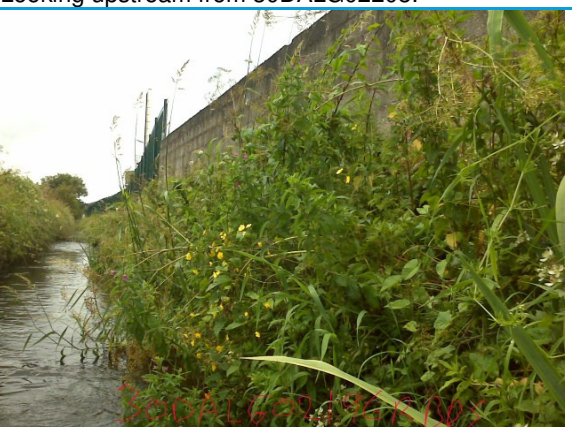
2.4.2 Walls

Informal ineffective structures identified with the AFA are detailed in Table 2-3. These structures are not assumed to function as flood defences and are either bypassed in the model or have been removed to allow flooding beyond them.

Table 2-3: Key hydraulic structures

Description and Location	Modelling Method	Photograph
<p>Type 3</p> <p>50m in length from 30CURR00174 to 30CURR00172.</p> <p>This is a masonry wall surrounding a car park. It ties in to the bridge parapet at the upstream end. It is in poor condition.</p>	<p>This wall is above the 0.1% AEP river level, therefore it has been left in the model as surveyed.</p>	

Description and Location	Modelling Method	Photograph
<p>Type 1</p> <p>40m in length from 30CURR00031 to 30CURR0026.</p> <p>This is a retaining wall structure upstream of Station Rise. It is tied in to high ground at the upstream end but not at the downstream end.</p>	<p>Flood waters will bypass this structure at the downstream end and as such it has been left in the model as surveyed.</p>	 <p>Looking downstream from 30CURR00030.</p>
<p>Type 2</p> <p>50m in length from 30DALG02249 to 30DALG02242.</p> <p>This is a single skin block wall found at the rear of Dalaney's Garden Centre (right bank of River Dalgan upstream of Ballyhaunis Bridge). There are gaps in this wall that flood water passes through.</p>	<p>This structure is not considered to provide a flood defence function. Including the structure as surveyed would dictate the flood extent in this area, therefore it has been removed from the model.</p>	 <p>Looking upstream from 30DALG02232.</p>
<p>Type 3</p> <p>60m in length from 30DALG02239 to 30DALG02235.</p> <p>This structure is a retaining wall that rises above bank top level. It is tied into Ballyhaunis Bridge parapet at the upstream end and high ground at the downstream end.</p>	<p>This structure has been modelled as surveyed; flood water will not reach bank top level.</p>	 <p>Looking upstream from 30DALG02238.</p>
<p>Type 2</p> <p>50m in length at 30DALG02224.</p> <p>This structure is a mortared stone wall found on the right bank of the River Dalgan. It can be bypassed.</p>	<p>Whilst this structure can be bypassed its short length means it was not picked up in survey cross sections. For this reason the structure has not been modelled and is effectively removed from the model.</p>	

Description and Location	Modelling Method	Photograph
<p>Type 2</p> <p>40m in length upstream of 30DALG02216.</p> <p>This structure is a mortared stone masonry wall. It is bypassed at the upstream end.</p>	<p>Flood waters will bypass this structure at the upstream end. Due to its length the structure has been removed from the model to represent this flow route.</p>	<p>Looking downstream from 30DALG02224.</p>  <p>Looking upstream from 30DALG02216.</p>
<p>Type 2</p> <p>70m in length upstream of 30DALG02208.</p> <p>This structure is a single skin breeze block wall with gaps along its length.</p>	<p>This structure is not of a sufficient standard to provide a flood defence function and as such has been removed from the model.</p>	 <p>Looking upstream from 30DALG02208.</p>
<p>Type 2</p> <p>20m in length downstream of 30DALG02196J.</p> <p>This structure is a single skin breeze block wall. Structure is bypassed at both ends.</p>	<p>This structure is not of a sufficient standard to provide a flood defence function and as such has been removed from the model.</p>	 <p>Looking downstream from 30DALG02196.</p>

2.5 Floodplain

A 2D cell size of 4m has been selected to give a balance between model runs times and the detail of flow routes within the 2D floodplain. There is little evidence of fluvial flooding to the urban areas of Ballyhaunis, so it was not considered necessary to add additional detail to the floodplain to model complex flow routes around buildings.

The culverts passing beneath the railway embankment to the south west of Ballyhaunis have been incorporated into the 2D domain as standalone 1D ESTRY elements to allow flows to pass through this structure, but without the original channel being explicitly modelled in 1D.

3 Flood history, model calibration and sensibility checking

3.1 Calibration versus sensibility checking

Where a recording flow gauge is located in or near the site and this data is accompanied by historical data from a flood event (such as flood extents, or spot levels), then it is possible to undertake calibration of the model. This process would involve running the records flows through the model and changing model parameters, such as Manning's n, to match the flood extents or levels that were observed. Ideally, a second event would then be run through the model and used to validate the outputs. While it is possible to simulate flows recorded at a gauge in the model, without any record of the impact of the event the model cannot be calibrated and the checking process is limited to a confirmation that predicted extents match expectations based on topography and local knowledge. If there is no gauge data available but there are historical records of flooding then the predicted extent from an appropriate design event with a similar exceedence probability to the historical flood event can be used as a sensibility check of the predicted flooding frequency.

3.2 Flood history

Key flood risk areas have been identified in the Flood Risk Review⁷ and Inception Reports⁸. Table 3-1 shows a summary of historical flood events, and includes a note on whether they have been used to calibrate or validate the model.

Table 3-1: Summary of flood history

Area affected	Main flood mechanisms	Recorded flood event date	Use in model check
Some out of bank flow through the town centre and at the Dawn Meats Plant. No property flooded.	River Dalgan	Nov 2009	Limited verification using observed extents and flow record.
Right bank, downstream of Ballyhaunis bridge	River Dalgan	Nov 1999	Not used
Prolonged high water levels across the catchment	River Dalgan, but linked to pre-arterial drainage works conditions	1968-69	Not used

3.2.1 November 2009

Within the Ballyhaunis AFA there is only limited supporting historical flood data available is for the November 2009 event. A verbal report is recorded of flooding to the rear of Delaney's Garden Centre. This indicated that the flood extent inundated the open ground at the back of the garden centre by approximately 0.05m only. Flow was also documented as coming out of bank by the Dawn Meats Plant during this event, but this did not result in the flooding of properties. Mayo County Council have advised that Dawn Meats submitted a planning application for their landholding. The submission included a flood risk assessment, which included estimates of flow, water level and flood extent. The FRA design flows were similar in magnitude to those generated through this CFRAM. The water levels and corresponding flood extents were lower than the CFRAM results, a feature which could be attributed to the shorter modelled reach and use of 1D modelling approach in the FRA. The FRA notes that highest water levels experience at the site, which is downstream of Ballyhaunis, occurred in November 2011 and is not supported by the gauge record.

⁷ JBA Consulting, Western CFRAM Flood Risk Review, Final Report May (2012)

⁸ JBA Consulting, Western CFRAM Units of Management 30 - Corrib and 31 - Owengowla Inception Report, Final Report, October 2012

3.2.2 November 1999

There are also reports of flooding at Donnellan's Joinery, downstream of Ballyhaunis Bridge, during the November 1999 event. Mayo County Council also reported that Keans Kitchens Limited had experienced some flooding; it was thought this was 10 years ago, but was probably linked to the 1999 event. It is not known if the workshop was flooded, or if it was the back yard which was impacted. Whilst the Ballyhaunis gauge was in operation during the 1999 event the data collected at the time is not of sufficient frequency (it is not 15 minute measurements) to support the development of a hydrograph for this event.

3.2.3 Pre-arterial drainage works

There are records of prolonged flooding for the period November 1968 to January 1969, which seems to coincide with the commencement of arterial drainage works so the impact of this event was highly variable across the region. Small areas of flooding were reported at Culnachlea Bridge, some 8km downstream from Ballyhaunis.

3.3 Calibration outcomes

This gauge is located on the River Dalgan approximately 50m downstream of Ballyhaunis Bridge. Levels extracted from this gauge have been converted to flows using the updated rating curve developed as part of the rating review work documented in the WCFRAM Hydrology Report for UoM 30. Detailed 15 minute data was not available from the gauge for the 1999 event and as such the model validation has focused on the November 2009 event. However, the model calibration that is possible for Ballyhaunis is somewhat limited as there is only evidence of the impact of high flows for one flood event, and this information is in the form of anecdotal evidence from the business owner. Flow data for the event have been extracted from the Ballyhaunis gauge.

To develop the inflows for the calibration event the flows derived from the gauge have been applied at the upstream limits of the model. The gauge is located on the River Dalgan downstream of the confluence with the Curries Watercourse, and consequently the Devlis Watercourse. The inflows to each watercourse have therefore been split based upon the proportion of flow contributed to QMED as extracted from the downstream limit of each watercourse.

3.3.1 November 2009 event

Figure 3-1 and Figure 3-2 present the modelled flood extent within the AFA for the November 2009 event.

Figure 3-1: November 2009 modelled flood extent (overall)

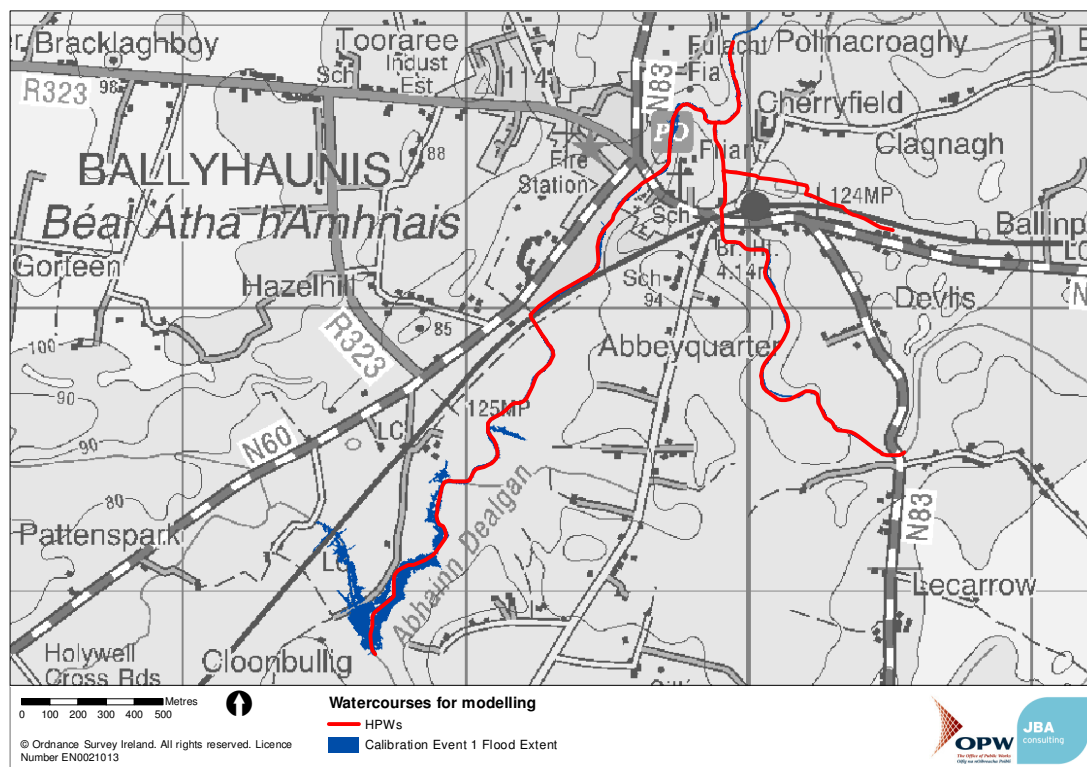
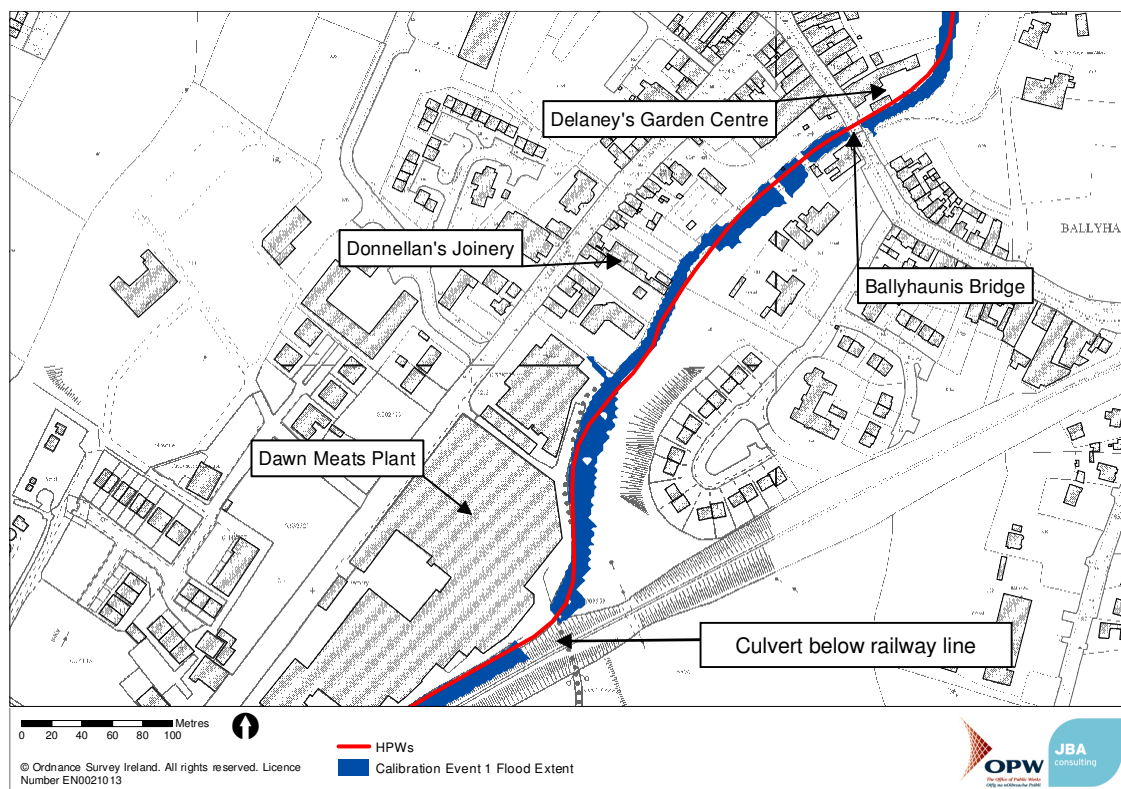


Figure 3-2: November 2009 modelled flood extent (detail)



From discussions with the owner of Delaney's Garden Centre, it is known that the rear of the property saw a very small amount of flooding from the River Dalgan to a very shallow depth during this event. The model results show that a limited number of cells on the river bank are wetted at the rear of the Garden Centre property from this event, but not to the extent that was reported. However, upon further discussion with the property owner, it is apparent that water seeped through

the walls of the storage shed, which is constructed within the river channel, and it is through this route that the flooding of the yard occurred. It was confirmed that water levels did not overtop the river walls surrounding the garden centre, which supports the modelled flood extent.

The model results also show the River Dalgan overtopped its banks a number of other locations including 200m upstream of Ballyhaunis Bridge, downstream of Ballyhaunis Bridge at the gauging station and upstream of the culvert adjacent to Dawn Meats Plant.

The water level at the gauge are recorded so it is apparent that out of bank flows would have occurred in the vicinity of the gauge would have occurred in this event; however, the flows are contained within the channel topography, and are within the 1D cross section used to develop the rating. It is also known that the River Dalgan has historically come out of bank adjacent to Dawn Meats Plant, but has not impacted properties. The calibration results reflect this; the site is relatively well confined and no properties are predicted to have flooded in this location in the 2009 event.

Whilst the November 2009 is the largest event on record for Ballyhaunis, there is insufficient detailed data over the modelled reach to justify any changes to the model parameters to improve the calibration. Broadly speaking, the model outputs agree with the locations and extents of flooding reported in Ballyhaunis during the November 2009 but this data is limited at best.

3.4 Stakeholder Engagement

Throughout this process OPW regional engineers and local authority engineers have been consulted in the form of steering group, progress group and engineer meetings and their input has fed into the flood maps.

Public Consultation Day (PCD) - 13th of November 2014

On November 13th 2014 a public consultation was held at Parochial Hall in Ballyhaunis to present the flood maps for the town and solicit comments and feedback.

This PCD was attended by 9 people. At the PCD attendees were invited to leave feedback, in the form of a questionnaire. The questionnaire sought feedback on resident's knowledge of flooding in the town including the locations of flooding and the frequency of flooding.

Table 3-2 outlines the feedback received at the day relevant to the study and a note regarding how this information has been accommodated by the study.

Table 3-2: PCD Feedback

Comments Received	Study Response
Flooding of the back gardens behind the Friary used to flood as shown in maps. The maps look to represent the flooding in Ballyhaunis.	This report agrees with the flood extents for Ballyhaunis.
Upstream on the curries watercourse, map on OS (1890s) said liable to flooding. The new bridge at the downstream of this watercourse that may have changed things, as may OPW works.	This report does not provide information which can be used to validate the flood maps.

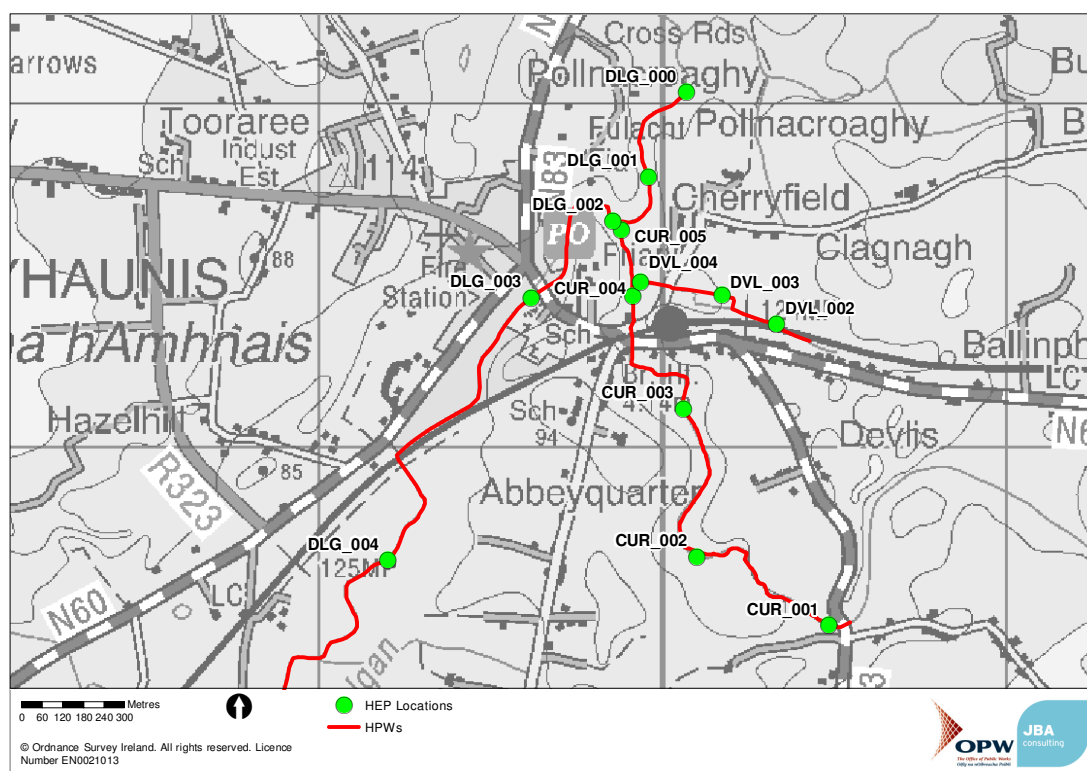
4 Application of hydrology

4.1 Hydrological estimation points

Design flows have been developed at a series of Hydrological Estimation Points (HEPs) throughout the catchment. Full details of the development of these flows are provided in the WCFRAM Hydrology Report for UoM 30.

The locations and names of all the HEPs within the Ballyhaunis AFA are presented in Figure 4-1, and are shown in more detail on the Cross Section Plan in Volume 3 of the UoM 30 and 31 Hydraulic Modelling Report.

Figure 4-1: Ballyhaunis AFA HEP locations



The design peak flows for a range of return periods at each of the AFA HEPs are shown in Table 4-1.

The November 2009 event peaked at 9.2m³/s, based on the revised rating curve derived for Ballyhaunis gauge (DLG_003). This would give the event a return period between the 1% and 0.5% AEP event. The November 2009 event was reported to be in excess of the 1% AEP event at the Ballygaddy and Corrofin gauges located further downstream on the Clare River⁹, so whilst this return period seems on the high side it is considered to be of an appropriate order of magnitude.

The flow estimates listed above were checked for consistency. The flows downstream of confluence of Devlis with Curries are generally the sum of the inflows from the two watercourses suggesting that the response of the catchments is similar and flood peaks will coincide. The flows downstream of the confluence of the Curries and Dalgan (DLG_002) watercourses are lower than the sum of the inflows reflecting the fact that the Dalgan is a larger watercourse and will peak later than the tributaries.

⁹ Study to Identify Practical Measures to Address Flooding on the Clare River, Volume 1 Report, Office of Public Works, June 2010.

The calculated design flows decrease going downstream between DLG_002 to DLG_003. This is due to a change in the pooling group used to develop the flows, which is in turn linked to anomalies in the catchment descriptors at the HEPs¹⁰; BFI increases, whilst SAAR is unchanged between the two HEPs. This discrepancy has been managed within the application of the hydrology to the model, as detailed in Section 4.2.

4.2 Application of design flow estimates

4.2.1 Hydrograph shapes

Inflow hydrograph shapes for each watercourse have been developed from the Flood Studies Report (FSR) rainfall runoff method. This approach has been tested (with results detailed in the Hydrology Report) and with the exception of a few gauges this found the FSR approach to provide the best fit against gauge data. Inflows are located at the upstream limit of each watercourse.

A consistent design storm duration of 15 hours has been applied across all boundaries and has been selected as the critical storm duration for the catchment to DLG_003 (Ballyhaunis gauge) on the River Dalgan. The FSR method, applied using a uniform design storm for all sub-catchments within a model, imposes a structure on the model inflows with realistic relative timings of the hydrographs. This avoids the need to apply the FSU regression model for relative timings of hydrographs at a confluence; an approach which is associated with a large standard error. Because the FSR method is being used only to control the shape of the hydrographs rather than the magnitude of the peak flows (which are based on the HEPs), there is no benefit to identifying a critical storm duration, i.e. one that results in the highest peak flow or water level. However, in order to ensure a realistic flood duration, the duration of the design storm has been related to the time to peak for the principal watercourse in the model, using the FSR formula that evaluates storm duration from time to peak and SAAR. The potential impact of the critical storm duration on tributary flood extents has been reviewed and is discussed in Section 6.

A time to peak coefficient of 2.00 has been applied to the inflow hydrographs along the River Dalgan. The reason for this choice of factor is provided in the Western CFRAM UoM30 and 31 Hydrology Report. This was required to provide a better match to the duration of observed hydrographs at the Ballyhaunis gauging station. The time to peak coefficients for the Devlis and Curries watercourse has been left at the default of 1.00; these watercourses are expected to give a much quicker response due to their size in relation to the River Dalgan.

4.2.2 Scaling to hydrological estimation points

A simplified approach was taken to apply the Curries and Devlis watercourse inflows. The peak inflow for each watercourse was scaled to fit the HEP located at the midpoint of each watercourse (CURR_003 and DLV_003) as the upstream and downstream flows are within 10% of each other. This provides a reasonable approximation of the design flows along the length of each watercourse without the need for lateral inflows to be applied.

As mentioned in Section 4.1, there is a discrepancy in flow estimations in that the flows on the River Dalgan do not consistently increase downstream, from DLG_002 to DLG_003. DLG_003 is located at the Ballyhaunis gauge and as such has been considered the key HEP to scale to on the River Dalgan. To achieve this, the calculated design flows to DLG_002 have been omitted in favour of those at the gauge.

The peak flow estimates in the model at DLG_003 have been matched to the flows given for the HEP by adjusting the scaling of the River Dalgan inflow. The flow estimations at DLG_004 (just outside of Ballyhaunis town) were achieved by scaling a lateral inflow unit applied between DLG_003 and DLG_004.

A summary of the model inflows and application of the design hydrology through these is provided in Table 4-1.

¹⁰ It should be noted that the catchment descriptors are as provided by OPW and have not been amended or updated in anyway.

4.3 Downstream boundary

There is no obvious downstream limit to the hydraulic model dictating water levels for this AFA on the River Dalgan. To ensure all downstream backwater influences are accounted for, the downstream boundary of the River Dalgan model has been extracted from the River Clare MPW model in the form of a rating relationship.

The downstream boundaries on the tributaries are related to the flow in the main channel. The watercourses have not been modelled independently, and no testing of the probability of events of different magnitudes occurring has been carried out. The aim of the CFRAM is to map the design event as calculated at all the HEPs, on both main rivers and tributaries.

As the aim of the CFRAM hydrology is to match the flows at an HEP to those being generated through the model there is no benefit, or scope within the brief, to carry out joint probability analysis. The downstream boundaries on the tributaries are related to the flow in the main channel. The watercourses have not been modelled independently, and no testing of the probability of events of different magnitudes occurring has been carried out. The aim of the CFRAM is to map the design event as calculated at all the HEPs, on both main rivers and tributaries. Joint probability analysis would not deliver the required results.

Table 4-1: Summary of hydraulic model design inflows

HEP reference	Cross section	Peak Flow Estimates (m³/s)				Flow in Model (m³/s)				Comments (note: where blank, no changes have been made)
		50% AEP	10% AEP	1% AEP	0.1% AEP	50% AEP	10% AEP	1% AEP	0.1% AEP	
DLG_000	30DALG02335	3.5	5.0	7.3	11.1	4.2	6.0	8.5	11.7	Catchments of Devlis and Curries peak significantly earlier than Dalgan and do not contribute to peak. Therefore flows on Dalgan are a result of inflows on the Dalgan only. Key flow point is the gauge site at DLG_003 and because there is no flood risk in the upstream reaches to simplify the model, flows equivalent to DLG_003 have been put into to the upstream limit of the model.
DLG_001	30DALG02304	3.6	5.1	7.4	11.3	4.2	6.0	8.5	11.7	
DLG_002	30DALG02277	4.4	6.2	9.0	13.7	4.4	6.2	8.8	12.2	
DLG_003	30DALG02239	4.2	6.0	8.5	13.0	4.4	6.2	8.8	12.2	Gauging station 30020. See above for application of hydrology.
DLG_004	30DALG02168B	4.9	7.0	10.1	15.4	5.1	7.2	10.4	14.7	Downstream AFA boundary on River Dalgan. Lateral inflow applied between DLG_003 and DLG_004; scaled to match DLG_004.
DVL_002	30DEVL00057	0.04	0.06	0.09	0.14	0.05	0.08	0.13	0.21	Upstream modelled extent of Devlis watercourse.
DVL_003	30DEVL00030	0.05	0.08	0.13	0.21	0.05	0.08	0.13	0.21	Devlis inflow scaled to match estimates at DVL_003 as a simplification (DVL_003 is approximately the midpoint of watercourse).
DVL_004	30DEVL00011A	0.08	0.12	0.20	0.31	0.05	0.08	0.13	0.21	Downstream extent of Devlis watercourse. Flows have not been directly scaled to match this HEP.
CUR_001	30CURR00174	0.88	1.31	2.07	3.23	0.95	1.43	2.24	3.47	Curries inflow scaled to match estimates at CUR_003 as a simplification (CUR_003 is approximately the midpoint of watercourse).
CUR_002	30CURR00115	0.95	1.41	2.19	3.37	0.95	1.43	2.24	3.47	
CUR_003	30CURR00075	0.95	1.43	2.24	3.47	0.95	1.43	2.24	3.47	
CUR_004	30CURR00020	0.99	1.46	2.24	3.39	0.95	1.43	2.23	3.46	Upstream of the confluence with Devlis.
CUR_005	30CURR00010	1.07	1.58	2.40	3.57	0.99	1.50	2.36	3.65	Downstream extent of Curries watercourse (downstream of confluence with Devlis). Flows have not been directly scaled to match this HEP.

5 Model results

5.1 Model runs

The model has been run for the following fluvial events: 50%, 10%, 5%, 2%, 1%, 0.5% and 0.1% AEP design events.

In addition, the potential impact of climate change has been investigated for the 10%, 1% and 0.1% AEP design events for both the medium range and high end future scenarios. Further details of the allowances within the calculations are included in the Hydrology Report, but the future scenarios include for the impacts of urbanisation and climate change. Resulting peak flows are shown in Table 5-1 and Table 5-2.

Table 5-1: Peak flows for the Mid-Range Future Scenario

HEP reference	Predicted Peak Flows for the MRFS (m ³ /s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
DLG_000	4.2	5.3	6.0	6.8	7.8	8.7	9.8	13.3
DLG_003	5.1	6.4	7.2	8.0	9.2	10.2	11.5	15.6
DLG_004	6.0	7.5	8.5	9.5	11.0	12.2	13.8	18.7
DVL_002	0.04	0.06	0.07	0.08	0.10	0.11	0.13	0.17
DVL_003	0.06	0.09	0.10	0.12	0.14	0.16	0.18	0.25
DVL_004	0.09	0.12	0.14	0.16	0.20	0.23	0.26	0.36
CUR_001	1.1	1.4	1.6	1.8	2.2	2.5	2.8	3.9
CUR_002	1.1	1.5	1.7	1.9	2.3	2.6	3.0	4.1
CUR_003	1.2	1.5	1.8	2.0	2.4	2.7	3.1	4.2
CUR_004	1.2	1.5	1.8	2.1	2.5	2.8	3.2	4.4
CUR_005	1.3	1.6	1.9	2.2	2.6	2.9	3.3	4.5

Table 5-2: Peak flows for the High-End Future Scenario

HEP reference	Predicted Peak Flows for the HEFS (m ³ /s)		
	10% AEP	1% AEP	0.1% AEP
DLG_000	6.5	9.4	14.4
DLG_003	7.8	11.1	16.9
DLG_004	9.3	13.3	20.4
DVL_002	0.08	0.12	0.19
DVL_003	0.11	0.18	0.27
DVL_004	0.15	0.25	0.39
CUR_001	1.7	2.7	4.2
CUR_002	1.8	2.8	4.4
CUR_003	1.9	3.0	4.6
CUR_004	2.0	3.1	4.7
CUR_005	2.1	3.2	4.9

5.2 Flood risk mapping

Flood risk extents for the present day and MRFS 10%, 1% and 0.1% AEP design events along with long section profiles for present day 10%, 1% and 0.1% AEP design events are presented in Volume 3 of the UoM 30 and 31 Hydraulic Modelling Report.

5.3 Key flood risk mechanisms

Further to the information presented in the flood risk maps, a brief description of the key flood risk sites and flooding mechanisms is provided below. In general, the flood extents produced are less than might be expected from a fully natural series of watercourses. However, as discussed through this report, there is evidence of man-made intervention on all three of the modelled watercourses so the natural regime is no longer fully in place. The result of these changes has been increased channel capacity, and a change from the natural flow regimes and resulting

overtopping patterns. This fact, coupled with the records of two recent flood events, give confidence that the under-prediction of flood extents is realistic.

5.3.1 Flooding upstream of Ballyhaunis Bridge on the River Dalgan.

Immediately upstream of Ballyhaunis Bridge, a small and confined amount of flooding is predicted to the rear of Delaney's Garden Centre (car park). This is predicted to occur from the 10% AEP event upwards, but no properties are at risk as a result. Water levels in this section of river are dictated by the capacity of the channel, which is a reflection of the fact that even in large events floodplain flow is limited. The modelling has shown that Ballyhaunis Bridge is not a significant control structure in this location, with head losses associated with the structure less than 0.1m in the 1% AEP event.

The River Dalgan is predicted to flood the fields found a short distance upstream of Ballyhaunis Bridge from the 10% AEP event onwards. No properties are at risk as a result.

5.3.2 Flooding downstream of Ballyhaunis gauge

Model results show the River Dalgan exceeds bank top level upstream of the control weir of the Ballyhaunis gauge as a result of the limited channel capacity as frequently as the 10% AEP event (see Figure 5-1). The floodplain is well confined around the gauging station itself and this results in no flooding of properties.

Approximately 80m downstream of the gauge, the 1% AEP event is predicted to cause flooding to Donnellan's Joinery on Clare Road and to the rear of neighbouring properties on Clare Road. This flooding can be attributed to a localised drop in the bank levels allowing flows to discharge onto the floodplain.

Figure 5-1: Wrack marks near Ballyhaunis gauge

Wrack marks clearly visible on the wire mesh fencing downstream of the Ballyhaunis gauge, on the right bank. The photograph was taken in June 2013, supporting the relatively high frequency of inundation of footpath.



5.3.3 Flooding at Dawn Meats Plant

Out of bank flow is predicted as frequently as the 10% AEP event upstream of the culvert adjacent to Dawn Meats Plant. However, it is not until the 0.1% AEP event that the river level upstream of the culvert is great enough to cause the river to bypass the culvert. Flood levels are shown to reach Dawn Meats Plant and also Keane Kitchens Ltd upstream in the 0.1% AEP event, but not to flood these properties.

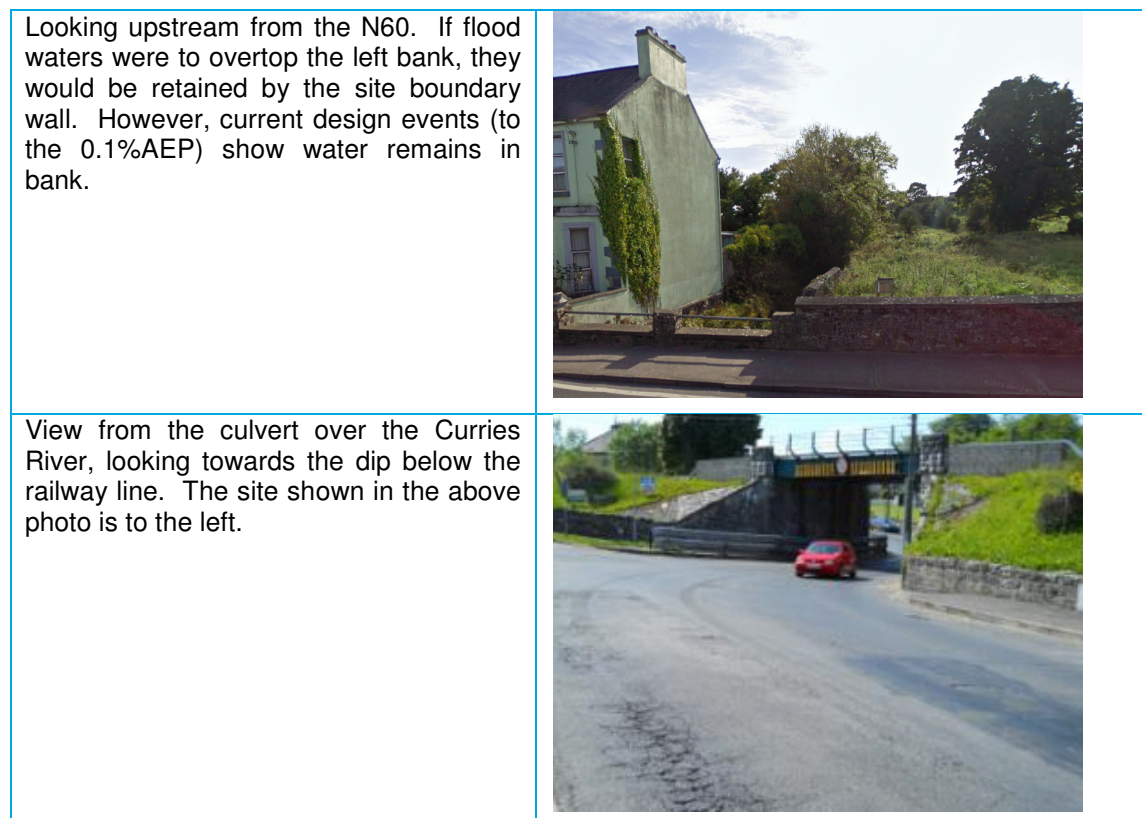
5.3.4 Flooding downstream of railway bridge

The greatest extent of flooding within the Ballyhaunis AFA occurs in the fields downstream of the town; this is the area where drainage works are thought to have taken place. Under regular flow conditions the watercourse is extremely slow flowing, with a wide flat floodplain, and in extreme events it is unlikely water would discharge downstream very quickly; instead it is likely to spread across the floodplain. Downstream of the railway bridge on the River Dalgan, near Clare Road, flooding is predicted from the 10% AEP event onwards, also resulting in flooding to Hazelhill Road. No properties are at risk as a result of this flooding.

5.3.5 Curries Watercourse

The Curries watercourse is shown to present no risk of flooding to properties in Ballyhaunis up to the extreme 0.1% AEP event. Examination of the water level profile through the key culverts at the N60 and the railway bridge shows some headloss through both culverts. Despite this, the water remains in bank. In the Q1000 event, water levels upstream of the N60 are close to the top of the right bank, but if water were to overtop at this location it would be prevented from flowing onto the road by the field boundary wall.

Figure 5-2: Curries watercourse



A potential risk of flooding to the N60 as it dips below the railway bridge has been identified. However, as discussed above, it has been shown that the Curries watercourse does not overtop the bank in the current scenario. If the capacity of the culverts were to be reduced or flows to increase (such as in a future scenario) overtopping may occur. However, property is unlikely to be impacted on, although passage through the railway tunnel would be obstructed. Surface water flooding at this location is more likely under the current situation. Water ponds in the dip, and is discharged through road gullies. It is assumed that this discharge is directly to the Curries watercourse. If the discharge through the outfall pipes was blocked, for example through high levels in the river, the surface water would not drain away. As with fluvial flooding though, this will block access through the tunnel, but will not impact on property.

5.3.6 Devlis Watercourse

The Devlis watercourse is shown to present no risk of flooding to properties in Ballyhaunis up to the extreme 0.1% AEP event, with all flows shown to remain within the drainage channel. This is a reflection of the over-capacity of the manmade drainage channel, coupled with the small catchment area draining into it.

Inspection during the site visit showed blockage of the culvert to be a likely occurrence, and this is discussed further in Section 7.2.

6 Sensitivity testing

6.1 Screening of sensitivity tests

The suite of potential sensitivity tests is detailed in Volume 1a: Hydraulic Modelling Method Statement. The application of the sensitivity tests has been an iterative process which allowed certain criteria to be screened out. Table 6-1 summarises the full suite of potential sensitivity tests, and highlights those which are not applicable, and those which have been screened out. Further details of these criteria are provided in the following sections.

The results of testing those criteria which are relevant to Ballyhaunis are detailed in Section 6.2.

Table 6-1: Sensitivity test summary

Sensitivity test	Relevance to Ballyhaunis
Peak flow	Tested
Flow volume	Screened out
Critical storm duration	Screened out
Roughness	Tested
Building representation	Screened out
Afflux / headloss at key structures	Tested at a number of structures
Water level boundaries and joint probability	Not applicable
Timing of tributaries	Screened out
Timing of fluvial and tidal peaks	Not applicable
Cell size	Screened out

6.1.1 Peak flow

The flow sensitivity scoring mechanism is detailed in the Overarching Hydraulic Modelling Report, and produces a score of 6 for the River Dalgan and 8 for the Curries and Devlin watercourses. Table 6-1 details the flow sensitivity tests required as a result of these scores.

Table 6-2: Flow sensitivity scaling factors

Return period of event	River Dalgan	Curries and Devlin Watercourses
10%	No sensitivity test required.	Use QMED uncertainty
1%	Use QMED uncertainty then multiply flows by 1.1	Use QMED uncertainty then multiply flows by 1.2

6.1.2 Flow volume

The sensitivity test to flow volume is required where the flow hydrograph has been generated from limited or no data. In the case of Ballyhaunis a flood event of the order of the 1% AEP event has been observed and this data has been used in the hydrology report to support a lag analysis and improve the hydrograph shape for the River Dalgan. The lag analysis was not applied to the Curries and Devlin tributaries, however design flows on these watercourses are insufficient to cause flooding and a sensitivity test to flow volume would not assist in developing an understanding of these watercourses. It is not proposed to carry out this test.

6.1.3 Critical storm duration

The critical storm duration for the three watercourses has been set at 15 hours which is higher than would occur on the two tributaries, but is appropriate for the main river. The flood extents from the tributaries have been examined and are limited in extent, with virtually no out of bank flooding. Reducing the storm duration on these tributaries would reduce the volume of water in the hydrograph, thus further reducing the flood extents. It is therefore considered that the approach taken is conservative, but not excessive, and will not be further examined.

6.1.4 Roughness

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

because of the presence of an observed event of the order of a 1% AEP design event and the limited flood extents associated with this the sensitivity to roughness has not been appraised for the 10% AEP event.

The specific maintenance regime undertaken by Mayo County Council is not known, but site inspection shows the channel through the town to be well maintained. Downstream of the town it would appear that the landowner keeps the river banks in a similarly good condition. This indicates that although channel and bank roughness (i.e. vegetation growth) may increase, it will probably be within reasonable bounds.

Table 6-2 summarises the current roughness values applied within the model over the various reaches and the increased values to be applied for the 10% AEP events and 1% AEP events.

Table 6-3: Sensitivity to roughness scenarios

Upstream and downstream cross section	Roughness values (Manning's n) and materials		
	Existing risk	10% AEP roughness sensitivity	1% AEP roughness sensitivity
30DALG02240A to 30DALG02335	Bed - 0.035 Rocks Banks - 0.050 Mainly bushes with some trees	No change	Bed - 0.04 Banks - 0.070
30DALG02240B to 30DALG02231	Bed - 0.035 Concrete Channel sides - 0.020 Concrete Banks - 0.070 Bushes and Trees	No change	Bed - 0.035 Channel sides - 0.020 Banks - 0.100
30DALG02231 to 30DALG01964	Bed - 0.035 Rocks Banks - 0.050 Trees	No change	Bed - 0.04 Banks - 0.080
30CURR00174 to CURR00000*	Bed - 0.030 Gravel Banks - 0.040 Long Grass/ Scrub	No change	Bed - 0.040 Banks - 0.060
30DEVL00057 to 30DEVL00011A	Bed - 0.030 Gravel / Stones and Silt Banks - 0.040 Grass / Scrub	No change	Bed - 0.040 Banks - 0.06

Roughness values in the floodplain have been increased to the upper bound of those values quoted in the Hydraulic Modelling methods report for the 1% AEP event only.

6.1.5 Building representation

The current flood risk extents in the 1% AEP event show no inundation of properties so no test related to the representation of buildings in the 2D domain has been undertaken.

6.1.6 Afflux at key structures

Structures which may be particularly sensitive to head loss have been identified by examination of the long section water level plot through the structure, a review of nearby receptors at risk and an assessment of likely flow routes around the structure.

Three key structures have been identified for review as part of this sensitivity test; Ballyhaunis Bridge, the culvert adjacent to the Dawn Meat's Factory on the River Dalgan and the culvert at the downstream limit of the Devlis watercourse.

A review of predicted head losses through Ballyhaunis Bridge in the 1% AEP event shows the structure increasing water levels upstream by approximately 60 mm. These levels are approximately 2 m below the nearest property and as such Ballyhaunis Bridge is not considered to be a source of flood risk uncertainty.

The culvert at the Dawn Meats Factory is already bypassed in large events and the current 1% AEP event is approximately 0.5 m below local property levels. A review of the implications of the modelling approach for this structure has been undertaken, see below.

The existing 1% AEP water level upstream of the culvert on the Devlis watercourse is approximately 1.5 m below the road crest level so an increase in headloss will not impact on flood risk in this area.

Headloss at the N60 and railway culvert on the Curries watercourse has also been reviewed, and was discussed in Section 5.3.5. The N60 culvert is a complex structure, changing from a twin arch at the upstream face to a large box culvert a short way through its length. In view of the proximity of the Q1000 level to the top of bank, and the potential impact of future extreme flows, the implications of the modelling approach at the N60 culvert has been assessed, see below.

To review the head losses associated with the culvert structures, additional losses have been applied at the upstream and downstream faces to account for potential additional complexity within the culvert, notably as a result in the change in dimension at some point within the structure. Head loss units have been applied at the upstream and downstream faces of the Dawn Meat culvert with K values of 0.3 and 0.5 respectively. Slightly higher values have been used to test the N60 culvert, reflecting the increased complexity resulting from the change in opening profile; in this case K values of 0.45 and 0.65 have been used.

It is important to note that contraction and expansion losses at these faces have already been modelled and these values have been used to consider the implications of additional complexity only.

6.1.7 Timing of tributaries

Adjustments to the timing of tributaries could result in higher flows downstream on the Dalgan if peak flows on the Curries and Devlin watercourses were delayed. This test is only recommended where there is good confidence in the hydrology and the increase in flows resulting from the shift in timing would exceed the increase in flows investigated as part of the flow sensitivity. In this instance, a shift in the timing of tributaries would increase flows on the Dalgan by approximately 0.3 m³/s. However, the test for sensitivity to flow requires an increase in flows greater 0.3 m³/s, so further testing of a lower flow increase would not be informative.

6.1.8 Cell size

Although the Ballyhaunis model has been run at a 4m cell size, there is very limited out of bank flow in the town centre. This indicates there is little potential for complex flow paths to develop so not sensitivity to cell size has been undertaken.

6.2 Sensitivity testing results

The results of the sensitivity tests have been used to inform the uncertainty bounds as detailed in the Hydraulic Modelling Method Statement. The uncertainty bound in effect presents the most sensitive hydraulic parameter/s as assessed within the bounds identified in Section 6.1 at all locations along the modelled reach.

To simplify the presentation of the sensitivity tests, the uncertainty bound for the 10% AEP (Figure 6-1) and 1% AEP (Figure 6-2) events has been presented only. Where different parameters have contributed to the development of the uncertainty bound, these are highlighted in the adjoining text.

The model to the north of the railway line, and indeed for a short distance downstream of the railway crossing is not particularly sensitive not particularly sensitive to the parameters tested for either the 10% or 1% AEP events, largely because the flooding is mainly in-bank, and the channel has sufficient capacity. The lower part of the model, where there is more out of bank flooding, shows a greater sensitivity to both flows and roughness changes. This is reflected in the increased flood extents, and also in flooding along the unmodelled tributary to the south of the domain, with water backing up under the railway line. Although inundating greater areas of agricultural land, there is no increase in the number of properties at risk.

Overall, the hydraulic model was generally not shown to be sensitive to the parameters selected in the sensitivity testing. This is with the exception of sensitivity to peak flow, which produced the largest change in flood extents. All models are likely to be sensitive to this test, and it is indicative only of the upper bounds of uncertainty in the peak flow estimation. As the overall configuration

of the model was shown to be satisfactory, no additional changes were made to this hydraulic model.

Figure 6-1: 10% AEP event uncertainty bounds

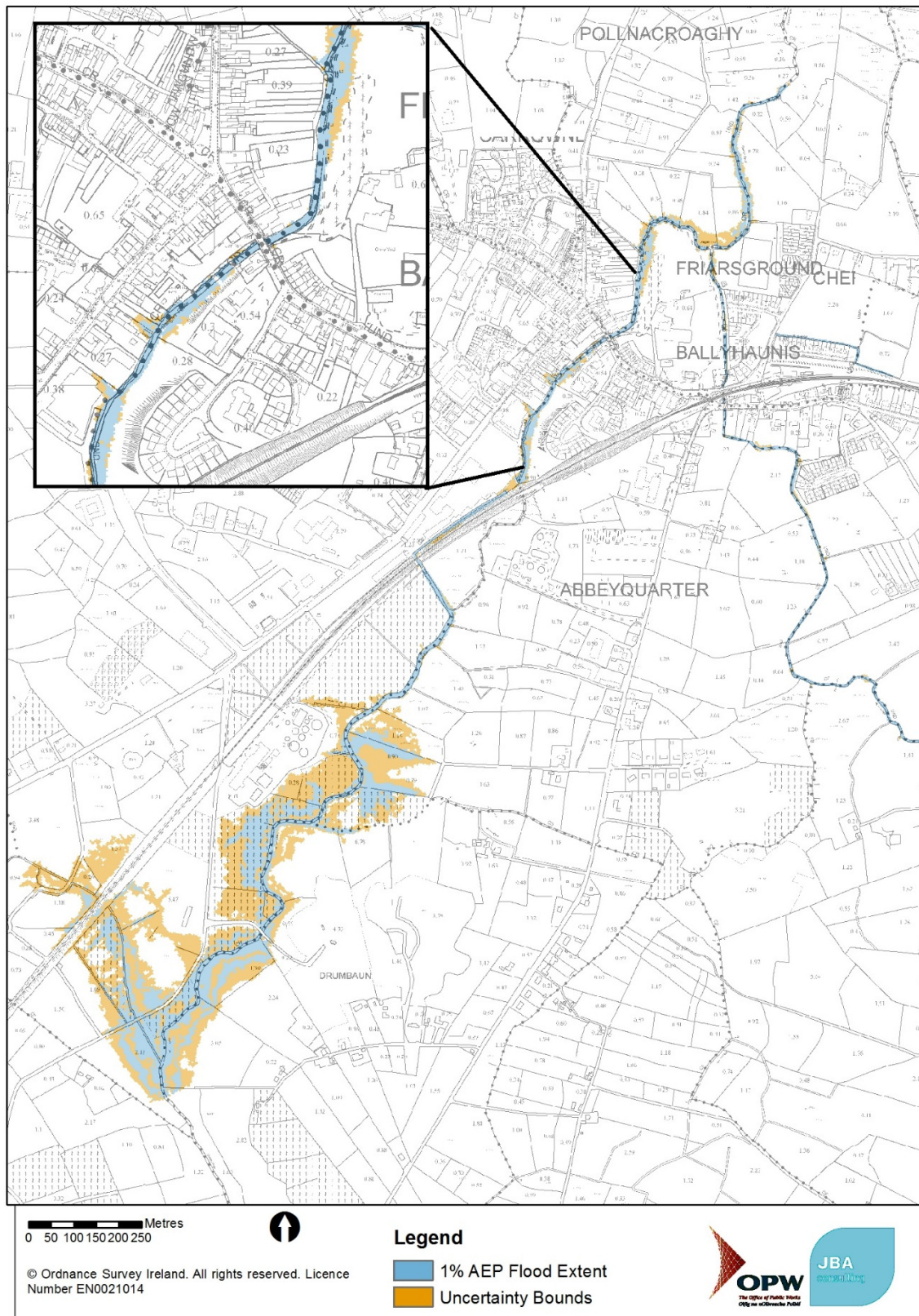
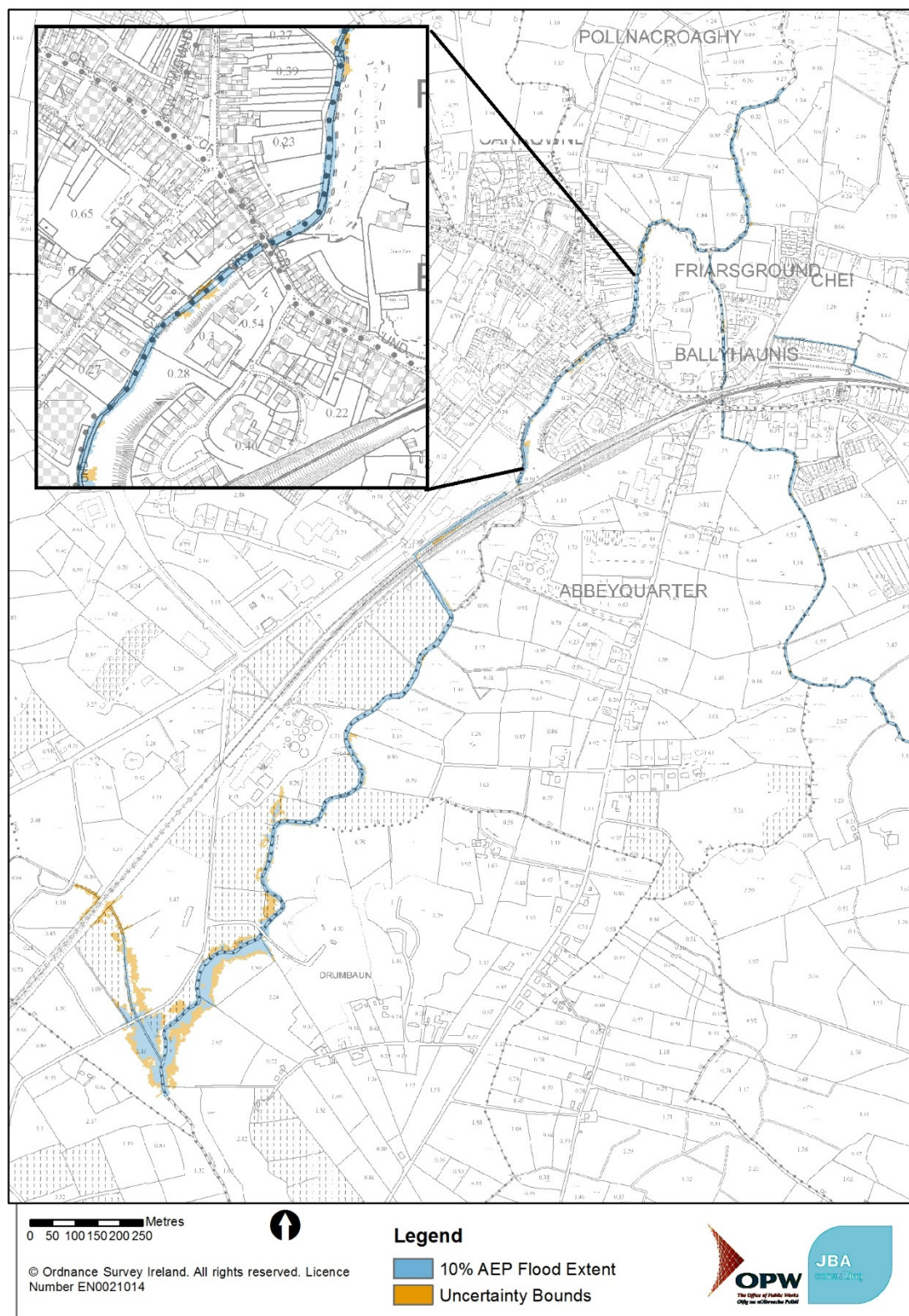


Figure 6-2: 1% AEP event uncertainty bounds



7 Model limitations

7.1 Hazelhill - Groundwater stream

Hazelhill Stream is a tributary of the Dalgan River and enters the Dalgan upstream of the WWTP and the Meat Processing Plant discharges (see Table 7-1).



The Hazelhill gauging station was installed to monitor the well outflow and establish the contribution of this outflow to the Dalgan River and in particular at times of low flow when it contributes a significant portion of the flow upstream of the WWTP discharge and the Industrial discharge.

In earlier years, Hazelhill Well was also the source of the Ballyhaunis WS, but this abstraction has since ceased. There were also other abstractions from the Hazelhill Well; these were the Meat Processing Plant, Hollywell GWS and Greenwood GWS.

The additional inflow to the River Dalgan from Hazelhill Stream has not been included in the model. There was not enough data from the gauge located on this spring (30045) to allow any analysis of flows to be undertaken, and communication from the EPA indicates that the inflows were only significant at low flows.

It is considered that the location at which the stream joins the River Dalgan is sufficiently far downstream of the Ballyhaunis AFA for the effects of omitting this inflow to be negligible.

Table 7-1: Hazelhill Stream

Looking upstream to the pond at the source of the Hazelhill Stream. The location of the (now obsolete and removed) gauge is at the front of the photograph.	
Looking downstream of the Hazelhill Stream, towards its confluence with the Dalgan River.	

7.2 Channel blockage

Blockage of culverts and small span bridges has the potential to increase flood risk on any watercourse. In Ballyhaunis the culvert on the Devils watercourse at section 30DEVL000111, below Station Rise, looks particularly prone to blockage, with evidence of dumping of household waste, coupled with natural debris in the upstream channel (Table 7-2). If the culvert blocked, water would back up in the channel, before overtopping onto the field on the right bank, which is at a slightly lower elevation than the gardens and properties on the left bank. The natural flow path from this field is in a westerly direction, but it is unlikely that this would happen as the natural capacity of the field is relatively large. Although not investigated in more detail in this model, it is unlikely that culvert blockage will increase flood risk to property.

Table 7-2: Station Rise culvert

Culvert below Station Rise on the Devils watercourse. Evidence of dumping and natural debris accumulations evident during the site visit (June 2013).



7.3 Geomorphological changes

As highlighted in section 2.1, there is evidence of gravel and silt deposition on the Curries watercourse between the N60 and railway embankment crossing. Under present conditions this has been shown not to result in flood risk. However, the impact of changes to the geomorphology of the watercourse, and in particular greater gravel accumulations will need to be reviewed to determine the likely impact this could have on flood risk in the future.

A Hydraulic model results

A.1 1D model flows

Table A-1: 1D model peak current flows

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30DEVL00057	0.05	0.07	0.08	0.1	0.12	0.13	0.15	0.21
30DEVL00055A	0.05	0.07	0.08	0.1	0.12	0.13	0.15	0.21
30DEVL00042B	0.05	0.07	0.08	0.1	0.12	0.13	0.15	0.21
30DEVL00034	0.05	0.07	0.08	0.1	0.12	0.13	0.15	0.21
30DEVL00030	0.05	0.07	0.08	0.1	0.12	0.13	0.15	0.21
30DEVL00021	0.05	0.07	0.081	0.1	0.12	0.13	0.15	0.21
30DEVL00012	0.05	0.07	0.08	0.1	0.12	0.13	0.15	0.21
30DEVL00011A	0.05	0.07	0.08	0.1	0.12	0.13	0.15	0.21
30CURR00174	0.95	1.23	1.43	1.65	1.96	2.24	2.56	3.47
30CURR00172A	0.95	1.23	1.43	1.65	1.96	2.24	2.56	3.47
30CURR00171B	0.95	1.23	1.43	1.65	1.96	2.24	2.56	3.47
30CURR00170	0.95	1.23	1.43	1.65	1.96	2.24	2.56	3.47
30CURR00158	0.95	1.23	1.43	1.65	1.96	2.24	2.559	3.469
30CURR00142	0.95	1.23	1.43	1.65	1.961	2.24	2.56	3.469
30CURR00128	0.951	1.231	1.431	1.651	1.96	2.238	2.559	3.468
30CURR00115	0.95	1.231	1.43	1.649	1.959	2.24	2.56	3.468
30CURR00104	0.95	1.23	1.429	1.649	1.958	2.238	2.557	3.467
30CURR00094	0.95	1.229	1.429	1.648	1.957	2.237	2.559	3.466
30CURR00085	0.948	1.228	1.427	1.647	1.957	2.236	2.557	3.466
30CURR00075	0.948	1.227	1.427	1.646	1.956	2.235	2.557	3.465
30CURR00067	0.948	1.227	1.426	1.646	1.954	2.235	2.557	3.464
30CURR00059	0.947	1.227	1.425	1.645	1.954	2.234	2.555	3.366
30CURR00052	0.947	1.226	1.425	1.645	1.953	2.234	2.557	3.447
30CURR00044	0.947	1.226	1.425	1.644	1.953	2.233	2.555	3.465
30CURR00037	0.947	1.226	1.425	1.645	1.953	2.233	2.557	3.465
30CURR00036A	0.946	1.226	1.425	1.645	1.953	2.233	2.556	3.465
30CURR00035B	0.946	1.226	1.424	1.644	1.953	2.232	2.555	3.465
30CURR00035	0.946	1.226	1.424	1.644	1.952	2.232	2.555	3.465
30CURR00034	0.946	1.226	1.424	1.644	1.952	2.233	2.555	3.465
30CURR00033A	0.946	1.226	1.425	1.644	1.953	2.233	2.555	3.465
30CURR00031B	0.946	1.226	1.425	1.644	1.953	2.233	2.556	3.465
30CURR00030	0.946	1.226	1.425	1.644	1.953	2.233	2.556	3.465
30CURR00026	0.946	1.226	1.425	1.644	1.953	2.232	2.556	3.465
30CURR00020	0.947	1.226	1.425	1.645	1.953	2.233	2.556	3.464
CURR00019*A	0.947	1.226	1.425	1.645	1.953	2.233	2.555	3.465
CURR00019*B	0.997	1.296	1.505	1.745	2.073	2.363	2.705	3.675
30CURR00016	0.997	1.296	1.505	1.745	2.072	2.362	2.705	3.674
30CURR00010	0.997	1.296	1.505	1.743	2.071	2.361	2.704	3.672
30CURR00003	0.994	1.293	1.501	1.741	2.068	2.357	2.699	3.652
CURR00000*	0.993	1.291	1.5	1.739	2.065	2.354	2.696	3.663
30DALG02335	4.23	5.28	5.98	6.68	7.67	8.48	9.36	11.68
30DALG02326	4.229	5.281	5.979	6.679	7.671	8.48	9.361	11.681
30DALG02319	4.229	5.281	5.979	6.679	7.67	8.481	9.361	11.681
30DALG02311	4.229	5.281	5.979	6.678	7.67	8.27	8.702	10.393
30DALG02304	4.23	5.282	5.978	6.68	7.517	8.159	8.914	10.643
30DALG02297	4.23	5.302	6.006	6.712	7.711	8.507	9.296	11.195
30DALG02291	4.23	5.302	6.006	6.712	7.711	8.529	9.387	11.013
30DALG02286A	4.23	5.302	6.006	6.714	7.711	8.53	9.435	11.324
30DALG02286B	4.399	5.503	6.23	6.959	7.986	8.833	9.778	11.749
30DALG02277	4.399	5.504	6.231	6.959	7.986	8.832	9.736	11.77
30DALG02270	4.399	5.503	6.231	6.958	7.976	8.51	9.19	11.32
30DALG02263	4.399	5.502	6.232	6.948	7.846	8.473	8.795	9.13

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30DALG02255	4.399	5.502	6.231	6.955	7.945	8.716	9.551	11.003
30DALG02249	4.398	5.503	6.231	6.955	7.983	8.83	9.773	12.233
30DALG02242	4.398	5.503	6.231	6.955	7.983	8.829	9.774	12.233
30DALG02240A	4.398	5.503	6.23	6.955	7.983	8.829	9.78	12.233
30DALG02240B	4.398	5.503	6.23	6.955	7.983	8.829	9.78	12.233
30DALG02239	4.398	5.503	6.23	6.955	7.983	8.83	9.774	12.233
30DALG02238	4.398	5.502	6.231	6.955	7.983	8.829	9.778	12.232
30DALG02237A	4.398	5.502	6.23	6.955	7.983	8.829	9.769	12.233
30DALG02236B	4.398	5.502	6.23	6.955	7.983	8.829	9.769	12.233
30DALG02235	4.398	5.503	6.231	6.955	7.983	8.829	9.77	12.233
30DALG02234	4.398	5.502	6.231	6.955	7.983	8.829	9.772	12.233
30DALG02234A	4.398	5.502	6.23	6.955	7.983	8.829	9.769	12.233
30DALG02233B	4.398	5.502	6.23	6.955	7.983	8.829	9.769	12.233
30DALG02232	4.398	5.502	6.23	6.955	7.983	8.829	9.769	12.159
30DALG02231	4.398	5.502	6.231	6.955	7.924	8.682	9.459	11.275
30DALG02224	4.633	5.799	6.568	7.348	8.447	9.352	10.368	13.038
30DALG02216	4.631	5.798	6.567	7.346	8.447	9.351	10.286	12.634
30DALG02208	4.632	5.797	6.568	7.341	8.037	8.439	9.024	10.329
30DALG02201	4.864	6.095	6.907	7.739	8.985	9.961	10.841	12.424
30DALG02200A	4.864	6.094	6.907	7.739	8.923	9.897	10.982	13.862
30DALG02196B	4.864	6.093	6.907	7.739	8.922	9.897	10.982	13.862
30DALG02196	4.863	6.093	6.907	7.739	8.922	9.897	10.982	13.862
30DALG02193	4.864	6.094	6.907	7.739	8.922	9.897	10.982	13.862
30DALG02185	4.864	6.093	6.907	7.738	8.922	9.897	10.982	13.861
30DALG02179	4.864	6.094	6.907	7.738	8.922	9.897	10.982	13.861
30DALG02173	5.096	6.389	7.246	8.131	9.388	10.426	11.584	14.673
30DALG02170A	5.096	6.39	7.246	8.132	9.388	10.426	11.584	14.673
30DALG02169B	5.096	6.39	7.246	8.132	9.388	10.426	11.584	14.673
30DALG02169	5.096	6.39	7.246	8.132	9.388	10.426	11.584	14.664
30DALG02168	5.096	6.39	7.246	8.132	9.388	10.426	11.584	14.664
30DALG02168A	5.096	6.39	7.246	8.132	9.387	10.426	11.584	14.672
30DALG02168B	5.096	6.39	7.246	8.132	9.387	10.426	11.584	14.672
30DALG02160	5.095	6.389	7.244	8.128	9.383	10.42	11.58	14.67
30DALG02150	5.093	6.384	7.241	8.121	9.376	10.413	11.578	14.66
30DALG02140	5.087	6.38	7.238	8.116	9.371	10.406	11.573	14.646
30DALG02130	5.085	6.374	7.233	8.114	9.36	10.397	11.562	14.627
30DALG02120	5.083	6.373	7.229	8.107	9.353	10.39	11.477	14.065
30DALG02110	5.077	6.366	7.229	8.1	9.331	10.287	11.266	13.125
30DALG02096	5.071	6.358	7.218	8.09	9.292	10.302	11.339	13.297
30DALG02081	5.065	6.262	7.081	7.904	9.073	9.933	10.732	12.583
30DALG02070	5.06	6.343	7.209	8.062	9.241	10.16	11.133	13.293
30DALG02058	5.054	6.337	7.19	8.027	9.156	10.034	10.999	14.166
30DALG02058A	5.052	6.338	7.202	8.059	9.217	10.143	11.18	13.722
30DALG02058B	5.052	6.338	7.202	8.059	9.217	10.143	11.18	13.722
30DALG02056	5.051	6.266	6.978	7.579	8.278	8.795	9.438	11.216
30DALG02050	5.051	6.331	7.177	7.962	8.851	9.405	9.981	11.343
30DALG02042	5.048	6.33	7.166	7.878	8.616	9.071	9.505	10.658
30DALG02033	5.043	6.327	7.19	7.966	8.895	9.364	9.886	11.471
30DALG02019	5.042	6.296	7.097	7.786	8.487	8.715	8.852	9.212
30DALG02008	5.037	6.315	7.119	7.95	8.998	9.926	10.898	13.112
30DALG01995	5.034	6.312	7.119	7.931	8.998	9.913	10.882	13.122
30DALG01981	5.029	6.306	7.112	7.923	8.991	9.91	10.844	13.115
30DALG01964	5.024	6.3	7.102	7.92	8.988	9.904	10.817	13.105

Table A-2: 1D model peak MRFS flows

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30DEVL00057	0.064	0.085	0.1	0.117	0.141	0.163	0.184	0.253
30DEVL00055A	0.064	0.085	0.1	0.117	0.141	0.163	0.184	0.253
30DEVL00042B	0.064	0.085	0.1	0.117	0.141	0.163	0.184	0.253
30DEVL00034	0.064	0.085	0.1	0.117	0.141	0.163	0.184	0.253
30DEVL00030	0.064	0.085	0.1	0.117	0.141	0.163	0.184	0.253
30DEVL00021	0.064	0.085	0.1	0.117	0.141	0.163	0.184	0.253
30DEVL00012	0.064	0.085	0.1	0.117	0.141	0.163	0.184	0.253
30DEVL00011A	0.064	0.085	0.1	0.117	0.141	0.163	0.184	0.253
30CURR00174	1.75	2.177	2.478	2.794	3.256	3.649	4.102	5.556
30CURR00172A	1.75	2.177	2.478	2.794	3.256	3.649	4.102	5.555
30CURR00171B	1.75	2.177	2.478	2.794	3.256	3.649	4.102	5.555
30CURR00170	1.75	2.177	2.478	2.793	3.255	3.649	4.102	5.554
30CURR00158	1.749	2.176	2.478	2.794	3.256	3.649	4.102	5.559
30CURR00142	1.751	2.178	2.478	2.792	3.256	3.648	4.105	5.551
30CURR00128	1.749	2.177	2.477	2.794	3.254	3.647	4.101	5.552
30CURR00115	1.75	2.176	2.476	2.791	3.253	3.646	4.103	5.528
30CURR00104	1.75	2.175	2.476	2.792	3.251	3.645	4.106	5.472
30CURR00094	1.748	2.174	2.474	2.79	3.251	3.644	4.101	5.399
30CURR00085	1.747	2.173	2.473	2.79	3.248	3.643	4.105	5.527
30CURR00075	1.746	2.173	2.474	2.788	3.247	3.642	4.1	5.521
30CURR00067	1.746	2.173	2.472	2.788	3.247	3.642	4.106	5.413
30CURR00059	1.746	2.171	2.471	2.789	3.245	3.511	3.897	5.122
30CURR00052	1.744	2.17	2.471	2.786	3.245	3.507	3.885	4.642
30CURR00044	1.745	2.17	2.47	2.787	3.246	3.643	4.099	5.499
30CURR00037	1.744	2.169	2.47	2.788	3.246	3.643	4.107	5.498
30CURR00036A	1.744	2.17	2.47	2.787	3.246	3.643	4.102	5.494
30CURR00035B	1.744	2.17	2.469	2.787	3.246	3.643	4.099	5.494
30CURR00035	1.744	2.17	2.469	2.787	3.246	3.643	4.099	5.494
30CURR00034	1.744	2.17	2.469	2.787	3.246	3.643	4.098	5.495
30CURR00033A	1.744	2.169	2.47	2.787	3.246	3.643	4.098	5.495
30CURR00031B	1.744	2.169	2.47	2.787	3.246	3.643	4.095	5.496
30CURR00030	1.744	2.17	2.47	2.787	3.246	3.643	4.097	5.495
30CURR00026	1.744	2.17	2.47	2.787	3.246	3.643	4.098	5.495
30CURR00020	1.744	2.169	2.47	2.787	3.246	3.643	4.096	5.495
CURR00019*A	1.744	2.169	2.47	2.787	3.246	3.643	4.096	5.494
CURR00019*B	1.808	2.254	2.569	2.903	3.387	3.806	4.28	5.747
30CURR00016	1.809	2.254	2.569	2.903	3.386	3.805	4.281	5.749
30CURR00010	1.808	2.254	2.568	2.902	3.385	3.804	4.278	5.761
30CURR00003	1.805	2.251	2.565	2.899	3.38	3.798	4.228	5.456
CURR00000*	1.804	2.25	2.563	2.897	3.377	3.795	4.27	5.751
30DALG02335	5.094	6.354	7.193	8.042	9.232	10.207	11.48	15.595
30DALG02326	5.093	6.353	7.194	8.042	9.232	10.199	11.481	15.445
30DALG02319	5.093	6.353	7.194	8.043	9.233	10.199	11.48	15.621
30DALG02311	5.093	6.352	7.197	8.024	8.609	9.327	10.256	13.33
30DALG02304	5.09	6.352	7.187	7.75	8.792	9.577	10.501	12.791
30DALG02297	5.109	6.384	7.237	8.086	9.177	10.01	11.035	14.22
30DALG02291	5.108	6.384	7.236	8.086	9.253	9.953	10.895	13.711
30DALG02286A	5.108	6.385	7.238	8.088	9.292	10.233	11.173	13.45
30DALG02286B	5.372	6.693	7.573	8.455	9.726	10.691	11.684	14.206
30DALG02277	5.373	6.693	7.574	8.457	9.691	10.597	11.67	14.339
30DALG02270	5.372	6.693	7.573	8.324	9.143	10.055	11.203	14.415
30DALG02263	5.372	6.692	7.499	8.2	8.789	9.007	9.127	11.353
30DALG02255	5.372	6.693	7.559	8.38	9.516	10.196	10.962	11.419
30DALG02249	5.372	6.695	7.574	8.455	9.722	10.776	12.116	16.49
30DALG02242	5.371	6.693	7.573	8.455	9.721	10.775	12.105	16.473
30DALG02240A	5.371	6.692	7.573	8.455	9.726	10.776	12.105	16.458
30DALG02240B	5.371	6.692	7.573	8.455	9.726	10.776	12.105	16.458

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30DALG02239	5.371	6.692	7.573	8.455	9.718	10.776	12.109	16.462
30DALG02238	5.371	6.692	7.573	8.455	9.725	10.776	12.111	16.458
30DALG02237A	5.371	6.692	7.573	8.454	9.715	10.776	12.109	16.444
30DALG02236B	5.371	6.692	7.573	8.454	9.715	10.776	12.109	16.444
30DALG02235	5.371	6.692	7.573	8.455	9.713	10.776	12.108	16.445
30DALG02234	5.371	6.692	7.573	8.455	9.715	10.776	12.108	16.443
30DALG02234A	5.37	6.692	7.573	8.455	9.712	10.776	12.108	16.44
30DALG02233B	5.37	6.692	7.573	8.455	9.712	10.776	12.108	16.44
30DALG02232	5.37	6.692	7.573	8.455	9.712	10.776	12.109	15.839
30DALG02231	5.371	6.692	7.573	8.414	9.565	10.467	11.591	14.013
30DALG02224	5.381	6.705	7.585	8.47	9.732	10.795	12.13	16.46
30DALG02216	5.38	6.704	7.584	8.47	9.731	10.741	11.991	15.447
30DALG02208	5.379	6.703	7.584	8.358	8.98	9.423	10.541	12.179
30DALG02201	5.388	6.715	7.598	8.55	9.896	11.069	12.269	19.49
30DALG02200A	5.387	6.715	7.598	8.492	9.767	10.834	12.172	15.584
30DALG02196B	5.388	6.715	7.597	8.492	9.768	10.834	12.173	15.584
30DALG02196	5.388	6.715	7.597	8.492	9.768	10.834	12.173	15.933
30DALG02193	5.388	6.715	7.598	8.491	9.768	10.834	12.172	15.929
30DALG02185	5.387	6.715	7.597	8.491	9.767	10.834	12.172	16.267
30DALG02179	5.388	6.715	7.597	8.491	9.767	10.834	12.172	16.263
30DALG02173	5.396	6.727	7.611	8.507	9.786	10.856	12.197	16.298
30DALG02170A	5.396	6.726	7.61	8.506	9.786	10.856	12.197	16.348
30DALG02169B	5.396	6.726	7.61	8.506	9.786	10.856	12.197	16.348
30DALG02169	5.396	6.726	7.61	8.506	9.786	10.856	12.198	16.345
30DALG02168	5.396	6.726	7.61	8.506	9.786	10.856	12.198	16.345
30DALG02168A	5.396	6.726	7.61	8.506	9.787	10.856	12.197	16.344
30DALG02168B	5.396	6.726	7.61	8.506	9.787	10.856	12.197	16.344
30DALG02160	5.395	6.725	7.609	8.505	9.782	10.853	12.194	16.34
30DALG02150	5.394	6.721	7.607	8.501	9.775	10.849	12.19	16.286
30DALG02140	5.391	6.72	7.605	8.499	9.768	10.843	12.184	16.217
30DALG02130	5.387	6.715	7.602	8.493	9.761	10.838	12.179	16.126
30DALG02120	5.384	6.712	7.6	8.489	9.753	10.807	12.121	15.005
30DALG02110	5.379	6.709	7.611	8.478	9.7	10.684	11.732	14.065
30DALG02096	5.378	6.699	7.609	8.473	9.692	10.727	11.802	14.124
30DALG02081	5.363	6.591	7.42	8.265	9.437	10.264	11.1	13.303
30DALG02070	5.374	6.693	7.564	8.444	9.634	10.59	11.684	14.036
30DALG02058	5.366	6.682	7.536	8.395	9.529	10.466	11.574	16.785
30DALG02058A	5.366	6.686	7.557	8.437	9.614	10.607	11.81	14.311
30DALG02058B	5.366	6.686	7.557	8.437	9.614	10.607	11.81	14.311
30DALG02056	5.368	6.564	7.259	7.773	8.464	9.058	9.822	11.766
30DALG02050	5.364	6.677	7.511	8.257	9.073	9.618	10.229	11.876
30DALG02042	5.362	6.682	7.49	8.131	8.774	9.2	9.781	11.085
30DALG02033	5.357	6.675	7.542	8.285	9.077	9.539	10.157	11.956
30DALG02019	5.354	6.63	7.418	8.082	8.522	8.77	9.073	9.691
30DALG02008	5.345	6.661	7.459	8.333	9.444	10.371	11.464	14.644
30DALG01995	5.34	6.654	7.446	8.311	9.446	10.377	11.464	14.641
30DALG01981	5.339	6.651	7.441	8.304	9.434	10.374	11.463	14.641
30DALG01964	5.336	6.65	7.436	8.294	9.435	10.347	11.462	14.641

A.2 HEP flows

Table A-3: Current peak flows at HEPs

HEP Reference	Cross Section	Peak Flow in Model (m3/s)								Comments (note: where blank, no changes have been made)
		50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	
DLG_000	30DALG02335	4.23	5.28	5.98	6.68	7.67	8.48	9.36	11.68	Catchments of Devlis and Curries peak significantly earlier than Dalgan and do not contribute to peak. Therefore flows on Dalgan are a result of inflows on the Dalgan only. Key flow point is the gauge site at DLG_003 and because there is no flood risk in the upstream reaches to simplify the model, flows equivalent to DLG_003 have been put into to the upstream limit of the model.
DLG_001	30DALG02304	4.23	5.282	5.978	6.68	7.517	8.159	8.914	10.643	DS of Grange confluence. Flows become low after the 10% AEP event due to floodplain flow bypassing this HEP.
DLG_002	30DALG02277	4.399	5.504	6.231	6.959	7.986	8.832	9.736	11.77	River well contained through this reach by Corrofin Bridge so key location for flow checks in AFA centre. Lateral inflow applied upstream of this HEP. Modelled and predicted flows show good match.
DLG_003	30DALG02239	4.398	5.503	6.23	6.955	7.983	8.83	9.774	12.233	Gauging station 30020. See above for application of hydrology.
DLG_004	30DALG02168B	5.096	6.39	7.246	8.132	9.387	10.426	11.584	14.672	Downstream AFA boundary on River Dalgan. Lateral inflow applied between DLG_003 and DLG_004; scaled to match DLG_004.
DVL_002	30DEVL00057	0.05	0.07	0.08	0.1	0.12	0.13	0.15	0.21	Upstream modelled extent of Devlis watercourse.
DVL_003	30DEVL00030	0.05	0.07	0.08	0.1	0.12	0.13	0.15	0.21	Devlis inflow scaled to match estimates at DVL_003 as a simplification (DVL_003 is approximately the midpoint of watercourse).
DVL_004	30DEVL00011A	0.05	0.07	0.08	0.1	0.12	0.13	0.15	0.21	Downstream extent of Devlis watercourse. Flows have not been directly scaled to match this HEP.
CUR_001	30CURR00174	0.95	1.23	1.43	1.65	1.96	2.24	2.56	3.47	Upstream modelled extent of Curries watercourse.
CUR_002	30CURR00115	0.95	1.231	1.43	1.649	1.959	2.24	2.56	3.468	
CUR_003	30CURR00075	0.948	1.227	1.427	1.646	1.956	2.235	2.557	3.465	Curries inflow scaled to match estimates at CUR_003 as a simplification (CUR_003 is approximately the midpoint of watercourse).
CUR_004	30CURR00020	0.947	1.226	1.425	1.645	1.953	2.233	2.556	3.464	Upstream of the confluence with Devlis.
CUR_005	30CURR00010	0.997	1.296	1.505	1.743	2.071	2.361	2.704	3.672	Downstream extent of Curries watercourse (downstream of confluence with Devlis). Flows have not been directly scaled to match this HEP.

Table A-4: MRFS peak flows at HEPs

HEP Reference	Cross Section	Peak Flow in Model (m3/s)								Comments (note: where blank, no changes have been made)
		50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	
DLG_000	30DALG02335	5.094	6.354	7.193	8.042	9.232	10.207	11.48	15.595	Catchments of Devlis and Curries peak significantly earlier than Dalgan and do not contribute to peak. Therefore flows on Dalgan are a result of inflows on the Dalgan only. Key flow point is the gauge site at DLG_003 and because there is no flood risk in the upstream reaches to simplify the model, flows equivalent to DLG_003 have been put into to the upstream limit of the model.
DLG_001	30DALG02304	5.09	6.352	7.187	7.75	8.792	9.577	10.501	12.791	DS of Grange confluence. Flows become low after the 10% AEP event due to floodplain flow bypassing this HEP.
DLG_002	30DALG02277	5.373	6.693	7.574	8.457	9.691	10.597	11.67	14.339	River well contained through this reach by Corrofin Bridge so key location for flow checks in AFA centre. Lateral inflow applied upstream of this HEP. Modelled and predicted flows show good match.
DLG_003	30DALG02239	5.371	6.692	7.573	8.455	9.718	10.776	12.109	16.462	Gauging station 30020. See above for application of hydrology.
DLG_004	30DALG02168B	5.396	6.726	7.61	8.506	9.787	10.856	12.197	16.344	Downstream AFA boundary on River Dalgan. Lateral inflow applied between DLG_003 and DLG_004; scaled to match DLG_004.
DVL_002	30DEVL00057	0.064	0.085	0.1	0.117	0.141	0.163	0.184	0.253	Upstream modelled extent of Devlis watercourse.
DVL_003	30DEVL00030	0.064	0.085	0.1	0.117	0.141	0.163	0.184	0.253	Devlis inflow scaled to match estimates at DVL_003 as a simplification (DVL_003 is approximately the midpoint of watercourse).
DVL_004	30DEVL00011A	0.064	0.085	0.1	0.117	0.141	0.163	0.184	0.253	Downstream extent of Devlis watercourse. Flows have not been directly scaled to match this HEP.
CUR_001	30CURR00174	1.75	2.177	2.478	2.794	3.256	3.649	4.102	5.556	Upstream modelled extent of Curries watercourse.
CUR_002	30CURR00115	1.75	2.176	2.476	2.791	3.253	3.646	4.103	5.528	
CUR_003	30CURR00075	1.746	2.173	2.474	2.788	3.247	3.642	4.1	5.521	Curries inflow scaled to match estimates at CUR_003 as a simplification (CUR_003 is approximately the midpoint of watercourse).
CUR_004	30CURR00020	1.744	2.169	2.47	2.787	3.246	3.643	4.096	5.495	Upstream of the confluence with Devlis.
CUR_005	30CURR00010	1.808	2.254	2.568	2.902	3.385	3.804	4.278	5.761	Downstream extent of Curries watercourse (downstream of confluence with Devlis). Flows have not been directly scaled to match this HEP.



Registered Office

**24 Grove Island
Corbally
Limerick
Ireland**

T: +353 (0) 61 345463
e: info@jbaconsulting.com

**JBA Consulting Engineers and
Scientists Limited**

Registration number 444752

Visit our website
www.jbaconsulting.com

Western CFRAM UoM 30 - Corrib Hydraulic Modelling Report: Volume 2b - Corrofin

Final

September 2016

**Office of Public Works
Trim
Co. Meath**



**WESTERN
CFRAM
STUDY**
CATCHMENT FLOOD RISK
ASSESSMENT AND MANAGEMENT

JBA Consulting

24 Grove Island
Corbally
Limerick
Ireland

JBA Project Manager

Sam Willis BSc MSc CEnv CSci MCIWEM C.WEM

Revision History

Revision ref / Date issued	Amendments	Issued to
Version 1.0		Rosemarie Lawlor
V2.0 / December 2014	Updated to reflect model updates following review and public consultation. Report updated to reflect client and TAS review.	Rosemarie Lawlor, OPW
V3.0 / January 2015	Report renamed	Rosemarie Lawlor, OPW
V4.0 / September 2106	Final updates	Clare Butler, OPW

Contract

This report describes work commissioned by The Office of Public Works, by a letter dated (28/07/11). The Office of Public Works' representative for the contract was Rosemarie Lawlor. Sam Willis, Chris Smith and Elizabeth Russell of JBA Consulting carried out this work.

Prepared by Chris Smith BSc PhD C.Env. MCIWEM C.WEM.
MCM

Reviewed by Elizabeth Russell BSc MSc CEnv MCIWEM
C.WEM

Purpose

This document has been prepared as a draft report for The Office of Public Works. 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.

JBA Consulting has no liability regarding the use of this report except to the Office of Public Works.

Copyright

Copyright is with Office of Public Works. All rights reserved. No part of this report may be copied or reproduced by any means without the prior written permission of the Office of Public works.

Legal Disclaimer

This report is subject to the limitations and warranties contained in the contract between the commissioning party (Office of Public Works) and JBA.

Carbon Footprint

A printed copy of the main text in this document will result in a carbon footprint of 132g if 100% post-consumer recycled paper is used and 168g if primary-source paper is used. These figures assume the report is printed in black and white on A4 paper and in duplex.

JBA is aiming to achieve carbon neutrality.

Contents

Legal Disclaimer	ii
1 Introduction	1
1.1 Scope of report	1
1.2 Model and report overview	1
1.3 Watercourse and catchment overview	2
1.4 Available data	4
2 Hydraulic modelling	6
2.1 Context.....	6
2.2 Key hydraulic structures	6
2.3 Hydraulic roughness	7
2.4 1D-2D boundary	8
2.5 Defences and walls.....	8
2.6 Floodplain	11
3 Flood history, model calibration and sensibility checking	12
3.1 Calibration versus sensibility checking	12
3.2 Flood history	12
3.3 Calibration outcomes.....	13
3.4 Stakeholder Engagement.....	16
4 Application of hydrology	17
4.1 Hydrological estimation points.....	17
4.2 Application of design flow estimates.....	17
4.3 Downstream Boundary	18
5 Model results.....	20
5.1 Model runs	20
5.2 Flood risk mapping	20
5.3 Key flood risk mechanisms	20
6 Sensitivity testing	22
6.1 Screening of sensitivity tests	22
6.2 Sensitivity testing results and uncertainty bounds.....	24
7 Model limitations	27
7.1 Bankside embankments	27
7.2 Influence of tributaries and groundwater	27
A Hydraulic model results	28

List of Figures

Figure 1-1: Overview of rivers in the Corrofin catchment	2
Figure 1-2: Corrofin AFA overview	3
Figure 1-3: Historic river routes	4
Figure 2-1: Key structure locations	6
Figure 2-2 - Defence and wall locations	9
Figure 2-3: ESTRY units in Corrofin Bridge.....	11
Figure 3-1: Flood history in the Corrofin AFA	12
Figure 3-2: Calibration of rating curve at 30004 Corrofin gauge	14
Figure 3-3: November 2009 modelled flood extent	14
Figure 3-4: November 2009 modelled flood extent detail at Ballybanagher	15
Figure 3-5: December 2006 modelled flood extent	16
Figure 4-1: Corrofin AFA HEP locations	17
Figure 5-1: Corrofin flood mechanism	21
Figure 6-1: 10% AEP event uncertainty bounds.....	25
Figure 6-2: 1% AEP event uncertainty bounds.....	25
Figure 6-3: 1% AEP event - Clare River only test	26
Figure 7-1: Karst features in the vicinity of Corrofin	27

List of Tables

Table 1-1: Abbreviated watercourse names.....	4
Table 1-2: Hydrometric gauging stations in the vicinity of the AFA	5
Table 2-1: Key hydraulic structures	7
Table 2-2: Reach hydraulic roughness values	7
Table 2-3: Key hydraulic structures	9
Table 4-1: Summary of hydraulic model design inflows	19
Table 5-1: Peak flows for the Mid-Range Future Scenario	20
Table 5-2: Peak flows for the High-End Future Scenario	20
Table 6-1: Sensitivity test summary.....	22
Table A-1: 1D model peak current flows	28
Table A-2: 1D model peak MRFS flows	29
Table A-3: Current peak flows at HEPs.....	32
Table A-4: MRFS peak flows at HEPs.....	32

Abbreviations

AEP	Annual exceedence probability
AFA	Area for further assessment
AMAX	Annual maximum
CFRAM	Catchment flood risk assessment and management
DAD	Defence asset database
DAS	Defence asset survey
DEM	Digital elevation model (Includes surfaces of structures, vegetation, etc)
DTM	Digital terrain model ('bare earth' model; does not include surfaces of structures, vegetation, etc
ESTRY	One-dimensional model from the TUFLOW suite
FRISM	Flood risk metrics (a flood risk tool developed by JBA)
FRMP	Flood risk management plan
FRR	Flood risk review
FSR	Flood studies report
FSU	Flood studies update
GIS	Geographical information system
HEFS	High-end future scenario
HEP	Hydrological estimation point
HPW	High priority watercourse
HWA	Hydrograph width analysis
IBIDEM	Interactive bridge invoking the design event method
ICPSS	Irish coastal protection strategy study
ISIS	One-dimensional hydraulic modelling software
LA	Local authority
LIDAR	Light detection and ranging
mOD	Metres above Ordnance datum (unless stated this refers to the Malin datum)
MPW	Medium priority watercourse
MRFS	Mid-range future scenario
NDHM	National digital height model (a DTM by Intermap)
OSi	Ordnance Survey Ireland
PFRA	Preliminary flood risk assessment
Q(T)	Flow for a given return period
QMED	Median annual flood, used in FSU methods
SAAR	Standard annual average rainfall
SoP	Standard of protection (in relation to flood defences)
T	Return period, inverse of AEP
Tp	Time to peak
TUFLOW	Two-dimensional hydraulic modelling software

UoM Unit of Management

* Asterisks at the end of a cross section label denotes interpolated
model cross sections

1 Introduction

1.1 Scope of report

This report summarises the hydraulic modelling work for the Corrofin AFA hydraulic model. This document is specific to the AFA itself and should be read in conjunction with Volume 1a: Hydraulic Modelling Method Statement for details of the modelling approaches.

The report covers the overall hydraulic modelling process from model build through to the development of design runs, with the aim of providing a detailed understanding of the hydraulic controls and flood mechanisms identified throughout the study.

The hydraulic modelling work summarised in this and the Unit of Management 30 Hydraulic Modelling Report, of which this report is an Annex, forms one element of the Western Catchment-based Flood Risk Assessment and Management (WCFRAM) study process. The process to date has included amongst other tasks a Flood Risk Review (FRR)¹, a project inception stage², a Strategic Environmental Assessment (SEA)³ and the development of the catchment hydrology⁴. Where the work completed in these tasks contains information relevant to the analysis discussed in this document, references have been included directing the reader to the relevant report for further background information.

The report is not a user manual for the hydraulic model itself, full details of which are provided in the model handover check files accompanying the hydraulic model.

1.2 Model and report overview

There is only one HPW model for Corrofin, which covers the Clare River, and its tributary, the Grange River. The model starts a short distance upstream of the AFA boundary. The HPW sits within the Tuam to Lough Corrib MPW model. The MPW model is based on extended cross sections and is run in 1D only. It is intended to allow flows to be routed down the River Clare and the impact of management measures to be tested through the whole catchment. The resolution and accuracy of the MPW model is lower than the HPW, so where there is an overlap the outputs of the HPW model have been used in preference.

The model codes relevant to these rivers are:

- Clare and Grange HPW - L1
- Tuam to Lough Corrib - 90

Reports which are relevant to this AFA are:

- Western CFRAM Flood Risk Review Report
- Western CFRAM UoM 30 Inception Report
- Western CFRAM UoM 30 Hydrology Report
- Western CFRAM UoM 30 Hydraulic Modelling Report
- Western CFRAM UoM 30 Hydraulic Modelling Report: Volume 1 - Hydraulic Modelling Method Statement
- Western CFRAM UoM 30 Hydraulic Modelling Report: Volume 3 - Flood Risk Maps
- Corrofin AFA Hydraulic Model Check File
- Western CFRAM UoM 30 Hydraulic Modelling Report: Volume 2i - Tuam to Lough Corrib

Cross Section, long section and flood extent plots are provided in Volume 3 of the UoM30 Hydraulic Modelling report

¹ JBA Consulting (2012), Western CFRAM Flood Risk Review, Final Report, Office of Public Works

² JBA Consulting (2012), Western CFRAM Unit of Management 30 - Corrib Inception Report, Final Report, Office of Public Works

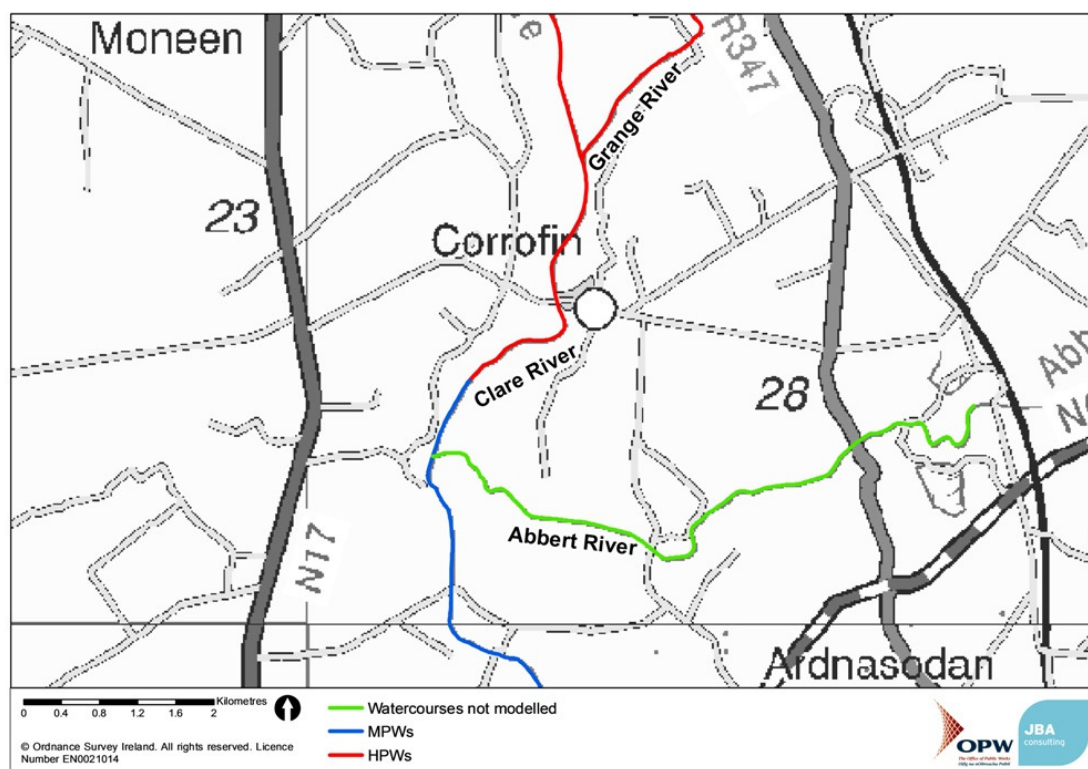
³ JBA Consulting (2013), Western River Basin District Catchment-based Flood Risk Assessment and Management (CFRAM) Strategic Environmental Assessment, Scoping Report, Office of Public Works.

⁴ JBA Consulting (2014), Western CFRAM Unit of Management 30 - Corrib Hydrology Report, Final Report, Office of Public Works

1.3 Watercourse and catchment overview

The study area encompasses the Corrofin AFA and includes the Clare River, the main river passing through Corrofin village, and Grange River, a tributary of the Clare River. The watercourses are all classed as High Priority Watercourses (HPWs) as they flow through the AFA, and have been included in the model. Figure 1-1 provides an overview of the area, with more detail of the AFA shown in Figure 1-2.

Figure 1-1: Overview of rivers in the Corrofin catchment

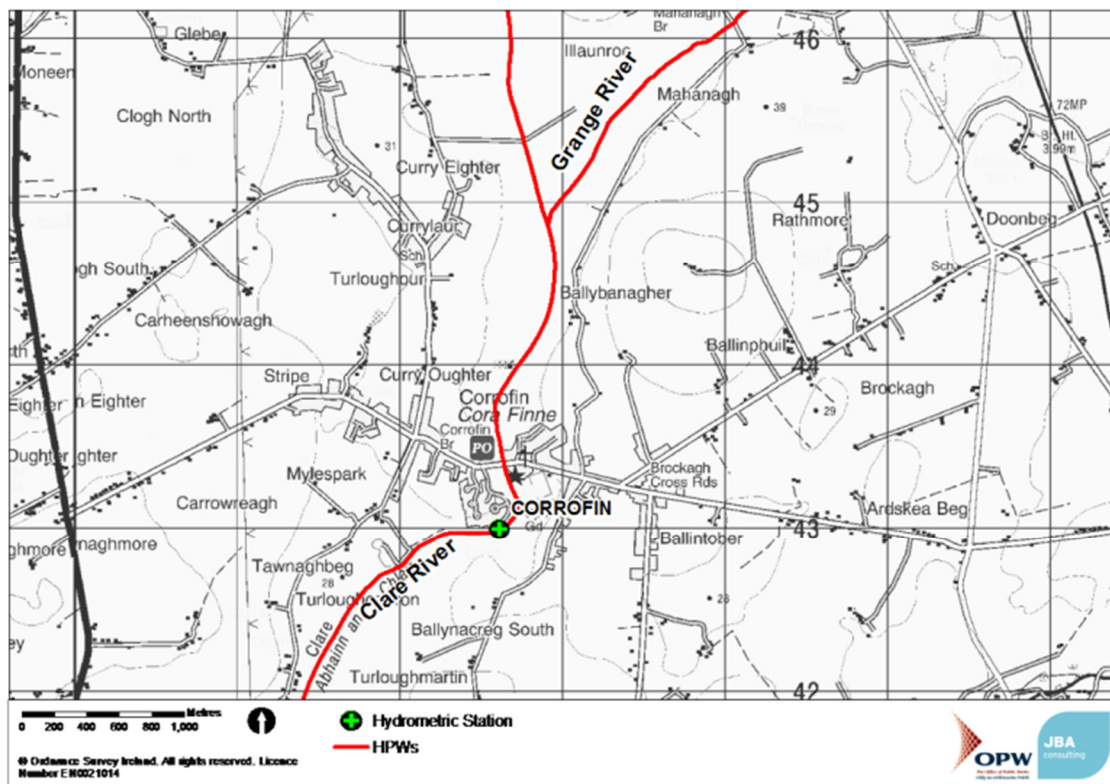


1.3.1 Clare River

The upstream modelled extent of the Clare is located approximately 1.5 km upstream of the confluence with the Grange River, and the downstream modelled extent is near Daly's Bridge, approximately 4.5km downstream of Corrofin Bridge, or 1.5 km downstream of the confluence with the River Abbert. The gradient of the Clare River through this reach is very shallow, at 0.0007 (~ 1 in 1400), dropping at a rate of 0.7 m/km.

The Clare River channel has been extensively worked on over centuries and is historically part of the Clare-Corrib arterial drainage scheme. This is evidenced by the extensive informal embankments along the river channel that appear to be made up of dredged material. Historic OSi mapping also suggests the river has been significantly altered (see Figure 1-3). The mapping shows the area upstream of Corrofin, incorporating the Grange River confluence and further upstream, was historically Cloonkeen Lough which is marked as a permanent water body. That was apparent in mapping dated 1829-41 but by 1897-1913 the river channels appear as they do now and Cloonkeen Lough had disappeared. It also appears that Corrofin Bridge was changed between these two maps from a bridge with multiple small arches all the way across, to the one used today with a main span and remaining small side arches, now largely unused. The main river channel was moved to the east slightly, deepened and widened at this time to create the gorge where the current bridge spans. Continuing downstream of Corrofin, the Clare River used to flow into a large turlough between Corrofin and Turloughmore from which there was no overland outflow to Lough Corrib. The river channels now in existence were built in the 19th century to improve the land drainage. The Clare River channel is maintained by OPW as part of the arterial drainage programme.

Figure 1-2: Corrofin AFA overview



1.3.2 Grange River

The modelled length of the Grange River is 2.2 km. The gradient of this watercourse is approximately 0.001 (1 in 1000), dropping at 1 m/km. As with the River Clare, the Grange River has been subject to historical alteration, particularly downstream of Mahanagh Bridge. The Grange River would have flowed into Cloonkeen Lough before the improved drainage works were implemented in the 19th century.

Figure 1-3: Historic river routes

1.4 Available data

1.4.1 Survey data

Cross sectional survey was collected by CCS Surveying in Work Packages 1 and 2 as part of the National Survey Contract No. 6 and delivered in November 2012.

The abbreviated version of each watercourse name as represented in the hydraulic models are detailed in Table 1-1.

Table 1-1: Abbreviated watercourse names

Reference	Description	Model Code
CLAR	Clare River	L1
GRAN	Grange River	L1

LIDAR data has been collected for use in the model. Data has been provided in both filtered and unfiltered formats in a 2 m grid resolution. The LIDAR was flown between Nov 2011 and August 2012.

A comparison of LIDAR levels against the surveyed cross sections was completed as part of the survey review process. This compared spot levels collected on roads or in open spaces and found an average difference between the two of 80mm, therefore no adjustment to the LIDAR was required to match the survey data.

1.4.2 Existing hydraulic model

An existing hydraulic model of the River Clare was made available by the OPW for this study. The model is the HEC-RAS model developed by Ryan Hanley Consulting Engineers for the "Study to Identify Practical Measures to Address Flooding on the River Clare" report in 2010. Cross section data from this model was used to extend the hydraulic model of the River Clare, developed using the survey data in Section 1.4.1, further downstream. Extending the River Clare further downstream of Corrofin meant that the hydraulic effect of the River Abbert inflow could be represented.

A direct comparison of the HEC-RAS model cross sections with the recently surveyed sections could not be made as the sections did not overlap. A comparison of LIDAR levels against the bank levels in several cross sections of the HEC-RAS model was undertaken, and generally showed a good correlation between the two datasets. The difference was typically within a few hundred millimetres and was considered acceptable enough to model any backwater effects from downstream of the Corrofin gauging station that could affect the rating. This is discussed further in Section 3.1.

1.4.3 Hydrometric data

A summary of hydrometric data within the AFA is provided in Table 1-2 and an overview of gauge locations is provided in Figure 1-1.

Table 1-2: Hydrometric gauging stations in the vicinity of the AFA

Number	Type	Use in calibration
30004 Corrofin	Active flow site	Rating review calibrated to gaugings. Primary calibration location. Data from 1964 to present.

As part of the study a review of the rating curve at gauge 30004 Corrofin has been completed. Full details of this review are detailed in the WCFRAM Hydrology Report for UoM 30.

The largest recorded events on record occurred in 1968, 2009 and 2006. These are estimated to be equivalent to a 0.5% AEP, 1% AEP and 5% AEP event respectively. The 1968 event is highly uncertain in terms of the peak level as there has been a datum change since then and it is likely changes in the channel have occurred since. The 1968 event is therefore not considered further in this modelling.

2 Hydraulic modelling

2.1 Context

This section should be read in conjunction with the Hydraulic Model Report: Volume 1a: Hydraulic Modelling Method Statement and the Corrofin Hydraulic Model Check File. The Method Statement provides an overview of the elements of both the 1D and 2D model construction and the following section of the report describes how they were applied to the Corrofin AFA.

2.2 Key hydraulic structures

Key hydraulic structures that dictate water levels and flow routes in the vicinity of key flood risk areas are summarised in Table 2-1 and shown in Figure 2-1. There is only one structure within the Corrofin AFA which is Corrofin Bridge.

Figure 2-1: Key structure locations

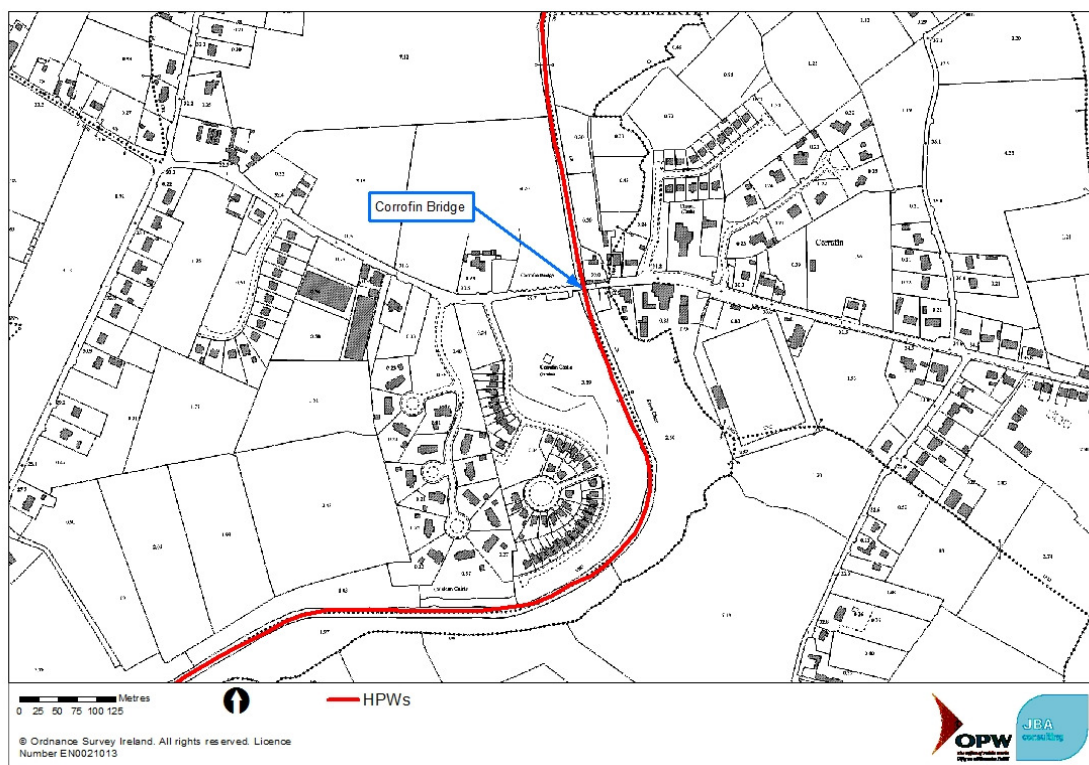





Table 2-1: Key hydraulic structures


Structure Name	Description	Photograph
Corrofin Bridge	Arched stone road bridge at high elevation above the channel. The river channel is within a deep and contained stone lined channel in contrast to the much lower banks and wide floodplains evident upstream and downstream. There are a number of flood relief arches across the right bank.	

2.3 Hydraulic roughness

Reaches of similar hydraulic roughness have been identified from survey photos and drawings. Manning's 'n' values for both the river bed and banks to bank top within each of these reaches are summarised in Table 2-2.

Table 2-2: Reach hydraulic roughness values

Upstream and Downstream Cross Section	Roughness Values (Manning's 'n') and materials	Photograph
30GRAN00219 to 30GRAN00006	0.022 (silt) 0.040 (Scrub/grass)	
30CLAR03153 to 30CLAR02785	0.040 (coarse gravel and cobbles) 0.040 (Scrub/grass)	

Upstream and Downstream Cross Section	Roughness Values (Manning's 'n') and materials	Photograph
30CLAR02775 to 30CLAR02669	0.040 (coarse gravel and cobbles) 0.070 (trees/bushes)	
30CLAR02649 to 30CLAR02265	0.040 (coarse gravel and cobbles) 0.040 (Scrub/grass)	<p>No survey or photo available as these cross sections have been taken from an existing hydraulic model, Section 1.4.2.</p> <p>Bank roughness values have been determined from a review of aerial photography covering this reach.</p> <p>A review of cross section profiles and the channel slope confirms this reach is comparable with upstream reaches. Bed roughness has therefore been assumed to be consistent with the upstream model.</p>

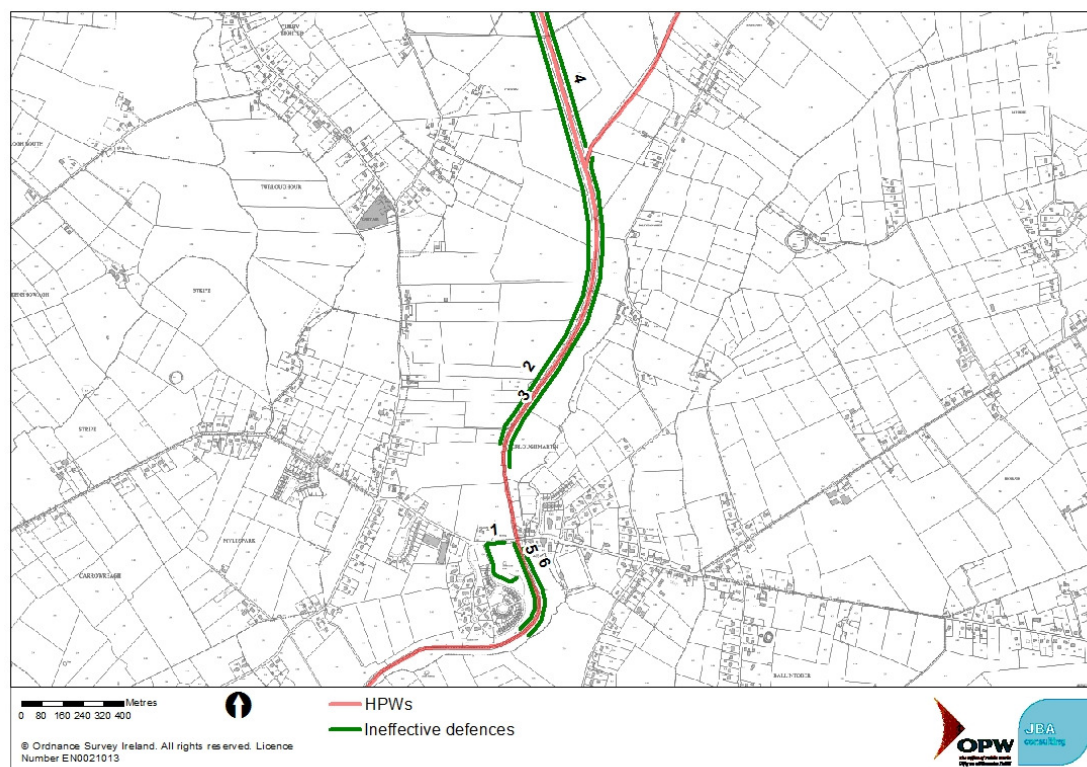
2.4 1D-2D boundary

Bank top survey was collected as part of the topographic survey and has been used to develop the 1D-2D boundary. Additional points from LIDAR were used to define the bank top, mainly to better represent the gaps in the embankment that runs along both banks of the Clare River, ensuring these flow routes were relatively well represented.

2.5 Defences and walls

The location of flood defences in Corrofin are shown in Figure 2-2.

Figure 2-2 - Defence and wall locations




2.5.1 Defences



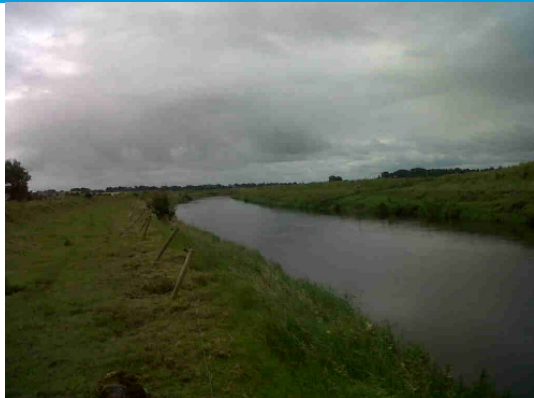
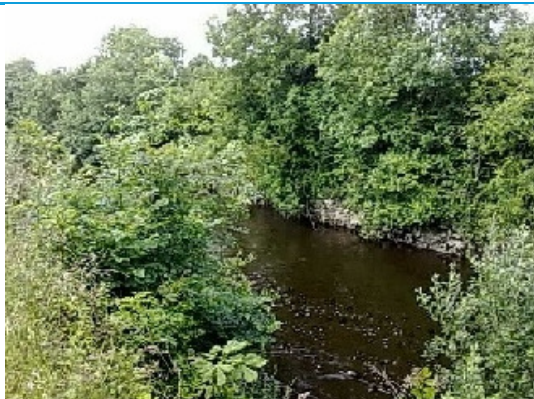
No formal or informal effective defences have been identified with the AFA.

2.5.2 Ineffective defences

Informal ineffective structures identified with the AFA are detailed in Table 2-3. These structures are not assumed to function as flood defences and are either bypassed in the model or have been removed to allow flooding beyond them.

Table 2-3: Key hydraulic structures

ID	Description and Location	Modelling Method	Photograph
1	Wall along road at entrance to housing estate.	Gaps incorporated	

ID	Description and Location	Modelling Method	Photograph
2	Informal channel side embankment.	Gaps incorporated	
3	Informal channel side embankment.	Gaps incorporated	
4	Informal channel side embankment.	Gaps incorporated	
5	Informal channel side embankment.	Gaps incorporated	

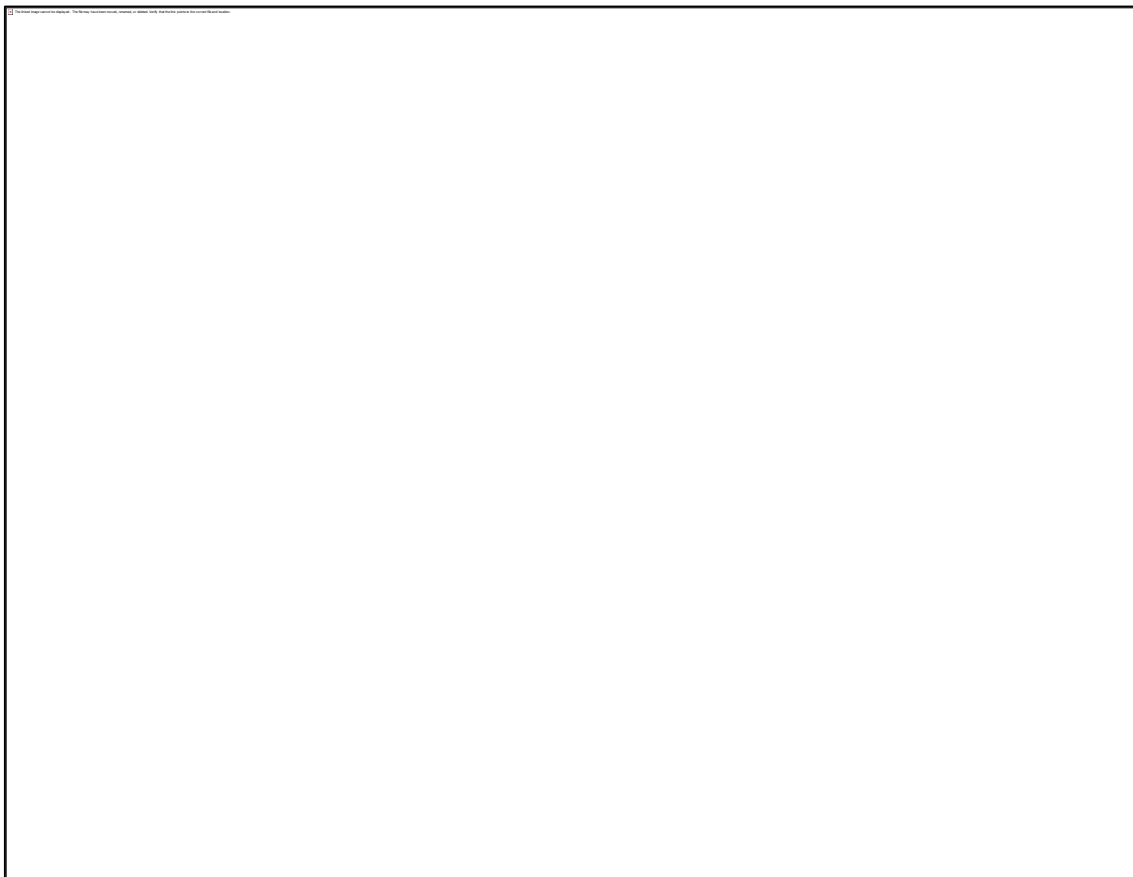
ID	Description and Location	Modelling Method	Photograph
6	Informal channel side embankment.	Gaps incorporated	

2.6 Floodplain

A 2D cell size of 8 m has been used because this is considered appropriate for the almost entirely rural floodplain and large watercourses. It also ensures run times remain reasonable and the main flow routes are represented.

In order to represent the multiple flood relief arches of the Corrofin Bridge, ESTRY culverts have been inserted into the 2D domain (see Figure 2-3). These culverts allow out of bank flows to pass from upstream to downstream. Culvert details were collected through the topographic survey.

Figure 2-3: ESTRY units in Corrofin Bridge



3 Flood history, model calibration and sensibility checking

3.1 Calibration versus sensibility checking

Where a recording flow gauge is located in or near the site and this data is accompanied by historical data from a flood event (such as flood extents, or spot levels), then it is possible to undertake calibration of the model. This process would involve running the recorded flows through the model and changing model parameters, such as Manning's 'n', to match the flood extents or levels that were observed. Ideally, a second event would then be run through the model and used to validate the outputs. While it is possible to simulate flows recorded at a gauge in the model, without any record of the impact of the event the model cannot be calibrated and the checking process is limited to a confirmation that predicted extents match expectations based on topography and local knowledge. If there is no gauge data available but there are historical records of flooding then the predicted extent from an appropriate design event with a similar exceedence probability to the historical flood event can be used as a sensibility check of the predicted flooding frequency.

Calibration of the hydraulic model has been attempted using the Corrofin gauge. The Corrofin gauge is centrally located within the AFA. Levels extracted from the gauge have been converted to flows using the updated rating curves detailed in the WCFRAM Hydrology Report for UoM 30.

The calibration is limited by the single gauge being used to provide the inflows and assess the outputs but it is still a useful exercise to give some confidence in model results.

3.2 Flood history

3.2.1 November 2009

Aerial photography commissioned by OPW at the time provides good data for calibration of the November 2009 event. (see Figure 3-1 for location, and Table 3-1 for summary of details). There is property flooding close to the confluence of the Clare and Grange Rivers at Ballybanagher, and extensive inundation of the rural floodplains adjacent to the channel. Elsewhere groundwater flooding is observed separate from the river corridor.

Figure 3-1: Flood history in the Corrofin AFA

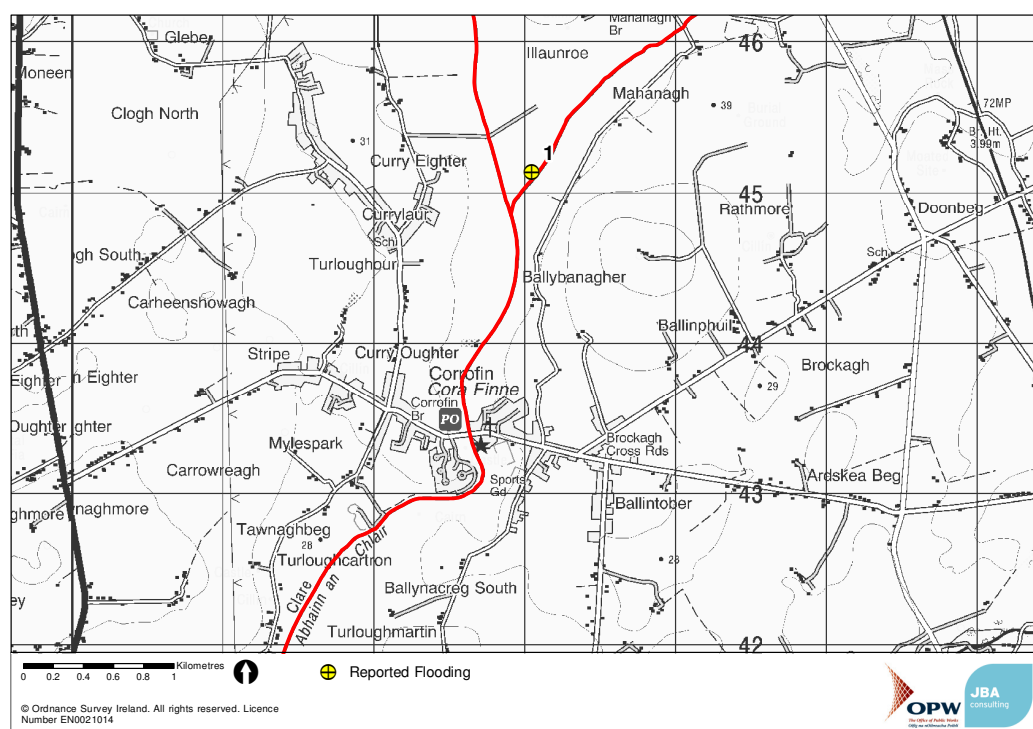


Table 3-1: Summary of flood history

Area affected	Main flooding mechanisms	Recorded flood event data	Use in model check
Ballybanagher	Fluvial flooding from Clare and Grange rivers	November 2009	Verification run using aerial photography.
Unknown, but third highest stage recorded. Extensive floodplain inundation anticipated.	Fluvial	2006	Sensibility check
Unknown, but recorded stage is higher than 2009	Fluvial	1968	Not used - measurement is highly uncertain given a datum change since then and likely channel changes
Rural floodplain	Fluvial, surface water, drains and potentially groundwater	Recurring	Sensibility check

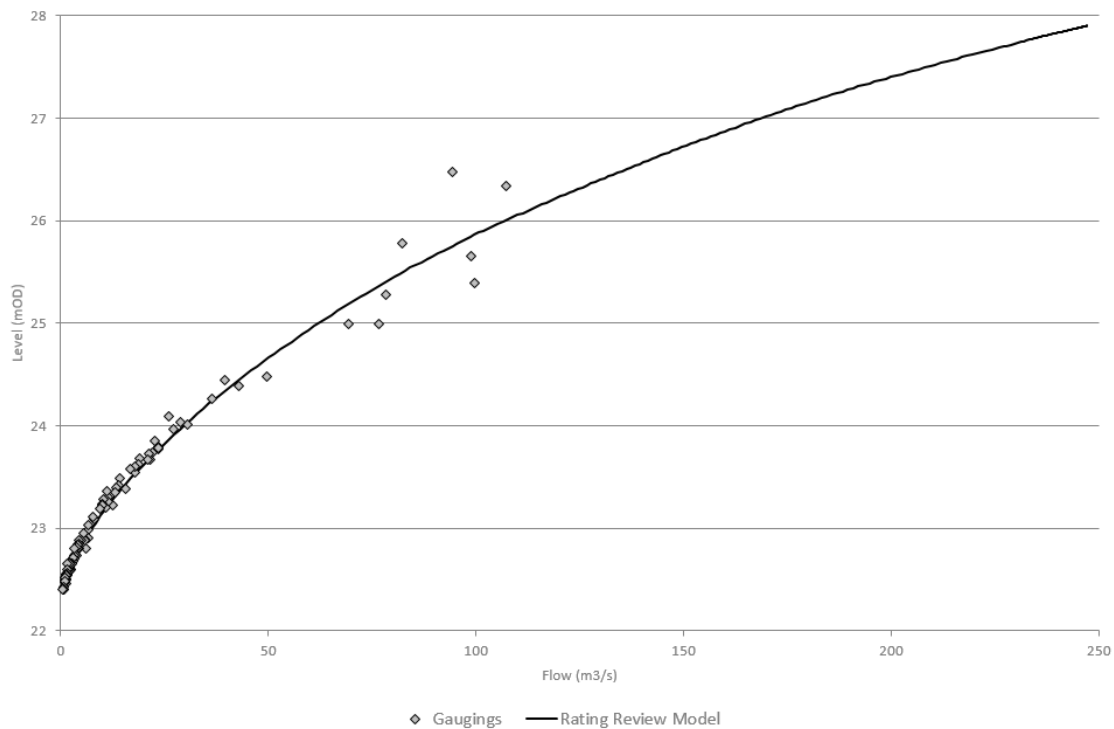
3.3 Calibration outcomes

To calibrate the model to this data the 2006 and 2009 events, flows from the gauge have been applied at the upstream limit of the model (split between Clare and Grange rivers) based on an approximate ratio of the calculated design flows between the watercourses (0.75 and 0.25). An inflow for the Abbert River has also been included, again based on an approximate ratio of design flows (0.4 of the flows at the gauge). The Abbert River may have some influence on the Corrofin Gauge although model runs undertaken at the time of the rating review suggest this has little impact on water level recorded at the gauge. Groundwater in this area may be a greater influence although there is no evidence to confirm this.

3.3.1 Rating review check

Figure 3-1 shows the rating review fit at 30004 which is a key part of the model calibration. This is the only location where river levels and flows have been measured. The model fits well through the gaugings but there is uncertainty generated by the spread of gaugings at higher flows. There is a suggestion this may be due to a backwater effect from the confluence with the Abbert but this is not replicated in the modelling and would be difficult to quantify without a more accurate estimate of inflow from the Abbert, which is ungauged. Furthermore, the area around the confluence with the Abbert is a turlough so it may actually be groundwater levels influencing the gauge. Either way, additional monitoring would be needed to try to understand the system more fully.

Figure 3-2: Calibration of rating curve at 30004 Corrofin gauge



3.3.2 November 2009 flood event

The modelled flood extent recreating the 2009 event is shown in Figure 3-2. It seems to generally match that observed. The detail of the flooding at Ballybanagher is shown in Figure 3-3 and compares very closely to the aerial photos of the event. The centre of Corrofin has little flooding due to the deeply incised channel through Corrofin Bridge.

Figure 3-3: November 2009 modelled flood extent

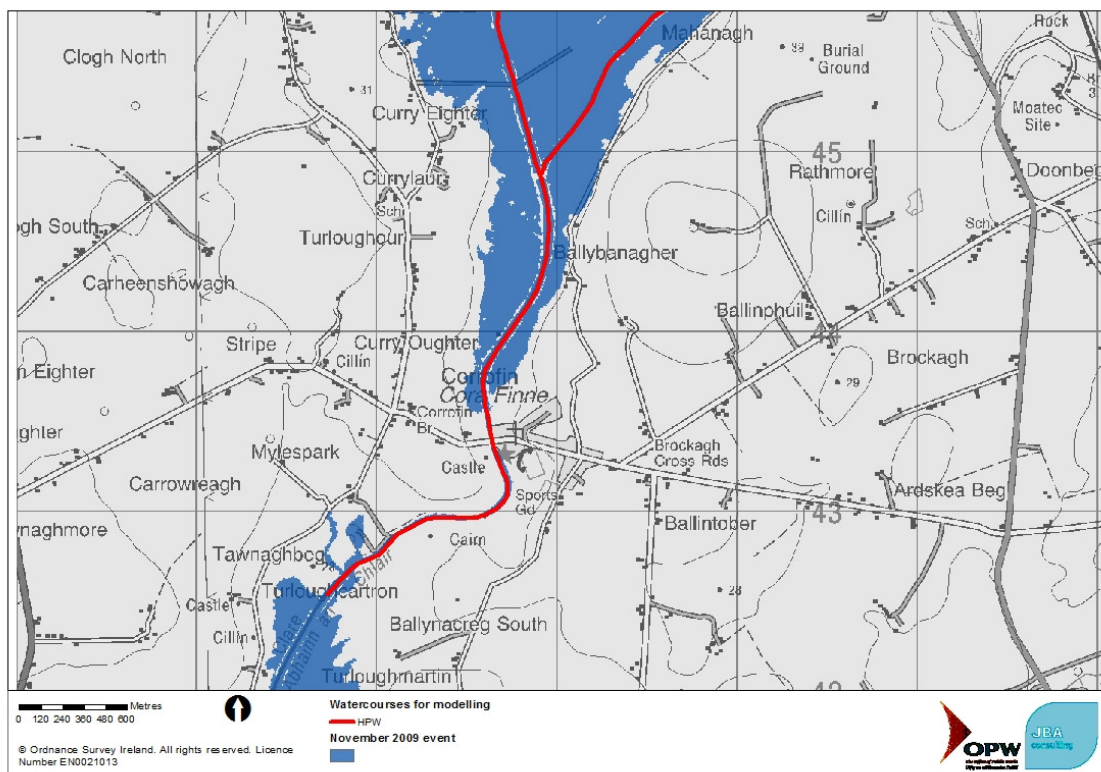
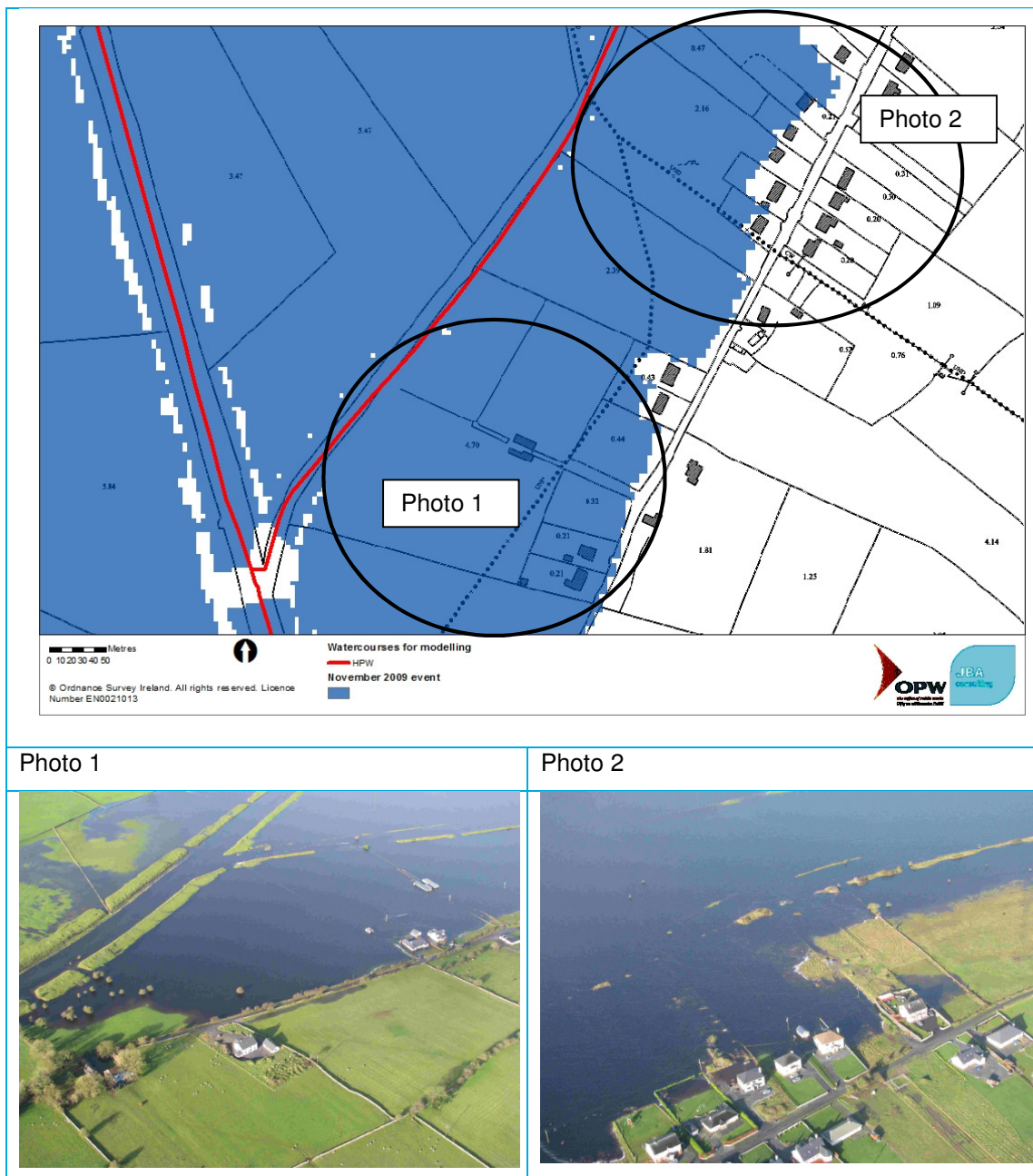


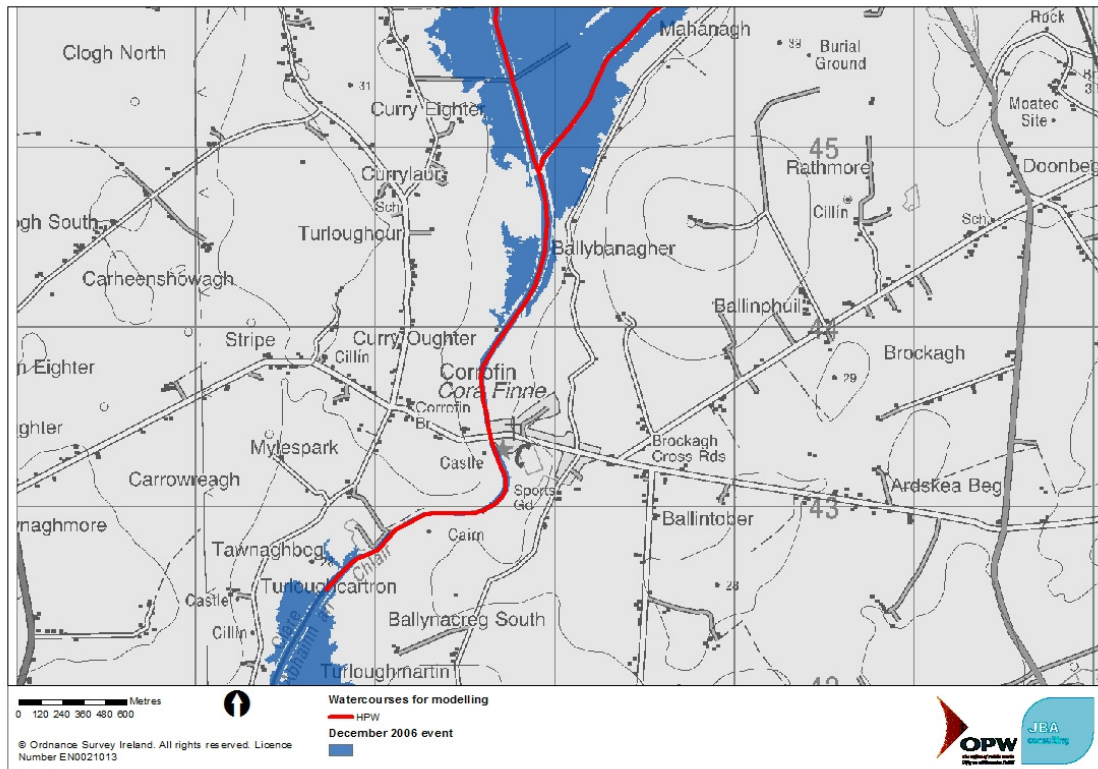
Figure 3-4: November 2009 modelled flood extent detail at Ballybanagher



3.3.3 December 2006 flood event

The 2006 event is another large flood event recorded at the Corrofin gauge. This event had a recorded peak level of 4.53 mOD (gauge datum) compared to the 2009 peak level of 5.17 mOD. There is no evidence of property flooding during this event although it is assumed large areas of the floodplain would have been inundated.

Figure 3-5: December 2006 modelled flood extent



3.4 Stakeholder Engagement

Throughout this process OPW regional engineers and local authority engineers have been consulted in the form of steering group, progress group and engineer meetings and their input has feed into the flood maps.

Public Consultation Day (PCD) – 14th of October 2014

On October 14th 2014 a public consultation was held at Dr Duggan Hall in Corrofin to present the flood maps for the town and solicit comments and feedback.

This PCD was attended by 16 people. At the PCD attendees were invited to leave feedback, in the form of a questionnaire. The questionnaire sought feedback on resident's knowledge of flooding in the town including the locations of flooding and the frequency of flooding.

A large number of comments were received for locations outside of the AFA boundary and as such these comments could not be used to validate the modelled flood extent.

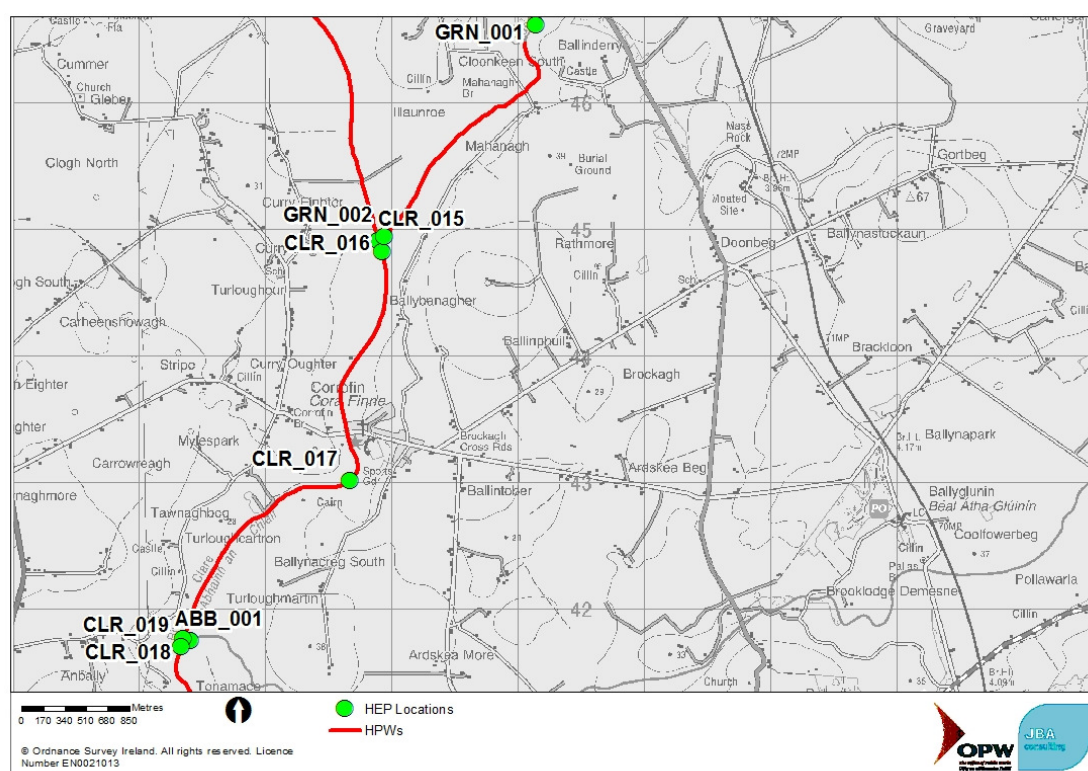
4 Application of hydrology

4.1 Hydrological estimation points

Design flows have been developed at a series of Hydrological Estimation Points (HEPs) throughout the catchment. It is these flows which have provided the inflows to the hydraulic model, both as direct inflows at the upstream end, and as point inflows along the watercourses to tie the flows in downstream. Full details of the development of these flows are provided in the WCFRAM Hydrology Report for UoM 30.

The locations and names of all the HEPs within the Corrofin AFA are presented in Figure 4-1 and are also shown on the cross section plan contained in Volume 3 of the Hydraulic Modelling Report.

Figure 4-1: Corrofin AFA HEP locations



4.2 Application of design flow estimates

4.2.1 Hydrograph shapes

Inflow hydrograph shapes for each watercourse have been developed from the Flood Studies Report (FSR) rainfall runoff method. The T_p parameter for the hydrograph has been calibrated to recorded data at the gauge using a coefficient of 2.49 for the Clare River. In the absence of any other information this has also been applied to the Grange and Abbert tributaries. Inflows are located at the upstream limit of each watercourse.

The FSR method, applied using a uniform design storm for all sub-catchments within a model, imposes a structure on the model inflows with realistic relative timings of the hydrographs. This avoids the need to apply the FSU regression model for relative timings of hydrographs at a confluence; an approach which is associated with a large standard error. Because the FSR method is being used only to control the shape of the hydrographs rather than the magnitude of the peak flows (which are based on the HEPs), there is no benefit to identifying a critical storm duration, i.e. one that results in the highest peak flow or water level. However, in order to ensure a realistic flood duration, the duration of the design storm has been related to the time to peak for the principal watercourse in the model, using the FSR formula that evaluates storm duration from

time to peak and SAAR. The potential impact of the critical storm duration on tributary flood extents has been reviewed and is discussed in Section 6.

A consistent design storm duration has been applied across all boundaries and has been selected as the critical storm duration for the catchment to Corrofin on the Clare River. A critical storm duration of 87 hours has been applied. This may be slightly conservative on the Grange River but sensitivity to this parameter will be tested (see Section 6).

4.2.2 Scaling to hydrological estimation points

For the Clare River the inflow hydrograph has been scaled to the upstream HEP point (CLR_015). The first significant tributary inflow is the Grange River and the inflow hydrograph has been scaled to the upstream HEP point (GRN_001) on this watercourse as well.

The calculated flow values further downstream have been compared with the flows generated at the corresponding cross section. Where a mismatch of more than $\pm 5\%$ occurs, the reason for this has been identified and additional flows, in the form of lateral inflows, have been added to the model where appropriate.

To reflect the increase in flows downstream of the confluence of the Clare and Grange Rivers, lateral inflows have been applied between HEP points CLR_016 and CLR_017. These have been derived to give an appropriate peak flow at CLR_017. The remaining inflow is the Abbert River, which is represented as a simple inflow hydrograph scaled to the HEP peak flow that joins the Clare River some distance downstream of the AFA.

There is a lot of floodplain flow in this model making the measurement of flow at some HEP points difficult. Where possible we have used a model node at or near the HEP where flow is contained within the 1D model to report the modelled design flows. HEP CLR_017 is the key HEP for the model as it is a well contained site at the centre of the AFA.

A comparison of the peak flow estimates with the modelled flows is provided in Table 4-1. This table also provides an explanation for differences of greater than 5% between the two sets of data, and indicates where lateral inflows have been used in the model.

4.3 Downstream Boundary

The downstream boundary of the hydraulic model is downstream of the confluence with the Abbert River, approximately 4.5 km from Corrofin Bridge. A normal depth boundary is used with the gradient set to the bed slope. This is far enough downstream not to impact the flood risk areas in the AFA.

Table 4-1: Summary of hydraulic model design inflows

HEP reference	Cross Section	Peak flow estimates (m ³ /s)					Flow in model (m ³ /s)					Comments
		50% AEP	10% AEP	2% AEP	1% AEP	0.1% AEP	50% AEP	10% AEP	2% AEP	1% AEP	0.1% AEP	
CLR_015	30CLAR03153	70.0	93.3	116.9	128.5	192.4	70.0	93.3	116.9	128.5	192.4	HEP reporting location moved to upstream of model to show inflow hydrograph.
CLR_016	30CLAR02897	84.0	123.8	156.9	170.9	255.9	89.6	118.2	134.5	133.3	133.7	DS of Grange confluence. Flows become low after the 10% AEP event due to floodplain flow bypassing this HEP.
CLR_017	30CLAR02705	84.3	124.3	157.5	171.5	256.9	89.6	130.8	159.9	176.5	261.7	River well contained through this reach by Corrofin Bridge so key location for flow checks in AFA centre. Lateral inflow applied upstream of this HEP. Modelled and predicted flows show good match.
CLR_018	30CLAR02507	84.6	124.7	158.0	172.1	257.7	89.2	110.1	103.9	115.6	118.9	Upstream of Abbert. Significant flow on floodplain. Very similar flows to CLR_017 which would show here if not on floodplain.
CLR_019	30CLAR02440	107.1	157.9	200.0	217.8	327.6	120.8	167.5	200.0	218.0	339.8	Fairly well contained location just downstream of HEP point. Containment lessens particularly in 0.1% AEP event.
GRN_001	30GRAN00219	23.2	30.6	37.4	40.5	61.3	23.2	30.6	37.4	40.5	61.3	Grange River inflow location.
GRN_002	30GRAN00006	22.1	29.9	37.6	41.3	62.5	22.3	55.0	64.2	64.1	64.8	Flow has joined the Grange River via floodplain flow from Clare River left bank hence modelled flow is high.
ABB_001	ABBERT	33.8	46.0	58.4	64.6	99.7	33.8	46.0	58.4	64.6	99.7	Abbert River inflow.

5 Model results

5.1 Model runs

The model has been run for a present day and two future scenarios, a Mid-Range Future Scenario (MRFS) and a High-End Future Scenario, which consider the potential impact of climate change. Full details of the allowances incorporated into the two climate change scenarios are provided in the Western CFRAM UoM35 Hydrology Report².

The 50%, 10%, 2%, 1%, 0.1%, 50%, 10%, 2%, 1% and 0.1% AEP design events have been run for the current and MRFS. Only the 10%, 1% and 0.1% AEP design events have been run for the HEFS. Table 5-1 and Table 5-2 details the full suite of design flows for the HEPs for the MRFS and HEFS.

Table 5-1: Peak flows for the Mid-Range Future Scenario

HEP Name	Predicted Peak Flows for the MRFS (m³/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
CLR_015	84.2	100.8	112.2	123.9	140.6	154.6	172.9	231.5
CLR_016	101.0	130.8	148.9	166.3	188.7	205.5	229.8	307.8
CLR_017	101.4	131.3	149.5	166.9	189.4	206.3	230.6	308.9
CLR_018	101.7	131.8	150.0	167.5	190.1	207.0	231.4	309.9
CLR_019	128.7	166.7	189.7	211.9	240.4	261.8	293.1	393.8
GRN_001	27.9	33.2	36.7	40.1	44.8	48.6	54.5	73.5
GRN_002	26.5	32.1	35.9	39.7	45.1	49.5	55.6	75.0
ABB_001	40.6	49.3	55.2	61.3	70.1	77.5	87.4	119.7

Table 5-2: Peak flows for the High-End Future Scenario

HEP Name	Predicted Peak Flows for the HEFS (m³/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
CLR_015	91.3	109.4	121.7	134.4	152.6	167.7	187.5	251.1
CLR_016	109.6	141.9	161.5	180.4	204.7	222.9	249.2	333.8
CLR_017	110.0	142.4	162.1	181.0	205.4	223.7	250.1	335.0
CLR_018	110.3	142.9	162.6	181.6	206.1	224.4	251.0	336.1
CLR_019	139.6	180.7	205.7	229.7	260.7	283.9	317.8	426.9
GRN_001	30.2	36.0	39.8	43.5	48.6	52.7	59.1	79.7
GRN_002	28.7	34.8	38.9	43.0	48.9	53.7	60.2	81.2
ABB_001	44.0	53.4	59.8	66.4	76.0	83.9	94.7	129.6

5.2 Flood risk mapping

Flood extents and risk maps for the present day and MRFS 10%, 1% and 0.1% AEP design events along with long section profiles for present day 10%, 1% and 0.1% AEP design events are presented in Volume 3 of the Western CFRAM UoM 30 Hydraulic Modelling report.

5.3 Key flood risk mechanisms

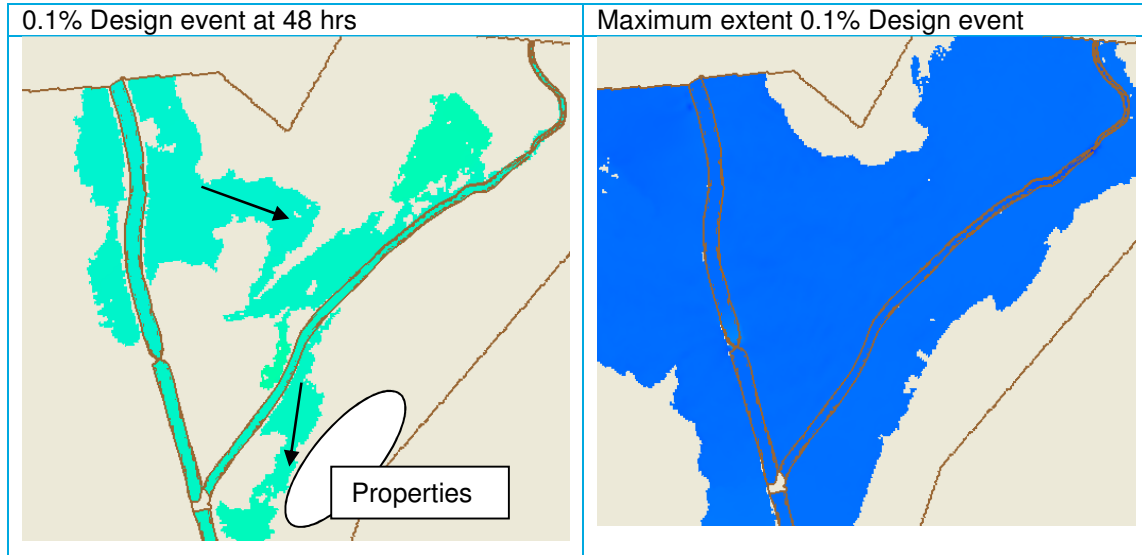
Further to the information presented in the flood risk maps, a brief description of the key flood risk sites and flooding mechanisms is provided below.

5.3.1 Flooding to properties in Ballybanagher

The only area of property flooding within the AFA is upstream of Corrofin Bridge on the combined Clare and Grange floodplain. The area where property is at risk is close to the confluence of the two rivers on the eastern edge of the floodplain where development has encroached. The flood risk mechanism in this area is simply the large floodplain filling up to a level to cause flooding to the property.

Flood water on the left bank floodplain of the Clare River flows into the River Grange channel and the combined flow comes out of that channel into the area of the properties. Figure 5-1, below shows early flood routes and then the full flood extent during the 0.1% AEP design run.

Figure 5-1: Corrofin flood mechanism



It is noted that there are a number of buildings shown on the left bank upstream of Corrofin Bridge in the 0.1% AEP event. These have been abandoned and as such flood risk to these properties is not discussed further.

6 Sensitivity testing

6.1 Screening of sensitivity tests

The suite of potential sensitivity tests is detailed in Volume 1a: Hydraulic Modelling Method Statement. The application of the sensitivity tests has been an iterative process which allowed certain criteria to be screened out. Table 6-1 summarises the full suite of potential sensitivity tests, and highlights those which are not applicable, and those which have been screened out. Further details of these criteria are provided in the following sections.

The results of testing those criteria which are relevant to each hydraulic model within the Corrofin AFA are detailed in the following sections, and the results are described in Section 6.2.

Table 6-1: Sensitivity test summary

Sensitivity test	Relevance to Clare River	Relevance to Grange River
Peak flow	Tested	Tested
Flow volume	Tested	Screened out
Critical storm duration	Not applicable	Tested
Roughness	Tested	Tested
Building representation	Screened out	Screened out
Afflux / headloss at key structures	Screened out	Screened out
Water level boundaries and joint probability	Screened out	Not applicable
Timing of tributaries	Screened out	Screened out
Timing of fluvial and tidal peaks	Not applicable	Not applicable
Cell size	Screened out	Screened out

6.1.1 Peak flow

The flow sensitivity scoring mechanism is detailed in the generic Hydraulic Model Development Methodology and produces a score of 10 for the Clare River and 26 for the Grange River. Table 6-2 details the flow sensitivity tests required as a result of these scores.

Table 6-2: Flow sensitivity scaling factors

Return period of event	Clare River	Grange River
10%	Use QMED uncertainty	Use QMED uncertainty
1%	Use QMED uncertainty then multiply flows by 1.2	Use QMED uncertainty then multiply flows by 1.5

6.1.2 Flow volume

The sensitivity test to flow volume is required where the flow hydrograph has been generated from limited or no data. At Corrofin the T_p coefficient has been calibrated to observed records which does give some data input to the hydrograph but a full hydrograph width analysis has not been undertaken. Flow volume was therefore a required sensitivity test, particularly as the floodplain storage may be sensitive to volume. The current design storm used is 87 hours. Given the long duration events that can occur on the Clare, influenced by the karst geology, a duration multiplier of 2.5 was used.

A shorter duration was considered for the Grange tributary without using the 2.49 T_p scaling factor. That would move the peak flows on the tributary forward and make the hydrograph narrower. The result would be a lower peak flow on the Clare River. This would not provide an acceptable match to the HEP at Corrofin gauge downstream of the Grange confluence and would have to be compensated for with an increased lateral inflow. Therefore as the flood risk area is mainly dominated by the Clare volume, there seems little benefit in shortening the tributary hydrograph to be compensated for by additional lateral inflow. If there were independent risk areas on the tributary outside the influence of the Clare River then this sensitivity test would be appropriate but under the circumstances described it would not add any value.

6.1.3 Critical storm duration

The critical storm duration of 87 hours applied to the Clare River was also applied to the Grange River in the design runs. The FSR unit calculated that a storm duration of 65 hours is more critical

to the Grange River. Flow volume, and consequently flooding from the Grange River, may be slightly overestimated using the longer duration from the Clare River. Due to the connectivity of the floodplain between the Clare River and the Grange River this makes it difficult to understand exactly what contribution the Grange River has to the overall flood extent.

Two sensitivity tests were run with a low flow on the Clare River, so as to assess the Grange River on its own: one run with a storm duration of 87 hours, and the other run with a storm duration of 65 hours. The model was also run with an event only on the Clare River, to gain a fuller understanding of flooding on the Grange River.

6.1.4 Roughness

On the Clare River the limited risk to property in the existing risk design events mean there is little benefit to testing the sensitivity of the model results to a reduction in roughness values, as such a reduction would only further reduce extents by speeding the passage of water through the model domain and into the extensive rural floodplain downstream. Similarly, because of the lack of flooding in the 10% AEP event the sensitivity to roughness has not been appraised for the 10% AEP event. Although channel and bank roughness (i.e. vegetation growth) may increase, it will probably be within reasonable bounds.

Table 6-3 summarises the current roughness values applied within the model over the various reaches and the increased values to be applied for the 10% AEP events and 1% AEP events.

Table 6-3: Sensitivity to roughness scenarios

Upstream and downstream cross section	Roughness values (Manning's 'n') and materials		
	Existing risk	10% AEP roughness sensitivity	1% AEP roughness sensitivity
30GRAN00219 to 30GRAN00006	0.022 (silt) 0.040 (Scrub/grass)	No change	Bed - 0.025 Banks - 0.080
30CLAR03153 to 30CLAR02785	0.040 (coarse gravel and cobbles) 0.040 (Scrub/grass)	No change	Bed - 0.055 Banks - 0.070
30CLAR02775 to 30CLAR02669	0.040 (coarse gravel and cobbles) 0.070 (trees/bushes)	No change	Bed - 0.055 Banks - 0.130
30CLAR02649 to 30CLAR02265	0.040 (coarse gravel and cobbles) 0.040 (Scrub/grass)	No change	Bed - 0.055 Banks - 0.070

Roughness values in the floodplain have been increased to the upper bound of those values quoted in the Hydraulic Modelling methods report for the 1% AEP event only.

6.1.5 Building representation

The current flood risk extent in the 1% AEP event shows inundation of very few properties at the edge of the flood extent. Properties are currently modelled using a mean LIDAR level. Given that these properties are on the fringe of the flood extent the only changes from adjusting the building representation will be very localised and therefore not significant to the model as a whole. This test is therefore not required.

6.1.6 Afflux at key structures

Within the AFA the only key structure is Corrofin Bridge. This structure is not surcharged during the 0.1% AEP event. The river channel is a much more significant control on water levels than the bridge and as such no sensitivity test is required for this.

6.1.7 Water level boundaries

The model was extended far enough downstream of the AFA to account for any backwater effects in the AFA. This test will have no impact and will not be carried out.

6.1.8 Timing of tributaries

Adjustments to the timing of the tributary could result in higher flows downstream on the Clare if peak flows on the Grange were delayed. This test is only recommended where there is good confidence in the hydrology and the increase in flows resulting from the shift in timing would exceed the increase in flows investigated as part of the flow sensitivity. In this instance, a shift in the timing of tributaries would increase flows on the Clare by a small amount. However, the uncertainty associated with flows requires a greater increase, so further testing of a lower flow increase would not be informative.

6.1.9 Cell size

The hydraulic model of the Clare and Grange Rivers uses a 2D model cell size of 8 m. The floodplain is rural, and there is limited flooding to properties in the 1% AEP event. As a result, the sensitivity test for cell size in this hydraulic model was screened out.

6.2 Sensitivity testing results and uncertainty bounds

The results of the sensitivity tests have been used to inform the uncertainty bounds as detailed in the Hydraulic Modelling Method Statement. The uncertainty bound in effect presents the most sensitive hydraulic parameter/s as assessed within the bounds identified in Section 6.1 at all locations along the modelled reach.

To simplify the presentation of the sensitivity tests, the uncertainty bound for the 10% AEP and 1% AEP events has been presented only. Where different parameters have contributed to the development of the uncertainty bound, these are highlighted on the map and in the accompanying text.

6.2.1 Clare and Grange River

The uncertainty bound for the hydraulic model of the Clare and Grange River in the 10% AEP event is presented in Figure 6-1 against the original 10% AEP event extent.

Only the peak flow test was carried out for sensitivity testing in the 10% AEP event; consequently, any increase in flooding shown in the figure is as a direct result of this test.

The greatest change in flood extent from sensitivity testing of the 10% AEP event is to the fields upstream of Corrofin Bridge, adjacent to Ballybanagher. One additional property is shown to be at risk of flooding in Ballybanagher.

The uncertainty bound for the 1% AEP event is presented in Figure 6-2 against the original 1% AEP event extent. Compared to the original flood extent for the event, the increase in flooding as a result of the sensitivity testing is not dramatic. Flooding is shown to reach much nearer to properties in Corrofin itself, however this still does not result in the flooding of any properties in this location. As for the 10% AEP event, the increase in flooding shown in the uncertainty bounds is attributable directly to the peak flow test.

Figure 6-1: 10% AEP event uncertainty bounds

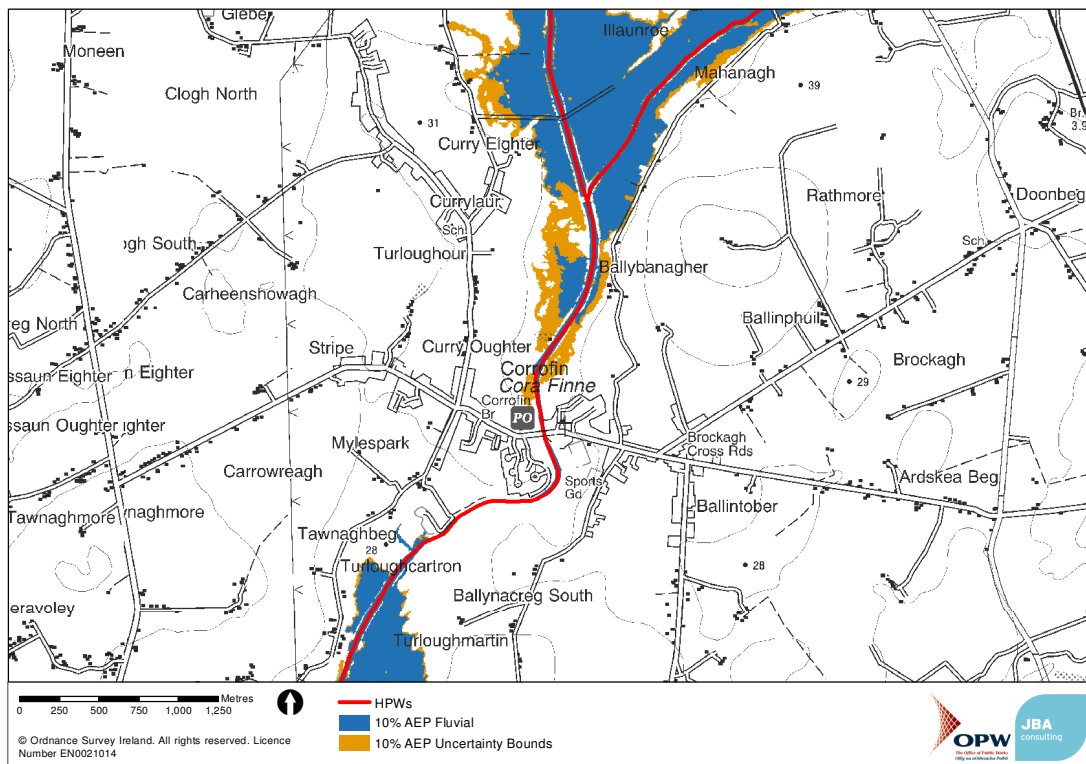
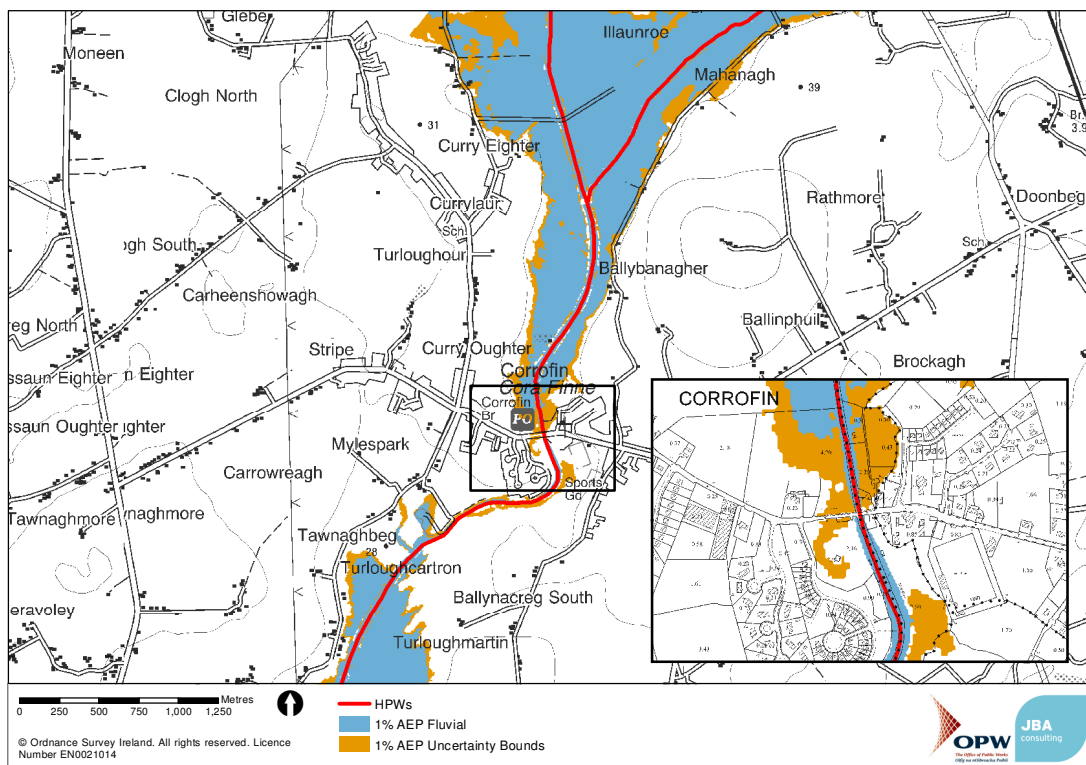


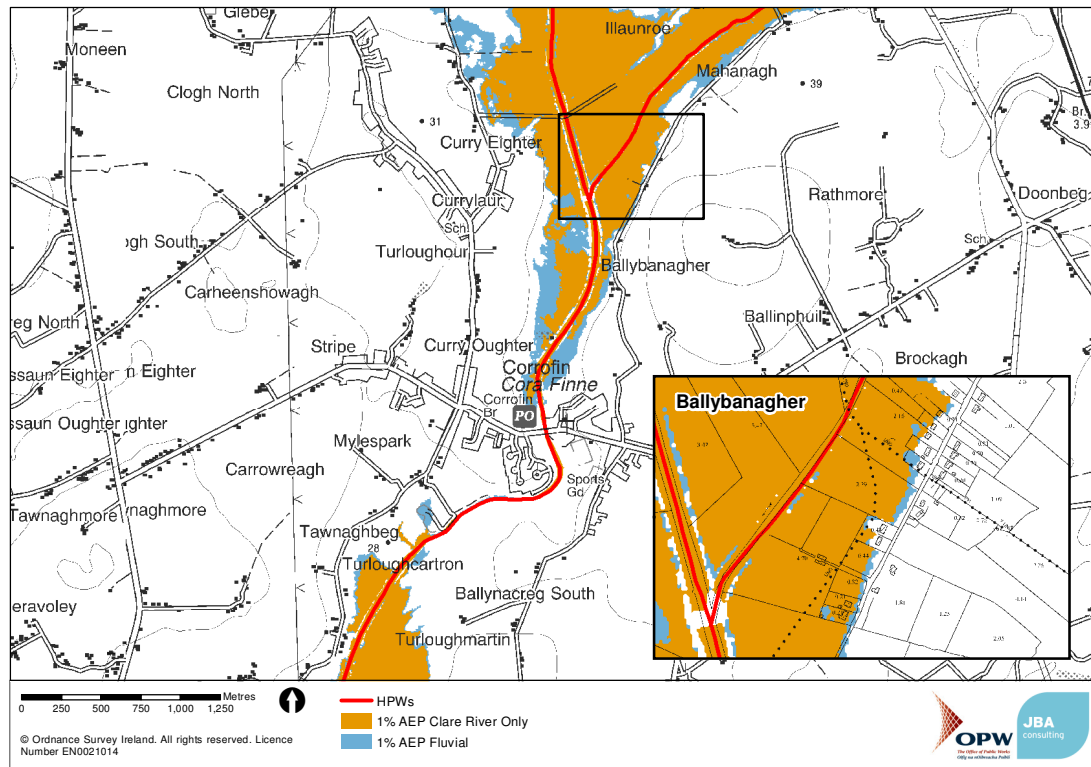
Figure 6-2: 1% AEP event uncertainty bounds



Testing of the critical storm duration of the Grange River was discussed in the sensitivity test screening in Section 7.1. Figure 6-3 presents the extent of flooding where a storm event was run only on the Clare River against the original extent for the 1% AEP event; this was carried out to understand what contribution the Grange River gives to the flooding on it. (Please note that in this case the sensitivity test extent overlies the original modelled extent to draw comparison).

The figure demonstrates quite clearly that the flooding shown on the Grange River is almost completely attributable to the levels within the main river, the Clare River, particularly around the key flood risk area of Ballybanagher. This test revealed that there was no benefit of testing the sensitivity of the Grange River to the storm duration used, as this river contributes little to the flood extent. Consequently these tests are not part of the 1% AEP uncertainty bounds.

Figure 6-3: 1% AEP event - Clare River only test



The hydraulic model was generally not shown to be sensitive to the parameters selected in the sensitivity testing. This is with the exception of sensitivity to peak flow, which produced the largest change in flood extents. All models are likely to be sensitive to this test, and it is indicative only of the upper bounds of uncertainty in the peak flow estimation. As the overall configuration of the model was shown to be satisfactory, no additional changes were made to this hydraulic model.

7 Model limitations

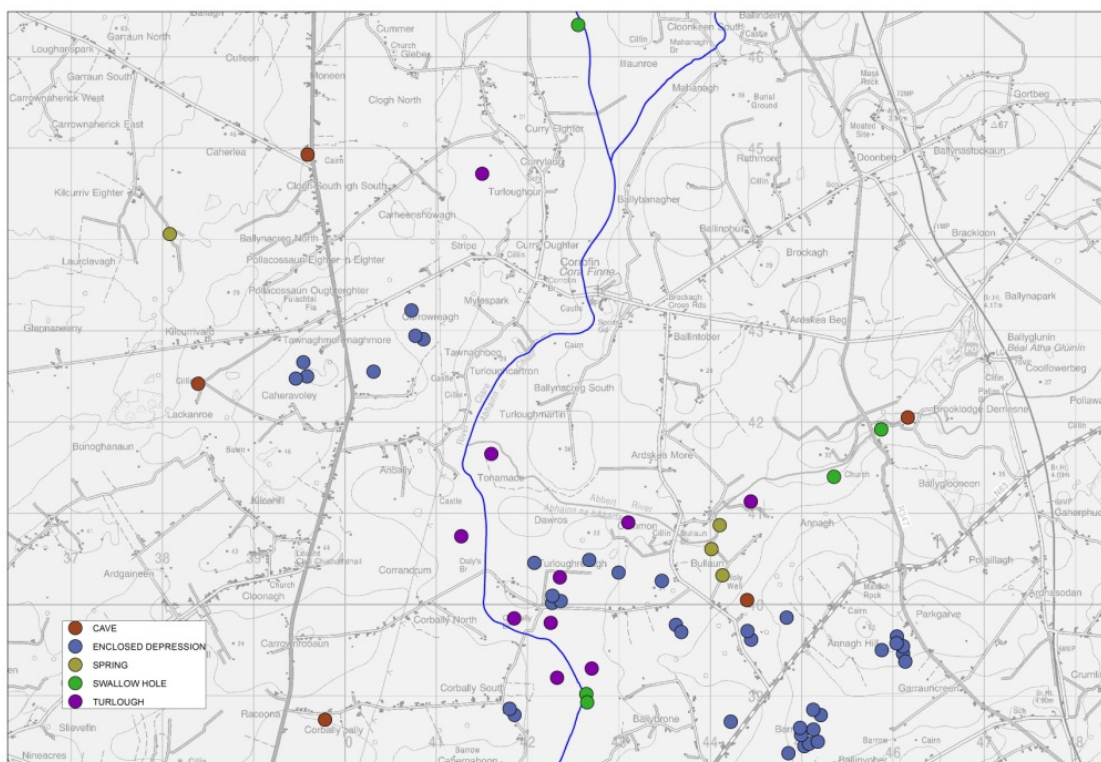
7.1 Bankside embankments

The river banks along the Clare and Grange rivers are generally in the form of informal raised embankments that have gaps in them. As far as possible in the model these have been represented as they have been surveyed. The model is, however, a simplification of the actual situation and may not accurately model the flow paths onto the floodplain. Despite this, the overall effect looks realistic when compared with aerial photography of the 2009 flood, and local knowledge.

7.2 Influence of tributaries and groundwater

There is a wide spread of gaugings at the Corrofin gauge and it is suggested that is because of a backwater effect from the Abbert confluence downstream. The modelling has not shown this to be significant but there are also turloughs in this area which may be contributing to elevated river levels (Figure 7-1). Further investigation could help understanding of the situation, but such detailed groundwater assessment is outside the scope of the CFRAM. Ideally, additional monitoring of water levels would be required downstream of the gauge location to understand the variation of water surface profile through that area; it is likely that this effect would only be seen during extreme events.

Figure 7-1: Karst features in the vicinity of Corrofin



A Hydraulic model results

A.1 1D model flows

Table A-1: 1D model peak current flows

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30GRAN00219	23.20	27.70	30.60	33.40	37.40	40.50	45.40	61.30
30GRAN00208	23.20	27.68	30.57	33.15	37.42	42.06	46.61	61.21
30GRAN00199	23.18	27.67	30.55	33.18	36.26	37.69	43.70	60.56
30GRAN00190	23.19	27.65	30.64	35.08	39.22	41.53	43.70	53.17
30GRAN00180	23.17	27.69	29.44	30.72	40.21	34.11	47.46	58.26
30GRAN00173	20.58	22.43	23.08	24.30	32.27	28.92	36.44	52.25
30GRAN00173A	22.57	26.55	27.10	30.23	33.67	31.90	33.97	37.02
30GRAN00173B	22.57	26.55	27.10	30.23	33.67	31.90	33.97	37.02
30GRAN00171	25.27	30.75	34.89	38.64	43.38	42.66	44.10	48.16
30GRAN00156	23.14	27.61	34.53	40.93	47.89	46.57	49.50	54.20
30GRAN00140	22.45	25.03	29.74	35.34	41.29	40.03	42.52	46.56
30GRAN00124	22.72	25.16	27.20	32.69	38.63	37.31	39.83	43.41
30GRAN00109	22.75	24.75	25.60	30.70	36.19	34.93	37.35	40.55
30GRAN00091	22.48	24.90	26.16	32.18	38.58	37.32	40.20	43.36
30GRAN00076	22.68	30.52	32.61	33.99	34.88	34.71	35.70	48.23
30GRAN00063	22.39	29.67	32.07	33.43	34.21	33.67	34.43	52.38
30GRAN00049	22.34	32.86	31.12	31.59	34.57	34.11	35.82	54.92
30GRAN00034	22.31	38.35	41.23	41.58	41.49	41.40	41.53	58.94
30GRAN00020	22.29	39.50	51.92	52.84	53.06	53.19	53.39	54.28
30GRAN00006	22.27	39.47	55.02	62.47	64.29	64.19	64.57	64.81
GRAN00000*A	22.26	39.43	54.98	62.87	64.30	64.64	64.77	68.44
30CLAR03153	70.00	83.80	93.30	103.00	116.90	128.50	143.70	192.40
30CLAR03134	69.99	83.78	93.27	102.97	116.85	128.46	143.65	195.37
30CLAR03117	69.98	83.77	93.27	102.97	116.86	128.47	143.67	194.39
30CLAR03102	69.97	83.74	93.23	102.91	116.77	128.38	143.57	196.33
30CLAR03087	69.95	83.75	93.23	102.95	116.82	128.44	143.64	204.41
30CLAR03072	69.95	83.71	93.19	102.85	116.68	128.30	143.48	213.27
30CLAR03055	69.93	83.71	93.18	102.91	116.77	128.40	143.60	221.33
30CLAR03037	69.93	83.67	93.11	101.56	108.60	112.18	125.26	194.55
30CLAR03023	69.40	79.22	87.55	93.49	97.24	99.61	107.05	303.24
30CLAR03003	67.72	68.86	65.67	68.92	74.85	80.15	90.85	232.18
30CLAR02987	68.38	68.13	66.67	67.30	67.45	68.33	76.18	144.02
30CLAR02973	68.39	68.22	66.81	67.46	67.64	67.11	71.77	124.22
30CLAR02959	68.89	69.89	68.34	69.17	69.45	69.04	68.79	109.59
30CLAR02957A	68.87	69.91	68.35	69.19	69.47	69.05	68.81	66.75
30CLAR02957B	68.87	69.91	68.35	69.19	69.47	69.05	68.81	66.75
30CLAR02954	68.88	69.92	68.36	69.20	69.48	69.27	69.08	67.16
30CLAR02941	68.88	69.97	68.45	69.29	69.60	69.40	69.21	67.30
30CLAR02928	68.88	70.05	68.55	69.41	69.73	69.54	69.37	69.25
30CLAR02913	68.88	70.10	68.65	69.51	69.85	69.68	69.52	70.57
CLAR02904*A	68.89	70.16	68.71	69.60	71.06	70.27	70.69	70.53
CLAR02904*B	89.56	106.93	118.19	128.84	134.60	133.54	134.23	134.50
30CLAR02897	89.57	106.94	118.20	128.57	134.46	133.30	134.26	133.72
30CLAR02888	89.56	106.96	118.22	128.88	134.65	133.66	134.37	134.66
30CLAR02878	89.58	106.92	118.19	128.56	134.42	133.35	134.31	133.85
30CLAR02869	89.56	109.13	124.54	135.77	145.41	146.84	148.21	149.67
30CLAR02857	89.58	109.10	123.87	132.34	140.67	142.25	144.49	147.87
30CLAR02848	89.56	108.10	119.26	123.79	124.69	127.41	128.22	128.59
30CLAR02837	89.57	108.05	119.20	123.50	123.83	124.87	125.17	125.16
30CLAR02828	89.56	109.10	124.45	131.49	132.80	135.85	136.27	136.59
30CLAR02817	89.57	109.07	124.37	134.70	140.70	145.11	145.73	146.02
30CLAR02808	89.56	109.10	124.44	136.11	144.43	147.85	148.56	149.08

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30CLAR02797	89.57	109.07	124.38	136.02	149.64	155.04	156.38	157.19
30CLAR02785	89.56	109.10	124.44	136.19	149.83	155.36	157.11	158.41
30CLAR02775	89.57	109.06	124.39	135.95	149.68	154.34	156.07	157.76
30CLAR02765	89.57	109.11	124.44	136.16	152.90	168.29	178.54	181.68
30CLAR02755	89.57	111.24	130.76	142.80	159.87	176.41	196.44	221.54
30CLAR02747	89.57	111.24	130.78	142.87	159.93	176.59	196.65	254.34
30CLAR02746A	89.57	111.23	130.77	142.82	159.90	176.48	196.49	263.13
30CLAR02745B	89.57	111.23	130.77	142.82	159.90	176.48	196.49	263.13
30CLAR02744	89.57	111.24	130.78	142.83	159.91	176.54	196.62	263.02
30CLAR02742	89.57	111.26	130.78	142.83	159.89	176.56	196.55	263.16
30CLAR02737	89.57	111.24	130.78	142.83	159.92	176.48	196.62	263.17
30CLAR02729	89.57	111.25	130.78	142.83	159.89	176.59	196.61	263.30
30CLAR02722	89.57	111.26	130.78	142.83	159.90	176.53	196.57	263.33
30CLAR02714	89.57	111.27	130.78	142.83	159.90	176.62	196.73	261.70
30CLAR02705	89.57	111.26	130.78	142.83	159.90	176.52	196.53	261.72
30CLAR02694	89.57	111.26	130.78	142.83	159.91	176.57	196.72	257.16
30CLAR02669	89.57	111.27	130.78	142.82	159.90	176.35	194.55	244.28
30CLAR02649	89.58	111.25	130.78	142.82	159.92	176.56	196.77	261.52
30CLAR02633	89.58	111.27	130.78	142.82	159.91	176.59	196.48	263.01
30CLAR02609	89.58	111.27	130.55	142.52	158.91	174.95	194.44	254.62
30CLAR02582	86.52	106.22	124.05	135.16	151.62	166.38	184.27	311.19
30CLAR02551	87.47	93.89	95.31	106.31	107.89	117.10	126.57	153.13
30CLAR02523	89.23	98.72	105.08	104.57	101.17	109.17	110.02	111.09
30CLAR02522	89.23	98.72	105.08	104.57	101.18	109.19	110.04	114.25
30CLAR02507	89.24	99.36	110.14	106.96	103.92	115.65	116.93	118.92
30CLAR02502A	89.71	110.59	119.12	127.71	123.96	126.31	127.88	130.92
30CLAR02502B	120.86	140.43	157.66	154.12	159.33	163.95	164.92	197.42
30CLAR02482	120.86	141.63	172.09	172.11	199.84	202.71	203.88	205.56
30CLAR02460	120.86	141.57	171.34	171.36	195.68	204.13	208.82	211.73
30CLAR02440	120.77	139.71	167.50	167.51	200.07	218.00	238.21	286.51
30CLAR02418	120.77	141.68	172.13	172.14	212.29	235.00	265.07	370.32
30CLAR02398	120.76	133.72	135.96	136.12	161.98	169.85	181.14	192.16
30CLAR02379	120.74	134.93	137.71	137.86	153.47	181.15	210.35	286.61
30CLAR02360A	120.74	134.90	137.64	137.81	138.57	138.98	139.26	139.77
30CLAR02359B	120.74	134.90	137.64	137.81	138.57	138.98	139.26	139.77
30CLAR02337	120.74	134.33	137.93	137.76	138.83	139.04	139.28	139.55
30CLAR02308	120.75	140.76	171.00	171.00	201.07	206.01	206.09	206.36
30CLAR02287	120.75	140.76	171.02	171.02	209.23	231.03	240.37	243.08
30CLAR02265	120.75	140.76	171.02	171.02	210.62	234.78	262.39	361.03

Table A-2: 1D model peak MRFS flows

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30GRAN00219	27.90	33.20	36.70	40.10	44.80	48.60	54.50	61.30
30GRAN00208	27.88	33.04	36.01	40.71	45.69	49.91	57.60	61.04
30GRAN00199	27.93	33.02	36.00	39.48	39.95	47.48	53.27	68.92
30GRAN00190	28.08	33.69	38.42	41.30	44.08	45.31	50.40	51.84
30GRAN00180	28.05	30.92	38.79	43.60	38.43	47.30	50.13	66.13
30GRAN00173	22.80	24.37	31.51	34.33	32.68	41.38	38.56	53.18
30GRAN00173A	27.00	29.33	32.94	32.06	34.25	35.07	36.38	36.96
30GRAN00173B	27.00	29.33	32.94	32.06	34.25	35.07	36.38	36.96
30GRAN00171	30.90	37.58	42.37	41.53	44.52	45.59	47.26	48.08
30GRAN00156	27.77	39.32	46.61	46.63	50.10	51.25	53.06	54.14
30GRAN00140	25.47	33.81	40.17	40.11	43.04	44.05	45.55	46.47
30GRAN00124	25.76	31.10	37.47	37.50	40.15	41.07	42.41	43.29
30GRAN00109	25.41	29.22	35.13	35.13	37.56	38.40	39.64	40.47
30GRAN00091	25.42	30.55	37.50	37.63	40.14	41.00	42.33	43.26

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30GRAN00076	30.50	33.93	35.25	35.84	35.93	36.52	37.65	38.13
30GRAN00063	29.58	33.27	34.53	35.06	34.94	35.13	36.11	38.25
30GRAN00049	33.98	31.88	34.11	34.39	36.07	36.49	37.65	45.95
30GRAN00034	37.31	42.00	41.82	42.15	42.15	41.63	42.19	53.51
30GRAN00020	37.49	53.29	53.32	53.39	53.69	53.47	53.88	53.49
30GRAN00006	37.49	61.80	64.79	64.83	66.05	65.63	66.16	64.59
GRAN000000*A	37.49	61.77	64.74	65.30	66.02	65.61	66.12	64.39
30CLAR03153	84.20	100.80	112.20	123.90	140.60	154.60	172.90	192.40
30CLAR03134	84.18	100.77	112.16	123.86	140.55	154.57	172.83	201.64
30CLAR03117	84.17	100.76	112.15	123.86	140.56	154.52	172.79	200.20
30CLAR03102	84.15	100.72	112.09	123.79	140.48	154.53	172.85	202.98
30CLAR03087	84.14	100.72	112.10	123.83	140.52	154.44	173.10	203.58
30CLAR03072	84.11	100.67	112.02	123.72	140.38	154.49	172.83	207.89
30CLAR03055	84.10	100.68	112.06	123.78	140.48	154.35	172.62	208.93
30CLAR03037	84.08	99.97	107.02	110.89	122.37	136.12	157.94	234.22
30CLAR03023	79.78	92.86	96.25	99.12	104.40	116.30	156.82	223.97
30CLAR03003	70.83	67.62	73.00	77.74	88.29	99.85	130.54	214.50
30CLAR02987	69.44	67.28	67.56	68.28	73.85	83.43	100.76	122.47
30CLAR02973	69.44	67.43	67.73	67.70	70.59	79.39	100.44	163.47
30CLAR02959	71.23	69.06	69.49	69.58	69.25	68.80	76.00	89.39
30CLAR02957A	71.24	69.07	69.51	69.60	69.27	68.82	68.30	66.85
30CLAR02957B	71.24	69.07	69.51	69.60	69.27	68.82	68.30	66.85
30CLAR02954	71.26	69.08	69.52	69.62	69.53	69.11	68.62	67.27
30CLAR02941	71.31	69.18	69.63	69.74	69.66	69.24	68.75	67.43
30CLAR02928	71.37	69.29	69.75	69.87	69.82	69.40	68.95	67.61
30CLAR02913	71.43	69.40	69.87	70.71	69.96	69.62	70.57	68.72
CLAR02904*A	71.46	69.47	70.29	72.38	71.48	71.44	71.46	71.23
CLAR02904*B	107.42	126.87	134.64	136.07	136.07	135.51	136.39	133.60
30CLAR02897	107.42	126.86	134.63	135.92	136.03	135.46	136.14	134.32
30CLAR02888	107.43	126.90	134.68	136.11	135.95	135.37	136.27	133.65
30CLAR02878	107.43	126.85	134.59	135.83	135.88	135.46	135.95	134.54
30CLAR02869	107.41	132.81	143.13	147.77	148.91	148.73	150.64	149.22
30CLAR02857	107.42	130.41	137.70	144.01	144.85	146.41	146.91	147.14
30CLAR02848	106.87	122.98	124.14	125.76	129.03	128.37	129.80	128.26
30CLAR02837	106.86	122.90	124.03	124.26	125.86	126.01	125.89	125.77
30CLAR02828	107.41	130.46	132.80	133.31	136.82	136.13	137.17	135.91
30CLAR02817	107.41	132.68	140.43	141.38	146.26	146.67	146.34	146.60
30CLAR02808	107.40	133.06	143.37	145.26	149.12	148.65	149.67	148.46
30CLAR02797	107.41	132.99	145.93	153.75	156.96	157.44	157.51	157.76
30CLAR02785	107.40	133.06	146.06	154.14	157.76	157.73	158.76	158.19
30CLAR02775	107.41	132.99	145.69	153.77	156.68	157.32	157.90	157.94
30CLAR02765	107.41	133.06	146.97	161.77	178.39	180.43	182.09	181.54
30CLAR02755	107.40	138.90	153.11	168.27	189.35	209.18	222.02	221.61
30CLAR02747	107.40	138.93	153.16	168.41	189.49	209.12	232.96	255.88
30CLAR02746A	107.40	138.92	153.14	168.32	189.42	209.18	232.94	266.63
30CLAR02745B	107.40	138.92	153.14	168.32	189.42	209.18	232.94	266.63
30CLAR02744	107.40	138.93	153.15	168.36	189.39	209.28	232.91	266.88
30CLAR02742	107.40	138.93	153.15	168.34	189.49	209.17	233.47	266.64
30CLAR02737	107.41	138.93	153.15	168.35	189.50	209.41	233.06	267.01
30CLAR02729	107.41	138.93	153.15	168.35	189.49	209.35	233.51	266.61
30CLAR02722	107.41	138.93	153.15	168.34	189.57	209.56	233.63	266.74
30CLAR02714	107.41	138.93	153.15	168.36	189.53	209.51	234.00	265.10
30CLAR02705	107.41	138.93	153.15	168.34	189.54	209.56	233.73	264.72
30CLAR02694	107.40	138.93	153.15	168.36	189.46	209.46	232.57	260.26
30CLAR02669	107.41	138.93	153.15	168.34	188.38	205.99	225.97	246.27
30CLAR02649	107.41	138.93	153.16	168.36	189.49	209.48	233.69	264.70
30CLAR02633	107.41	138.93	153.16	168.35	189.57	209.45	233.65	266.54
30CLAR02609	107.42	138.52	152.35	167.08	187.43	207.08	228.94	257.36

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30CLAR02582	102.59	131.32	144.43	159.15	178.12	195.95	218.30	317.86
30CLAR02551	91.18	99.57	105.29	111.83	123.18	132.36	143.47	152.48
30CLAR02523	95.46	106.15	100.90	101.71	109.88	110.54	110.90	111.30
30CLAR02522	95.47	106.15	100.91	101.72	109.88	110.54	110.90	115.05
30CLAR02507	95.95	111.70	103.50	104.65	116.63	117.66	118.36	118.96
30CLAR02502A	106.82	121.19	123.27	125.03	127.52	128.83	129.99	130.92
30CLAR02502B	142.33	159.79	158.81	159.75	164.66	165.35	166.15	196.22
30CLAR02482	143.96	182.56	196.35	201.76	203.66	204.31	205.04	205.66
30CLAR02460	143.86	180.64	190.63	200.44	208.61	209.62	210.65	211.48
30CLAR02440	141.87	177.32	192.48	210.05	231.28	250.37	274.46	287.79
30CLAR02418	143.98	183.21	202.57	223.89	254.00	285.77	324.82	371.59
30CLAR02398	133.89	145.16	157.65	163.25	177.91	186.26	189.34	191.48
30CLAR02379	135.27	138.15	140.11	171.97	198.78	229.55	258.72	287.07
30CLAR02360A	135.25	138.02	138.42	138.77	139.17	139.38	139.63	139.75
30CLAR02359B	135.25	138.02	138.42	138.77	139.17	139.38	139.63	139.75
30CLAR02337	135.22	138.67	138.84	139.01	139.07	139.31	139.23	139.54
30CLAR02308	143.13	181.41	195.69	204.66	206.03	206.30	206.05	206.08
30CLAR02287	143.13	182.45	200.32	219.94	238.40	242.16	242.32	242.43
30CLAR02265	143.13	182.45	200.99	222.46	252.12	278.57	312.56	363.10

A.2 HEP flows

Table A-3: Current peak flows at HEPs

HEP Reference	Cross Section	Peak Flow in Model (m3/s)								Comments (note: where blank, no changes have been made)
		50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	
CLR_015	30CLAR03153	70.00	83.80	93.30	103.00	116.90	128.50	143.70	192.40	HEP reporting location moved to upstream of model to show inflow hydrograph.
CLR_016	30CLAR02897	89.57	106.94	118.20	128.57	134.46	133.30	134.26	133.72	DS of Grange confluence. Flows become low after the 10% AEP event due to floodplain flow bypassing this HEP.
CLR_017	30CLAR02705	89.57	111.26	130.78	142.83	159.90	176.52	196.53	261.72	River well contained through this reach by Corrofin Bridge so key location for flow checks in AFA centre. Lateral inflow applied upstream of this HEP. Modelled and predicted flows show good match.
CLR_018	30CLAR02507	89.24	99.36	110.14	106.96	103.92	115.65	116.93	118.92	Upstream of Abbert. Significant flow on floodplain. Very similar flows to CLR_017 which would show here if not on floodplain.
CLR_019	30CLAR02440	120.77	139.71	167.50	167.51	200.07	218.00	238.21	286.51	Fairly well contained location just downstream of HEP point. Containment lessens particularly in 0.1% AEP event.
GRN_001	30GRAN00219	23.20	27.70	30.60	33.40	37.40	40.50	45.40	61.30	Grange River inflow location.
GRN_002	30GRAN00006	22.27	39.47	55.02	62.47	64.29	64.19	64.57	64.81	Flow has joined the Grange River via floodplain flow from Clare River left bank hence modelled flow is high.

Table A-4: MRFS peak flows at HEPs

HEP Reference	Cross Section	Peak Flow in Model (m3/s)								Comments (note: where blank, no changes have been made)
		50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	
CLR_015	30CLAR03153	84.20	100.80	112.20	123.90	140.60	154.60	172.90	192.40	HEP reporting location moved to upstream of model to show inflow hydrograph.
CLR_016	30CLAR02897	107.42	126.86	134.63	135.92	136.03	135.46	136.14	134.32	DS of Grange confluence. Flows become low after the 10% AEP event due to floodplain flow bypassing this HEP.
CLR_017	30CLAR02705	107.41	138.93	153.15	168.34	189.54	209.56	233.73	264.72	River well contained through this reach by Corrofin Bridge so key location for flow checks in AFA centre. Lateral inflow applied upstream of this HEP. Modelled and predicted flows show good match.
CLR_018	30CLAR02507	95.95	111.70	103.50	104.65	116.63	117.66	118.36	118.96	Upstream of Abbert. Significant flow on floodplain. Very similar flows to CLR_017 which would show here if not on floodplain.
CLR_019	30CLAR02440	141.87	177.32	192.48	210.05	231.28	250.37	274.46	287.79	Fairly well contained location just downstream of HEP point. Containment lessens particularly in 0.1% AEP event.
GRN_001	30GRAN00219	27.90	33.20	36.70	40.10	44.80	48.60	54.50	61.30	Grange River inflow location.
GRN_002	30GRAN00006	37.49	61.80	64.79	64.83	66.05	65.63	66.16	64.59	Flow has joined the Grange River via floodplain flow from Clare River left bank hence modelled flow is high.



Registered Office

**24 Grove Island
Corbally
Limerick
Ireland**

T: +353 (0) 61 345463
e: info@jbaconsulting.com

**JBA Consulting Engineers and
Scientists Limited**

Registration number 444752

Visit our website
www.jbaconsulting.com

Western CFRAM UoM 30 - Corrib Hydraulic Modelling Report: Volume 2c - Galway City

Final

September 2016

**Office of Public Works
Trim
Co. Meath**



**WESTERN
CFRAM
STUDY**
CATCHMENT FLOOD RISK
ASSESSMENT AND MANAGEMENT

JBA Consulting

24 Grove Island
Corbally
Limerick
Ireland

JBA Project Manager

Sam Willis BSc MSc MCIWEM C.WEM CEnv CSci

Revision History

Revision ref / Date issued	Amendments	Issued to
Version 1.0		Rosemarie Lawlor, OPW
V2.0	Report updated to reflect client and TAS review.	Rosemarie Lawlor, OPW
V3.0 / September 2016	Final updates	Clare Butler, OPW

Contract

This report describes work commissioned by the Office of Public Works, by a letter dated (28/07/11). The Office of Public Works' representative for the contract was Clare Butler. Ethan McGowan and Chris Smith of JBA Consulting carried out this work.

Prepared by Ethan McGowan BEng MIEI

Reviewed by Chris Smith BSc PhD CEnv MCIWEM C.WEM
MCMi

Elizabeth Russell BSc MSc CEnv MCIWEM
C.WEM

Purpose

This document has been prepared as a draft report for the Office of Public Works. 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.

JBA Consulting has no liability regarding the use of this report except to the Office of Public Works.

Copyright

Copyright – Copyright is with the Office of Public Works. All rights reserved. No part of this report may be copied or reproduced by any means without the prior written permission of the Office of Public works.

Legal Disclaimer

This report is subject to the limitations and warranties contained in the contract between the commissioning party (the Office of Public Works) and JBA.

Carbon Footprint

A printed copy of the main text in this document will result in a carbon footprint of 297g if 100% post-consumer recycled paper is used and 378g if primary-source paper is used. These figures assume the report is printed in black and white on A4 paper and in duplex.

JBA is aiming to achieve carbon neutrality.

Contents

1	Introduction.....	1
1.1	Scope of report	1
1.2	Model and report overview	1
1.3	Watercourse and catchment overview	2
1.4	Available data	9
2	Flood history	13
2.1	Summary	13
2.2	Flooding winter 2013/14	13
3	Fluvial hydraulic modelling	17
3.1	Context.....	17
3.2	Key hydraulic structures	17
3.3	Salmon Weir Barrage operation	18
3.4	Hydraulic roughness	19
3.5	1D-2D boundary	25
3.6	Defences and walls.....	25
3.7	Floodplain	36
4	Fluvial model calibration and sensibility checking.....	37
4.1	Calibration versus sensibility checking	37
4.2	Baseline sensibility checking	37
4.3	Gauge calibration.....	37
4.4	November 2009 calibration event.....	38
4.5	Stakeholder Engagement	40
5	Application of hydrology	42
5.1	Hydrological estimation points	42
5.2	Application of design flow estimates.....	42
5.3	Downstream boundaries.....	43
6	Fluvial model results	47
6.1	Fluvial model runs.....	47
6.2	Flood risk mapping	47
6.3	Key flood risk mechanisms	47
7	Fluvial sensitivity testing	54
7.1	Screening of fluvial sensitivity tests	54
7.2	Fluvial sensitivity testing results	58
8	Coastal hydraulic modelling.....	61
8.1	Context.....	61
8.2	Defence and walls	61
8.3	Floodplain	61
8.4	LIDAR adjustments.....	62
8.5	Wave Overtopping	63
9	Coastal model calibration and sensibility checking	65
9.1	Calibration data.....	65
9.2	1st February 2014 event.....	65
9.3	3rd January 2014 event.....	66
9.4	Calibration results	68
10	Coastal model results	69

10.1	Model runs	69
10.2	Coastal flood risk mapping	69
11	Coastal sensitivity testing	74
11.1	Screening of coastal sensitivity testing	74
11.2	Coastal sensitivity	74
11.3	Coastal sensitivity testing results	74
12	Model limitations	76
12.1	Fluvial model	76
12.2	Coastal model	77
A	Hydraulic model results	78

List of Figures

Figure 1-1: Galway City AFA catchment overview	3
Figure 1-2: Upper Corrib MPW overview.....	4
Figure 1-3: Upper Corrib overview	5
Figure 1-4: Castlegar overview.....	5
Figure 1-5: Inner city canal system overview (circa 1837-1841)	6
Figure 1-6: Inner city canal system overview	7
Figure 1-7: Salthill Promenade	7
Figure 1-8: Galway coastal overview.....	8
Figure 1-9: Claddagh Area	8
Figure 1-10: Historical evidence of reclamation from the sea	9
Figure 1-4: New Sluice on Persse's Distillery River	10
Figure 1-11: Locations of wave data supplied from the ICWWS.....	12
Figure 2-1: Water levels in Galway City 18 Dec 2014	14
Figure 2-2: Water levels in Galway City 03 Jan 2014	15
Figure 2-3: Water levels in Galway City 01 Feb 2014	16
Figure 3-1: Galway City defence overview	25
Figure 4-1: October-31 December 2009 (a) gauge data and (b) gate opening.....	38
Figure 4-2: November-December 2009 calibration plot at the 30098 gauge Dangan.....	39
Figure 4-3: November-December 2009 calibration plot at the 30098 Salmon Weir Barrage....	39
Figure 4-4: November-December 2009 calibration plot at the 30061 Wolfe Tone gauge.....	40
Figure 5-1: Galway City AFA HEP locations	42
Figure 5-2: Hydrograph storm duration sensitivity result.....	43
Figure 5-3: ICPSS extreme sea level calculation points	44
Figure 5-4: Castlegar Sinkhole	45
Figure 6-1: Tidal influence extent	48
Figure 6-2: Corrib MPW flooding	48
Figure 6-3: Overview of flood extent in the upper Corrib HPW	49
Figure 6-4: Overview of Castlegar flood extent	50
Figure 6-5: Overview of Distillery River flood extent	51
Figure 6-6: Overview of right bank canal flood extent	52
Figure 6-7: Overview of area at Wolfe Tone Bridge	53
Figure 7-1: Joint probability tests.....	57
Figure 7-2: Downstream boundary test	57
Figure 7-3: Claddagh area sensitivity overview 1% AEP	58
Figure 7-4: Claddagh area sensitivity overview 10% AEP	59
Figure 7-5: Upper Corrib sensitivity 1% AEP.....	59
Figure 7-6: Claddagh area sensitivity overview 10% AEP	60
Figure 8-1: 2D model tidal boundary	61

Figure 8-2: Location of 1D ESTRY components in floodplain within Galway City	62
Figure 8-3: LIDAR adjustments	63
Figure 8-4: Surveyed cross section locations	64
Figure 9-1: Tidal graph for 1st January 2014 event (0-70)	65
Figure 9-2: Galway City coastal modelled extent for 01 February 2014	66
Figure 9-3: Overview of observed flooding in Salthill	67
Figure 9-4: Comparison of observed and 1% AEP event Salthill	67
Figure 10-1: Selection of tide levels input into model	69
Figure 10-2: Overview of Salthill	70
Figure 10-3: Overview of Spanish Arch and Dock Road	71
Figure 10-4: Overview of Claddagh Basin	72
Figure 10-5: Wave overtopping results Salthill	73
Figure 10-6: Wave overtopping results Docklands	73
Figure 11-1: Overview of sensitivity at Salthill	75
Figure 11-2: Overview of sensitivity at Salthill	75

List of Tables

Table 1-1: Abbreviated watercourse names	9
Table 1-2: Hydrometric gauging stations in the vicinity of the AFA	11
Table 1-3: Extreme sea levels (mOD Malin)	11
Table 1-4: Galway coastal gauges	11
Table 2-1: Summary of Flood History	13
Table 2-2: Peak gauge water levels during winter 2013/14	13
Table 3-1: Key hydraulic structures	17
Table 3-2: Reach hydraulic roughness values	19
Table 3-3: Formal and informal effective defences	25
Table 3-4: Wall defences	26
Table 4-1: Initial conditions	37
Table 4-2: PCD Feedback	41
Table 5-1: ICPSS extreme sea level estimates	44
Table 5-2: Summary of hydraulic model design inflows	46
Table 6-1: Peak flows for the Mid-Range Future Scenario	47
Table 6-2: Peak flows for the High-End Future Scenario	47
Table 7-1: Sensitivity test summary	54
Table 7-2: Flow sensitivity scaling factors	54
Table 7-3: Sensitivity to roughness scenarios	55
Table 8-1: 1D ESTRY components in floodplain in Galway City AFA	62
Table 8-2: The maximum overtopping flows per m length of coastal frontage calculated	

from the combination of conditions run in the wave overtopping model.	64
Table 10-1: Extreme sea levels (mOD) - current and future scenarios	69
Table 11-1: Floodplain roughness range.....	74
Table 12-1: Excluded watercourses	77
Table A-1: 1D model peak current flows	78
Table A-2: 1D model peak MRFS flows	86
Table A-3: Current peak flows at HEPs.....	95
Table A-4: MRFS peak flows at HEPs.....	95

Abbreviations

AEP	Annual exceedence probability
AFA	Area for further assessment
AMAX	Annual maximum
CFRAM	Catchment flood risk assessment and management
DAD	Defence asset database
DAS	Defence asset survey
DEM	Digital elevation model (Includes surfaces of structures, vegetation, etc)
DTM	Digital terrain model ('bare earth' model; does not include surfaces of structures, vegetation, etc
ESTRY	One-dimensional model from the TUFLOW suite
FRISM	Flood risk metrics (a flood risk tool developed by JBA)
FRMP	Flood risk management plan
FRR	Flood risk review
FSR	Flood studies report
FSU	Flood studies update
GIS	Geographical information system
HEFS	High-end future scenario
HEP	Hydrological estimation point
HPW	High priority watercourse
HWA	Hydrograph width analysis
IBIDEM	Interactive bridge invoking the design event method
ICPSS	Irish coastal protection strategy study
ISIS	One-dimensional hydraulic modelling software
LA	Local authority
LIDAR	Light detection and ranging
mOD	Metres above Ordnance datum (unless stated this refers to the Malin datum)
MPW	Medium priority watercourse
MRFS	Mid-range future scenario
NDHM	National digital height model (a DTM by Intermap)
OSi	Ordnance Survey Ireland
PFRA	Preliminary flood risk assessment
Q(T)	Flow for a given return period
QMED	Median annual flood, used in FSU methods
SAAR	Standard annual average rainfall
SoP	Standard of protection (in relation to flood defences)
T	Return period, inverse of AEP
Tp	Time to peak

TUFLOW..... Two-dimensional hydraulic modelling software

UoM Unit of Management

* Asterisks at the end of a cross section label denotes interpolated model cross

1 Introduction

1.1 Scope of report

This report summarises the hydraulic modelling work for the Galway City hydraulic model. This document is specific to the Area for Further Assessment (AFA) itself and should be read in conjunction with the generic Hydraulic Model Development Methodology for details on the modelling approaches and wider context of the study.

The report covers the overall hydraulic modelling process from model build through to the development of design runs with the aim of providing a detailed understanding of the hydraulic controls and flood mechanisms identified throughout the study. It covers both the fluvial and coastal models of the city.

The report is not a user manual for the hydraulic model itself, full details of which are provided in model handover check files accompanying the hydraulic model.

The hydraulic modelling work summarised in this and the UoM 30 Hydraulic Modelling Report, of which this report is an Annex, forms one element of the Western Catchment-based Flood Risk Assessment and Management (WCFRAM) study process. The process to date has included amongst other tasks a Flood Risk Review (FRR)¹, a project inception stage², a Strategic Environmental Assessment (SEA)³ and the development of the catchment hydrology⁴. Where the work completed in these tasks contains information relevant to the analysis discussed in this document, references have been included directing the reader to the relevant report for further background information.

1.2 Model and report overview

There are three models within the Galway City AFA. Included are the Galway City High Priority Watercourse (HPW) model, the Lough Corrib to Galway Bay Medium Priority Watercourse (MPW) model and the Galway City coastal model. The River Corrib MPW model extends from Lough Corrib for 2.5km downstream to the Dangan gauge. The requirement for the MPW model is discussed in Section 1.3.1. The Galway City HPW model covers the urbanised centre of the AFA and follows a more detailed fluvial modelling approach. Whilst the HPW model includes some element of tidal risk in the form of a tide curve at the downstream boundary, risk arising specifically from coastal inundation of still water sea levels has also been examined through the Galway City Coastal model. This approach is discussed further in Section 1.3.5. In addition, the impact of wave overtopping across the quays and coastal walls has also been modelled and mapped.

The other main tributaries of Lough Corrib are the River Clare, flowing south from Ballyhaunis, and Owenriff which drains from the west through Oughterard. These watercourses have also been modelled through the CFRAM and are detailed in their own reports.

The model codes associated to this report are:

- Galway City - N1
- Galway City Coastal - C1
- Lough Corrib to Galway Bay - 95
- Oughterard - U1
- River Clare MPW (Tuam to Lough Corrib) - 90

Reports which are relevant to this AFA are:

- Western CFRAM Flood Risk Review Report
- Western CFRAM UoM30 and 31 Inception Report
- Western CFRAM UoM30 and 31 Hydrology Report

¹ JBA Consulting (2012), Western CFRAM Flood Risk Review, Final Report, Office of Public Works

² Western CFRAM Units of Management 30 - Corrib and 31 - Owengowla Inception Report, Final Report, Office of Public Works

³ JBA Consulting (2013), Western River Basin District Catchment-based Flood Risk Assessment and Management (CFRAM) Strategic Environmental Assessment, Scoping Report, Office of Public Works.

⁴ Western CFRAM Unit of management 30 - Corrib Hydrology Report, Final Report, Office of Public Works

- Western CFRAM UoM30 and 31 Hydraulic Modelling Report
- Western CFRAM UoM30 and 31 Hydraulic Modelling Report: Volume 1 - Hydraulic Modelling Method Statement
- Western CFRAM UoM30 and 31 Hydraulic Modelling Report: Volume 3 - Flood Risk Maps (which includes long section and cross section plans)
- Galway City AFA Fluvial Hydraulic Model Check File
- Galway City AFA Coastal Hydraulic Model Check File
- Western CFRAM UoM 30 Corrib Hydraulic Modelling Report: Volume 2e - Oughterard
- Western CFRAM UoM 30 Corrib Hydraulic Modelling Report: Volume 2d - Tuam to Lough Corrib

1.3 Watercourse and catchment overview

Unit of Management 30, also referred to as the Corrib catchment, covers an area of 3,113 square kilometres of the Western RBD. The area is predominantly within County Galway but there are also areas of County Mayo and Roscommon included. The Corrib catchment drains out to Galway Bay through Galway City. It is the extent of the Corrib, and its tributaries and offshoots with Galway City that form the focus of this report. The extent is shown within Figure 1-1.

The Corrib flows along a short channel through Galway City which joins the outlet of Lough Corrib to the sea. Its catchment to the outfall is large (3,140km²). Loughs Corrib and Mask form a dividing line between two quite different portions of the catchment. To the east of the Loughs, where the bulk of the catchment lies, the land is low-lying with moderate rainfall and karst limestone geology. The smaller tributaries flowing into the Loughs from the west are much steeper, draining impermeable mountainous catchments with high rainfall.

For the Corrib catchment as a whole the mean altitude is 65m and the gradient (S1085) of the longest watercourse is 0.58m which is very low. The mean annual rainfall across the catchment is 1422mm.

The major influence of Loughs Corrib and Mask is measured by the catchment descriptor FARL (Flood Attenuation due to Reservoirs and Lakes) which is 0.66. Lough Corrib is the second largest lake in Ireland, with an area of 178km². It has a major influence on the nature of flood flows along the River Corrib through Galway. A quarter of the Corrib catchment area drains via Lough Mask connecting to the north of Lough Corrib. This has an area of 89km² and drains into Lough Corrib via underground karst conduits.

The management of Lough Corrib has changed over the years. In the 12th century, the Friars Cut was built to provide another outlet from the Lough into the River Corrib in an attempt to allow boats to access the Lough from the sea. Between 1846 and 1850 the lake was lowered to reduce flooding of surrounding farm land (Freeman, 1957). Between 1848 and 1857, the Eglinton canal was built, connecting the River Corrib to the sea. It allowed boats to access the Lough via a single lock and also made provision for improved operation of over 30 mills.

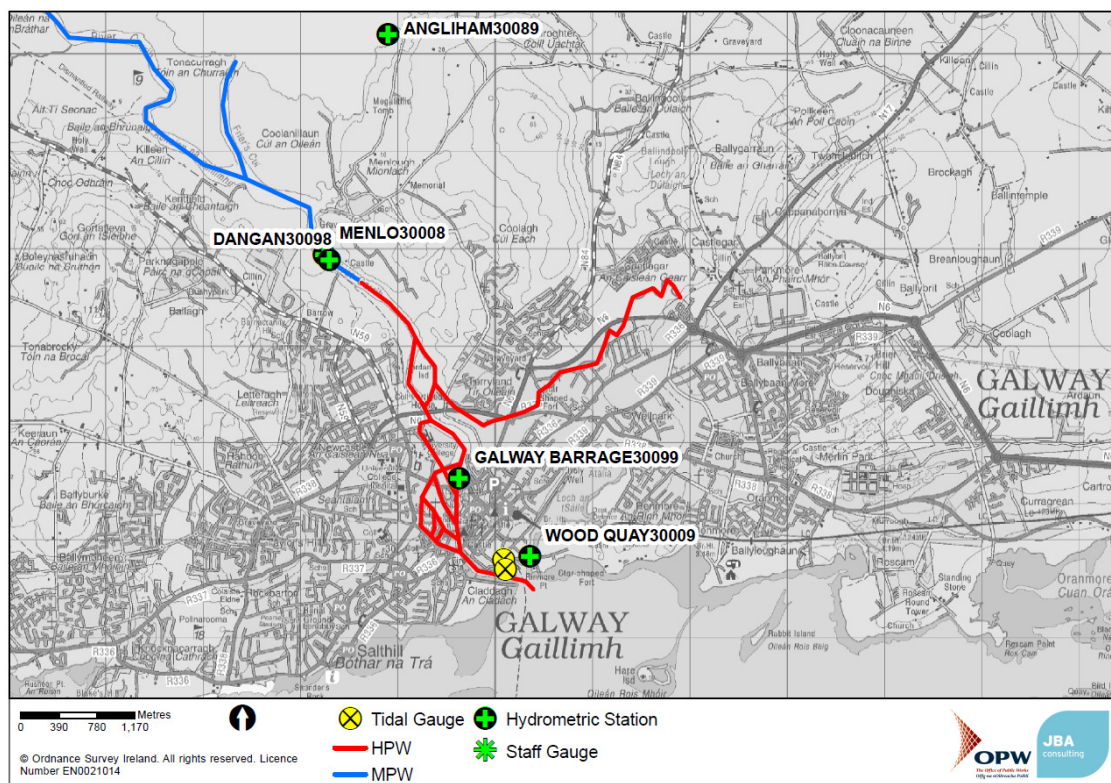
In 1959, a weir constructed in the 1850s was replaced with a sluice barrage (the Salmon Weir) consisting of 16 gates. The barrage is close to the centre of Galway, 800m upstream of Wolfe Tone Bridge, immediately downstream of the point where the Eglinton Canal leaves the river. This is 7.8km downstream of the main outlet from Lough Corrib. A small amount of flow can bypass this structure via various canals and mill races.

The barrage was intended to keep levels on the Lough between 5.84 and 6.44mAOD Malin (i.e. 28-30 feet above OD Poolbeg). The upper limit is intended to avoid flooding of shoreline and lower reaches of tributary rivers. The original design envisaged that this upper limit level would be reached at a flow of 311m³/s. This upper limit has been exceeded almost every year, apart from 1995 and 2005.

Due to the large size of Lough Corrib, wind setup can result in significant differences between water levels at opposite ends of the lake (up to 0.4m). This can reduce water level at the outlet, thus reducing discharge so that high lake levels persist longer.

There are numerous small channels that link into and out of the Corrib River. The flow regime is very complex with numerous structures. The hydraulics of the various reaches of the modelled river system is discussed in the following sections of report.

Figure 1-1: Galway City AFA catchment overview



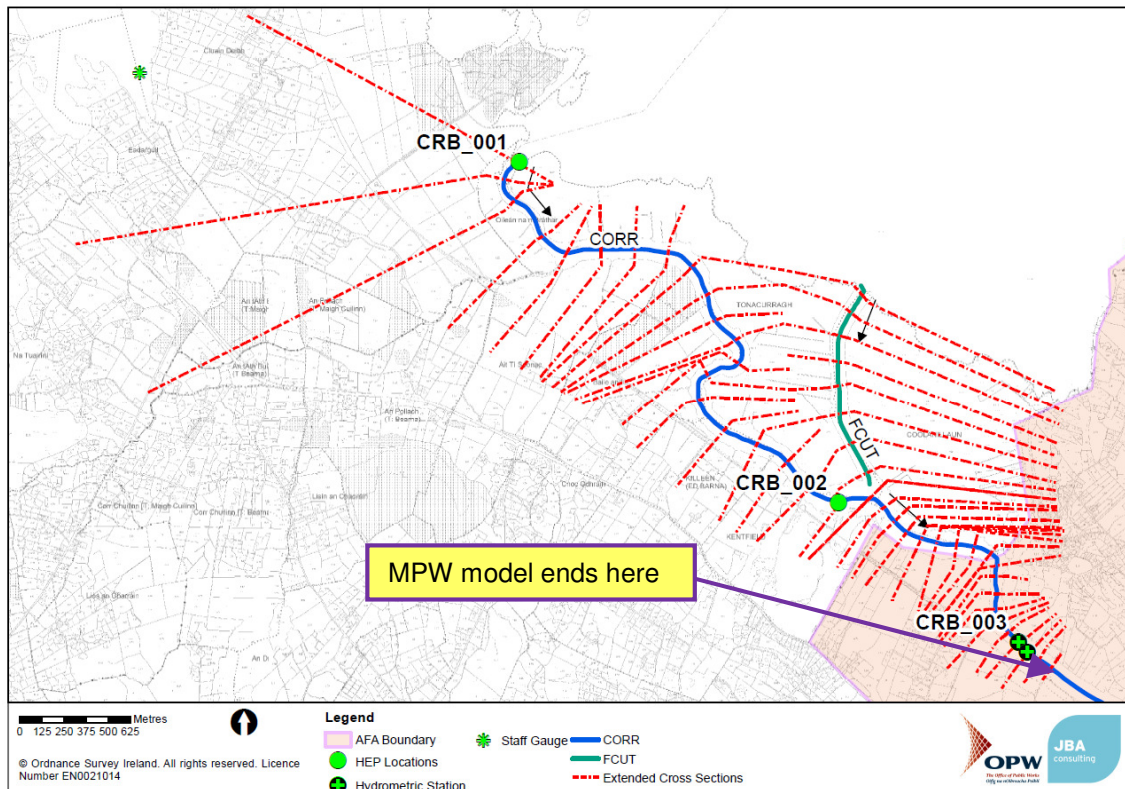
For the purpose of a catchment wide study the Lough Corrib to Galway Bay fluvial reach is divided into two models, the Medium Priority Watercourse (MPW) and the High Priority Watercourse (HPW). The HPW model is a more detailed study of the flood risk mechanisms required for an urban area. It starts at the Dangan gauge and continues to Galway Bay.

The MPW outputs are to be used to investigate the key controlling elements of the watercourse system and support the AFA modelling decisions. Specifically, this model will be used to assess the impacts of the Salmon Weir Barrage on Lough Corrib and the River Clare. Figure 1-1 shows the overview of the HPW and MPW models. A third model has been constructed to look at the impacts of direct coastal inundation and wave overtopping. The extent of this model is discussed in Section 1.3.5. The split between these two models has been placed at the Dangan gauging station where the river is constrained into a single channel with not floodplain flow. This is the only logical option for the dividing point. Extending the HPW model further upstream would have run into difficulties approaching Lough Corrib and the MPW model is required for further testing of the Galway area on upstream areas, such as Claregalway.

1.3.1 Upper Corrib MPW model

The upper Corrib MPW model begins with the two main channels leaving Lough Corrib. Here the channel is wide and begins conveying flow south towards Galway Bay. The land on both sides of the bank is marshy and boggy in nature with little settlement on the flood plain until further downstream near Menlo. There are silt deposits visible in the rivers upper reach from aerial photographs and are also evident in a cross sectional survey that was carried out. Figure 1-2 also shows the cross section extensions that were used to incorporate this area in the 1D domain. This area is much better modelled in 1D with extended cross sections as there will be extensive flooding and little impact. The 1D-2D model joins onto this at a narrowing of the floodplain which forces all flow back into the channel.

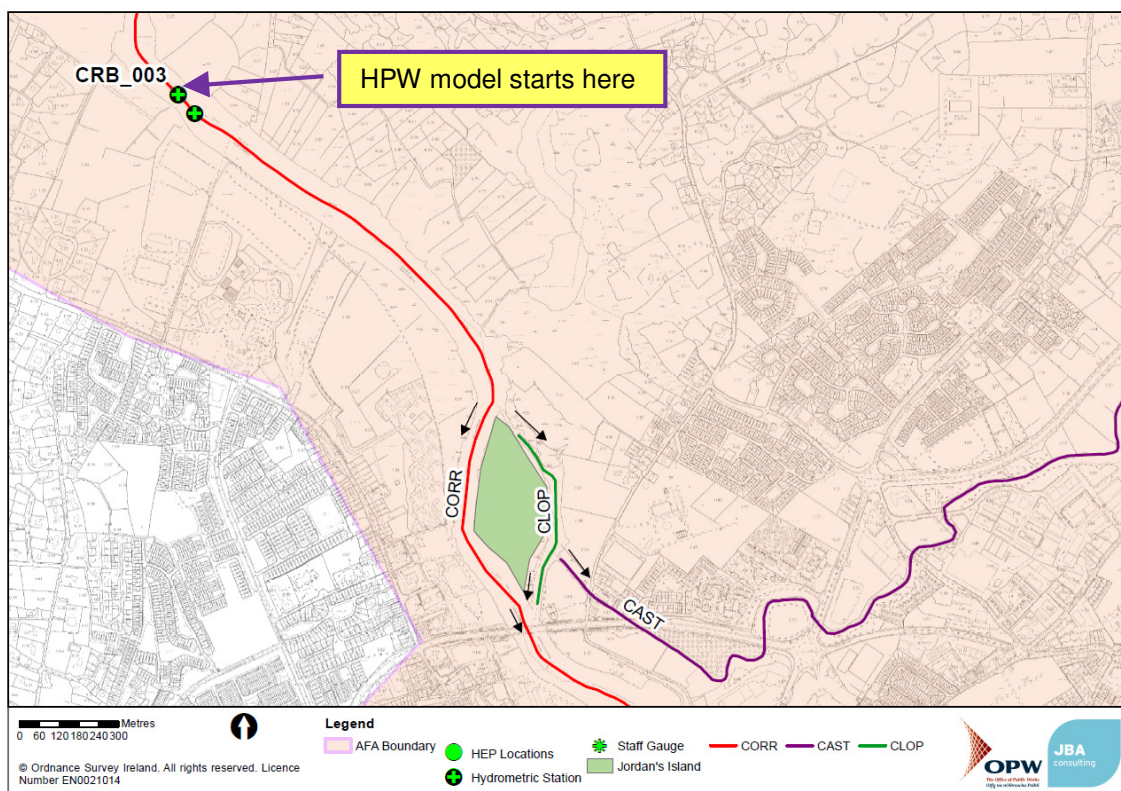
Figure 1-2: Upper Corrib MPW overview



1.3.2 Upper Corrib HPW

The 1D-2D model starts at CRB_003 where a narrowing of floodplain makes an ideal location to switch from the 1D only model upstream. The Corrib flows for approximately 4km past the Dangan gauge where it splits to form Jordan's Island. This river island provides the inflow to the Castlegar River and also forms a loop taking flow back into the Corrib. The flow around the Corrib loop is stagnant in nature with rough reed banks. Figure 1-3 shows the overview of the relating tributaries.

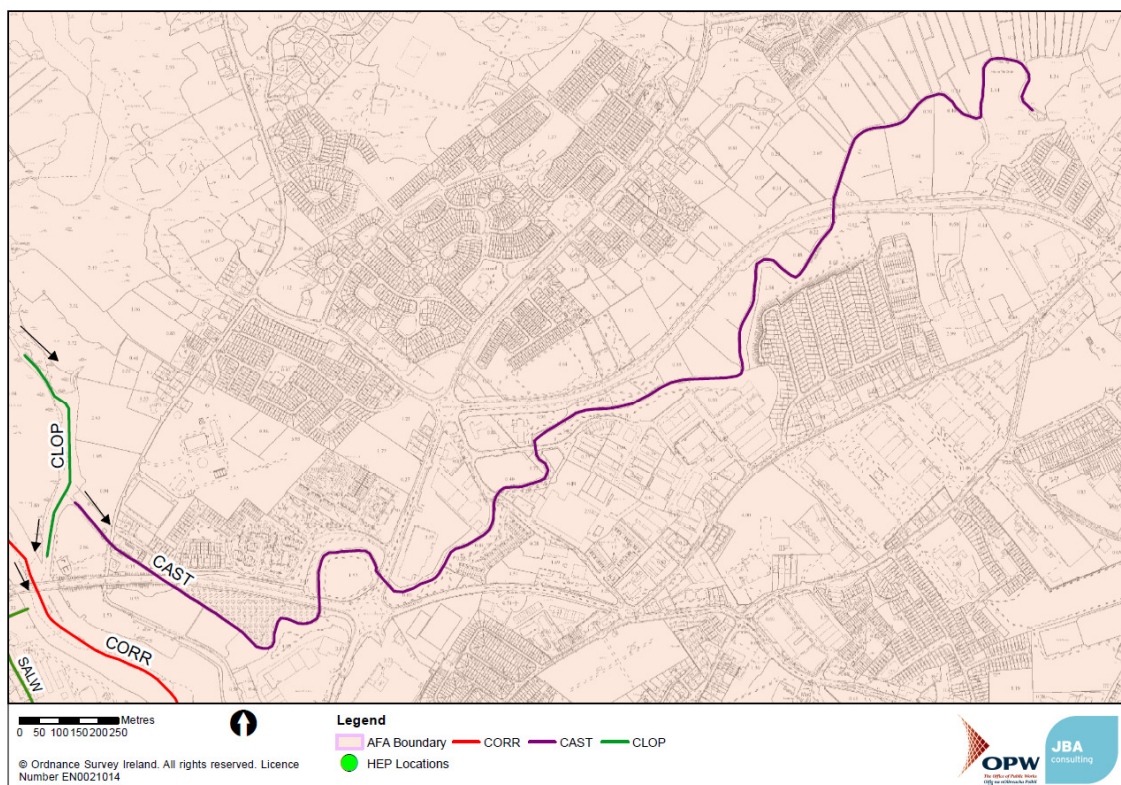
Figure 1-3: Upper Corrib overview



1.3.3 Castlegar

The Castlegar River flows east from the Corrib towards a sinkhole that drains the flow into the karst limestone beneath. The river has been used historically for water abstraction for the Galway City environs.

Figure 1-4: Castlegar overview



1.3.4 Galway city canal system

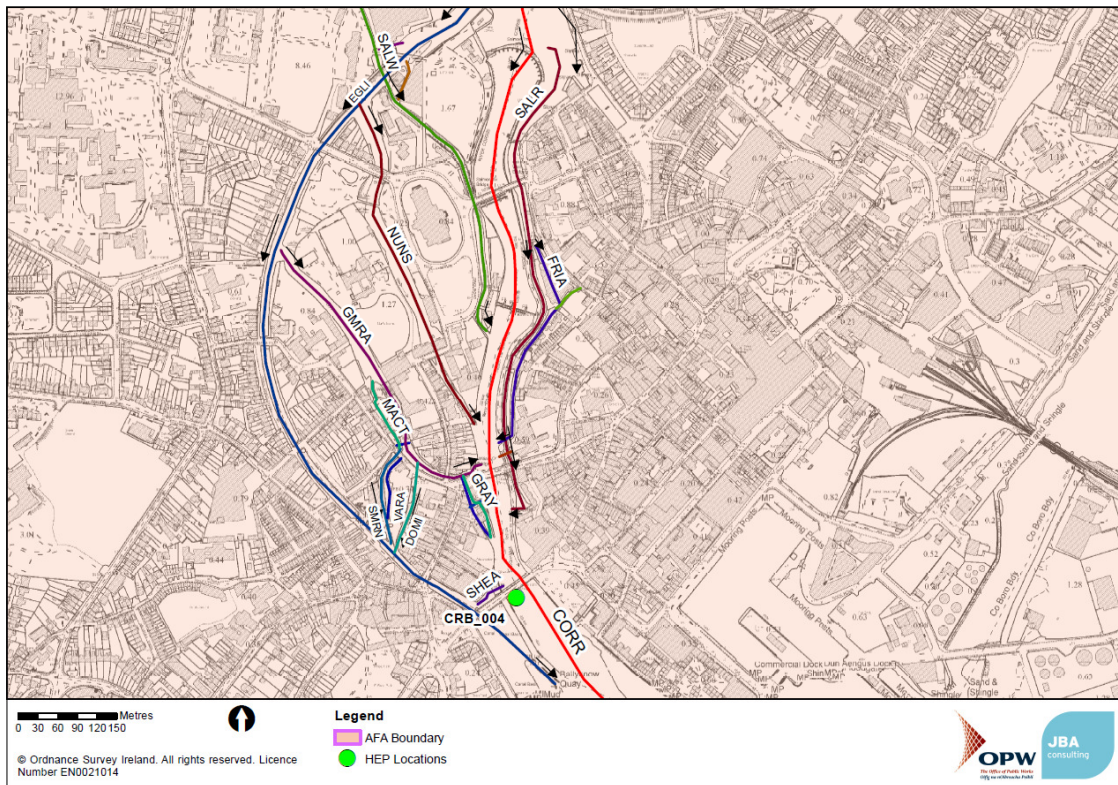
Galway city has numerous canals. These canals were built as part of major engineering works that was carried out on the River Corrib in the 19th century. The canals provided navigation, water power and a source for water supply to Galway city and surrounding areas. Figure 1-5 shows the limited canal structures pre the 1900s construction and Figure 1-6 shows the present day canals that have been included in the hydraulic model. There are numerous culverts and structures that formed old head races and tail races with the city along with controlling weirs and sluices.

Figure 1-5: Inner city canal system overview (circa 1837-1841⁵)



⁵ Mapping © 2014 Ordnance Survey Ireland and sourced from <http://maps.osi.ie/publicviewer/#V1,529610,725228,5,7>

Figure 1-6: Inner city canal system overview



1.3.5 Coastal domain overview

Galway City has a coastline of approximately 13.5km that stretches from Black Rock in the west to Roscam Point to the east. Figure 1-8 shows the extent of the coastline and outline of the AFA area. The key areas of flood risk within the AFA are properties along the Salthill promenade, Claddagh Point and the Docklands. The area around Claddagh Point and the Docklands are also influenced by the River Corrib which discharges to Galway Bay, the area of tidal influence is highlighted in Figure 6-1. The properties that encompass Lough Atalia are also an area of possible risk.

Figure 1-7 shows a photograph stretch along the Salthill Promenade with properties in a linear pattern to the contour of the coast. Many hotels and restaurants are located in close proximity to the promenade due to the attraction of tourists all year round. Figure 1-9 shows the Claddagh area coast line with various types of residential and commercial properties in the background.

Figure 1-7: Salthill Promenade



Figure 1-8: Galway coastal overview

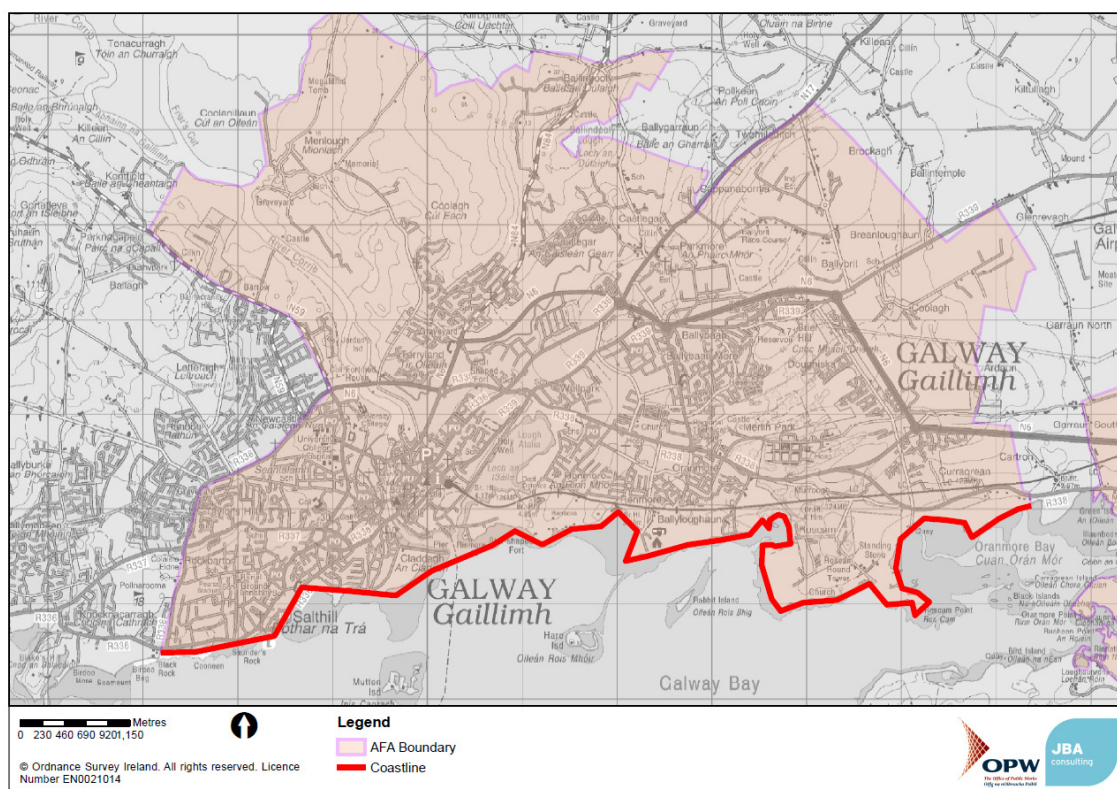
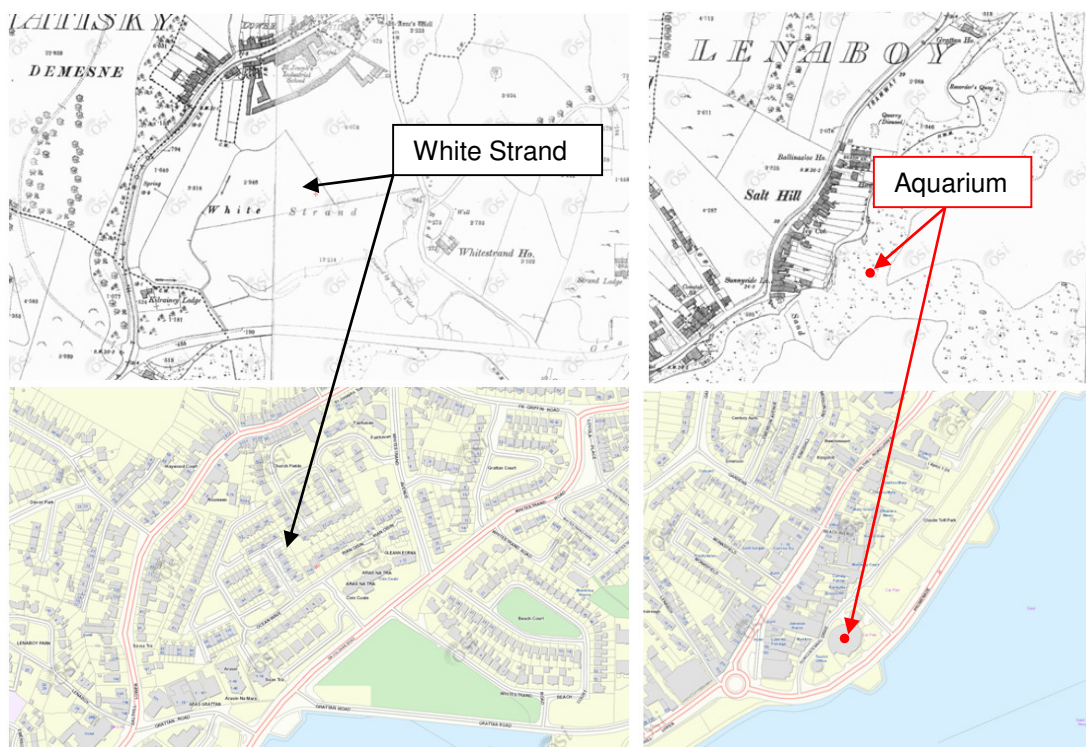


Figure 1-9: Claddagh Area



There is substantial evidence from historical OSi maps that reclamation of lands from the sea occurred in Salthill during the last century. Figure 1-10, on the left, shows the reclamation of White Strand to its present day state. Also on the right, Toft Park, the Aquarium and car park are all located on reclaimed land.

Figure 1-10: Historical evidence of reclamation from the sea⁶



1.4 Available data

1.4.1 Survey data

Cross sectional survey was collected by CCS Surveying as part of the National Survey Contract 6, Work Package 4 – delivered March 2013. Additional survey data was gathered under WCFFRAM Infill Contract 4 in September 2013. This was infill survey for some more complex structures. Finally, survey of the coastal defences and a number of threshold levels was collected through WCFFRAM Infill Contract 7, which was delivered in March 2014 and followed the flooding of January 2014.

The abbreviated versions of each watercourse name as represented in the hydraulic model are detailed in Table 1-1.

Table 1-1: Abbreviated watercourse names

Reference	Description	Corresponding Model Code
CORR	Corrib River	N1/95
CAST	Castlegar River	N1
CLOP	Corrib Loop	N1
EGLI	Eglinton Canal	N1
NUNS	Nuns Island	N1
GMRA	Galway Mill Run Area	N1
FRIA	Friary River	N1
SALR	Middle River	N1
SALW	Persse's Distillery River	N1
MACT	Madeira Court	N1
LIME	Lime Kiln	N1
DOMI	Dominic	N1
BRIM	The Bridge Mill	N1
SMRN	Somple Mill Run	N1
SHEA	Shearwater House	N1
LOCK	Lock Run	N1
VARA	Parkavara	N1
GRAY	Grannary Suites	N1

⁶ Mapping © 2014 Ordnance Survey Ireland and sourced from maps.osi.ie/publicviewer/#V1,528522,723935,7,9

Reference	Description	Corresponding Model Code
GMOF	Galway Mill Overflow	N1
BWRN	Bridge Street Weir Run	N1
COIS	Cois Teampall	N1
FCUT	Friars Cut	95
CLOP	Corrib Loop	N1
BRID	Bridge Mills	N1

LIDAR data has been commissioned by the OPW for use in the model. The data has been provided in both filtered and unfiltered formats in a 2m grid resolution. The LIDAR was flown between November 2011 and August 2012. A comparison of LIDAR levels against the surveyed cross sections was completed as part of the survey review process; 1200 spot levels were examined. This comparison of spot levels collected on roads or in open spaces found an average difference between the two of 69mm. The cross section survey was generally being higher than the LIDAR, but there was not enough difference to warrant amendment to the LIDAR or survey levels for the purposes of constructing the fluvial model. Some edits were made to ensure flow paths in the coastal model domain were correctly represented and these are detailed in Section 8.4.

Changes following completion of the baseline survey

Following the completion of the baseline survey topographic survey of the National University of Ireland Galway was submitted. Spot levels and threshold levels were collected to validate this topographic survey before use. In addition, a sluice gate has since been installed on Persse's Distillery River. This structure is located to the north of the National University of Ireland Galway and has the potential to reduce pass forward flows along the River in the event of blockage or structural failure of culvert under the Eglinton Canal downstream. There also exists a lock gate at Eglinton canal shown in Figure 1-4. This has been replaced and a new crest level has been surveyed. The validation survey and survey of the new sluice gate were collected by Six-West Ltd in May 2015.

Figure 1-11: New Sluice on Persse's Distillery River



The effect of the incorporation of this data is to reduce the flood risk to the university in the 0.1% AEP event. The university is not predicted to be at risk of flooding in the 1% AEP event regardless.

Owing to the later date of the survey for this structure, this hydraulic model report has not been revised to reflect this change on the ground. The changes are however incorporated into the final flood maps.

1.4.2 Hydrometric data

1.4.2.1 Flow data

A summary of hydrometric data within the AFA is provided in Table 1-2 and an overview of gauge locations is provided in Figure 1-12.

Table 1-2: Hydrometric gauging stations in the vicinity of the AFA

Number	Type	Use in calibration
30098- Dangan	Automatic recorder at Dangan on the River Corrib. In use since 13 Dec 1977	Yes (Stage compared at location).
30099- Salmon Weir Barrage	Automatic recorder upstream in the vicinity of the Salmon Weir barrage. In use since 25 Nov 1972.	Yes (Stage compared at location).
30061- Wolfe Tone Bridge	Automatic recorder at Wolfe Tone Bridge near the outlet. In use in current location since 18 Aug 2009.	Yes (flows input at upper limit of model)

Full details of the gauge study and analysis is detailed in the WCFRAM Hydrology Report for UoM 30.

The largest recorded event on record occurred on the River Corrib in January 1975. Although the event in November 2009 was significant, a flow value for this flood event cannot be calculated because the gauge 30061 Wolfe Tone Bridge was moved in 2004 and the rating curve is not valid thereafter.

Most gauging stations in UoM 30 show distinct flood seasonality, with floods generally occurring in October to April. At Galway, the onset of the flood season is rather later, in late November, presumably due to the lag time and storage available in Lough Corrib.

1.4.2.2 Tide data

The term extreme still water sea-level refers to the level that the sea is expected to reach during a storm event of a particular AEP due to a high tide and the passage of a storm surge. The extreme sea level tidal graphs were developed using Highest Astronomical Tide (HAT) tidal data for Galway Bay. An appropriate surge profile was then applied which increases sea levels above the tidal levels. This was done for a variety of return periods. The extreme sea levels were informed by the Irish Coastal Protection Strategy Study (ICPSS) deliverables. Full details of the procedure are provided in the WCFRAM Hydrology Report for UoM 30. A summary of the tide data within the AFA is provided in Table 1-3.

Table 1-3: Extreme sea levels (mOD Malin)

AEP	50%	20%	10%	5%	2%	1%	0.5%	0.1%
Sea Level	3.055	3.208	3.317	3.424	3.564	3.669	3.774	4.018

There are two tide gauges in the vicinity of the AFA with which the hydraulic model could be calibrated. These are operated by the Marine Institute/ Galway Port Company and the Galway Dock. They are shown in Figure 1-1.

Table 1-4: Galway coastal gauges

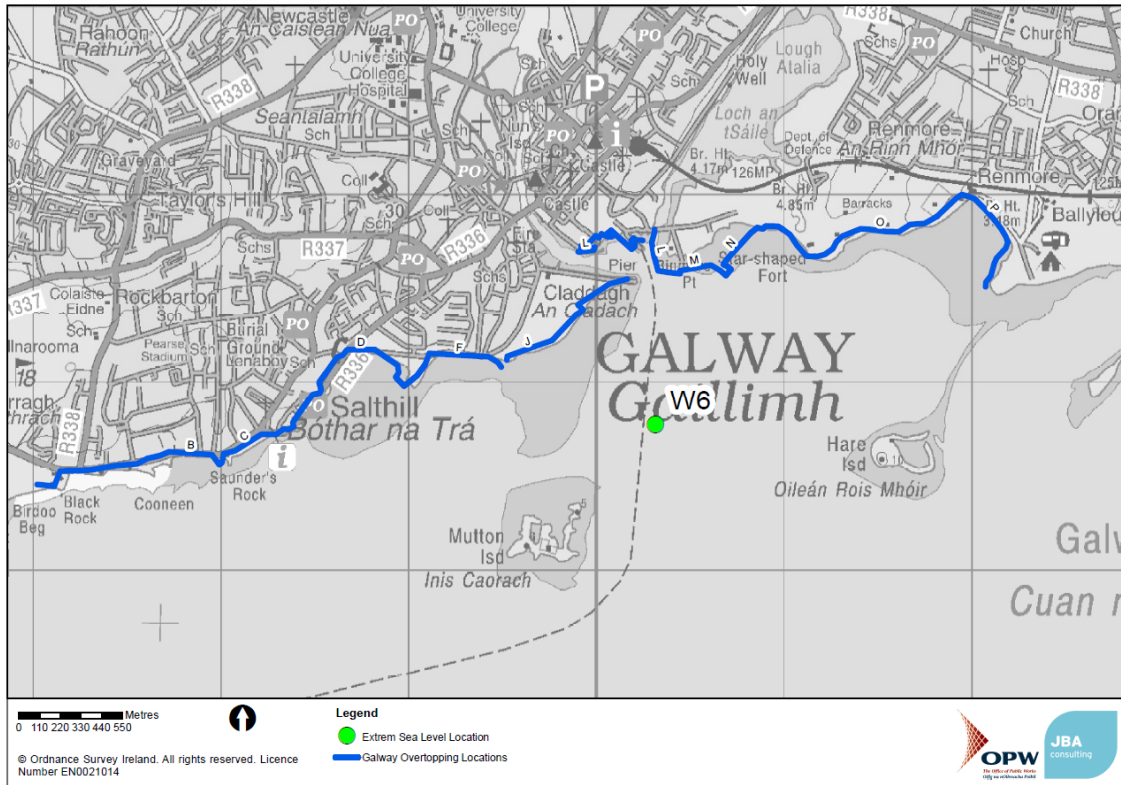
Name	Operating Authority	Start of Record	End of Record
Galway Port	Marie Institute/ Galway Port Company	Mar 2007	ongoing
Galway Dock	OPW	Sep 1985	Nov 1989

1.4.2.3 Wave overtopping data

Galway City AFA was one of the sites identified across the WCFRAM in the Irish Coastal Wave and Water Level Modelling Study (ICWWS) report as being susceptible to wave overtopping. For

Galway City wave data was provided at 21 locations along the front, see Figure 1-12. The wave data has been calculated at specific depths using both wind and swell waves for 8 return periods, the 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1% AEP wave events. For each return period the wave data was provided with six joint probability combinations of water level and wave height for both the wind wave and swell wave components. The overarching report describes this approach in more detail.

Figure 1-12: Locations of wave data supplied from the ICWWS



2 Flood history

Key flood risk areas have been identified in the Flood Risk Review and Inception Reports. For the purposes of the hydraulic modelling work this data is most beneficial when accompanied by supporting details such as photos or anecdotal evidence which confirm the maximum extent or depth of flooding at any given location. As far as possible, evidence related to the historical flood events will be used to calibrate the fluvial and coastal models. This process, and the results, are discussed in Sections 4 (fluvial) and 9 (coastal).

2.1 Summary

The flooding of the downstream in the River Corrib is mainly due to tidal and storm combined events. There was significant flooding in the winter of 2013/14 and this is detailed in the following sections. Localised flooding occurs in Flood Street on an almost yearly basis. The worst event in recent times was in January 1995 where there was significant flooding in Quay Street, Flood Street, and the Docks Areas. Flooding of the Spanish Arch area can lead to flooding in Quay Street, Flood Street and Fr. Griffin road. This flooding can lead to the R336 becoming impassable and block traffic moving east – west between the docks area of the city and Salthill. There has also been some flooding in the past along Grattan Road, caused by a sea surge prior to 1990. There has been flooding along Seapoint Promenade, particularly the car park adjacent to the Aquarium. There have been incidents of localized flooding along the Salthill sea front from sea surges and high winds. There has been localized flooding to the west of the N17 opposite the access to Ballybrit racecourse.

Table 2-1: Summary of Flood History

Area affected	Main Flood Mechanisms	Recorded Flood Event
Spanish Arch, Quay Street, Flood Street and the Docks area, Lower Salthill	Due to high tide, low atmospheric pressure, wind direction, heavy rain.	Jan 1995, High tides in 2006, Jan & Feb 2014, recurring
Grattan Road	Overtopping, high tides and onshore winds.	Recurring
Seapoint Promenade	Overtopping, high tides and onshore winds.	Jan & Feb 2014, recurring
N17 at Two Mile Ditch	Heavy rain	Jan 1995, 1999, 2005, Nov 2009, recurring
Salthill, Fr. Griffin Road, Claddagh and Spanish Arch Areas	Heavy rain, gale force winds, high tide	Feb 2002 recurring
Headford rd/Ballindooley	Ballindooley lake margin increased during heavy rain	Feb 2002, prone to flooding
Doughiska	Turlough	Recurring
Menlough	Turlough heavy rain	Nov 2009, recurring

2.2 Flooding winter 2013/14

There has been recent flooding in Galway City since the modelling phase began. Valuable flood data has become available as a result of successive storms that hit the west coast in the winter of 2013/14. Table 2-2 is a summary of the peak water levels recorded at various gauge locations in the Galway City and Bay area during the period.

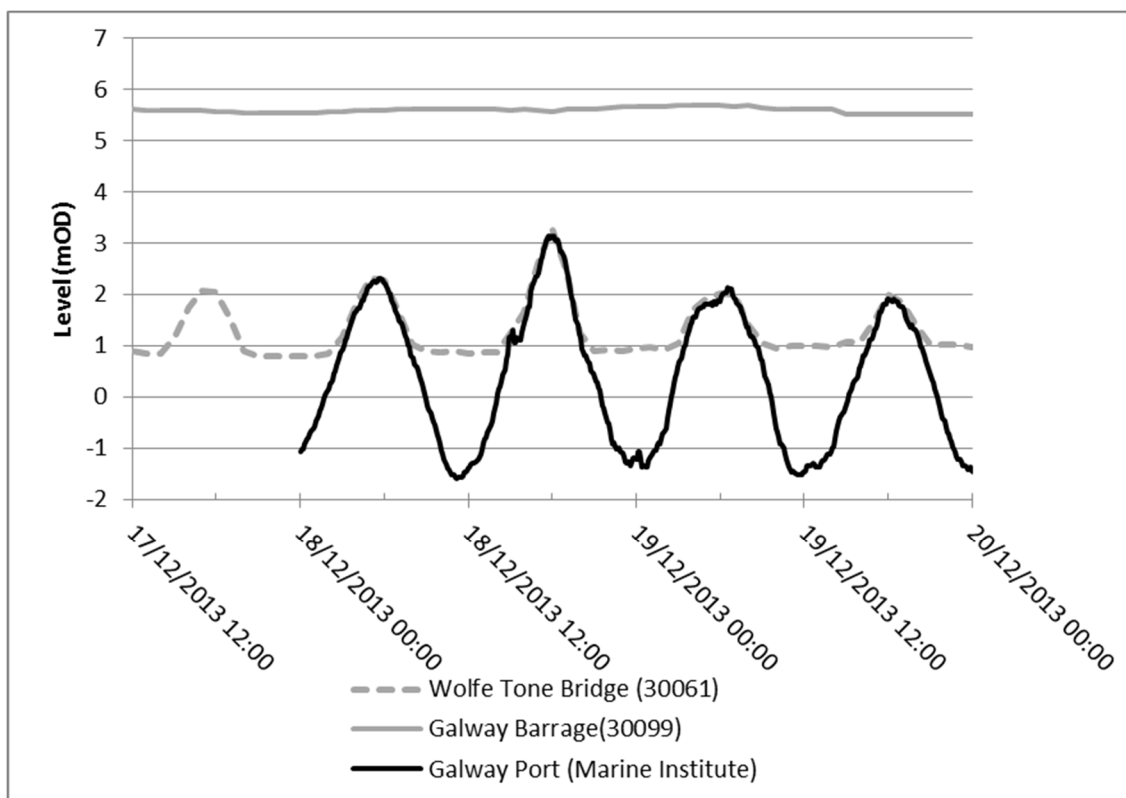
Table 2-2: Peak gauge water levels during winter 2013/14

Gauge Name	Gauge Ref	18 Dec 2013	03 Jan 2014	01 Feb 2014
Galway Port	Marine institute	3.16	3.56	3.59
Wolfe Tone Bridge	30061	3.32	3.59	3.39
Rossaveel	31061	2.81	3.41	3.67
Oranmore Bridge	29015	3.34	3.59	3.58

2.2.1 18th December 2014

The extent of flooding observed on 18 December 2013 was a result of waves on top of high tides and a storm surge with a peak level of 3.16 (mOD) recorded at Galway Port. There is some variation in tide levels in Galway Bay, with observed levels appearing to be higher in the east; however, more data is required to discount local variations in topography and bathymetry. The south westerly direction of waves exposes a long section of the coastline in Galway City to wave overtopping.

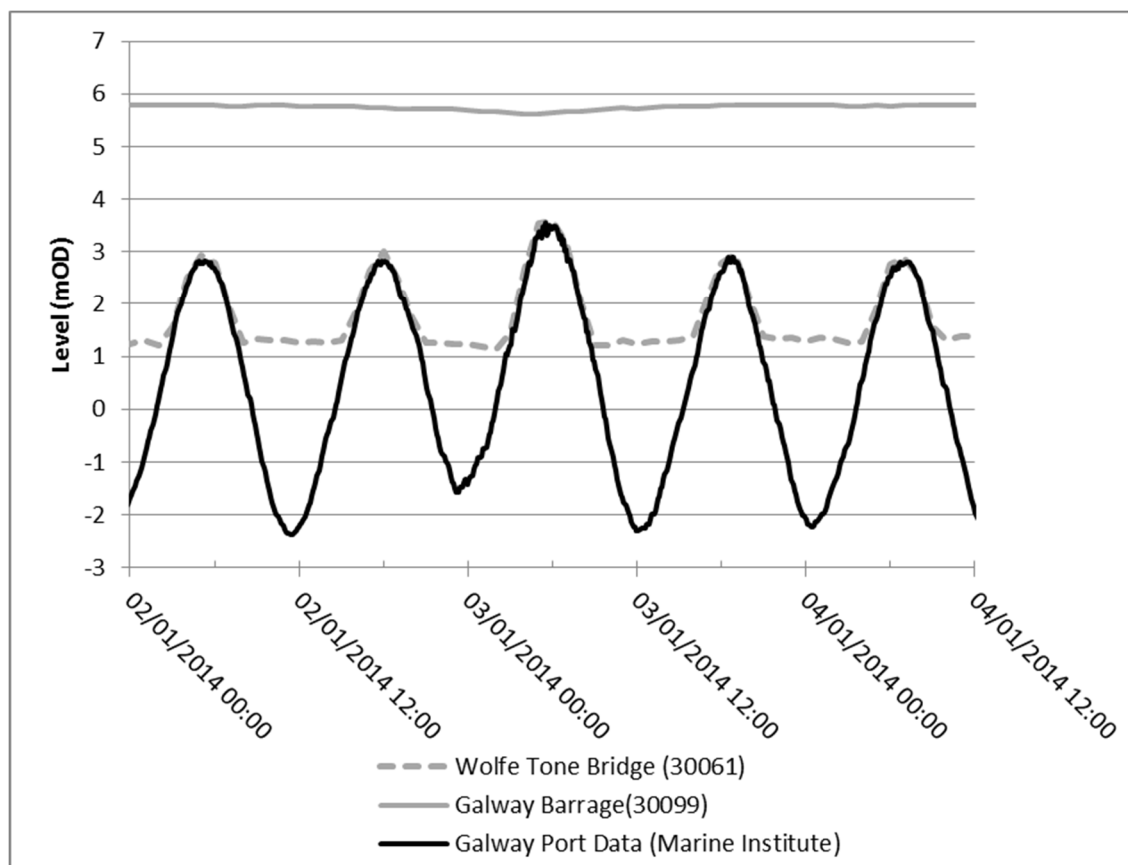
Figure 2-1: Water levels in Galway City 18 Dec 2014



2.2.2 3rd January 2014

The extent of flooding observed on 03 January 2014 was a result of waves on top of high tides and a storm surge with a peak level of 3.56 mOD at Galway Port. The south westerly direction of waves exposes a long section of the coastline in Galway City to wave overtopping. Flooding was observed in Salthill, the Claddagh, Fishermans Quay, Lough Atalia and Ballyloughane Beach. All of the locations affected by flooding on 03 January 2014 are known flood risk spots and have experienced flooding before. 14 properties flooded internally and a further 11 were affected by flooding.

Figure 2-2: Water levels in Galway City 03 Jan 2014



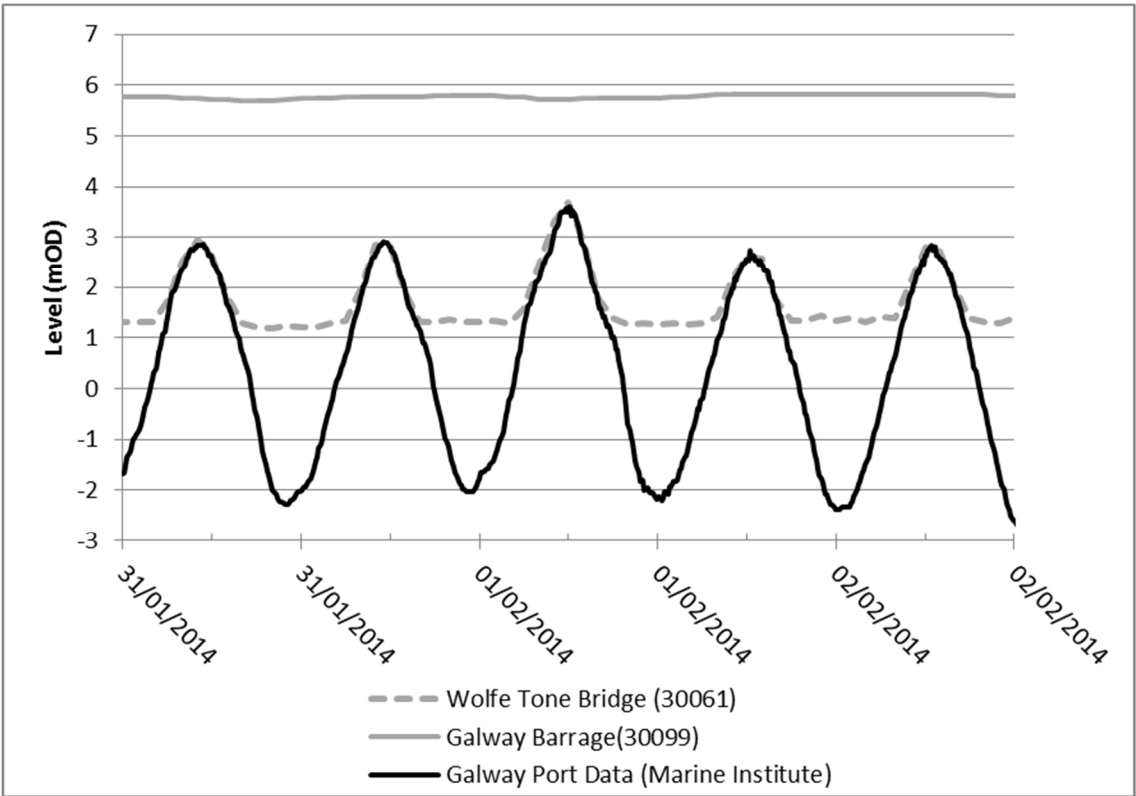
2.2.3 1st February 2014

The extent of flooding observed on 01 February 2014 in Salthill was a result of waves on top of high tides and a storm surge with a peak level of 3.59 mOD at Galway Port. In Galway City Centre the flooding was a result of high tides and a storm surge only. The flooding was less severe in Salthill than previous flooding on 18 December 2013 and 03 January 2014. In the city centre the flooding was more severe than these two recent events.

The south westerly direction of waves exposes a long section of the coastline in Galway City to wave overtopping. All of the locations affected by flooding are known flood risk spots and have experienced flooding before. It is unclear how many properties flooded internally, but a significant number were affected by the flooding.

As the 1st of February 2014 event is the largest of the recent records. Section 9 will investigate this event in greater detail. The will form the calibration portion of this report

Figure 2-3: Water levels in Galway City 01 Feb 2014



3 Fluvial hydraulic modelling

3.1 Context

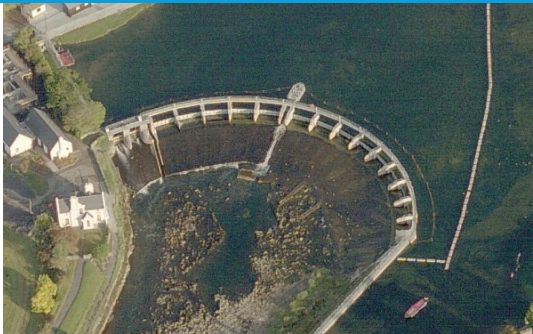

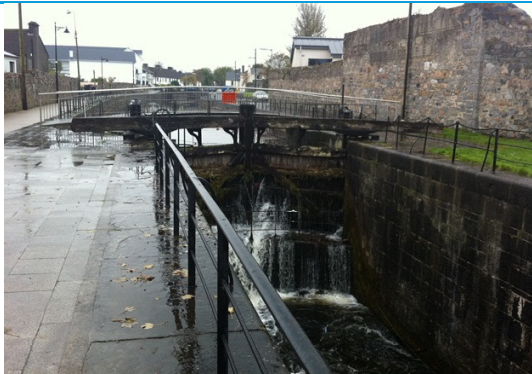
This section should be read in conjunction with the Hydraulic Model Report: Volume 1a: Hydraulic Modelling Method Statement and the Galway City Hydraulic Model Check Files. The Method Statement provides an overview of the elements of both the 1D and 2D model construction and the following section of the report describes how they were applied to the Galway City fluvial model.




In addition, a coastal model of Galway City has been constructed to specifically examine flood risk due to high tide levels, and the impact of wave overtopping. This model is discussed further in Section 8.

3.2 Key hydraulic structures

There are a considerable number of structures, including bridges, culverts, weirs and sluices, within the Galway City Corrib system. Only those key hydraulic structures which dictate water levels and flows routes in the vicinity of key flood risk areas are summarised in Table 3-1. All others are details in the hydraulic model check file.

Table 3-1: Key hydraulic structures

Structure Name	Description	Photograph
Salmon Weir Barrage 30CORR00155W	Structure containing 16 sluices gates controlling upstream level of Corrib. Barrage gauge 30099 is 30m upstream and gate operation greatly controls the recorded stage	
Weir at 30SHEA0000W	Controls flow out of EGLI and right bank canal system to the Corrib. More importantly is frequently drowned out by tide and allows reverse flow up EGLI canal.	
Lock gate at 30EGLI00040D	Old Lock gate on the EGLI canal. Holds the level of the EGLI canal upstream of structure.	

Structure Name	Description	Photograph
Weir at 30SALR00045W	Weir where FRIA and SALR split. First controlling structure taking flow into the left bank canal system	
Waterworks at 30CAST00018A	Old Waterworks limits the flow from the Corrib and further downstream to CAST.	
Culvert at 30MACT00006A	Two culverts through building. Flow constricted here.	

3.3 Salmon Weir Barrage operation

The discharge on the River Corrib is regulated by the Salmon Weir Barrage. The barrage was constructed in 1959 and consists of 14 steel gates along with 2 wooden gates. The report conducted by the OPW, "Hydraulic and Hydrologic Investigation of Lough Corrib Flow Regime and of Gate Manipulation Policy at Galway Sluice barrage", detailed the initial purpose of the barrage. The stated purpose in the design was to maintain the water level in Lough Corrib:

- at or above 8.53m OD Poolbeg (i.e. 5.83 OD Malin) and
- at or below 3.14m OD Poolbeg (i.e. 6.44 OD Malin).

The current operation of the gates is conducted by the Office of Public Works and is depended upon the following conditions.



- The water levels from the gauge recordings at
- Anglinham, Annaghdown and Cong Pier on the Lough Corrib.
- Corrofin on the Clare River.
- Dagan and the Salmon Weir on the River Corrib.
- The weather forecast.
- The time and season of the year.
- The wind direction.
- The various preconditions for various stakeholders i.e. Galway City Council, Corrib Navigation Trustees and Western Regional Fisheries Board.



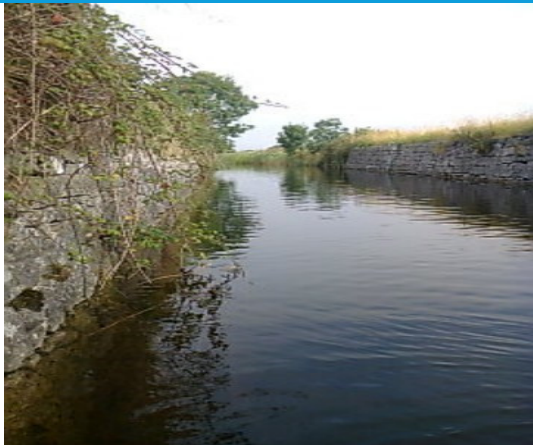
The decision to increase or decrease the discharge through the barrage is then based on experience. For the purpose of modelling the fluvial design events and the calibration event, the gates are all assumed to be open which fits with the usual gate position in winter.

3.4 Hydraulic roughness



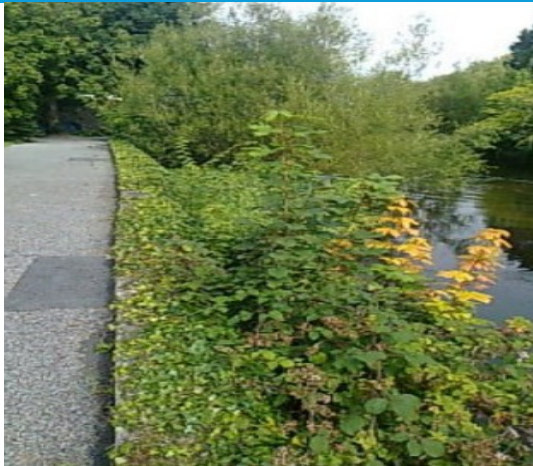
Reaches of similar hydraulic roughness have been identified from survey photos and drawings. Manning's 'n' values for both the river bed and banks to bank top within each of these reaches are summarised in Table 3-2.




Table 3-2: Reach hydraulic roughness values

Upstream and Downstream Cross Section	Roughness Values (Manning's 'n') and materials	Photograph
30CORR00951-30CORR00442	Bed - 0.020 for mud material. Bank - 0.040 for grassy floodplains and 0.050 to account for trees.	 Photo taken looking downstream (Section 30CORR00605)
30CORR00442-30CORR00158	Bed - 0.035 for stone and mud material. Bank - 0.045 for banks of rocks, reeds and weeds. 0.050 for the flood plain and the presence of occasional trees.	 Photo taken looking at left bank (Section 30CORR00317)

Upstream and Downstream Cross Section	Roughness Values (Manning's 'n') and materials	Photograph
30CORR00158-30CORR00000	Bed - 0.040 for stone and mud material as in previous reach. Bank - 0.025 for urbanised reach where banks comprise of wall banks.	 <p>Photo taken looking at upstream (Section 30CORR00082)</p>
30CAST00001-30CAST00001	Bed - 0.030 for mud material. Bank - 0.040 for grassy banks.	 <p>Photo taken looking at upstream (Section 30CAST00001)</p>
30CAST00008O-30CAST00018B	Bed - 0.030 for mud material as in previous reach. Bank -0.025 stone walls represented entering and leaving waterworks building.	 <p>Photo taken looking at upstream (Section 30CAST00008O)</p>

Upstream and Downstream Cross Section	Roughness Values (Manning's 'n') and materials	Photograph
30CAST00023-30CAST00398	Bed - 0.030 for bed material of mud and silt. Bank - 0.040 for grassy/reed banks.	 <p>Photo taken looking at left bank (Section 30CAST00084)</p>
30CLOP00064 - 30CLOP00001	Bed - 0.035 for a stone mud material. Bank - 0.040 for a grassy/reed banks and floodplain.	 <p>Photo taken looking at right bank (Section 30CLOP00008)</p>
30EGLI00135 - 30EGLI00103D	Bed - 0.030 for silt material. Bank - 0.025 for urbanised reach with stone walls.	 <p>Photo taken looking at right bank (Section 30EGLI00119)</p>

Upstream and Downstream Cross Section	Roughness Values (Manning's 'n') and materials	Photograph
30EGLI00103D - 30EGLI00000	Bed - 0.035 for silt stone material. Bank - 0.025 for walls as per previous reach.	 <p>Photo taken looking at downstream (Section 30EGLI00035)</p>
30NUNS00052 - 30NUNS00000	Bed - 0.035 for stone mud material. Bank - 0.025 for stone walls and where local trees and shrubs exists 0.060 is used.	 <p>Photo taken looking at upstream (Section 30NUNS00037)</p>
30GMRA00043 - 30GMRA00000	Bed - 0.035 stone silt material Bank - 0.025 for stone walls and where bushed and shrubs are noted, 0.060 is used	 <p>Photo taken looking at upstream (Section 30GMRA00043)</p>

Upstream and Downstream Cross Section	Roughness Values (Manning's 'n') and materials	Photograph
30FRIA00034 - 30FRIA00000	Bed - 0.035 for stone, silt and concrete material. Bank - 0.025 for stone walls and where bushes and shrubs are noted, 0.060 is used	 <p>Photo taken looking at upstream (Section 30FRIA00014D)</p>
30SALR00061- 30SALR00000A	Bed - 0.035 for stone silt and concrete material. Bank - 0.025 for stone walls throughout.	 <p>Photo taken looking at downstream (Section 30SALR00020D)</p>
30SALW00111 - 30SALW00104I	Bed - 0.035 for stone and silt bed material. Bank - 0.040 for grassy banks.	 <p>Photo taken looking at downstream (Section 30SALW00109)</p>
30SALW00103J- 30SALW00022D	Bed - 0.035 for stone and silt bed material. Bank - 0.025 for stone walls and where bushes and shrubs are noted, 0.060 is used	 <p>Photo taken looking at downstream (Section 30SALW0057)</p>

Upstream and Downstream Cross Section	Roughness Values (Manning's 'n') and materials	Photograph
30MACT00011-30MACT00001	Bed - 0.040 stone material. Bank - 0.060 for vegetated ivy banks and 0.025 where localised bare concrete walls are evident.	 <p>Photo taken looking downstream 9Section 30MACT00001)</p>
30SMRN00015-30SMRN00002	Bed - 0.040 stone material. Bank - 0.060 for vegetated ivy banks and 0.025 where localised bare stone walls are evident.	 <p>Photo taken looking downstream (Section 30SMRN00014E)</p>
30VARA00006-30VARA00001	Bed - 0.040 stone material. Bank - 0.025 stone walls.	 <p>Photo taken looking upstream (Section 30VARA00040D)</p>
30DOMI000010J-30DOMI00001	Bed - 0.040 stone material. Bank - 0.025 stone walls.	 <p>Photo taken looking downstream (30DOMI00002D)</p>

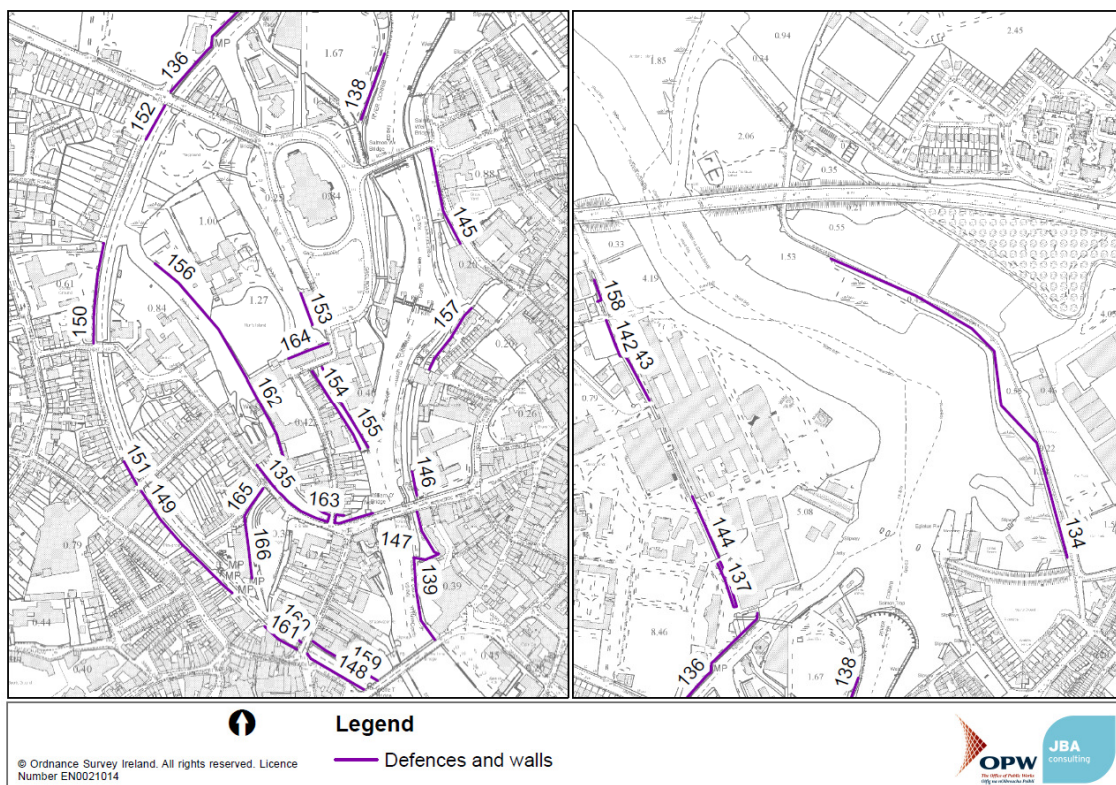
3.5 1D-2D boundary

Bank top levels were collected as part of the topographic survey and have for the most part been used to develop the 1D-2D boundaries.

3.6 Defences and walls

Figure 3-1 provides an overview of the defences and walls discussed in the following sections. Identification numbers for each structure are included in the relevant tables.

Figure 3-1: Galway City defence overview

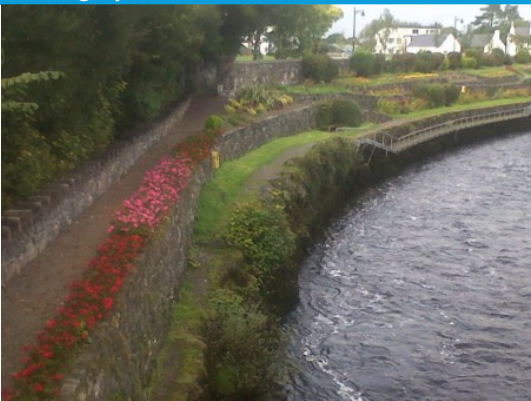



3.6.1 Defences

A number of formal (i.e. OPW, local authority or privately maintained defences) flood defences have been identified with the AFA and are detailed in Table 3-3. The two effective structures have been modelled as surveyed and are assumed to retain flood waters to the crest of the structure. The ineffective quay wall is so called because it forms an incomplete run of defence. However, the full length of the quay has been included in the model as per the survey details.

Table 3-3: Formal and informal effective defences


Description and Location	Photograph
<p>134 The dyke in Galway City runs from (129885, 225803) to (129549, 226241) in a North - North-West direction for 597.5m. The dyke has an elevation average of 6.8m.</p> <p>Formal effective.</p>	




Description and Location	Photograph
<p>138 30CORR00146-30CORR00140 Retaining wall on right bank of River Corrib. River will spill out on left bank before this defence becomes effective.</p> <p>Formal effective.</p> <p>Included in model as surveyed.</p>	
<p>139 30CORR00083- 30CORR00072D Only a small fraction of quay wall highlighted on the OPW database of formal defences. Some gaps in raised section.</p> <p>Formal ineffective Type 3</p> <p>Included in model as surveyed.</p>	


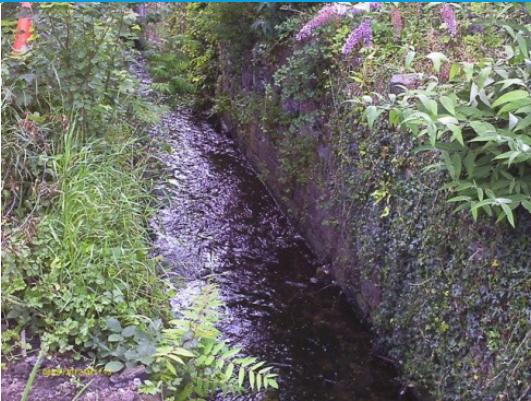

3.6.2 Walls


Informal ineffective structures identified with the AFA are detailed in Table 3-4. These structures are not assumed to function as flood defences and are either bypassed in the model or have been removed to allow flooding beyond them. The ID numbers in the table below (i.e. 135) relates to the ID shown on Figure 3-1, above.


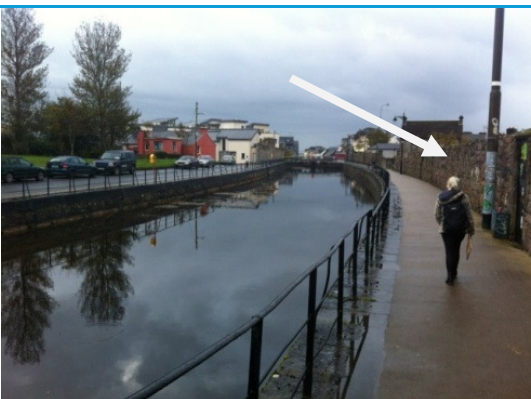
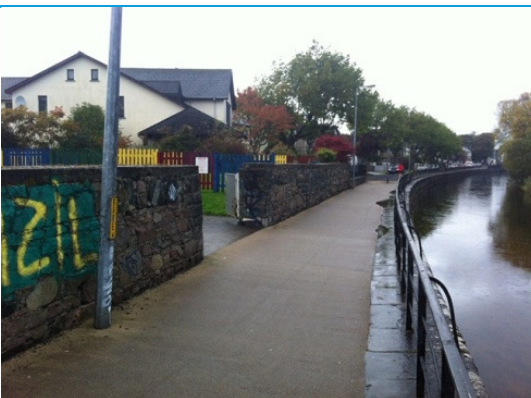
Table 3-4: Wall defences




Description and Location	Modelling Method	Photograph
<p>135 30GMRA00012- 30GMRA00005D</p> <p>Substantial wall which may have some defence function.</p>	<p>Informal ineffective Type 1</p> <p>Modelled as surveyed.</p>	




Description and Location	Modelling Method	Photograph
<p>136 30EGLI00119- 30EGLI00098</p> <p>Substantial wall but probably will flood behind from US of SALW.</p>	<p>Informal Ineffective Type1</p> <p>Modelled as surveyed. 1% AEP doesn't reach the wall.</p>	
<p>137 30SALW00057- 30SALW00051D</p> <p>Locally may have defence function but not reached at 1% level.</p>	<p>Informal Ineffective Type 3</p> <p>Modelled as surveyed.</p>	
<p>140 30CAST00160- 30CAST00161E</p> <p>More of a retaining wall and does not provide defence function.</p>	<p>Informal Ineffective Type1</p> <p>Modelled as surveyed.</p>	

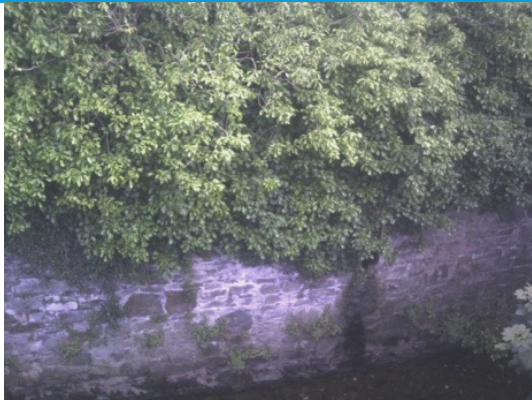

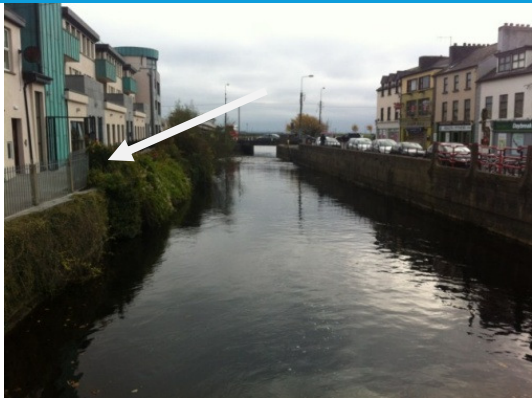
Description and Location	Modelling Method	Photograph
<p>141 30CAST00160- 30CAST00161E</p> <p>More of a retaining wall and does not provide defence function.</p>	<p>Informal Ineffective Type1</p> <p>Modelled as surveyed.</p>	
<p>142 30SALW00096E- 30SALW00090D</p> <p>Locally may have flood defence function but bypassed from US and DS.</p>	<p>Informal Ineffective Type1</p> <p>Modelled as surveyed.</p>	
<p>143 30SALW00092- 30SALW00083D</p> <p>Locally may have flood defence function but bypassed from US.</p>	<p>Informal Ineffective Type1</p> <p>Modelled as surveyed.</p>	


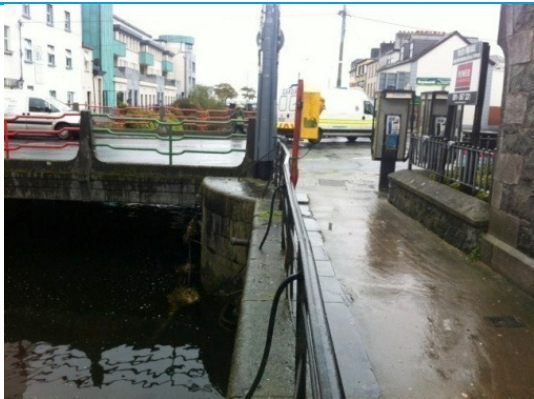
Description and Location	Modelling Method	Photograph
144 30SALW00068- 30SALW00058D Locally may have flood defence function but bypassed from US.	Informal Ineffective Type1 Modelled as surveyed.	
145 30SALR00053- 30SALR00044 Locally may have flood defence function but has gaps in it.	Informal Ineffective Type1 Modelled as surveyed.	
146 30SALR00015- 30SALR00008D Locally may have flood defence function but has gaps in it.	Informal Ineffective Type1 Modelled as surveyed.	
147 30SALR00007E- 30SALR00000 Building wall with ground level entrances.	Informal Ineffective Type2 Bank modelled at building entrance level.	

Description and Location	Modelling Method	Photograph
<p>148 30EGLI00025E- 30EGLI000018</p> <p>Very low wall with railing above.</p>	<p>Informal Ineffective Type1</p> <p>Bank crest modelled.</p>	
<p>149 30EGLI00052- 30EGLI00009</p> <p>Locally may have flood defence function but has gaps in it.</p>	<p>Informal Ineffective Type1</p> <p>Modelled as surveyed.</p>	
<p>150 30EGLI00079- 30EGLI00071D</p> <p>Locally may have flood defence function but has gaps in it.</p>	<p>Informal Ineffective Type1</p> <p>Modelled bank as surveyed. 1% AEP not expected to reach wall.</p>	




Description and Location	Modelling Method	Photograph
<p>151 30EGLI00055- 30EGLI00054D</p> <p>Locally may have flood defence function but has gaps in it.</p>	<p>Informal Ineffective Type1</p>	
<p>152 30EGLI000101- 30EGLI00098</p> <p>Locally may have flood defence function but easily bypassed.</p>	<p>Informal Ineffective Type1</p> <p>Modelled bank as surveyed</p>	
<p>153 30NUNS00017</p> <p>Building wall bypassed from US.</p>	<p>Informal Ineffective Type2</p> <p>Modelled at building entrance level</p>	

Description and Location	Modelling Method	Photograph
154 30NUNS00012E- 30NUNS00000 Walls at this location in state of disrepair	Informal Ineffective Type2 Removed from model	
155 30NUNS00012E- 30NUNS00000 On left bank of watercourse, walls are in disrepair. Photographs are poor.	Informal Ineffective Type2	
156 30GMRA00043- 30GMRA00027 Wall on left bank	Informal Ineffective Type1 Modelled as surveyed	

Description and Location	Modelling Method	Photograph
157 30FRIA00021- 30FRIA00004 Wall on left forming bank.	Informal Ineffective Type1 Modelled as surveyed	
158 30SALW00101- 30SALW00099D Locally may have flood defence but bypassed from US.	Informal Ineffective Type1 Modelled as surveyed.	
159 30EGLI00025E- 30EGLI00018 Building wall with multiple ground level entrances.	Informal Ineffective Type2 Modelled to entrance level.	

Description and Location	Modelling Method	Photograph
<p>160 30EGLI00031- 30EGLI00026D</p> <p>Left bank building wall with multiple ground level entrances.</p>	<p>Informal Ineffective Type2</p> <p>Modelled to entrance level.</p>	
<p>161 30EGLI00031- 30EGLI00026D</p> <p>Right bank building wall with multiple ground level entrances.</p>	<p>Informal Ineffective Type2</p> <p>Modelled to entrance level.</p>	

Description and Location	Modelling Method	Photograph
<p>162 30GMRA00024D- 30GMRA00015</p> <p>Building wall with multiple ground level entrances.</p>	<p>Informal Ineffective Type2</p> <p>Modelled to entrance level.</p>	
<p>163 30GMRA00005- 30GMRA00000</p> <p>Wall forming bank around structure.</p>	<p>Informal Ineffective Type1</p> <p>Modelled as surveyed.</p>	

Description and Location	Modelling Method	Photograph
<p>164 30NUNS00014</p> <p>Building wall with multiple ground level entrances.</p>	<p>Informal Ineffective Type2</p> <p>Modelled to entrance level.</p>	
<p>165 30SMRN00014E- 30SMRN00009</p> <p>Substantial wall.</p>	<p>Informal Ineffective Type1</p> <p>Modelled as surveyed.</p>	
<p>166 30SMRN00009</p> <p>Building side to high level.</p>	<p>Informal Ineffective Type1</p> <p>Modelled as surveyed.</p>	

3.7 Floodplain

A 2D cell size of 8m in the rural part of the domain and 4m in the urban area has been selected to give a balance between model run times and the detail of flow routes within the 2D floodplain. Initially the model run time was approximately 24 hours for a complete 4m cell domain cell size. However, splitting the model domain to include a 8m cell size in the rural parts upstream of the Salmon Barrage and review of the hydrograph allowed a 4m grid to be retained in the city and run times to be reduced to 14 hours (for the 1% AEP event). These adjustments allow the model to be run with the most acceptable balance between detail (flow paths) and run time.

4 Fluvial model calibration and sensibility checking

4.1 Calibration versus sensibility checking

Where a recording flow gauge is located in or near the site and this data is accompanied by historical data from a flood event (such as flood extents, or spot levels), then it is possible to undertake calibration of the model. This process would involve running the records flows through the model and changing model parameters, such as Manning's 'n', to match the flood extents or levels that were observed. Ideally, a second event would then be run through the model and used to validate the outputs. While it is possible to simulate flows recorded at a gauge in the model, without any record of the impact of the event the model cannot be calibrated and the checking process is limited to a confirmation that predicted extents match expectations based on topography and local knowledge. If there is no gauge data available but there are historical records of flooding then the predicted extent from an appropriate design event with a similar exceedence probability to the historical flood event can be used as a sensibility check of the predicted flooding frequency.

In Galway, event based calibration is very difficult to achieve given the lack of a consistent flow record on the Corrib, and limited fluvial flood history (Section 2). It has therefore been necessary to build confidence in several stages. Firstly, it was important to establish starting water levels in the mill streams, canals and other watercourses through the system. The second check is on the behaviour at the Salmon Weir and finally a calibration for the November 2009 event has been attempted, but given the lack of reliable flow data this is fairly uncertain.

4.2 Baseline sensibility checking

Given the complexity of the flow network and linkages the first check is on the baseline conditions at the start of the model run. If the model were not set up correctly these could be very different from those expected. The starting conditions in the model have been compared to the surveyed water levels at points on the key watercourses. Although surveyed water levels is not a definitive level and can vary significantly it does at least give us an indication of a realistic baseline. The larger variations in Table 4-1 occur in the vicinity of the Salmon Weir Barrage where the sluice operations can result greater fluctuations in water levels. Further downstream though where the Salmon Weir Barrage has a less immediate impact, the correlation between the initial stage in the model and the surveyed water level is less than 250mm. This is deemed to be satisfactory in determining the model is starting at closely the appropriate level.

Table 4-1 shows the initial conditions at various sections throughout the model.

Table 4-1: Initial conditions

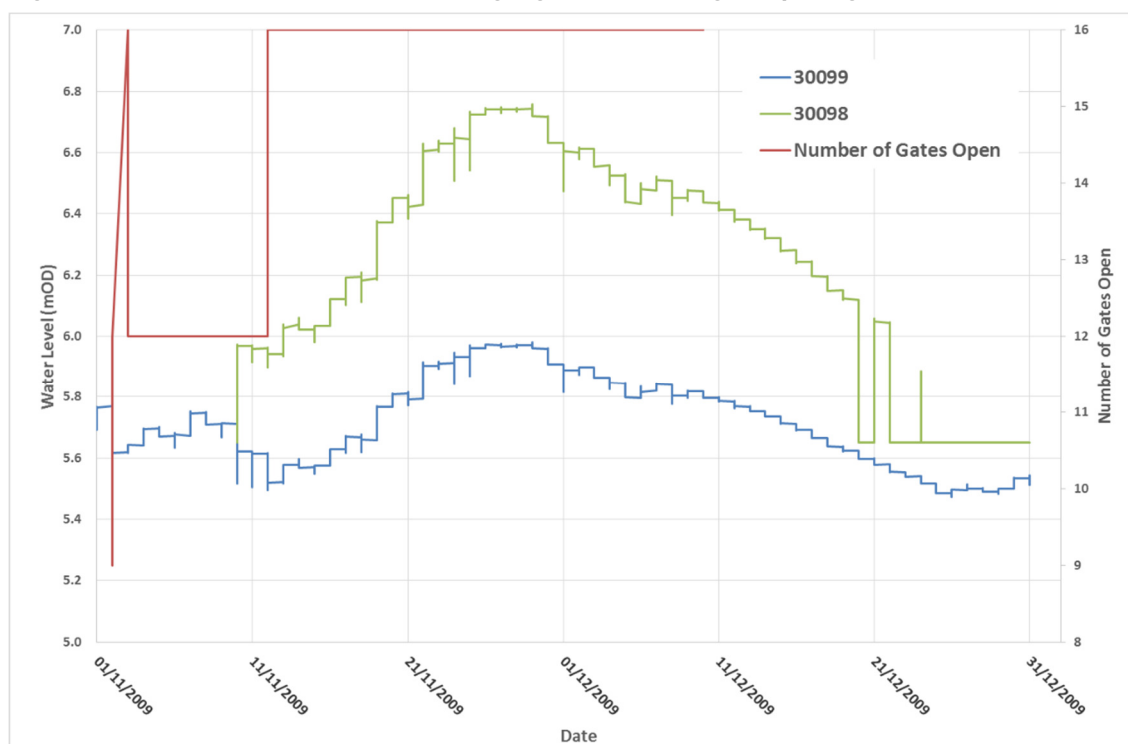
Cross section label	Initial stage m(OD)	Surveyed water level
30CORR00426	6.11	5.86
30EGLI00135	5.80	4.65
30NUNS00052	5.79	5.57
30GMRA00048	5.78	5.78
30GMRA00001A	4.00	3.78
30DOMI00009D	2.40	2.73
30CAST00001	5.91	5.82
30CAST00398	1.99	1.44
30SALR00051	5.80	5.63
30SALR00031	4.95	4.94
30FRIA00034	4.97	4.84
30MACT00012B	5.44	5.49
30SMRN00015	2.20	2.57
30VARA00103B	4.02	3.67

4.3 Gauge calibration

Calibration of the River Corrib hydraulic model has been completed using the Dangan, Barrage and Wolfe Tone Bridge gauges. Flows for the gauge at 30061 Wolfe Tone have been estimated from rating curve. Based on the data available calibration runs have been completed for the 2009 event.

The data suggests that the Salmon Weir does not control peak water levels upstream as far as Dangan. For example in November 2009 the peak level at Dangan was 6.77mOD, in the south end of Lough Corrib at Angliham was 7.15mOD but at the Salmon Weir only 6.00mOD. A plot of the gauges, see Figure 4-1, through the 2009 event shows that the levels at 30099 and 30098 deviate as the levels increase upstream. Therefore it is clear from the data alone that the Salmon Weir has little impact on flooding further upstream in the Corrib system. The Salmon Weir opening during the event will contribute to the level remaining relatively stable at that location and the river channel itself will be the main control on levels further upstream towards Dangan and up to Lough Corrib. The stated design water levels for Lough Corrib of 5.83mOD to 6.44mOD are generally maintained at the Salmon Weir but that is not translated upstream to the lough and in large events there can be over a metre difference in level between the barrage and the lough.

Figure 4-1: October-31 December 2009 (a) gauge data and (b) gate opening



4.4 November 2009 calibration event

To calibrate the model to this data, flows from the gauge have been applied at the upstream limit of the model and the stage compared at gauge locations.

Figure 4-2, Figure 4-3 and Figure 4-4 detail the calibration of the November 2009 event at the gauges. The recorded flows at 30061 Wolfe Tone Bridge were input at the upper limit of the model. The estimated flows at the Wolfe Tone Bridge gauge are reported to be unreliable due to the tidal influence and the gauge being moved in 2004. However, other than extracting flows from the model, a better option of estimating flow is not apparent. A moving average of 20 was used to smooth the peaks and scatter of the original hydrograph and better represent the changing flow in the River Corrib. The sluice gates are all open for the calibration event; as shown in Figure 4-1, all 16 gates were open during the peak of the event.

The stage at the gauge locations was calibrated by adjusting the co-efficient on the salmon weir sluice gates. The resulting stage correlated quite well considering the poor nature of the input flows. The gauge at 30099 Dangan, Figure 4-2, is the plot of the Salmon Weir barrage, the data is well within the 0.2m vertical accuracy required for HPW models. The calibrated model has been used for the design runs.

The resulting flood extent for the 2009 event shows no flooding in the urbanised centre and there is no record on hand of flooding actually occurring.

Although this event calibration is fairly unreliable it does give some confidence in the model and along with the other parts of the calibration shows the model appears reasonable.

Figure 4-2: November-December 2009 calibration plot at the 30098 gauge Dangan

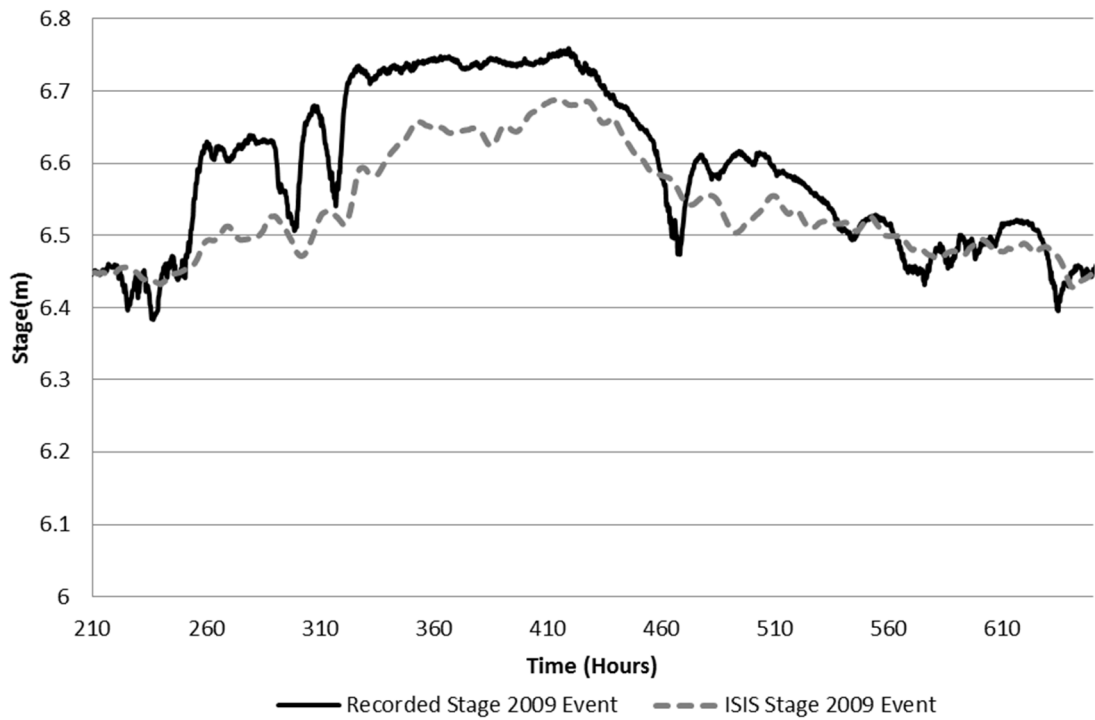


Figure 4-3: November-December 2009 calibration plot at the 30098 Salmon Weir Barrage

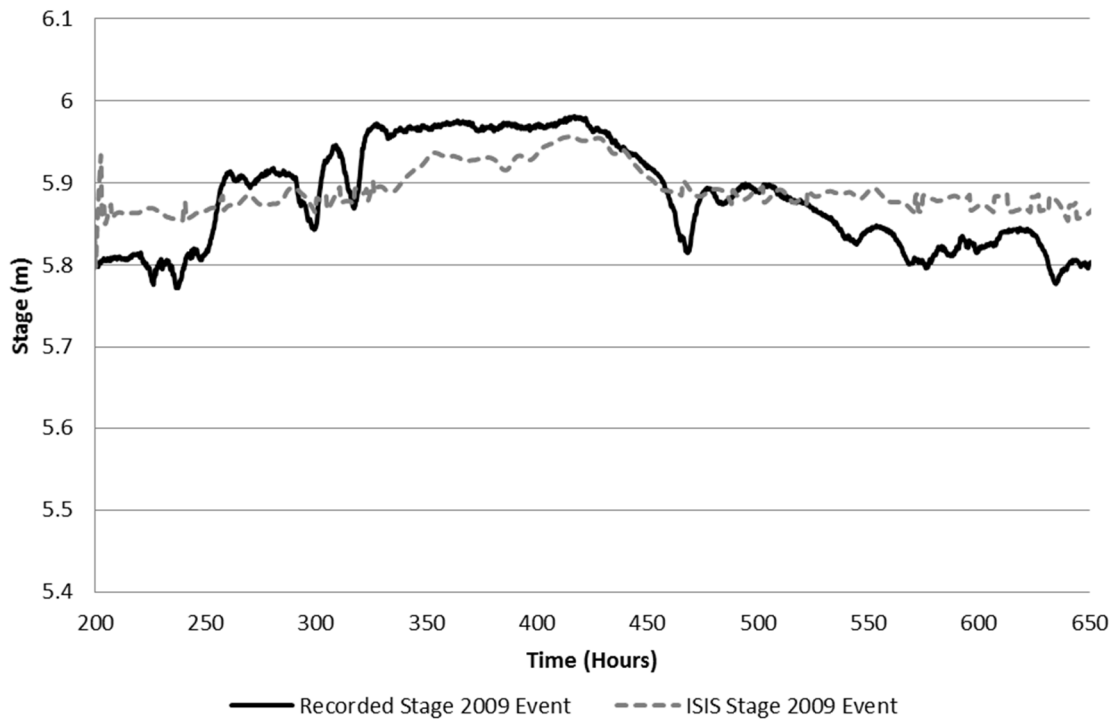
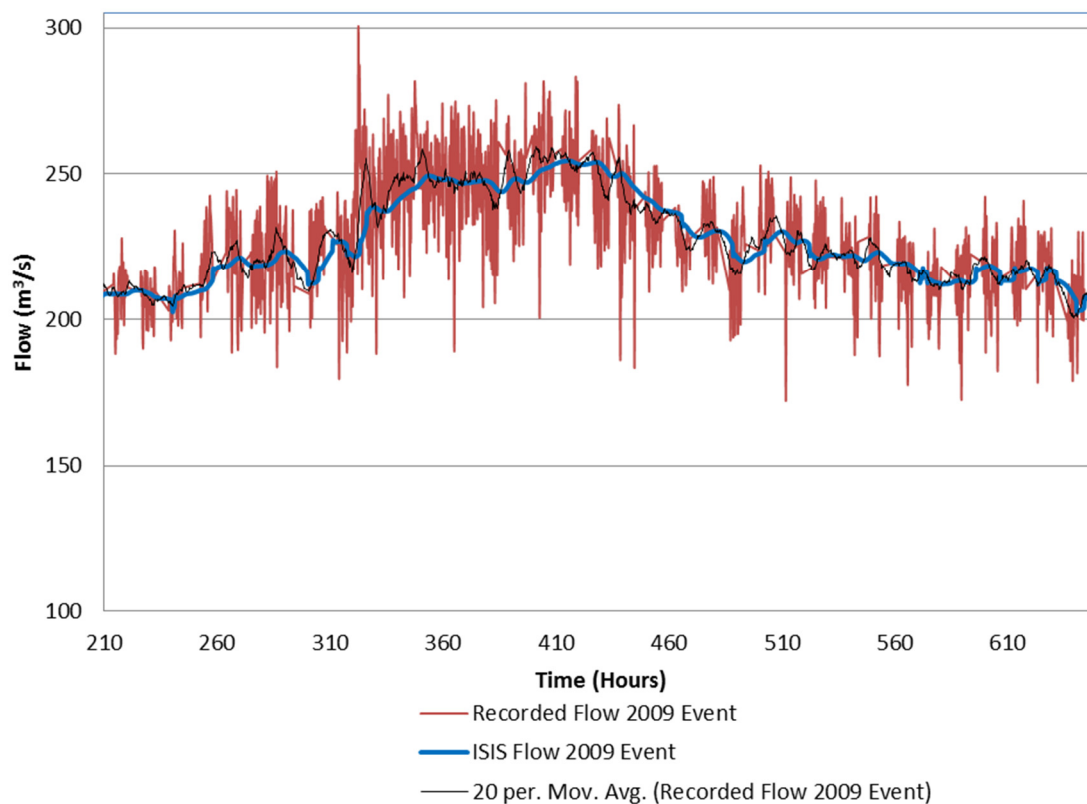


Figure 4-4: November-December 2009 calibration plot at the 30061 Wolfe Tone gauge



4.5 Stakeholder Engagement

Throughout this process OPW regional engineers and local authority engineers have been consulted in the form of steering group, progress group and engineer meetings and their input has feed into the flood maps.

Public Consultation Day (PCD) - 5th of November 2014

On November 5th 2014 a public consultation was held at the Radisson Blu Hotel in Galway to present the flood maps for the town and solicit comments and feedback.

This PCD was attended by 47 people. At the PCD attendees were invited to leave feedback, in the form of a questionnaire. The questionnaire sought feedback on resident's knowledge of flooding in the town including the locations of flooding and the frequency of flooding.

Table 4-2 outlines the feedback received at the day relevant to the study and a note regarding how this information has been accommodated by the study. In general, there was good agreement between observations from the public and the flood maps.

Table 4-2: PCD Feedback

Comments Received	Study Response
Flooding occurs on laneway in Salthill.	A review of the flood maps shows that flooding to laneway in Salthill is shown in both the tidal and wave overtopping flood risk extents. This report validates the modelled extents.
There is flooding behind properties on Lenaboy Road in Salthill.	This report is related to pluvial flooding. Gullies cannot carry the water away. The CFRAM has not considered flood risk from pluvial sources and as such this report cannot be used to validate the model extents. This report has been passed on to Galway City Council to take forward.
The Mutton Island causeway is thought to be exacerbating tidal flood risk by deflecting waves.	Tidal flood risk has been assessed at the shoreline only as part of the CFRAM study and as such a detailed analysis of the impact of the causeway cannot be completed.
Lough Corrib lake levels are excessively low and silting on the main channel is occurring.	This report cannot be used to validate the modelled flood extents. The impacts of the siltation are relevant to the next stages of the study and will be considered as part of any options development work.

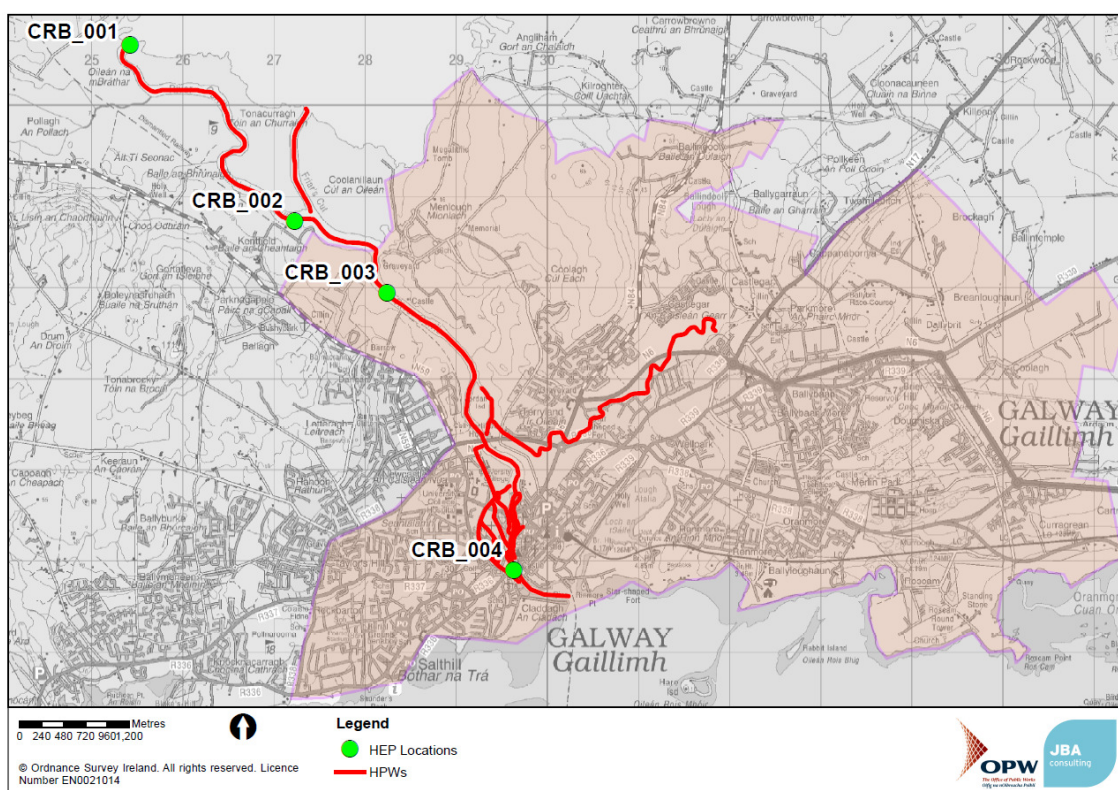
5 Application of hydrology

5.1 Hydrological estimation points

Design flows have been developed at series of Hydrological Estimation Points (HEPs) throughout the catchment. Full details of the development of these flows are provided in the WCFRAM Hydrology Report for UoM 30.

The locations and names of all the HEPs within the Galway City AFA are presented in Figure 5-1 and are shown on the cross section maps in Volume 3 of the Hydraulics Report.

Figure 5-1: Galway City AFA HEP locations



The design peak flows have been estimated using the Flood Studies Update (FSU) method as described in research reports produced from FSU work packages 2.2 and 2.3. There is a spatial inconsistency between CRB_002 and CRB_003 (i.e. flows decrease instead of increase) which is explained as a physical cause where floodwaters spread into the floodplain or loughs, primarily as a result of turloughs on the left bank of the River Corrib between these HEPs.

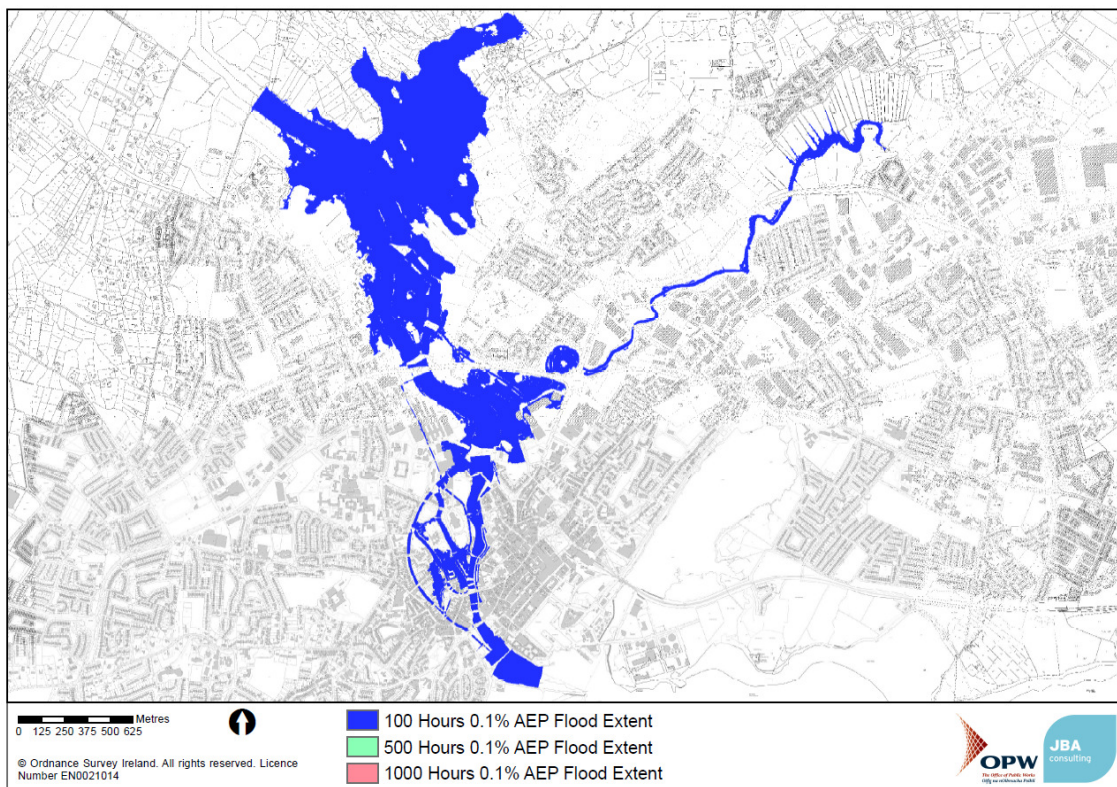
5.2 Application of design flow estimates

5.2.1 Hydrograph shapes

Inflow hydrograph shapes for each watercourse have been developed from the Flood Studies Report (FSR) rainfall runoff method. Inflows are located at the upstream limit of each watercourse.

A consistent design storm duration has been applied across the inflow boundary and a critical storm duration of 131 hours has been applied. Since the critical storm was 2000 hours and severely lengthened the model run time, a test was carried out to find out how using a shorter storm duration would affect the flood extent. Figure 5-2 shows the 0.1% event flood extents for the 100, 500 and 1000 hour hydrograph with no downstream boundary. After inspection of the results, it was shown that the peak flow was the critical factor in determining flood extent and was not influenced by the critical storm duration length.

Figure 5-2: Hydrograph storm duration sensitivity result



5.2.2 Scaling to hydrological estimation points

A summary of the model inflows and application of the design hydrology through these is provided in Table 5-2.

5.3 Downstream boundaries

5.3.1 Tidal boundary

The downstream boundary of the main hydraulic model is tidal. Extreme sea levels have been developed as part of the Irish Coastal Protection Study Strategy (ICPSS) at a series of points around the WCFRAM coastline. Figure 5-3 details the location of the nearest ICPSS point to the downstream boundary of the hydraulic model.

Calculated levels from the ICPSS point are assumed to be appropriate at the downstream boundary of the model as the point is located 0.8km offshore, directly opposite the Corrib and is unlikely to be significantly impacted by bathymetry.

The tidal boundary has been developed from the Highest Astronomical Tide (HAT) series and typical surge profile; full details are provided in the WCFRAM Hydrology Report for UoM 30.

Figure 5-3 details the extreme sea levels at the W39 ICPSS calculation point for a range of return periods. A 50% AEP downstream tidal boundary was used with the fluvial events to conservatively assess the risk associated. Table 5-1 shows the ICPSS extreme sea levels for the give AEP events.

Figure 5-3: ICPSS extreme sea level calculation points

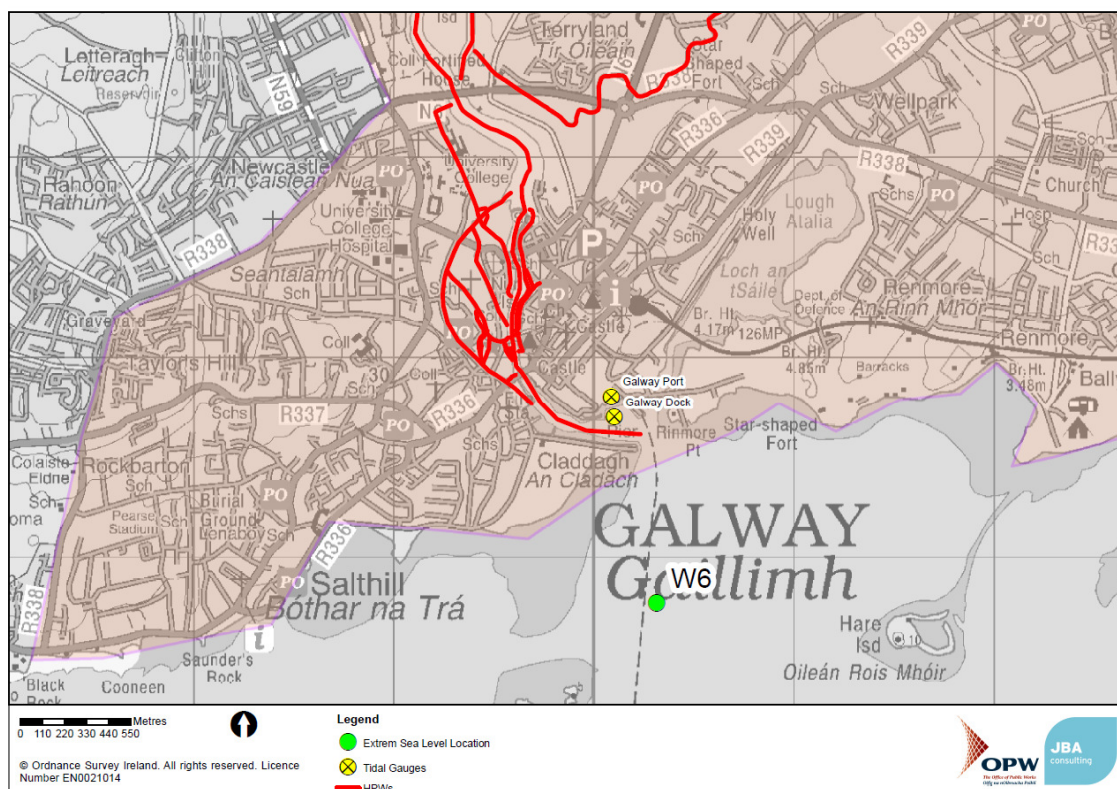


Table 5-1: ICPSS extreme sea level estimates

ICPSS Label	Predicted Extreme Sea Levels (mOD)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
W6	3.055	3.208	3.317	3.424	3.564	3.669	3.774	4.018

5.3.2 Groundwater boundary

The downstream boundary at Castlegar is unusual in that it flows to a sinkhole that drains into the karst limestone bedrock. No specific analysis of the capacity or operation of the sinkhole was carried out as this is outside the scope of the CFRAM study. Instead, various downstream boundaries were tested until the model resulted in a similar water profile as was recorded in the survey. This will inevitably change with variations in groundwater conditions, but is also beyond the scope of the CFRAM to investigate. The results assume the ground conditions do not change for the duration of the design event. Given the scope of CFRAM, data availability and level of flood risk arising from the Castlegar, this approach is considered acceptable.

Figure 5-4: Castlegar Sinkhole

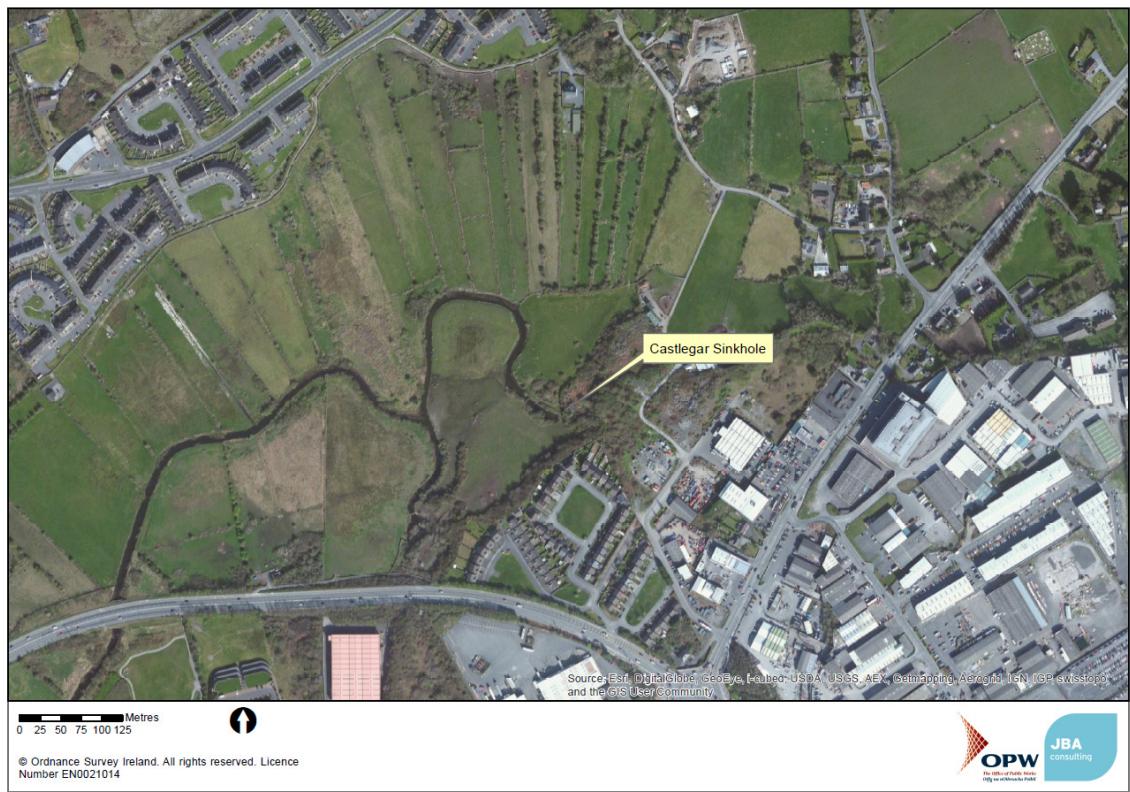


Table 5-2: Summary of hydraulic model design inflows

HEP reference	Cross section	Peak Flow Estimates (m³/s)					Flow in Model (m³/s)					Comments (note: where blank, no changes have been made)
		50% AEP	20% AEP	10% AEP	1% AEP	0.1% AEP	50% AEP	20% AEP	10% AEP	1% AEP	0.1% AEP	
CRB_003	30CORR00449	246.9	295.5	327.3	438.9	654.8	240.5	279.1	306.1	404.2	615.9	Upper modelled extent of River Corrib at Dangan gauge
CRB_004	30CORR00070	237.2	283.9	314.5	421.8	629.4	249.3	292.3	313.0	412.5	566.2	Downstream extent of model where River Corrib flows into Galway bay

At most of the HEPs, the flow estimation is not equating to the flow that is observed in the model. There is some discrepancy in the 0.1% AEP event where the CRB_004 does not match the peak flow estimate. This is because the flow in this event overtops the dyke road further upstream and a significant amount of volume is attenuated here.

6 Fluvial model results

6.1 Fluvial model runs

The model has been run for the following fluvial events: 50%, 10%, 5%, 2%, 1%, 0.5% and 0.1% AEP design events, all with the 2 year tidal boundary at the downstream end.

In addition, the potential impact of climate change has been investigated for the 10%, 1% and 0.1% AEP design events for both the medium range and high end future scenarios. Further details of the allowances within the calculations are included in the Hydrology Report, but the future scenarios include for the impacts of urbanisation and climate change. Resulting peak flows are shown in Table 6-1 and Table 6-2.

Table 6-1: Peak flows for the Mid-Range Future Scenario

HEP reference	Predicted Peak Flows for the MRFS (m ³ /s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
CRB_003	291.38	348.72	386.30	423.87	475.90	517.99	578.40	771.99
CRB_004	295.18	353.26	391.34	429.40	482.11	524.75	585.99	782.32

Table 6-2: Peak flows for the High-End Future Scenario

HEP reference	Predicted Peak Flows for the HEFS (m ³ /s)		
	10% AEP	1% AEP	0.1% AEP
CRB_003	418.74	561.48	836.81
CRB_004	424.36	569.02	848.33

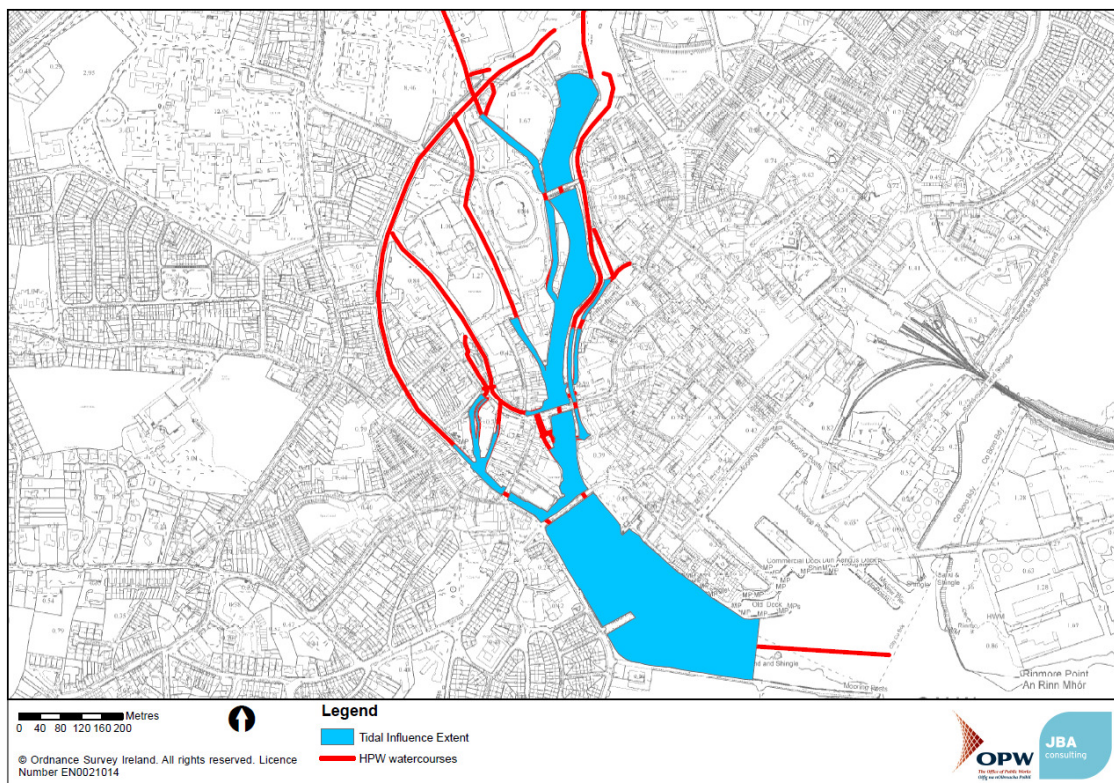
6.2 Flood risk mapping

Flood risk extents for the present day and MRFS 10%, 1% and 0.1% AEP design events along with long section profiles for present day 10%, 1% and 0.1% AEP design events are presented in Volume 3 of the UoM 30 and 31 Hydraulic Modelling Report.

6.3 Key flood risk mechanisms

Further to the information presented in the flood risk maps, a brief description of the key flood risk sites and flooding mechanisms is provided below. In each case, a flood extent map has been included. For ease of viewing these maps only show the 10%, 1% and 0.1% AEP flood events with a 50% AEP tidal event, although the full suite of models have been run. The downstream tidal boundary has a significant influence on a number of watercourses; the tidally influenced watercourse extent is shown in Figure 6-1. The floodwaters from the tidal element are prevented from translating upstream by numerous weirs and sluices in Galway City.

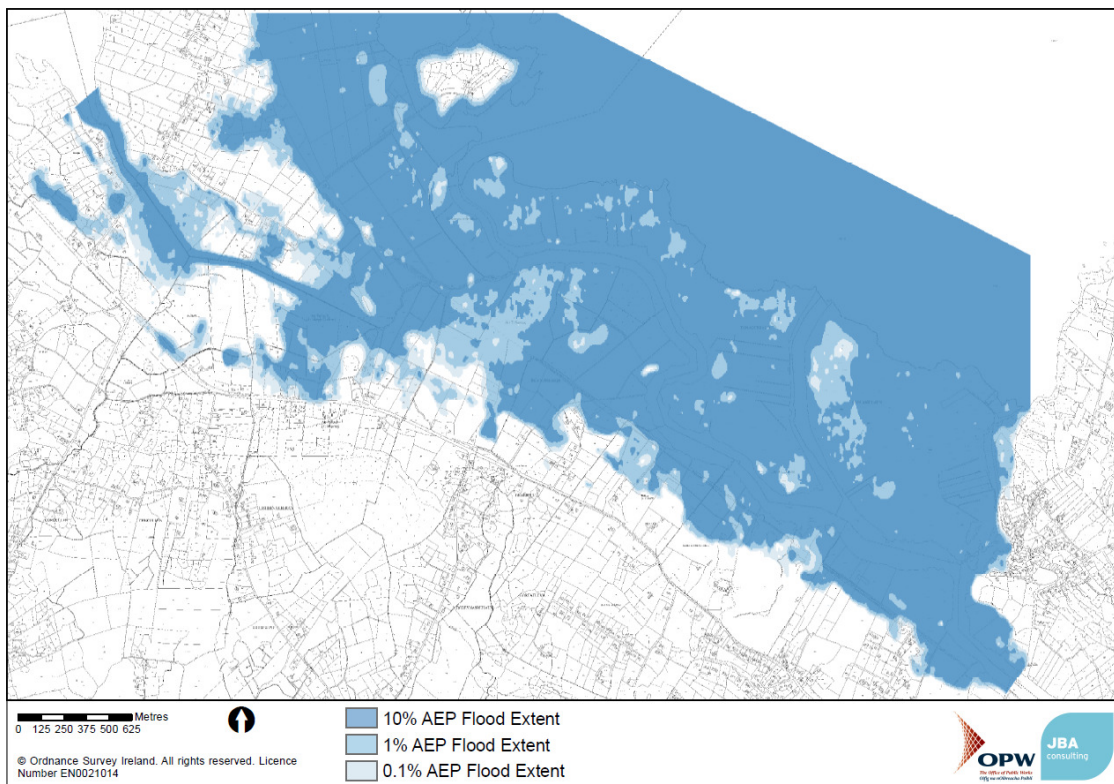
Figure 6-1: Tidal influence extent



6.3.1 Flooding of Upper Corrib MPW

The flood extents arising from the MPW model on the Upper Corrib show much inundation in the 10% AEP event but this is mainly encroachment onto marsh bog land. There are no properties affected.

Figure 6-2: Corrib MPW flooding

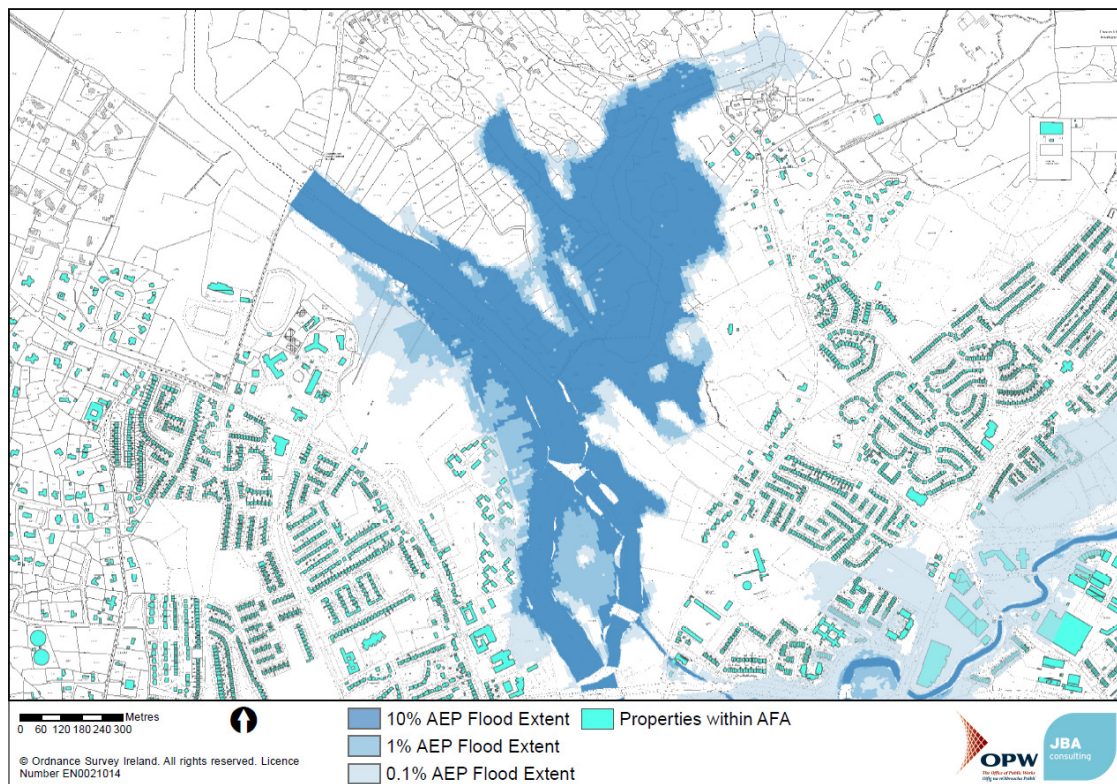


6.3.2 Flooding of Upper Corrib HPW

The Upper Corrib is known to flood frequently into the marshy floodplains on both banks of the river. Figure 6-3 shows an overview of the flood extent. Floodwaters enter the turloughs on the left bank, increasing the lake area and causing back watering to various streams that provide drainage to the area.

There are no properties at risk in this area as this land appears to have been liable to flooding in the past and development in this area has been avoided. This is indicated on the OSi historic 25" maps circa 1897-1913.

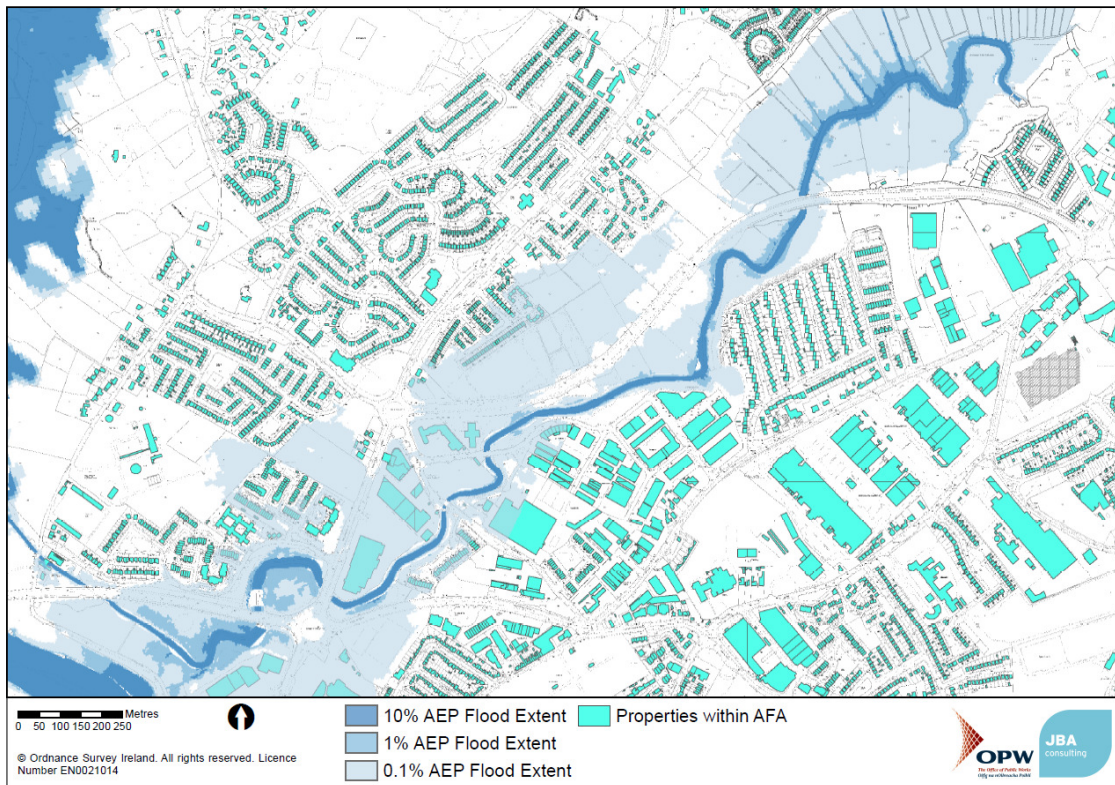
Figure 6-3: Overview of flood extent in the upper Corrib HPW



6.3.3 Flooding at Castlegar

The flooding on Castlegar is controlled by the amount of floodwater that can be conveyed through the sinkhole at the downstream and the inlet from the waterworks structure, both of which are uncertain. The 1% AEP extent shows the Dyke road embankment overtopped and allowing flow into the Castlegar area. This contributes mostly to the flooding in Castlegar. The backing up of drains at the downstream is evident. No properties are affected in this area. Figure 6-4 shows an overview of the flood extent.

Figure 6-4: Overview of Castlegar flood extent

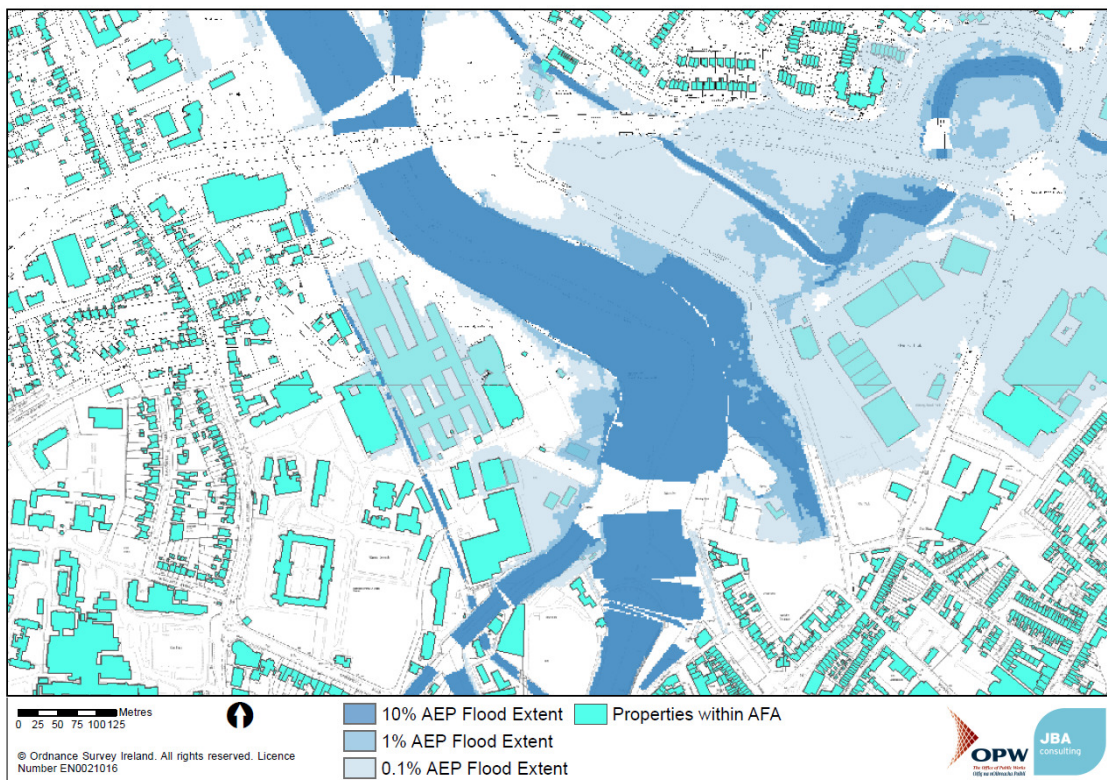


6.3.4 Flooding of Distillery River

The Distillery River is a complex area of the Galway City AFA. The controlling structure of the watercourse is a siphon under the Eglinton (EGLI) canal in the middle of the watercourse. Floodwaters from the Eglinton canal can spill over its banks adding to floodwater in the Distillery (SALW) River. No flooding occurs in the 10% AEP or 1% AEP event, however the 0.1% shows properties affected. The properties affected are mainly belonging to NUI Galway. There have been improvements to this channel since the CFRAM topographic survey was collected following recommendations in a report titled, NUI Galway Campus Flood Prevention⁷, the impact of which will be investigated in the next stages of the CFRAM.

⁷ NUI Galway Campus Flood Prevention, University Road Galway

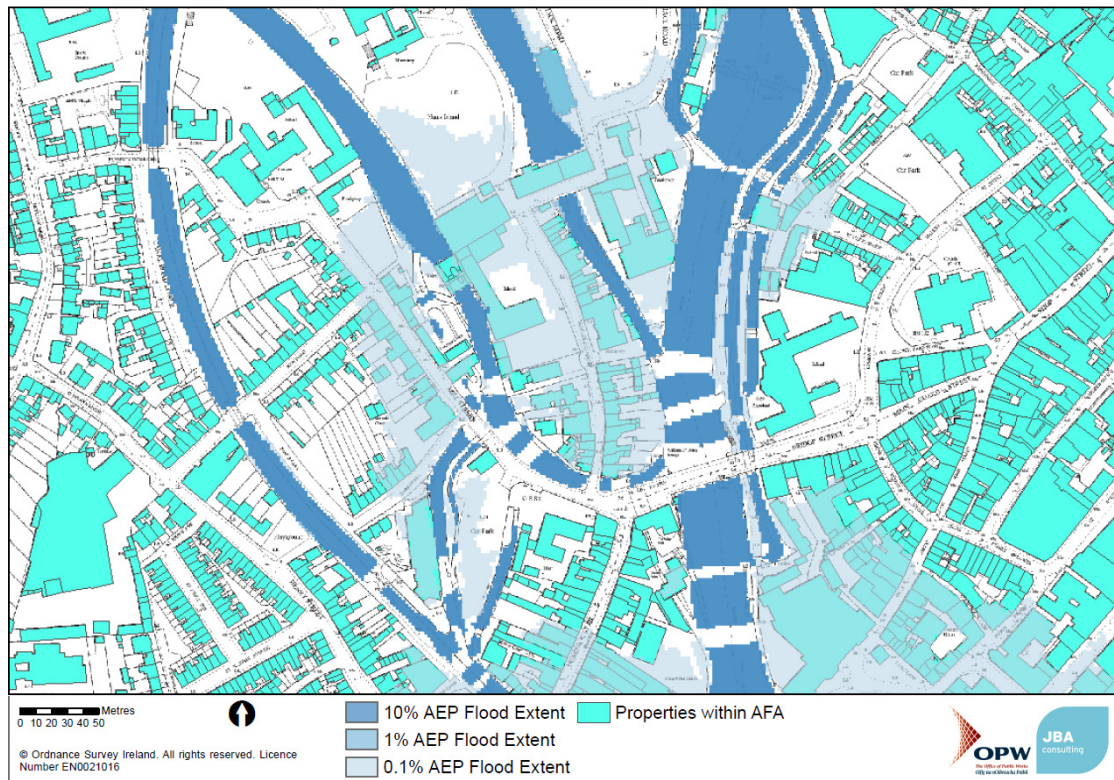
Figure 6-5: Overview of Distillery River flood extent



6.3.5 Flooding of right bank canal system

The right bank canal system represents the canals whose flood waters are fed by the branch upstream of the Salmon Weir barrage. The Eglinton (EGLI) canal feeds a number of old mill races through the heavily urbanised area. Flooding occurs in the 0.1% AEP event, along with right bank flooding from the Madeira Court (MACT) watercourse due to the culverts described in Table 3-1 surcharging.

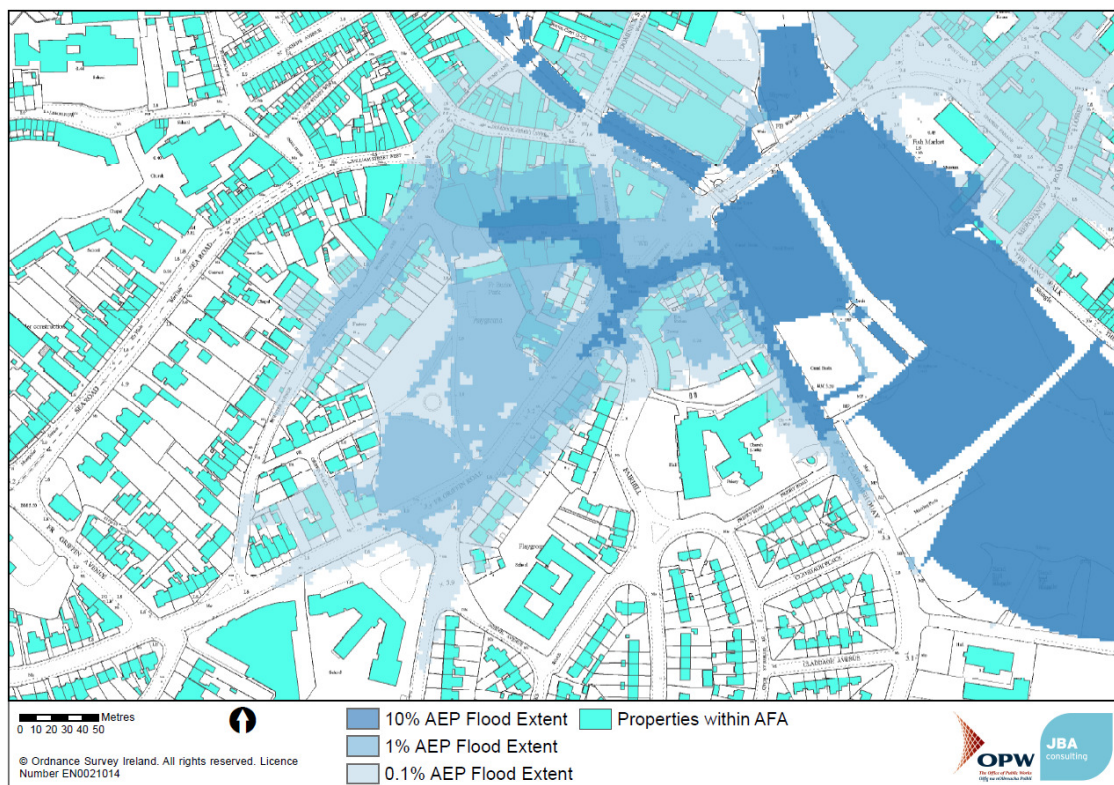
Figure 6-6: Overview of right bank canal flood extent



6.3.6 Flooding of downstream at Wolfe Tone Bridge

Flooding is evident in this area in the 1% and 0.1% AEP fluvial events that are run concurrently with a 50% AEP tidal events. Figure 6-7 highlights the flood extent at Wolfe Tone Bridge. In the 1% event the low lying area near the Claddagh basin floods from the downstream of the Eglinton (EGLI) canal and the basin itself overflowing. The area is greatly influenced by the tidal boundary and the fluvial event alone would not be expected to be sufficient to flood this area. The 0.1% event flooding shows further exacerbation on the right bank around Wolfe Tone Bridge. The area is a known area of flood risk from high tides. Refer to section 10.2.3 for more discussion on flooding downstream of Wolfe Tone bridge as the areas flood risk is tidally dominated.

Figure 6-7: Overview of area at Wolfe Tone Bridge



7 Fluvial sensitivity testing

7.1 Screening of fluvial sensitivity tests

The suite of potential sensitivity tests is detailed in Volume 1a: Hydraulic Modelling Method Statement. The application of the sensitivity tests has been an iterative process which allowed certain criteria to be screened out. Table 7-1 summarises the full suite of potential sensitivity tests, and highlights those which are not applicable, and those which have been screened out. Further details of these criteria are provided in the following sections.

The results of testing those criteria which are relevant to Galway City fluvial model are detailed in Section 7.2.

Table 7-1: Sensitivity test summary

Sensitivity test	Relevance to Galway City
Peak flow	Tested
Flow volume	Tested
Critical storm duration	Screened out
Roughness	Tested
Building representation	Tested
Afflux / head loss at key structures	Tested
Water level boundaries and joint probability	Screened out
Timing of tributaries	Screened out
Timing of fluvial and tidal peaks	Screened out
Cell size	Tested

7.1.1 Peak flow

The flow sensitivity scoring mechanism is detailed in the Overarching Hydraulic Modelling Report. Table 6-1 details the flow sensitivity tests required as a result of these scores.

Table 7-2: Flow sensitivity scaling factors

Return period of event	Distillery River	River Corrib
10%	Use QMED uncertainty	Use QMED uncertainty
1%	Use QMED uncertainty then multiply flows by 1.3	Use QMED uncertainty then multiply flows by 1.2

7.1.2 Flow volume

A sensitivity to flow volume was carried out at the commencement of the modelling phase to reduce run times to a more practical level. Details of this sensitivity are in Section 5.2.1.

7.1.3 Critical storm duration

There are no significant tributaries on the River Corrib downstream of the Lough so no testing of critical storm durations combinations is required.

7.1.4 Roughness

The flood extents for the existing risk design events show flood risk to property in the 10% AEP and 1% AEP events, so testing the sensitivity of the model results to roughness will be worthwhile for both these events.

The specific maintenance regime undertaken by Galway City Council and the OPW is not known, but site inspection shows some parts of canal channels to be poorly maintained.

Table 7-3 summarises the current roughness values applied within the model over the various reaches and the increased values to be applied for the 10% AEP events and 1% AEP events.

Table 7-3: Sensitivity to roughness scenarios

Upstream and Downstream Cross Section	Roughness Values (Manning's 'n') and materials	
	Existing Risk	10% and 1% AEP roughness bound
30CORR00951-30CORR00442	Bed - 0.040 for mud material. Bank - 0.040 for grassy floodplains and 0.050 to account for trees.	Bed - 0.045 for mud material. Bank - 0.045 for grassy floodplains and 0.055 to account for trees.
30CORR00442-30CORR00158	Bed - 0.040 for stone and mud material. Bank - 0.045 for banks of rocks, reeds and weeds. 0.050 for the flood plain and the presence of occasional trees.	Bed - 0.045 for stone and mud material. Bank - 0.050 for banks of rocks, reeds and weeds. 0.055 for the flood plain and the presence of occasional trees.
30CORR00158-30CORR00000	Bed - 0.040 for stone and mud material as in previous reach. Bank - 0.025 for urbanised reach where banks comprise of wall banks.	Bed - 0.045 for stone and mud material as in previous reach. Bank - 0.030 for urbanised reach where banks comprise of wall banks.
30CAST00001-30CAST00001	Bed - 0.030 for mud material. Bank - 0.040 for grassy banks.	Bed - 0.033 for mud material. Bank - 0.045 for grassy banks.
30CAST00008O-30CAST00018B	Bed - 0.030 for mud material as in previous reach. Bank -0.025 stone walls represented entering and leaving waterworks building.	Bed - 0.033 for mud material as in previous reach. Bank -0.030 stone walls represented entering and leaving waterworks building.
30CAST00023-30CAST00398	Bed - 0.030 for bed material of mud and silt. Bank - 0.040 for grassy/reed banks.	Bed - 0.033 for bed material of mud and silt. Bank - 0.045 for grassy/reed banks
30CLOP00064 - 30CLOP00001	Bed - 0.035 for a stone mud material. Bank - 0.040 for a grassy/reed banks and floodplain.	Bed - 0.040 for a stone mud material. Bank - 0.045 for a grassy/reed banks and floodplain.
30EGLI00135 - 30EGLI00103D	Bed - 0.030 for silt material. Bank - 0.025 for urbanised reach with stone walls.	Bed - 0.033 for silt material. Bank - 0.030 for urbanised reach with stone walls.
30EGLI00103D - 30EGLI00000	Bed - 0.035 for silt stone material. Bank - 0.025 for walls as per previous reach.	Bed - 0.040 for silt stone material. Bank - 0.030 for walls as per previous reach.
30NUNS00052 - 30NUNS00000	Bed - 0.035 for stone mud material. Bank - 0.025 for stone walls and where local trees and shrubs exists 0.060 is used.	Bed - 0.040 for stone mud material. Bank - 0.030 for stone walls and where local trees and shrubs exists 0.060 is used.
30GMRA00043 - 30GMRA00000	Bed - 0.035 stone silt material Bank - 0.025 for stone walls and where bushed and shrubs are noted, 0.060 is used	Bed - 0.040 stone silt material Bank - 0.030 for stone walls and where bushed and shrubs are noted, 0.065 is used
30FRIA00034 - 30FRIA00000	Bed - 0.035 for stone silt and concrete material. Bank - 0.025 for stone walls throughout.	Bed - 0.040 for stone silt and concrete material. Bank - 0.030 for stone walls throughout.
30SALR00061-30SALR00000A	Bed - 0.035 for stone, silt and concrete material. Bank - 0.025 for stone walls throughout.	Bed - 0.040 for stone, silt and concrete material. Bank - 0.030 for stone walls throughout.
30SALW00111 - 30SALW00104I	Bed - 0.035 for stone and silt bed material. Bank - 0.040 for grassy banks.	Bed - 0.040 for stone and silt bed material. Bank - 0.045 for grassy banks
30SALW00103J-30SALW00022D	Bed - 0.035 for stone and silt bed material. Bank - 0.025 for mainly stone walls throughout.	Bed - 0.040 for stone and silt bed material. Bank - 0.030 for mainly stone walls throughout

Upstream and Downstream Cross Section	Roughness Values (Manning's 'n') and materials	
	Existing Risk	10% and 1% AEP roughness bound
30MACT00011-30MACT00001	Bed - 0.040 stone material. Bank - 0.060 for vegetated ivy banks and 0.025 where localised bare concrete walls are evident.	Bed - 0.045 stone material. Bank - 0.065 for vegetated ivy banks and 0.030 where localised bare concrete walls are evident.
30SMRN00015-30SMRN00002	Bed - 0.040 stone material. Bank - 0.060 for vegetated ivy banks and 0.025 where localised bare stone walls are evident.	Bed - 0.045 stone material. Bank - 0.065 for vegetated ivy banks and 0.030 where localised bare stone walls are evident
30VARA00006-30VARA00001	Bed - 0.040 stone material. Bank - 0.025 stone walls.	Bed - 0.045 stone material. Bank - 0.030 stone walls
30DOMI000010J-30DOMI00001	Bed - 0.040 stone material. Bank - 0.025 stone walls.	Bed - 0.045 stone material. Bank - 0.030 stone walls.

Roughness values in the floodplain have been increased to the upper bound of those values quoted in the Hydraulic Modelling methods report for the 10% and 1% AEP event.

7.1.5 Building representation

As the Galway City AFA is heavily urbanised it was worthwhile to investigate how the increase on the building elevation would affect the flood extent. The building representation in the 2D domain will be raised by 100mm and 200mm to examine if any development of previously unknown flow paths are significant.

7.1.6 Afflux at key structures

The roughness was tested at structures where the length exceeded 30m. They were four culverts on the Castlegar River tested, along with one culvert on the Friary River and one culvert on the Distillery River. The roughness of the culverts was increased to assess the sensitivity of the culverts. Any significant increase in water levels upstream was investigated to ensure proper representation of the culvert and also by examining the receptors upstream, critical culverts could be determined.

7.1.7 Water level boundary and joint probability

To determine the extent to which a joint fluvial-tidal design event will result in additional flood risk a combined flood event has been modelled. A conservative approach has been adopted at this stage and the 20% AEP fluvial event was combined with the 20% tidal event. This will be equivalent to an event in excess of the 1% AEP event but will highlight the sensitivity of the site to a combined event. The outputs are shown Figure 7-1, along with the 0.5% AEP flood extent derived from the coastal model (see Section 8 for more details of this model). The joint probability run shows a slightly larger extent for the combined event than arises from either the design fluvial or design tidal event, with a number of additional properties brought into the flood extent. This has been investigated further to determine the sensitivity of the model to tide levels specifically, rather than to a joint probability event

The design events described above use a 50% AEP tidal event in conjunction with the different fluvial AEP event. In the lower Corrib area, the tidal component will be large influence on the flood extent even though it is primarily considered a fluvial event. To test this, a 1% AEP fluvial event has also been run with a Mean High Water Spring (MHWS) tide which is lower than the 50% AEP tide. Figure 7-2 shows that using the MHWS tide removes most of the flooding in the lower Corrib in the 1% AEP fluvial event. Therefore, this area is largely influenced by the tidal element rather than the fluvial and is less sensitive to a joint probability event that it is to a larger tidal boundary.

Figure 7-1: Joint probability tests

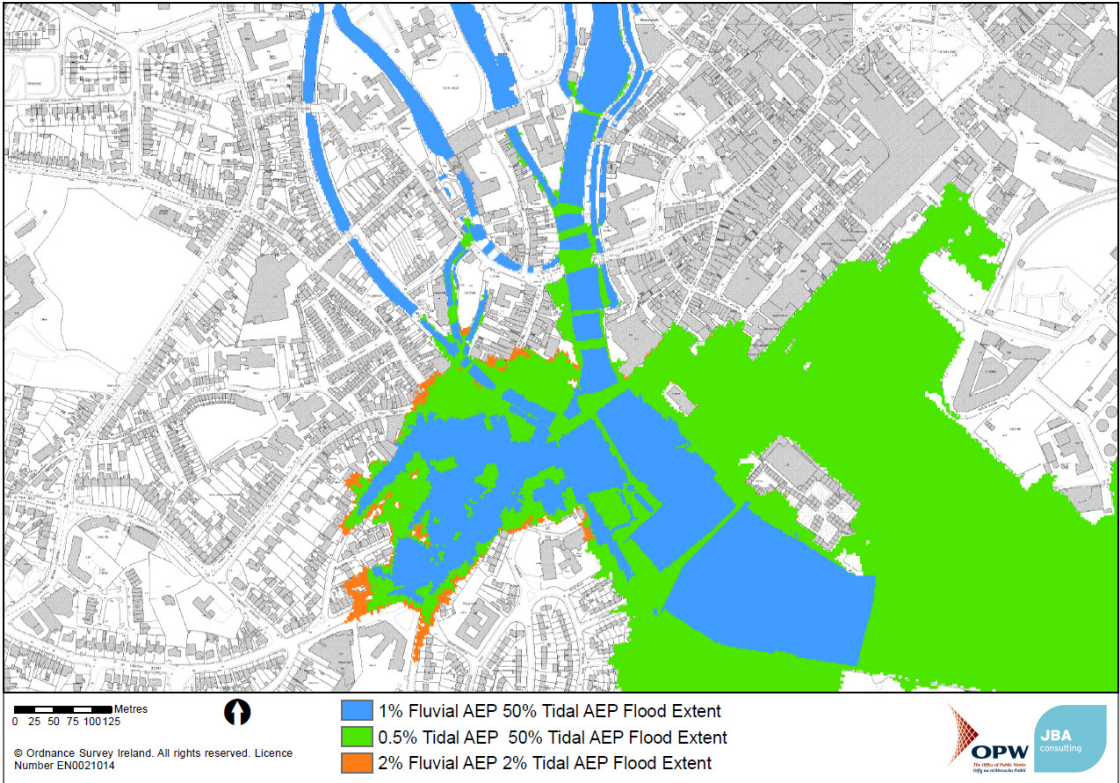
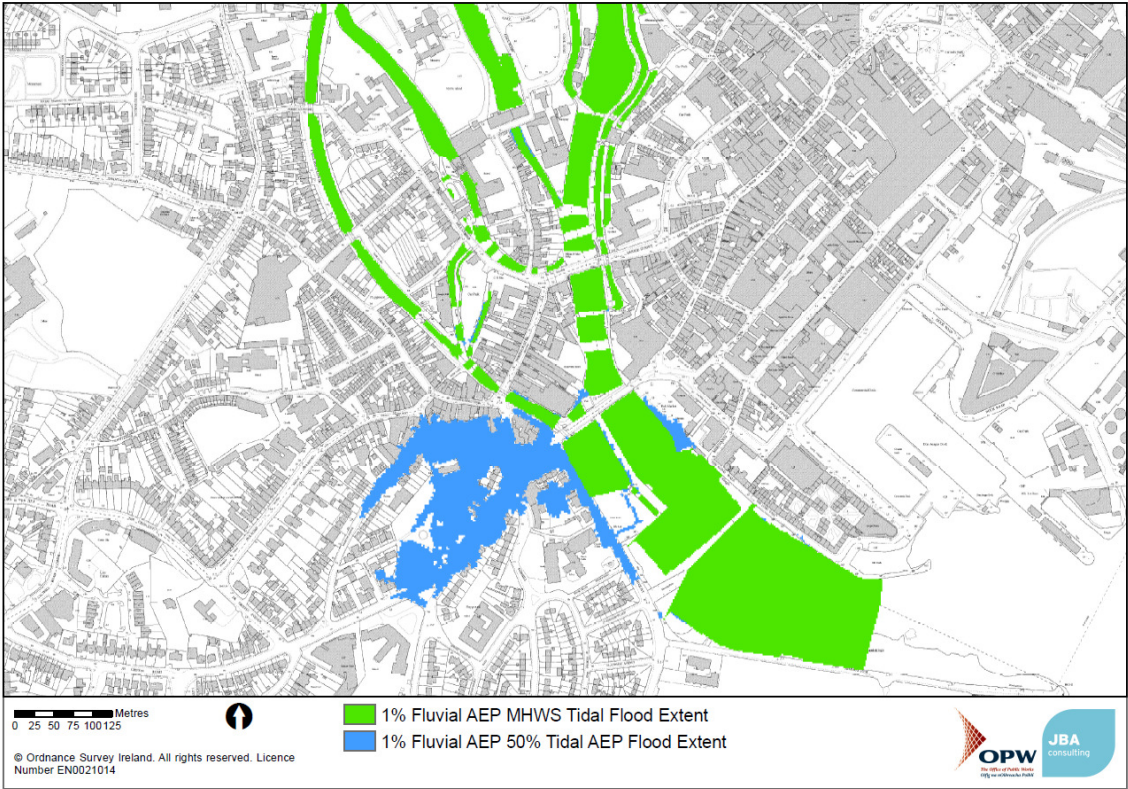


Figure 7-2: Downstream boundary test



7.1.8 Timing of tributaries

There is only one small tributary that outfalls to the River Corrib. This is the Distillery River that flows through the NUIG campus. The Distillery River hydrograph peak is assumed to peak along with River Corrib peak. This is accepted as a conservative approach and no other variations are tested the flood extent will not increase.

7.1.9 Timing of fluvial and tidal peaks

For the fluvial design model runs, the fluvial peak has been timed to coincide with the tidal peak, to give a conservative result. No further testing of timing is needed.

7.1.10 Cell size

The design run cell size is set at 8m rural/4m urban. This provides detail while keeping run times reasonably at circa 14 hours. The cell size was tested at 4m rural/2m urban to examine if any flow paths are been obscured by the 8m and 4m grids.

7.2 Fluvial sensitivity testing results

The results of the sensitivity tests have been used to inform the uncertainty bounds as detailed in the Hydraulic Modelling Report. The uncertainty bound in effect presents the most sensitive hydraulic parameter/s as assessed within the bounds identified in at all locations along the modelled reach.

Figure 7-3, Figure 7-4, Figure 7-5 and Figure 7-6 represents an overview of the Upper Corrib and Claddagh area for the 1% fluvial AEP and 10% fluvial AEP events. There is a significant difference between the design 1% AEP model run and the sensitivity runs. The most noticeable increase in flood extents along the Castlegar River is due to the increased flow sensitivity test. This causes the dyke road defence to overtop and exacerbate the flooding in this area. There is less sensitivity in the 10% fluvial AEP event but the increase in flood extent, most notably in parts of the Upper Corrib and the Claddagh area, is attributed to the flood peak sensitivity test.

Figure 7-3: Claddagh area sensitivity overview 1% AEP

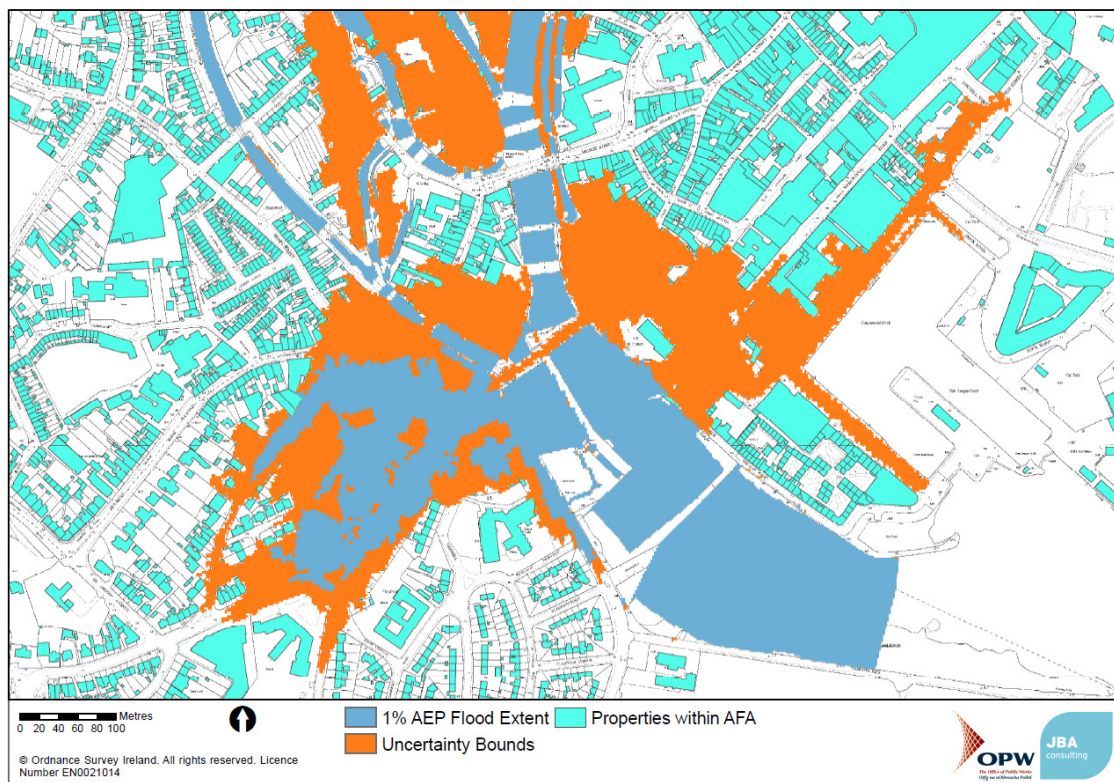


Figure 7-4: Claddagh area sensitivity overview 10% AEP

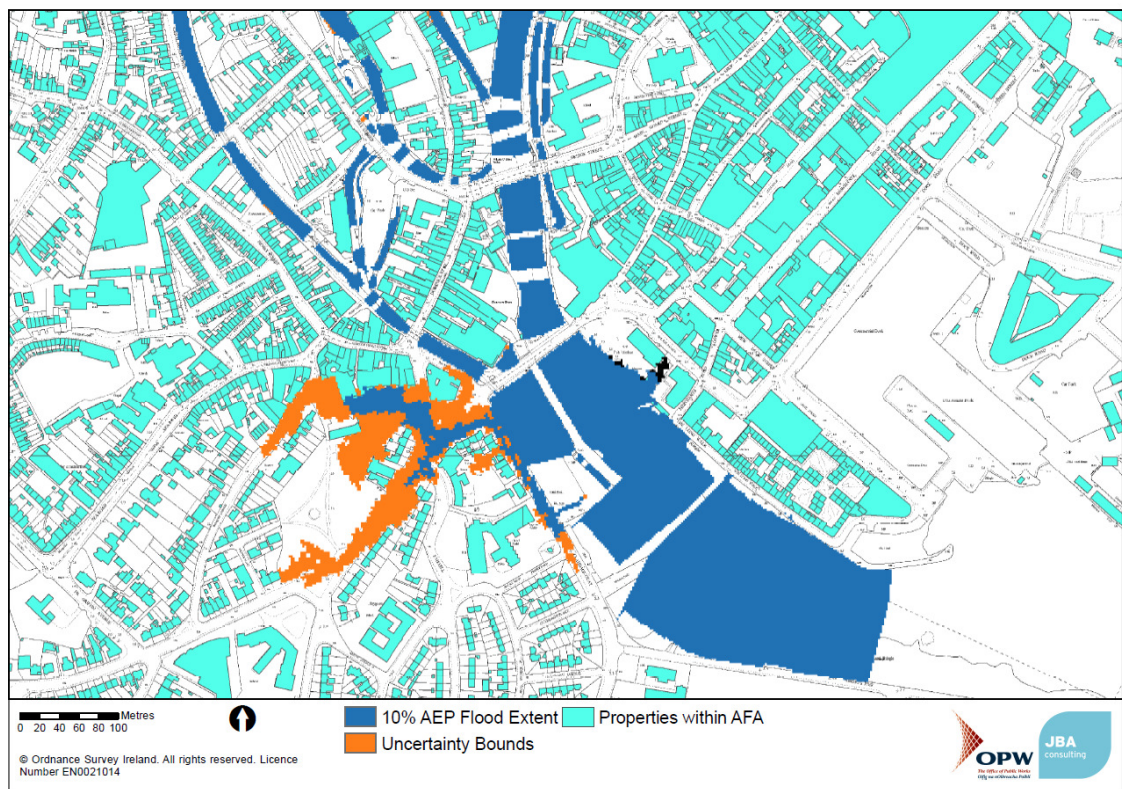


Figure 7-5: Upper Corrib sensitivity 1% AEP

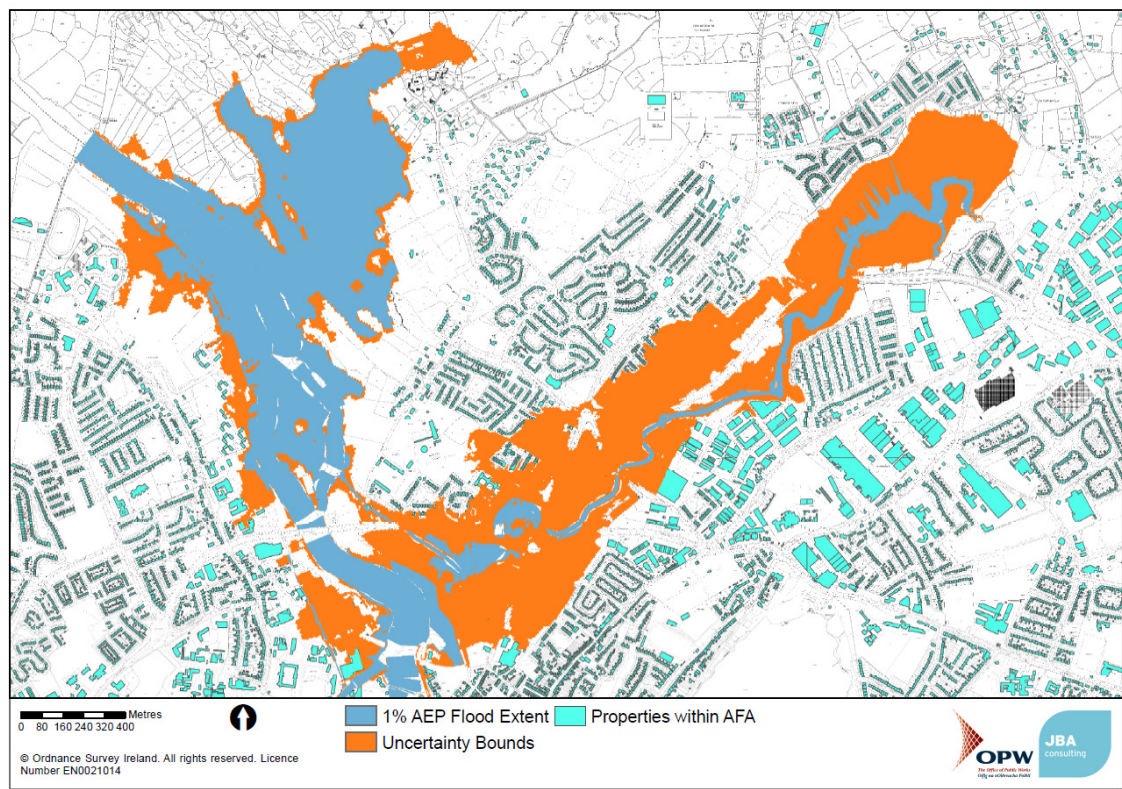
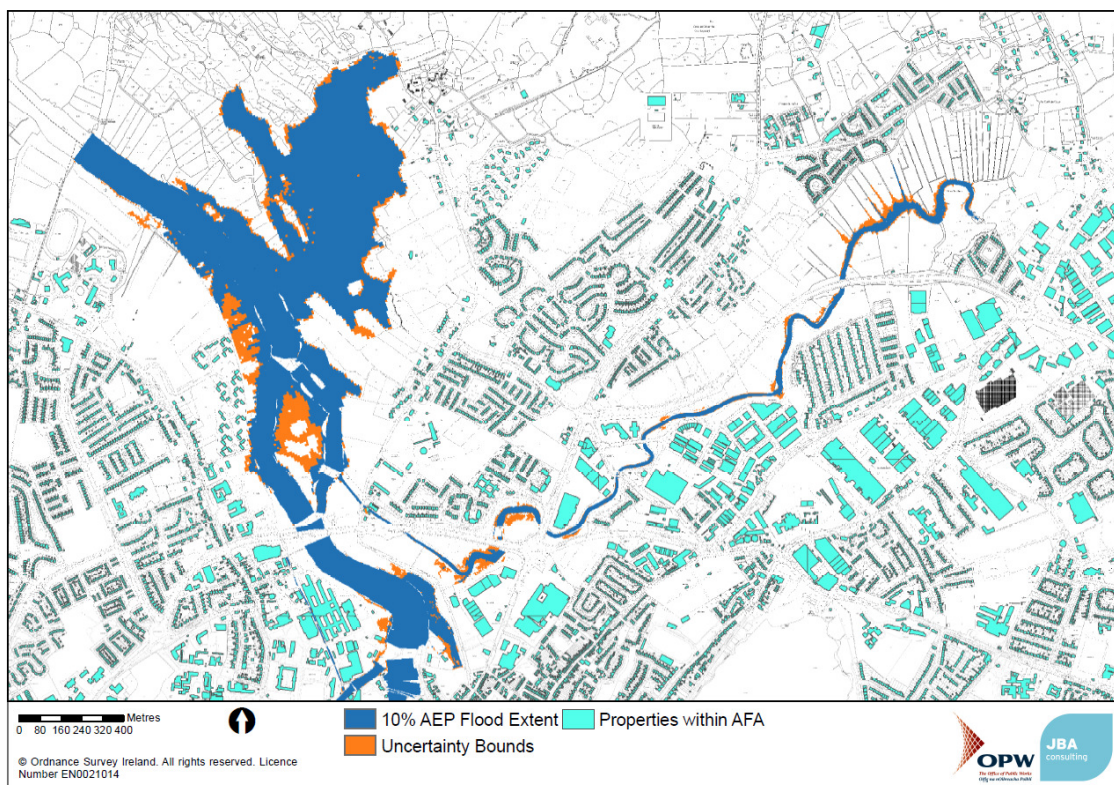


Figure 7-6: Claddagh area sensitivity overview 10% AEP



It was found that an increase in peak flow resulted in the greatest uncertainty extent. The effects of roughness change are marginal. The increase in building threshold has an impact of increasing flooding in areas while decreasing it at the same time in other areas.

No changes were made to the hydraulic model of the Galway City model based on the results of the sensitivity testing carried out.

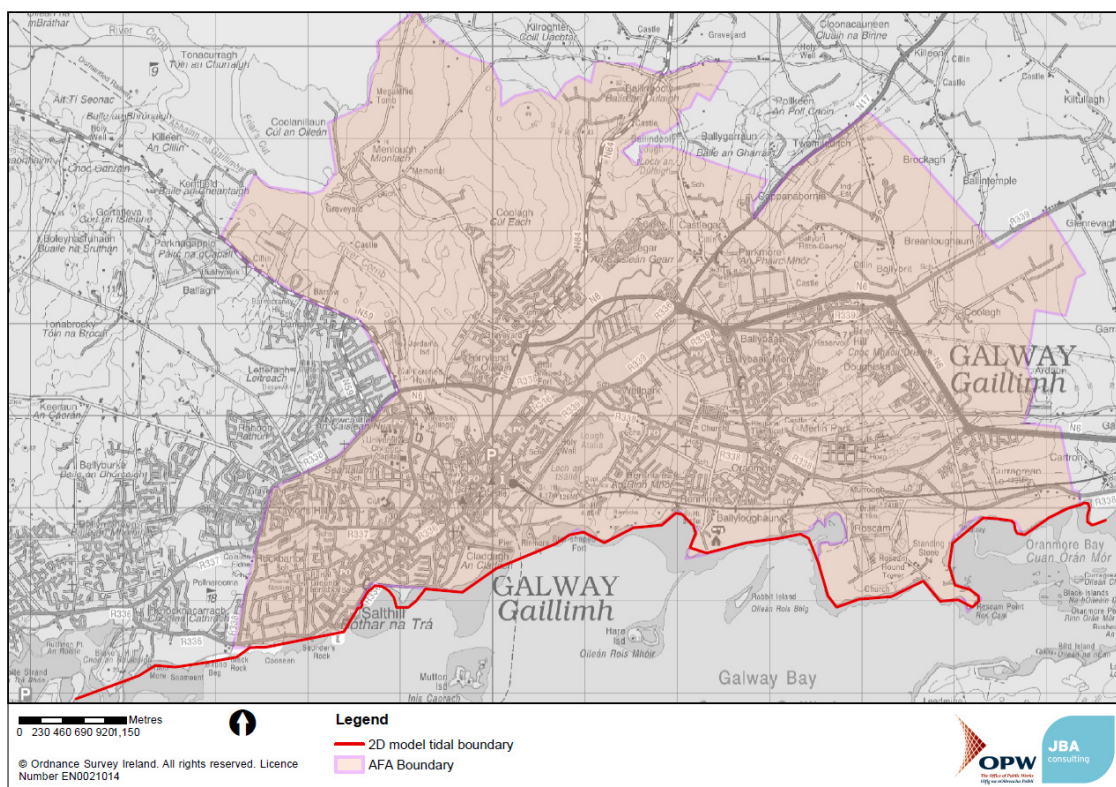
8 Coastal hydraulic modelling

8.1 Context

A 2D TUFLOW model has been constructed incorporating the coastline identified in Figure 8-1. The model has been given the ID code C1. The coastal flooding at Galway City is produced by a different flooding mechanism so this has been modelled separately.

The tidal boundary has generally followed the same path as the coastline described in the OSi 5k mapping. However, in some areas the boundary had to be adjusted to maintain stability in the model. The boundary had to be placed away from landfall due to the complicated geometry of the headlands. However, this has no effect on the final results.

Figure 8-1: 2D model tidal boundary



8.2 Defence and walls

8.2.1 Defences

There are no formal or informal effective coastal defences (i.e. OPW, local authority or privately maintained defences) in Galway City.

8.2.2 Walls

Informal ineffective structures are structures that are not assumed to function as flood defences and are either bypassed in the model or have been removed to allow flooding beyond them, such as garden walls. Within Galway City AFA, there are a handful of these structures within the limits of the tidal domain but have not been included in the model as all are bypassed.

8.3 Floodplain

A 2D cell size of 4m has been used as it was deemed to provide a sufficient level of detail whilst ensuring that model run times were kept to a reasonable length.

The active model area was determined using the LIDAR data for the AFA. Areas of high ground were deemed 'natural boundaries' and serve well as inland model extents.

To realistically represent flow routes in the coastal domain, various structures had to be included as standalone 1D elements in the 2D domain. This is to allow flow to be conveyed through the structure rather than having it pond and subsequently overtopped. The structures included in the 2D floodplain are identified in Table 8-1. The locations of the 1D element in the 2D domain are shown in Figure 8-2.

Table 8-1: 1D ESTRY components in floodplain in Galway City AFA


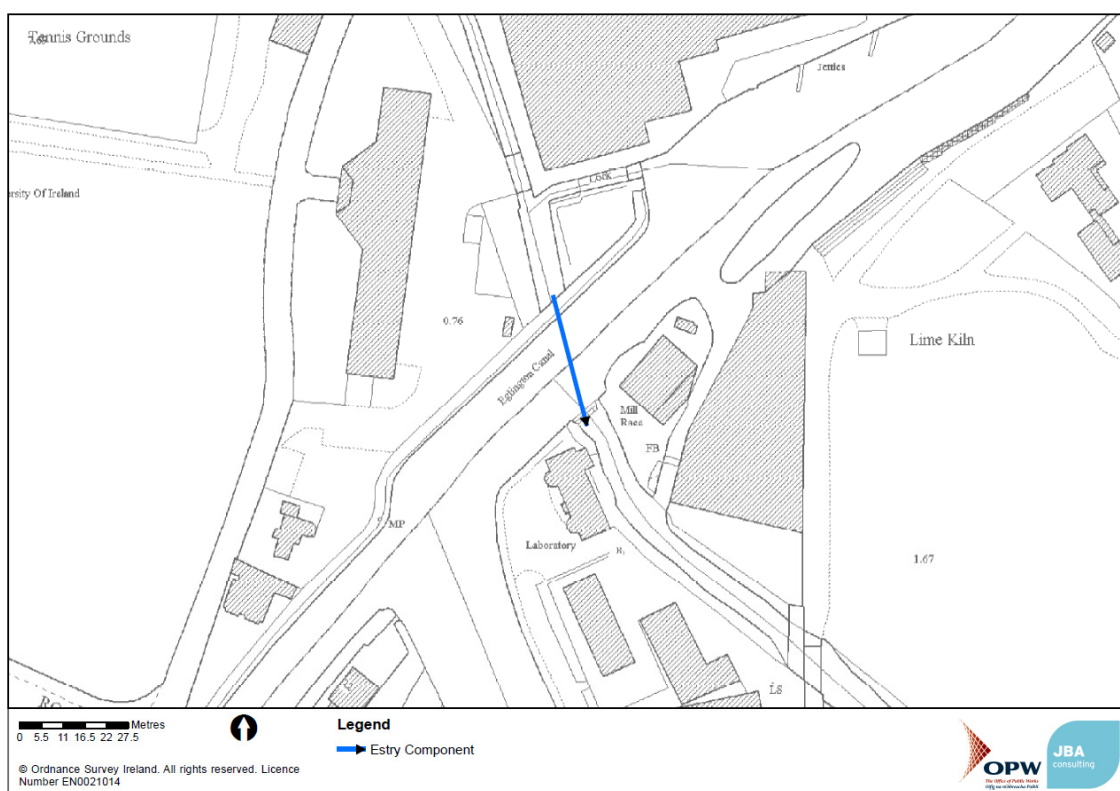
Description and Location	Modelling Method	Photograph
Location at the SALW siphon under the EGLI canal.	This structure has been represented as a circular conduit and using the 'as-surveyed' upstream and downstream invert levels.	

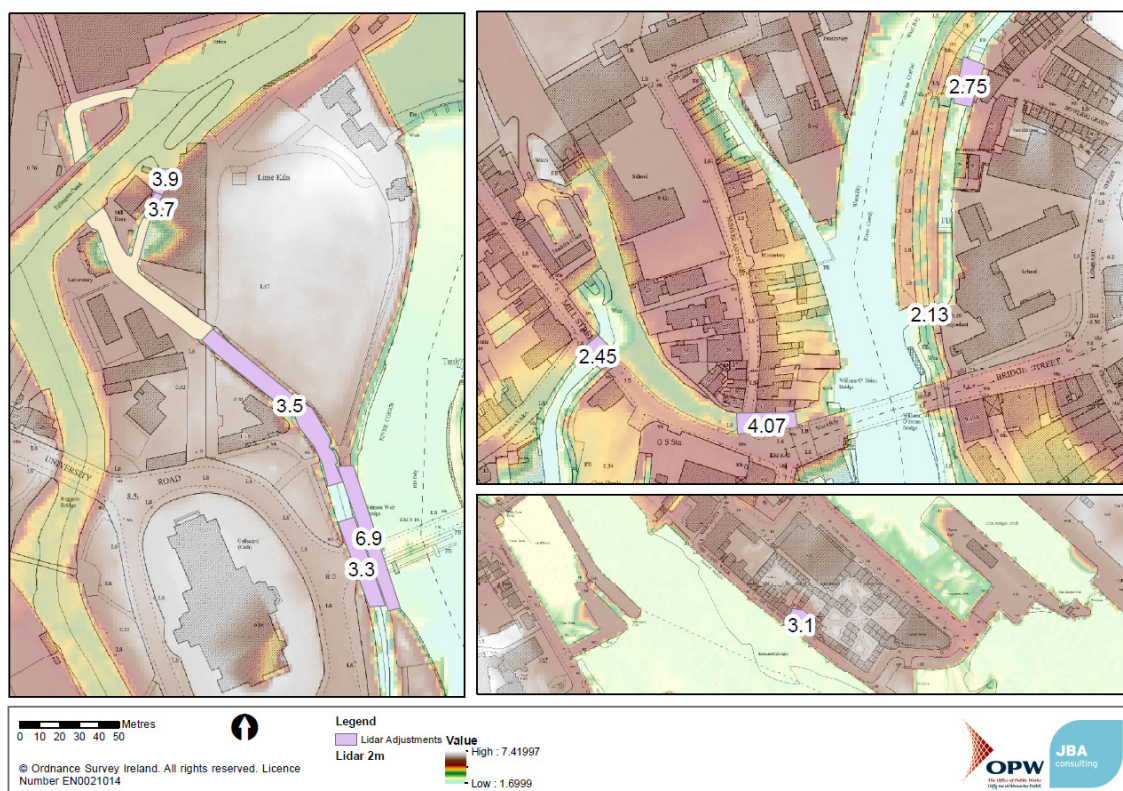
Figure 8-2: Location of 1D ESTRY components in floodplain within Galway City



8.4 LIDAR adjustments

The LIDAR adjustments are highlighted in Figure 8-3. The adjustments alter the underlying elevation due to the limitations of LIDAR technology and processing algorithms. These changes are used to open flow routes that will be inundated by the tidal flow such as river channels which was represented in the fluvial model using topographic cross section survey.

Figure 8-3: LIDAR adjustments



8.5 Wave Overtopping

Building on the analysis completed in the ICWWS report, reaches have been identified for a wave overtopping assessment. Within this reach, 21 different coastal frontages have been identified comprising variously raised sea walls or rocky coastline. These are highlighted in Figure 8-4.

Profiles perpendicular to the coastline were developed for all 21 coastal frontages from survey data, flood defence survey data and site visit and photos.

Overtopping calculations were performed for all joint probability combinations of water level and height as detailed in the Hydraulic Model Development Methodology report. The worst case i.e. the highest overtopping volume was selected for each return period at each of the schematised overtopping profiles. For input into the flood inundation models the wave overtopping is therefore a composite of the worst case overtopping at each individual defence which may be made up of a number of different combinations of water level and wave height within each return period.

The maximum wave overtopping rates for the 0.5% AEP tide per metre length of defence are provided for each profile in Table 8-2. From the flood history in Section 2, wave overtopping is highlighted as a source of flooding in areas of Salthill.

Figure 8-4: Surveyed cross section locations

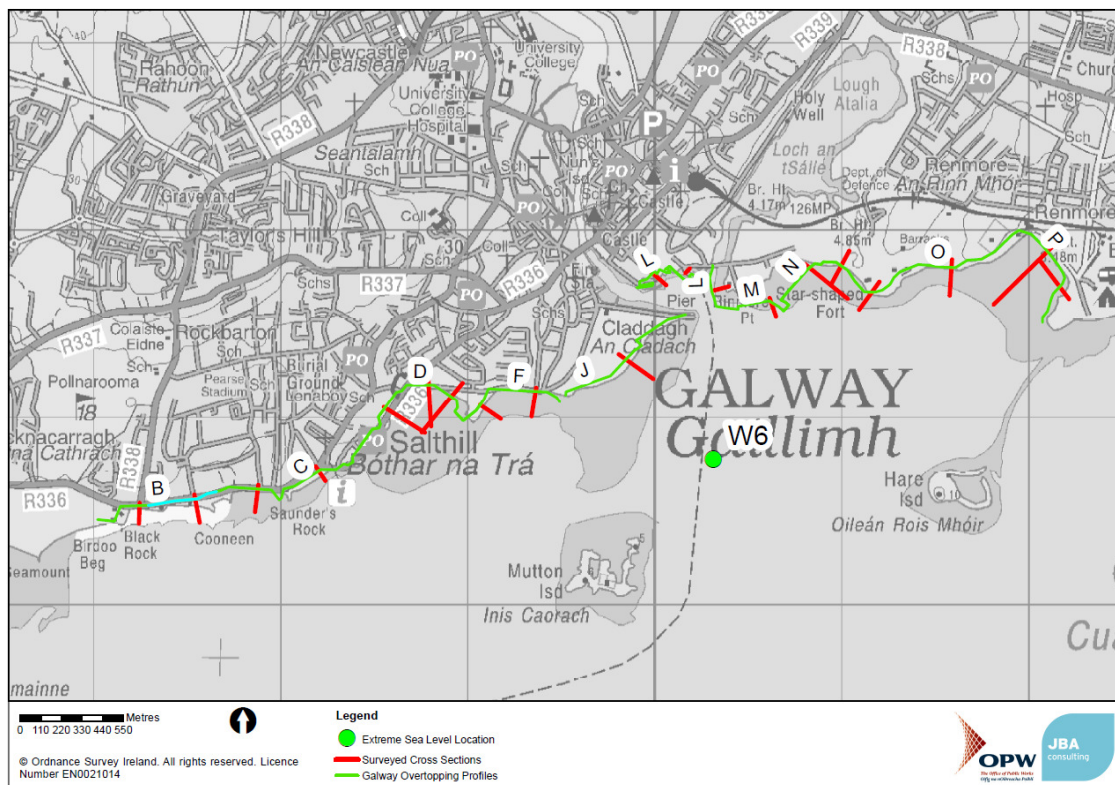


Table 8-2: The maximum overtopping flows per m length of coastal frontage calculated from the combination of conditions run in the wave overtopping model.

Location	Profile No.	Max T200 Qm (l/s/m)	Indicative Defence crest (m OD)	AEP still water overtops defences
Galway	1	6.48E-04	5.8	0.1%
Galway	2	3.00E-03	6.0	0.1%
Galway	3	3.25E-02	5.3	0.1%
Galway	4	3.17E-02	4.2	0.1%
Galway	5	3.04E-02	4.3	0.1%
Galway	6	7.90E-03	4.5	0.1%
Galway	7	1.04E-02	4.5	0.1%
Galway	8	1.23E-04	5.2	0.1%
Galway	9	1.20E-03	5.0	0.1%
Galway	10	1.02E-03	4.1	0.1%
Galway	11	7.28E-03	3.0	50%
Galway	12	1.78E-03	3.6	1%
Galway	13	0.00E-03	7.5	0.1%
Galway	14	0.00E-03	5.3	0.1%
Galway	15	7.82E-03	4.8	0.1%
Galway	16	0.00E-03	5.2	0.1%
Galway	17	2.63E-02	3.8	0.1%
Galway	18	4.17E-05	6.5	0.1%
Galway	19	5.99E-05	5.8	0.1%
Galway	20	2.03E-02	4.3	0.1%
Galway	21	7.65E-04	4.4	0.1%

9 Coastal model calibration and sensibility checking

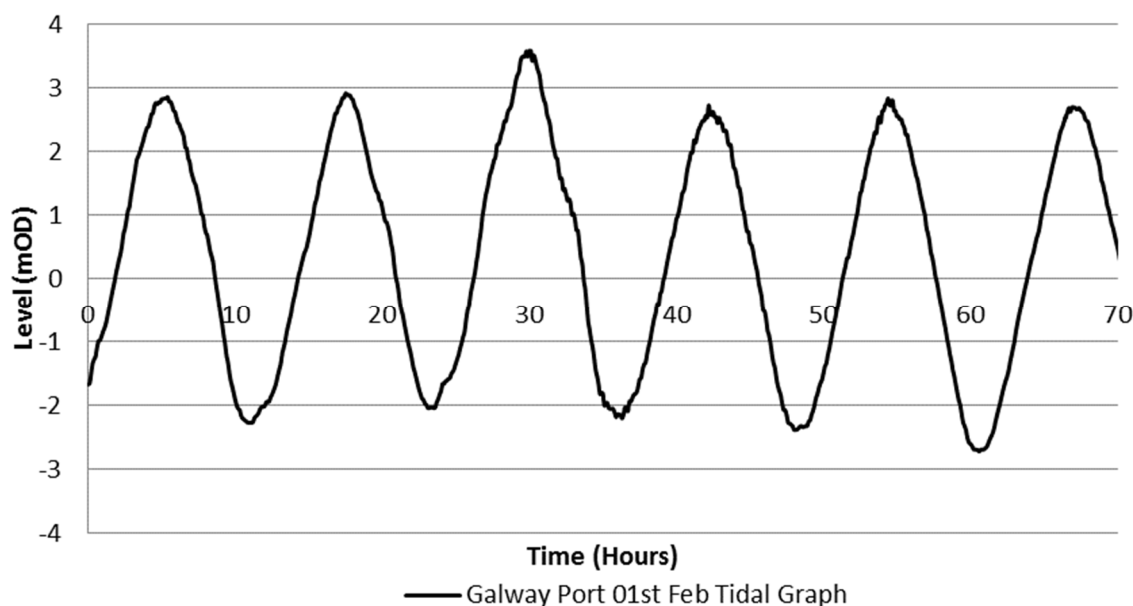
9.1 Calibration data

As detailed in Section 4, calibration of the model is important to ensure appropriate representation of flood mechanisms. Galway City has experienced tidal flooding on a number of occasions in the recent past, with observed flood events being recorded by JBA for a couple of them. It was decided to calibrate the Spanish Arch/Claddagh area of the city with the 1st of February 2014 event as this was found to be the critical event in this area. The flooding was less severe in Salthill than previous flooding on the 18th December 2013 and 3rd January 2014. Therefore, the Salthill area is calibrated using the 3rd of January 2014 event and the wave overtopping results.

9.2 1st February 2014 event

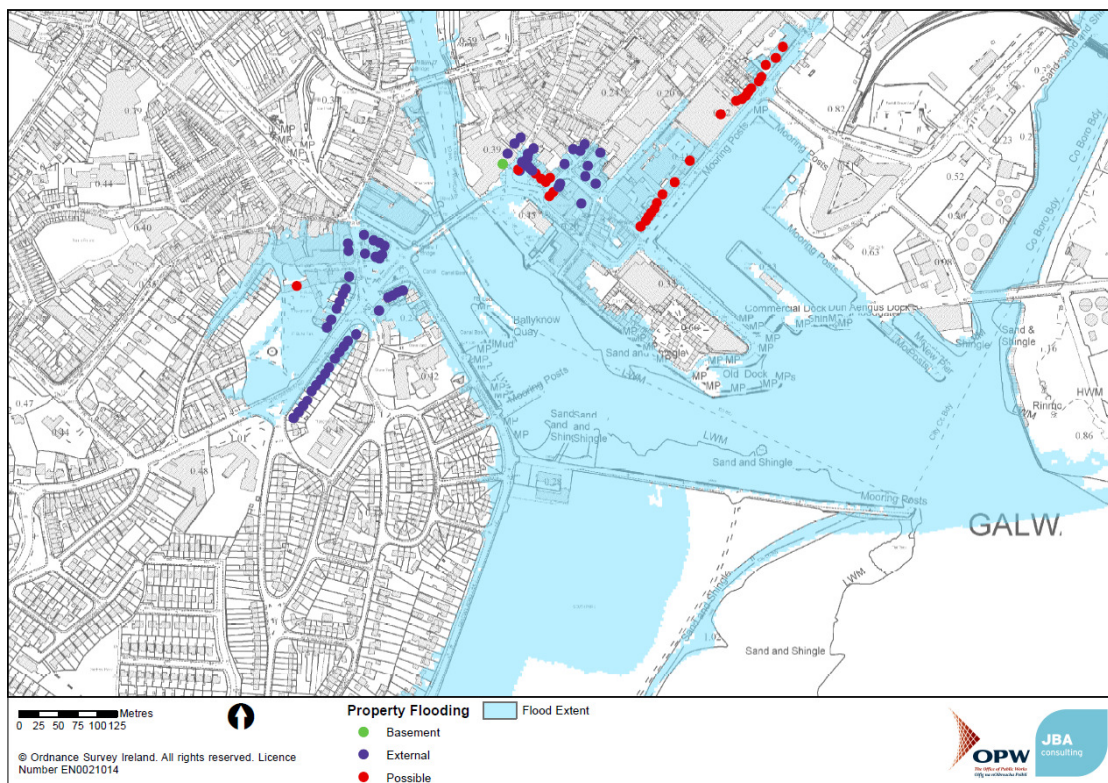
The Galway Port Tide Gauge was used to provide water level data for this calibration event. Figure 9-1 shows the tide curve input into the model to replicate the flood extent observed for the 3rd of January 2014 event.

Figure 9-1: Tidal graph for 1st January 2014 event (0-70)



The modelled extents do not show any flooding in Salthill or from Lough Atalia, although the area did flood in February 2014. This suggests that flood mechanisms other than the high tide with a storm surge are in place here. In Salthill a combination of wave overtopping and storm drains unable to discharge to the sea could be the cause. Interrogation of the LIDAR elevation data along Salthill Promenade in front of Toft Park shows that the lowest elevation is 3.6 mOD (see Figure 3 4), which is just above the peak water level of 3.59 mOD recorded at Galway Port (which is not influenced by wind generated waves). This goes some way to confirming that wave overtopping is a critical flood mechanism in Salthill and that in Galway City Centre and the Docks peak tide levels are critical.

Figure 9-2: Galway City coastal modelled extent for 01 February 2014⁸



9.3 3rd January 2014 event

Figure 9-3 shows an overview of the observed flooding in Salthill for the January 2014 flood event. The probable areas of flooding are based upon ground elevation but were not actually witnessed to have flooded as the observation were made after the peak of the event. During the event, waves overtopped the Promenade and flooded low lying land either side of the Promenade road. The low lying land at Toft Park near the Aquarium, around Leisureland and the new Circle of Life Commemorative Gardens was flooded. As was observed on 18th of December 2013, flood water flowed through Toft Park and then along a footpath between the Galway Business School and a residential property causing flooding.

The modelled extent for the 1% AEP event was compared to the observed flood extent for the 3rd of January event. While the AEP for the event was not determined, the event is expected to be less than the 1% AEP and greater than the 10% AEP. Wave overtopping was not used for the event either as no wave height data could be collected. The comparison shows that the areas of flood risk identified from the modelling process are indicative of the observed flood extents.

⁸ 2011s5275-I-N002-2 Galway City Flooding 01 Feb 2014 v2

Figure 9-3: Overview of observed flooding in Salthill⁹

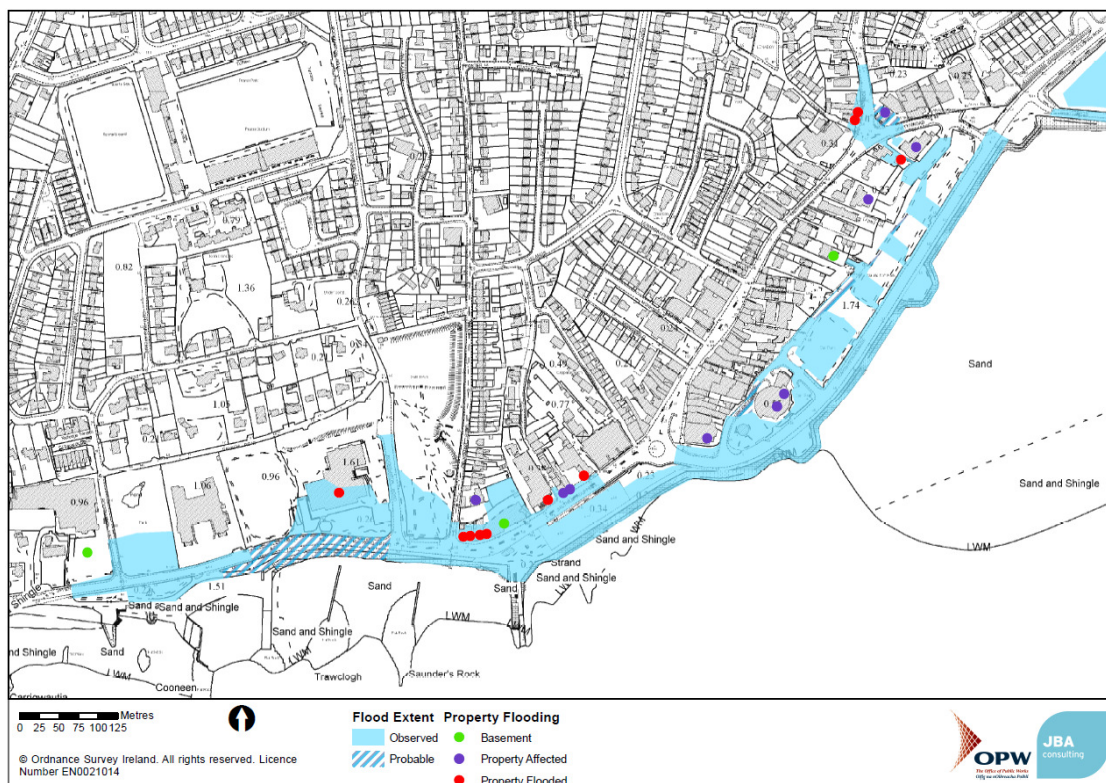
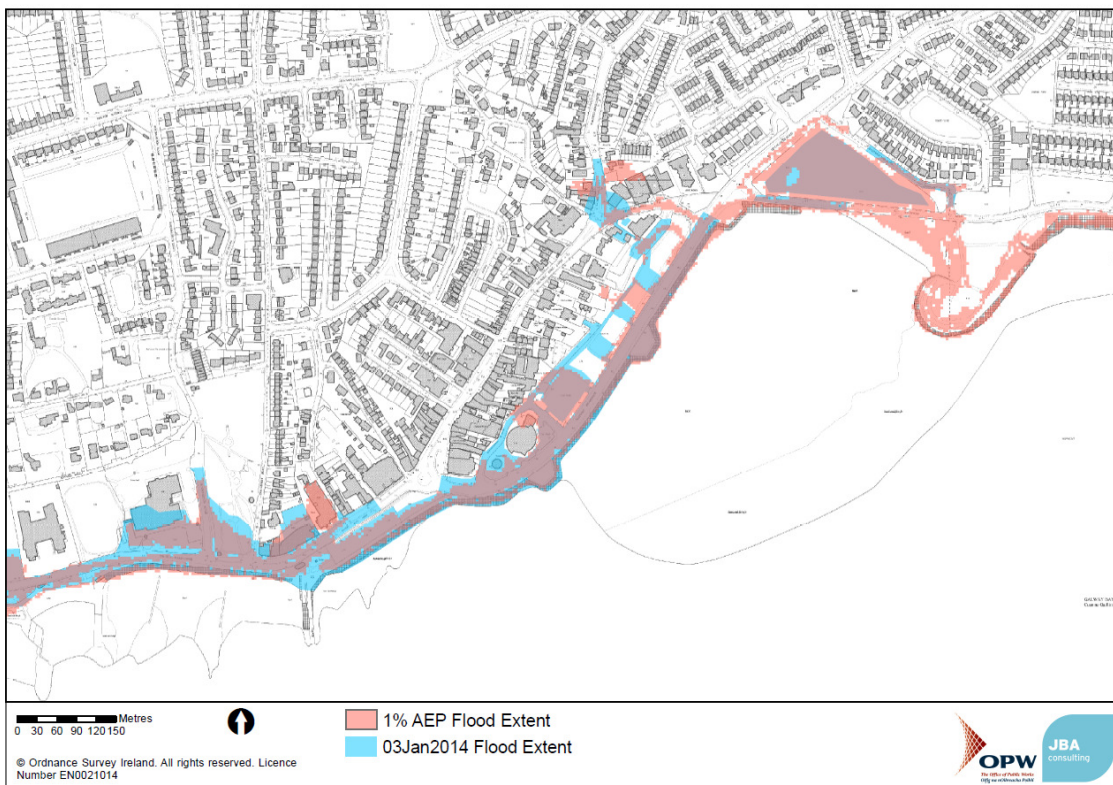


Figure 9-4: Comparison of observed and 1% AEP event Salthill



⁹ 2011s5275-I-N002-2 Galway City Flooding 03 Jan 2014 v2

9.4 Calibration results

Reducing the cell size improved the calibration of the coastal model as the definition of flow routes were improved. This change was carried forward and incorporated for further runs. The calibration of the January event generally conforms to the outline of the 1% event. While the modelled extent doesn't match the observed extent in areas, there are aspects surrounding the event that may explain the uncertainty and for this reason not further adjustments were made as part of the calibration. Firstly, the observed or probable extent may not be representative of what actually occurred on the 3rd of January 2014. The peak of the event may have passed before a reasonable extent could have been established. Secondly, surface water runoff could have contributed to the problem as the outfall to the sea was confined by the high tide. The ponding could have been observed as tidal flooding which cannot be accurately modelled. Thirdly and which is likely to have a significant effect in Salthill is the wave overtopping. This was not modelled in the calibration run as the over topping rates could not be reasonably estimated.

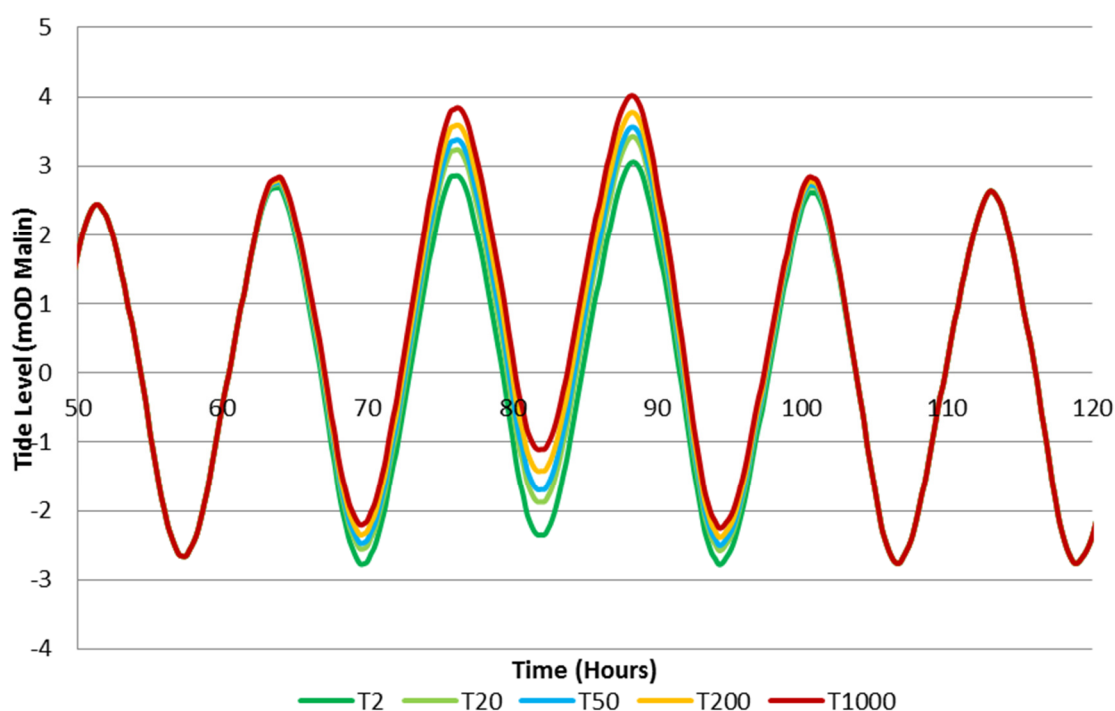
10 Coastal model results

10.1 Model runs

The model has been run for the following present day and MRFS fluvial and tidal events: 50%, 10%, 5%, 2%, 1%, 0.5% and 0.1% AEP design events. Only the 10%, 0.5% and 0.1% AEP design events have been run for the HEFS.

An extract of the tide data used to derive the current extents have been illustrated in Figure 10-1.

Figure 10-1: Selection of tide levels input into model



Future scenarios have been developed as part of the hydrological analysis and are described in detail in the WCFRAM Hydrology Report for UoM 30.

With regard to coastal flooding, accounting for future scenarios requires the addition of 500mm and 1000mm respectively for the Mid-Range Future Scenario (MRFS) and High-End Future Scenario (HEFS) to the existing tide profiles for each exceedance probability. The extreme sea levels for future scenarios are detailed in Table 10-1.

Table 10-1: Extreme sea levels (mOD) - current and future scenarios

Annual Exceedance Period	50%	20%	10%	5%	2%	1%	0.5%	0.1%
Current	3.06	3.21	3.32	3.42	3.56	3.67	3.77	4.02
MRFS	3.56	3.71	3.82	3.92	4.06	4.17	4.27	4.52
HEFS	4.06	4.21	4.32	4.42	4.56	4.67	4.77	5.02

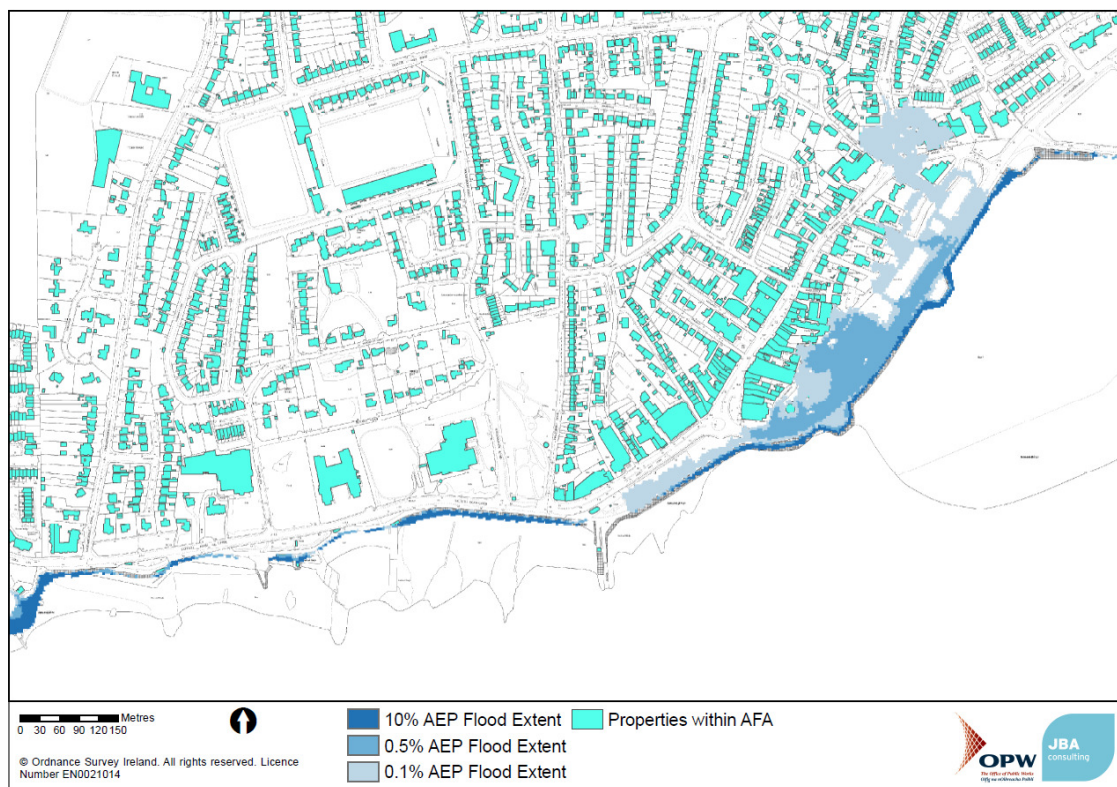
10.2 Coastal flood risk mapping

Flood risk extents for the present day and MRFS 10%, 0.5% and 0.1% AEP design events along with long section profiles for present day 10%, 1% and 0.1% AEP design events are presented in Volume 3 of the UoM 30 Hydraulic Modelling Report.

10.2.1 Flooding in the Salthill area

The flood extent map for the Salthill area of Galway City shows much inundation in the 10% AEP event. Figure 10-2 gives an overview of the flooding and the affected properties within the AFA. Known areas of flooding such as Toft Park and along the promenade are shown flooded in the 10% AEP. The flooding is more extensive through Grattan Road in the 0.5% AEP and shows further properties affected.

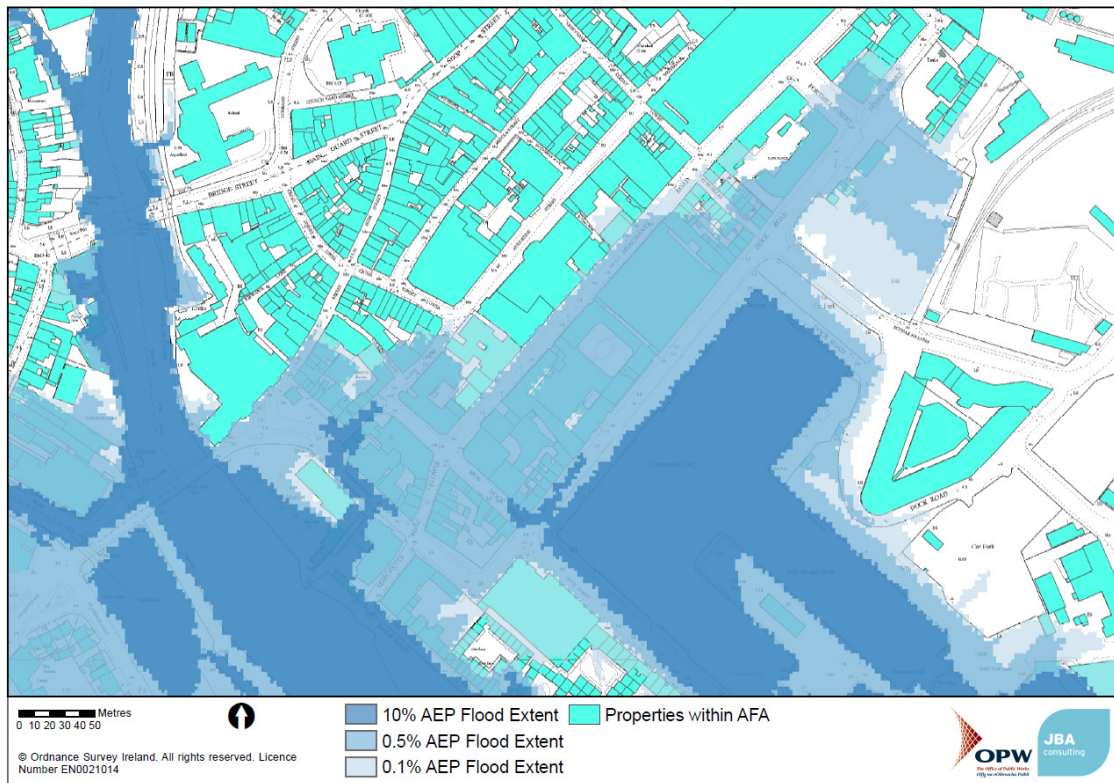
Figure 10-2: Overview of Salthill



10.2.2 Flooding at Spanish Arch and Dock Road

The area around Spanish Arch, Flood Street and Dock Road is a known area of flood risk from historical evidence and the more recent event of winter 2013/14. From the flood maps produced, shown in Figure 10-3, much of the flooding occurs in the 0.5% AEP event in comparison to the 10% AEP event which does not show extensive flooding. There is a marginal difference in flood extent between the 0.5% AEP and the 0.1% AEP.

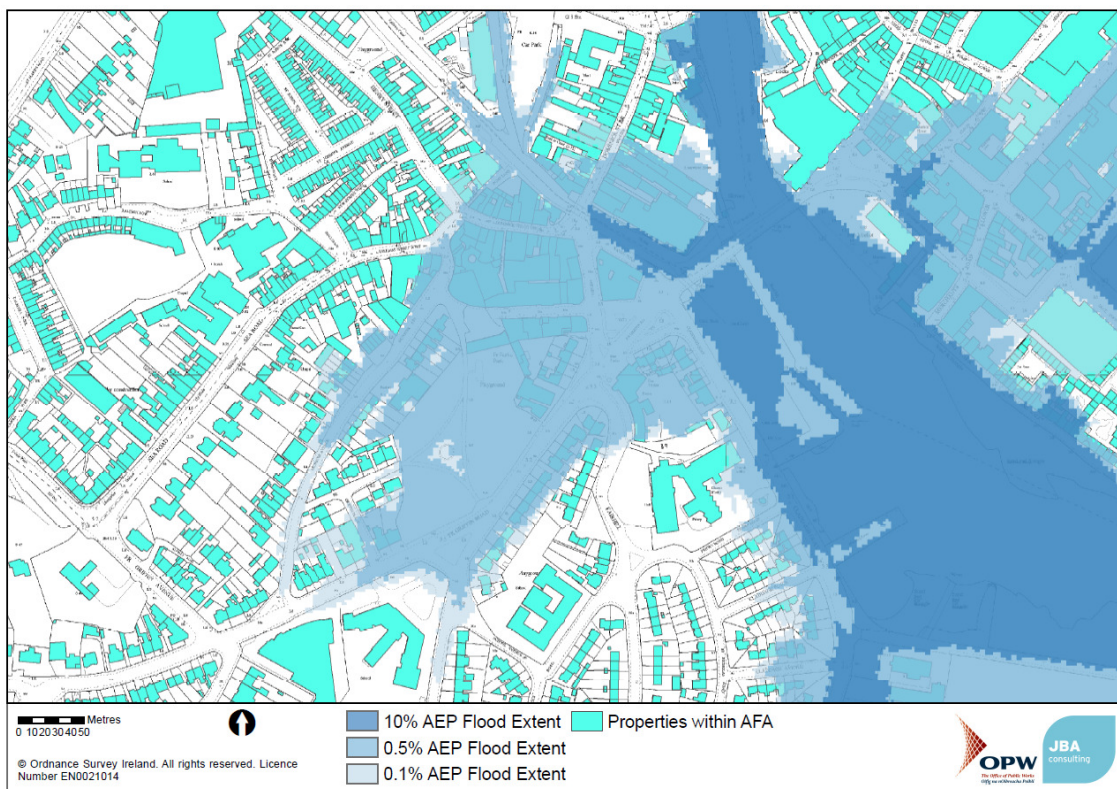
Figure 10-3: Overview of Spanish Arch and Dock Road



10.2.3 Flooding at Claddagh Basin

Figure 10-4 below shows the flood extent produced for the various events around the Claddagh area. No flooding is shown in the 10% AEP event but the 0.5% AEP shows expansive flooding down Father Burke road onto Father Griffin road. There are historical records of this flooding and the maps reinforce the flood risk potential present in this area.

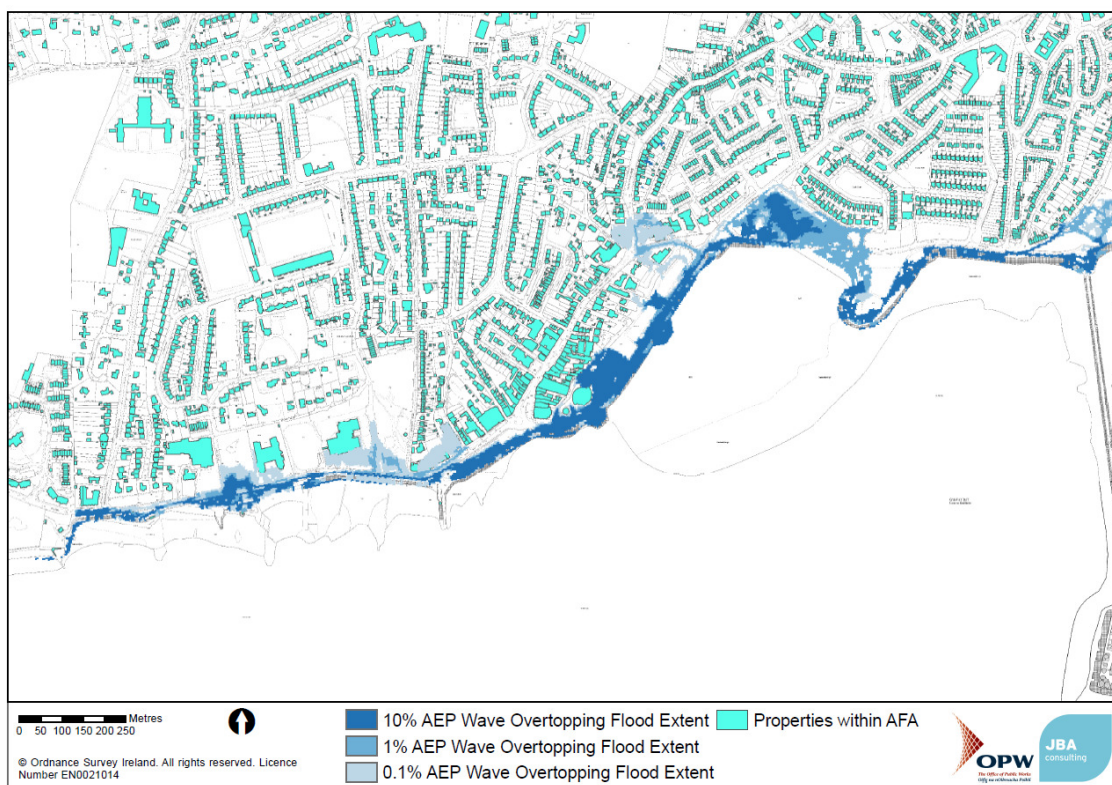
Figure 10-4: Overview of Claddagh Basin



10.2.4 Coastal wave overtopping flood risk mapping

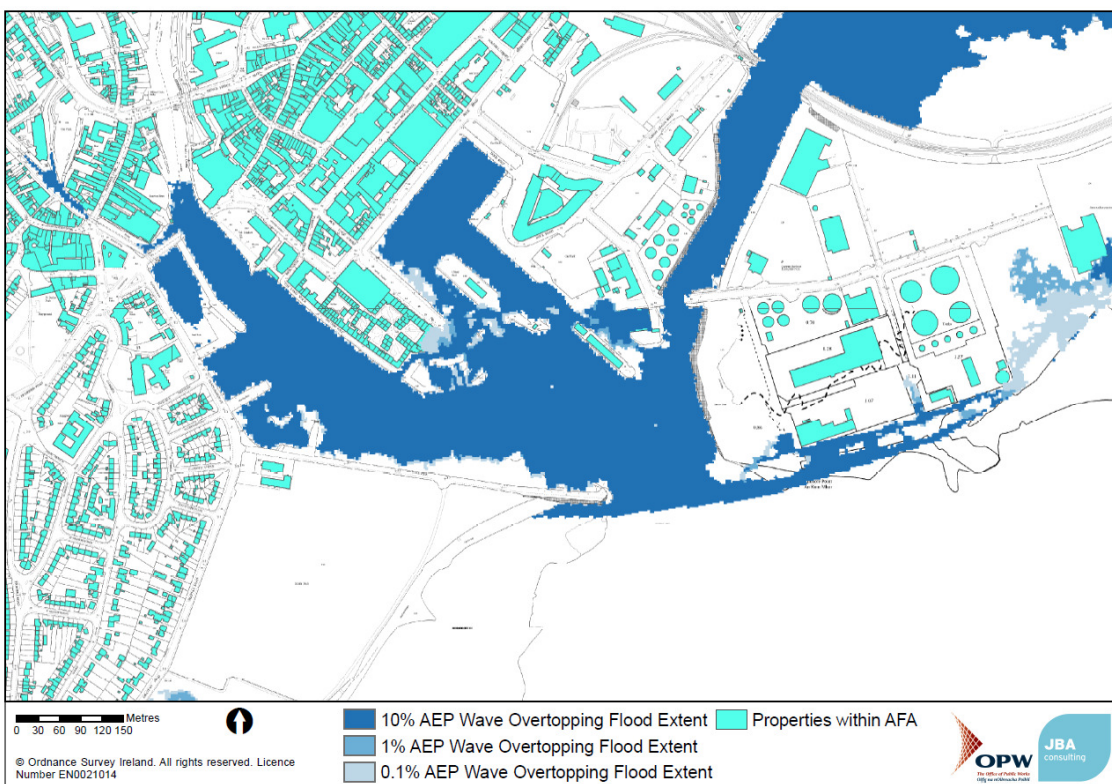
Figure 10-5 shows the flood extents produced in Salthill from the application of the wave overtopping rates in Table 8-2. The wave overtopping results indicate that the Salthill area is susceptible to wave overtopping and experiences flooding from this mechanism at an AEP greater than 10%. This was to be expected and is evident from the flood history of the area.

Figure 10-5: Wave overtopping results Salthill



Similar results for the docklands is shown in Figure 10-6. From the results the area is not prone to wave overtopping. There is sufficient slope to return the wave volume breaking onto the ground.

Figure 10-6: Wave overtopping results Docklands



11 Coastal sensitivity testing

11.1 Screening of coastal sensitivity testing

For the purpose of testing the Galway City model, a screening assessment has been completed to determine which of these sensitivity tests is applicable. The coastal sensitivity follows the same method of testing described in Section 7.1, the fluvial sensitivity testing. The results of the screening are detailed in the following sections. Only the tests for roughness, water level boundaries, building representation and cell size are applicable to the coastal model.

11.2 Coastal sensitivity

11.2.1 Roughness

It is proposed that sensitivity to both lower and upper bound roughness values for the 0.5% AEP event, as shown in Table 11-1, will be tested as part of the next phase of CFRAM work.

Table 11-1: Floodplain roughness range

Floodplain Material	Roughness Values (Manning's 'n')		
	Typical Value	Lower Bound Value	Upper Bound Value
General natural Surfaces	0.040	0.030	0.050
Buildings	0.300	0.100	1.000
Roads, Tracks and Paths	0.015	0.013	0.017
Rock	0.050	0.040	0.070

11.2.2 Water level boundaries

The effect of rising sea levels has been investigated through the MRFS and HEFS climate change scenarios and is considered sufficient to test the model against. This increase has not been taken into account when developing the uncertainty bounds.

11.2.3 Building representation

A sensitivity test to raise the building threshold level in the model to 300mm assessed the uncertainty in the way buildings are represented. The increased threshold level for buildings can alter flood flow routes and alter the number of properties at risk and flood extent.

11.2.4 Cell size

A 2m cell size was tested to observe any flow paths that may be misrepresented by the modelling of a 4m cell size.

11.3 Coastal sensitivity testing results

The results of the sensitivity tests have been used to inform the uncertainty bounds as detailed in the Hydraulic Modelling Report. The uncertainty bound in effect presents the most sensitive hydraulic parameter/s as assessed within the bounds identified in at all locations along the modelled reach. Note, the uncertainty bound does not include the increase in water levels resulting from the future scenarios.

To simplify the presentation of the sensitivity tests, the uncertainty bound for the 0.5% AEP events has been presented in Figure 11-1 and Figure 11-2.

The sensitivity of the Galway City coastal model to the tests are very marginal and indicate the model is insensitive to the parameters tested. No changes were made to the Galway City coastal hydraulic model based on the results of the sensitivity testing carried out.

Figure 11-1: Overview of sensitivity at Salthill

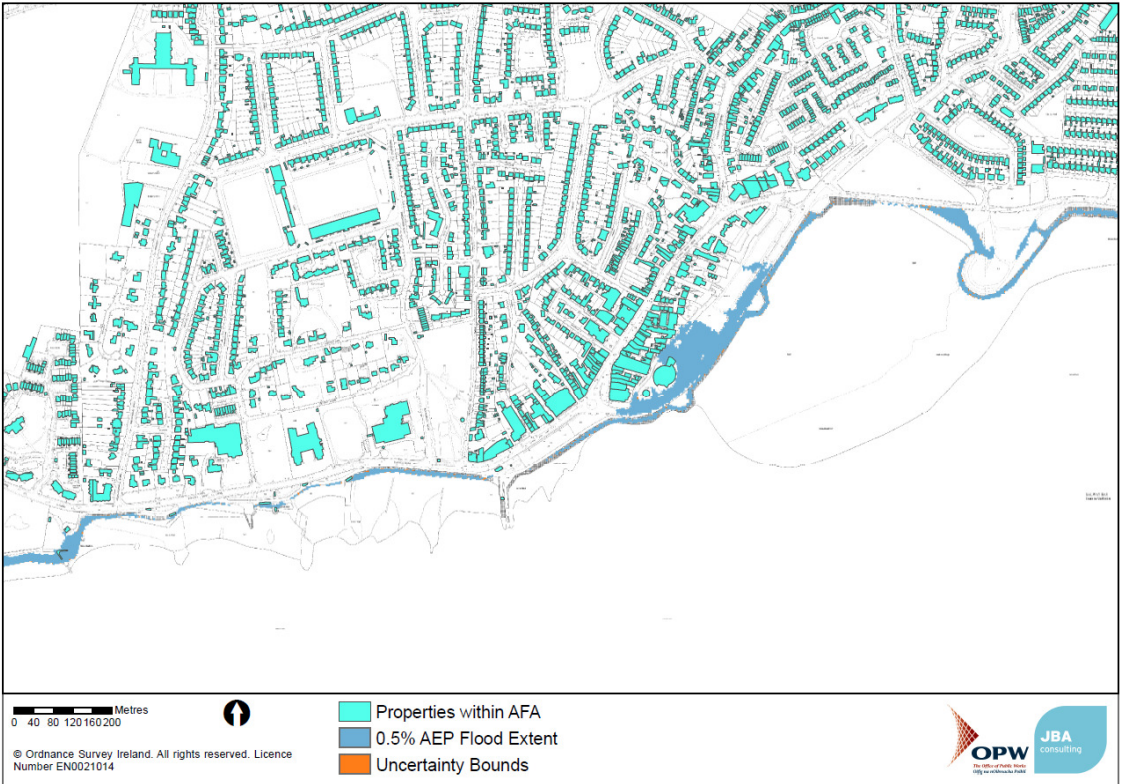
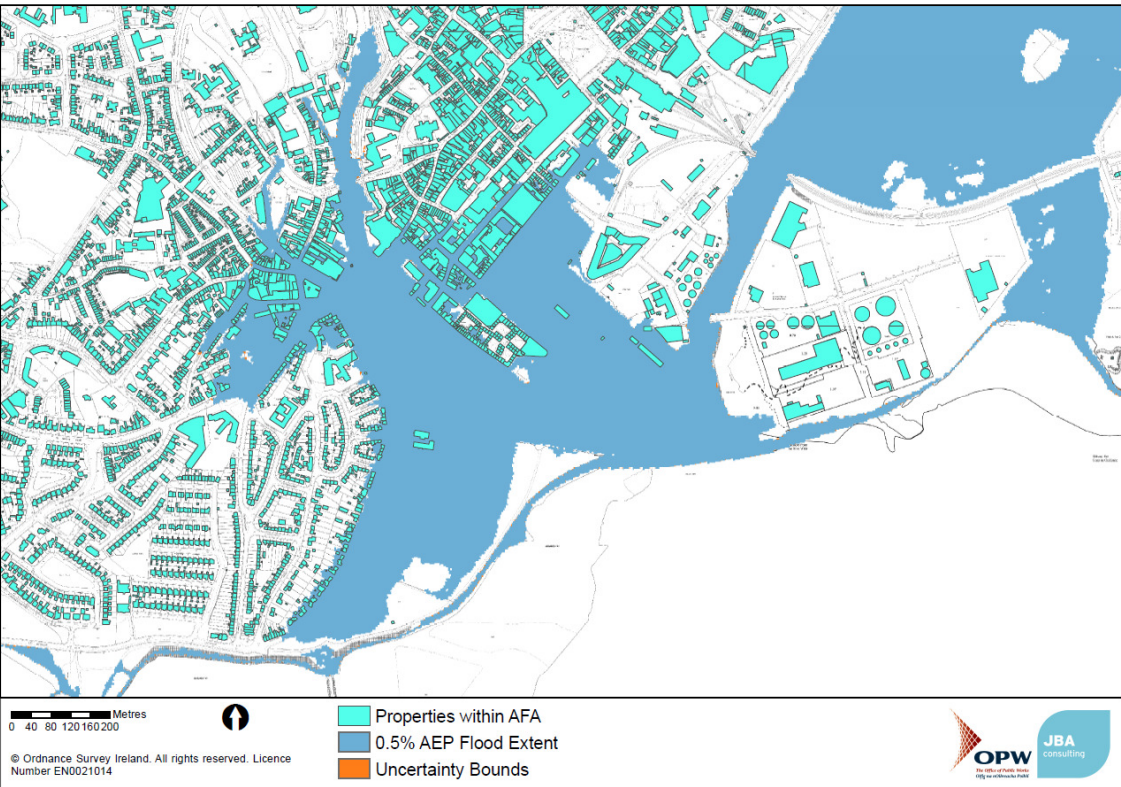


Figure 11-2: Overview of sensitivity at Salthill



12 Model limitations

12.1 Fluvial model

12.1.1 Channel blockage

Blockage of culverts and small span bridges has the potential to increase flood risk on any watercourse. In Galway City, the canals are slow moving and from various site visits and survey results it is clear that some of the structures are heavily blocked. If these culverts blocked, water would back up in the channel, before overtopping onto into the urban area putting properties at increased risk of flooding. Blockage has not been investigated in more detail in this model as it is outside the scope of the CFRAM, but it is possible that blockage of these structures would exacerbate flood risk to adjacent properties.

12.1.2 Salmon Weir

The water level upstream of the Salmon Weir Barrage, and the flow to the canals is controlled by the operation of the 16 gates that form the structure. The gates are operated based on the water levels upstream on the Lough Corrib, present weather, weather forecast and operator experience. As a more conservative (i.e. higher flow) scenario, it has been assumed that the gates would be open for all the design events carried out in this study. This assumption is supported by operational evidence from the 2009 event and feedback that the gates are normally opened during the winter period.

12.1.3 Structure representation

There is uncertainty in the modelling of structures where health and safety and technical issues meant there was limited survey data collected. At the Distillery River (SALW) siphon under the Eglinton (EGLI) Canal, it was not possible to establish the dimensions of the culvert. The culvert is represented as an orifice and survey levels replicated to achieve the head loss through the structure. This method was also used where the Nuns Island (NUNS) watercourse flows through a building.

There is flood prevention works being carried out on the Distillery River (works ongoing at the time of modelling). This works include a penstock which is not surveyed and not represented in the fluvial model.

The water treatment works along the Castlegar River is significant in conveying flow to the downstream of the watercourse. It is not clear what happens inside this building but the surveyed head loss through the structure was applied in the model even though flood waters could be stopped completely if a sluice existed.

12.1.4 MPW modelling

The MPW model entails extending cross section which have been extended using LIDAR data. In any cases there are jumps in elevation between the channel survey and the DTM. This will result in uncertainty in the flood extents and also the cross sectional area where river levels exceed the extent of the surveyed cross section.

12.1.5 Geomorphological change

The upstream of the River Corrib is heavily silted and there is a high potential for geomorphological change. The channel bed constantly shifts and may be easily eroded by high river flows. These geomorphological changes have not been investigated in the modelling process, but will be looked at as part of the CFRAM study.

12.1.6 Karst features

The Castlegar River that flows to the sink hole is a significant uncertainty in the fluvial model. Karst features are very hard to predict in terms of pathway and flow rate. They are highly dependent on groundwater conditions and seasonal variations. However, analysis of the groundwater system is outside the scope of the CFRAM.

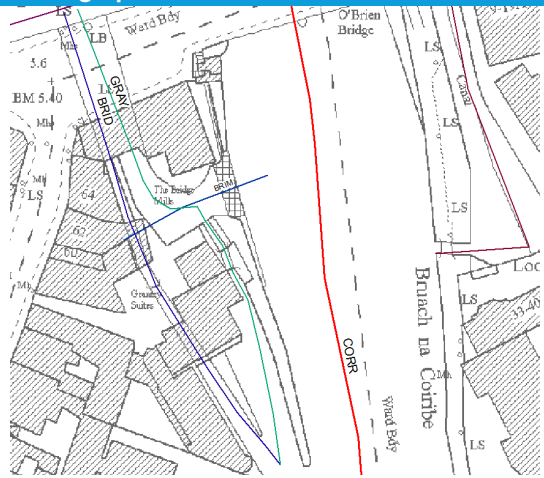
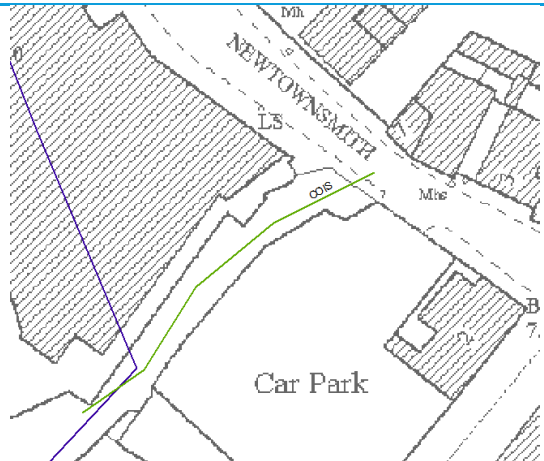
12.1.7 Model calibration

A programme of water level monitoring across the canal system would provide valuable information to help calibrate the model.

12.1.8 Inclusion of all the mill races and connections

A number of connections were not modelled as they have no influence on flood risk and the modelling of which would have only increased complexity and uncertainty. BRID/GRAY stream takes water from GMRA using an orifice and this is included in the model. These watercourses are summarised in Table 12-1.

Table 12-1: Excluded watercourses

Name	Description	Photograph
BRID/GRAY	The BRID/GRAY area is not an area of flood risk. There is a wide channel and weir to convey flow. The only way the properties could be flooded is from the level of the River Corrib reaching the building level threshold and likely to be driven by the tide.	
COIS	The COIS watercourse is excluded as it appears to convey no flow. It was probably used as an old mill or urban drain.	

12.2 Coastal model

12.2.1 ESTRY Components

Various assumptions and simplifications had to be made when allowing for 1D structures to be represented as ESTRY components in the model. The width of these structures cannot be smaller than the 2D domain cell size.

A Hydraulic model results

A.1 1D model flows

Table A-1: 1D model peak current flows

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30CORR00951	66.26	82.24	93.08	103.85	118.57	130.55	147.75	200.74
30CORR00939	65.96	81.60	92.16	102.63	117.00	128.69	145.50	197.38
30CORR00924	65.73	81.02	91.30	101.44	115.38	126.65	142.91	193.29
30CORR00897	65.18	79.93	89.76	99.33	112.68	123.45	139.11	188.13
30CORR00881	64.85	79.38	88.98	98.24	111.32	121.91	137.16	185.75
30CORR00861	64.64	79.01	88.39	97.38	110.07	120.41	135.15	183.26
30CORR00842	64.45	78.58	87.68	96.39	108.59	118.67	133.03	180.70
30CORR00822	64.17	77.93	86.56	94.95	106.65	116.49	130.80	178.06
30CORR00806	63.78	77.09	85.26	93.38	104.80	114.49	128.65	175.59
30CORR00788	63.35	76.13	83.89	91.74	102.93	112.50	126.42	173.29
30CORR00772	62.97	75.31	82.83	90.55	101.69	111.12	124.91	171.75
30CORR00757	62.54	74.48	81.84	89.51	100.52	109.92	123.63	170.53
30CORR00741	62.28	73.85	81.15	88.73	99.67	109.02	122.67	169.60
30CORR00722	62.10	73.27	80.53	88.05	98.94	108.22	121.78	168.74
30CORR00705	62.02	72.97	80.20	87.67	98.58	107.77	121.25	168.26
30CORR00683	61.90	72.73	79.91	87.36	98.25	107.39	120.80	167.85
30CORR00662	61.82	72.58	79.78	87.20	98.08	107.21	120.58	167.65
30CORR00642	61.77	72.51	79.73	87.14	98.03	107.15	120.49	167.54
30CORR00622	61.77	72.50	79.75	87.17	98.07	107.20	120.52	167.51
30CORR00605	61.77	72.52	79.77	87.23	98.12	107.24	120.56	167.54
30CORR00588A	61.83	72.63	79.91	87.42	98.31	107.42	120.75	167.65
30CORR00588B	240.80	280.26	307.51	335.11	373.90	406.18	453.48	616.98
30CORR00576	240.69	280.05	307.29	334.86	373.64	405.92	453.16	616.70
30CORR00566	240.59	279.87	307.10	334.67	373.41	405.70	452.89	616.45
30CORR00557	240.51	279.72	306.93	334.48	373.21	405.48	452.63	616.26
30CORR00547	240.44	279.58	306.77	334.32	373.03	405.28	452.41	616.11
30CORR00537	240.38	279.47	306.65	334.17	372.87	405.10	452.24	615.96
30CORR00527	240.30	279.35	306.51	334.02	372.70	404.94	452.05	615.80
30CORR00517	240.25	279.25	306.40	333.90	372.57	404.79	451.88	615.68
30CORR00506	240.22	279.18	306.31	333.80	372.47	404.68	451.78	615.58
30CORR00500	240.20	279.14	306.26	333.74	372.40	404.62	451.69	615.50
30CORR00492	240.20	279.11	306.23	333.71	372.37	404.58	451.63	615.46
30CORR00482	240.18	279.09	306.19	333.67	372.32	404.54	451.57	615.42
30CORR00472	240.17	279.06	306.16	333.63	372.29	404.51	451.53	615.38
30CORR00465	240.17	279.05	306.13	333.60	372.25	404.48	451.48	615.34
30CORR00457	240.16	279.03	306.11	333.56	372.22	404.44	451.45	615.31
30CORR00449	240.15	279.01	306.08	333.54	372.20	404.41	451.40	615.27
30CORR00442	240.14	279.00	306.07	333.52	372.18	404.39	451.38	615.25
30CORR00434	240.14	278.99	306.06	333.52	372.17	404.39	451.36	615.23
30CORR00426	240.14	278.98	306.06	333.51	372.16	404.38	451.36	615.22
30CORR00419	240.13	278.98	306.05	333.50	372.16	404.37	451.35	613.90
30CORR00412	240.13	278.98	306.04	333.50	372.15	404.37	451.34	615.10
30CORR00404	240.13	278.97	306.04	333.49	372.15	404.36	450.83	612.97
30CORR00395	240.12	278.96	306.03	333.48	372.14	404.35	451.32	610.36
30CORR00387	240.12	278.96	306.02	333.47	372.10	403.58	448.42	604.24
30CORR00381	239.13	277.55	303.66	329.04	363.76	391.96	432.02	564.64
30CORR00372	237.83	273.41	296.83	319.12	348.81	372.72	404.40	505.13
30CORR00364	235.23	267.93	288.58	307.47	331.17	352.77	377.16	452.38
30CORR00357	237.75	271.34	293.27	313.49	339.49	359.75	383.79	450.82
30CORR00347	238.37	272.99	294.83	314.93	339.36	358.26	382.62	446.78
30CORR00337	238.09	272.73	294.35	314.18	338.56	355.90	377.26	433.29
30CORR00326	237.73	273.98	298.16	321.45	351.91	373.80	403.03	484.24

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30CORR00317	239.09	276.68	302.12	327.35	360.47	386.08	422.09	529.37
30CORR00309A	236.76	270.99	293.36	315.03	343.80	365.55	396.37	486.41
30CORR00309B	213.41	238.28	253.48	267.84	284.50	293.36	303.10	323.66
30CORR00301	213.04	237.76	253.21	266.79	280.86	287.30	294.07	315.41
30CORR00294	214.39	241.98	259.66	276.36	298.00	309.70	318.77	342.06
30CORR00286	214.15	241.22	259.15	276.71	298.68	312.44	325.98	356.08
30CORR00279	214.39	242.04	260.36	278.47	302.00	318.12	336.12	377.40
30CORR00271	214.16	241.80	259.92	277.61	301.62	320.32	346.38	409.39
30CORR00264	214.39	242.38	261.01	279.80	306.36	328.21	360.88	459.95
30CORR00256	214.39	242.38	261.01	279.80	306.41	328.76	362.29	465.41
30CORR00249	214.39	242.38	261.00	279.80	306.41	328.75	362.45	471.67
30CORR00241	214.39	242.37	261.00	279.80	306.41	328.75	362.47	484.38
30CORR00236	235.80	273.43	299.40	325.75	363.49	394.72	441.10	603.05
30CORR00235A	235.80	273.43	299.40	325.75	363.49	394.72	441.10	603.05
30CORR00235B	235.80	273.43	299.40	325.75	363.49	394.72	441.10	603.05
30CORR00231	235.80	273.43	299.40	325.75	363.49	394.71	441.10	603.05
30CORR00226	235.80	273.43	299.40	325.75	363.49	394.69	441.10	601.83
30CORR00217	235.80	273.43	299.39	325.75	363.06	394.11	439.91	599.46
30CORR00211	235.80	273.43	299.39	325.75	363.49	394.71	440.98	601.36
30CORR00203	235.80	273.42	299.39	325.75	363.48	394.42	440.28	597.13
30CORR00196	235.80	273.42	299.39	325.75	363.43	394.64	440.69	594.50
30CORR00192	235.80	273.44	299.41	325.74	363.50	394.83	441.31	595.98
30CORR00185	235.80	273.34	299.20	325.33	362.18	392.26	436.51	577.50
30CORR00178	235.65	273.01	298.45	324.01	358.79	386.36	426.41	541.64
30CORR00170A	235.80	273.42	299.39	325.76	363.52	394.72	440.94	566.04
30CORR00170B	235.80	273.42	299.39	325.76	363.52	394.72	441.02	568.01
30CORR00168A	235.80	273.42	299.39	325.76	363.53	394.85	441.47	570.71
30CORR00168B	217.95	251.00	273.57	296.24	328.34	354.56	392.71	479.50
30CORR00161	217.95	251.00	273.57	296.24	328.38	354.78	393.55	482.82
30CORR00158A	217.95	251.00	273.57	296.24	328.38	354.77	393.74	490.26
30CORR00155B	217.95	251.00	273.57	296.24	328.38	354.77	393.74	490.26
30CORR00152	217.96	250.97	273.52	296.24	328.42	354.83	393.80	491.70
30CORR00146	217.95	251.05	273.58	296.29	328.49	354.91	393.88	490.23
30CORR00140	217.96	250.92	273.82	296.40	328.65	355.08	394.01	492.12
30CORR00135	217.95	250.94	274.12	296.79	328.83	355.25	394.13	494.25
30CORR00134A	217.95	250.97	274.17	296.87	328.86	355.27	394.14	492.78
30CORR00134B	217.95	250.97	274.17	296.87	328.86	355.27	394.14	492.78
30CORR00114	220.23	254.77	276.90	299.63	329.90	356.34	394.89	507.67
30CORR00110A	221.18	255.19	277.61	300.15	330.14	356.58	395.42	495.81
30CORR00110B	223.76	258.39	281.24	304.43	334.92	361.95	401.86	507.07
30CORR00103	224.75	259.66	282.00	304.12	335.87	362.24	402.00	504.61
30CORR00097A	225.09	260.64	282.18	304.17	336.80	362.56	402.30	507.95
30CORR00097B	230.30	266.01	287.22	309.22	342.79	367.71	407.43	513.41
30CORR00094A	230.46	265.89	287.27	309.80	343.31	367.86	408.23	513.96
30CORR00094B	233.75	270.96	292.95	316.76	352.58	378.16	421.14	530.08
30CORR00091A	234.24	271.01	293.52	317.48	353.21	378.36	420.60	531.51
30CORR00091B	235.73	273.53	296.58	321.00	357.36	383.03	426.03	538.15
30CORR00090A	235.82	273.59	296.72	321.09	357.43	383.06	426.05	538.02
30CORR00090B	235.82	273.59	296.72	321.09	357.43	383.06	426.05	538.02
30CORR00088	236.19	274.03	297.61	321.28	357.78	383.20	426.18	537.87
30CORR00082A	236.17	274.65	298.60	320.81	360.15	383.55	426.51	537.89
30CORR00082B	237.25	275.79	299.76	321.99	361.36	384.78	427.78	540.01
30CORR00080A	236.91	275.39	299.30	321.74	361.95	385.03	428.30	539.95
30CORR00080B	238.95	277.83	301.94	324.57	365.05	388.37	431.96	544.40
30CORR00072	239.88	277.34	300.39	326.78	364.92	391.00	437.43	543.96
30CORR00072A	240.03	277.43	300.35	327.01	365.12	391.29	437.18	543.92
30CORR00072B	251.38	291.47	313.28	340.96	389.79	410.43	468.89	572.07
30CORR00070	252.36	292.30	313.21	342.60	391.03	412.64	472.11	572.22

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30CORR00059	255.96	297.50	318.29	354.15	391.60	425.28	499.69	574.90
30CORR00049A	255.52	298.85	333.57	369.21	387.36	434.99	485.97	585.37
30CORR00049B	255.57	298.91	333.94	369.55	387.63	435.19	483.25	586.10
30CORR00038	260.44	300.36	351.00	382.92	407.79	441.08	468.51	592.69
30CORR00025	273.62	313.50	358.09	386.50	419.58	445.82	472.71	598.74
Galway_Bay_2	293.71	339.15	358.79	387.88	426.16	458.50	489.35	609.71
Galway_Bay_1	302.83	352.28	365.22	391.31	458.96	465.45	494.40	621.15
30FCUT00116	181.42	213.98	235.20	256.75	286.60	310.60	345.40	460.71
30FCUT00103	181.06	213.29	234.29	255.69	285.31	309.14	343.94	459.26
30FCUT00088	180.77	212.60	233.34	254.54	283.90	307.58	342.26	457.52
30FCUT00074	180.51	211.95	232.53	253.57	282.70	306.23	340.74	456.13
30FCUT00060	180.32	211.37	231.82	252.72	281.61	305.03	339.47	454.92
30FCUT00043	180.10	210.70	231.00	251.74	280.44	303.76	338.07	453.64
30FCUT00025	179.84	209.97	230.19	250.80	279.32	302.52	336.79	452.56
30FCUT00008	179.53	209.03	229.24	249.67	278.07	301.23	335.43	451.37
30EGLI00135	18.98	18.98	18.98	21.15	24.77	28.13	33.95	68.34
30EGLI00128	18.91	18.91	18.91	21.15	24.71	27.76	32.53	55.64
30EGLI00120A	18.51	18.51	18.85	21.15	24.71	27.81	32.60	54.78
30EGLI00120B	18.38	18.38	18.38	19.89	22.84	25.39	29.30	48.65
30EGLI00119	18.26	18.26	18.26	19.89	22.84	25.39	29.30	48.65
30EGLI00113A	17.76	17.76	17.98	19.89	22.84	25.39	29.29	48.65
30EGLI00113B	12.08	12.08	12.98	14.89	17.84	20.39	24.29	35.61
30EGLI00108	11.65	11.65	12.98	14.89	17.84	20.39	24.29	35.60
30EGLI00103	11.16	11.25	12.98	14.89	17.84	20.39	24.29	35.60
30EGLI00103A	11.07	11.25	12.98	14.89	17.84	20.39	24.29	35.60
30EGLI00102B	11.00	11.25	12.98	14.89	17.84	20.39	24.29	35.60
30EGLI00101	10.98	11.25	12.98	14.89	17.84	20.39	24.29	35.66
30EGLI00098	10.81	11.25	12.98	14.89	17.84	20.39	24.29	35.67
30EGLI00094	10.20	11.25	12.98	14.89	17.84	20.39	24.29	35.65
30EGLI00086A	10.20	11.25	12.98	14.89	17.84	20.39	24.29	35.54
30EGLI00086B	4.55	4.55	4.55	4.55	4.99	5.35	5.87	7.10
30EGLI00079	4.49	4.49	4.49	4.54	4.99	5.35	5.87	7.11
30EGLI00072	4.47	4.47	4.47	4.54	4.99	5.35	5.87	7.09
30EGLI00071A	4.43	4.43	4.43	4.54	4.99	5.35	5.87	7.08
30EGLI00071B	4.40	4.40	4.40	4.54	4.99	5.35	5.87	7.09
30EGLI00070	4.36	4.36	4.36	4.54	4.99	5.35	5.87	7.09
30EGLI00063	3.96	3.96	4.22	4.54	4.99	5.35	5.87	7.09
30EGLI00055	3.69	3.90	4.22	4.54	4.99	5.35	5.87	7.08
30EGLI00054A	3.69	3.90	4.22	4.54	4.99	5.35	5.87	7.08
30EGLI00053B	3.69	3.90	4.22	4.54	4.99	5.35	5.87	7.09
30EGLI00052	3.69	3.90	4.22	4.54	4.99	5.35	5.87	7.09
30EGLI00046	3.68	3.90	4.22	4.54	4.98	5.35	5.87	7.08
30EGLI00041A	3.68	3.90	4.22	4.54	4.98	5.35	5.87	7.08
30EGLI00041B	2.85	2.88	2.91	2.95	3.00	3.03	3.08	3.58
30EGLI00040A	2.85	2.88	2.91	2.95	3.00	3.03	3.08	3.58
30EGLI00039B	2.85	2.88	2.91	2.95	3.00	3.03	3.08	3.58
30EGLI00035	3.16	3.23	3.30	3.24	3.53	3.16	3.66	4.37
30EGLI00033A	3.34	3.45	3.49	3.39	3.80	3.27	3.93	4.66
30EGLI00033B	6.95	8.23	8.33	9.69	13.51	13.25	16.40	37.21
30EGLI00031A	7.21	8.62	8.46	9.75	13.93	13.37	16.56	36.55
30EGLI00031B	8.02	9.52	9.27	10.44	14.91	14.09	17.27	37.90
30EGLI00027	8.28	9.97	9.44	10.44	15.47	14.31	18.12	35.04
30EGLI00026A	8.32	10.04	9.46	10.42	15.59	14.36	19.04	34.21
30EGLI00025B	8.34	10.08	9.46	10.42	15.71	14.43	19.42	34.21
30EGLI00018A	8.52	10.47	9.71	10.75	17.28	15.54	20.80	36.16
30EGLI00018B	2.61	8.27	3.29	4.65	9.87	8.83	15.73	18.00
30EGLI00015A	2.57	8.08	3.28	4.64	9.78	8.83	15.39	17.81
30EGLI00014B	1.75	2.27	3.12	4.49	6.59	8.55	11.75	17.17

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30EGLI00005A	1.75	2.26	2.66	3.11	3.86	4.57	5.96	11.06
30EGLI00005B	1.75	2.26	2.66	3.11	3.86	4.57	5.96	11.06
30EGLI00004	1.75	2.26	2.66	3.11	3.86	4.57	5.99	11.13
30EGLI00004A	1.75	2.26	2.66	3.11	3.86	4.57	5.84	10.40
30EGLI00004B	1.75	2.26	2.66	3.11	3.86	4.57	5.84	10.40
30EGLI00000	1.77	2.27	2.67	3.13	3.87	4.59	6.19	11.99
30SHEA00004	11.88	17.06	12.77	13.62	24.17	18.74	32.56	36.10
30SHEA00002	11.95	17.19	12.83	13.71	24.33	18.87	32.53	36.20
30SHEA00002W	12.19	17.49	12.92	13.94	24.67	19.13	31.72	36.38
30SHEA00001A	12.20	17.50	12.92	13.95	24.67	19.14	31.71	36.38
30NUNS00052	5.68	5.68	5.68	5.68	5.68	5.68	5.68	13.05
30NUNS00044	5.73	5.73	5.73	5.73	5.73	5.73	5.73	12.92
30NUNS00043A	5.81	5.81	5.81	5.81	5.81	5.81	5.81	13.06
30NUNS00043B	5.81	5.81	5.81	5.81	5.81	5.81	5.81	13.06
30NUNS00041	5.93	5.93	5.93	5.93	5.93	5.93	5.93	13.05
30NUNS00038	6.01	6.01	6.01	6.01	6.01	6.01	6.01	13.05
30NUNS00037A	6.00	6.00	6.00	6.01	6.01	6.01	6.01	13.05
30NUNS00037B	6.00	6.00	6.00	6.01	6.01	6.01	6.01	13.05
30NUNS00037	6.00	6.00	6.00	6.00	6.00	6.00	6.00	13.07
30NUNS00027	5.64	5.64	5.64	5.64	5.64	5.64	5.64	12.87
30NUNS00017	5.18	5.18	5.18	5.18	5.18	5.18	5.18	12.11
30NUNS00016A	5.08	5.08	5.08	5.08	5.08	5.08	5.08	9.46
30NUNS00013A	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
30NUNS00012B	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
30NUNS00011	5.01	5.03	5.01	5.01	5.07	5.01	5.07	5.71
30NUNS00009	5.02	5.06	5.05	5.03	5.28	5.04	5.31	5.92
30NUNS00005	5.09	5.13	5.12	5.08	5.63	5.09	5.42	6.18
30NUNS00002	5.28	5.27	5.19	5.12	5.85	5.13	5.24	6.48
30NUNS00000	5.57	5.55	5.43	5.15	5.97	5.16	5.48	6.69
30NUNS00000A	5.60	5.60	5.45	5.16	5.98	5.16	5.50	6.72
30GMRA00048	6.47	7.35	8.76	10.35	12.86	15.04	18.42	28.50
30GMRA00043	6.47	7.35	8.76	10.35	12.86	15.04	18.42	28.61
30GMRA00033	6.45	7.35	8.76	10.35	12.86	15.04	18.42	28.62
30GMRA00027A	6.44	7.35	8.76	10.35	12.86	15.04	18.41	27.37
30GMRA00027B	5.18	5.71	6.54	7.54	9.19	10.67	12.96	19.23
30GMRA00024A	5.18	5.71	6.54	7.54	9.19	10.67	12.96	18.91
30GMRA00024C	5.18	5.71	6.54	7.54	9.19	10.67	12.96	18.31
30GMRA00021B	5.18	5.71	6.54	7.54	9.19	10.67	12.96	18.31
30GMRA00019	5.18	5.71	6.54	7.54	9.19	10.67	12.96	18.82
30GMRA00016	5.18	5.71	6.54	7.54	9.19	10.67	12.96	18.94
30GMRA00015A	5.18	5.71	6.54	7.54	9.19	10.67	12.96	18.80
30GMRA00015B	5.90	6.50	7.20	7.83	8.71	9.41	10.43	12.89
30GMRA00012A	5.90	6.50	7.20	7.83	8.71	9.41	10.43	12.89
30GMRA00012B	4.28	4.84	5.49	6.09	6.91	7.58	8.54	10.90
30GMRA00010A	4.27	4.84	5.49	6.09	6.91	7.58	8.54	10.90
30GMRA00010B	3.85	4.44	5.09	5.68	6.50	7.16	8.13	10.43
30GMRA00006	3.85	4.44	5.09	5.68	6.50	7.16	8.13	10.44
30GMRA00005A	3.85	4.44	5.09	5.68	6.50	7.16	8.13	10.43
30GMRA00005B	3.13	3.57	4.05	4.48	5.05	5.51	6.18	7.78
30GMRA00004A	3.13	3.57	4.05	4.48	5.05	5.51	6.18	7.78
30GMRA00004B	1.57	1.98	2.43	2.84	3.38	3.81	4.45	5.98
30GMRA00001A	1.57	1.98	2.43	2.84	3.38	3.81	4.45	5.98
30DOMI00009D	0.43	0.43	0.44	0.45	0.46	0.47	0.48	0.52
30DOMI00007	0.48	0.50	0.51	0.51	0.55	0.52	0.57	0.70
30DOMI00002	0.71	0.77	0.76	0.68	0.87	0.68	0.80	1.35
30DOMI00002A	0.74	0.80	0.79	0.69	0.90	0.69	0.82	1.35
30DOMI00002B	0.74	0.80	0.79	0.69	0.90	0.69	0.82	1.35
30DOMI00001A	0.81	0.91	0.84	0.72	0.98	0.72	0.85	1.35

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30CLOP00064	23.34	32.71	39.88	47.19	59.31	72.20	93.31	162.83
30CLOP00059	21.95	28.82	33.69	38.89	49.04	61.36	81.66	148.11
30CLOP00049	21.26	25.00	26.81	28.34	30.25	32.83	38.65	60.96
30CLOP00042	24.75	34.57	40.72	45.96	52.16	57.73	68.74	109.52
30CLOP00032	25.19	35.82	43.31	51.26	61.60	70.67	84.88	131.77
30CLOP00022	25.17	36.01	44.24	52.35	63.19	72.38	86.36	136.84
30CLOP00019A	25.19	36.42	44.73	52.83	63.53	72.41	85.73	134.45
30CLOP00019B	21.42	31.01	38.18	45.14	54.91	63.14	75.79	123.45
30CLOP00013	20.90	28.68	33.53	38.77	46.26	51.59	59.60	90.12
30CLOP00008	21.42	31.05	38.39	45.95	57.08	65.97	78.65	126.45
30CLOP00002	21.41	31.05	38.39	45.95	57.08	65.97	78.63	118.68
30CAST00001	3.77	5.41	6.55	7.69	8.63	9.27	9.94	11.65
30CAST00008A	3.77	5.41	6.55	7.69	8.63	9.42	10.41	13.02
30CAST00008B	3.77	5.41	6.55	7.69	8.63	9.42	10.41	13.02
30CAST00014	3.77	5.41	6.55	7.69	8.63	9.42	10.41	13.02
30CAST00015A	3.77	5.41	6.55	7.69	8.63	9.42	10.41	12.22
30CAST00017B	3.77	5.41	6.55	7.69	8.63	9.42	10.41	12.22
30CAST00018A	3.77	5.41	6.55	7.69	8.63	9.42	10.41	12.74
30CAST00018B	3.77	5.41	6.55	7.69	8.63	9.42	10.41	12.74
30CAST00023	3.77	5.41	6.55	7.69	8.62	9.42	10.40	12.94
30CAST00027	3.77	5.41	6.55	7.69	8.62	9.42	10.40	27.00
30CAST00029A	3.77	5.41	6.55	7.69	8.62	9.42	10.40	12.94
30CAST00034B	3.77	5.41	6.55	7.69	8.62	9.42	10.40	12.94
30CAST00036	3.77	5.41	6.55	7.69	8.62	9.41	10.40	11.49
30CAST00042	3.77	5.41	6.55	7.69	8.62	9.41	10.40	16.35
30CAST00052	3.77	5.41	6.55	7.68	8.62	9.41	10.26	10.87
30CAST00062	3.77	5.40	6.55	7.64	8.39	9.07	10.05	20.77
30CAST00072	3.77	5.40	6.53	7.67	8.53	9.08	10.03	14.47
30CAST00080	3.77	5.40	6.53	7.65	8.50	9.17	9.89	28.40
30CAST00084	3.77	5.40	6.53	7.65	8.55	9.26	10.08	15.75
30CAST00085A	3.77	5.40	6.53	7.65	8.57	9.34	10.24	16.59
30CAST00085B	3.77	5.40	6.53	7.65	8.57	9.34	10.24	16.59
30CAST00088	3.77	5.40	6.53	7.65	8.57	9.34	10.26	17.26
30CAST00095	3.77	5.40	6.52	7.65	8.56	9.17	9.64	15.32
30CAST00102	3.77	5.40	6.52	7.64	8.48	8.89	9.18	14.09
30CAST00110	3.77	5.39	6.52	7.64	8.41	8.82	9.04	11.73
30CAST00114	3.77	5.39	6.52	7.64	8.55	9.31	10.18	15.60
30CAST00115A	3.77	5.39	6.52	7.64	8.55	9.31	10.18	18.15
30CAST00115B	3.77	5.39	6.52	7.64	8.55	9.31	10.18	18.15
30CAST00120	3.77	5.39	6.52	7.64	8.55	9.31	10.18	20.07
30CAST00127	3.77	5.39	6.52	7.64	8.54	9.23	9.82	18.16
30CAST00136	3.77	5.39	6.52	7.63	8.54	9.31	10.17	20.19
30CAST00144	3.77	5.39	6.51	7.63	8.54	9.30	10.17	26.75
30CAST00152	3.77	5.39	6.51	7.63	8.54	9.30	10.17	27.84
30CAST00159	3.77	5.39	6.51	7.63	8.54	9.30	10.17	24.87
30CAST00159A	3.77	5.39	6.51	7.63	8.54	9.30	10.17	24.76
30CAST00159B	3.77	5.39	6.51	7.63	8.54	9.30	10.17	24.76
30CAST00160	3.77	5.39	6.51	7.63	8.54	9.30	10.17	26.14
30CAST00161A	3.77	5.39	6.51	7.63	8.54	9.30	10.17	26.14
30CAST00161B	3.77	5.39	6.51	7.63	8.54	9.30	10.17	26.14
30CAST00163	3.77	5.39	6.51	7.63	8.54	9.30	10.17	31.20
30CAST00170	3.77	5.39	6.51	7.62	8.54	9.30	10.16	39.18
30CAST00177	3.77	5.38	6.51	7.62	8.53	9.13	10.00	40.99
30CAST00182	3.77	5.38	6.51	7.62	8.53	9.30	10.16	34.61
30CAST00183A	3.76	5.38	6.51	7.62	8.53	9.30	10.16	22.46
30CAST00183B	3.76	5.38	6.51	7.62	8.53	9.30	10.16	22.46
30CAST00185	3.76	5.38	6.51	7.62	8.53	9.30	10.16	23.46
30CAST00192	3.76	5.38	6.51	7.62	8.53	9.30	10.16	22.99

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30CAST00200	3.76	5.38	6.50	7.62	8.53	9.29	10.15	42.00
30CAST00207	3.76	5.38	6.50	7.61	8.53	9.29	10.15	41.72
30CAST00215	3.76	5.38	6.50	7.61	8.52	9.29	10.15	42.87
30CAST00222	3.76	5.38	6.50	7.61	8.52	9.29	10.14	39.08
30CAST00229	3.76	5.38	6.50	7.60	8.52	9.29	10.14	32.79
30CAST00237	3.76	5.37	6.50	7.60	8.52	9.29	10.13	24.95
30CAST00245	3.76	5.37	6.49	7.60	8.59	9.45	10.47	35.87
30CAST00252	3.76	5.37	6.49	7.60	8.51	9.28	10.05	27.49
30CAST00260	3.76	5.37	6.49	7.58	8.48	9.22	10.01	30.55
30CAST00267	3.76	5.37	6.49	7.57	8.42	9.12	9.84	33.11
30CAST00275	3.75	5.37	6.48	7.59	8.50	9.28	10.10	29.15
30CAST00286	3.75	5.36	6.48	7.58	8.44	9.15	9.79	28.55
30CAST00295	3.75	5.36	6.48	7.58	8.47	9.16	9.83	27.88
30CAST00301	3.75	5.36	6.48	7.58	8.49	9.27	10.10	28.15
30CAST00302A	3.75	5.36	6.48	7.58	8.49	9.27	10.10	25.82
30CAST00302B	3.75	5.36	6.48	7.58	8.49	9.27	10.10	25.82
30CAST00305	3.75	5.36	6.48	7.58	8.49	9.27	10.10	25.98
30CAST00312	3.75	5.36	6.48	7.56	8.41	9.11	9.84	22.24
30CAST00321	3.75	5.36	6.47	7.55	8.37	9.11	9.63	23.47
30CAST00327	3.75	5.36	6.47	7.55	8.35	9.05	9.67	19.53
30CAST00337	3.75	5.35	6.41	7.36	8.03	8.66	9.21	30.33
30CAST00347	3.75	5.35	6.47	7.52	8.31	8.96	9.37	19.85
30CAST00357	3.75	5.35	6.47	7.53	8.37	9.15	9.67	26.61
30CAST00367	3.75	5.35	6.37	7.32	8.02	8.51	8.94	13.20
30CAST00377	3.75	5.35	6.47	7.56	8.43	9.07	9.85	18.80
30CAST00387	3.75	5.35	6.46	7.52	8.38	9.03	9.92	12.40
30CAST00397	3.75	5.35	6.46	7.56	8.47	9.14	10.06	19.98
30CAST00397A	3.75	5.35	6.46	7.56	8.47	9.14	10.06	20.00
30CAST00397B	3.75	5.35	6.46	7.56	8.47	9.14	10.06	20.00
30CAST00398	3.75	5.35	6.46	7.56	8.47	9.14	10.06	19.98
30SALR00051	4.80	5.66	6.98	8.38	10.42	12.16	14.82	23.36
30SALR00061	4.79	5.66	6.98	8.38	10.42	12.16	14.82	23.36
30SALR00060A	4.79	5.66	6.98	8.38	10.42	12.16	14.82	23.36
30SALR00060B	4.79	5.66	6.98	8.38	10.42	12.16	14.82	23.36
30SALR00060	4.79	5.66	6.98	8.38	10.42	12.16	14.82	23.36
30SALR00057	4.79	5.66	6.98	8.38	10.42	12.16	14.82	22.62
30SALR00054	4.78	5.66	6.98	8.38	10.42	12.16	14.82	22.10
30SALR00054A	4.78	5.66	6.98	8.38	10.42	12.16	14.82	22.10
30SALR00054B	4.78	5.66	6.98	8.38	10.42	12.16	14.82	22.10
30SALR00053	4.78	5.66	6.98	8.38	10.42	12.16	14.82	22.10
30SALR00045	4.77	5.66	6.98	8.38	10.42	12.16	14.82	21.48
30SALR00046	4.77	5.66	6.98	8.38	10.42	12.16	14.82	21.48
30SALR00045A	4.77	5.66	6.98	8.38	10.42	12.16	14.82	21.48
30SALR00045B	1.72	1.73	1.83	1.91	2.02	2.10	2.21	2.44
30SALR00044	1.72	1.73	1.83	1.91	2.02	2.10	2.21	2.43
30SALR00037	1.69	1.73	1.83	1.91	2.02	2.10	2.21	2.42
30SALR00031	1.66	1.73	1.83	1.91	2.02	2.10	2.20	2.47
30SALR00027	1.66	1.73	1.83	1.91	2.02	2.10	2.20	2.42
30SALR00026A	1.66	1.73	1.83	1.91	2.02	2.10	2.20	2.42
30SALR00026B	1.66	1.73	1.83	1.91	2.02	2.10	2.20	2.42
30SALR00026	1.66	1.73	1.83	1.91	2.02	2.10	2.20	2.42
30SALR00024	1.66	1.73	1.83	1.91	2.02	2.10	2.20	2.42
30SALR00024W	1.66	1.73	1.83	1.91	2.02	2.10	2.20	2.42
30SALR00023A	1.66	1.73	1.83	1.91	2.02	2.10	2.20	2.42
30SALR00023B	1.66	1.73	1.83	1.91	2.02	2.10	2.20	2.42
30SALR00022	1.66	1.73	1.83	1.91	2.02	2.10	2.21	2.43
30SALR00020	1.66	1.73	1.83	1.91	2.02	2.10	2.22	4.02
30SALR00015	1.66	1.73	1.83	1.91	2.02	2.10	2.26	6.95

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30SALR00012A	1.66	1.73	1.83	1.91	2.02	2.10	2.28	8.66
30SALR00012B	1.12	1.14	1.17	1.19	1.21	1.23	1.64	9.40
30SALR00010	1.12	1.14	1.17	1.19	1.21	1.23	1.64	9.55
30SALR00009	1.12	1.14	1.17	1.19	1.21	1.23	1.64	9.51
30SALR00008A	1.12	1.14	1.17	1.19	1.21	1.23	1.64	9.87
30SALR00007B	1.12	1.14	1.17	1.19	1.21	1.23	1.64	9.87
30SALR00007	1.12	1.14	1.17	1.19	1.21	1.23	1.64	9.37
30SALR00003	1.12	1.14	1.17	1.19	1.21	1.23	1.64	8.06
30SALR00001	1.12	1.14	1.17	1.19	1.21	1.23	1.64	4.93
30SALR00001A	1.12	1.14	1.17	1.19	1.21	1.23	1.64	5.26
30SALR00000A	1.12	1.14	1.17	1.19	1.21	1.23	1.64	5.26
30FRIA00034	3.10	3.92	5.16	6.46	8.41	10.07	12.61	19.97
30FRIA00033	3.10	3.92	5.16	6.46	8.41	10.07	12.61	19.97
30FRIA00030A	3.09	3.92	5.16	6.46	8.41	10.07	12.61	19.97
30FRIA00023B	3.09	4.03	5.23	6.50	8.53	10.10	12.67	19.97
30FRIA00021	3.09	4.16	5.29	6.57	8.63	10.11	12.69	19.97
30FRIA00015	3.09	4.51	5.43	6.71	8.77	10.16	12.76	19.97
30FRIA00015A	3.09	4.53	5.44	6.72	8.78	10.17	12.76	19.97
30FRIA00015B	3.09	4.53	5.44	6.72	8.78	10.17	12.76	19.97
30FRIA00014	3.09	4.56	5.46	6.73	8.79	10.17	12.77	19.97
30FRIA00014A	3.09	4.58	5.47	6.74	8.79	10.18	12.78	19.97
30FRIA00012B	3.09	4.65	5.52	6.75	8.82	10.19	12.79	19.97
30FRIA00011	3.09	4.70	5.56	6.75	8.85	10.20	12.80	20.06
30FRIA00005	3.15	4.94	5.66	6.80	9.03	10.25	12.87	18.70
30FRIA00005A	3.16	4.96	5.66	6.81	9.05	10.26	12.87	18.68
30FRIA00005B	3.16	4.96	5.66	6.81	9.05	10.26	12.87	18.68
30FRIA00004	3.19	4.99	5.66	6.83	9.08	10.26	12.88	18.69
30FRIA00002	3.28	5.06	5.67	6.93	9.24	10.30	12.92	18.68
30FRIA00001A	3.29	5.06	5.68	6.95	9.27	10.31	12.93	18.68
30FRIA00000B	3.29	5.06	5.68	6.95	9.27	10.31	12.93	18.68
30FRIA00000W	3.29	5.06	5.68	6.96	9.27	10.31	12.93	18.69
30SALW00103B	1.38	1.75	2.00	2.25	2.59	2.85	3.12	3.79
30SALW00102	1.38	1.75	2.00	2.25	2.59	2.85	3.12	3.79
30SALW00101	1.38	1.75	2.00	2.25	2.59	2.85	3.12	3.78
30SALW00100	1.38	1.75	2.00	2.25	2.59	2.85	3.12	3.80
30SALW00099A	1.38	1.75	2.00	2.25	2.59	2.85	3.12	3.81
30SALW00096B	1.38	1.75	2.00	2.25	2.59	2.85	3.12	3.81
30SALW00095	1.38	1.75	2.00	2.25	2.59	2.85	3.12	3.81
30SALW00094	1.38	1.75	2.00	2.25	2.59	2.85	3.12	3.81
30SALW00094A	1.38	1.75	2.00	2.25	2.59	2.85	3.12	3.81
30SALW00093B	1.38	1.75	2.00	2.25	2.59	2.85	3.12	3.81
30SALW00093	1.38	1.75	2.00	2.25	2.59	2.85	3.12	3.81
30SALW00092	1.38	1.75	2.00	2.25	2.59	2.84	3.11	4.34
30SALW00092B	1.38	1.75	2.00	2.25	2.59	2.84	3.11	3.74
30SALW00091B	1.38	1.75	2.00	2.25	2.59	2.84	3.11	3.74
30SALW00091	1.38	1.75	2.00	2.24	2.59	2.84	3.11	3.52
30SALW00090	1.38	1.75	2.00	2.24	2.58	2.84	3.11	3.52
30SALW00090A	1.38	1.75	1.99	2.24	2.58	2.84	3.10	3.52
30SALW00090B	1.38	1.75	1.99	2.24	2.58	2.84	3.10	3.52
30SALW00089	1.38	1.75	1.99	2.24	2.58	2.84	3.10	3.51
30SALW00084	1.38	1.74	1.99	2.24	2.58	2.82	3.08	3.36
30SALW00083A	1.38	1.74	1.99	2.24	2.58	2.82	3.08	3.35
30SALW00082B	1.38	1.74	1.99	2.24	2.58	2.82	3.08	3.35
30SALW00081	1.38	1.74	1.99	2.24	2.58	2.82	3.07	3.34
30SALW00077	1.38	1.74	1.99	2.24	2.57	2.81	3.06	3.30
30SALW00076A	1.37	1.74	1.99	2.24	2.57	2.81	3.06	3.19
30SALW00075B	1.37	1.74	1.99	2.24	2.57	2.81	3.06	3.19
30SALW00074	1.37	1.74	1.99	2.24	2.57	2.81	3.06	3.21

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30SALW00068	1.37	1.74	1.99	2.23	2.57	2.81	3.06	3.24
30SALW00067A	1.37	1.74	1.99	2.23	2.57	2.81	3.06	3.24
30SALW00065B	1.37	1.74	1.99	2.23	2.57	2.81	3.06	3.24
30SALW00064	1.37	1.74	1.99	2.23	2.57	2.81	3.06	3.24
30SALW00059	1.37	1.74	1.99	2.23	2.57	2.81	3.07	3.26
30SALW00058A	1.37	1.74	1.99	2.23	2.57	2.82	3.07	3.26
30SALW00057B	1.37	1.74	1.99	2.23	2.57	2.82	3.07	3.26
30SALW00057	1.37	1.74	1.99	2.23	2.57	2.82	3.08	3.27
30SALW00051	1.37	1.74	1.99	2.24	2.57	2.83	3.08	3.28
30SALW00051A	1.37	1.74	1.99	2.24	2.57	2.83	3.09	3.28
30SALW00050B	1.37	1.75	1.99	2.24	2.57	2.83	3.09	3.28
30SALW00049A	1.37	1.75	2.00	2.24	2.58	2.83	3.09	3.28
30SALW00049B	1.37	1.75	2.00	2.24	2.58	2.83	3.09	3.28
30SALW00047	1.37	1.75	2.00	2.25	2.58	2.84	3.09	3.29
30SALW00047A	1.37	1.76	2.00	2.25	2.58	2.84	3.10	3.29
30SALW00047B	1.37	1.76	2.00	2.25	2.58	2.84	3.10	3.49
30SALW00044A	1.43	1.80	2.02	2.26	2.59	2.86	3.12	4.27
30SALW00044B	1.53	2.30	2.88	3.52	4.46	5.28	6.42	10.16
30SALW00036A	1.53	2.32	2.92	3.57	4.49	5.31	6.44	9.41
30SALW00035B	1.53	2.32	2.92	3.58	4.49	5.31	6.45	9.40
30SALW00027A	1.65	2.39	3.02	3.65	4.57	5.38	6.51	9.95
30SALW00027B	1.65	2.39	3.02	3.65	4.57	5.38	6.51	9.95
30SALW00022A	1.85	2.49	3.14	3.77	4.61	5.42	6.54	9.51
30SALW00021B	1.92	2.56	3.18	3.78	4.62	5.43	6.54	9.51
30SALW00000A	2.58	3.20	3.62	4.28	4.79	5.57	6.66	11.58
30MACT00011X	1.26	1.64	2.22	2.82	3.66	4.37	5.45	8.22
MACT00011*1	1.26	1.64	2.22	2.82	3.66	4.37	5.45	8.11
30MACT00011	1.26	1.64	2.22	2.82	3.66	4.37	5.45	8.11
30MACT00011A	1.26	1.64	2.22	2.82	3.66	4.37	5.45	8.11
30MACT00010B	1.26	1.64	2.22	2.82	3.66	4.37	5.45	8.11
30MACT00010A	1.26	1.64	2.22	2.82	3.66	4.37	5.45	8.12
MACT00008L	0.26	0.35	0.48	0.61	0.80	0.95	1.18	1.77
MACT00006AL	0.26	0.35	0.48	0.61	0.80	0.95	1.18	1.70
MACT00003BL	0.26	0.35	0.48	0.61	0.80	0.95	1.18	1.70
MACT00002L	0.26	0.35	0.48	0.61	0.80	0.95	1.18	1.71
MACT00008R	0.28	0.38	0.55	0.71	0.94	1.13	1.41	2.04
MACT00006AR	0.28	0.38	0.55	0.71	0.94	1.13	1.41	2.04
MACT00003BR	0.28	0.38	0.55	0.71	0.94	1.13	1.41	2.04
MACT00002R	0.28	0.38	0.55	0.71	0.94	1.13	1.41	2.04
30MACT00002	0.55	0.86	1.59	2.56	4.20	5.69	8.06	28.01
30MACT00001	0.55	0.87	1.60	2.57	4.21	5.69	8.06	28.02
30SMRN00015	0.55	0.98	1.61	2.57	4.21	5.70	8.07	28.02
30SMRN00015A	0.55	1.03	1.64	2.58	4.21	5.70	8.07	28.01
30SMRN00014B	0.55	1.11	1.68	2.59	4.23	5.71	8.07	28.01
30SMRN00014	0.55	1.14	1.70	2.59	4.25	5.72	8.07	28.01
30SMRN00009	0.92	1.57	1.87	2.88	4.84	5.80	8.15	28.02
30SMRN00002A	1.23	1.85	1.93	3.10	5.51	5.87	8.25	29.40
30SMRN00002B	3.44	4.58	4.95	6.47	9.43	10.04	12.96	34.63
30SMRN00000	3.60	4.78	5.02	6.55	9.71	10.09	13.06	33.66
30VARA00103B	1.62	1.67	1.71	1.75	1.80	1.84	1.89	2.17
30VARA00100	1.62	1.67	1.71	1.75	1.80	1.84	1.89	2.13
30VARA00070	1.62	1.67	1.71	1.75	1.80	1.84	1.89	2.12
30VARA00060	1.62	1.67	1.71	1.75	1.80	1.84	1.89	2.12
30VARA00050D	1.62	1.67	1.71	1.75	1.80	1.84	1.89	2.12
30VARA00040A	1.62	1.67	1.71	1.75	1.80	1.84	1.89	2.12
30VARA00040B	1.62	1.67	1.71	1.75	1.80	1.84	1.89	2.12
30VARA00030A	1.62	1.67	1.71	1.75	1.80	1.84	1.89	2.12
30VARA00030B	1.62	1.67	1.71	1.75	1.80	1.84	1.89	2.12

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30VARA00020A	1.62	1.67	1.71	1.75	1.80	1.84	1.89	2.12
30VARA00020B	1.62	1.67	1.71	1.75	1.80	1.84	1.89	2.12
30VARA00015O	1.62	1.67	1.71	1.75	1.80	1.84	1.89	2.12
30VARA00011	1.62	1.68	1.71	1.76	1.84	1.84	1.90	2.12
30VARA00010	1.62	1.68	1.71	1.77	1.86	1.84	1.91	2.13
30VARA00008	1.62	1.72	1.72	1.79	1.93	1.85	1.93	2.13

Table A-2: 1D model peak MRFS flows

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30CORR00951	83.75	102.52	114.77	127.33	145.82	159.99	180.04	239.13
30CORR00939	83.10	101.24	113.26	125.51	143.62	157.50	176.99	235.46
30CORR00924	82.53	100.06	111.77	123.58	141.12	154.53	173.35	231.18
30CORR00897	81.43	98.03	109.16	120.41	137.36	150.21	168.69	225.71
30CORR00881	80.85	96.99	107.84	118.83	135.45	148.14	166.42	223.49
30CORR00861	80.47	96.15	106.68	117.32	133.46	145.82	164.08	221.10
30CORR00842	80.06	95.21	105.26	115.61	131.37	143.54	161.55	218.74
30CORR00822	79.40	93.75	103.37	113.42	129.12	141.14	158.96	216.36
30CORR00806	78.53	92.14	101.49	111.41	127.04	138.91	156.61	214.26
30CORR00788	77.48	90.40	99.50	109.34	124.85	136.64	154.22	212.21
30CORR00772	76.55	89.09	98.10	107.87	123.35	135.12	152.61	210.87
30CORR00757	75.62	87.92	96.92	106.66	122.10	133.80	151.24	209.83
30CORR00741	74.89	87.09	96.04	105.71	121.14	132.87	150.20	208.97
30CORR00722	74.20	86.32	95.20	104.89	120.26	132.01	149.23	208.26
30CORR00705	73.83	85.89	94.73	104.41	119.75	131.50	148.67	207.69
30CORR00683	73.50	85.52	94.32	103.99	119.29	131.06	148.20	207.29
30CORR00662	73.27	85.31	94.14	103.78	119.07	130.82	147.97	207.08
30CORR00642	73.13	85.20	94.08	103.69	118.97	130.73	147.84	206.98
30CORR00622	73.10	85.19	94.09	103.71	118.92	130.67	147.81	206.94
30CORR00605	73.09	85.22	94.13	103.75	118.87	130.63	147.80	206.96
30CORR00588A	73.16	85.36	94.26	103.92	118.82	130.70	147.89	207.01
30CORR00588B	281.38	331.45	364.82	399.10	448.23	488.82	548.51	752.95
30CORR00576	281.17	331.20	364.55	398.83	447.93	488.52	548.21	752.71
30CORR00566	280.98	330.97	364.33	398.60	447.66	488.26	547.93	752.49
30CORR00557	280.82	330.78	364.12	398.38	447.41	488.02	547.72	752.29
30CORR00547	280.68	330.62	363.95	398.18	447.19	487.83	547.50	752.11
30CORR00537	280.57	330.48	363.79	398.01	446.97	487.63	547.25	752.00
30CORR00527	280.45	330.33	363.62	397.83	446.72	487.39	547.09	751.85
30CORR00517	280.36	330.22	363.49	397.70	446.55	487.22	546.94	751.73
30CORR00506	280.28	330.13	363.39	397.61	446.43	487.11	546.82	751.63
30CORR00500	280.23	330.05	363.31	397.54	446.34	487.02	546.72	751.56
30CORR00492	280.20	330.02	363.28	397.52	446.30	486.98	546.67	751.52
30CORR00482	280.17	329.98	363.24	397.44	446.25	486.91	546.61	751.48
30CORR00472	280.15	329.95	363.21	397.39	446.20	486.88	546.57	751.44
30CORR00465	280.13	329.92	363.17	397.36	446.16	486.83	546.52	751.40
30CORR00457	280.11	329.89	363.14	397.33	446.13	486.79	546.48	751.37
30CORR00449	280.09	329.87	363.12	397.30	446.08	486.75	546.44	751.34
30CORR00442	280.08	329.85	363.10	397.28	446.06	486.73	546.41	751.31
30CORR00434	280.07	329.85	363.10	397.27	446.05	486.71	546.39	751.30
30CORR00426	280.07	329.84	363.08	397.27	446.04	486.70	546.38	751.28
30CORR00419	280.06	329.83	363.08	397.26	446.03	486.68	546.65	748.18
30CORR00412	280.06	329.83	363.07	397.25	446.02	486.68	546.36	748.97
30CORR00404	280.05	329.82	363.06	397.24	445.55	486.13	545.15	744.20
30CORR00395	280.04	329.81	363.06	397.23	446.00	486.67	546.27	736.15
30CORR00387	280.04	329.81	363.03	396.74	443.35	481.87	539.54	729.01
30CORR00381	278.47	325.46	355.43	385.57	427.51	461.92	511.01	669.75

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30CORR00372	274.16	315.69	341.38	367.04	400.88	428.16	464.13	584.10
30CORR00364	268.39	304.21	324.80	347.55	374.43	395.37	422.29	513.18
30CORR00357	271.81	310.15	332.41	354.66	381.05	399.50	423.67	502.69
30CORR00347	273.46	311.57	332.79	353.14	380.08	397.94	420.49	494.12
30CORR00337	273.24	310.81	332.11	350.92	375.14	390.10	409.50	477.69
30CORR00326	274.71	317.94	344.63	368.20	399.39	421.23	450.47	543.71
30CORR00317	277.55	323.75	352.42	379.97	417.91	446.42	486.49	611.72
30CORR00309A	271.47	311.57	336.58	360.03	392.73	416.63	450.47	555.57
30CORR00309B	237.83	264.68	279.48	289.48	301.81	308.53	314.79	338.54
30CORR00301	237.65	263.63	276.26	283.73	293.34	299.07	306.04	330.67
30CORR00294	241.86	273.08	292.27	305.45	317.98	323.02	331.92	361.84
30CORR00286	241.09	273.41	292.71	307.87	324.77	332.78	343.26	377.51
30CORR00279	241.96	275.16	295.68	313.13	334.31	345.72	360.55	403.43
30CORR00271	241.74	274.28	295.06	315.00	343.73	362.38	385.57	438.71
30CORR00264	242.37	276.49	299.42	322.61	357.11	383.09	420.58	519.40
30CORR00256	242.37	276.50	299.46	323.11	358.44	385.96	424.59	545.87
30CORR00249	242.37	276.50	299.45	323.13	358.50	386.60	426.60	557.48
30CORR00241	242.37	276.50	299.46	323.11	358.49	387.65	432.34	586.40
30CORR00236	274.32	322.06	354.54	387.78	435.65	475.10	534.75	735.57
30CORR00235A	274.31	322.06	354.54	387.77	435.65	475.11	534.75	735.56
30CORR00235B	274.31	322.06	354.54	387.77	435.65	475.11	534.75	735.56
30CORR00231	274.32	322.06	354.54	387.76	435.65	475.10	534.75	735.59
30CORR00226	274.32	322.06	354.54	387.76	435.65	474.99	534.15	732.90
30CORR00217	274.31	322.01	354.13	387.29	434.53	473.45	532.13	729.91
30CORR00211	274.31	322.06	354.54	387.78	435.54	474.74	533.75	732.43
30CORR00203	274.31	322.06	354.54	387.46	434.92	473.53	531.42	722.78
30CORR00196	274.31	322.06	354.49	387.69	435.30	473.52	529.52	720.25
30CORR00192	274.34	322.05	354.55	387.91	435.84	475.10	533.08	715.99
30CORR00185	274.20	321.58	353.27	385.34	431.31	468.10	519.55	690.60
30CORR00178	273.74	320.15	349.96	379.34	421.71	454.71	498.44	616.10
30CORR00170A	274.31	322.07	354.57	387.78	435.45	473.79	522.79	633.14
30CORR00170B	274.31	322.07	354.57	387.76	435.52	474.09	523.71	635.92
30CORR00168A	274.31	322.07	354.58	387.92	435.93	474.81	525.28	642.91
30CORR00168B	250.68	291.28	318.42	345.78	388.24	418.46	453.50	513.42
30CORR00161	250.68	291.28	318.46	346.01	388.99	419.80	455.75	517.76
30CORR00158A	250.68	291.28	318.46	346.01	389.11	420.85	459.63	532.76
30CORR00155B	250.68	291.28	318.46	346.01	389.11	420.85	459.63	532.76
30CORR00152	250.60	291.32	318.57	346.14	388.94	421.18	459.46	532.77
30CORR00146	250.55	291.50	318.77	346.30	388.88	421.44	459.34	532.72
30CORR00140	250.85	291.86	319.10	346.58	388.65	421.81	459.51	535.14
30CORR00135	251.25	292.20	319.41	346.83	388.55	422.16	462.12	537.23
30CORR00134A	251.30	292.24	319.45	346.86	388.54	422.20	461.13	537.19
30CORR00134B	251.30	292.24	319.45	346.86	388.54	422.20	461.13	537.19
30CORR00114	253.30	294.04	321.06	348.18	387.78	425.91	473.08	539.43
30CORR00110A	254.72	294.44	321.42	348.48	387.68	425.64	461.22	539.01
30CORR00110B	257.79	299.05	327.21	355.51	393.42	433.38	470.08	552.86
30CORR00103	258.98	299.51	327.63	355.92	393.15	441.26	471.14	558.42
30CORR00097A	260.41	301.59	328.93	356.36	392.94	460.94	472.98	563.26
30CORR00097B	266.22	307.57	334.87	361.55	397.85	474.07	477.98	569.30
30CORR00094A	267.08	308.73	335.22	361.77	397.89	474.90	478.41	569.84
30CORR00094B	272.67	316.54	344.56	372.39	410.03	492.76	492.73	582.11
30CORR00091A	273.45	317.69	344.99	372.67	409.90	496.40	494.00	584.34
30CORR00091B	276.16	321.30	349.15	377.43	415.16	508.63	495.96	576.77
30CORR00090A	276.24	321.48	349.24	377.48	415.16	509.41	495.95	576.71
30CORR00090B	276.24	321.48	349.24	377.48	415.16	509.41	495.95	576.71
30CORR00088	276.72	322.46	350.36	377.65	415.13	511.15	500.42	577.35
30CORR00082A	278.52	324.78	350.71	381.64	415.06	513.24	508.73	578.06
30CORR00082B	279.67	325.97	351.92	382.87	416.31	515.47	510.20	583.25

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30CORR00080A	280.16	327.10	351.45	388.58	416.18	514.16	499.89	583.21
30CORR00080B	282.67	329.96	354.55	391.93	419.76	518.03	505.14	590.74
30CORR00072	282.77	333.07	355.98	399.43	419.80	514.04	505.90	590.71
30CORR00072A	282.89	333.30	356.09	400.17	419.05	513.67	505.94	590.69
30CORR00072B	302.07	357.87	380.34	428.71	432.58	529.31	539.91	633.40
30CORR00070	303.02	358.59	379.99	431.40	432.30	529.09	538.88	633.53
30CORR00059	306.69	358.22	378.21	446.22	430.76	518.40	544.51	637.18
30CORR00049A	307.12	365.19	387.82	445.15	428.26	498.90	561.27	641.22
30CORR00049B	307.42	366.15	388.33	446.25	428.30	503.07	563.13	645.14
30CORR00038	320.37	382.93	400.15	422.29	444.24	513.52	561.85	655.36
30CORR00025	333.63	385.68	398.65	427.65	448.36	529.04	568.03	660.90
Galway_Bay_2	334.84	393.24	432.38	437.20	441.52	530.10	576.59	668.98
Galway_Bay_1	354.21	380.49	460.80	446.40	446.58	570.00	584.99	677.80
30FCUT00116	213.80	254.43	280.65	306.69	341.57	370.86	413.64	555.92
30FCUT00103	213.02	253.38	279.43	305.30	339.97	369.30	412.06	554.65
30FCUT00088	212.28	252.34	278.18	303.82	338.28	367.47	410.18	553.25
30FCUT00074	211.60	251.38	277.04	302.50	336.74	365.82	408.54	551.90
30FCUT00060	211.02	250.56	276.05	301.28	335.52	364.54	407.20	550.86
30FCUT00043	210.40	249.65	274.94	300.00	334.12	363.10	405.70	549.75
30FCUT00025	209.78	248.76	273.83	298.75	332.87	361.85	404.40	548.75
30FCUT00008	209.10	247.70	272.65	297.47	331.52	360.43	402.98	547.68
30EGLI00135	18.28	22.13	25.71	29.79	33.19	39.76	52.75	108.89
30EGLI00128	18.09	22.13	25.65	29.40	31.95	36.53	45.03	85.07
30EGLI00120A	17.86	22.13	25.65	29.46	32.02	36.66	44.95	80.61
30EGLI00120B	17.73	20.29	22.88	25.63	28.83	32.68	39.90	71.22
30EGLI00119	17.70	20.29	22.88	25.63	28.83	32.68	39.90	71.23
30EGLI00113A	17.40	20.29	22.88	25.64	28.83	32.67	39.90	71.23
30EGLI00113B	11.83	15.29	17.88	20.63	23.82	27.18	31.75	43.27
30EGLI00108	11.83	15.29	17.88	20.63	23.82	27.18	31.74	43.26
30EGLI00103	11.83	15.29	17.88	20.63	23.82	27.18	31.75	43.27
30EGLI00103A	11.83	15.29	17.88	20.63	23.82	27.18	31.75	43.26
30EGLI00102B	11.83	15.29	17.88	20.63	23.82	27.18	31.75	43.27
30EGLI00101	11.83	15.29	17.88	20.63	23.82	27.18	31.79	43.39
30EGLI00098	11.83	15.29	17.88	20.63	23.82	27.18	31.80	43.39
30EGLI00094	11.83	15.29	17.88	20.63	23.82	27.18	31.80	43.39
30EGLI00086A	11.83	15.29	17.88	20.63	23.82	27.16	31.71	43.19
30EGLI00086B	4.62	4.62	4.99	5.38	5.81	6.26	6.62	7.85
30EGLI00079	4.37	4.60	4.99	5.38	5.81	6.26	6.62	7.84
30EGLI00072	4.34	4.60	4.99	5.38	5.81	6.26	6.61	7.85
30EGLI00071A	4.29	4.60	4.99	5.38	5.81	6.26	6.61	7.84
30EGLI00071B	4.26	4.60	4.99	5.38	5.81	6.26	6.61	7.84
30EGLI00070	4.19	4.60	4.99	5.38	5.81	6.26	6.62	7.84
30EGLI00063	4.01	4.60	4.99	5.38	5.81	6.26	6.60	7.93
30EGLI00055	4.01	4.60	4.99	5.38	5.81	6.25	6.60	7.87
30EGLI00054A	4.01	4.60	4.99	5.38	5.81	6.25	6.60	7.85
30EGLI00053B	4.01	4.60	4.99	5.38	5.81	6.25	6.60	7.84
30EGLI00052	4.01	4.60	4.99	5.38	5.81	6.25	6.59	7.84
30EGLI00046	4.01	4.60	4.99	5.38	5.81	6.25	6.60	7.84
30EGLI00041A	4.01	4.60	4.99	5.38	5.81	6.25	6.60	7.84
30EGLI00041B	2.89	2.96	3.00	3.03	3.07	3.11	3.28	4.10
30EGLI00040A	2.89	2.96	3.00	3.03	3.07	3.11	3.28	4.10
30EGLI00039B	2.89	2.96	3.00	3.03	3.07	3.11	3.28	4.10
30EGLI00035	3.33	4.12	3.47	3.51	3.34	3.45	4.33	4.11
30EGLI00033A	3.55	4.31	3.76	3.85	3.48	3.73	4.53	4.11
30EGLI00033B	9.24	11.63	13.11	13.67	15.70	28.21	34.56	51.70
30EGLI00031A	9.62	12.08	13.53	14.47	15.18	27.52	33.54	50.07
30EGLI00031B	10.54	12.97	14.55	15.31	15.52	28.55	34.81	52.10
30EGLI00027	11.00	13.54	15.11	16.63	15.52	25.70	30.86	43.45

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30EGLI00026A	11.10	13.66	15.23	16.67	15.52	24.33	29.50	43.21
30EGLI00025B	11.18	13.77	15.33	16.60	15.52	24.33	29.50	43.21
30EGLI00018A	12.11	14.90	17.42	16.85	15.52	27.50	32.90	44.86
30EGLI00018B	12.34	16.80	20.06	23.55	30.13	26.51	26.68	33.38
30EGLI00015A	11.76	15.78	18.67	21.69	28.99	25.41	26.19	32.83
30EGLI00014B	11.71	15.70	18.58	21.59	58.05	32.86	40.56	78.33
30EGLI00005A	7.43	8.17	8.66	9.18	19.58	15.66	19.71	30.93
30EGLI00005B	7.43	8.17	8.66	9.18	19.58	15.66	19.71	30.93
30EGLI00004	7.43	8.16	8.66	9.17	17.91	15.32	19.11	28.04
30EGLI00004A	7.43	8.16	8.66	9.17	10.48	12.98	15.00	25.39
30EGLI00004B	7.43	8.16	8.66	9.17	10.48	12.98	15.00	25.39
30EGLI00000	7.43	8.17	8.66	9.17	16.18	18.28	25.21	26.96
30SHEA00004	18.92	24.13	23.65	27.81	19.59	32.44	35.40	44.15
30SHEA00002	18.99	24.26	23.88	28.17	19.64	32.47	35.74	44.17
30SHEA00002W	19.18	24.56	24.25	28.53	19.74	32.45	36.41	44.32
30SHEA00001A	19.18	24.57	24.26	28.54	19.74	32.45	36.42	44.32
30NUNS00052	5.72	5.69	5.68	5.67	5.79	5.79	8.16	27.96
30NUNS00044	5.62	5.62	5.62	5.62	5.75	5.75	8.11	27.41
30NUNS00043A	5.67	5.67	5.67	5.67	5.80	5.80	8.16	27.95
30NUNS00043B	5.67	5.67	5.67	5.67	5.80	5.80	8.16	27.95
30NUNS00041	5.78	5.78	5.77	5.77	5.90	5.89	8.16	27.97
30NUNS00038	5.87	5.87	5.87	5.87	5.98	5.98	8.16	27.95
30NUNS00037A	5.88	5.88	5.88	5.88	5.99	5.99	8.15	27.98
30NUNS00037B	5.88	5.88	5.88	5.88	5.99	5.99	8.15	27.98
30NUNS00037	5.88	5.88	5.88	5.88	6.00	6.00	8.16	27.94
30NUNS00027	5.47	5.47	5.47	5.47	5.52	5.52	8.08	27.50
30NUNS00017	5.07	5.07	5.07	5.07	5.07	5.50	8.07	24.81
30NUNS00016A	5.03	5.03	5.03	5.03	5.03	5.51	7.14	18.52
30NUNS00013A	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
30NUNS00012B	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
30NUNS00011	5.02	5.04	5.06	5.05	5.02	7.06	5.32	6.55
30NUNS00009	5.12	5.10	5.22	5.23	5.06	11.20	5.35	7.42
30NUNS00005	5.41	5.42	5.55	5.60	5.11	12.59	5.38	10.00
30NUNS00002	5.61	5.68	5.77	5.84	5.15	11.74	5.41	11.82
30NUNS00000	5.79	5.94	5.91	5.97	5.23	12.74	5.45	13.48
30NUNS00000A	5.82	5.98	5.94	5.99	5.25	13.12	5.57	13.75
30GMRA00048	7.82	10.69	12.89	15.25	18.01	20.94	25.19	35.39
30GMRA00043	7.82	10.69	12.89	15.25	18.01	20.97	25.28	35.59
30GMRA00033	7.82	10.68	12.89	15.25	18.01	20.97	25.27	35.58
30GMRA00027A	7.82	10.68	12.89	15.25	18.00	20.83	24.59	32.90
30GMRA00027B	5.98	7.75	9.21	10.81	12.68	14.57	17.22	22.54
30GMRA00024A	5.98	7.75	9.21	10.81	12.68	14.58	16.97	21.93
30GMRA00024C	5.98	7.75	9.21	10.81	12.68	14.58	16.75	20.59
30GMRA00021B	5.98	7.75	9.21	10.81	12.68	14.58	16.75	20.59
30GMRA00019	5.98	7.75	9.21	10.81	12.68	14.59	16.98	22.37
30GMRA00016	5.98	7.75	9.21	10.81	12.68	14.61	17.01	23.53
30GMRA00015A	5.98	7.75	9.21	10.81	12.68	14.64	16.99	23.52
30GMRA00015B	6.76	7.95	8.71	9.47	10.29	11.10	12.08	12.67
30GMRA00012A	6.76	7.95	8.71	9.47	10.29	11.10	12.07	12.67
30GMRA00012B	5.08	6.20	6.91	7.63	8.41	9.18	10.11	10.68
30GMRA00010A	5.08	6.20	6.91	7.63	8.41	9.18	10.11	10.68
30GMRA00010B	4.72	5.83	6.54	7.28	8.03	8.80	9.70	10.29
30GMRA00006	4.72	5.83	6.54	7.28	8.03	8.79	9.70	10.29
30GMRA00005A	4.72	5.83	6.54	7.28	8.02	8.79	9.70	10.29
30GMRA00005B	3.76	4.56	5.06	5.56	6.09	6.62	7.24	7.67
30GMRA00004A	3.76	4.56	5.06	5.56	6.09	7.90	7.24	7.67
30GMRA00004B	2.46	3.26	3.75	4.25	4.63	6.51	5.46	5.88
30GMRA00001A	2.46	3.26	3.75	4.25	4.63	5.02	5.46	5.88

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30DOMI00009D	0.44	0.45	0.46	0.47	0.47	0.49	0.50	0.51
30DOMI00007	0.52	0.62	0.61	0.61	0.54	0.55	0.63	0.55
30DOMI00002	0.78	0.81	0.89	0.87	0.75	1.04	1.29	2.18
30DOMI00002A	0.82	0.81	0.91	0.90	0.77	1.05	1.29	2.10
30DOMI00002B	0.82	0.81	0.91	0.90	0.77	1.05	1.29	2.10
30DOMI00001A	0.92	0.89	1.03	1.08	0.82	1.14	1.32	2.06
30CLOP00064	33.65	46.89	57.10	70.56	90.93	108.14	135.99	217.77
30CLOP00059	29.40	38.65	46.95	59.84	79.33	96.07	122.35	199.52
30CLOP00049	25.13	28.13	29.89	32.31	37.95	43.32	51.96	80.21
30CLOP00042	35.37	45.62	51.14	56.74	67.45	77.50	93.08	145.40
30CLOP00032	36.62	50.90	59.74	69.35	83.28	95.06	112.58	168.12
30CLOP00022	37.02	51.98	61.25	71.02	84.76	96.76	115.55	178.38
30CLOP00019A	37.46	52.46	61.61	71.11	84.20	95.79	114.01	174.72
30CLOP00019B	31.85	44.75	53.13	61.88	74.32	85.36	102.83	164.57
30CLOP00013	29.26	38.43	44.90	50.70	58.78	65.34	77.19	114.57
30CLOP00008	31.95	45.56	55.09	64.67	77.16	88.24	105.73	168.44
30CLOP00002	31.95	45.56	55.09	64.67	77.16	87.49	102.45	149.34
30CAST00001	5.61	7.70	8.49	9.23	9.88	10.42	11.19	11.89
30CAST00008A	5.61	7.70	8.49	9.36	10.30	11.03	11.91	15.11
30CAST00008B	5.61	7.70	8.49	9.36	10.30	11.03	11.91	15.11
30CAST00014	5.61	7.70	8.49	9.36	10.30	11.03	11.91	15.65
30CAST00015A	5.61	7.70	8.49	9.36	10.30	11.03	11.91	12.81
30CAST00017B	5.61	7.70	8.49	9.36	10.30	11.03	11.91	12.81
30CAST00018A	5.61	7.70	8.49	9.36	10.30	11.03	11.91	13.01
30CAST00018B	5.61	7.70	8.49	9.36	10.30	11.03	11.91	13.01
30CAST00023	5.61	7.70	8.49	9.36	10.30	11.02	12.08	21.53
30CAST00027	5.61	7.70	8.48	9.35	10.29	11.02	21.05	43.38
30CAST00029A	5.61	7.70	8.48	9.35	10.29	11.02	11.86	39.14
30CAST00034B	5.61	7.70	8.48	9.35	10.29	11.02	11.86	39.14
30CAST00036	5.61	7.70	8.48	9.35	10.29	11.02	12.53	18.59
30CAST00042	5.61	7.70	8.48	9.35	10.29	10.99	11.23	17.33
30CAST00052	5.61	7.69	8.48	9.34	10.17	10.70	13.19	50.09
30CAST00062	5.61	7.65	8.28	9.01	9.93	10.76	11.14	375.74
30CAST00072	5.60	7.68	8.42	9.04	9.86	11.31	17.49	432.84
30CAST00080	5.60	7.65	8.38	9.12	9.81	10.84	14.57	251.68
30CAST00084	5.60	7.66	8.42	9.21	9.96	11.07	14.78	117.45
30CAST00085A	5.60	7.66	8.44	9.28	10.09	11.35	15.58	21.59
30CAST00085B	5.60	7.66	8.44	9.28	10.09	11.35	15.58	21.59
30CAST00088	5.60	7.66	8.44	9.28	10.11	11.47	16.17	49.35
30CAST00095	5.60	7.66	8.43	9.13	9.61	10.16	14.28	35.76
30CAST00102	5.60	7.65	8.37	8.86	9.16	9.29	13.08	20.66
30CAST00110	5.59	7.65	8.32	8.79	9.03	9.12	10.92	35.20
30CAST00114	5.59	7.65	8.42	9.26	9.99	11.23	14.86	21.38
30CAST00115A	5.59	7.65	8.42	9.25	9.99	11.22	17.13	18.77
30CAST00115B	5.59	7.65	8.42	9.25	9.99	11.22	17.13	18.77
30CAST00120	5.59	7.65	8.42	9.25	9.99	11.22	17.82	19.11
30CAST00127	5.59	7.65	8.41	9.19	9.75	10.55	16.92	31.08
30CAST00136	5.59	7.64	8.42	9.25	9.97	11.20	17.50	51.19
30CAST00144	5.59	7.64	8.41	9.25	9.97	11.19	20.10	63.25
30CAST00152	5.59	7.64	8.41	9.25	9.96	11.19	20.36	55.89
30CAST00159	5.59	7.64	8.41	9.25	9.96	11.18	20.42	50.42
30CAST00159A	5.59	7.64	8.41	9.25	9.96	11.18	21.16	28.12
30CAST00159B	5.59	7.64	8.41	9.25	9.96	11.18	21.16	28.12
30CAST00160	5.59	7.64	8.41	9.25	9.96	11.18	20.97	27.59
30CAST00161A	5.59	7.64	8.41	9.25	9.96	11.18	20.81	27.59
30CAST00161B	5.59	7.64	8.41	9.25	9.96	11.18	20.81	27.59
30CAST00163	5.59	7.64	8.41	9.25	9.95	11.18	20.83	36.43
30CAST00170	5.59	7.63	8.41	9.25	9.95	11.18	20.82	49.65

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30CAST00177	5.58	7.63	8.41	9.08	9.71	10.81	20.16	48.71
30CAST00182	5.58	7.63	8.41	9.24	9.94	11.17	19.69	49.26
30CAST00183A	5.58	7.63	8.41	9.24	9.94	11.17	19.61	24.28
30CAST00183B	5.58	7.63	8.41	9.24	9.94	11.17	19.61	24.28
30CAST00185	5.58	7.63	8.40	9.24	9.94	11.17	19.97	25.43
30CAST00192	5.58	7.63	8.40	9.24	9.93	11.09	18.68	26.06
30CAST00200	5.58	7.63	8.40	9.24	9.92	11.15	20.39	67.11
30CAST00207	5.58	7.62	8.40	9.24	9.91	11.14	20.07	80.40
30CAST00215	5.58	7.62	8.40	9.24	9.91	11.14	20.29	82.31
30CAST00222	5.58	7.62	8.39	9.23	9.90	11.13	19.28	81.11
30CAST00229	5.57	7.62	8.39	9.23	9.89	11.10	17.55	61.45
30CAST00237	5.57	7.61	8.39	9.23	9.88	11.32	20.55	56.46
30CAST00245	5.57	7.61	8.45	9.39	10.12	11.75	23.37	68.63
30CAST00252	5.57	7.61	8.38	9.23	9.83	10.91	17.72	54.74
30CAST00260	5.57	7.59	8.37	9.16	9.77	10.90	18.17	55.38
30CAST00267	5.57	7.58	8.30	9.06	9.64	10.68	18.39	64.59
30CAST00275	5.57	7.60	8.37	9.22	9.83	11.01	16.44	53.53
30CAST00286	5.56	7.59	8.32	9.10	9.64	10.52	15.80	53.74
30CAST00295	5.56	7.60	8.35	9.11	9.65	10.62	15.25	51.12
30CAST00301	5.56	7.59	8.37	9.22	9.81	11.03	18.65	49.84
30CAST00302A	5.56	7.60	8.37	9.22	9.81	11.03	19.03	28.26
30CAST00302B	5.56	7.60	8.37	9.22	9.81	11.03	19.03	28.26
30CAST00305	5.56	7.60	8.37	9.22	9.81	11.03	19.15	28.41
30CAST00312	5.56	7.57	8.30	9.06	9.61	10.65	16.56	25.38
30CAST00321	5.56	7.56	8.26	9.06	9.60	10.18	15.52	25.45
30CAST00327	5.56	7.56	8.25	8.99	9.55	10.28	14.60	23.24
30CAST00337	5.54	7.37	7.93	8.59	9.10	9.86	14.18	27.50
30CAST00347	5.55	7.53	8.25	8.86	9.34	9.65	13.00	24.59
30CAST00357	5.55	7.54	8.26	9.05	9.58	10.14	12.54	27.75
30CAST00367	5.54	7.34	7.94	8.46	8.72	9.28	9.97	20.11
30CAST00377	5.55	7.57	8.31	9.02	9.41	10.49	11.38	21.52
30CAST00387	5.55	7.53	8.27	8.98	9.39	10.62	12.12	12.70
30CAST00397	5.55	7.57	8.35	9.09	9.51	10.91	16.13	21.07
30CAST00397A	5.55	7.57	8.35	9.09	9.51	10.91	15.86	21.10
30CAST00397B	5.55	7.57	8.35	9.09	9.51	10.91	15.86	21.10
30CAST00398	5.55	7.57	8.35	9.09	9.51	10.91	16.19	21.09
30SALR00051	6.11	8.66	10.46	12.35	14.50	16.84	19.66	33.09
30SALR00061	6.11	8.66	10.46	12.35	14.50	16.84	19.66	33.08
30SALR00060A	6.11	8.66	10.46	12.35	14.50	16.84	19.66	33.08
30SALR00060B	6.11	8.66	10.46	12.35	14.50	16.84	19.66	33.08
30SALR00060	6.11	8.66	10.46	12.35	14.50	16.84	19.66	33.08
30SALR00057	6.11	8.66	10.46	12.35	14.50	16.84	19.60	29.93
30SALR00054	6.11	8.66	10.46	12.35	14.50	16.84	19.56	27.30
30SALR00054A	6.11	8.66	10.46	12.35	14.50	16.84	19.56	27.30
30SALR00054B	6.11	8.66	10.46	12.35	14.50	16.84	19.56	27.30
30SALR00053	6.11	8.66	10.46	12.35	14.50	16.84	19.56	27.30
30SALR00045	6.11	8.66	10.46	12.35	14.50	16.84	19.55	24.61
30SALR00046	6.11	8.66	10.46	12.35	14.50	16.84	19.55	24.61
30SALR00045A	6.11	8.66	10.46	12.35	14.50	16.84	19.55	24.61
30SALR00045B	1.77	1.93	2.02	2.11	2.19	2.28	2.36	2.43
30SALR00044	1.77	1.93	2.02	2.11	2.19	2.28	2.37	2.43
30SALR00037	1.77	1.93	2.02	2.11	2.19	2.28	2.36	2.42
30SALR00031	1.77	1.93	2.02	2.11	2.19	2.27	2.37	2.42
30SALR00027	1.77	1.93	2.02	2.11	2.19	2.27	2.37	2.42
30SALR00026A	1.77	1.93	2.02	2.11	2.19	2.27	2.36	2.42
30SALR00026B	1.77	1.93	2.02	2.11	2.19	2.27	2.36	2.42
30SALR00026	1.77	1.93	2.02	2.11	2.19	2.27	2.36	2.42
30SALR00024	1.77	1.93	2.02	2.11	2.19	2.27	2.36	2.42

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30SALR00024W	1.77	1.93	2.02	2.11	2.19	2.27	2.36	2.42
30SALR00023A	1.77	1.93	2.02	2.11	2.19	2.27	2.36	2.42
30SALR00023B	1.77	1.93	2.02	2.11	2.19	2.27	2.36	2.42
30SALR00022	1.77	1.93	2.02	2.11	2.20	2.41	2.41	2.42
30SALR00020	1.77	1.95	2.05	2.14	2.19	3.77	3.59	4.49
30SALR00015	1.79	1.98	2.12	2.20	2.19	5.89	6.04	8.03
30SALR00012A	1.80	2.01	2.17	2.25	2.19	6.54	7.55	10.13
30SALR00012B	1.22	1.56	1.84	2.16	2.34	7.87	9.71	15.39
30SALR00010	1.22	1.55	1.84	2.16	2.32	6.38	9.80	15.91
30SALR00009	1.22	1.55	1.84	2.16	2.32	6.37	9.74	15.83
30SALR00008A	1.22	1.55	1.84	2.16	2.32	6.44	10.13	15.49
30SALR00007B	1.22	1.55	1.84	2.16	2.32	6.44	10.13	15.49
30SALR00007	1.22	1.55	1.84	2.16	2.31	6.28	9.61	14.61
30SALR00003	1.22	1.55	1.84	2.15	2.28	6.13	8.21	11.27
30SALR00001	1.22	1.55	1.83	2.15	2.27	4.81	4.93	5.12
30SALR00001A	1.22	1.55	1.83	2.15	2.28	4.87	5.28	5.84
30SALR00000A	1.22	1.55	1.83	2.15	2.28	4.87	5.28	5.84
30FRIA00034	4.34	6.74	8.44	10.24	12.31	15.18	18.13	23.29
30FRIA00033	4.34	6.74	8.44	10.24	12.31	15.18	18.13	23.29
30FRIA00030A	4.34	6.74	8.44	10.24	12.30	15.18	18.13	23.30
30FRIA00023B	4.49	6.77	8.60	10.32	12.27	15.18	18.13	23.30
30FRIA00021	4.65	6.80	8.71	10.34	12.26	15.18	18.13	23.30
30FRIA00015	4.86	6.87	8.95	10.40	12.22	15.19	18.14	24.24
30FRIA00015A	4.87	6.91	8.96	10.41	12.22	15.19	18.14	24.06
30FRIA00015B	4.87	6.91	8.96	10.41	12.22	15.19	18.14	24.06
30FRIA00014	4.89	6.98	8.98	10.42	12.22	15.29	18.14	23.57
30FRIA00014A	4.90	7.00	8.99	10.42	12.21	15.38	18.14	23.41
30FRIA00012B	4.96	7.14	9.03	10.43	12.21	15.38	18.14	23.41
30FRIA00011	5.03	7.21	9.06	10.45	12.20	15.75	18.16	24.38
30FRIA00005	5.32	7.50	9.24	10.54	12.19	16.98	16.97	18.30
30FRIA00005A	5.34	7.52	9.26	10.55	12.19	17.03	16.97	18.29
30FRIA00005B	5.34	7.52	9.26	10.55	12.19	17.03	16.97	18.29
30FRIA00004	5.39	7.56	9.27	10.56	12.19	17.09	16.96	18.29
30FRIA00002	5.56	7.76	9.33	10.62	12.18	17.70	16.95	18.28
30FRIA00001A	5.59	7.80	9.34	10.63	12.18	17.85	16.97	18.27
30FRIA00000B	5.59	7.80	9.34	10.63	12.18	17.85	16.97	18.27
30FRIA00000W	5.59	7.81	9.34	10.63	12.18	17.85	16.99	18.28
30SALW00103B	1.66	2.10	2.40	2.70	3.03	3.42	3.74	4.55
30SALW00102	1.66	2.10	2.40	2.70	3.03	3.41	3.74	4.55
30SALW00101	1.66	2.10	2.40	2.70	3.03	3.38	3.73	4.55
30SALW00100	1.65	2.10	2.40	2.70	3.03	3.37	3.73	4.54
30SALW00099A	1.65	2.10	2.40	2.70	3.03	3.35	3.73	4.54
30SALW00096B	1.65	2.10	2.40	2.70	3.03	3.35	3.72	4.54
30SALW00095	1.65	2.10	2.40	2.70	3.03	3.35	3.72	4.54
30SALW00094	1.65	2.10	2.40	2.70	3.03	3.35	3.72	4.54
30SALW00094A	1.65	2.10	2.40	2.70	3.03	3.35	3.72	4.54
30SALW00093B	1.65	2.10	2.40	2.70	3.03	3.35	3.72	4.54
30SALW00093	1.65	2.10	2.40	2.70	3.03	3.34	3.72	4.54
30SALW00092	1.65	2.10	2.39	2.69	3.02	3.34	4.20	5.75
30SALW00092B	1.65	2.10	2.39	2.69	3.02	3.31	3.67	4.68
30SALW00091B	1.65	2.10	2.39	2.69	3.02	3.31	3.67	4.68
30SALW00091	1.65	2.09	2.39	2.69	3.02	3.31	3.49	4.15
30SALW00090	1.65	2.09	2.39	2.68	3.01	3.30	3.49	4.16
30SALW00090A	1.65	2.09	2.38	2.68	3.01	3.30	3.49	4.17
30SALW00090B	1.65	2.09	2.38	2.68	3.01	3.30	3.49	4.17
30SALW00089	1.65	2.09	2.38	2.68	3.00	3.29	3.49	4.16
30SALW00084	1.65	2.08	2.36	2.65	2.97	3.24	3.37	3.04
30SALW00083A	1.65	2.08	2.36	2.65	2.96	3.24	3.37	2.67

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30SALW00082B	1.65	2.08	2.36	2.65	2.96	3.24	3.37	2.67
30SALW00081	1.65	2.08	2.36	2.65	2.96	3.23	3.36	3.45
30SALW00077	1.65	2.07	2.35	2.64	2.93	3.24	3.35	6.63
30SALW00076A	1.65	2.07	2.35	2.64	2.93	3.19	3.29	2.52
30SALW00075B	1.65	2.07	2.35	2.64	2.93	3.19	3.29	2.52
30SALW00074	1.65	2.07	2.35	2.64	2.92	3.26	3.30	2.45
30SALW00068	1.65	2.08	2.38	2.66	2.87	3.30	3.39	2.84
30SALW00067A	1.65	2.08	2.39	2.66	2.87	3.31	3.39	2.62
30SALW00065B	1.65	2.08	2.39	2.66	2.87	3.31	3.39	2.62
30SALW00064	1.65	2.09	2.39	2.67	2.86	3.31	3.40	2.63
30SALW00059	1.65	2.10	2.43	2.69	2.84	3.34	3.42	2.66
30SALW00058A	1.65	2.11	2.43	2.70	2.84	3.35	3.43	2.66
30SALW00057B	1.65	2.11	2.43	2.70	2.84	3.35	3.43	2.66
30SALW00057	1.66	2.11	2.44	2.71	2.83	3.36	3.43	2.66
30SALW00051	1.67	2.13	2.46	2.73	2.82	3.38	3.45	2.68
30SALW00051A	1.68	2.13	2.47	2.73	2.81	3.39	3.46	2.68
30SALW00050B	1.69	2.14	2.47	2.73	2.81	3.39	3.46	2.68
30SALW00049A	1.69	2.14	2.48	2.74	2.81	3.39	3.46	2.73
30SALW00049B	1.69	2.14	2.48	2.74	2.81	3.39	3.46	2.73
30SALW00047	1.71	2.16	2.49	2.75	2.80	3.41	3.48	2.75
30SALW00047A	1.72	2.17	2.50	2.76	2.79	3.42	3.48	2.76
30SALW00047B	1.78	2.66	3.39	4.10	2.79	3.42	3.49	3.91
30SALW00044A	1.83	2.70	3.42	4.13	2.77	3.46	3.73	3.95
30SALW00044B	2.45	4.04	5.29	6.60	5.96	7.43	8.72	11.59
30SALW00036A	2.52	4.10	5.34	6.65	5.94	7.50	8.54	11.62
30SALW00035B	2.54	4.11	5.35	6.65	5.93	7.50	8.55	11.59
30SALW00027A	2.68	4.24	5.46	6.75	5.86	7.62	8.64	11.64
30SALW00027B	2.68	4.24	5.46	6.75	5.86	7.62	8.64	11.64
30SALW00022A	2.76	4.31	5.52	6.80	5.84	7.69	8.69	11.68
30SALW00021B	2.78	4.33	5.53	6.81	5.84	7.69	8.69	11.68
30SALW00000A	3.08	4.61	5.78	7.03	5.74	7.93	8.89	23.19
30MACT00011X	1.84	2.94	3.68	4.44	5.32	6.30	7.37	10.37
MACT00011*1	1.84	2.94	3.68	4.44	5.32	6.30	7.37	9.94
30MACT00011	1.84	2.94	3.68	4.44	5.32	6.30	7.37	9.94
30MACT00011A	1.84	2.94	3.68	4.44	5.32	6.30	7.37	9.93
30MACT00010B	1.84	2.94	3.68	4.44	5.32	6.30	7.37	9.93
30MACT00010A	1.84	2.94	3.68	4.44	5.32	6.30	7.37	10.05
MACT00008L	0.39	0.64	0.80	0.97	1.15	1.36	1.59	2.75
MACT00006AL	0.39	0.64	0.80	0.97	1.15	1.36	1.57	1.95
MACT00003BL	0.39	0.64	0.80	0.97	1.15	1.36	1.57	1.95
MACT00002L	0.39	0.64	0.80	0.97	1.15	1.36	1.57	1.95
MACT00008R	0.44	0.75	0.95	1.15	1.38	1.62	1.88	2.32
MACT00006AR	0.44	0.75	0.95	1.15	1.38	1.62	1.88	2.32
MACT00003BR	0.44	0.75	0.95	1.15	1.38	1.62	1.88	2.32
MACT00002R	0.44	0.75	0.95	1.15	1.38	1.63	1.88	2.32
30MACT00002	1.21	2.97	4.47	6.15	7.94	20.95	26.67	37.38
30MACT00001	1.21	2.97	4.47	6.15	7.98	20.95	26.67	37.38
30SMRN00015	1.22	2.97	4.47	6.15	8.01	20.95	26.67	37.38
30SMRN00015A	1.22	2.97	4.47	6.15	8.01	20.95	26.67	37.37
30SMRN00014B	1.22	2.98	4.48	6.16	8.01	20.95	26.67	37.37
30SMRN00014	1.23	2.98	4.48	6.16	8.00	20.95	26.68	37.37
30SMRN00009	1.87	3.49	4.93	6.17	7.91	20.96	26.68	37.36
30SMRN00002A	2.53	3.83	5.34	6.18	7.98	21.11	27.41	41.15
30SMRN00002B	5.42	7.27	9.16	10.27	12.52	25.81	32.26	46.32
30SMRN00000	5.69	7.49	9.38	10.36	12.44	25.13	31.33	47.70
30VARA00103B	1.69	1.76	1.80	1.84	1.88	1.95	2.03	3.49
30VARA00100	1.69	1.76	1.80	1.84	1.88	1.95	2.02	3.50
30VARA00070	1.69	1.76	1.80	1.84	1.88	1.96	2.03	3.26

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30VARA00060	1.68	1.76	1.80	1.84	1.88	1.96	2.03	2.30
30VARA00050D	1.68	1.76	1.80	1.84	1.88	1.96	2.03	2.30
30VARA00040A	1.68	1.76	1.80	1.84	1.88	1.96	2.03	2.20
30VARA00040B	1.68	1.76	1.80	1.84	1.88	1.96	2.03	2.20
30VARA00030A	1.68	1.76	1.80	1.84	1.88	1.96	2.03	2.20
30VARA00030B	1.68	1.76	1.80	1.84	1.88	1.96	2.03	2.20
30VARA00020A	1.68	1.76	1.80	1.84	1.88	1.96	2.03	2.20
30VARA00020B	1.68	1.76	1.80	1.84	1.88	1.96	2.03	2.20
30VARA00015O	1.68	1.76	1.80	1.84	1.88	1.96	2.03	2.20
30VARA00011	1.72	1.79	1.81	1.85	1.88	1.99	2.04	2.20
30VARA00010	1.73	1.81	1.81	1.86	1.88	2.00	2.04	2.20
30VARA00008	1.79	1.85	1.87	1.89	1.88	2.07	2.05	2.20

A.2 HEP flows

Table A-3: Current peak flows at HEPs

HEP Reference	Cross Section	Peak Flow in Model (m3/s)								Comments (note: where blank, no changes have been made)
		50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	
CRB_003	30CORR00449	240.15	279.01	306.08	333.54	372.20	404.41	451.40	615.27	Upper modelled extent of River Corrib at Dangan gauge
CRB_004	30CORR00070	252.36	292.30	313.21	342.60	391.03	412.64	472.11	572.22	Downstream extent of model where River Corrib flows into Galway bay

Table A-4: MRFS peak flows at HEPs

HEP Reference	Cross Section	Peak Flow in Model (m3/s)								Comments (note: where blank, no changes have been made)
		50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	
CRB_003	30CORR00449	280.09	329.87	363.12	397.30	446.08	486.75	546.44	751.34	Upper modelled extent of River Corrib at Dangan gauge
CRB_004	30CORR00070	303.02	358.59	379.99	431.40	432.30	529.09	538.88	633.53	Downstream extent of model where River Corrib flows into Galway bay



Registered Office

**24 Grove Island
Corbally
Limerick
Ireland**

T: +353 (0) 61 345463
e: info@jbaconsulting.com

**JBA Consulting Engineers and
Scientists Limited**

Registration number 444752

Visit our website
www.jbaconsulting.com

Western CFRAM UoM 30 - Corrib Hydraulic Modelling Report: Volume 2e - Oughterard

Final

September 2016

**Office of Public Works
Trim
Co. Meath**



**WESTERN
CFRAM
STUDY**
CATCHMENT FLOOD RISK
ASSESSMENT AND MANAGEMENT

JBA Consulting

24 Grove Island
Corbally
Limerick
Ireland

JBA Project Manager

Sam Willis BSc MSc CEnv CSci MCIWEM C.WEM

Revision History

Revision ref / Date issued	Amendments	Issued to
Version 1.0	Initial Issue	Rosemarie Lawlor, OPW
V2.0 / January 2015	Updated to reflect model updates following review and public consultation. Report updated to reflect client and TAS review.	Rosemarie Lawlor, OPW
V3.0 / September 2016	Final updates	Clare Butler, OPW

Contract

This report describes work commissioned by The Office of Public Works, by a letter dated (28/07/11). The Office of Public Works' representative for the contract was Rosemarie Lawlor. Sam Willis, Chris Smith and Elizabeth Russell of JBA Consulting carried out this work.

Prepared by Chris Smith BSc PhD C.Env. MCIWEM C.WEM.
MCM

David Moran BEng, MEng, MIEI

Reviewed by Sam Willis BSc MSc CEnv CSci MCIWEM C.WEM

Elizabeth Russell BSc MSc CEnv MCIWEM
C.WEM

Purpose

This document has been prepared as a draft report for The Office of Public Works. 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.

JBA Consulting has no liability regarding the use of this report except to the Office of Public Works.

Copyright

Copyright – Copyright is with Office of Public Works. All rights reserved. No part of this report may be copied or reproduced by any means without the prior written permission of the Office of Public works.

Legal Disclaimer

This report is subject to the limitations and warranties contained in the contract between the commissioning party (Office of Public Works) and JBA.

Carbon Footprint

A printed copy of the main text in this document will result in a carbon footprint of 148g if 100% post-consumer recycled paper is used and 189g if primary-source paper is used. These figures assume the report is printed in black and white on A4 paper and in duplex.

JBA is aiming to achieve carbon neutrality.

Contents

1	Introduction.....	1
1.1	Scope of report	1
1.2	Model and report overview	1
1.3	Watercourse and catchment overview	1
1.4	Available data	3
2	Hydraulic modelling	5
2.1	Context.....	5
2.2	Key hydraulic structures	5
2.3	Hydraulic roughness	6
2.4	1D-2D boundary	9
2.5	Defences and walls.....	9
2.6	Floodplain	10
3	Flood history, model calibration and sensibility checking	11
3.1	Calibration versus sensibility checking	11
3.2	Flood history	11
3.3	Calibration data.....	11
3.4	Calibration outcomes	12
3.5	Stakeholder Engagement.....	15
4	Application of hydrology	18
4.1	Hydrological estimation points	18
4.2	Application of design flow estimates.....	18
4.3	Downstream Boundary	21
5	Model results.....	22
5.1	Model runs	22
5.2	Flood risk mapping	22
5.3	Key flood risk mechanisms	22
6	Sensitivity testing	24
6.1	Screening of sensitivity tests	24
6.2	Sensitivity testing results and uncertainty bounds.....	26
7	Model limitations	29
7.1	Channel blockage	29
7.2	Cascades	29
7.3	Swallow hole on the Tonweeroe watercourse	29
A	Hydraulic model results	30

List of Figures

Figure 1-1: Oughterard AFA catchment overview	2
Figure 1-2: Owenriff River gradient changes.....	2
Figure 2-1: Key structures' locations	5
Figure 2-2: Defences and walls locations.....	9
Figure 3-1: November 1999 calibration plot at the 30044 staff gauge	12
Figure 3-2: November 1999 modelled flood extent	13
Figure 3-3: Model rating curve and check gaugings at 30101 Oughterard D/S gauge.....	14
Figure 3-4: November 2011 modelled flood extent	14
Figure 3-5: N59 Flooding December 2015	15
Figure 4-1: Oughterard AFA HEP locations	18
Figure 6-1: 10% AEP uncertainty bound	27
Figure 6-2: 1% AEP uncertainty bound	27
Figure 7-1: Tonweeroe culvert with flat culvert (30TONW0016)	29

List of Tables

Table 1-1: Abbreviated watercourse names.....	3
Table 1-2: Hydrometric gauging stations in the vicinity of the AFA.....	3
Table 2-1: Key hydraulic structures	5
Table 2-2: Reach hydraulic roughness values	7
Table 2-3: Informal ineffective walls and embankments	10
Table 3-1: Summary of flood history.....	11
Table 3-2: PCD Feedback	16
Table 4-1: Summary of hydraulic model design inflows	20
Table 4-2: Extreme level estimates for Lough Corrib	21
Table 5-1: Peak flows for the Mid-Range Future Scenario	22
Table 5-2: Peak flows for the High-End Future Scenario	22
Table 6-1: Sensitivity test summary.....	24
Table 6-2: Flow sensitivity scaling factors	24
Table 6-3: Sensitivity to roughness scenarios	25
Table A-1: 1D model peak current flows	30
Table A-2: 1D model peak MRFS flows	31
Table A-3: Current peak flows at HEPs.....	33
Table A-4: MRFS peak flows at HEPs.....	33

Abbreviations

AEP	Annual exceedence probability
AFA	Area for further assessment
AMAX	Annual maximum
CFRAM	Catchment flood risk assessment and management
DAD	Defence asset database
DAS	Defence asset survey
DEM	Digital elevation model (Includes surfaces of structures, vegetation, etc.)
DTM	Digital terrain model ('bare earth' model; does not include surfaces of structures, vegetation, etc.)
ESTRY	One-dimensional model from the TUFLOW suite
FRISM	Flood risk metrics (a flood risk tool developed by JBA)
FRMP	Flood risk management plan
FRR	Flood risk review
FSR	Flood studies report
FSU	Flood studies update
GIS	Geographical information system
HEFS	High-end future scenario
HEP	Hydrological estimation point
HPW	High priority watercourse
HWA	Hydrograph width analysis
IBIDEM	Interactive bridge invoking the design event method
ICPSS	Irish coastal protection strategy study
ISIS	One-dimensional hydraulic modelling software
LA	Local authority
LIDAR	Light detection and ranging
mOD	Metres above Ordnance datum (unless stated this refers to the Malin datum)
MPW	Medium priority watercourse
MRFS	Mid-range future scenario
NDHM	National digital height model (a DTM by Intermap)
OSi	Ordnance Survey Ireland
PFRA	Preliminary flood risk assessment
Q(T)	Flow for a given return period
QMED	Median annual flood, used in FSU methods
SAAR	Standard annual average rainfall
SoP	Standard of protection (in relation to flood defences)
T	Return period, inverse of AEP
Tp	Time to peak

TUFLOW.....Two-dimensional hydraulic modelling software

UoM Unit of Management

* Asterisks at the end of a cross section label denotes interpolated model cross sections

1 Introduction

1.1 Scope of report

This report summarises the hydraulic modelling work for the Oughterard Area for Further Assessment (AFA) High Priority Watercourse (HPW) hydraulic model. This document is specific to the AFA itself and should be read in conjunction the various reports detailed in Section 1.3 for details on the modelling approaches and wider context of the study.

The report covers the overall hydraulic modelling process from model build through to the development of design runs, with the aim of providing a detailed understanding of the hydraulic controls and flood mechanisms identified throughout the study.

The report is not a user manual for the hydraulic model itself, full details of which are provided in the model handover check files accompanying the hydraulic model.

The hydraulic modelling work summarised in this and the Unit of Management 30 Hydraulic Modelling Report, of which this report is an Annex, forms one element of the Western Catchment-based Flood Risk Assessment and Management (WCFRAM) study process. The process to date has included amongst other tasks a Flood Risk Review (FRR)¹, a project inception stage², a Strategic Environmental Assessment (SEA)³ and the development of the catchment hydrology⁴. Where the work completed in these tasks contains information relevant to the analysis discussed in this document, references have been included directing the reader to the relevant report for further background information.

1.2 Model and report overview

There is one model for Oughterard which consists of the Owenriff and Tonweeroe watercourses. The model starts a short distance upstream of the AFA boundary and ends where Owenriff discharges to Lough Corrib. The watercourse is influenced by extreme lake level in Lough Corrib, and this is represented by the downstream boundary. The lough itself has not been explicitly modelled, although the River Clare, which is its other main tributary, and the River Corrib outfall through Galway City has also been modelled. Both these models are discussed in their own reports.

The model code relevant to this river is U1:

Reports which are relevant to this AFA are:

- Western CFRAM Flood Risk Review Report
- Western CFRAM UoM_30 Inception Report
- Western CFRAM UoM_30 Hydrology Report
- Western CFRAM UoM_30 Hydraulic Modelling Report
- Western CFRAM UoM_30 Hydraulic Modelling Report: Volume 1 - Hydraulic Modelling Method Statement
- Western CFRAM UoM_30 Hydraulic Modelling Report: Volume 3 - Flood Risk maps
- Oughterard AFA Hydraulic Model Check File

Cross section, long section and flood extent plots are provided in Volume 3 of the UoM 30 Hydraulic Modelling report.

1.3 Watercourse and catchment overview

The study area encompasses the Oughterard AFA and includes the Owenriff River, which is the main river passing through Oughterard town centre, and Tonweeroe Watercourse, a tributary of Owenriff River. The watercourses are all classed as High Priority Watercourses (HPWs) as they flow through the centre of the

¹ JBA Consulting (2012), Western CFRAM Flood Risk Review, Final Report, Office of Public Works

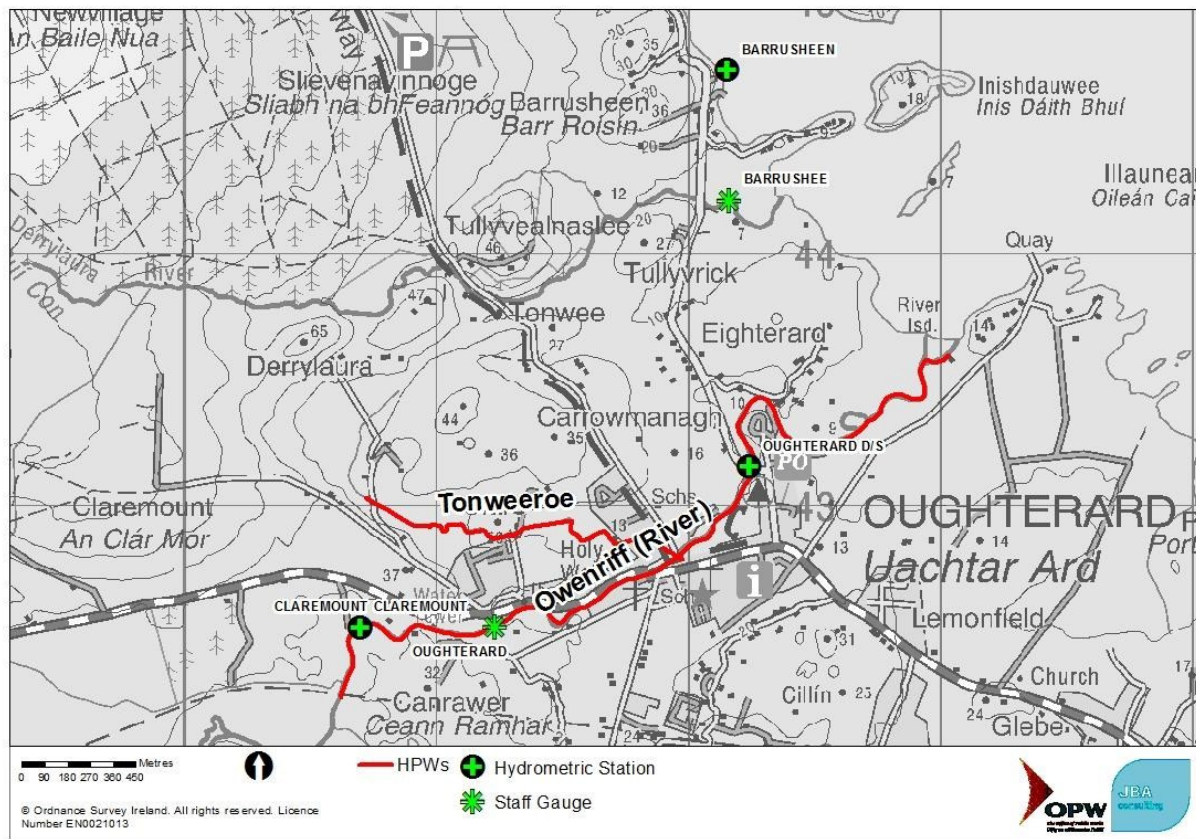
² JBA Consulting (2012), Western CFRAM Unit of Management 30 and 31 – Corrib and Owengola Inception Report, Final Report, Office of Public Works

³ JBA Consulting (2013), Western River Basin District Catchment-based Flood Risk Assessment and Management (CFRAM) Strategic Environmental Assessment, Scoping Report, Office of Public Works.

⁴ JBA Consulting (2014), Western CFRAM Unit of Management 30 and 31 – Corrib and Owengola Hydrology Report, Final Report, Office of Public Works

AFA, and have been included in the model. Figure 1-1 provides an overview of the area. The Owenriff River discharges into Lough Corrib a short distance downstream of Oughterard.

Figure 1-1: Oughterard AFA catchment overview



1.3.1 Owenriff River

The upstream modelled extent of the Owenriff is located at the old railway crossing approximately 1.5km upstream of the N59 Bridge, and the downstream modelled extent is at Lough Corrib. The model covers 3,700m of the Owenriff and 1,465m of the Tonweeroe. Across the modelled reaches their bed elevations drop 21.4m and 14.1m respectively. The gradient of the Owenriff River through this reach is very variable, from extremely steep cascades towards the upstream end to very flat gradient as it flows into the Lough.

The Owenriff River channel appears fairly natural and reference to historic maps shows very little change in course over the past nearly 200 years.

Figure 1-2: Owenriff River gradient changes



Owenriff River approaching Lough Corrib towards the downstream end of the model (30ORIF00064).



Owenriff River cascades towards the upstream end of the model (30ORIF00283).

1.3.2 Tonweeroe Watercourse

The modelled length of the Tonweeroe watercourse is 1.5km. There are several small culverts along the length of the watercourse that can restrict extreme flows. The longest of these is located at the downstream end of the Tonweeroe watercourse beneath the houses of Abhainn Na Coille to the point of discharge into the Owenriff River. This culvert is around 130m long and has a screen on the inlet (see Figure 2-1).

Inspection of the route of the Tonweeroe watercourse during site visits indicated that not all the flows reach this downstream culvert and it is often dry which suggests some water may be lost into the ground. At extreme flows this is likely to be less significant. Analysis of the historical mapping available through the OSi shows the downstream extent of this watercourse does not link to the Owenriff, but it is not clear where the channel does discharge to.

1.4 Available data

1.4.1 Survey data

Cross sectional survey was collected by CCS Surveying in Work Packages 1 and 2 as part of the National Survey Contract No. 6 and delivered in November 2012. Cross section survey was impacted by the presence of Fresh Water Pearl Mussels which limited the access to the watercourse and resulted in fewer cross sections being collected than was originally scoped.

The abbreviated version of each watercourse name as represented in the hydraulic models are detailed in Table 1-1.

Table 1-1: Abbreviated watercourse names

Reference	Description	Model Code
ORIF	Owenriff River	U1
TONW	Tonweeroe watercourse	U1

LIDAR data has been collected for use in the model. Data has been provided in both filtered and unfiltered formats in a 2m grid resolution. The LIDAR was flown between November 2011 and August 2012.

A comparison of LIDAR levels against the surveyed cross sections was completed as part of the survey review process. This compared spot levels collected on roads or in open spaces and found an average difference between the two of 161mm, therefore no adjustment to the LIDAR was required to match the survey data.

Additional CCTV survey has been requested in some AFAs where long, non-linear culverts of variable dimensions in key flood risk areas were identified. In Oughterard one culvert was discussed as a possible for CCTV survey although this was not carried out as investigation on the ground gave enough confidence to proceed without the survey. This is the culvert located at the downstream end of the Tonweeroe watercourse which runs beneath the houses of Abhainn Na Coille to the point of discharge into the Owenriff River. This culvert is around 130m long, has different inlet and outlet shapes, a 90 degree bend and flows under properties in a known flood risk area. The culvert is discussed in more detail in Section 2.2, and has been subject to sensitivity testing which is detailed in Section 6.

1.4.2 Hydrometric data

A summary of hydrometric data within the AFA is provided in Table 2-1 and an overview of gauge locations is provided in Figure 1-1.

Table 1-2: Hydrometric gauging stations in the vicinity of the AFA

Gauge Reference	Type	Use in calibration
30101 - Oughterard D/S	Active flow site	Rating review calibrated to gaugings. Primary calibration location. Data from 2001 to present.
30019 - Claremount	Inactive flow site	Rating review calibrated to gaugings, although difficulties meant amendments to align more with 30101 during the short period of record. Data from 1976 to 2003.
30044 - Oughterard	Inactive staff gauge	Surveyed gauge board level at footbridge 30ORIF00261, DS face. 1m on gauge board = 12.89mAOD. Spot gaugings here 1989-2001.
30088 - Barrusheen	Active Level gauge	This gauge gives 15minute levels on Lough Corrib and may give downstream boundary levels for calibration events (post 2001). Data from 1976 to

Gauge Reference	Type	Use in calibration
		present.

As part of the study a review of the rating curve at gauges 30101 Oughterard D/S and 30019 Claremount has been completed. Full details of this review are detailed in the WCFRAM Hydrology Report for UoM 30.

The nearest level gauge on Lough Corrib is 30088 Barrusheen located approximately 1.5km to the north of where the Owenriff enters the Lough.

2 Hydraulic modelling

2.1 Context

This section should be read in conjunction with the Hydraulic Model Report: Volume 1a: Hydraulic Modelling Method Statement and the Oughterard Hydraulic Model Check File. The Method Statement provides an overview of the elements of both the 1D and 2D model construction and the following section of the report describes how they were applied to the Oughterard AFA.

2.2 Key hydraulic structures

Key hydraulic structures that dictate water levels and flow routes in the vicinity of key flood risk areas are summarised in Table 2-1 and shown in Figure 2-1.

Figure 2-1: Key structures' locations

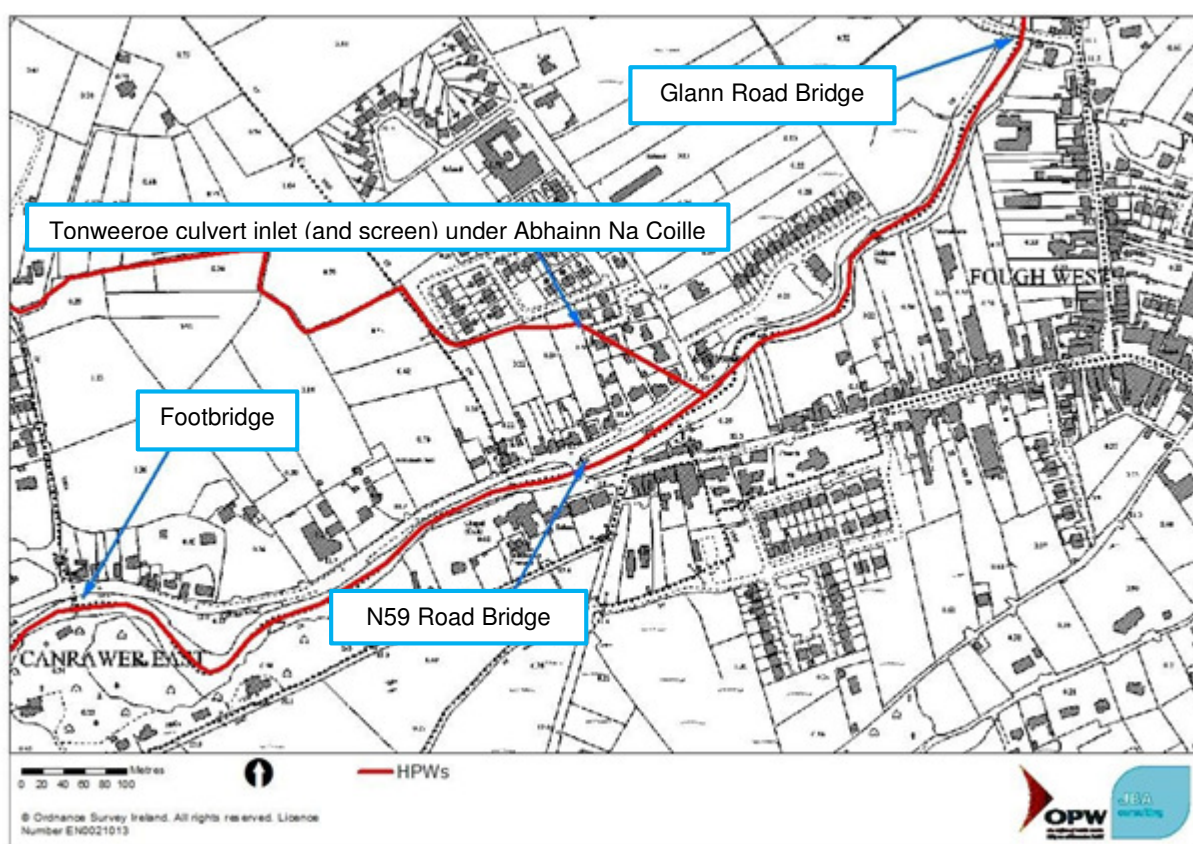






Table 2-1: Key hydraulic structures

Structure Name	Description	Photograph
Footbridge (30ORIF00261)	Flat concrete footbridge with large openings. Overtopping of structure assumed to be efficient (smooth concrete deck). Railings not included in model as unlikely to cause flow obstruction.	

Structure Name	Description	Photograph
N59 Road Bridge (30ORIF00203)	Stone arched bridge with 3 arches. Likely to be bypassed on left bank rather than overtopped.	
Glann Road Bridge (30ORIF00142)	Location of gauge 30101 Oughterard D/S. Single arch bridge. Deck elevations taken as concrete deck and not top of railings, as water can flow through railings; however efficiency of overtopping was reduced to allow for effect of railings.	
Abhainn Na Coille Culvert (30TONW00016)	The inlet to this culvert is circular, but the outlet is square, so circular conduit units have been used for the upstream end, and rectangular conduit units for the downstream end. The junction has been placed 8m from the downstream end of the culvert. There are some other small structures on this watercourse a short distance upstream, including a 1m diameter culvert and a bridge 1.75mx1m, 26m and 52m upstream respectively. The flooding impact of these structures are deemed non-critical so have not been listed in this table.	

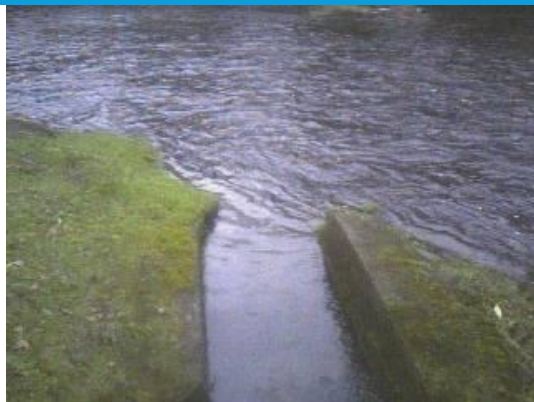
2.3 Hydraulic roughness

Reaches of similar hydraulic roughness have been identified from survey photos and drawings. Manning's 'n' values for both the river bed and banks to bank top within each of these reaches are summarised in Table 2-2.

Table 2-2: Reach hydraulic roughness values

Upstream and downstream cross section	Roughness values (Manning's 'n') and materials	Photograph
30ORIF00365E to 30ORIF00297	0.04 (Coarse gravel and cobbles) 0.06 (scrub, trees and bushes)	
ORIF002850* to 30ORIF00203D	0.05 (coarse gravel and cobbles) Left Bank: 0.05 (Scrub/grass) Right Bank: 0.065 (trees/bushes) Note channel values in this reach were increased from those originally selected to calibrate at staff gauge 30044 Oughterard.	
ORIF00203B to ORIF001936*B	0.04 (coarse gravel and cobbles) Left Bank: 0.04 (Scrub/grass) Right Bank: 0.065 (trees/bushes)	
30ORIF00187D to 30ORIF00142D	0.035 (coarse gravel) Left bank: 0.055 (grass/trees) Right bank: 0.065 (trees/bushes)	

Upstream and downstream cross section	Roughness values (Manning's 'n') and materials	Photograph
30ORIF00139 to 30ORIF00104D	0.035 (coarse gravel) 0.065 (trees/bushes)	
30ORIF00088 to 30ORIF00064	0.03 (gravel) 0.055 (grass/trees/ bushes)	
30ORIF00047 to 30ORIF00002	0.04 (silt/sand/reeds) 0.05 (reeds/bushes)	
30TONW00147 to 30TONW00003	0.04 (gravel, cobbles) 0.06 (scrub, trees and bushes)	

Upstream and downstream cross section	Roughness values (Manning's 'n') and materials	Photograph
30TONW00003B to 30TONW0000	0.02 (concrete) 0.02 (concrete) 0.035 (short grass)	

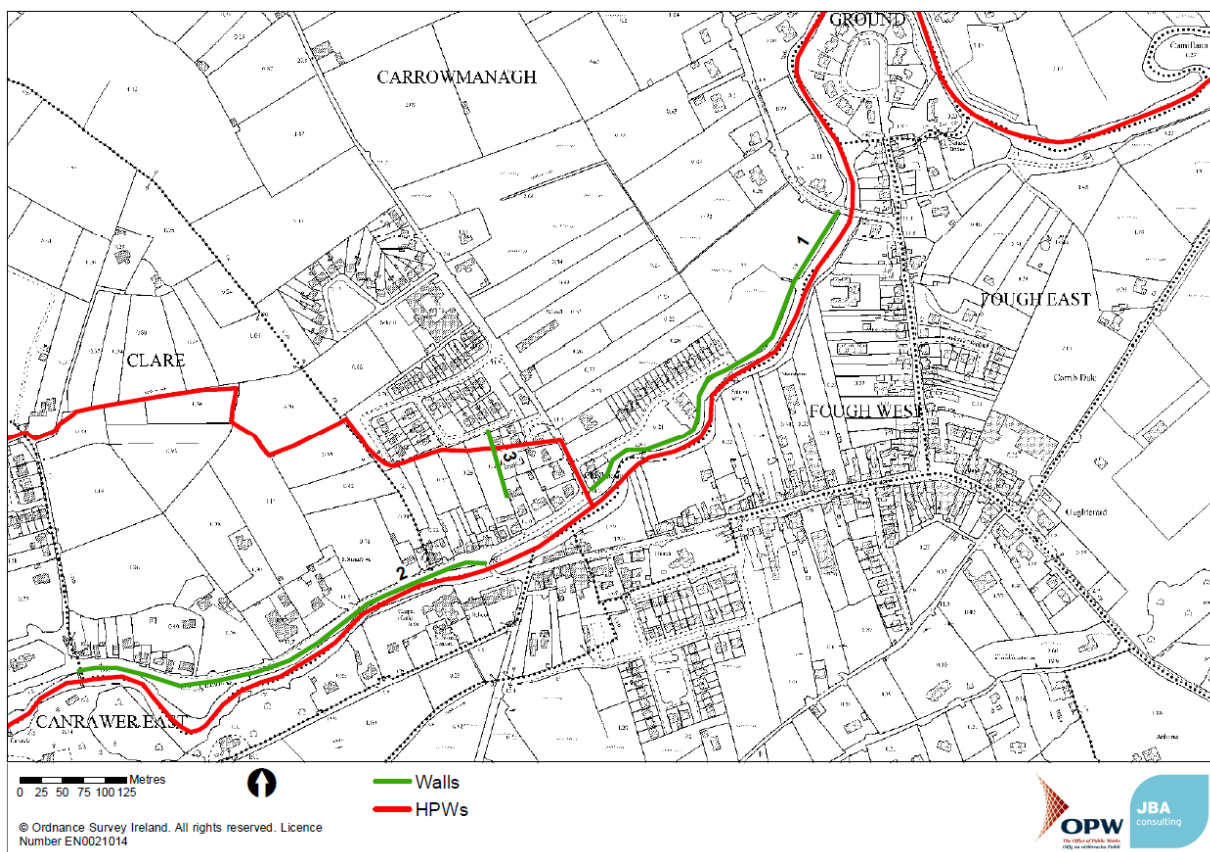
2.4 1D-2D boundary

Bank top spot level survey data is available between the majority of cross sections along the Owenriff and Tonweeroe rivers and has been used to develop the 1D-2D boundary along this watercourse. Where levels were not surveyed between cross sections there was little change in the profile of the bank and the crest height has been interpolated between sections.

2.5 Defences and walls

The locations of defences and walls within the AFA are shown in Figure 2-2.

Figure 2-2: Defences and walls locations






2.5.1 Defences

There are no formal (i.e. OPW, local authority or privately maintained defences) in Oughterard. Neither are there any informal effective defences within the AFA.

2.5.2 Walls

Informal ineffective structures identified with the AFA are detailed in Table 2-3. These structures are not assumed to function as flood defences and are either bypassed in the model or have been removed to allow flooding beyond them.

Table 2-3: Informal ineffective walls and embankments

ID	Description and location	Modelling method	Photograph
1	This structure is a stone wall extending upstream for approximately 400m on the left bank from gauging station 30101. There are gaps under the wall to allow drainage from the field. These will allow flood water to pass under the wall into the field.	Gaps incorporated in wall	
2	This structure is a stone wall extending upstream for approximately 500m on the left bank from the N18 bridge over the Owenriff. The structure has gaps in it and can be bypassed with flow along the N18 parallel to the river.	Gaps incorporated in wall	
3	This structure is a single skin block wall extending over the inlet to the downstream culvert on the Tonweeroe watercourse. The inlet has a screen and looks prone to blockage. Sensitivity tests reviewing the effect of this wall are discussed in Section 6.	Included as wall in 2D model domain	

2.6 Floodplain

A 2D cell size of 4m has been used because this is considered appropriate for the mix of watercourses represented from small stream to lake shore. It also ensures run times remain reasonable and the main flow routes are represented. Roughness values have been assigned to the floodplain using the values detailed in the Modelling Method Statement.

3 Flood history, model calibration and sensibility checking

3.1 Calibration versus sensibility checking

Where a recording flow gauge is located in or near the site and this data is accompanied by historical data from a flood event (such as flood extents, or spot levels), then it is possible to undertake calibration of the model. This process would involve running the recorded flows through the model and changing model parameters, such as Manning's 'n', to match the flood extents or levels that were observed. Ideally, a second event would then be run through the model and used to validate the outputs. While it is possible to simulate flows recorded at a gauge in the model, without any record of the impact of the event the model cannot be calibrated and the checking process is limited to a confirmation that predicted extents match expectations based on topography and local knowledge. If there is no gauge data available but there are historical records of flooding then the predicted extent from an appropriate design event with a similar exceedence probability to the historical flood event can be used as a sensibility check of the predicted flooding frequency.

3.2 Flood history

3.2.1 Flood history

Key flood risk areas have been identified in the Flood Risk Review¹ and Inception Reports². For the purposes of the hydraulic modelling work this data is most beneficial when accompanied by supporting details such as photos or anecdotal evidence which confirm the maximum extent or depth of flooding at any given location.

Within the Oughterard AFA supporting flood history data is available in some locations. There is evidence to support flooding from the Owenriff River on the left bank along the N59 upstream of the bridge and in the area towards the downstream end of the Tonweeroe watercourse. The largest recorded events on record occurred in 1999, 2011 and 2015. The 1999 and 2011 events are estimated to be equivalent to a 0.1% AEP and 0.5% AEP event respectively. The upstream gauge failed for the 2015 event. This is summarised in Table 3-1.

Table 3-1: Summary of flood history

Area affected	Main flood mechanisms	Recorded flood event date	Use in model check
N59 Road	Fluvial	4/05/2015	Sensibility run
Abhainn Na Coille	Fluvial	07/02/2000	Calibration run
Abhainn Na Coille	Fluvial	28/11/1999	Calibration run
Low lying field near Lough Corrib	Lake	5 year reoccurring	Sensibility check on design extents

3.3 Calibration data

Calibration of the hydraulic model has been completed using the Claremount and Oughterard D/S gauges. The Claremount gauge is located at the upstream end of the AFA. The Oughterard D/S gauge is centrally located within the AFA. Levels extracted from the gauges have been converted to flows using the updated rating curves at both sites detailed in the WCFRAM Hydrology Report for UoM 30. A staff gauge is also present in Oughterard which is used in the hydraulic model calibration.

Based on the data available calibration runs have been completed for 1999 and 2011 events. These have been selected because they are the largest on record on the Owenriff River. The 1999 event is based on the now defunct Claremount gauge (high uncertainty) and the 2011 on the current Oughterard D/S gauge. A period of overlap in record at the gauges was used to adjust the Claremount gauge to make it more consistent with the records at Oughterard D/S.

To calibrate the model to this data, flows from the gauges have been applied at the upstream limit of the model. Flows on the Tonweeroe tributary have been estimated based on a ratio of the design flows between the watercourses. Level data for the downstream boundary has been based on the Barrusheen gauge on Lough Corrib using the AMAX level value for the year of the calibration event to give a maximum extent at the downstream end for that year.

3.4 Calibration outcomes

3.4.1 November 1999 calibration event

Figure 3-1 and Figure 3-2 detail the calibration of the November 1999 event and the resulting modelled flood extent within the AFA respectively. The inflow to the model is derived directly from the 30019 Claremount gauge and has an estimated peak flow of 57m³/s. The rating here is fairly uncertain and had to be amended away from the gauged data to fit better with the downstream gauge. There is no data available for gauge 30101 Oughterard D/S for this event.

To calibrate the model to the staff gauge 30044, roughness values were slightly increased (0.04 to 0.05) in the section of the Owenriff between the cascades and the N59 Bridge. This change does not affect the calibration from the initial rating review as the roughness change occurs some distance from the other gauges. This local adjustment provided a better fit to the information available at higher flows, but stops short of full calibration to this site given data limitations. The high end gaugings which it fits reasonably are from 1999 and 1990.

There is evidence of extensive flooding in Oughterard during this event including along the N59 upstream of the N59 Bridge (floodmaps.ie). This flow route is represented in this model run.

Figure 3-1: November 1999 calibration plot at the 30044 staff gauge

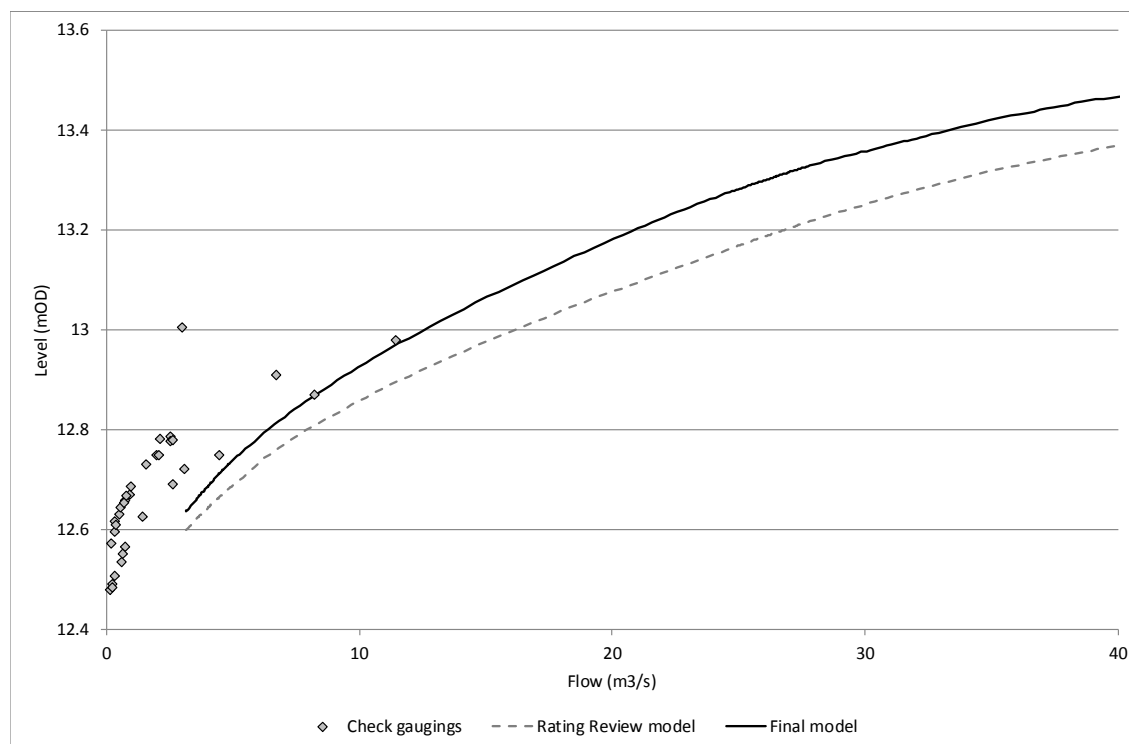
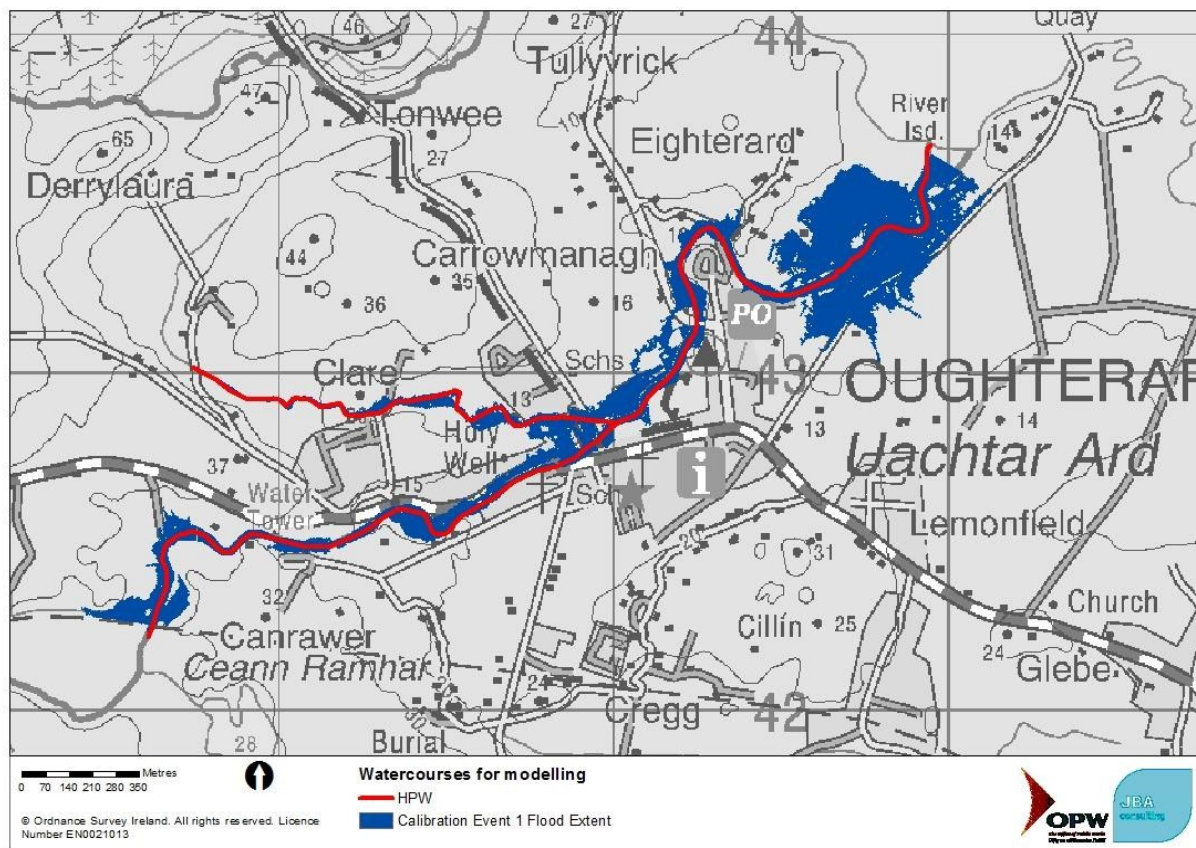


Figure 3-2: November 1999 modelled flood extent



3.4.2 November 2011 calibration event

The hydraulic model at the gauge 30101 Oughterard has been calibrated for a rating review. This gives good confidence in the model in this central reach of the Owenriff River. The flow record from this gauge has been used to derive the event inflow which has a peak of $48\text{m}^3/\text{s}$.

Figure 3-3: Model rating curve and check gaugings at 30101 Oughterard D/S gauge

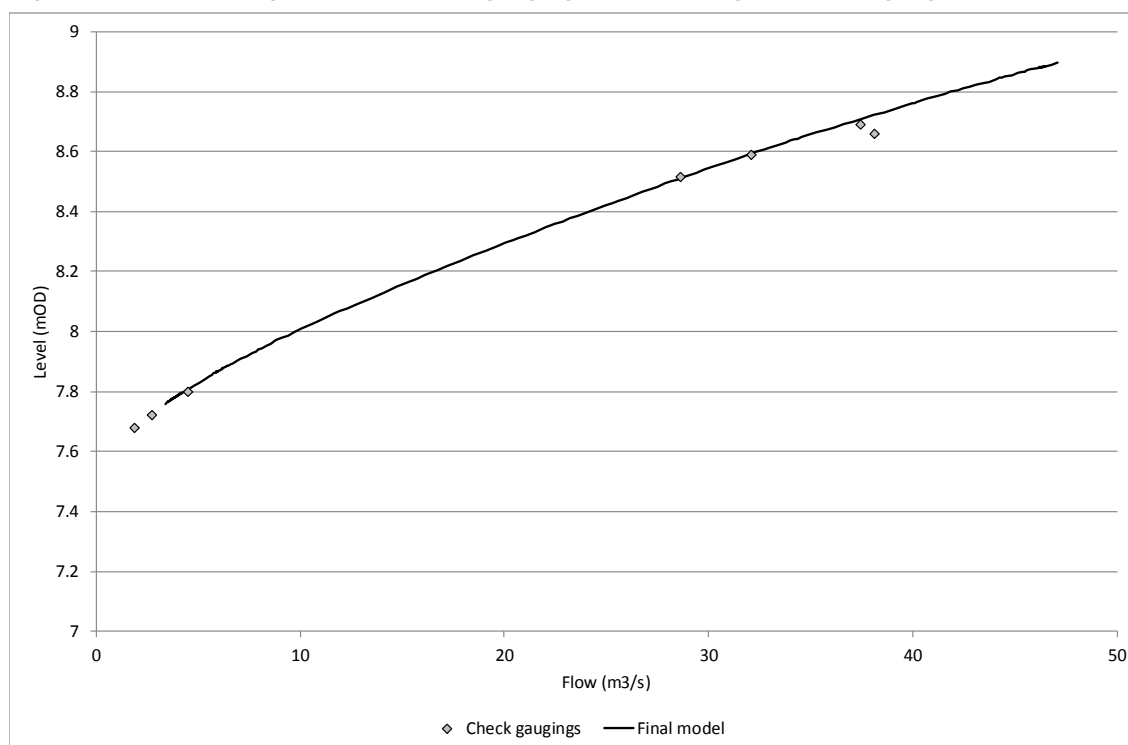
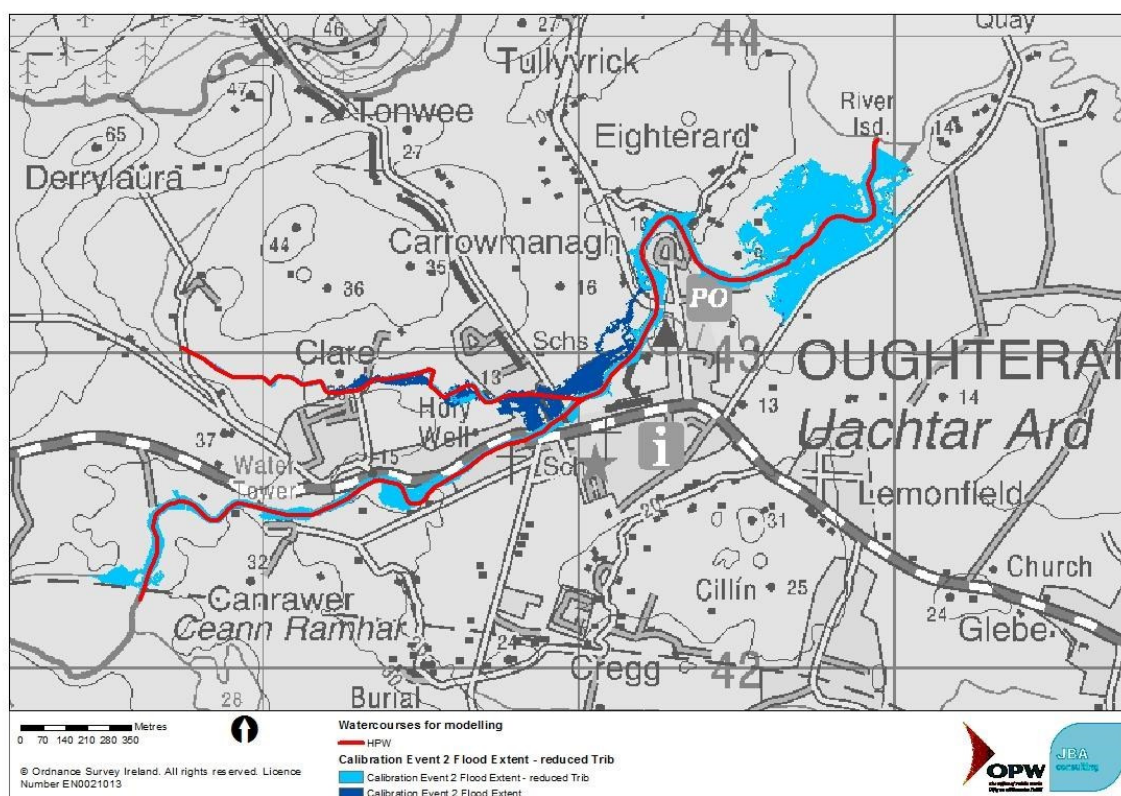


Figure 3-4: November 2011 modelled flood extent



The first attempt at this calibration event appeared more extensive than anything that was reported for this event (dark blue extent). The majority of flooding is coming from the Tonweeroe watercourse which does not have any gauged data and simply has an estimated inflow scaled in relation to the recorded Owenriff flows in a ratio the same as design events. It could be that this calibration event is overestimating the

tributary flows. A second attempt at this event has been modelled with reduced tributary flows which now gives a much reduced flood extent and one more in line with the lack of observations of flooding associated with this event (light blue extent). The tributary flows are only a very small contribution to the total Owenriff peak flows and likely to occur earlier so this scenario is very plausible.

3.4.3 December 2015 Flooding

On the weekend of the 4th/5th of December 2015 flooding was reported on the N59 road upstream of Oughterard Bridge on the left bank. Flood waters came out of bank upstream at near Sweeny's Hotel, flowed down the road and ponded in the area just upstream of the bridge. Flood depths were approximately 100mm on the road. During the event emergency works involved breaking a hole in the wall upstream of the bridge to allow waters to return to the main Owenriff channel (Figure 3-5). The N59, though close to being closed, remained open during the event. There was no reported internal property flooding during the event,

The flood mapping and hydraulic model was examined following this event. In events greater than the 1% AEP water exits the channel upstream near Sweeny's hotel as happened in this event, flows down the road and ponds behind this wall. Gauge records of the downstream bridge were sought but unfortunately the gauge was down during the event. This prevented the study determining the return period of the event.

Figure 3-5: N59 Flooding December 2015



3.5 Stakeholder Engagement

Throughout this process OPW regional engineers and local authority engineers have been consulted in the form of steering group, progress group and engineer meetings and their input has feed into the flood maps.

Public Consultation Day (PCD) – 16th of October 2014

On October 16th 2014 a public consultation was held at The Boat Inn to present the flood maps for the town and solicit comments and feedback.

This PCD was attended by 19 people. At the PCD attendees were invited to leave feedback, in the form of a questionnaire. The questionnaire sought feedback on resident's knowledge of flooding in the town including the locations of flooding and the frequency of flooding.

Table 3-2 outlines the feedback received at the day relevant to the study and a note regarding how this information has been accommodated by the study.

Table 3-2: PCD Feedback

Comments Received	Study Response
The ground floor of apartments in the Canrawer development were flooding up to a depth of 9 inches. An adjacent field is the source of the flood. Flood water builds up in the field and cannot flow to Owenriff.	This report describes surface water flooding. The focus of this study has been on fluvial flood risk. This report cannot be used to validate the flood extents.
There are possibly natural underground flow routes to the north of existing route of the Tonweeroe, through Waterfield. An underground route comes out at Waterlily.	This report provides some validation of the suggestion that there may be a swallow hole along the Tonweeroe. The influence of this groundwater system has not be considered in the development of the flood extent.
Houses in Waterfield flooded up to window sill in 1998/1999.	This event has been run for the purposes of calibration and properties in the Waterfield area are shown to be at risk of flooding.
A raised bog adjacent to Leas na Creige estate currently floods.	This report describes surface water flooding. The focus of this study has been on fluvial flood risk. This report cannot be used to validate the flood extents.
A culvert blocked at Sweeney's Hotel resulting in localised flooding. The flood extents appear accurate.	This report describes surface water flooding. The focus of this study has been on fluvial flood risk. This report cannot be used to validate the flood extents.
The rear garden in the Carrowmanagh Park estate flooded 4 years ago. Pathways in the area uplifted by floodwater. Gullies were cleaned to alleviate floodwater. Floodwater came from the rear and remained for a few days. The area is very marshy. Area in front of developments is very saturated	This report describes groundwater flooding. The focus of this study has been on fluvial flood risk. The influence of this groundwater system has not be considered in the development of the flood extent.
The Waterfield estate was constructed in 2000/2002. Flooding has occurred from the Tonweeroe and kerbs were smashed and taken out to let floodwater drain into the Owenriff. Rubbish blocks the Tonweeroe culvert and locals clear it. Flood waters also come up from ground.	This report provides confirmation of the flow route shown from the Tonweeroe overland to the Owenriff. The report confirms the culvert inlet is sensitive to blockage.
An error in the existing "Flood Depth 250mm" map as currently prepared. A flood depth of 250mm in the field west of Abhainn na Coille could not generate a similar depth in Abhainn na Coille (estate) considering that the Finished Road Level in the estate is several feet higher than the field. The original maps of October 2014 showed an open channel stream flowing south east through Abhainn na Coille. Map seen today corrects this error to show that the "stream" discharges into a surface water sewer running east along the road in Abhainn na	The flood maps are based on LIDAR data, which represents the best available data. The fields in the LIDAR data are lower than the Abhainn na Coille road level, although not by the several feet highlighted. The local wall at the end of Abhain na Coille has now been included in the model and so flooding of the Abhain na Coille estate no longer occurs. Flows are now directed to the south to discharge into the Owenriff River, reflecting the feedback. It is noted that the local wall is not a constructed flood defence and whilst it will

<p>Coille and connecting into the trunk storm sewer on the Main Road. Although the routing has been corrected the original flood risk zone has not altered and in its present form/ extent/ depth, it is not logical.</p> <p>Flooding in 1999 affected the field, west of the estate, but did not affect the Abhainn na Coille housing estate. Water directly overflows to the Owenriff River.</p> <p>The FFLs of the houses here 300mm higher than the finished road level.</p>	<p>divert low depths, there is a risk is could fail and the flow route through the Abhainn na Coille estate reinstated. Further comment on this wall is provided throughout this report and in the sensitivity tests.</p>
--	---

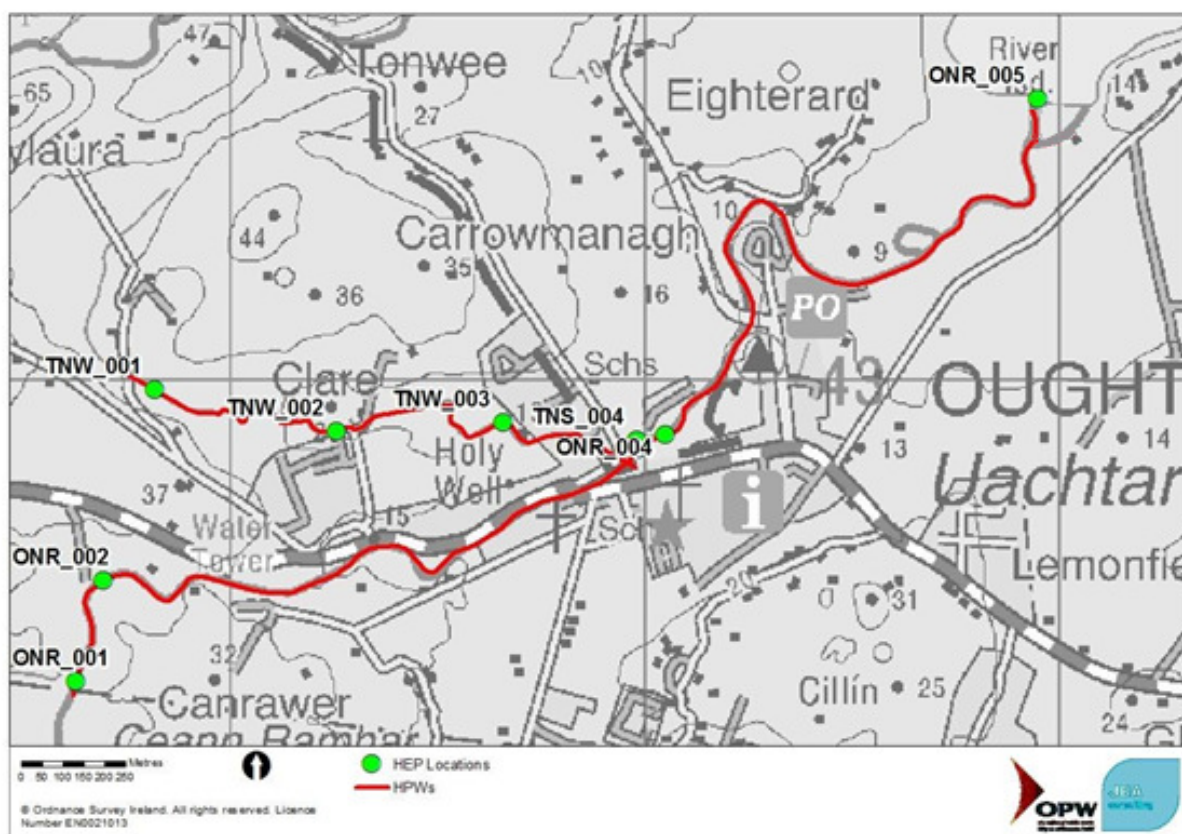
4 Application of hydrology

4.1 Hydrological estimation points

Design flows have been developed at a series of Hydrological Estimation Points (HEPs) throughout the catchment. Full details of the development of these flows are provided in the WCFRAM Hydrology Report for UoM 30.

The locations and names of all the HEPs within the Oughterard AFA are presented in Figure 4-1 and are also shown in the Volume 3 maps.

Figure 4-1: Oughterard AFA HEP locations



4.2 Application of design flow estimates

4.2.1 Hydrograph shapes

Inflow hydrograph shapes for each watercourse have been developed from the Flood Studies Report (FSR) rainfall runoff method. This approach has been tested (as detailed in the Hydrology Report) and, with the exception of a few gauges this found the FSR approach to provide the best fit against gauge data. Inflows are located at the upstream limit of each watercourse.

The FSR method, applied using a uniform design storm for all sub-catchments within a model, imposes a structure on the model inflows with realistic relative timings of the hydrographs. This avoids the need to apply the FSU regression model for relative timings of hydrographs at a confluence; an approach which is associated with a large standard error. Because the FSR method is being used only to control the shape of the hydrographs rather than the magnitude of the peak flows (which are based on the HEPs), there is no benefit to identifying a critical storm duration, i.e. one that results in the highest peak flow or water level. However, in order to ensure a realistic flood duration, the duration of the design storm has been related to the time to peak for the principal watercourse in the model, using the FSR formula that evaluates storm duration from time to peak and SAAR. The potential impact of the critical storm duration on tributary flood extents has been reviewed and is discussed in Section 6.

A consistent design storm duration has been applied across all boundaries and has been selected as the critical storm duration for the catchment to Oughterard on the Owenriff watercourse. A critical storm duration of 15 hours has been applied.

4.2.2 Scaling to hydrological estimation points

For the Owenriff watercourse the inflow hydrograph has been scaled to the upstream HEP point (ONR_001). To reflect the increase in flows downstream lateral inflows have been applied between HEP points ONR_001 and ONR_003 and between ONR_004 and ONR_005. These have been derived by subtracting the scaled hydrograph shapes between the HEP points.

The resulting flows downstream of the confluence of the Tonweeroe watercourse and the Owenriff watercourse have been reviewed against the design flows. These show good agreement to the design flows on the Owenriff. Design flows in the model on the Tonweeroe watercourse do not show good agreement to the HEP flows due to hydraulic constrictions on the watercourse. Lateral inflows are applied to the watercourse to give the appropriate design flow increases downstream but these are not clearly seen in the modelled results.

A summary of the model inflows and application of the design hydrology through these is provided in Table 4-1.

Table 4-1: Summary of hydraulic model design inflows

HEP reference	Cross Section	Peak flow estimates (m ³ /s)					Flow in model (m ³ /s)					Comments
		50% AEP	10% AEP	2% AEP	1% AEP	0.1% AEP	50% AEP	10% AEP	2% AEP	1% AEP	0.1% AEP	
ONR_001	30ORIF003704*	23.6	31.1	38.6	42.2	63.7	23.6	31.1	38.6	42.2	63.7	Upstream extent of model. Gauging station 30019 just downstream.
ONR_003	30ORIF001936*A	25.4	33.4	41.5	45.4	68.4	25.8	34.0	42.1	46.0	68.7	Upstream of confluence with the Tonweeroe
ONR_004	30ORIF001936*B	26.6	35.0	43.4	47.5	71.6	26.4	34.8	43.1	47.1	69.7	Downstream of confluence with Tonweeroe. Close to gauge 30101.
ONR_005	30ORIF00002	27.2	35.8	44.5	48.6	73.6	27.5	36.3	44.9	49.1	72.3	Downstream extent of model at Lough Corrib.
TNW_001	30TONW00147	0.47	0.67	0.88	0.98	1.51	0.47	0.67	0.88	0.98	1.51	Upstream extent of model.
TNW_002	30TONW00092	0.58	0.81	1.06	1.19	1.82	0.56	0.80	1.06	1.19	1.84	This is the section immediately upstream of the HEP location.
TNW_003	30TONW00076	0.70	0.99	1.31	1.48	2.27	0.69	0.98	1.32	1.47	2.30	This is slightly upstream of the HEP but shows the inflow is applied. Closer to the HEP location the impact of structures and flow into the 2D domains means flows start to reduce in channel. At the selected location the flow remains in channel.
TNW_004	30TONW00016A	0.79	1.12	1.48	1.66	2.56	0.77	1.09	1.45	1.63	2.40	Downstream of Tonweeroe. Taken at upstream face of the long culvert to avoid complications with the confluence with Owenriff.

4.3 Downstream Boundary

The downstream boundary of the hydraulic model is Lough Corrib. Water levels from Lough Corrib could be expected to impact water levels within the downstream reach of the model. However, water levels in the lough are not closely correlated with those on the Owenriff River, with the lough generally responding to much longer duration events. AMAX values are often for entirely different events during a year.

This meant that the design runs did not involve the coincidence of peak levels in Lough Corrib and peak flows in the Owenriff; the fluvial peak flow occurs first and subsides and is only then followed by the same return period peak level in Lough Corrib. This means that both lake level and flow are represented at the same return period in single model run yet avoids much less likely joint events.

To determine initial design levels on Lough Corrib the four level gauges on the Lough have been considered. From this analysis it is clear that the levels across the lake are remarkably similar during high water level AMAX events. In some cases wind may cause some deviation but in general the levels are very consistent. The highest levels were recorded in 2006 and show a maximum value within 0.1m from the four gauges across the lake from very upstream to very downstream extents (approx. 30km apart). The longest gauged lake record (Cong Pier) has been used to estimate initial return periods for lake level. These have been developed using a 2 parameter log normal distribution for the single site record. The highest recorded level in 40 years of record at Cong Pier is 7.16 mOD, just under a 1% AEP lake level. Table 4-2 details the levels at Lough Corrib for a range of return periods.

Table 4-2: Extreme level estimates for Lough Corrib

Location	Predicted peak water levels (mOD)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
Lough Corrib	6.71	6.87	6.96	7.02	7.12	7.17	7.23	7.33

5 Model results

5.1 Model runs

The model has been run for a present day and two future scenarios, a Mid-Range Future Scenario (MRFS) and a High-End Future Scenario, which consider the potential impact of climate change. Further details of the allowances within the calculations are included in the Hydrology Report, but the increased flows include for the impacts of urbanisation and climate change.

The model has been run for the following present day and MRFS fluvial and extreme lake events: 50%, 10%, 5%, 2%, 1%, 0.5% and 0.1% AEP design events. Only the 10%, 1% and 0.1% AEP design events have been run for the HEFS. For all the fluvial events, the equivalent lake level has been used as the downstream boundary.

Table 5-1: Peak flows for the Mid-Range Future Scenario

HEP reference	Predicted peak flows for the MRFS (m ³ /s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
ONR_001	28.3	33.7	37.3	41.0	46.3	50.7	56.8	76.5
ONR_003	30.5	36.2	40.1	44.1	49.8	54.5	61.1	82.2
ONR_004	31.9	38.0	42.0	46.2	52.2	57.1	64.0	86.1
ONR_005	32.7	38.9	43.1	47.4	53.5	58.5	65.6	88.3
TNW_001	0.57	0.70	0.80	0.90	1.05	1.18	1.33	1.81
TNW_002	0.70	0.86	0.98	1.10	1.27	1.42	1.60	2.19
TNW_003	0.84	1.04	1.19	1.34	1.57	1.77	2.00	2.72
TNW_004	0.95	1.19	1.35	1.53	1.79	2.02	2.27	3.10

Table 5-2: Peak flows for the High-End Future Scenario

HEP reference	Predicted peak flows for the HEFS (m ³ /s)		
	10% AEP	1% AEP	0.1% AEP
ONR_001	40.4	54.9	82.8
ONR_003	43.5	59.1	89.1
ONR_004	45.6	61.9	93.3
ONR_005	46.8	63.5	95.8
TNW_001	0.87	1.28	1.96
TNW_002	1.06	1.54	2.37
TNW_003	1.29	1.92	2.95

5.2 Flood risk mapping

Flood risk extents for the present day and MRFS 10%, 1% and 0.1% AEP design events along with long section profiles for present day 10%, 1% and 0.1% AEP design events are presented in Volume 3 of the UoM 30 Hydraulic Modelling Report.

5.3 Key flood risk mechanisms

Further to the information presented in the flood risk maps, a brief description of the key flood risk sites and flooding mechanisms is provided below.

5.3.1 Flooding upstream of N59 Bridge on left bank

In extreme events greater than 1% AEP, the water can rise over the left bank onto the N59 Clifden Road and flow along the road parallel to the river. The road is slightly elevated above the river level but there is no consistent raised wall along here. The N59 Bridge causes elevated upstream water levels due to it constricting the flow area. However, given the river's steepness and extent the road can flood, the bridge does not solely control this elevated water level.

5.3.2 Flooding at Oughterard gauging station (Glann Road) bridge

There is flooding on the left bank around the Glann Road Bridge for extreme events greater than 0.5% AEP. The calibration runs have suggested this is primarily from water from the Tonweeroe watercourse which flows overland to this area without entering the Owenriff. There is a connection

from the Owenriff to this area but capacity of the flow route is limited as it is flowing under the channel side wall (flow in 0.1% AEP event is modelled as 0.35 m³/s).

On the right bank is a care home that sits fairly close to the river. Flooding is not modelled as impacting the care home even in the 0.1% AEP event.

5.3.3 Flooding towards Lough Corrib

At the downstream extent of the Owenriff is a wide expanse of low lying land on the fringes of Lough Corrib. This area floods much more extensively from high lake levels than from the river but there is no property at risk here. Modelling the lake levels as peaking after the river means the risk from the lake levels is included for the same return period as the fluvial results.

5.3.4 Flooding from Tonweeroe watercourse

The most extensive property flooding modelled in Oughterard is associated with the Tonweeroe watercourse. The flooding appears primarily related to a small culvert along the lower reach of the watercourse, and particularly the final 130m culvert connecting to the Owenriff River that is undersized and cannot convey the design flows. Flood water flows out of the lower Tonweeroe channel towards property are initiated between the 10% and the 2% AEP event. This flooding has the potential to increase significantly in the event of culvert blockage which is fairly likely given the flat screen on the final (downstream) culvert. There is little evidence of geomorphological issues on this channel from the survey photos and no sign of siltation at the inlet of the final culvert.

The wall above the inlet to this culvert protects flooding to the properties to the west of the culvert entrance (Wall 3 in Figure 2-1). The performance of this wall as a flood defence is key in preventing flooding to properties in Abhainn na Coille and Carrowmanagh housing estates.

6 Sensitivity testing

6.1 Screening of sensitivity tests

The suite of potential sensitivity tests is detailed in Volume 1a: Hydraulic Modelling Method Statement. The application of the sensitivity tests has been an iterative process which allowed certain criteria to be screened out. Table 6-1 summarises the full suite of potential sensitivity tests, and highlights those which have are not applicable, and those which have been screened out. Further details of these criteria are provided in the following sections.

The results of testing those criteria which are relevant to Oughterard are detailed in Section 6.2.

Table 6-1: Sensitivity test summary

Sensitivity test	Relevance to Oughterard
Peak flow	Tested
Flow volume	Tested
Critical storm duration	Screened out
Roughness	Tested
Building representation	Tested
Afflux / headloss at key structures	Tested at a number of structures
Water level boundaries and joint probability	Tested
Timing of tributaries	Screened out
Timing of fluvial and tidal peaks	Not applicable
Cell size	Screened out
Local wall on Tonweeroe	Tested

6.1.1 Peak flow

The flow sensitivity scoring mechanism is detailed in the generic Hydraulic Model Development Methodology and produces a score of 10 for the Owenriff River and 22 for the Tonweeroe watercourse. Table 6-2 details the flow sensitivity tests required as a result of these scores.

Table 6-2: Flow sensitivity scaling factors

Return period of event	Owenriff River	Tonweeroe Watercourse
10%	Use QMED uncertainty	Use QMED uncertainty
1%	Use QMED uncertainty then multiply flows by 1.2	Use QMED uncertainty then multiply flows by 1.3

6.1.2 Flow volume

The sensitivity test to flow volume is required where the flow hydrograph has been generated from limited or no data. This is the case in Oughterard so a test of the flow volume was deemed beneficial. Given the fairly extensive lakes in the upper catchment of the Owenriff a multiplier of 2.5 in event duration was applied, taking the design event to 37.5hrs.

6.1.3 Roughness

On the Owenriff River the limited flood extents in the existing risk design events mean there is little benefit to testing the sensitivity of the model results to a reduction in roughness values, as such a reduction would only further reduce extents by speeding the passage of water through the model domain and into the lake, rather than to another risk receptor. Similarly, because of the lack of flooding in the 1% AEP event the sensitivity to roughness has not been appraised for the 10% AEP event. The specific maintenance regime undertaken by Galway County Council is not known, but site inspection shows the channel through the town to be well maintained. This indicates that although channel and bank roughness (i.e. vegetation growth) may increase, it will probably be within reasonable bounds.

On the Tonweeroe watercourse the channel is less well maintained and more prone to flooding, even in the 10% AEP event. For this watercourse there is benefit in assessing an increase and decrease in roughness for the 10% AEP and 1% AEP events.

Table 6-3 summarises the current roughness values applied within the model over the various reaches and the increased values applied for the 10% AEP events and 1% AEP events.

Table 6-3: Sensitivity to roughness scenarios

Upstream and downstream cross section	Roughness values (Manning's 'n') and materials		
	Existing risk	10% AEP roughness sensitivity	1% AEP roughness sensitivity
30ORIF00365E to 30ORIF00297	0.04 (Coarse gravel and cobbles) 0.06 (scrub, trees and bushes)	No change	Bed - 0.05 Banks - 0.080
ORIF002850* to 30ORIF00203D	0.05 (coarse gravel and cobbles) Left Bank: 0.05 (Scrub/grass) Right Bank: 0.065 (trees/bushes)	No change	Bed - 0.07 Channel sides - 0.07 Banks - 0.085
ORIF00203B to ORIF001936*B	0.04 (coarse gravel and cobbles) Left Bank: 0.04 (Scrub/grass) Right Bank: 0.065 (trees/bushes)	No change	Bed - 0.05 Channel sides - 0.05 Banks - 0.085
30ORIF00187D to 30ORIF00142D	0.035 (coarse gravel) Left bank: 0.055 (grass/trees)) Right bank: 0.065 (trees/bushes)	No change	Bed - 0.045 Channel sides - 0.075 Banks - 0.085
30ORIF00139 to 30ORIF00104D	0.035 (coarse gravel) 0.065 (trees/bushes)	No change	Bed - 0.045 Banks - 0.085
30ORIF00088 to 30ORIF00064	0.03 (gravel) 0.055 (grass/trees/bushes)	No change	Bed - 0.04 Banks - 0.075
30ORIF00047 to 30ORIF00002	0.04 (silt/sand/reeds) 0.05 (reeds/bushes)	No change	Bed - 0.05 Banks - 0.07
30TONW00147 to 30TONW00003	0.04 (gravel, cobbles) 0.06 (scrub, trees and bushes)	Bed - 0.03 to 0.05 Banks - 0.04 to 0.08	Bed - 0.03 to 0.05 Banks - 0.04 to 0.08

Roughness values in the floodplain have been increased to the upper bound of those values quoted in the Hydraulic Modelling methods report for the 1% AEP event only.

6.1.4 Building representation

The current flood risk extent in the 1% AEP event shows inundation of many properties primarily close to the Tonweeroe tributary. Properties are currently modelled using a mean LIDAR level. To test the sensitivity of the building representation a raised property threshold level of 150mm was applied. The properties impacted in Oughterard do not appear to have significantly raised thresholds so this value seems appropriate for this test.

6.1.5 Afflux at key structures

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

Two key structures have been identified for review as part of this sensitivity test; N59 Bridge, and the series of small structures at the downstream end of the Tonweeroe watercourse (2 culverts and 1 bridge). These are the structures that pose a significant impact to neighbouring receptors and/or have a significant modelled afflux.

A review of predicted head losses through the N59 Bridge in the 1% AEP event shows the structure increasing water levels upstream by approximately 340 mm. Although flood water does not reach the level of the N59 road in this event greater afflux could cause this flow route to activate. To consider this further a head loss unit will be applied at the upstream face of the bridge with K value of 0.3.

The structures on the lower Tonweeroe currently initiate flooding between the 10% and 2% AEP events. It is possible the most downstream of these could block as it has a screen at the upstream face. A relatively small change in level in this area in the 10% AEP event could initiate flooding. The sensitivity test focused on the most downstream of these culverts as it is the longest and most prone to (a) blockage and (b) unknown internal factors. This culvert already has a bend unit and a shape change included within the representation. The screen in an unblocked state is also included in the model.

To review the head losses associated with the culvert, additional losses were applied at the upstream face to account for potential additional complexity within the culvert, notably as a result in the change in dimension at some point within the structure. A head loss unit was applied at the upstream face of the culvert with K value of 0.3.

It is important to note that contraction and expansion losses at these faces, and on all other structures, have already been modelled and these values have been used to consider the implications of additional complexity only.

6.1.6 Water level boundaries

A water level boundary at Lough Corrib is used to model flood level and extent at the downstream end of the model. The level is based on a simple statistical extrapolation of gauge data but the lake level is relatively stable, as shown by the long records producing a fairly shallow growth curve. A sensitivity test to the lake level boundary was deemed beneficial but was constrained as a large increase in level would be very unlikely as it would require a huge additional volume to be present. To test the sensitivity, an increase of 0.25m on the 1% AEP value was applied, which takes it up beyond the 0.1% AEP level. In reality this would represent an increase in lake storage in the region of 50 million m³.

6.1.7 Timing of tributaries

Adjustments to the timing of the tributary could result in higher flows downstream on the Owenriff if peak flows on the Tonweeroe watercourses were delayed. This test is only recommended where there is good confidence in the hydrology and the increase in flows resulting from the shift in timing would exceed the increase in flows investigated as part of the flow sensitivity. In this instance, a shift in the timing of tributaries would increase flows on the Owenriff by a very small amount as inflows from the Tonweeroe represent a small proportion of the whole catchment. There is also a high degree of uncertainty in the hydrology and the increase in flows is less than has been modelled under the peak flow sensitivity test.

6.1.8 Local wall on Tonweeroe

A defence wall is applied to the 2D domain to model the local wall after the upstream face of the long culvert on the Tonweeroe. This wall is the western boundary wall of the Abhainn na Coille housing estate which has been concluded to provide a flood defence. As this wall is not a formal flood defence a sensitivity run has been modelled with the wall removed to determine the lands and properties benefiting from the wall.

6.2 Sensitivity testing results and uncertainty bounds

The results of the sensitivity tests have been used to inform the uncertainty bounds as detailed in the Hydraulic Modelling Method Statement. The uncertainty bound in effect presents the most sensitive hydraulic parameter/s as assessed within the bounds identified in Section 6.1 at all locations along the modelled reach.

To simplify the presentation of the sensitivity tests, the uncertainty bound for the 10% AEP and 1% AEP events has been presented only. Where different parameters have contributed to the development of the uncertainty bound, these are highlighted on the map and in the following text.

The 10% AEP uncertainty bound is compared to the equivalent predicted flood extent for the Oughterard AFA in Figure 6-1. The increase in flood extent is as a result of the peak flow sensitivity. This is an expected result due to the increase in flow for this test. The other tests showed no increase in flood extent.

Figure 6-1: 10% AEP uncertainty bound

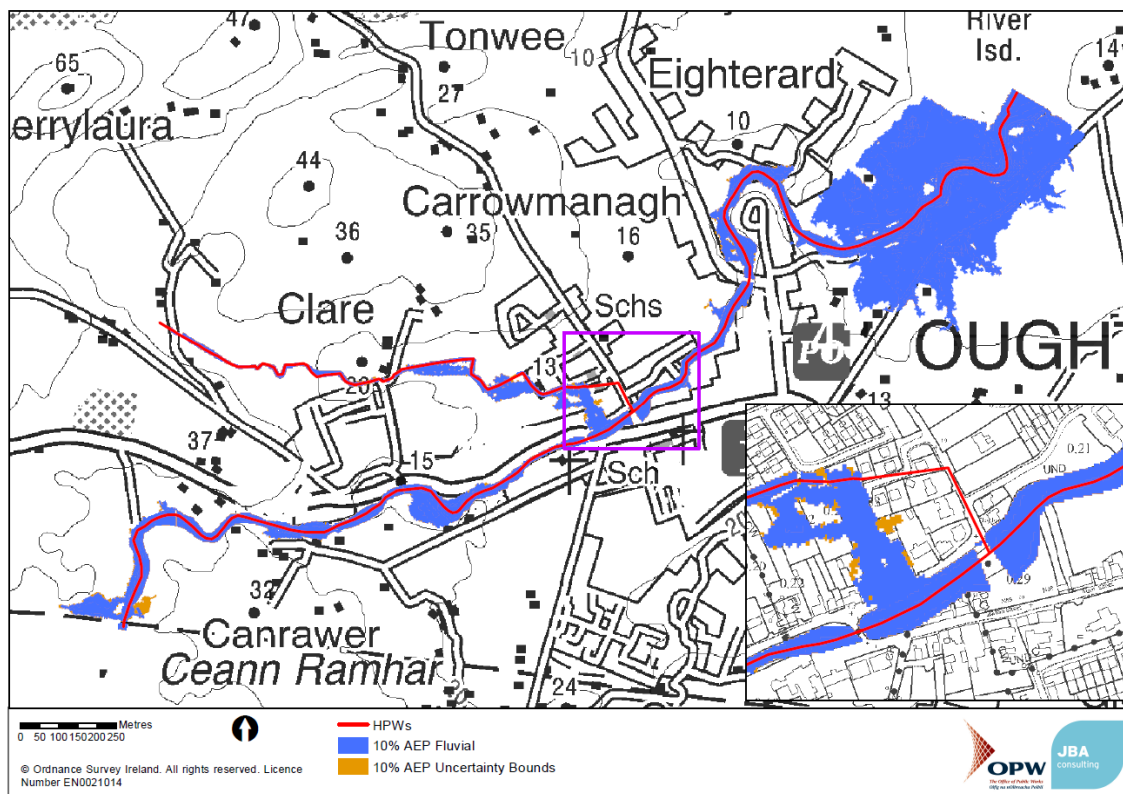
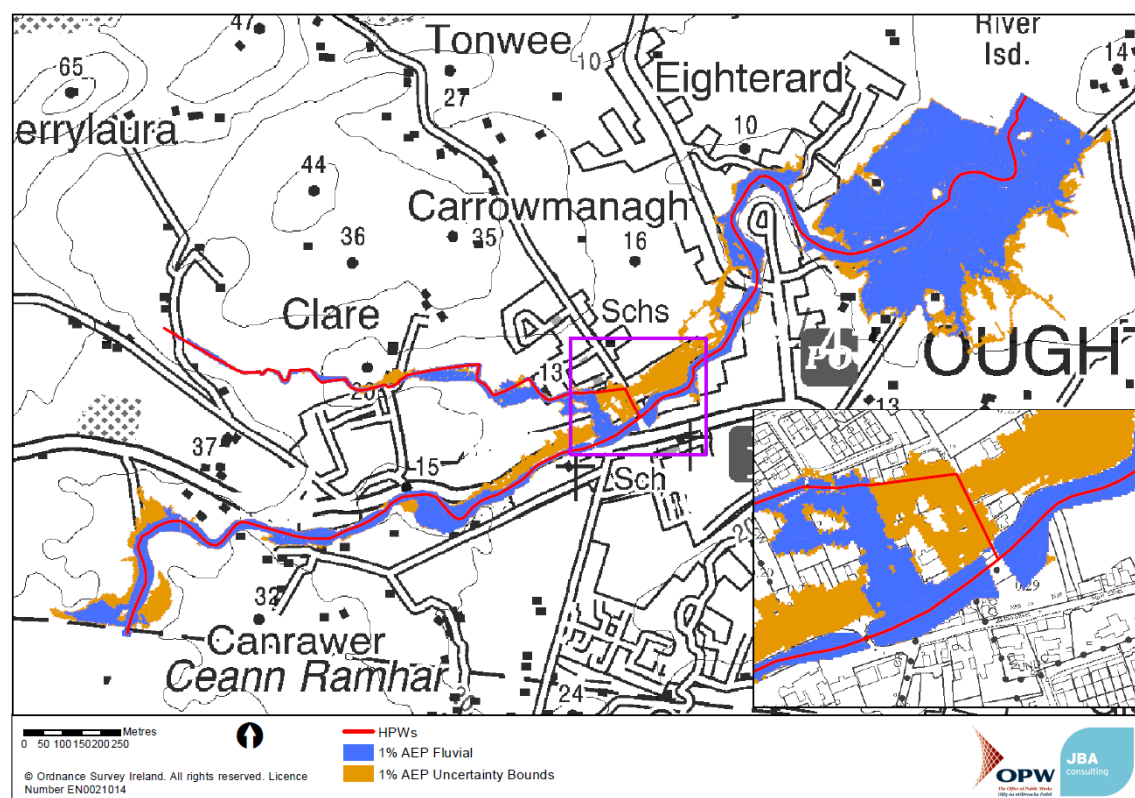


Figure 6-2: 1% AEP uncertainty bound



The 1% AEP uncertainty bound is compared to the equivalent predicted flood extent for the Oughterard AFA in Figure 6-2. The major increase in flood extent is seen in the magnified insert on the figure. This is primary due to the sensitivity result from the local Tonweeroe wall. This wall blocks a flow path that has the potential to flood a significant number of properties. The other increases in flood extent are as a result of the peak flow sensitivity, and the water level sensitivity at the downstream part of the Owenriff. This is an expected result due to the increase in flow and level for these tests. The building representation showed a minor increase, but was not deemed critical. The other tests showed no increase in flood extent.

7 Model limitations

7.1 Channel blockage

Blockage of culverts and small span bridges has the potential to increase flood risk on any watercourse. In Oughterard the culverts on the Tonweeroe watercourse look particularly prone to blockage particularly at the screen. If the culvert blocked, water would back up in the channel, before overtopping onto the field into nearby properties. Although not investigated in more detail in this model, it is likely that culvert blockage will increase flood risk to property.

Figure 7-1: Tonweeroe culvert with flat culvert (30TONW0016)



7.2 Cascades

The cascades on the Owenriff River are extremely steep and have been simplified into a single drop in the ISIS model. This is a simplification of reality but considered acceptable to achieve model stability and because there is no flood risk in the immediate area.

7.3 Swallow hole on the Tonweeroe watercourse

There appears to be a swallow hole on the Tonweeroe watercourse as flow typically seems to be greater towards the upstream end, and almost dry under normal conditions at the downstream end. This has been ignored for design event models as it is assumed the swallow hole is overwhelmed and all the design flow peak will travel down the watercourse channel.

A Hydraulic model results

A.1 1D model flows

Table A-1: 1D model peak current flows

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
ORIF003704*	23.613	28.084	31.11	34.204	38.599	42.242	47.339	63.727
30ORIF00365A	23.61	28.082	31.107	34.201	38.596	42.237	47.339	63.608
30ORIF00365B	23.61	28.082	31.107	34.201	38.596	42.237	47.339	63.608
30ORIF00355	23.528	28.039	31.05	34.13	38.259	41.5	46.036	60.034
30ORIF00339	23.501	28	31.009	34.083	38.45	42.059	47.096	61.932
30ORIF00334	25.391	30.242	33.477	36.784	41.485	45.371	50.712	64.396
30ORIF00328A	25.39	30.237	33.472	36.779	41.484	45.375	50.716	67.32
30ORIF00328B	25.39	30.237	33.472	36.779	41.484	45.375	50.716	67.32
30ORIF00311	25.385	30.232	33.467	36.778	41.483	45.376	50.709	67.583
30ORIF00297	25.384	30.221	33.378	36.418	40.613	43.894	48.424	62.726
ORIF002850*A	15.212	18.503	20.69	22.954	26.041	28.496	31.737	41.23
ORIF002850*B	15.212	18.503	20.69	22.954	26.041	28.496	31.737	41.23
30ORIF00268	25.742	30.636	33.865	37.203	41.921	45.825	51.141	67.826
30ORIF00266	25.741	30.635	33.866	37.199	41.92	45.824	51.142	67.86
30ORIF00261A	25.741	30.636	33.858	37.203	41.923	45.825	51.142	65.829
30ORIF00261B	25.741	30.636	33.858	37.203	41.923	45.825	51.142	65.829
30ORIF00253	25.405	29.293	31.626	33.912	36.705	39.019	41.979	48.968
30ORIF00243	24.853	28.702	30.812	32.745	35.058	36.39	37.616	41.547
30ORIF00229	25.809	30.801	34.031	37.371	42.108	46.027	51.332	63.838
30ORIF00222	25.809	30.798	34.02	37.368	42.108	46.029	51.36	63.736
30ORIF00203A	25.804	30.802	34.031	37.369	42.109	46.029	51.359	66.5
30ORIF00203B	25.804	30.802	34.031	37.369	42.109	46.029	51.359	66.5
ORIF001936*A	25.796	30.792	34.015	37.367	42.111	46.037	51.439	68.682
30TONW00147	0.473	0.586	0.666	0.751	0.876	0.983	1.108	1.51
30TONW00147A	0.473	0.586	0.666	0.751	0.876	0.983	1.108	1.51
30TONW00146B	0.473	0.586	0.666	0.751	0.876	0.983	1.108	1.51
30TONW00146A	0.473	0.586	0.666	0.751	0.876	0.983	1.108	1.51
30TONW00145B	0.473	0.586	0.666	0.751	0.876	0.983	1.108	1.51
30TONW00145	0.473	0.586	0.666	0.751	0.876	0.983	1.108	1.509
30TONW00132	0.472	0.585	0.664	0.749	0.874	0.981	1.106	1.508
30TONW00122A	0.472	0.584	0.664	0.749	0.873	0.98	1.105	1.506
30TONW00122B	0.472	0.584	0.664	0.749	0.873	0.98	1.105	1.506
30TONW00112	0.471	0.583	0.664	0.749	0.873	0.981	1.106	1.505
30TONW00102	0.564	0.703	0.803	0.903	1.058	1.193	1.348	1.843
30TONW00092	0.564	0.703	0.801	0.904	1.057	1.192	1.346	1.842
30TONW00086	0.564	0.703	0.802	0.905	1.057	1.19	1.336	1.332
30TONW00085A	0.564	0.703	0.801	0.903	1.057	1.19	1.341	1.599
30TONW00084B	0.564	0.703	0.801	0.903	1.057	1.19	1.341	1.599
30TONW00083	0.564	0.703	0.801	0.903	1.057	1.19	1.341	1.599
30TONW00082A	0.564	0.703	0.801	0.903	1.057	1.19	1.341	1.598
30TONW00080B	0.564	0.703	0.801	0.903	1.056	1.19	1.341	1.598
30TONW00078	0.564	0.703	0.8	0.903	1.061	1.197	1.341	1.797
30TONW00076	0.686	0.861	0.983	1.109	1.317	1.466	1.461	1.951
30TONW00075A	0.686	0.861	0.983	1.109	1.303	1.468	1.615	2.025
30TONW00075B	0.686	0.861	0.983	1.109	1.303	1.468	1.615	2.025
30TONW00071	0.686	0.854	0.951	1.04	1.141	1.218	1.283	1.495
30TONW00066	0.648	0.704	0.728	0.746	0.763	0.772	0.777	0.787
30TONW00056	0.648	0.704	0.728	0.745	0.762	0.773	0.777	0.787
30TONW00048	0.684	0.852	0.966	1.09	1.27	1.422	1.604	2.178
30TONW00044	0.56	0.584	0.597	0.611	0.622	0.621	0.65	0.783
30TONW00040A	0.545	0.546	0.546	0.545	0.546	0.545	0.545	0.545
30TONW00039B	0.545	0.546	0.546	0.545	0.546	0.545	0.545	0.545

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30TONW00037A	0.545	0.546	0.546	0.549	0.546	0.545	0.545	0.545
30TONW00037B	0.545	0.546	0.546	0.549	0.546	0.545	0.545	0.545
30TONW00022A	0.771	0.955	1.09	1.206	1.314	1.414	1.57	1.888
30TONW00022B	0.771	0.955	1.09	1.206	1.314	1.414	1.57	1.888
30TONW00019A	0.77	0.955	1.09	1.206	1.249	1.275	1.313	1.441
30TONW00019B	0.77	0.955	1.09	1.206	1.249	1.275	1.313	1.441
30TONW00016A	0.771	0.955	1.09	1.158	1.173	1.178	1.183	1.188
30TONW00003B	0.77	0.954	1.09	1.158	1.173	1.178	1.183	1.188
TONW00000*A	0.77	0.954	1.09	1.158	1.173	1.178	1.182	1.187
ORIF001936*B	26.421	31.478	34.754	38.165	43.07	47.144	52.545	69.675
30ORIF00187	27.538	32.802	36.212	39.749	44.84	49.096	54.678	72.329
30ORIF00172	27.536	32.799	36.216	39.745	44.828	49.082	54.675	72.321
30ORIF00156A	27.533	32.796	36.206	39.739	44.836	49.088	54.672	72.319
30ORIF00156	27.533	32.796	36.206	39.739	44.827	49.079	54.657	71.942
30ORIF00146	27.532	32.796	36.209	39.74	44.832	49.015	54.452	70.227
30ORIF00142A	27.532	32.795	36.203	39.737	44.827	49.08	54.655	71.944
30ORIF00142B	27.532	32.795	36.203	39.737	44.827	49.08	54.655	71.944
30ORIF00139	27.532	32.795	36.208	39.737	44.832	49.086	54.658	71.946
30ORIF00118	27.466	32.114	34.693	37.133	41.973	45.114	49.585	63.031
30ORIF00104A	26.188	30.155	32.658	35.208	38.924	42.25	46.363	59.535
30ORIF00104B	26.188	30.155	32.658	35.208	38.924	42.25	46.363	59.535
30ORIF00088	27.545	32.817	36.252	39.795	44.869	49.123	54.65	72.332
30ORIF00064	27.546	32.817	36.253	39.798	44.877	49.131	54.655	72.337
30ORIF00047	27.548	32.82	36.255	39.798	44.86	49.128	54.651	72.331
30ORIF00036	27.548	32.819	36.256	39.799	44.866	49.133	54.656	72.334
30ORIF00020	27.547	32.819	36.258	39.798	44.863	49.13	54.652	72.332
30ORIF00010	27.547	32.821	36.257	39.798	44.869	49.134	54.657	72.334
30ORIF00002	27.548	32.822	36.257	39.798	44.866	49.131	54.653	72.331

Table A-2: 1D model peak MRFS flows

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
ORIF003704*	28.336	33.7	37.331	41.045	46.319	50.69	56.807	76.472
30ORIF00365A	28.333	33.697	37.328	41.041	46.315	50.686	56.802	76.441
30ORIF00365B	28.333	33.697	37.328	41.041	46.315	50.686	56.802	76.441
30ORIF00355	28.282	33.626	37.102	40.514	45.066	48.831	54.025	71.555
30ORIF00339	28.245	33.582	37.196	40.879	46.075	50.26	55.936	71.988
30ORIF00334	30.532	36.278	40.162	44.13	49.734	54.383	60.303	72.936
30ORIF00328A	30.528	36.273	40.157	44.133	49.736	54.383	60.783	75.563
30ORIF00328B	30.528	36.273	40.157	44.133	49.736	54.383	60.783	75.563
30ORIF00311	30.526	36.271	40.157	44.132	49.728	54.382	60.779	81.041
30ORIF00297	30.507	35.968	39.403	42.846	47.594	51.423	56.888	74.011
ORIF002850*A	18.699	22.61	25.185	27.728	31.154	33.9	37.579	47.859
ORIF002850*B	18.699	22.61	25.185	27.728	31.154	33.9	37.579	47.859
30ORIF00268	30.923	36.693	40.589	44.593	50.173	54.773	61.05	81.158
30ORIF00266	30.923	36.694	40.587	44.59	50.158	54.786	61.092	81.19
30ORIF00261A	30.923	36.69	40.587	44.596	50.168	54.78	60.331	75.533
30ORIF00261B	30.923	36.69	40.587	44.596	50.168	54.78	60.331	75.533
30ORIF00253	29.506	33.56	35.927	38.29	41.445	43.867	46.475	53.182
30ORIF00243	28.913	32.476	34.492	36.043	37.521	38.336	39.585	45.561
30ORIF00229	31.093	36.858	40.764	44.78	50.367	54.427	59.035	73.611
30ORIF00222	31.094	36.858	40.763	44.786	50.367	54.993	60.398	68.731
30ORIF00203A	31.093	36.861	40.764	44.784	50.372	55.007	61.158	75.047
30ORIF00203B	31.093	36.862	40.764	44.784	50.372	55.007	61.158	75.047
ORIF001936*A	31.084	36.848	40.759	44.787	50.406	55.146	61.532	82.019
30TONW00147	0.568	0.703	0.799	0.901	1.051	1.18	1.329	1.811
30TONW00147A	0.568	0.703	0.799	0.901	1.051	1.18	1.329	1.811

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30TONW00146B	0.568	0.703	0.799	0.901	1.051	1.18	1.329	1.811
30TONW00146A	0.568	0.703	0.799	0.901	1.051	1.18	1.329	1.811
30TONW00145B	0.568	0.703	0.799	0.901	1.051	1.18	1.329	1.811
30TONW00145	0.568	0.703	0.799	0.901	1.051	1.18	1.328	1.81
30TONW00132	0.567	0.701	0.797	0.899	1.049	1.178	1.327	1.808
30TONW00122A	0.566	0.701	0.797	0.898	1.048	1.177	1.325	1.806
30TONW00122B	0.566	0.701	0.797	0.898	1.048	1.177	1.325	1.806
30TONW00112	0.566	0.702	0.797	0.898	1.048	1.177	1.327	1.776
30TONW00102	0.677	0.845	0.962	1.084	1.27	1.431	1.616	2.223
30TONW00092	0.677	0.844	0.96	1.084	1.269	1.429	1.611	2.222
30TONW00086	0.677	0.847	0.962	1.084	1.267	1.335	1.342	1.741
30TONW00085A	0.677	0.843	0.96	1.083	1.267	1.424	1.581	1.601
30TONW00084B	0.677	0.843	0.96	1.083	1.267	1.424	1.581	1.601
30TONW00083	0.677	0.843	0.96	1.083	1.267	1.425	1.581	1.6
30TONW00082A	0.677	0.843	0.96	1.083	1.267	1.425	1.581	1.601
30TONW00080B	0.677	0.844	0.96	1.082	1.267	1.425	1.581	1.601
30TONW00078	0.677	0.843	0.96	1.087	1.267	1.425	1.601	2.113
30TONW00076	0.824	1.033	1.179	1.345	1.422	1.534	1.706	2.407
30TONW00075A	0.824	1.033	1.179	1.333	1.542	1.683	1.834	2.305
30TONW00075B	0.824	1.033	1.179	1.333	1.542	1.683	1.834	2.305
30TONW00071	0.821	0.986	1.08	1.153	1.25	1.319	1.399	1.628
30TONW00066	0.694	0.736	0.752	0.765	0.774	0.779	0.782	0.805
30TONW00056	0.694	0.736	0.752	0.764	0.774	0.78	0.783	0.807
30TONW00048	0.816	1.015	1.156	1.297	1.51	1.693	1.895	2.619
30TONW00044	0.578	0.605	0.62	0.62	0.626	0.672	0.712	0.919
30TONW00040A	0.546	0.546	0.546	0.546	0.545	0.546	0.546	0.546
30TONW00039B	0.546	0.546	0.546	0.546	0.545	0.546	0.546	0.546
30TONW00037A	0.546	0.546	0.546	0.546	0.545	0.545	0.545	0.545
30TONW00037B	0.546	0.546	0.546	0.546	0.545	0.545	0.545	0.545
30TONW00022A	0.917	1.133	1.242	1.327	1.468	1.626	1.736	2.038
30TONW00022B	0.917	1.133	1.242	1.327	1.468	1.626	1.736	2.038
30TONW00019A	0.918	1.132	1.227	1.252	1.283	1.333	1.374	1.551
30TONW00019B	0.918	1.132	1.227	1.252	1.283	1.333	1.374	1.551
30TONW00016A	0.918	1.132	1.163	1.174	1.18	1.184	1.187	1.189
30TONW00003B	0.918	1.132	1.163	1.174	1.18	1.184	1.187	1.189
TONW00000*A	0.918	1.132	1.163	1.174	1.18	1.184	1.186	1.189
ORIF001936*B	31.749	37.606	41.604	45.779	51.51	56.231	62.577	82.938
30ORIF00187	33.102	39.196	43.352	47.678	53.705	58.601	65.193	86.031
30ORIF00172	33.098	39.191	43.343	47.658	53.692	58.598	65.178	85.572
30ORIF00156A	33.097	39.187	43.348	47.669	53.694	58.597	65.178	86.005
30ORIF00156	33.097	39.186	43.339	47.66	53.681	58.505	64.944	85.609
30ORIF00146	33.097	39.191	43.344	47.622	53.508	58.203	64.004	80.551
30ORIF00142A	33.096	39.189	43.336	47.659	53.683	58.505	64.944	82.339
30ORIF00142B	33.096	39.189	43.336	47.659	53.683	58.505	64.944	82.339
30ORIF00139	33.096	39.185	43.342	47.664	53.689	58.507	64.953	82.354
30ORIF00118	32.373	36.769	39.789	43.984	48.83	52.604	57.898	70.733
30ORIF00104A	30.381	34.8	37.845	41.166	45.6	49.436	54.303	64.528
30ORIF00104B	30.381	34.8	37.845	41.166	45.6	49.436	54.303	64.528
30ORIF00088	33.126	39.243	43.377	47.701	53.697	58.444	65.12	86.179
30ORIF00064	33.126	39.241	43.383	47.706	53.702	58.449	65.117	86.246
30ORIF00047	33.129	39.242	43.379	47.699	53.702	58.446	65.122	86.14
30ORIF00036	33.13	39.243	43.385	47.703	53.705	58.448	65.118	86.257
30ORIF00020	33.131	39.244	43.382	47.699	53.7	58.447	65.122	86.172
30ORIF00010	33.133	39.246	43.386	47.703	53.705	58.449	65.119	86.272
30ORIF00002	33.131	39.246	43.383	47.699	53.702	58.45	65.122	86.149

A.2 HEP flows

Table A-3: Current peak flows at HEPs

HEP Reference	Cross Section	Peak Flow in Model (m3/s)								Comments (note: where blank, no changes have been made)
		50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	
ONR_001	30ORIF003704*	23.613	28.084	31.11	34.204	38.599	42.242	47.339	63.727	Upstream extent of model. Gauging station 30019 just downstream.
ONR_003	30ORIF001936*A	25.796	30.792	34.015	37.367	42.111	46.037	51.439	68.682	Upstream of confluence with the Tonweeroe
ONR_004	30ORIF001936*B	26.421	31.478	34.754	38.165	43.07	47.144	52.545	69.675	Downstream of confluence with Tonweeroe. Close to gauge 30101.
ONR_005	30ORIF00002	27.548	32.822	36.257	39.798	44.866	49.131	54.653	72.331	Downstream extent of model at Lough Corrib.
TNW_001	30TONW00147	0.473	0.586	0.666	0.751	0.876	0.983	1.108	1.51	Upstream extent of model.
TNW_002	30TONW00092	0.564	0.703	0.801	0.904	1.057	1.192	1.346	1.842	This is the section immediately upstream of the HEP location.
TNW_003	30TONW00076	0.686	0.861	0.983	1.109	1.317	1.466	1.461	1.951	This is slightly upstream of the HEP but shows the inflow is applied. Closer to the HEP location the impact of structures and flow into the 2D domains means flows start to reduce in channel. At the selected location the flow remains in channel.
TNW_004	30TONW00016A	0.771	0.955	1.09	1.158	1.173	1.178	1.183	1.188	Downstream of Tonweeroe. Taken at upstream face of the long culvert to avoid complications with the confluence with Owenriff. Flows are below design flows here as 2D out of bank flows bypass this location and constrictions in 1D model limit flows through the small culverts. The lateral inflows along this watercourse are appropriate to give the expected flow increases downstream as seen at other HEPs.

Table A-4: MRFS peak flows at HEPs

HEP Reference	Cross Section	Peak Flow in Model (m3/s)								Comments (note: where blank, no changes have been made)
		50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	
ONR_001	30ORIF003704*	28.336	33.7	37.331	41.045	46.319	50.69	56.807	76.472	Upstream extent of model. Gauging station 30019 just downstream.
ONR_003	30ORIF001936*A	28.336	33.7	37.331	41.045	46.319	50.69	56.807	76.472	Upstream of confluence with the Tonweeroe
ONR_004	30ORIF001936*B	31.749	37.606	41.604	45.779	51.51	56.231	62.577	82.938	Downstream of confluence with Tonweeroe. Close to gauge 30101.
ONR_005	30ORIF00002	33.131	39.246	43.383	47.699	53.702	58.45	65.122	86.149	Downstream extent of model at Lough Corrib.
TNW_001	30TONW00147	0.568	0.703	0.799	0.901	1.051	1.18	1.329	1.811	Upstream extent of model.
TNW_002	30TONW00092	0.677	0.844	0.96	1.084	1.269	1.429	1.611	2.222	This is the section immediately upstream of the HEP location.
TNW_003	30TONW00076	0.824	1.033	1.179	1.345	1.422	1.534	1.706	2.407	This is slightly upstream of the HEP but shows the inflow is applied. Closer to the HEP location the impact of structures and flow into the 2D domains means flows start to reduce in channel. At the

HEP Reference	Cross Section	Peak Flow in Model (m3/s)								Comments (note: where blank, no changes have been made)
		50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	
TNW_004	30TONW00016A	0.918	1.132	1.163	1.174	1.18	1.184	1.187	1.189	<p>selected location the flow remains in channel.</p> <p>Downstream of Tonweeroe. Taken at upstream face of the long culvert to avoid complications with the confluence with Owenriff. Flows are below design flows here as 2D out of bank flows bypass this location and constrictions in 1D model limit flows through the small culverts. The lateral inflows along this watercourse are appropriate to give the expected flow increases downstream as seen at other HEPs.</p>

Registered Office

**24 Grove Island
Corbally
Limerick
Ireland**

t: +353 (0) 61 345463
e: info@jbaconsulting.ie

**JBA Consulting
Engineers and Scientists
Limited**

**Registration number
444752**



Visit our website
www.jbaconsulting.ie

**Western CFRAM
UoM 30 - Corrib
Hydraulic Modelling Report
Volume 2f - Tuam**

Final

September 2016

**Office of Public Works
Trim
Co. Meath**



**WESTERN
CFRAM
STUDY**
CATCHMENT FLOOD RISK
ASSESSMENT AND MANAGEMENT

JBA Consulting

24 Grove Island
Corbally
Limerick
Ireland

JBA Project Manager

Sam Willis BSc MSc CEnv CSci MCIWEM C.WEM

Revision History

Revision ref / Date issued	Amendments	Issued to
Version 1.0		Rosemarie Lawlor, OPW
V2.0	Update to site categorisation table	Richael Duffy, OPW
V3.0 / September 2015	Report updated to reflect client and TAS review.	Richael Duffy, OPW
V4.0 / September 2016	Final updates	Clare Butler, OPW

Contract

This report describes work commissioned by The Office of Public Works, by a letter dated (28/07/11). The Office of Public Works' representative for the contract was Rosemarie Lawlor. Joanne Flanagan, Chris Smith and Elizabeth Russell of JBA Consulting carried out this work.

Prepared by Joanne Flanagan BEng MSc DIC
Assistant Engineer

Reviewed by Chris Smith BSc PhD CEnv MCIWEM C.WEM
MCMI
Principal Analyst

Purpose

This document has been prepared as a draft report for The Office of Public Works. 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.

JBA Consulting has no liability regarding the use of this report except to the Office of Public Works.

Copyright

Copyright – Copyright is with Office of Public Works. All rights reserved. No part of this report may be copied or reproduced by any means without the prior written permission of the Office of Public works.

Legal Disclaimer

This report is subject to the limitations and warranties contained in the contract between the commissioning party (Office of Public Works) and JBA.

Carbon Footprint

A printed copy of the main text in this document will result in a carbon footprint of 214g if 100% post-consumer recycled paper is used and 651g if primary-source paper is used. These figures assume the report is printed in black and white on A4 paper and in duplex.

JBA is aiming to achieve carbon neutrality.

Contents

1	Introduction.....	1
1.1	Scope of report	1
1.2	Model and report overview	1
1.3	Watercourse and catchment overview	2
1.4	Available data	2
2	Hydraulic modelling	4
2.1	Context.....	4
2.2	Key hydraulic structures	4
2.3	Hydraulic roughness	5
2.4	1D-2D boundary	10
2.5	Defences and walls.....	10
2.6	Floodplain	15
3	Flood History, model calibration and sensibility checking.....	16
3.1	Calibration versus sensibility checking	16
3.2	Flood history	16
3.3	Calibration and validation data	16
3.4	November 2009 validation event	16
3.5	Stakeholder Engagement	18
4	Application of hydrology	19
4.1	Hydrological estimation points.....	19
4.2	Application of design flow estimates.....	21
4.3	Downstream Boundary	24
5	Model results.....	25
5.1	Model runs	25
5.2	Flood risk mapping	26
5.3	Key flood risk mechanisms	26
6	Sensitivity testing	27
6.1	Screening of sensitivity tests	27
6.2	Sensitivity testing results and uncertainty bounds.....	30
7	Model limitations	35
7.1	Hydrology.....	35
7.2	Channel blockage	35
A	Hydraulic model results	36

List of Figures

Figure 1-1: Tuam AFA catchment overview	2
Figure 2-1: Location of informal ineffective structures in Tuam centre	14
Figure 2-2: Location of informal ineffective structures upstream of Tuam centre	15
Figure 3-1: November 2009 modelled flood extent and photo looking downstream	17
Figure 4-1: River Nanny and tributary HEP locations.....	19
Figure 4-2: River Suileen HEP locations	20
Figure 4-3: Clare River HEP locations.....	20
Figure 6-1: 10% AEP fluvial uncertainty bound for the River Clare.....	31
Figure 6-2: 1% AEP fluvial uncertainty bound for the River Clare.....	31
Figure 6-3: 10% AEP fluvial uncertainty bound for the River Nanny.....	32
Figure 6-4: 1% AEP fluvial uncertainty bound for the River Nanny.....	32
Figure 6-5: 10% AEP fluvial uncertainty bound for the River Suileen	33
Figure 6-6: 1% AEP fluvial uncertainty bound for the River Suileen	34

List of Tables

Table 1-1: Abbreviated watercourse names.....	3
Table 1-2: Hydrometric gauging stations in the vicinity of the AFA	3
Table 2-1: Key hydraulic structures	4
Table 2-2: Reach hydraulic roughness values	5
Table 2-3: Key hydraulic structures	10
Table 3-1: PCD Feedback	18
Table 4-1: Summary of hydraulic model design inflows for the River Nanny and its tributaries.....	22
Table 4-2: Summary of hydraulic model design inflows for the Suileen River	22
Table 4-3: Summary of hydraulic model design inflows for the River Clare.....	23
Table 5-1 and.....	25
Table 5-1: Peak flows for the Mid-Range Future Scenario	25
Table 5-2: Peak flows for the High-End Future Scenario	25
Table 6-1: Sensitivity test summary.....	27
Table 6-2: Sensitivity to roughness scenarios	28
Table A-1: 1D model peak current flows	36
Table A-2: 1D model peak MRFS flows	42
Table A-3: Current peak flows at HEPs.....	49
Table A-4: MRFS peak flows at HEPs.....	49

Abbreviations

AEP	Annual exceedence probability
AFA	Area for further assessment
AMAX	Annual maximum
CFRAM	Catchment flood risk assessment and management
DAD	Defence asset database
DAS	Defence asset survey
DEM	Digital elevation model (Includes surfaces of structures, vegetation, etc)
DTM	Digital terrain model ('bare earth' model; does not include surfaces of structures, vegetation, etc
ESTRY	One-dimensional model from the TUFLOW suite
FRISM	Flood risk metrics (a flood risk tool developed by JBA)
FRMP	Flood risk management plan
FRR	Flood risk review
FSR	Flood studies report
FSU	Flood studies update
GIS	Geographical information system
HEFS	High-end future scenario
HEP	Hydrological estimation point
HPW	High priority watercourse
HWA	Hydrograph width analysis
IBIDEM	Interactive bridge invoking the design event method
ICPSS	Irish coastal protection strategy study
ISIS	One-dimensional hydraulic modelling software
LA	Local authority
LIDAR	Light detection and ranging
mOD	Metres above Ordnance datum (unless stated this refers to the Malin datum)
MPW	Medium priority watercourse
MRFS	Mid-range future scenario
NDHM	National digital height model (a DTM by Intermap)
OSi	Ordnance Survey Ireland
OPW	The Office of Public Works
PFRA	Preliminary flood risk assessment
Q(T)	Flow for a given return period
QMED	Median annual flood, used in FSU methods
SAAR	Standard annual average rainfall
SoP	Standard of protection (in relation to flood defences)
T	Return period, inverse of AEP
Tp	Time to peak

TUFLOW..... Two-dimensional hydraulic modelling software
UoM Unit of Management
* Asterisks at the end of a cross section label denotes interpolated
model cross sections

1 Introduction

1.1 Scope of report

This report summarises the hydraulic modelling work for the Tuam AFA HPW hydraulic models. This document is specific to the AFA itself and should be read in conjunction with the various reports detailed in Section 1.2 for details on the modelling approaches and wider context of the study.

The report covers the overall hydraulic modelling process from model build through to the development of design runs with the aim of providing a detailed understanding of the hydraulic controls and flood mechanisms identified throughout the study.

The report is not a user manual for the hydraulic model itself, full details of which are provided in model handover check files accompanying the hydraulic model.

The hydraulic modelling work summarised in this and the Unit of Management 30 Hydraulic Modelling Report, of which this report is an Annex, forms one element of the Western Catchment-based Flood Risk Assessment and Management (WCFRAM) study process. The process to date has included amongst other tasks a Flood Risk Review (FRR)¹, a project inception stage², a Strategic Environmental Assessment (SEA)³ and the development of the catchment hydrology⁴. Where the work completed in these tasks contains information relevant to the analysis discussed in this document, references have been included directing the reader to the relevant report for further background information.

1.2 Model and report overview

Three hydraulic models have been created for the Tuam AFA. One of these is of the River Clare high priority watercourse (HPW) model, which covers the river as it flows along the outskirts of the town. The second model consists of the River Nanny and its tributaries, the Nanny Upper and Deepark. The last model is that of the Suileen, a small watercourse to the South of the AFA. Upstream and downstream of Tuam, the River Clare has been modelled as two medium priority watercourse (MPW) models, connecting the watercourse from Ballyhaunis to Lough Corrib. Separate models have also been developed for the River Clare through Ballyhaunis and Corrofin. These models are discussed in their own hydraulics report.

The model codes relevant to these rivers are:

- River Clare - Y1
- Nanny - Y2
- Suileen - Y3
- Ballyhaunis to Tuam MPW - 92
- Tuam to Lough Corrib - 90
- Ballyhaunis AFA - D1
- Corrofin AFA - L1

Reports which are relevant to this AFA are:

- Western CFRAM Flood Risk Review Report
- Western CFRAM UoM 30 Inception Report
- Western CFRAM UoM 30 Hydrology Report

¹ JBA Consulting (2012), Western CFRAM Flood Risk Review, Final Report, Office of Public Works

² JBA Consulting (2012), Western CFRAM Unit of Management 30 – Corrib Inception Report, Final Report, Office of Public Works

³ JBA Consulting (2013), Western River Basin District Catchment-based Flood Risk Assessment and Management (CFRAM) Strategic Environmental Assessment, Scoping Report, Office of Public Works.

⁴ JBA Consulting (2014), Western CFRAM Unit of Management 30 – Corrib Hydrology Report, Final Report, Office of Public Works

- Western CFRAM UoM 30 Hydraulic Modelling Report
- Western CFRAM UoM 30 Hydraulic Modelling Report: Volume 1 - Hydraulic Modelling Method Statement
- Western CFRAM UoM 30 Hydraulic Modelling Report: Volume 3 - Flood Risk Maps
- Hydraulic Model Check Files for each model
- Western CFRAM UoM 30 Hydraulic Modelling Report: Volume 2g - Ballyhaunis to Tuam
- Western CFRAM UoM 30 Hydraulic Modelling Report: Volume 2i - Tuam to Lough Corrib

Cross Section, long section and flood extent plots are provided in the Maps Appendix (Volume 3) of the UoM30 Hydraulic Modelling report.

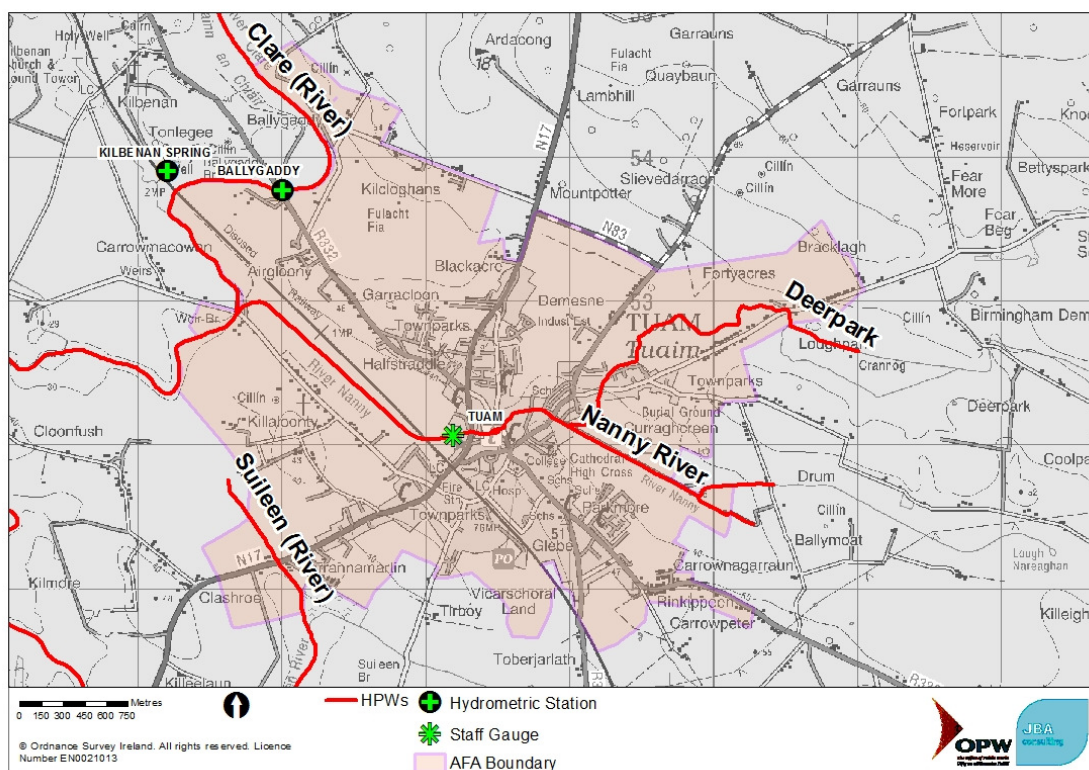
1.3 Watercourse and catchment overview

The River Clare flows along the outskirts of the town. There is a gauge present at the upstream end of Clare River, Ballygaddy, with flood peak data from 1974. The River Clare is a large watercourse with wide floodplains. There has been historical flooding from the River Clare.

The River Nanny and its tributaries, the Nanny Upper and Deerpark flow through the AFA and Tuam town centre. There are many hydraulic structures in the centre of Tuam. These watercourses are much smaller than the River Clare and have no history of flooding. The River Nanny flows into the Clare River downstream of the Ballygaddy gauging station.

The Suilleen is a small watercourse to the South of the AFA. This watercourse flows into the River Clare downstream of the AFA. There is no evidence of historical flooding from this watercourse.

Figure 1-1: Tuam AFA catchment overview



1.4 Available data

1.4.1 Survey data

Cross sectional survey was collected by CCS Surveying in Work Packages 1 and 2 as part of the National Survey Contract No. 6 and delivered in December 2012 and February 2013.

The abbreviated version of each watercourse name as represented in the hydraulic models are detailed in Table 1-1.

Table 1-1: Abbreviated watercourse names

Reference	Description	Model Code
CLAR	Clare River	Y1
NANN	River Nanny	Y2
SUIL	Suileen River	Y3
DEER	Deerpark	Y2
LNAR	Nanny Upper Tributary	Y2

LiDAR data has been collected for use in the model. Data has been provided in both filtered and unfiltered formats in a 2m grid resolution. The LiDAR was flown between Nov 2011 and August 2012. The mean variance between LiDAR and topographic survey data is 0.179m.

1.4.2 Hydrometric data

A summary of active gauged hydrometric data within the AFA is provided in Table 1-2 and an overview of gauge locations is provided in Figure 1-1.

Table 1-2: Hydrometric gauging stations in the vicinity of the AFA

Number	Name	Type	Use in calibration
30007	Ballygaddy	Active level gauge	Rating review calibrated to gaugings. Primary calibration location although not in the main AFA centre. Records from 1974.

As part of the study a review of the rating curve at this gauge has been completed. Full details of this review are detailed in the WCFRAM Hydrology Report for UoM 30.

The largest recorded events on record occurred in 1999 and 2009. These are estimated to be equivalent to a 5-10% AEP and 2-5% AEP event respectively.

2 Hydraulic modelling




2.1 Context



This section should be read in conjunction with the Hydraulic Model Report: Volume 1a: Hydraulic Modelling Method Statement and the Tuam Hydraulic Model Check Files. The Method Statement provides an overview of the elements of both the 1D and 2D model construction and the following section of the report describes how they were applied to the Tuam AFA.

2.2 Key hydraulic structures

Key hydraulic structures that dictate water levels and flows routes in the vicinity of key flood risk areas are summarised in Table 2-1.

Table 2-1: Key hydraulic structures

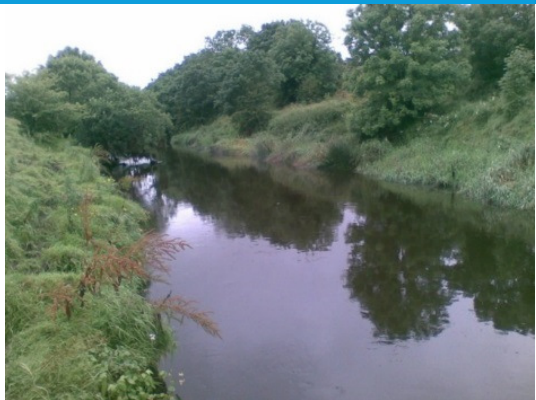
Structure Name	Description	Photograph
Weir downstream of Ballygaddy Gauging station 30CLAR04273.	The structure has been modelled by breaking the weir down into two parts; the weir crest where in channel flow occurs and the out of bank flow.	
Road bridge downstream of Ballygaddy Gauging station 30CLAR04266.	The bridge has been modelled using an arch bridge unit. During flood events flow is constrained by the parapet of the bridge.	
Weir downstream of Shop Street 30NANN00223 A	Flooding on right bank upstream of this structure.	





Structure Name	Description	Photograph
Footbridge at Chapel Lane 30NANN0022D.	Just below the weir this structure causes channel constriction and raised levels contributing to flood risk in Tuam town centre.	
Structure at 30SUIL00158D.	Structure imposes a head loss of approximately 500 mm.	

2.3 Hydraulic roughness


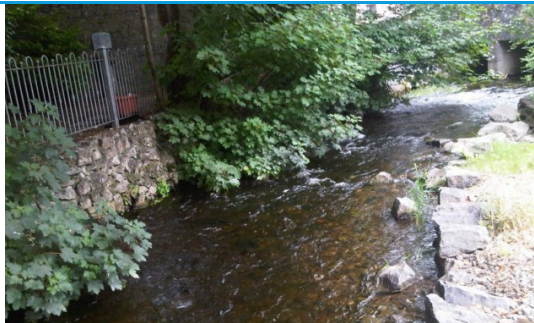


Reaches of similar hydraulic roughness have been identified from survey photos and drawings. Manning's 'n' values for both the river bed and banks to bank top within each of these reaches are summarised in Table 2-2.

Table 2-2: Reach hydraulic roughness values


Upstream and Downstream Cross Section	Roughness Values (Manning's 'n') and materials	Photograph
30CLAR04624 to 30CLAR04376	Bed - 0.035 Stone material. Bank - 0.045 Trees and Hedges	 Looking downstream 30CLAR04464

Upstream and Downstream Cross Section	Roughness Values (Manning's 'n') and materials	Photograph
30CLAR04351 to 30CLAR04288	Bed - 0.035 Stone material. Bank - 0.045 Trees and Hedges. 0.055 for rough stone prior to bank.	 <p>Looking downstream 30CLAR04344</p>
30CLAR04276 to 30CLAR04161	Bed - 0.035 Stone. Material Banks - 0.045 Grass.	 <p>Looking at right bank 30CLAR04288</p>
30CLAR04274A to 30CLAR04273B	Bed - 0.035 Stone. Lower Bank - 0.015 Masonry Wall Higher Bank - 0.045 Grass.	 <p>Looking at right bank 30CLAR04274</p>
30CLAR04146 to 30CLAR03981	Bed - 0.035 Stone material. Bank - 0.045 Trees and Hedges	

Upstream and Downstream Cross Section	Roughness Values (Manning's 'n') and materials	Photograph
30CLAR03971 to 30CLAR03849	Bed - 0.035 Stone material. Bank - 0.06 as per MPW model.	Looking at left bank 30CLAR04116 
30NANN00429 to 30NANN00289	Bed - 0.035 Stone. Banks - 0.055 Grassy banks with occasional hedges and trees.	Looking at downstream 30CLAR03849 
30NANN00281 to 30NANN00263	Bed - 0.035 Stone. Banks - 0.025 Masonry Walls.	Looking upstream 30NANN00309 
30NANN00259 to 30NANN00245	Bed - 0.035 Stone. Banks - 0.040 Stone walls with grassy earth banks, local change to 0.025 for stone walls.	Looking upstream 30NANN0269 
		Looking downstream 30NANN00251

Upstream and Downstream Cross Section	Roughness Values (Manning's 'n') and materials	Photograph
30NANN00238 to 30NANN00227D	Bed - 0.035 Stone. Bank - 0.025 Smooth and stone walls, 0.040 for grassy sections on bank prior to stone walls.	 <p>Looking downstream 30NANN00238</p>
30NANN00227E to 30NANN00203E	Bed - 0.035 Stone. Bank - 0.035 Rough stone walls with some lined with scrub. 0.040 used where grass is evident prior to stone walls.	 <p>Looking upstream 30NANN00218</p>
30NANN00202 to 30NANN00002D	Bed - 0.035 Stone. Bank - 0.055 Grassy banks with hedges and occasional trees. 0.025 to account for walls at local points.	 <p>Looking downstream 30NANN00034</p>
30TRAC00005 to 30TRAC00000	Bed - 0.035 Bank - 0.030 Coarse walls. 0.040 where grass grows before wall bank begins.	 <p>Looking at right bank 30TRAC0004A</p>

Upstream and Downstream Cross Section	Roughness Values (Manning's 'n') and materials	Photograph
30LNAR00055 to 30LNAR00003	Bed - 0.035 Stone. Bank - 0.060 Grassy banks with hedges and occasional trees.	 <p>Looking downstream 30CURR00158</p>
30DEER00296 to 30DEER00001	Bed - 0.035 Stone. Bank - 0.060 Grassy banks with dense hedge, bushes and occasional trees.	 <p>Looking upstream 30DEER00184</p>
30DEER00054 to 30DEER00053	Bed - 0.035 Stone. Bank - 0.025 Concrete walls	 <p>Looking downstream 30DEER00053</p>
30SUIL000365 to 30SUIL000174	Bed - 0.022 Mud and Silt material Bank - 0.045 Grassy with occasional trees and hedges.	 <p>Looking upstream 30SUIL00290</p>

Upstream and Downstream Cross Section	Roughness Values (Manning's 'n') and materials	Photograph
30SUIL000166 to 30SUIL000013	Bed - 0.030 Stones, gravel and sand. Bank - 0.045 Grassy with occasional trees and hedges.	 <p>Looking downstream from 30SUIL00052</p>

2.4 1D-2D boundary

Bank top survey were collected as part of the topographic survey and has for the most part been used to develop the 1D-2D boundary. In some instances, the bank top survey data was limited or not appropriate and crest levels have been interpolated between cross section data or extracted from LiDAR data.

2.5 Defences and walls


2.5.1 Defences


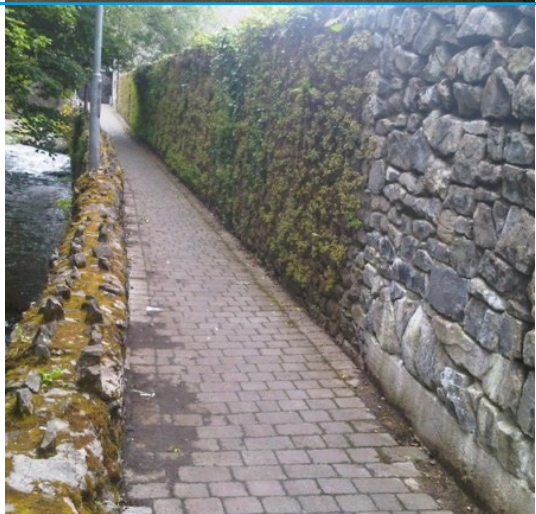


No formal and informal effective defences have been identified with the AFA.





2.5.2 Walls





Informal ineffective structures identified with the AFA are detailed in Table 2-3 and the locations are shown in Figure 2-1 and Figure 2-2. These structures are not assumed to function as flood defences and are either bypassed in the model or have been removed to allow flooding beyond them.

Table 2-3: Key hydraulic structures

ID	Description and Location	Modelling Method	Photograph
1	Block wall on left bank extending from 30NANN00202 to 30NANN00190	Not modelled as Q1000 flood levels in 2D do not reach this wall	

2	Building wall on left bank extending from 30NANN00211 to 30NANN00205	Included in 2D model.	
3	Structurally sound wall on left bank extending from 30NANN00213 to 30NANN00219	<p>The low wall on the left of the photo is the structure referenced. This has been included in the model but it can be bypassed at its downstream end at the bridge.</p> <p>The wall on the right of the photo is not included in the model. The 0.1% AEP HEFS event does not exceed the ground levels behind this wall.</p>	
4	Stone wall on right bank extending from 30NANN00213 to 30NANN00219	Remains in model as flows can bypass the wall at its upstream end.	
5	Building wall on right bank extending from 30NANN00226 to 30NANN00223	Not modelled as Q1000 flood levels in 2D do not reach this wall	

6	Building wall on left bank extending from 30NANN00226 to 30NANN00223	Not modelled as Q1000 flood levels in 2D do not reach this wall	
7	Building wall and parapet walls on left bank, right bank and upstream face of bridge extending from 30NANN00230E to 30NANN00227D	Walls included in model water levels in Q1000 event do not reach level of road therefore gap not modelled.	
8	Concrete walls on left and right bank extending from 30NANN00238D to 30NANN00232D	Walls included in model.	
9	Concrete walls on right bank extending from 30NANN00265D to 30NANN00259	Walls included in model.	

10	Stone and block wall on right and left bank extending from 30NANN00281 to 30 NANN00269D	Walls included in model.	
11	Embankment on right bank extending from 30LNAR00033 to 30 LNAR00008	Included in model.	
12	Concrete Wall at structure 30DEER0063	Included in model.	
13	Stone Wall on right bank extending from 30DEER00084 to 30DEER0068	Outside the scope of the 1D model and not modelled in 2D as flow in the 0.1% AEP HEFS event doesn't extend that far.	


14	Stone Wall on right bank extending from 30DEER00203 to 30DEER00154	Removed from model.	
----	--	---------------------	--

Figure 2-1: Location of informal ineffective structures in Tuam centre

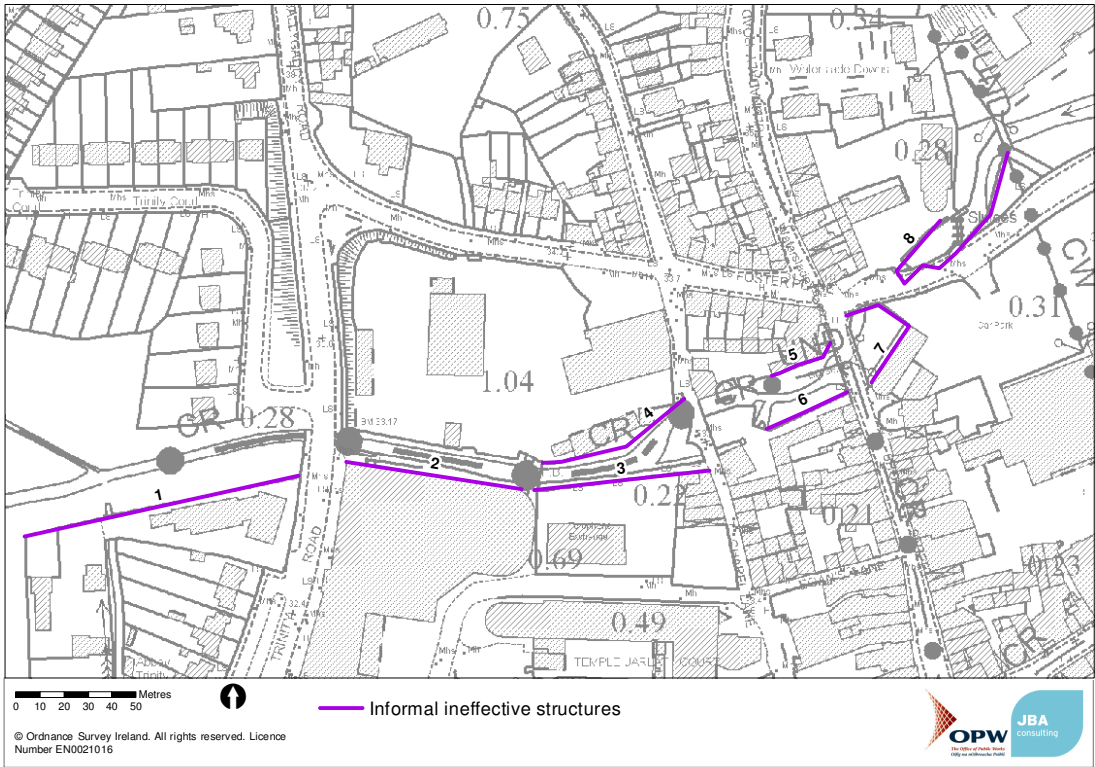
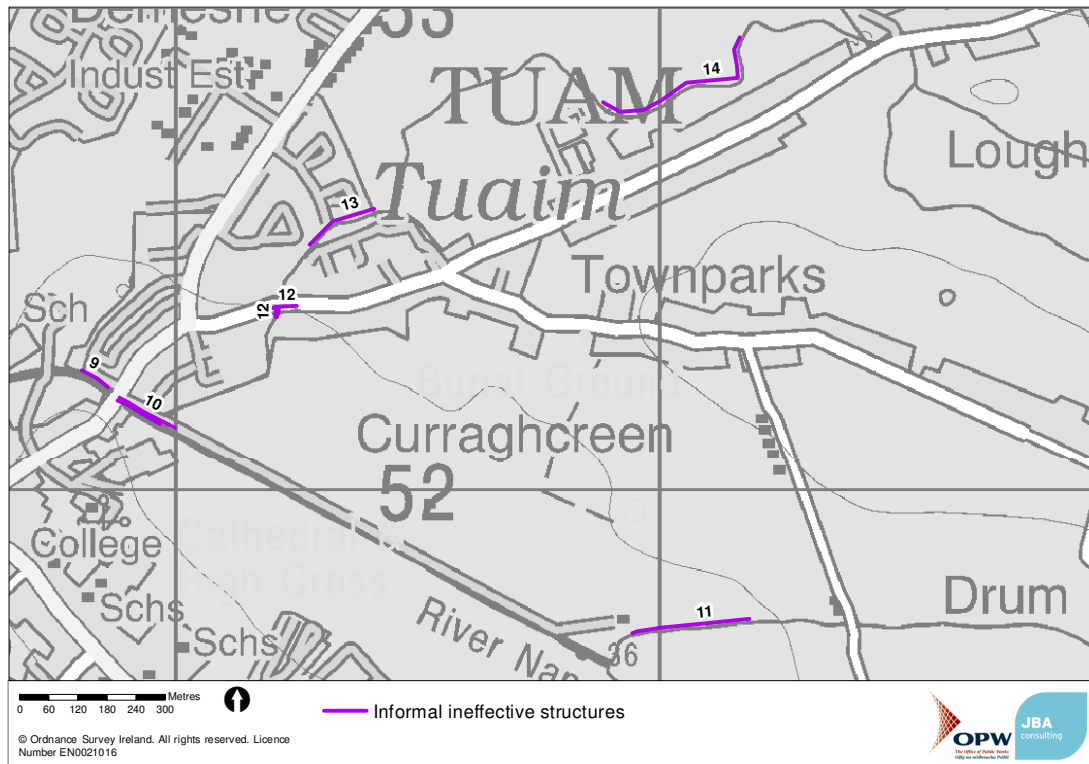


Figure 2-2: Location of informal ineffective structures upstream of Tuam centre



2.6 Floodplain

A 2D cells size of 4m has been used for the Nanny and Suileen models because this is the highest level of detail that produces acceptable model run times. For the River Clare an 8m grid cell size has been used as less detail is required for this model; there are less intricate flow paths and the volume of the river is significantly greater.

3 Flood History, model calibration and sensibility checking

3.1 Calibration versus sensibility checking

Where a recording flow gauge is located in or near the site and this data is accompanied by historical data from a flood event (such as flood extents, or spot levels), then it is possible to undertake calibration of the model. This process would involve running the recorded flows through the model and changing model parameters, such as Manning's 'n', to match the flood extents or levels that were observed. Ideally, a second event would then be run through the model and used to validate the outputs. While it is possible to simulate flows recorded at a gauge in the model, without any record of the impact of the event the model cannot be calibrated and the checking process is limited to a confirmation that predicted extents match expectations based on topography and local knowledge. If there is no gauge data available but there are historical records of flooding, then the predicted extent from an appropriate design event with a similar exceedence probability to the historical flood event can be used as a sensibility check of the predicted flooding frequency.

3.2 Flood history

Key flood risk areas have been identified in the Flood Risk Review⁵ and Inception Reports⁶. For the purposes of the hydraulic modelling work this data is most beneficial when accompanied by supporting details such as photos or anecdotal evidence which confirm the maximum extent or depth of flooding at any given location.

There have been reports of flooding within the Tuam AFA in 1950, 1991, 1995, 1999, 2002, 2005 and 2009. This flooding is mainly from the River Clare. There have also been some reports of flooding of the River Nanny along its downstream reach. This may be caused from the Clare River backing up into the Nanny floodplain.

3.3 Calibration and validation data

Validation of the River Clare hydraulic model has been completed using the Ballygaddy gauge. This gauge is located within the AFA. Flows have been derived using the updated rating curve detailed in the WCFRAM Hydrology Report for UoM 30.

Based on the data available validation runs have been completed for the 2009 event. These have been selected because photographic evidence of the extent of flooding is available.

To validate the model, flows from the gauge have been applied at the upstream limit of the model.

3.4 November 2009 validation event

Figure 3-1 and Figure 3-2 detail the calibration of the January 2009 event at the gauge and the resulting modelled flood extent within the AFA respectively.

During the 2009 flood event several aerial photographs were taken. During the validation process the flooding similar to that shown in the photograph was achieved. There was reported flooding at an industrial estate downstream of where the Nanny flows into the River Clare, see photograph above. The flood extents predicted by the model show a similar flood extent.

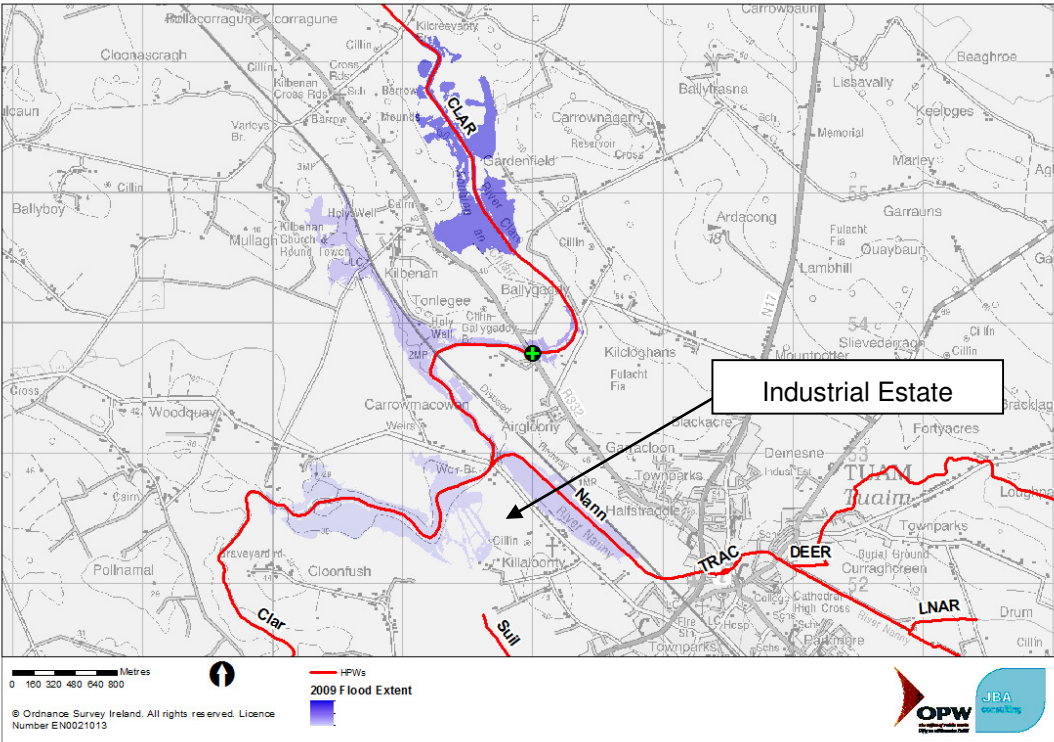
Due to the absence of any historical flood information from the River Nanny and its tributaries and the River Suileen no calibration or validation of these models has been carried out, although the flood outlines have been subject to a sensibility check.

No changes were made to the model following the validation exercise.

⁵ Western CFRAM Flood Risk Review Report. May 2012

⁶ Western CFRAM Unit of Management 30 - Corrib and 31 - Owengowla Inception Report. October 2012

Figure 3-1: November 2009 modelled flood extent and photo looking downstream



3.5 Stakeholder Engagement

Throughout this process OPW regional engineers and local authority engineers have been consulted in the form of steering group, progress group and engineer meetings and their input has feed into the flood maps.

Public Consultation Day (PCD) - 14th of October 2014

On October 14th 2014 a public consultation was held in Tuam Town Hall to present the flood maps for the town and solicit comments and feedback.

This PCD was attended by 15 people. At the PCD attendees were invited to leave feedback, in the form of a questionnaire. The questionnaire sought feedback on resident's knowledge of flooding in the town including the locations of flooding and the frequency of flooding.

Table 3-1 outlines the feedback received at the day relevant to the study and a note regarding how this information has been accommodated by the study.

Table 3-1: PCD Feedback

Comments Received	Study Response
Houses flooded from pluvial flooding on Athenry Street.	The flood extents assess flood risk from fluvial flooding only. This report cannot be used to verify the flood extents.

4 Application of hydrology

4.1 Hydrological estimation points

Design flows have been developed at a series of Hydrological Estimation Points (HEPs) throughout the catchment. Full details of the development of these flows are provided in the WCFRAM Hydrology Report for UoM 30 and the locations are shown on the cross section maps in Volume 3 of the Hydraulic Modelling Report. The locations of all the HEPs within the Tuam AFA are presented in Figure 4-1 to Figure 4-3.

Figure 4-1: River Nanny and tributary HEP locations

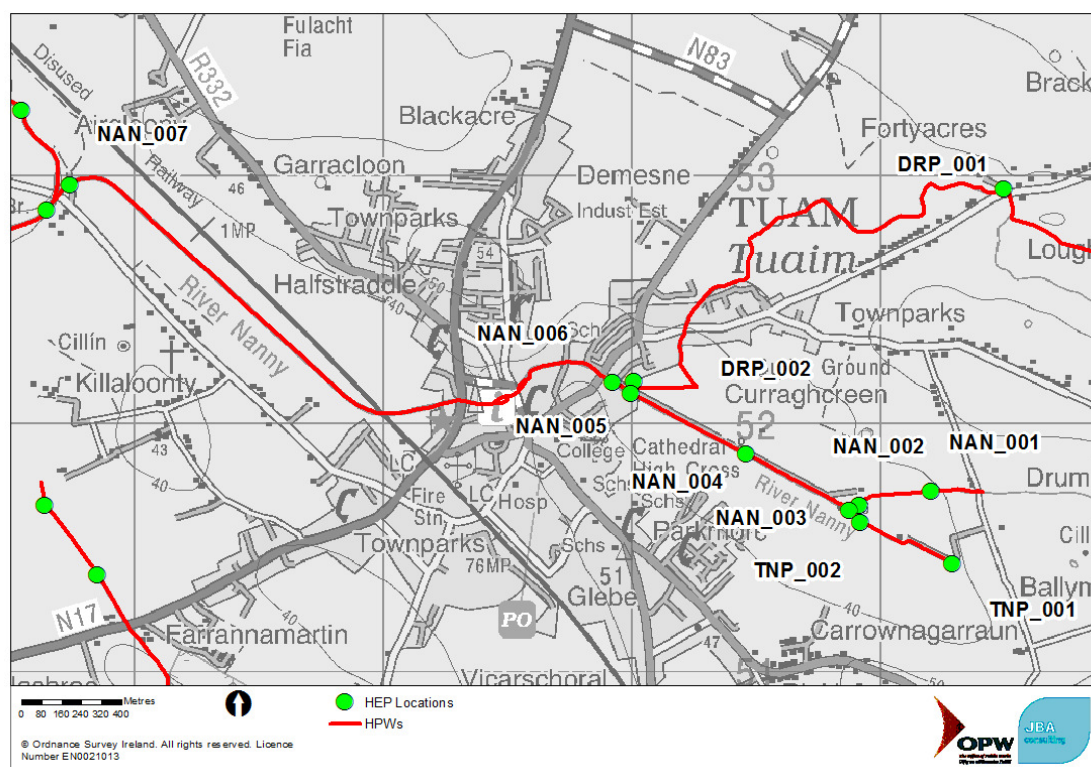


Figure 4-2: River Suileen HEP locations

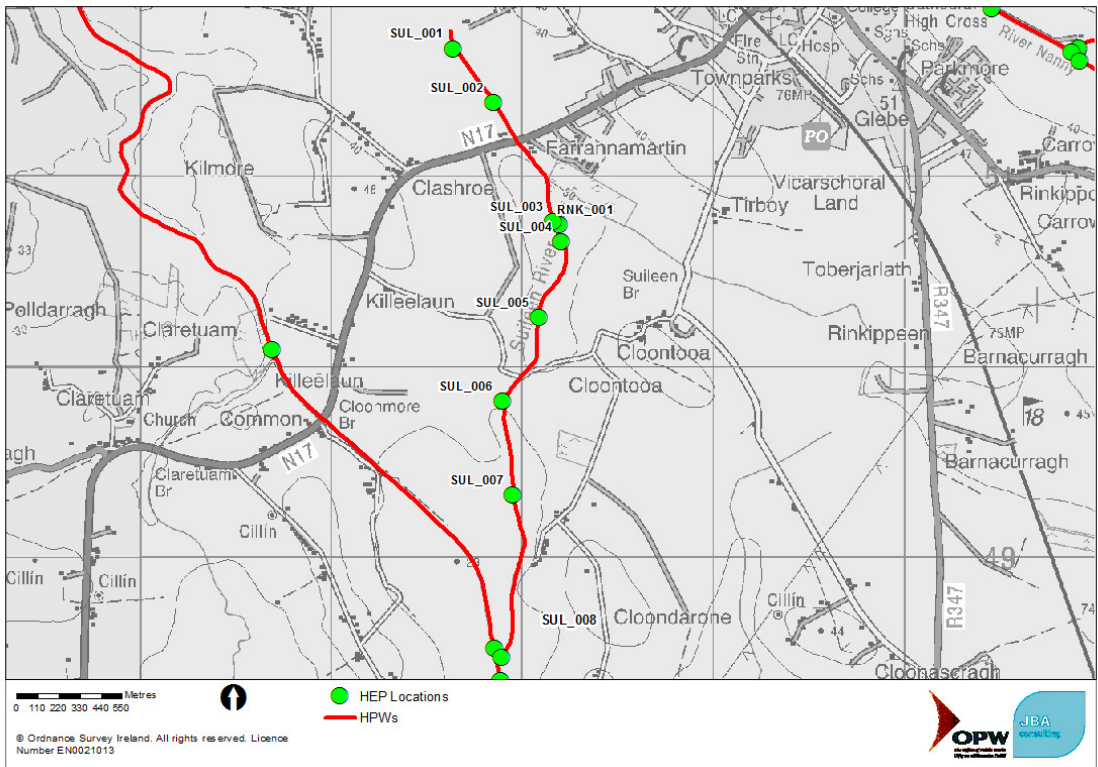
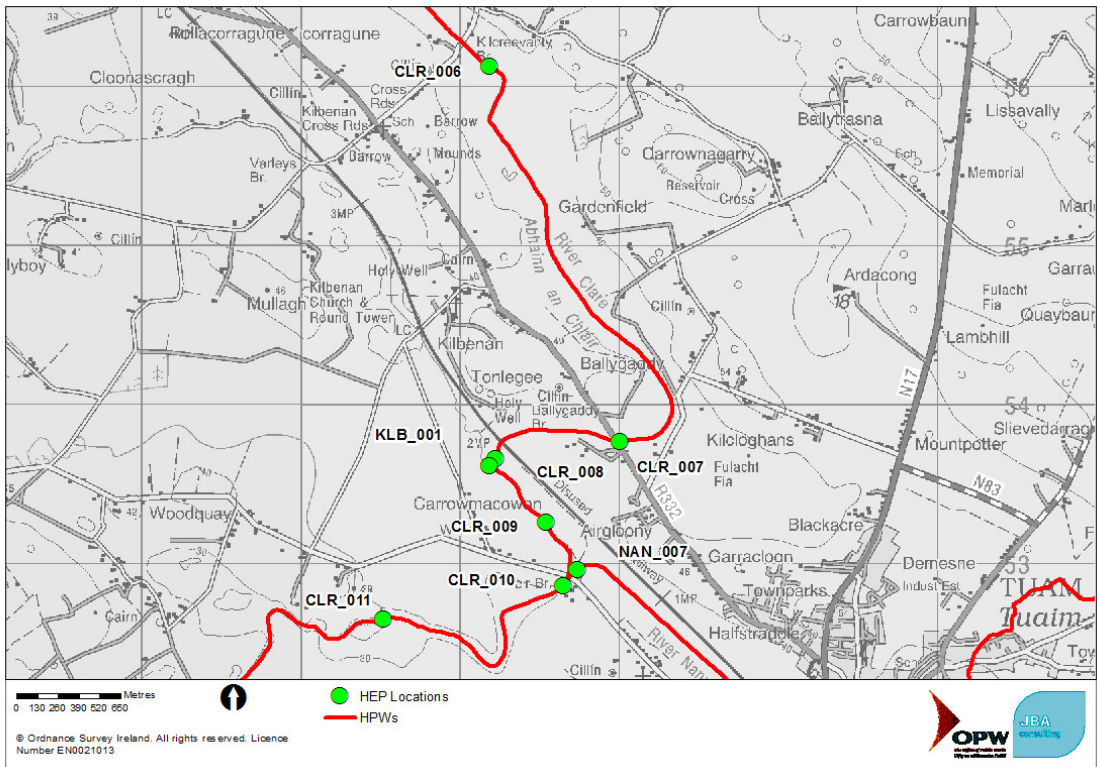


Figure 4-3: Clare River HEP locations



4.2 Application of design flow estimates

4.2.1 Hydrograph shapes

Inflow hydrograph shapes for each watercourse have been developed from the Flood Studies Report (FSR) rainfall runoff method. Inflows are located at the upstream limit of each watercourse.

A storm duration of 12 hours has been applied to the boundaries for the River Nanny its tributaries. A storm duration of 11 hours has been applied to the boundaries for the Suileen. These are based on recommended values from the FSR rainfall-runoff units.

For the River Clare, a longer storm duration of 45 hours has been used along with a T_p coefficient of 1.40. The hydrograph shape for the Clare River has been based upon the lag analysis completed at the Ballygaddy gauges, described in the WCFRAM Inception Report for UoM 30.

4.2.2 Scaling to hydrological estimation points

Calculated design flows on the various watercourses are consistent between the upstream and downstream limits with the exception of CLR_011 where a minor reduction is observed. The reduction to CLR_011 reflects the reduced slope of the catchment to this point compared with CLR_010.

Hydrograph shapes have been scaled to match the design flows at the most upstream HEP point. The flow matching at intermediate HEPs has mainly been carried out using a 1D only model. In the final 1D-2D model floodplain attenuation can cause the modelled flows to be lower than the design flow. FSR does not fully account for floodplain attenuation so these flows have been left below HEP values. This is mainly noticeable in the extreme events. A summary of the model inflows and application of the design hydrology through these is provided in Table 4-1 to Table 4-3.

Table 4-1: Summary of hydraulic model design inflows for the River Nanny and its tributaries

HEP Name	Cross Section Label	Predicted Peak Flows (m ³ /s)					Flow in Model (m ³ /s)					Comments
		50% AEP	10% AEP	2% AEP	1% AEP	0.1% AEP	50% AEP	10% AEP	2% AEP	1% AEP	0.1% AEP	
TNP_001	-	0.20	0.31	0.44	0.5	0.76	-	-	-	-	-	Not used. TNP_002 used as inflow to the model.
TNP_002	30NANN00429	0.42	0.66	0.93	1.1	1.6	0.42	0.66	0.93	1.1	1.6	FSR hydrograph scaled to match design flows.
NAN_002	30LNAR00055	0.41	0.64	0.90	1.0	1.6	0.41	0.64	0.90	1.0	1.6	FSR hydrograph scaled to match design flows.
NAN_006	30NANN00274	4.7	6.7	8.9	9.9	15	4.5	6.3	8.2	9.1	13	HEP downstream of Deerpark tributary. Increase in flows attributable the Deerpark tributary and a lateral inflow on the Nanny at 30NANN000339B. Lateral inflow estimated as the difference between NAN_004 and NAN_005.
NAN_007	30NANN00048 B	5.8	8.3	11	14	19	6.0	8.4	10	11	12	Lateral inflow at distributed between 30NANN00259 and 30NANN00048B. Lateral inflow estimated as the difference between NAN_006 and NAN_007.
DRP_001	30DEER00213	3.2	4.6	6.1	6.9	11	3.2	4.6	6.1	6.8	10	FSR hydrograph scaled to match design flows and applied between 30DEER00296 and 30DEER00246.
DRP_002	30DEER00042	3.8	5.4	7.2	8.1	12	3.6	5.3	7.0	7.6	10	Lateral inflow at distributed between 30DEER00225 and 30DEER00062. Lateral inflow estimated as the difference between DRP_001 and DRP_002.

Table 4-2: Summary of hydraulic model design inflows for the Suileen River

HEP Name	Cross Section Label	Predicted Peak Flows (m ³ /s)					Flow in Model (m ³ /s)					Comments
		50% AEP	10% AEP	2% AEP	1% AEP	0.1% AEP	50% AEP	10% AEP	2% AEP	1% AEP	0.1% AEP*	
SUL_002	30SUIL00365	0.18	0.28	0.4	0.46	0.85	0.18	0.28	0.40	0.46	N/A	FSR hydrograph scaled to match design flows.

HEP Name	Cross Section Label	Predicted Peak Flows (m3/s)					Flow in Model (m3/s)					Comments
		50% AEP	10% AEP	2% AEP	1% AEP	0.1% AEP	50% AEP	10% AEP	2% AEP	1% AEP	0.1% AEP*	
SUL_003	30SUIL00265	0.55	0.86	1.2	1.4	2.6	0.47	0.71	1.0	1.2	N/A	FSR hydrograph scaled to match design flows.
SUL_004	30SUIL00227	1.5	2.3	3.2	3.8	6.4	1.2	1.9	2.7	3.1	N/A	FSR hydrograph scaled to match design flows on incoming tributary.
SUL_005	30SUIL00197	1.5	2.3	3.2	3.8	6.4	1.2	1.9	2.7	3.0	N/A	Lateral inflow at 30SUIL00197. Lateral inflow estimated as the difference between SUL_004 and SUL_005.
SUL_008	30SUIL00072	1.7	2.5	3.6	4.1	6.9	1.3	2.0	2.7	3.0	N/A	Lateral inflow at 30SUIL00197. Lateral inflow estimated as the difference between SUL_007 and SUL_008.

* Flood risk in large events is dictated by the Clare.

Table 4-3: Summary of hydraulic model design inflows for the River Clare

HEP Name	Cross Section Label	Predicted Peak Flows (m³/s)					Flow in Model (m³/s)					Comments
		50% AEP	10% AEP	2% AEP	1% AEP	0.1% AEP	50% AEP	10% AEP	2% AEP	1% AEP	0.1% AEP	
CLR_006	30CLAR04624	58	81	106	119	177	59	82	107	120	179	FSR hydrograph scaled to match design flows at CLR_008.
CLR_007		59	82	107	120	179	-	-	-	-	-	
CLR_008	30CLAR04247	59	82	107	120	179	58	79	104	116	176	
KLB_001		1.2	1.6	2.6	3.0	5.0	-	-	-	-	-	Lateral inflow at 30CLAR04175. Inflow estimated by subtracting the resulting 1D flow from the required scaled design hydrograph at CLR_009, which incorporates KLB_001.
CLR_009		60	84	110	123	184	-	-	-	-	-	
CLR_010	30CLAR04076	65	91	119	133	199	64	84	109	121	184	Lateral inflow at 30CLAR04087. Inflow estimated by subtracting the resulting 1D flow from the required scaled design hydrograph at CLR_010.
CLR_011	30CLAR03849	65	90	118	133	198	64	84	109	121	184	Downstream limit of 1D model. No additional flows added to this HEP.

4.3 Downstream Boundary

Each model has a downstream boundary but each is fairly uncertain and should be checked using sensitivity testing.

The River Clare model has a QH (flow-level) boundary. This has been placed downstream of the HPW extent using cross sections from the River Clare MPW model and the QH boundary derived using the MPW model.

The Nanny model uses a normal depth boundary. The downstream boundary on this model is particularly uncertain as it is largely determined by the level in the River Clare, indeed a high level in the River Clare floods the lower Nanny floodplain and the mapping reflects this. Sensitivity testing of this boundary will be important to show the impact of this boundary on the Nanny and how far upstream the impact extends. The current downstream peak level on the Nanny for the 1% AEP event is 29.2mOD which is below a Clare River 50% AEP event peak level, but 1m above surveyed water level at the confluence. So the Nanny model is run essentially without a significant Clare event occurring at the same time, which is not unreasonable given the difference in responses of the two catchments.

The Suileen model uses a normal depth boundary. This is at a much lower elevation than the key areas in the model, but it will impact on the downstream end of the Suilleen.

5 Model results

5.1 Model runs

The model has been run for a present day and two future scenarios, a Mid-Range Future Scenario (MRFS) and a High-End Future Scenario, which consider the potential impact of climate change. Further details of the allowances within the calculations are included in the Hydrology Report, but the increased flows include for the impacts of urbanisation and climate change.

The model has been run for the following present day and MRFS fluvial and tidal events: 50%, 10%, 5%, 2%, 1%, 0.5% and 0.1% AEP design events. Only the 10%, 1% and 0.1% AEP design events have been run for the HEFS. For all the fluvial events, the 50% AEP tide level has been used as the downstream boundary. For the tidal events, the 50% AEP fluvial flow has been used as the inflow at the upstream end of the model.

Table 5-1 and

Table 5-2 detail the full suite of design flows for the HEPs for the MRFS and HEFS.

Table 5-1: Peak flows for the Mid-Range Future Scenario

HEP reference	Predicted Peak Flows for the MRFS (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
River Nanny and tributaries								
NAN_002	0.5	0.6	0.8	0.9	1.1	1.2	1.4	1.9
NAN_005	1.2	1.5	1.8	2.1	2.5	2.8	3.2	4.3
NAN_007	7.0	8.8	10.1	11.4	13.2	14.8	16.6	22.7
DRP_001	3.8	4.9	5.6	6.3	7.4	8.3	9.3	12.6
DRP_002	4.5	5.7	6.5	7.4	8.7	9.7	10.9	14.8
TNP_002	0.5	0.7	0.8	0.9	1.1	1.3	1.4	2.0
Suileen River								
SUL_002	0.2	0.3	0.4	0.4	0.5	0.6	0.7	1.1
SUL_003	0.7	0.9	1.1	1.3	1.5	1.8	2.1	3.3
SUL_004	1.8	2.4	2.8	3.3	4.0	4.7	5.4	7.9
SUL_005	1.8	2.4	2.8	3.3	4.0	4.7	5.4	7.9
SUL_008	2.0	2.7	3.1	3.6	4.4	5.1	5.9	8.5
River Clare								
CLR_008	70.9	86.9	98.3	110.5	128.6	144.2	161.1	215.3
CLR_009	72.6	89.1	100.9	113.5	132.2	148.3	165.7	221.6
CLR_010	78.3	96.1	108.9	122.5	142.6	160.0	178.8	239.1

Table 5-2: Peak flows for the High-End Future Scenario

HEP reference	Predicted Peak Flows for the HEFS (m3/s)		
	10% AEP	1% AEP	0.1% AEP
River Nanny and tributaries			
NAN_002	0.8	1.3	2.1
NAN_005	1.9	3.1	4.7
NAN_007	11.0	16.1	24.7
DRP_001	6.0	9.0	13.6
DRP_002	7.1	10.6	16.1
TNP_002	0.9	1.4	2.1
Suileen River			
SUL_002	0.4	0.7	1.2
SUL_003	1.2	2.0	3.6
SUL_004	3.1	5.1	8.7
SUL_005	3.1	5.1	8.7
SUL_008	3.4	5.6	9.3
River Clare			
CLR_008	106.6	156.3	233.5
CLR_009	109.4	160.8	240.3
CLR_010	118.1	173.6	259.4

5.2 Flood risk mapping

Flood risk extents for the present day and MRFS 10%, 1% and 0.1% AEP design events along with long section profiles for present day 10%, 1% and 0.1% AEP design events are presented in Volume 3 of the UoM 30 Hydraulic Modelling Report.

5.3 Key flood risk mechanisms

Further to the information presented in the flood risk maps a brief description of the key flood risk sites and flooding mechanisms is provided below.

5.3.1 River Nanny and its tributaries

During the 0.1% AEP event properties on the right bank downstream of Shop Street are at risk of flooding from the River Nanny. Downstream of the Garda station on Abbey Trinity Road there is flooding on the right bank during the 1% and 0.1% AEP events. The extent of flooding in this area is constrained by the right bank of the land drain.

There is limited flooding on the downstream reach of the River Nanny from the River Nanny itself. Historically there has been flooding in this area but it is modelled as arising from the River Clare.

There is a large area of flooding on left bank of the Deerpark watercourse just upstream of its confluence with the River Nanny. The majority of this flooding is a result of a low point on the left bank between cross sections 30DEER00031 and 30DEER00025. In the 1% AEP event, flow from the Deerpark River is diverted to the River Nanny via this floodplain. No properties are affected from flooding in this area.

Further upstream where the Deerpark watercourse flows under Bothar na Greanna, properties are predicted to be at risk of flooding in the 0.1% AEP event.

5.3.2 Clare River

The Clare River is low lying and flooding is predicted along the majority of its reach on the left and right bank for flows as low as the 50% AEP event. In the 0.1% AEP event 18 properties are at risk of flooding on the left bank upstream of the Ballygaddy gauging station. In the 0.5% AEP event only one of these 18 properties is predicted at risk of flooding.

Flow from the Clare River inundates the floodplains of the Kilbenan River and the Nanny River during the 50% AEP event. Although no properties within the AFA are predicted to be a risk of flooding along these floodplains up to the 0.5% AEP event, approximately 58 properties on the left bank of the river Nanny are predicted to be a risk of flooding in the 0.1% AEP event.

5.3.3 Suileen River

There is some flooding on the right and left bank of the Suileen watercourse in the Tuam AFA. There are no properties at risk of flooding.

6 Sensitivity testing

6.1 Screening of sensitivity tests

The suite of potential sensitivity tests is detailed in Volume 1a: Hydraulic Modelling Method Statement. The application of the sensitivity tests has been an iterative process which allowed certain criteria to be screened out. Table 6-1 summarises the full suite of potential sensitivity tests, and highlights those which are not applicable, and those which have been screened out. Further details of these criteria are provided in the following sections.

The results of testing those criteria which are relevant to Tuam are detailed in Section 6.2.

Table 6-1: Sensitivity test summary

Sensitivity test	Relevance to Tuam
Peak flow	Tested
Flow volume	Tested
Critical storm duration	Screened out
Roughness	Tested
Building representation	Tested
Afflux / headloss at key structures	Tested at a number of structures
Water level boundaries and joint probability	Tested
Timing of tributaries	Screened out
Timing of fluvial and tidal peaks	Not applicable
Cell size	Screened out

6.1.1 Peak flow

The flow sensitivity scoring mechanism is detailed in Guidance Note 22 and produces a score of 12 for the Clare River and 24 for the Nanny and 29 for the Suileen. Given the karst influence these scores give the same outcome for each model.

- 10% AEP event use QMED uncertainty.
- 1% AEP event use QMED uncertainty then multiply flows by 2.0.

6.1.2 Flow volume

The sensitivity test to flow volume is required where the flow hydrograph has been generated from limited or no data. Lag analysis has been used to assess a T_p coefficient at Ballygaddy gauge on the River Clare, giving a value of 1.4. However, to get a better fit to volume frequency analysis a higher value has been suggested (2.00). For the River Clare, given the long duration events that can occur and influence of the karst geology, a duration multiplier of 2.0 is recommended.

For the tributary models no lag analysis has been carried out so the flow volume multiplier of 2.0 has been used.

6.1.3 Critical storm duration

The objective of this sensitivity test is to review flood risk from tributaries where, as a result of applying a consistent storm duration for the catchment, a storm duration appropriate for the larger receiving watercourse has been applied and as a result flood risk on the tributary could be overestimated. Within Tuam each of the tributaries has been represented in a separate model and as such storm durations appropriate to the catchment size have been applied in each case. The only watercourse with a tributary is the Suileen and catchment sizes and appropriate storm durations are similar for each of these. For this reason, sensitivity testing of the critical storm durations of tributaries is not required.

6.1.4 Roughness

In Tuam the limited risk to property in the existing risk design events mean there is little benefit to testing the sensitivity of the model results to a reduction in roughness values, as such a reduction would only further reduce extents by speeding the passage of water through the model domain. The downstream limit of each of the tributaries is the River Clare, and the sensitivity of this watercourse to an increase in flows has been assessed in Section 6.1.1.

Table 6-2 summarises the current roughness values applied within the model over the various reaches and the increased values to be applied for the 10% and 1% AEP event.

Roughness values in the floodplain have been increased to the upper bound of those values quoted in the Hydraulic Modelling methods report for the 1% AEP event only.

Table 6-2: Sensitivity to roughness scenarios

Upstream and downstream cross section	Roughness values (Manning's 'n') and materials Existing risk	10% and 1% AEP roughness sensitivity
30CLAR04624 to 30CLAR04376	Bed - 0.035 Stone material. Bank - 0.045 Trees and Hedges	Bed - 0.04 Banks - 0.05
30CLAR04351 to 30CLAR04288	Bed - 0.035 Stone material. Bank - 0.045 Trees and Hedges. 0.055 for rough stone prior to bank.	Bed - 0.04 Banks - 0.05 0.065
30CLAR04276 to 30CLAR04161	Bed - 0.035 Stone. Material Banks - 0.045 Grass.	Bed - 0.04 Banks - 0.05
30CLAR04274A to 30CLAR04273B	Bed - 0.035 Stone. Lower Bank - 0.015 Masonry Wall Higher Bank - 0.045 Grass.	Bed - 0.04 Banks - 0.02 0.05
30CLAR04146 to 30CLAR03981	Bed - 0.035 Stone material. Bank - 0.045 Trees and Hedges	Bed - 0.04 Banks - 0.05
30CLAR03971 to 30CLAR03849	Bed - 0.035 Stone material. Bank - 0.06 as per MPW model.	Bed - 0.04 Banks - 0.06
30NANN00429 to 30NANN00289	Bed - 0.035 Stone. Banks - 0.055 Grassy banks with occasional hedges and trees.	Bed - 0.04 Banks - 0.065
30NANN00281 to 30NANN00263	Bed - 0.035 Stone. Banks - 0.025 Masonry Walls.	Bed - 0.04 Banks - 0.03
30NANN00259 to 30NANN00245	Bed - 0.035 Stone. Banks - 0.040 Stone walls with grassy earth banks, local change to 0.025 for stone walls.	Bed - 0.04 Banks - 0.045 0.03
30NANN00239 to 30NANN00227D	Bed - 0.035 Stone. Bank - 0.025 Smooth and stone walls, 0.040 for grassy sections on bank prior to stone walls.	Bed - 0.04 Banks - 0.03 0.045
30NANN00227E to 30NANN00203E	Bed - 0.035 Stone. Bank - 0.035 Rough stone walls with some lined with scrub. 0.040 used where grass is evident prior to stone walls.	Bed - 0.04 Banks - 0.04 0.045
30NANN00202 to 30NANN00002D	Bed - 0.035 Stone. Bank - 0.055 Grassy banks with hedges and occasional trees. 0.025 to account for walls at local points.	Bed - 0.04 Banks - 0.065 0.035
30TRAC00005 to 30TRAC00000	Bed - 0.035 Bank - 0.030 Coarse walls. 0.040 where grass grows before wall bank begins.	Bed - 0.04 Banks - 0.035 0.045
30LNAR00055 to 30LNAR00003	Bed - 0.035 Stone. Bank - 0.060 Grassy banks with hedges and occasional	Bed - 0.04 Banks - 0.07

Upstream and downstream cross section	Roughness values (Manning's 'n') and materials Existing risk	10% and 1% AEP roughness sensitivity
	trees.	
30DEER00296 to 30DEER00001	Bed - 0.035 Stone. Bank - 0.060 Grassy banks with dense hedge, bushes and occasional trees.	Bed - 0.04 Banks - 0.07
30DEER00054 to 30DEER00053	Bed - 0.035 Stone. Bank - 0.025 Concrete walls	Bed - 0.04 Banks - 0.03
30SUIL000365 to 30SUIL000174	Bed - 0.022 Mud and Silt material Bank - 0.045 Grassy with occasional trees and hedges.	Bed - 0.025 Banks - 0.05
30SUIL000166 to 30SUIL000013	Bed - 0.030 Stones, gravel and sand. Bank - 0.045 Grassy with occasional trees and hedges.	Bed - 0.035 Banks - 0.05

6.1.5 Building representation

The only area where building representation is potentially an issue is in central Tuam along the River Nanny. Although there is not a huge amount of flooding in this area building thresholds have been raised from the filtered mean LIDAR levels used within the original models to include a 300mm threshold. The 300mm value is typically the average height of a building threshold above the lowest ground level outside, like a road or driveway. This will represent the likely difference in ground level that filtered LIDAR will have stripped out and this may alter flooding patterns, redirecting flood waters and only allowing flood depths of >300mm to flood a building footprint.

6.1.6 Afflux at key structures

The key structures on the River Clare flagged in Section 2.2 are the weir and the bridge downstream of the Ballygaddy gauging station. Of these the bridge has a headloss of 0.5m across it currently but in both these instances the natural floodplain upstream does not currently impact any properties upstream. For the upstream properties to be affected would require an increased head loss across the structure of 0.6m. The current peak velocity through the bridge is 1.2m/s suggesting this additional head loss is not achievable through additional expansion and contraction losses. Rather the head loss across this structure is a result of the limited capacity, which is already well represented. No further investigation of the afflux at this structure is required.

Central Tuam contains a series of structures (bridges, culverts, weirs and sluices) that combine to control water levels. Flooding occurs from the reach near the mill channel on the right bank to the weir and Chapel Lane Bridge. In this location it is the weir that controls water levels resulting in out of bank flow affecting properties. The structure has been modelled as two parallel weirs representing in and out of bank flow. To test the sensitivity water levels to the modelling assumptions the in bank and out of bank spill coefficients have been reduced from 1.7 and 1.6 to 1.5 and 1.2 respectively.

The key structure on the Suileen is the culvert at 30SUIL00158D. This controls the water level for some distance upstream and has a headloss of approximately 0.5m across it. In reality however this structure does not dictate flood risk to local properties and any elevated levels resulting from it are exceeded by raised water levels backing up from the Clare downstream. No sensitivity testing of this structure has been undertaken.

6.1.7 Water level boundaries

Water level boundaries are a critical sensitivity test with this suite of models as the downstream boundaries have the potential to impact water levels.

The Clare uses a QH boundary extracted from the downstream MPW model. An appropriate increase in the downstream boundary has therefore been achieved by reducing the flow associated with a given level by 20%. This will effectively recreate the MRFS climate change event and highlight the impact on downstream water levels.

On the Nanny a normal depth boundary is used. The boundary is at the confluence with the Clare River. Flooding through this reach results from the elevated levels on the River Clare and the extent is derived from the River Clare model. The sensitivity of the elevated water levels on the Clare and the extent to which these back up the Nanny has therefore been assessed appropriately using the peak flow sensitivity test described in Section 6.1.1 and no further sensitivity testing is required.

On the Suileen the downstream water level again dictated by the Clare. The sensitivity to this boundary has been tested by applying an increase in water levels equivalent to an increase in flow on the Clare of 20%, equivalent to the MRFS climate change event.

6.1.8 Timing of tributaries

Adjustments to the timing of the tributaries could result in higher flows downstream on the Clare if peak flows on the Nanny were delayed. This test is only recommended where there is good confidence in the hydrology and the increase in flows resulting from the shift in timing would exceed the increase in flows investigated as part of the flow sensitivity. In this instance, a shift in the timing of tributaries would increase flows on the Clare by a small amount. However, the uncertainty associated with flows requires a greater increase, so further testing of a lower flow increase would not be informative.

6.1.9 Cell size

The flood extents for all of the Clare, Nanny and Suileen watercourses are dictated by the local topography only. That is there are no complicated flow routes observed that could be constricted by the size or orientation of the model grid applied. In areas where the flood extent does impact local receptors it is the ground level only that dictates the extent of flooding. Increasing the resolution of the model grid will not impact these local levels and as such no sensitivity of the model cell size has been undertaken.

6.2 Sensitivity testing results and uncertainty bounds

The results of the sensitivity tests have been used to inform the uncertainty bounds as detailed in the Hydraulic Modelling Method Statement. The uncertainty bound in effect presents the most sensitive hydraulic parameter/s as assessed within the bounds identified in Section 6.1 at all locations along the modelled reach.

To simplify the presentation of the sensitivity tests, the uncertainty bound for the 10% AEP and 1% AEP events has been presented only. Where different parameters have contributed to the development of the uncertainty bound, these are highlighted on the map and in the following text.

6.2.1 River Clare

The 10% AEP fluvial uncertainty bound is compared to the equivalent predicted flood extent for the River Clare in Figure 6-1. The 1% AEP fluvial uncertainty bound is shown in Figure 6-2.

Both the 10% and 1% AEP uncertainty bounds are based on the peak flow sensitivity test only. This results of the sensitivity testing show the peak flow is the greatest uncertainty associated with this model and the test produces the largest extent in all locations.

Figure 6-1: 10% AEP fluvial uncertainty bound for the River Clare

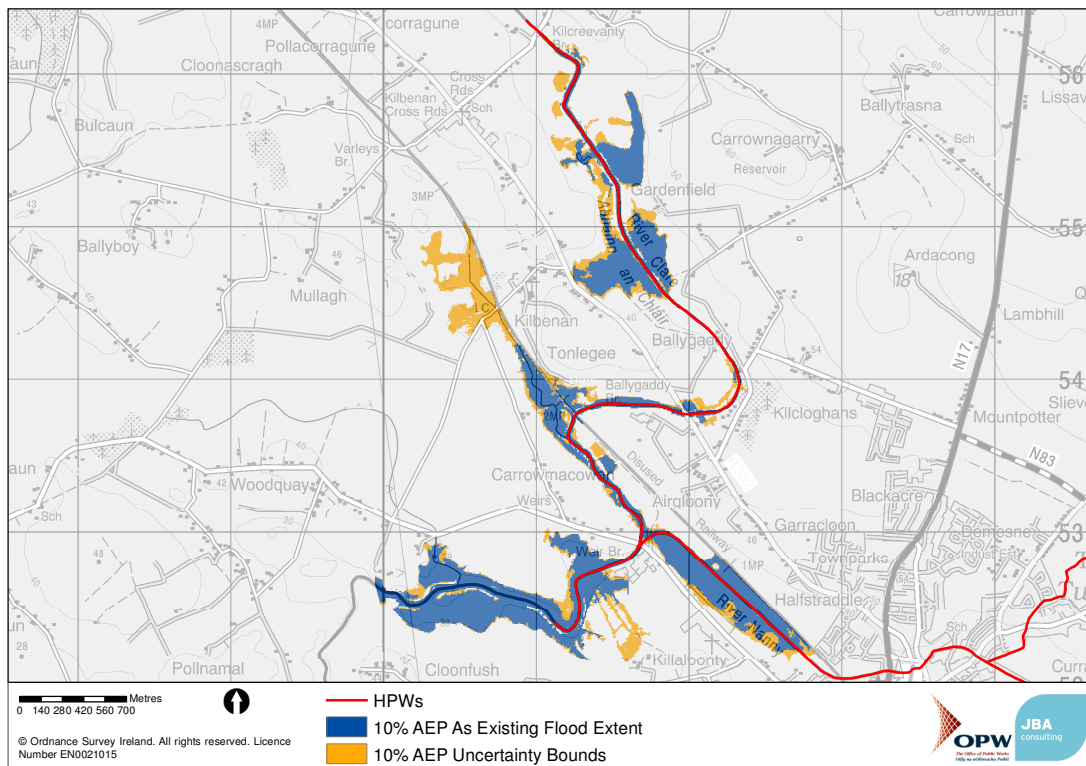
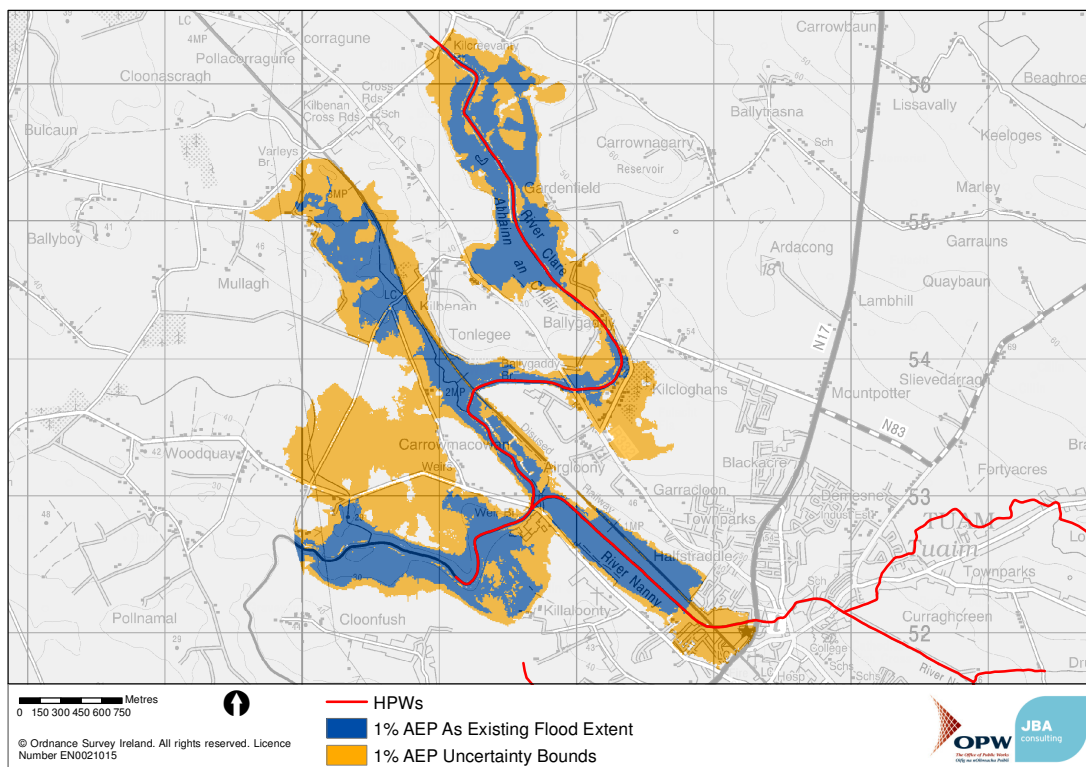


Figure 6-2: 1% AEP fluvial uncertainty bound for the River Clare



6.2.2 River Nanny

The 10% AEP fluvial uncertainty bound is compared to the equivalent predicted flood extent for the River Nanny in

Figure 6-3. The 1% AEP fluvial uncertainty bound is shown in Figure 6-4.

Both the 10% and 1% AEP uncertainty bounds are based on the peak flow sensitivity test only. This results of the sensitivity testing show the peak flow is the greatest uncertainty associated with this model and the test produces the largest extent in all locations.

Figure 6-3: 10% AEP fluvial uncertainty bound for the River Nanny

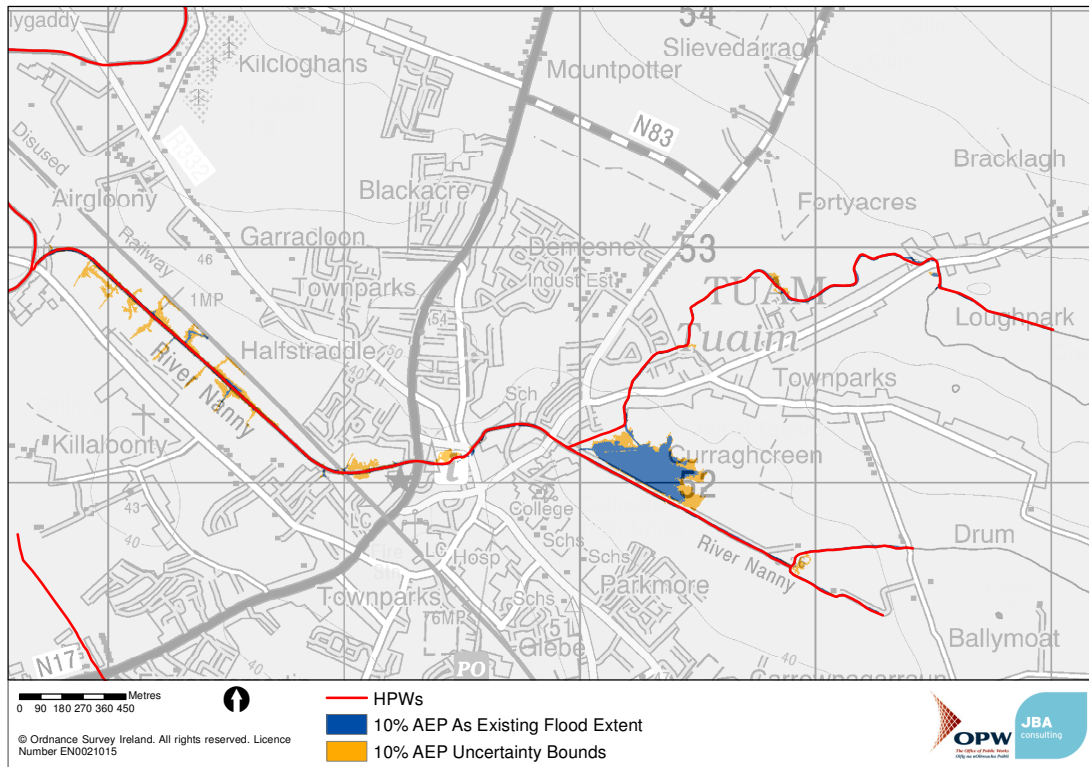
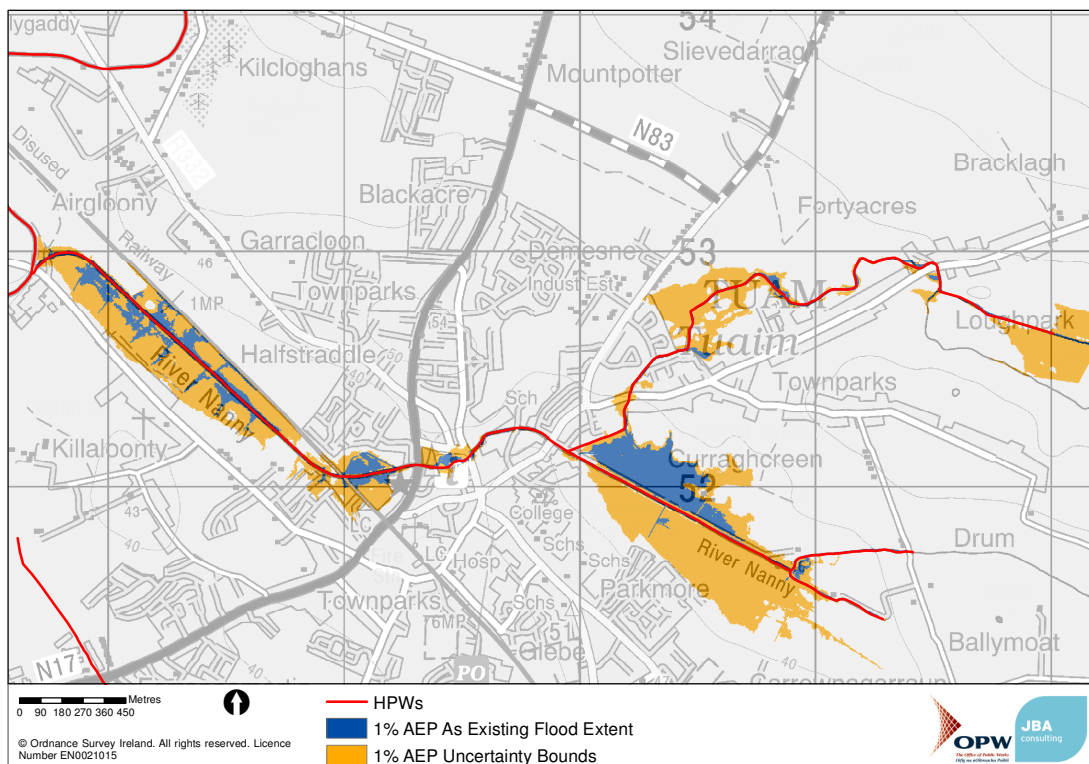


Figure 6-4: 1% AEP fluvial uncertainty bound for the River Nanny



6.2.3 River Suileen

The 10% AEP fluvial uncertainty bound is compared to the equivalent predicted flood extent for the River Suileen in Figure 6-5. The 1% AEP fluvial uncertainty bound is shown in Figure 6-6.

The 10% AEP uncertainty bounds is based on the peak flow sensitivity test only. This results show the watercourse is not particularly sensitivity to this parameter for this design event, but it reflects the greatest modelling uncertainty.

The 1% AEP uncertainty bound is determined by the peak flow and the water level sensitivity tests. These both produce similar extents, with the peak flow extent slightly larger at the upstream limit and the water level extent larger at the downstream limit of the model. It is not considered appropriate to investigate a combined event because these two sensitivity tests represent flood risk from either the Suileen or the Clare. Given the different size of the catchment of these two watercourses an assessment of a joint probability event is not appropriate. The uncertainty bound is therefore a combination of the two extents.

Figure 6-5: 10% AEP fluvial uncertainty bound for the River Suileen

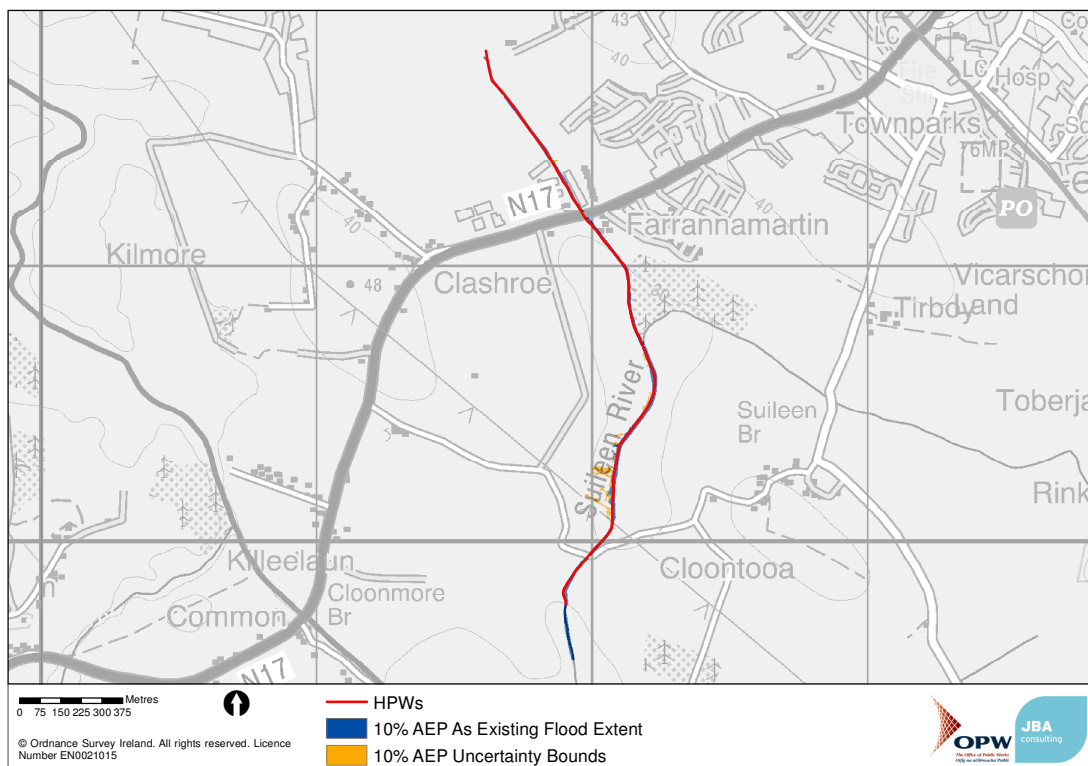
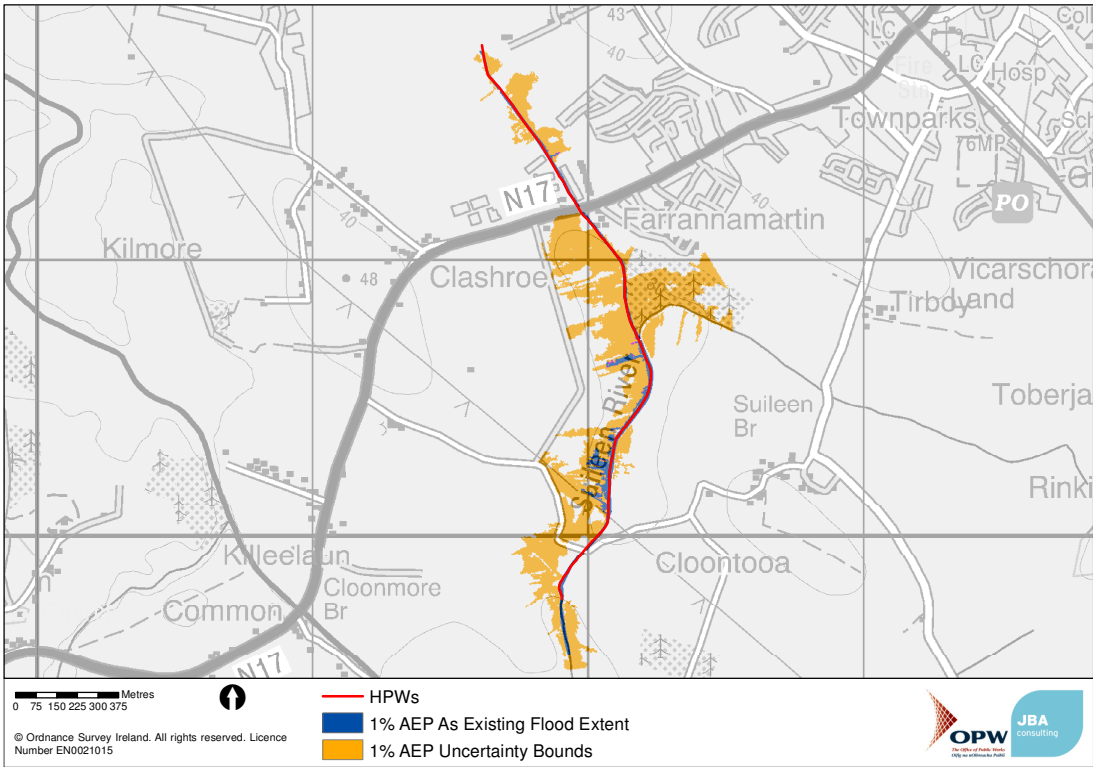


Figure 6-6: 1% AEP fluvial uncertainty bound for the River Suileen



7 Model limitations

7.1 Hydrology

The Nanny and Suileen models are based on hydrology derived without direct gauge data in their respective catchments. The hydrology is based on donor catchments from a pooling group of catchments with similar characteristics. Therefore, the flow estimates are based on a best fit estimate as they have not been confirmed by gauged data. Fortunately, the Clare River has a reliable flow gauge in the modelled reach that provides data on which to confirm and compare against flow estimates.

The combination of events on the different watercourses has not been directly modelled. The River Clare is a much larger river system than the Suileen or Nanny so we are not expecting joint events to occur. Where there is an overlap, the River Clare is modelled to fill the River Nanny floodplain to a greater extent than the Nanny itself. Therefore, two outlines have been created for this area from the two different models. To give a conservative representation of flooding in the study area the larger outline will be used in the flood maps.

7.2 Channel blockage

Blockage of culverts and small span bridges has the potential to increase the flood risk of a watercourse. In Tuam the culverts along the Nanny watercourse look particularly prone to blockage. If one of the culverts did block water would back up in the channel, before potentially causing flooding. Therefore, blockage has not been investigated in more detail in this model. However, where it does occur it is likely that culvert blockage will increase flood risk to properties.

A Hydraulic model results

A.1 1D model flows

Table A-1: 1D model peak current flows

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30CLAR04624	58.96	72.30	81.83	91.97	107.00	119.98	134.05	179.18
30CLAR04601	58.96	72.28	81.82	91.94	106.97	119.95	134.01	179.13
30CLAR04599A	58.96	72.28	81.82	91.93	106.96	119.94	134.00	179.13
30CLAR04598B	58.96	72.28	81.82	91.93	106.96	119.94	134.00	179.13
30CLAR04594	58.96	72.28	81.82	91.93	106.95	119.94	134.00	181.68
30CLAR04579	58.95	72.27	81.81	91.90	106.93	119.85	133.46	179.80
30CLAR04562	58.94	72.26	81.79	91.42	105.34	116.16	127.61	165.27
30CLAR04552	58.93	72.24	81.77	91.79	106.65	117.89	129.11	154.65
30CLAR04541	58.92	72.24	81.76	91.69	106.52	116.69	124.92	150.18
30CLAR04528	58.93	72.21	81.76	91.50	106.15	114.78	119.93	128.02
30CLAR04518	58.92	72.20	81.76	91.48	106.12	114.73	119.84	133.28
30CLAR04507	58.91	72.19	81.65	89.38	100.49	106.40	111.15	120.58
30CLAR04495	58.91	71.67	81.13	88.84	97.89	104.41	108.54	114.32
30CLAR04480	58.10	69.19	76.90	82.67	89.04	93.21	97.27	104.98
30CLAR04464	58.22	71.40	81.63	89.88	98.25	101.58	104.40	112.50
30CLAR04443	58.21	71.39	81.62	89.83	97.90	100.85	102.67	106.09
30CLAR04424	58.20	70.26	78.77	85.46	91.78	93.18	94.18	99.00
30CLAR04406	58.20	71.34	78.50	82.66	83.01	83.19	84.23	88.18
30CLAR04390	58.19	71.34	78.98	86.36	93.14	94.56	94.82	95.05
30CLAR04376	58.19	71.34	78.99	89.70	103.68	110.47	121.17	159.75
30CLAR04351	58.19	71.34	78.98	89.71	103.67	116.05	130.21	174.97
30CLAR04344	58.19	71.34	78.98	89.70	103.68	116.06	130.11	175.01
30CLAR04339	58.19	71.34	78.98	89.71	103.67	116.08	130.09	174.97
30CLAR04327	58.19	71.34	78.98	89.70	101.13	112.34	126.23	155.50
30CLAR04317	58.19	71.34	78.97	88.05	97.03	99.13	105.90	130.18
30CLAR04307	58.19	71.34	79.01	89.44	102.58	113.48	124.43	145.90
30CLAR04297	58.19	71.34	79.01	88.73	100.71	110.63	118.62	141.66
30CLAR04288	58.19	71.34	79.01	89.57	102.48	113.83	122.91	132.99
30CLAR04276	58.19	71.33	78.96	89.40	103.72	114.90	126.57	176.61
30CLAR04275	58.19	71.33	79.01	89.70	103.56	111.75	117.81	159.06
30CLAR04274A	58.19	71.33	78.71	87.46	95.98	100.33	104.20	134.54
30CLAR04273B	58.19	71.33	78.71	87.46	95.98	100.33	104.20	134.54
30CLAR04272	58.19	71.00	77.49	84.48	89.21	90.73	91.06	111.06
30CLAR04269	58.19	71.76	79.83	88.92	98.19	104.80	111.64	138.80
30CLAR04266A	58.19	71.34	79.01	89.73	103.62	116.05	129.60	172.10
30CLAR04266B	58.19	71.34	79.01	89.73	103.62	116.05	129.60	172.10
30CLAR04265	58.10	68.59	74.98	84.45	96.42	107.61	120.00	163.42
30CLAR04258	58.19	71.30	78.94	89.67	103.54	115.51	127.81	163.28
30CLAR04247	58.18	71.30	78.94	89.64	103.57	115.91	129.50	175.36
30CLAR04237	58.18	71.30	78.94	89.65	103.52	115.89	129.49	175.27
30CLAR04221	58.16	71.30	78.96	89.61	103.56	115.87	129.06	170.42
30CLAR04208	58.15	71.29	78.96	89.60	101.75	109.11	112.98	116.80
30CLAR04194	58.15	71.29	78.78	89.46	103.40	115.67	128.76	156.26
30CLAR04190A	58.14	71.28	78.78	89.45	103.33	115.66	128.75	156.10
30CLAR04190B	58.14	71.28	78.78	89.45	103.33	115.66	128.75	156.10
30CLAR04189	58.14	70.84	76.87	85.88	96.85	108.79	124.86	156.15
30CLAR04185	58.14	70.84	76.88	85.86	96.83	106.14	117.88	142.71
30CLAR04175A	58.07	70.05	77.01	84.41	92.26	100.20	108.60	128.59
30CLAR04175B	59.47	71.87	79.09	86.85	95.20	103.43	112.33	133.80
30CLAR04161	58.66	70.38	77.42	85.70	92.43	101.59	109.08	129.87
30CLAR04146	59.01	71.62	77.65	85.70	94.60	107.19	115.89	145.92
30CLAR04131	59.46	71.95	78.86	87.29	97.02	103.75	109.70	129.40

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30CLAR04116	59.45	72.90	80.66	90.44	102.90	116.13	126.07	153.84
30CLAR04104	59.04	69.95	76.44	83.74	90.49	99.37	104.64	120.59
30CLAR04094	59.45	72.10	78.38	84.94	91.58	99.71	105.20	118.57
30CLAR04088	59.45	71.83	78.25	88.93	99.86	107.60	114.01	128.64
30CLAR04087A	59.45	71.84	78.25	88.91	99.87	108.83	117.18	135.46
30CLAR04086B	64.09	77.55	84.12	95.65	107.35	117.06	126.83	148.53
30CLAR04085	64.09	77.55	84.12	95.46	106.07	116.78	127.83	173.83
30CLAR04076	64.08	77.55	84.13	95.87	109.48	121.36	133.87	174.53
30CLAR04067	64.08	77.43	83.98	95.50	108.70	119.96	131.90	173.31
30CLAR04056	64.06	76.68	82.65	94.02	107.26	117.93	128.88	167.89
30CLAR04046	63.53	75.30	80.30	90.43	103.31	114.50	126.06	166.66
30CLAR04031	63.94	76.70	81.15	88.00	95.50	102.87	111.92	148.49
30CLAR04016	63.73	76.52	82.95	92.87	102.75	108.96	115.61	142.23
30CLAR04001	63.89	76.37	82.17	91.15	99.42	104.84	110.73	137.19
30CLAR03991	62.39	74.13	79.49	87.10	94.31	98.34	102.38	121.05
30CLAR03981	62.71	74.56	79.77	87.64	95.48	100.91	106.12	127.08
30CLAR03971	63.18	75.01	78.60	85.90	93.25	99.36	105.10	129.68
30CLAR03962	63.60	74.05	77.84	84.75	92.32	98.77	104.49	126.20
30CLAR03951	63.62	73.48	76.78	82.32	90.05	97.08	103.49	135.15
30CLAR03941	63.81	73.63	76.59	80.39	85.52	91.08	96.45	105.70
30CLAR03926	63.84	74.22	77.39	78.89	81.02	85.70	90.44	153.03
30CLAR03909	63.83	74.81	78.95	81.52	83.21	83.60	83.80	92.23
30CLAR03898	63.83	74.81	79.09	83.10	86.13	86.74	87.03	89.10
30CLAR03880	63.82	76.57	83.92	94.84	104.89	112.28	118.37	133.41
30CLAR03864	63.82	76.57	83.89	94.88	108.90	120.65	132.62	187.40
30CLAR03849	63.82	76.58	83.88	94.89	108.87	120.60	132.67	185.33

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30NANN00429	0.419	0.557	0.657	0.766	0.929	1.072	1.206	1.641
30NANN00420	0.419	0.557	0.656	0.765	0.928	1.07	1.203	1.636
30NANN00410	0.418	0.555	0.654	0.763	0.924	1.066	1.199	1.629
30NANN00400	0.417	0.553	0.652	0.76	0.92	1.061	1.193	1.62
30NANN00390	0.415	0.55	0.649	0.757	0.916	1.056	1.188	1.611
30NANN00384A	0.413	0.547	0.647	0.754	0.913	1.052	1.182	1.59
30NANN00384B	0.817	1.084	1.282	1.492	1.808	2.086	2.344	3.165
30NANN00379	0.815	1.081	1.28	1.49	1.805	2.082	2.34	3.158
30NANN00369	0.812	1.075	1.274	1.484	1.798	2.073	2.332	3.142
30NANN00359	0.808	1.07	1.269	1.478	1.791	2.063	2.324	3.125
30NANN00349	0.803	1.063	1.262	1.47	1.781	2.053	2.316	3.103
30NANN00339A	0.799	1.058	1.257	1.464	1.773	2.044	2.307	3.08
30NANN00339B	0.949	1.208	1.407	1.614	1.936	2.23	2.516	3.361
30NANN00329	0.946	1.203	1.402	1.608	1.929	2.223	2.509	3.338
30NANN00319	0.941	1.197	1.396	1.6	1.919	2.203	2.454	3.132
30NANN00309	0.937	1.193	1.392	1.595	1.912	2.194	2.474	4.56
30NANN00299	0.929	1.186	1.384	1.585	1.901	2.18	2.462	6.381
30NANN00289	0.926	1.183	1.379	1.578	1.891	2.167	2.46	6.439
30NANN00281	0.924	1.182	1.376	1.573	1.886	2.16	2.458	6.44
30NANN00279A	0.923	1.181	1.374	1.572	1.884	2.157	2.458	6.44
30NANN00279B	4.471	5.621	6.317	7.035	8.085	8.98	10.027	13.447
30NANN00274	4.471	5.623	6.318	7.035	8.086	8.981	10.028	13.446
30NANN00269	4.471	5.623	6.319	7.036	8.085	8.981	10.028	13.447
30NANN00269A	4.471	5.623	6.319	7.036	8.086	8.981	10.028	13.447
30NANN00267B	4.471	5.623	6.319	7.036	8.086	8.982	10.028	13.446
30NANN00266	4.471	5.623	6.32	7.036	8.086	8.982	10.028	13.446
30NANN00265A	4.471	5.624	6.32	7.036	8.086	8.982	10.028	13.446
30NANN00264B	4.471	5.624	6.32	7.036	8.086	8.982	10.028	13.446

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30NANN00263	4.471	5.624	6.32	7.037	8.086	8.982	10.028	13.446
30NANN00259	4.471	5.626	6.322	7.038	8.087	8.984	10.028	13.446
30NANN00253	5.349	6.69	7.561	8.38	9.536	10.505	11.744	14.934
30NANN00253A	5.349	6.69	7.561	8.38	9.536	10.505	11.744	14.934
30NANN00253B	5.349	6.69	7.561	8.38	9.536	10.505	11.744	14.934
30NANN00251	5.349	6.69	7.561	8.38	9.535	10.505	11.744	14.934
30NANN00245	5.349	6.69	7.561	8.38	9.535	10.505	11.744	14.933
30NANN00239	5.349	6.69	7.56	8.38	9.536	10.505	11.744	14.933
30NANN00238A	5.349	6.69	7.56	8.38	9.536	10.505	11.744	14.933
30NANN00238B	5.349	6.69	7.56	8.38	9.536	10.505	11.744	14.933
30NANN00237	5.349	6.69	7.56	8.38	9.536	10.505	11.744	14.936
30NANN00235	5.349	6.69	7.56	8.38	9.536	10.505	11.744	14.936
30NANN00235A	5.349	6.69	7.561	8.38	9.536	10.505	11.744	14.936
30NANN00234B	5.349	6.69	7.561	8.38	9.536	10.505	11.744	14.936
30NANN00233A	5.348	6.69	7.561	8.38	9.535	10.505	11.743	14.936
30NANN00233B	3.683	4.437	4.898	5.339	5.947	6.468	7.265	9.305
30NANN00232A	3.683	4.437	4.897	5.339	5.947	6.468	7.265	9.305
30NANN00230J	3.683	4.437	4.897	5.339	5.947	6.468	7.265	9.305
30NANN00228A	3.683	4.437	4.897	5.339	5.948	6.468	7.265	9.305
30NANN00230B	1.665	2.252	2.663	3.04	3.588	4.036	4.479	5.63
30NANN00229A	1.665	2.252	2.663	3.041	3.59	4.036	4.479	5.631
30NANN00228B	5.348	6.69	7.56	8.38	9.538	10.505	11.743	14.936
30NANN00227A	5.348	6.69	7.561	8.38	9.535	10.505	11.743	14.936
30NANN00226B	5.348	6.69	7.561	8.38	9.536	10.505	11.743	14.936
30NANN00223	5.348	6.69	7.56	8.38	9.54	10.505	11.743	14.936
NANN002235A	5.348	6.69	7.56	8.38	9.54	10.48	11.671	14.642
NANN002235B	5.19	6.49	7.338	8.139	9.279	10.203	11.375	14.301
30NANN00223A	5.19	6.49	7.338	8.139	9.26	10.164	11.251	13.871
30NANN00222B	5.19	6.49	7.338	8.139	9.26	10.164	11.251	13.871
30NANN00222	5.19	6.49	7.338	8.139	9.265	10.176	11.3	14.091
30NANN00220A	5.19	6.49	7.338	8.139	9.263	10.178	11.314	14.123
30NANN00219B	5.19	6.49	7.338	8.139	9.263	10.178	11.314	14.123
30NANN00219	5.129	6.367	7.169	7.921	8.974	9.762	10.703	12.972
30NANN00218	5.129	6.367	7.169	7.921	8.974	9.772	10.718	12.995
30NANN00217A	5.129	6.367	7.169	7.921	8.973	9.771	10.72	12.925
30NANN00217B	5.549	6.89	7.76	8.58	9.725	10.688	11.9	14.898
30NANN00215	5.549	6.89	7.76	8.58	9.725	10.695	11.907	15.125
30NANN00213	5.549	6.89	7.76	8.58	9.726	10.696	11.907	14.981
30NANN00213A	5.549	6.89	7.76	8.58	9.726	10.696	11.905	14.512
30NANN00213B	5.549	6.89	7.76	8.58	9.726	10.696	11.905	14.512
30NANN00211	5.549	6.89	7.76	8.58	9.726	10.695	11.907	14.559
30NANN00208	5.549	6.89	7.76	8.58	9.731	10.711	11.955	14.892
30NANN00205	5.549	6.89	7.76	8.58	9.73	10.711	11.958	15.056
30NANN00204A	5.549	6.89	7.76	8.58	9.729	10.711	11.957	15.055
30NANN00203B	5.549	6.89	7.76	8.58	9.729	10.71	11.955	15.055
30NANN00202	5.549	6.89	7.76	8.58	9.728	10.711	11.956	15.056
30NANN00195	5.549	6.89	7.76	8.58	9.729	10.71	11.956	15.057
30NANN00190	5.549	6.89	7.761	8.58	9.724	10.42	11.399	13.535
30NANN00181	5.549	6.891	7.763	8.581	9.666	10.909	12.168	15.077
30NANN00179	5.549	6.891	7.762	8.581	9.325	9.508	9.42	11.413
30NANN00178A	5.549	6.892	7.762	8.581	9.325	9.48	9.359	9.286
30NANN00178B	5.549	6.892	7.762	8.581	9.325	9.48	9.359	9.286
30NANN00176	5.549	6.892	7.762	8.581	9.498	9.69	9.631	10.56
30NANN00174	5.55	6.892	7.762	8.582	9.501	9.738	9.964	12.191
30NANN00172A	5.551	6.893	7.763	8.583	9.718	10.549	11.893	15.167
30NANN00172B	5.551	6.893	7.763	8.583	9.718	10.549	11.893	15.167
30NANN00168	5.552	6.894	7.765	8.584	9.719	10.556	11.899	15.17
30NANN00161	5.961	7.398	8.365	9.282	10.449	11.279	12.65	15.233

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30NANN00153	5.961	7.398	8.364	9.28	10.449	11.35	12.908	16.335
30NANN00151	5.961	7.398	8.363	9.28	10.449	11.345	12.904	16.333
30NANN00150A	5.961	7.398	8.363	9.28	10.448	11.347	12.907	16.334
30NANN00150B	5.961	7.398	8.363	9.28	10.448	11.347	12.907	16.334
30NANN00148	5.961	7.398	8.363	9.28	10.448	11.345	12.905	16.333
30NANN00146	5.96	7.397	8.362	9.28	10.448	11.345	12.906	16.333
30NANN00138	5.96	7.397	8.362	9.278	10.446	11.342	12.9	16.33
30NANN00131	5.959	7.396	8.353	9.107	10.214	11.042	12.409	15.244
30NANN00123	5.958	7.396	8.357	8.886	9.855	10.45	11.498	13.651
30NANN00116	5.957	7.394	8.354	9.234	10.17	10.783	11.755	13.687
30NANN00108	5.956	7.389	8.325	9.146	10.134	10.844	11.924	13.015
30NANN00101	5.955	7.388	8.345	9.241	10.087	10.556	11.207	12.009
30NANN00093	5.955	7.388	8.344	9.197	10.33	11.156	12.339	13.752
30NANN00086	5.954	7.386	8.342	9.189	10.292	11.027	12.137	13.725
30NANN00078	5.954	7.384	8.341	9.181	10.291	11.056	12.005	13.193
30NANN00071	5.954	7.385	8.341	9.175	10.261	10.949	11.771	12.687
30NANN00063	5.955	7.387	8.341	9.163	10.29	11.009	11.672	12.22
30NANN00056	5.956	7.388	8.343	9.166	10.263	10.948	11.301	11.444
30NANN00048A	5.958	7.39	8.345	9.17	10.239	10.986	11.682	11.69
30NANN00048B	5.958	7.39	8.345	9.17	10.239	10.986	11.682	11.69
30NANN00041	6.356	7.875	8.911	9.797	10.934	11.512	12.104	12.538
30NANN00034	6.354	7.872	8.909	9.777	10.823	11.235	11.507	11.726
30NANN00026	6.353	7.871	8.908	9.786	10.928	11.679	12.815	13.644
30NANN00018	6.353	7.87	8.906	9.786	10.927	11.677	12.813	14.185
30NANN00013	6.352	7.869	8.906	9.787	10.927	11.677	12.813	15.763
30NANN00008	6.352	7.869	8.905	9.787	10.927	11.676	12.813	15.811
30NANN00004	6.352	7.87	8.906	9.787	10.927	11.676	12.813	15.927
30NANN00002D	6.352	7.869	8.905	9.787	10.927	11.676	12.812	15.927
30TRAC00005	0.158	0.2	0.222	0.241	0.261	0.277	0.296	0.341
30TRAC00004A	0.158	0.2	0.222	0.241	0.265	0.302	0.367	0.622
30TRAC00003B	0.358	0.4	0.422	0.441	0.465	0.502	0.567	0.822
TRAC00044A	0.358	0.4	0.422	0.441	0.465	0.502	0.567	0.822
TRAC00044B	0.358	0.4	0.422	0.441	0.465	0.502	0.567	0.822
30TRAC00002	0.358	0.4	0.422	0.441	0.465	0.502	0.567	0.822
TRAC000034A	0.358	0.4	0.422	0.441	0.465	0.502	0.567	0.822
TRAC000028B	0.358	0.4	0.422	0.441	0.465	0.502	0.567	0.822
30TRAC00001	0.419	0.523	0.591	0.659	0.753	0.917	1.181	1.973
30TRAC00000	0.419	0.523	0.591	0.659	0.753	0.917	1.18	1.973
30LNAR00055	0.405	0.539	0.637	0.741	0.899	1.038	1.168	1.589
30LNAR00054A	0.405	0.539	0.637	0.741	0.899	1.038	1.168	1.589
30LNAR00053B	0.405	0.539	0.637	0.741	0.899	1.038	1.168	1.589
30LNAR00052	0.405	0.539	0.637	0.741	0.899	1.038	1.168	1.589
30LNAR00043	0.405	0.539	0.637	0.741	0.899	1.038	1.168	1.588
30LNAR00033	0.405	0.539	0.636	0.74	0.898	1.037	1.167	1.587
30LNAR00023	0.405	0.538	0.636	0.74	0.898	1.036	1.166	1.587
30LNAR00013	0.404	0.538	0.636	0.74	0.898	1.036	1.166	1.586
30LNAR00009	0.404	0.538	0.636	0.74	0.898	1.036	1.166	1.586
30LNAR00008	0.404	0.538	0.636	0.74	0.898	1.036	1.166	1.586
30LNAR00008A	0.404	0.538	0.636	0.74	0.898	1.036	1.166	1.586
30LNAR00007B	0.404	0.538	0.636	0.74	0.898	1.036	1.166	1.586
30LNAR00007	0.404	0.538	0.636	0.74	0.898	1.036	1.166	1.586
30LNAR00003	0.404	0.538	0.636	0.739	0.897	1.035	1.165	1.584
30LNAR00000	0.404	0.537	0.635	0.738	0.895	1.034	1.163	1.581
30DEER00296	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
30DEER00291	0.503	0.504	0.505	0.506	0.507	0.508	0.509	0.514
30DEER00287	0.505	0.507	0.509	0.51	0.512	0.513	0.515	0.52
30DEER00281	0.509	0.512	0.515	0.516	0.519	0.522	0.525	0.532
30DEER00277	0.512	0.517	0.52	0.522	0.526	0.529	0.532	0.542

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30DEER00272	0.515	0.52	0.524	0.527	0.532	0.535	0.54	0.552
30DEER00266	0.518	0.524	0.529	0.533	0.538	0.542	0.547	0.562
30DEER00259	0.522	0.53	0.535	0.54	0.546	0.552	0.558	0.576
30DEER00256	0.525	0.533	0.539	0.544	0.551	0.557	0.564	0.584
30DEER00253	0.527	0.536	0.542	0.548	0.556	0.562	0.569	0.59
30DEER00252A	0.528	0.537	0.543	0.549	0.557	0.563	0.57	0.592
30DEER00252B	0.528	0.537	0.543	0.549	0.557	0.564	0.571	0.593
30DEER00251	0.528	0.537	0.544	0.55	0.557	0.564	0.571	0.593
30DEER00246	0.531	0.541	0.548	0.554	0.563	0.57	0.577	0.601
30DEER00241	0.535	0.546	0.554	0.561	0.571	0.579	0.588	0.627
30DEER00236	0.541	0.555	0.564	0.573	0.585	0.595	0.608	0.659
30DEER00235A	0.542	0.555	0.565	0.574	0.586	0.596	0.609	0.661
30DEER00234B	0.543	0.556	0.566	0.575	0.587	0.597	0.61	0.662
30DEER00233	0.543	0.557	0.566	0.576	0.588	0.598	0.611	0.663
30DEER00232	0.544	0.558	0.568	0.577	0.589	0.6	0.613	0.665
30DEER00231A	0.545	0.558	0.568	0.578	0.59	0.6	0.614	0.666
30DEER00231B	0.545	0.559	0.568	0.578	0.59	0.6	0.614	0.666
30DEER00230	0.545	0.559	0.569	0.579	0.591	0.601	0.617	0.667
30DEER00225	0.549	0.565	0.576	0.586	0.6	0.611	0.625	0.679
30DEER00221	3.193	4.036	4.622	5.234	6.125	6.85	7.722	10.427
30DEER00213	3.193	4.035	4.622	5.234	6.124	6.849	7.721	10.426
30DEER00203	3.193	4.035	4.622	5.234	6.125	6.85	7.722	10.428
30DEER00196	3.193	4.035	4.622	5.234	6.124	6.85	7.721	10.427
30DEER00191	3.193	4.036	4.622	5.235	6.125	6.851	7.723	10.428
30DEER00184	3.193	4.036	4.622	5.234	6.124	6.85	7.686	9.924
30DEER00174	3.194	4.037	4.623	5.236	6.126	6.852	7.724	10.428
30DEER00167	3.34	4.222	4.836	5.477	6.408	7.173	8.081	10.922
30DEER00159	3.34	4.223	4.836	5.477	6.407	7.179	8.083	10.79
30DEER00155	3.34	4.222	4.818	5.433	6.338	7.08	7.959	10.729
30DEER00155A	3.34	4.151	4.565	4.966	5.527	5.936	6.388	7.701
30DEER00154B	3.277	4.074	4.48	4.875	5.427	5.828	6.275	7.573
DEER001531A	3.277	4.144	4.672	5.184	5.883	6.372	6.872	8.247
DEER001531B	3.34	4.221	4.757	5.275	5.983	6.48	6.985	8.375
30DEER00153A	3.34	4.221	4.757	5.276	5.97	6.387	6.761	7.466
30DEER00152B	3.34	4.221	4.757	5.276	5.97	6.387	6.761	7.473
30DEER00145	3.34	4.222	4.839	5.47	6.086	6.165	6.175	6.41
30DEER00138	3.34	4.222	4.837	5.47	6.371	7.139	7.968	10.942
30DEER00129A	3.34	4.222	4.837	5.47	6.372	7.139	7.969	10.807
30DEER00129B	3.34	4.222	4.837	5.47	6.372	7.139	7.969	10.807
30DEER00122	3.34	4.222	4.837	5.471	6.372	7.14	7.968	10.806
30DEER00114	3.485	4.405	5.048	5.709	6.647	7.456	8.318	10.658
30DEER00107A	3.485	4.405	5.048	5.709	6.648	7.456	8.318	10.738
30DEER00107B	3.485	4.405	5.048	5.709	6.648	7.456	8.318	10.738
30DEER00099	3.485	4.405	5.048	5.709	6.649	7.456	8.318	11.211
30DEER00096	3.485	4.405	5.047	5.709	6.648	7.456	8.317	11.21
30DEER00084	3.485	4.405	5.048	5.709	6.647	7.296	8.058	10.583
30DEER00075	3.485	4.405	5.047	5.709	6.648	7.391	8.312	11.206
30DEER00068	3.485	4.405	5.047	5.709	6.648	7.391	8.313	11.206
30DEER00062	3.485	4.405	5.047	5.709	6.648	7.391	8.312	11.206
30DEER00056	3.633	4.593	5.262	5.952	6.933	7.716	8.664	11.396
30DEER00055A	3.633	4.593	5.262	5.952	6.932	7.716	8.663	9.302
30DEER00054B	3.633	4.593	5.262	5.952	6.932	7.716	8.664	9.302
30DEER00053	3.633	4.593	5.262	5.951	6.932	7.715	8.664	9.3
30DEER00049	3.633	4.593	5.262	5.952	6.933	7.716	8.664	10.374
30DEER00042	3.633	4.593	5.262	5.951	6.932	7.715	8.664	11.575
30DEER00039	3.633	4.593	5.262	5.951	6.848	7.534	8.333	10.84
30DEER00035	3.633	4.593	5.262	5.951	6.913	7.603	8.332	10.845
30DEER00031	3.633	4.593	5.262	5.951	6.82	7.287	7.615	9.062

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30DEER00025	3.018	3.352	3.563	3.671	3.738	3.779	4.462	6.895
30DEER00010	3.029	3.216	3.23	3.239	3.252	3.26	3.267	3.287
30DEER00001A	3.578	4.494	5.065	5.649	6.493	7.095	7.588	7.662
30DEER00001B	3.578	4.494	5.066	5.649	6.493	7.096	7.589	7.664
30DEER00000	3.578	4.494	5.066	5.649	6.493	7.096	7.589	7.664

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30SUIL00365	0.1	0.18	0.18	0.18	0.1	0.1	0.1	0.1
30SUIL00355	0.1	0.18	0.18	0.18	0.101	0.101	0.107	0.115
30SUIL00349	0.1	0.179	0.179	0.179	0.103	0.103	0.112	0.122
SUIL003488A	0.1	0.179	0.179	0.179	0.104	0.103	0.109	0.122
SUIL003485B	0.1	0.179	0.179	0.179	0.104	0.104	0.109	0.122
30SUIL00347	0.1	0.179	0.179	0.179	0.104	0.104	0.122	0.122
30SUIL00338	0.101	0.174	0.175	0.175	0.116	0.116	0.122	0.126
30SUIL00331	0.105	0.17	0.171	0.171	0.11	0.112	0.124	0.233
30SUIL00323	0.101	0.165	0.167	0.167	0.113	0.116	0.132	0.377
30SUIL00317	0.101	0.162	0.163	0.163	0.114	0.117	0.121	0.132
30SUIL00310	0.102	0.153	0.157	0.157	0.116	0.122	0.155	0.385
30SUIL00302	0.101	0.147	0.152	0.152	0.118	0.124	0.157	0.387
30SUIL00298	0.1	0.143	0.148	0.148	0.119	0.125	0.16	0.389
30SUIL00297A	0.101	0.141	0.148	0.148	0.12	0.125	0.139	0.389
30SUIL00295B	0.101	0.141	0.147	0.147	0.12	0.125	0.139	0.389
30SUIL00294	0.118	0.509	0.515	0.516	0.151	0.156	0.163	0.408
30SUIL00290	0.118	0.504	0.511	0.511	0.156	0.164	0.161	0.41
30SUIL00283	0.118	0.494	0.502	0.502	0.157	0.168	0.201	0.385
30SUIL00275	0.12	0.485	0.494	0.494	0.164	0.171	0.239	0.367
30SUIL00265	0.123	0.474	0.482	0.482	0.158	0.176	0.284	0.633
30SUIL00257	0.118	0.465	0.471	0.471	0.165	0.177	0.293	0.792
30SUIL00250	0.119	0.446	0.461	0.461	0.159	0.182	0.509	0.95
30SUIL00242A	0.123	0.434	0.453	0.453	0.165	0.183	0.569	1.195
30SUIL00242B	0.323	1.237	1.25	1.25	0.365	0.383	0.769	1.395
30SUIL00235	0.324	1.233	1.247	1.247	0.378	0.388	0.792	1.379
30SUIL00227	0.319	1.23	1.245	1.245	0.384	0.405	0.874	1.925
30SUIL00220	0.319	1.227	1.242	1.242	0.399	0.406	0.877	2.109
30SUIL00212	0.319	1.224	1.24	1.24	0.402	0.412	0.886	2.279
30SUIL00205	0.322	1.221	1.238	1.238	0.41	0.421	0.924	2.483
30SUIL00197	0.319	1.219	1.236	1.236	0.41	0.429	0.936	2.344
30SUIL00190	0.419	1.317	1.335	1.335	0.506	0.542	0.979	2.122
30SUIL00182	0.419	1.315	1.334	1.334	0.509	0.546	0.967	2.028
30SUIL00174	0.419	1.314	1.333	1.333	0.513	0.561	1.09	2.127
30SUIL00166	0.419	1.314	1.333	1.333	0.515	0.571	1.183	2.587
30SUIL00159	0.419	1.314	1.333	1.333	0.518	0.57	1.186	3.941
30SUIL00158A	0.419	1.314	1.333	1.333	0.509	0.57	1.186	3.941
30SUIL00157B	0.419	1.314	1.333	1.333	0.511	0.571	1.186	3.941
30SUIL00156	0.419	1.314	1.333	1.333	0.512	0.571	1.187	3.942
30SUIL00150	0.439	1.313	1.333	1.333	0.517	0.571	1.19	3.946
30SUIL00142	0.42	1.313	1.332	1.332	0.517	0.573	1.193	3.953
30SUIL00134	0.421	1.312	1.331	1.331	0.533	0.578	1.198	4.005
30SUIL00115	0.43	1.31	1.33	1.33	0.537	0.595	1.225	4.439
30SUIL00092	0.43	1.308	1.327	1.327	0.556	0.608	1.241	4.465
30SUIL00072	0.433	1.306	1.325	1.325	0.57	0.613	1.255	4.483
30SUIL00052A	0.776	1.513	1.525	1.525	0.613	0.651	1.299	4.529
30SUIL00052	0.776	1.513	1.525	1.525	0.613	0.651	1.299	4.529
30SUIL00032A	0.785	1.513	1.525	1.525	0.628	0.666	1.314	4.558
30SUIL00032	0.785	1.513	1.525	1.525	0.628	0.666	1.314	4.558
30SUIL00013A	1.395	1.514	1.525	1.525	0.665	0.691	1.332	4.593

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30SUIL00013	1.395	1.514	1.525	1.525	0.665	0.691	1.332	4.593
30SUIL00000	1.187	1.514	1.525	1.525	0.687	0.711	1.343	4.614

Table A-2: 1D model peak MRFS flows

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30CLAR04624	70.86	86.89	98.34	110.53	128.59	144.19	161.10	215.34
30CLAR04601	70.84	86.86	98.31	110.50	128.54	144.15	161.07	215.34
30CLAR04599A	70.84	86.86	98.31	110.49	128.53	144.14	161.06	215.55
30CLAR04598B	70.84	86.86	98.31	110.49	128.53	144.14	161.06	215.55
30CLAR04594	70.84	86.86	98.31	110.49	128.52	144.13	161.32	221.11
30CLAR04579	70.83	86.82	98.27	110.46	128.25	143.24	159.35	241.50
30CLAR04562	70.81	86.74	97.32	108.52	123.21	135.43	148.78	206.08
30CLAR04552	70.79	86.71	98.14	110.01	124.95	135.52	145.38	186.98
30CLAR04541	70.77	86.68	98.04	109.81	121.47	129.96	139.67	183.79
30CLAR04528	70.75	86.64	97.95	108.92	118.27	122.35	125.41	143.92
30CLAR04518	70.75	86.61	97.93	108.88	118.22	122.25	125.30	139.72
30CLAR04507	70.73	85.86	94.49	102.58	109.67	113.26	117.53	128.78
30CLAR04495	70.47	85.36	92.88	99.40	107.17	110.44	112.62	116.91
30CLAR04480	68.33	80.34	85.55	90.18	95.97	99.56	102.43	112.56
30CLAR04464	70.25	85.64	94.12	99.41	103.26	106.27	108.97	116.27
30CLAR04443	70.25	85.59	94.02	98.91	102.08	103.63	104.92	109.30
30CLAR04424	69.26	81.56	89.92	92.24	93.85	95.91	96.96	101.23
30CLAR04406	70.18	81.81	82.86	83.08	83.25	85.89	86.87	89.36
30CLAR04390	70.18	83.27	90.51	93.75	94.86	94.92	95.16	95.12
30CLAR04376	70.17	84.55	96.07	106.63	117.54	129.71	143.40	159.82
30CLAR04351	70.17	84.53	96.07	107.02	125.13	141.44	158.46	215.71
30CLAR04344	70.17	84.55	96.07	107.04	125.16	141.46	158.52	216.00
30CLAR04339	70.17	84.54	96.07	107.03	125.18	141.41	158.47	215.87
30CLAR04327	70.17	84.54	95.83	101.68	121.74	135.81	145.74	185.93
30CLAR04317	70.17	84.12	92.78	97.91	103.38	112.18	122.25	155.24
30CLAR04307	70.17	84.51	95.46	105.66	120.67	133.01	140.38	173.28
30CLAR04297	70.17	84.26	94.26	104.19	115.67	124.75	133.77	170.85
30CLAR04288	70.17	84.51	95.40	105.59	120.12	128.13	130.03	157.79
30CLAR04276	70.17	84.29	95.76	107.21	121.11	141.56	161.00	216.11
30CLAR04275	70.16	84.47	96.02	106.63	114.12	127.76	143.97	198.97
30CLAR04274A	70.16	83.39	91.77	97.68	101.89	111.27	122.10	155.36
30CLAR04273B	70.16	83.39	91.77	97.68	101.89	111.27	122.10	155.36
30CLAR04272	69.91	81.23	87.52	89.81	91.00	92.38	100.56	146.87
30CLAR04269	70.51	84.86	93.49	100.14	108.85	117.42	126.22	157.54
30CLAR04266A	70.17	84.47	96.01	106.95	124.62	140.31	155.88	173.32
30CLAR04266B	70.17	84.47	96.01	106.95	124.62	140.31	155.88	173.32
30CLAR04265	67.60	80.02	89.84	99.32	115.42	130.14	147.03	190.40
30CLAR04258	70.14	84.40	95.95	106.76	123.22	136.85	150.01	198.52
30CLAR04247	70.15	84.39	95.97	106.80	124.46	140.64	157.21	216.36
30CLAR04237	70.14	84.38	95.94	106.80	124.44	140.31	156.67	218.55
30CLAR04221	70.13	84.35	95.93	106.77	124.36	138.99	153.06	206.75
30CLAR04208	70.13	84.34	95.53	104.02	111.90	114.33	115.72	144.50
30CLAR04194	70.12	83.89	95.74	106.51	123.91	137.95	148.66	163.10
30CLAR04190A	70.11	83.84	95.72	106.50	123.92	137.91	148.66	163.76
30CLAR04190B	70.11	83.84	95.72	106.50	123.92	137.91	148.66	163.76
30CLAR04189	69.79	81.07	90.89	99.60	118.35	134.89	148.91	165.40
30CLAR04185	69.79	81.05	90.91	99.19	112.81	125.80	136.14	150.43
30CLAR04175A	69.03	80.55	88.56	94.29	105.40	114.35	122.77	135.12
30CLAR04175B	70.71	82.75	91.11	97.14	108.91	118.35	127.23	141.26
30CLAR04161	69.25	81.42	88.47	94.46	106.42	113.96	124.15	137.55
30CLAR04146	70.46	81.56	89.92	98.84	112.56	122.35	135.24	155.75

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30CLAR04131	70.76	82.82	91.98	98.09	107.47	113.97	121.03	137.63
30CLAR04116	71.65	85.36	95.84	106.26	122.43	132.23	142.96	171.13
30CLAR04104	69.14	80.13	87.02	92.53	103.04	107.59	113.12	131.45
30CLAR04094	71.10	81.85	88.02	93.15	103.53	107.65	111.85	129.23
30CLAR04088	70.87	83.95	93.79	102.21	112.05	117.96	122.30	137.86
30CLAR04087A	70.87	83.95	93.78	102.30	114.47	123.62	130.89	138.38
30CLAR04086B	76.51	90.31	101.11	110.28	123.62	133.70	142.67	155.58
30CLAR04085	76.51	90.31	99.99	109.12	124.26	136.18	155.78	197.28
30CLAR04076	76.51	90.33	101.86	112.82	129.78	141.57	156.50	199.21
30CLAR04067	76.41	90.09	101.35	111.95	128.05	140.21	155.00	196.44
30CLAR04056	75.71	88.61	99.89	110.39	125.37	136.53	150.39	189.87
30CLAR04046	74.43	85.57	95.96	106.50	122.33	134.23	148.70	189.82
30CLAR04031	75.80	84.98	91.14	97.57	108.90	118.88	131.90	170.32
30CLAR04016	75.65	88.30	97.81	104.54	113.47	119.03	127.95	161.44
30CLAR04001	75.48	87.10	95.37	101.02	108.80	114.10	123.08	157.80
30CLAR03991	73.32	83.62	91.07	95.59	101.05	104.36	109.67	136.05
30CLAR03981	73.72	84.02	91.34	97.13	104.46	108.59	115.11	141.95
30CLAR03971	74.24	82.55	89.11	95.04	103.31	108.04	116.10	145.80
30CLAR03962	73.34	81.58	88.08	94.11	102.72	107.19	113.49	143.00
30CLAR03951	72.91	79.57	85.43	91.96	101.53	107.12	120.56	151.17
30CLAR03941	73.07	78.58	82.24	87.00	94.79	98.85	100.13	128.87
30CLAR03926	73.35	78.43	79.43	82.19	89.03	120.24	139.26	156.25
30CLAR03909	73.80	80.50	82.62	83.34	83.73	83.91	84.39	100.27
30CLAR03898	73.78	81.25	85.12	86.34	86.94	87.18	87.36	96.65
30CLAR03880	75.30	89.66	99.48	106.86	116.55	123.30	128.14	133.93
30CLAR03864	75.31	89.66	100.86	112.02	128.64	145.20	164.89	225.67
30CLAR03849	75.30	89.68	100.84	112.03	128.63	145.24	164.86	223.06

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30NANN00429	0.502	0.668	0.789	0.919	1.115	1.286	1.448	1.97
30NANN00420	0.502	0.667	0.788	0.917	1.112	1.283	1.445	1.961
30NANN00410	0.501	0.665	0.785	0.914	1.109	1.278	1.439	1.947
30NANN00400	0.499	0.663	0.782	0.91	1.103	1.273	1.432	1.931
30NANN00390	0.496	0.66	0.778	0.905	1.097	1.268	1.425	1.916
30NANN00384A	0.494	0.658	0.776	0.902	1.093	1.262	1.417	1.888
30NANN00384B	0.979	1.302	1.537	1.789	2.167	2.502	2.81	3.783
30NANN00379	0.977	1.3	1.534	1.786	2.164	2.498	2.805	3.773
30NANN00369	0.971	1.295	1.528	1.778	2.157	2.49	2.792	3.7
30NANN00359	0.965	1.289	1.521	1.77	2.149	2.482	2.778	3.657
30NANN00349	0.957	1.282	1.512	1.761	2.14	2.471	2.761	3.599
30NANN00339A	0.951	1.276	1.504	1.752	2.132	2.46	2.744	3.525
30NANN00339B	1.101	1.426	1.654	1.924	2.338	2.695	3.003	3.869
30NANN00329	1.096	1.421	1.647	1.916	2.331	2.686	2.989	3.818
30NANN00319	1.09	1.415	1.638	1.906	2.279	2.604	2.846	3.514
30NANN00309	1.087	1.41	1.631	1.899	2.273	3.02	3.952	4.616
30NANN00299	1.082	1.404	1.621	1.887	2.26	3.098	4.7	8.692
30NANN00289	1.079	1.399	1.614	1.877	2.251	3.096	4.7	9.616
30NANN00281	1.077	1.396	1.609	1.871	2.246	3.096	4.699	9.617
30NANN00279A	1.077	1.395	1.608	1.869	2.244	3.097	4.7	9.617
30NANN00279B	5.34	6.553	7.376	8.241	9.496	10.886	12.248	15.184
30NANN00274	5.341	6.554	7.376	8.242	9.497	10.885	12.249	15.185
30NANN00269	5.343	6.554	7.377	8.243	9.498	10.885	12.248	15.185
30NANN00269A	5.343	6.554	7.377	8.243	9.498	10.885	12.248	15.185
30NANN00267B	5.343	6.555	7.377	8.243	9.498	10.885	12.249	15.185
30NANN00266	5.343	6.555	7.377	8.243	9.498	10.885	12.249	15.185
30NANN00265A	5.343	6.555	7.377	8.243	9.499	10.885	12.248	15.185

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30NANN00264B	5.344	6.555	7.377	8.244	9.499	10.884	12.248	15.185
30NANN00263	5.344	6.555	7.377	8.244	9.499	10.884	12.248	15.185
30NANN00259	5.347	6.557	7.377	8.246	9.502	10.884	12.248	15.185
30NANN00253	6.431	7.952	8.881	9.851	11.438	12.504	13.625	17.595
30NANN00253A	6.431	7.952	8.881	9.851	11.438	12.504	13.625	17.594
30NANN00253B	6.431	7.952	8.881	9.851	11.438	12.504	13.625	17.594
30NANN00251	6.431	7.952	8.881	9.851	11.438	12.504	13.625	17.595
30NANN00245	6.431	7.952	8.88	9.851	11.438	12.505	13.625	17.594
30NANN00239	6.431	7.952	8.88	9.851	11.438	12.504	13.625	17.593
30NANN00238A	6.431	7.952	8.88	9.851	11.438	12.504	13.625	17.593
30NANN00238B	6.431	7.952	8.88	9.851	11.438	12.504	13.625	17.593
30NANN00237	6.431	7.952	8.88	9.851	11.438	12.504	13.625	17.547
30NANN00235	6.431	7.952	8.88	9.851	11.438	12.504	13.625	17.593
30NANN00235A	6.431	7.952	8.88	9.851	11.438	12.504	13.625	17.593
30NANN00234B	6.431	7.952	8.88	9.851	11.438	12.504	13.625	17.593
30NANN00233A	6.431	7.952	8.88	9.851	11.438	12.504	13.624	17.593
30NANN00233B	4.299	5.108	5.604	6.108	7.074	7.747	8.468	10.999
30NANN00232A	4.299	5.108	5.604	6.108	7.074	7.747	8.468	10.999
30NANN00230J	4.299	5.108	5.604	6.108	7.074	7.747	8.468	10.999
30NANN00228A	4.299	5.108	5.604	6.11	7.074	7.747	8.468	10.999
30NANN00230B	2.132	2.844	3.276	3.742	4.364	4.757	5.156	6.594
30NANN00229A	2.132	2.844	3.276	3.745	4.364	4.757	5.156	6.594
30NANN00228B	6.431	7.952	8.88	9.854	11.438	12.504	13.624	17.592
30NANN00227A	6.431	7.952	8.88	9.851	11.438	12.504	13.624	17.592
30NANN00226B	6.431	7.952	8.88	9.851	11.438	12.504	13.624	17.592
30NANN00223	6.431	7.952	8.88	9.853	11.438	12.504	13.624	17.591
NANN002235A	6.431	7.952	8.88	9.846	11.38	12.394	13.441	17.041
NANN002235B	6.239	7.72	8.629	9.58	11.088	12.086	13.117	16.667
30NANN00223A	6.239	7.72	8.629	9.555	10.987	11.901	12.831	15.895
30NANN00222B	6.239	7.72	8.629	9.555	10.987	11.901	12.831	15.895
30NANN00222	6.239	7.72	8.629	9.562	11.023	11.994	12.983	16.275
30NANN00220A	6.239	7.72	8.629	9.562	11.033	12.007	13.004	16.35
30NANN00219B	6.239	7.72	8.629	9.562	11.033	12.007	13.004	16.35
30NANN00219	6.127	7.528	8.381	9.21	10.48	11.229	12.038	14.876
30NANN00218	6.127	7.528	8.381	9.214	10.494	11.242	12.062	14.651
30NANN00217A	6.127	7.528	8.381	9.213	10.496	11.245	12.062	14.032
30NANN00217B	6.631	8.152	9.08	10.04	11.598	12.639	13.729	16.606
30NANN00215	6.631	8.152	9.08	10.045	11.605	12.649	13.746	17.271
30NANN00213	6.631	8.152	9.08	10.043	11.607	12.651	13.745	17.373
30NANN00213A	6.631	8.152	9.08	10.043	11.606	12.656	13.649	15.244
30NANN00213B	6.631	8.152	9.08	10.043	11.606	12.656	13.649	15.244
30NANN00211	6.631	8.152	9.08	10.043	11.607	12.645	13.65	15.18
30NANN00208	6.631	8.152	9.08	10.049	11.649	12.717	13.753	15.922
30NANN00205	6.631	8.152	9.08	10.048	11.651	12.715	13.812	17.208
30NANN00204A	6.631	8.152	9.08	10.048	11.65	12.715	13.812	17.561
30NANN00203B	6.631	8.166	9.08	10.048	11.65	12.715	13.812	17.561
30NANN00202	6.631	8.176	9.08	10.049	11.651	12.716	13.812	17.563
30NANN00195	6.632	8.239	9.08	10.048	11.651	12.716	13.813	17.544
30NANN00190	6.632	8.247	9.072	10.046	11.171	12.011	12.803	14.62
30NANN00181	6.633	8.251	9.072	9.923	11.856	12.906	14.006	16.651
30NANN00179	6.633	8.253	9.032	9.373	9.52	9.571	10.447	13.257
30NANN00178A	6.633	8.256	9.033	9.345	9.438	9.278	9.282	9.309
30NANN00178B	6.633	8.256	9.033	9.345	9.438	9.278	9.282	9.309
30NANN00176	6.633	8.26	9.064	9.577	9.75	9.666	9.699	11.569
30NANN00174	6.634	8.266	9.066	9.594	9.842	10.567	11.33	12.402
30NANN00172A	6.635	8.262	9.067	10.019	11.568	12.666	13.865	17.203
30NANN00172B	6.635	8.262	9.067	10.019	11.568	12.666	13.865	17.203
30NANN00168	6.636	8.264	9.068	10.02	11.574	12.67	13.869	17.207

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30NANN00161	7.162	8.931	9.866	10.868	12.384	13.433	14.529	16.16
30NANN00153	7.161	8.966	9.863	10.867	12.595	13.83	15.162	18.602
30NANN00151	7.161	8.969	9.863	10.866	12.591	13.821	15.159	18.69
30NANN00150A	7.161	8.963	9.863	10.867	12.593	13.828	15.161	18.69
30NANN00150B	7.161	8.963	9.863	10.867	12.593	13.828	15.161	18.69
30NANN00148	7.161	8.952	9.862	10.866	12.591	13.833	15.159	18.689
30NANN00146	7.161	8.896	9.861	10.866	12.591	13.83	15.158	18.689
30NANN00138	7.16	8.887	9.857	10.865	12.585	13.823	15.156	18.686
30NANN00131	7.158	8.792	9.655	10.596	12.144	13.183	14.296	17.09
30NANN00123	7.156	8.765	9.413	10.134	11.32	12.074	12.918	14.991
30NANN00116	7.155	8.893	9.714	10.508	11.595	12.253	13.045	14.842
30NANN00108	7.153	8.792	9.617	10.485	11.742	12.332	12.757	13.55
30NANN00101	7.151	8.844	9.698	10.39	11.102	11.503	11.826	12.283
30NANN00093	7.15	8.831	9.775	10.693	12.097	12.877	13.434	14.147
30NANN00086	7.15	8.845	9.772	10.608	11.905	12.66	13.321	14.226
30NANN00078	7.149	8.755	9.764	10.614	11.82	12.401	12.864	13.593
30NANN00071	7.15	8.749	9.755	10.546	11.611	12.081	12.43	13.003
30NANN00063	7.15	8.733	9.769	10.612	11.562	11.825	12.06	12.381
30NANN00056	7.152	8.736	9.758	10.575	11.24	11.346	11.391	11.46
30NANN00048A	7.154	8.744	9.733	10.558	11.585	11.779	11.678	11.627
30NANN00048B	7.154	8.744	9.733	10.558	11.585	11.779	11.678	11.627
30NANN00041	7.664	9.386	10.461	11.235	12.032	12.278	12.442	12.722
30NANN00034	7.662	9.377	10.412	11.073	11.481	11.6	11.68	11.832
30NANN00026	7.661	9.373	10.429	11.286	12.562	13.353	13.576	13.719
30NANN00018	7.66	9.375	10.428	11.285	12.561	13.515	14.098	14.263
30NANN00013	7.659	9.378	10.427	11.285	12.561	13.562	14.773	17.135
30NANN00008	7.659	9.376	10.427	11.285	12.56	13.56	14.75	17.451
30NANN00004	7.659	9.373	10.427	11.285	12.56	13.56	14.772	17.921
30NANN00002D	7.659	9.374	10.427	11.285	12.56	13.56	14.771	17.921
30TRAC00005	0.192	0.232	0.251	0.266	0.292	0.308	0.324	0.375
30TRAC00004A	0.192	0.232	0.251	0.274	0.349	0.415	0.499	0.902
30TRAC00003B	0.392	0.432	0.451	0.474	0.549	0.615	0.7	1.102
TRAC00044A	0.392	0.432	0.451	0.474	0.549	0.615	0.699	1.102
TRAC00044B	0.392	0.432	0.451	0.474	0.549	0.615	0.699	1.102
30TRAC00002	0.392	0.432	0.451	0.474	0.549	0.615	0.7	1.102
TRAC000034A	0.392	0.432	0.451	0.475	0.549	0.615	0.7	1.102
TRAC000028B	0.392	0.432	0.451	0.475	0.549	0.615	0.7	1.102
30TRAC00001	0.504	0.623	0.699	0.828	1.102	1.393	1.667	2.575
30TRAC00000	0.504	0.623	0.699	0.828	1.102	1.394	1.667	2.574
30LNAR00055	0.487	0.647	0.764	0.89	1.079	1.245	1.402	1.907
30LNAR00054A	0.487	0.647	0.764	0.89	1.079	1.245	1.402	1.907
30LNAR00053B	0.487	0.647	0.764	0.89	1.079	1.245	1.402	1.907
30LNAR00052	0.487	0.647	0.764	0.89	1.079	1.245	1.402	1.907
30LNAR00043	0.487	0.647	0.764	0.89	1.079	1.244	1.401	1.906
30LNAR00033	0.487	0.646	0.763	0.889	1.078	1.244	1.401	1.905
30LNAR00023	0.486	0.646	0.763	0.889	1.077	1.243	1.4	1.905
30LNAR00013	0.486	0.646	0.763	0.888	1.077	1.243	1.4	1.904
30LNAR00009	0.486	0.646	0.763	0.888	1.077	1.243	1.4	1.904
30LNAR00008	0.486	0.646	0.763	0.888	1.077	1.243	1.4	1.904
30LNAR00008A	0.486	0.646	0.763	0.888	1.077	1.243	1.4	1.904
30LNAR00007B	0.486	0.646	0.763	0.888	1.077	1.243	1.4	1.904
30LNAR00007	0.486	0.646	0.763	0.888	1.077	1.243	1.4	1.904
30LNAR00003	0.486	0.645	0.762	0.888	1.076	1.242	1.399	1.901
30LNAR00000	0.485	0.645	0.761	0.886	1.075	1.24	1.396	1.896
30DEER00296	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
30DEER00291	0.504	0.505	0.506	0.507	0.51	0.51	0.511	0.687
30DEER00287	0.507	0.509	0.511	0.512	0.515	0.517	0.518	0.694
30DEER00281	0.512	0.515	0.518	0.52	0.524	0.526	0.529	0.705

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30DEER00277	0.516	0.521	0.524	0.527	0.531	0.535	0.538	0.714
30DEER00272	0.519	0.525	0.529	0.533	0.538	0.543	0.547	0.721
30DEER00266	0.523	0.53	0.534	0.539	0.545	0.55	0.555	0.73
30DEER00259	0.528	0.537	0.542	0.548	0.555	0.561	0.568	0.744
30DEER00256	0.531	0.541	0.547	0.553	0.561	0.568	0.577	0.751
30DEER00253	0.534	0.544	0.551	0.557	0.566	0.573	0.581	0.757
30DEER00252A	0.535	0.545	0.552	0.558	0.567	0.575	0.583	0.758
30DEER00252B	0.535	0.546	0.552	0.559	0.568	0.576	0.584	0.759
30DEER00251	0.535	0.546	0.552	0.559	0.568	0.576	0.584	0.759
30DEER00246	0.538	0.55	0.557	0.564	0.574	0.582	0.591	0.766
30DEER00241	0.543	0.556	0.564	0.572	0.584	0.594	0.607	0.818
30DEER00236	0.551	0.567	0.577	0.587	0.602	0.616	0.635	0.857
30DEER00235A	0.552	0.568	0.578	0.588	0.604	0.617	0.637	0.858
30DEER00234B	0.553	0.569	0.579	0.589	0.605	0.618	0.638	0.859
30DEER00233	0.553	0.57	0.58	0.59	0.605	0.619	0.64	0.861
30DEER00232	0.555	0.571	0.581	0.592	0.607	0.621	0.641	0.862
30DEER00231A	0.555	0.572	0.582	0.592	0.608	0.622	0.642	0.863
30DEER00231B	0.555	0.572	0.582	0.592	0.608	0.622	0.642	0.863
30DEER00230	0.556	0.573	0.583	0.595	0.611	0.623	0.643	0.865
30DEER00225	0.561	0.58	0.591	0.602	0.619	0.634	0.653	0.876
30DEER00221	3.839	4.852	5.557	6.294	7.359	8.267	9.283	11.99
30DEER00213	3.839	4.851	5.557	6.293	7.358	8.266	9.282	11.99
30DEER00203	3.839	4.852	5.557	6.294	7.359	8.267	9.283	11.99
30DEER00196	3.839	4.851	5.557	6.293	7.358	8.266	9.282	11.99
30DEER00191	3.84	4.852	5.557	6.294	7.359	8.267	9.283	11.991
30DEER00184	3.84	4.852	5.557	6.294	7.345	8.185	9.033	10.83
30DEER00174	3.84	4.853	5.558	6.295	7.361	8.269	9.285	11.993
30DEER00167	4.02	5.08	5.82	6.59	7.702	8.655	9.721	12.61
30DEER00159	4.02	5.081	5.815	6.588	7.704	8.654	9.689	12.328
30DEER00155	4.02	5.053	5.756	6.515	7.589	8.529	9.574	12.358
30DEER00155A	4.003	4.72	5.18	5.628	6.2	6.673	7.205	8.322
30DEER00154B	3.929	4.633	5.084	5.526	6.09	6.558	7.104	8.225
DEER001531A	3.946	4.87	5.461	6.01	6.661	7.165	7.104	8.225
DEER001531B	4.02	4.957	5.556	6.112	6.772	7.281	7.205	8.322
30DEER00153A	4.02	4.958	5.556	6.081	6.629	6.941	7.205	8.322
30DEER00152B	4.02	4.958	5.556	6.081	6.629	6.941	7.205	8.322
30DEER00145	4.02	5.077	5.77	6.134	6.171	6.179	6.238	7.352
30DEER00138	4.02	5.077	5.806	6.547	7.618	8.522	9.717	12.507
30DEER00129A	4.02	5.077	5.806	6.547	7.619	8.523	9.765	11.337
30DEER00129B	4.02	5.077	5.806	6.547	7.619	8.523	9.765	11.337
30DEER00122	4.02	5.077	5.807	6.548	7.62	8.522	9.766	11.332
30DEER00114	4.198	5.303	6.063	6.838	7.952	8.902	10.079	11.046
30DEER00107A	4.198	5.303	6.063	6.838	7.952	8.898	9.839	10.976
30DEER00107B	4.198	5.303	6.063	6.838	7.952	8.898	9.839	10.976
30DEER00099	4.198	5.303	6.063	6.838	7.95	8.899	9.838	12.716
30DEER00096	4.198	5.303	6.063	6.838	7.947	8.898	9.838	12.715
30DEER00084	4.198	5.303	6.063	6.83	7.75	8.525	9.392	11.93
30DEER00075	4.198	5.303	6.063	6.83	7.938	8.892	9.836	12.711
30DEER00068	4.198	5.303	6.063	6.83	7.938	8.893	9.836	12.713
30DEER00062	4.198	5.303	6.063	6.83	7.938	8.895	9.836	12.711
30DEER00056	4.379	5.532	6.326	7.127	8.262	9.271	10.167	12.723
30DEER00055A	4.379	5.532	6.326	7.127	8.261	9.153	9.288	9.389
30DEER00054B	4.379	5.532	6.326	7.127	8.261	9.153	9.288	9.389
30DEER00053	4.379	5.532	6.326	7.127	8.262	9.153	9.286	9.389
30DEER00049	4.379	5.532	6.326	7.127	8.26	9.255	9.792	11.061
30DEER00042	4.379	5.532	6.326	7.126	8.262	9.266	10.194	13.169
30DEER00039	4.379	5.532	6.325	7.019	7.992	8.849	9.655	12.107
30DEER00035	4.379	5.532	6.325	7.092	8.018	8.783	9.49	12.056

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30DEER00031	4.379	5.532	6.32	6.955	7.515	7.85	8.11	9.547
30DEER00025	3.287	3.613	3.701	3.748	3.802	5.008	5.825	7.269
30DEER00010	3.211	3.235	3.246	3.256	3.265	3.271	3.279	3.295
30DEER00001A	4.298	5.291	5.977	6.666	7.408	7.793	7.743	7.538
30DEER00001B	4.297	5.291	5.977	6.666	7.409	7.795	7.745	7.54
30DEER00000	4.297	5.291	5.977	6.666	7.409	7.794	7.745	7.541

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30SUIL00365	0.18	0.18	0.18	0.1	0.1	0.1	0.1	0.1
30SUIL00355	0.18	0.18	0.18	0.111	0.107	0.108	0.108	0.106
30SUIL00349	0.179	0.179	0.179	0.108	0.109	0.142	0.113	0.101
SUIL003488A	0.179	0.179	0.179	0.106	0.107	0.147	0.113	0.101
SUIL003485B	0.179	0.179	0.179	0.106	0.107	0.147	0.113	0.101
30SUIL00347	0.179	0.179	0.179	0.105	0.117	0.148	0.113	0.105
30SUIL00338	0.174	0.174	0.174	0.116	0.116	0.123	0.142	0.116
30SUIL00331	0.17	0.17	0.17	0.11	0.115	0.133	0.168	76.54
30SUIL00323	0.165	0.165	0.165	0.113	0.119	0.142	0.212	44.136
30SUIL00317	0.162	0.161	0.161	0.115	0.122	0.127	0.114	30.306
30SUIL00310	0.153	0.153	0.153	0.118	0.131	0.175	0.249	22.599
30SUIL00302	0.147	0.146	0.147	0.12	0.135	0.173	0.252	18.31
30SUIL00298	0.143	0.141	0.142	0.121	0.136	0.185	0.254	13.133
30SUIL00297A	0.141	0.14	0.14	0.122	0.131	0.161	0.254	0.641
30SUIL00295B	0.141	0.14	0.14	0.122	0.131	0.161	0.254	0.641
30SUIL00294	0.509	0.51	0.509	0.152	0.168	0.18	0.274	0.125
30SUIL00290	0.504	0.511	0.504	0.158	0.162	0.182	0.277	0.126
30SUIL00283	0.494	0.494	0.494	0.161	0.171	0.259	0.291	0.126
30SUIL00275	0.485	0.485	0.485	0.165	0.202	0.324	0.338	0.127
30SUIL00265	0.472	0.471	0.471	0.162	0.232	0.403	0.58	0.127
30SUIL00257	0.467	0.473	0.469	0.174	0.242	0.433	0.67	4.578
30SUIL00250	0.447	0.45	0.449	0.164	0.391	0.783	0.941	8.15
30SUIL00242A	0.434	0.434	0.434	0.178	0.438	0.875	1.1	22.949
30SUIL00242B	1.237	1.237	1.237	0.378	0.638	1.075	1.3	23.149
30SUIL00235	1.233	1.233	1.233	0.375	0.656	1.121	1.351	0.327
30SUIL00227	1.23	1.23	1.23	0.39	0.702	1.284	1.851	0.327
30SUIL00220	1.227	1.227	1.227	0.394	0.724	1.278	1.844	0.327
30SUIL00212	1.224	1.224	1.224	0.412	0.744	1.296	1.85	0.326
30SUIL00205	1.221	1.221	1.221	0.41	0.781	1.36	1.912	0.323
30SUIL00197	1.219	1.219	1.219	0.42	0.776	1.371	1.938	0.321
30SUIL00190	1.317	1.317	1.317	0.527	0.848	1.36	1.809	0.42
30SUIL00182	1.315	1.315	1.315	0.527	0.842	1.309	1.69	0.419
30SUIL00174	1.314	1.314	1.314	0.528	0.909	1.547	2.139	49.483
30SUIL00166	1.314	1.314	1.314	0.528	0.952	1.743	2.613	25.89
30SUIL00159	1.314	1.314	1.314	0.521	0.97	1.746	2.77	22.001
30SUIL00158A	1.314	1.314	1.314	0.514	0.953	1.746	2.769	6.753
30SUIL00157B	1.314	1.314	1.314	0.522	0.958	1.746	2.769	6.753
30SUIL00156	1.314	1.314	1.314	0.516	0.955	1.747	2.77	4.727
30SUIL00150	1.313	1.313	1.313	0.521	0.959	1.749	2.773	8.376
30SUIL00142	1.313	1.313	1.313	0.528	0.968	1.754	2.78	0.419
30SUIL00134	1.312	1.312	1.312	0.534	0.96	1.756	2.786	0.419
30SUIL00115	1.31	1.31	1.31	0.548	0.988	1.818	3.003	0.42
30SUIL00092	1.307	1.307	1.308	0.557	0.996	1.841	3.024	0.423
30SUIL00072	1.306	1.306	1.306	0.571	1.002	1.853	3.037	0.426
30SUIL00052A	1.513	1.514	1.514	0.618	1.046	1.892	3.083	0.46
30SUIL00052	1.513	1.514	1.514	0.618	1.046	1.892	3.083	0.46
30SUIL00032A	1.513	1.514	1.514	0.641	1.071	1.913	3.11	0.461
30SUIL00032	1.513	1.514	1.514	0.641	1.071	1.913	3.11	0.461

Cross Section	Peak Flow in Model (m3/s)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
30SUIL00013A	1.513	1.516	1.514	0.673	1.078	1.938	3.138	0.468
30SUIL00013	1.513	1.516	1.514	0.673	1.078	1.938	3.138	0.468
30SUIL00000	1.513	1.519	1.514	0.695	1.107	1.954	3.154	0.467

A.2 HEP flows

Table A-3: Current peak flows at HEPs

HEP Reference	Cross Section	Peak Flow in Model (m3/s)								Comments (note: where blank, no changes have been made)
		50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	
TNP_002	30NANN00429	0.419	0.557	0.657	0.766	0.929	1.072	1.206	1.641	FSR hydrograph scaled to match design flows.
NAN_002	30LNAR00055	0.405	0.539	0.637	0.741	0.899	1.038	1.168	1.589	FSR hydrograph scaled to match design flows.
NAN_006	30NANN00274									HEP downstream of Deerpark tributary. Increase in flows attributable the Deerpark tributary and a lateral inflow on the Nanny at 30NANN000339B. Lateral inflow estimated as the difference between NAN_004 and NAN_005.
		4.471	5.623	6.318	7.035	8.086	8.981	10.028	13.446	
NAN_007	30NANN00048B									Lateral inflow at distributed between 30NANN00259 and 30NANN00048B. Lateral inflow estimated as the difference between NAN_006 and NAN_007.
		5.958	7.39	8.345	9.17	10.239	10.986	11.682	11.69	
DRP_001	30DEER00213	3.193	4.035	4.622	5.234	6.124	6.849	7.721	10.426	FSR hydrograph scaled to match design flows and applied between 30DEER00296 and 30DEER00246.
DRP_002	30DEER00042									Lateral inflow at distributed between 30DEER00225 and 30DEER00062. Lateral inflow estimated as the difference between DRP_001 and DRP_002.
		3.633	4.593	5.262	5.951	6.932	7.715	8.664	11.575	
SUL_002	30SUIL00365	0.1	0.18	0.18	0.18	0.1	0.1	0.1	0.1	FSR hydrograph scaled to match design flows.
SUL_003	30SUIL00265	0.123	0.474	0.482	0.482	0.158	0.176	0.284	0.633	FSR hydrograph scaled to match design flows.
SUL_004	30SUIL00227	0.319	1.23	1.245	1.245	0.384	0.405	0.874	1.925	FSR hydrograph scaled to match design flows on incoming tributary.
SUL_005	30SUIL00197	0.419	1.317	1.335	1.335	0.506	0.542	0.979	2.122	Lateral inflow at 30SUIL00197. Lateral inflow estimated as the difference between SUL_004 and SUL_005.
SUL_008	30SUIL00072	0.433	1.306	1.325	1.325	0.57	0.613	1.255	4.483	Lateral inflow at 30SUIL00197. Lateral inflow estimated as the difference between SUL_007 and SUL_008.
CLR_006	30CLAR04624	58.96	72.30	81.83	91.97	107.00	119.98	134.05	179.18	FSR hydrograph scaled to match design flows at CLR_008.
CLR_008	30CLAR04247	58.18	71.30	78.94	89.64	103.57	115.91	129.50	175.36	
CLR_010	30CLAR04076									Lateral inflow at 30CLAR04087. Inflow estimated by subtracting the resulting 1D flow from the required scaled design hydrograph at CLR_010.
		64.08	77.55	84.13	95.87	109.48	121.36	133.87	174.53	
CLR_011	30CLAR03849	63.82	76.58	83.88	94.89	108.87	120.60	132.67	185.33	Downstream limit of 1D model. No additional flows added to this HEP.

Table A-4: MRFS peak flows at HEPs

HEP Reference	Cross Section	Peak Flow in Model (m3/s)								Comments (note: where blank, no changes have been made)
		50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	
TNP_002	30NANN00429	0.502	0.668	0.789	0.919	1.115	1.286	1.448	1.97	FSR hydrograph scaled to match design flows.

HEP Reference	Cross Section	Peak Flow in Model (m3/s)								Comments (note: where blank, no changes have been made)
		50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	
NAN_002	30LNAR00055	0.487	0.647	0.764	0.89	1.079	1.245	1.402	1.907	FSR hydrograph scaled to match design flows.
NAN_006	30NANN00274									HEP downstream of Deeppark tributary. Increase in flows attributable the Deeppark tributary and a lateral inflow on the Nanny at 30NANN000339B. Lateral inflow estimated as the difference between NAN_004 and NAN_005.
		5.341	6.554	7.376	8.242	9.497	10.885	12.249	15.185	
NAN_007	30NANN00048B									Lateral inflow at distributed between 30NANN00259 and 30NANN00048B. Lateral inflow estimated as the difference between NAN_006 and NAN_007.
		7.154	8.744	9.733	10.558	11.585	11.779	11.678	11.627	
DRP_001	30DEER00213	3.839	4.851	5.557	6.293	7.358	8.266	9.282	11.99	FSR hydrograph scaled to match design flows and applied between 30DEER00296 and 30DEER00246.
DRP_002	30DEER00042									Lateral inflow at distributed between 30DEER00225 and 30DEER00062. Lateral inflow estimated as the difference between DRP_001 and DRP_002.
		4.379	5.532	6.326	7.126	8.262	9.266	10.194	13.169	
SUL_002	30SUIL00365	0.18	0.18	0.18	0.1	0.1	0.1	0.1	0.1	FSR hydrograph scaled to match design flows.
SUL_003	30SUIL00265	0.472	0.471	0.471	0.162	0.232	0.403	0.58	0.127	FSR hydrograph scaled to match design flows.
SUL_004	30SUIL00227	1.23	1.23	1.23	0.39	0.702	1.284	1.851	0.327	FSR hydrograph scaled to match design flows on incoming tributary.
SUL_005	30SUIL00197	1.219	1.219	1.219	0.42	0.776	1.371	1.938	0.321	Lateral inflow at 30SUIL00197. Lateral inflow estimated as the difference between SUL_004 and SUL_005.
SUL_008	30SUIL00072									Lateral inflow at 30SUIL00197. Lateral inflow estimated as the difference between SUL_007 and SUL_008.
		1.306	1.306	1.306	0.571	1.002	1.853	3.037	0.426	
CLR_006	30CLAR04624	70.86	86.89	98.34	110.53	128.59	144.19	161.10	215.34	FSR hydrograph scaled to match design flows at CLR_008.
CLR_008	30CLAR04247	70.15	84.39	95.97	106.80	124.46	140.64	157.21	216.36	
CLR_010	30CLAR04076									Lateral inflow at 30CLAR04087. Inflow estimated by subtracting the resulting 1D flow from the required scaled design hydrograph at CLR_010.
		76.51	90.33	101.86	112.82	129.78	141.57	156.50	199.21	
CLR_011	30CLAR03849	75.30	89.68	100.84	112.03	128.63	145.24	164.86	223.06	Downstream limit of 1D model. No additional flows added to this HEP.



Registered Office

**24 Grove Island
Corbally
Limerick
Ireland**

T: +353 (0) 61 345463
e: info@jbaconsulting.com

**JBA Consulting Engineers and
Scientists Limited**

Registration number 444752

Visit our website
www.jbaconsulting.com