River Deel (Crossmolina) Drainage Scheme

Hydrology & Hydraulics Report Update

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Revision History

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v0.3 / Internal QA		Tim Cook, JBA
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v2.0 / Final Report	Updates following Ryan Hanley Review	Jonathan Reid, Ryan Hanley
V3.0 / Final Report	Further updates following Ryan Hanley Review	Jonathan Reid, Ryan Hanley
V4.0 / Final Report	Updated report to refer to detailed inlet structure modelling	Jonathan Reid, Ryan Hanley

Contract

This report describes work commissioned by Ryan Hanley, on behalf of The Office of Public Works, by a letter dated 18/05/2012. OPW's representative for the contract was Jonathan Reid of Ryan Hanley. Tom Sampson and Rosalie Scanlon of JBA Consulting carried out this work.

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Purpose

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1 Introduction

1.1 Watercourse and catchment overview

Crossmolina town is located on the River Deel, which is a tributary of the Moy that flows from the west to Lough Conn. The River Deel catchment covers an area of approximately 155km^2 upstream of Crossmolina. The catchment area of the River Deel is predominantly rural, with some urban development in Crossmolina town and environs. The upstream boundary of the model is located approximately 1km upstream of Ballycarroon gauge with the watercourse flowing through Crossmolina town. There are two tributaries downstream of the town, which are outside the scope of this study, and the downstream extent comprises a stage-time boundary where the River Deel flows into Lough Conn. Modelling of the lake water levels has shown them to have no effect on levels in the town, but do affect water levels at the Environmental Protection Agency (EPA) operated Knockdangan gauge some 6km downstream of Crossmolina. The general slope of the river is 5.54m/km. The river channel bed is made up of Visean Limestone and Calcareous Shale. There is one key hydraulic structure, the Jack Garrett Bridge in the centre of the town, which has been overtopped during past flood events. Figure 1-1 shows the catchment overview of the River Deel at Crossmolina.

A more detailed description of the River Deel catchment can be found in Section 2 of the OPW Feasibility Report on the Crossmolina Flooding Problem[1].

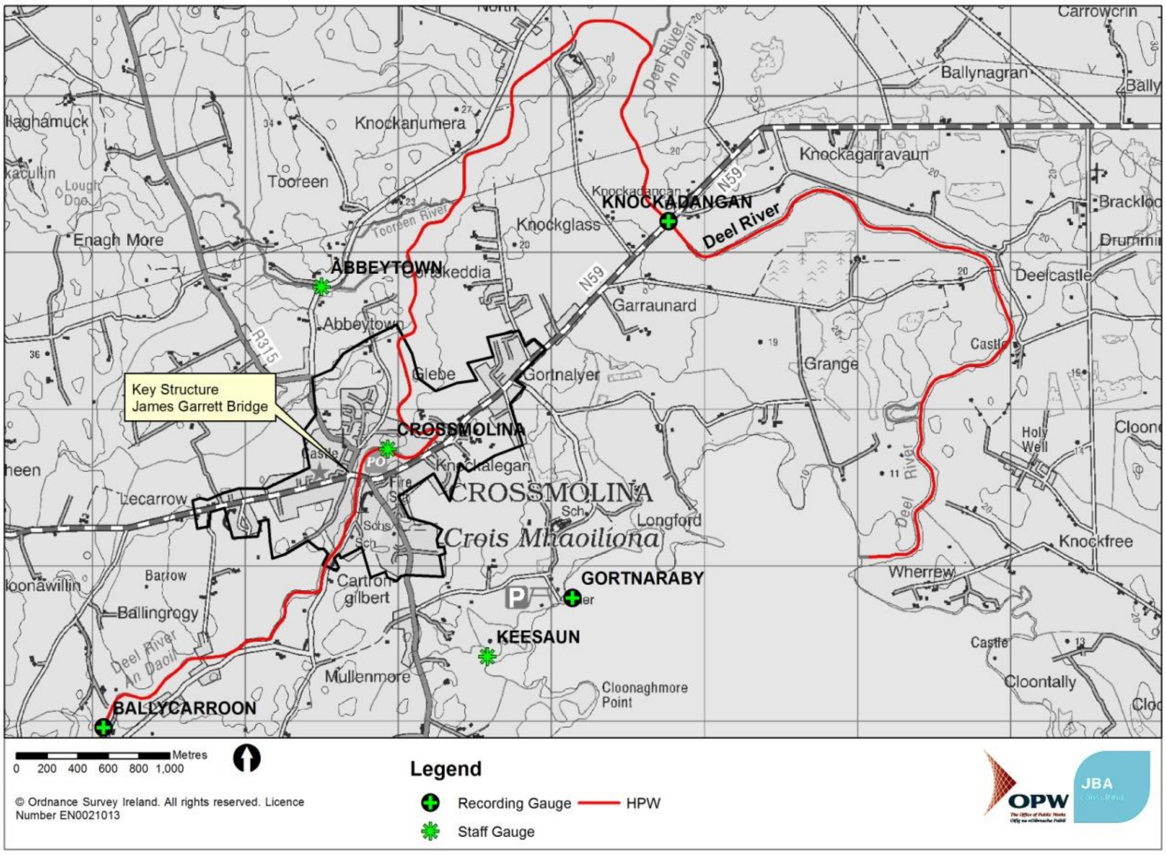


Figure 1-1. Crossmolina catchment overview

1.2 Aim of the Study

The Office of Public Works (OPW) commissioned Ryan Hanley, along with sub-consultants JBA Consulting, to undertake a Flood Relief Scheme Study in Crossmolina, County Mayo. Significant flood risk exists in Crossmolina from the River Deel, as evidenced by the floods in December and November 2015, October 1989 and December 2006. The official scheme name is the River Deel (Crossmolina) Drainage Scheme.

1 2092/RP/001/A (January 2012) - Feasibility Report on the Crossmolina Flooding Problem, OPW

The study being carried out follows on from the "Feasibility Report on the Crossmolina Flooding Problem" carried out by the OPW Design Section in January 2012, which produced a number of outline designs for the River Deel Flood Relief Scheme.

Through 1D-2D linked hydraulic modelling of the River Deel at Crossmolina, this study derives flood extent and depth maps for the 50%, 20%, 10%, 5%, 2%, 1%, 1% plus climate change, 0.5% and 0.1% AEP events. The model has been calibrated to the 2006, 1989 and 2015 (November and December) flood events. A number of flood relief options are considered in the hydraulic assessment and their hydraulic impact simulated.

1.3 Scope of report

This report summarises the hydrological and hydraulic modelling work for the Crossmolina hydraulic model. This document is specific to Crossmolina itself and should be read in conjunction with the generic Hydrology and Hydraulic Model Development Reports, which have been produced for the Western CFRAM. This report is an update on previously issued hydrology and hydraulics reports to take account of development and refinement of the proposed scheme.

1.3.1 Hydrology

Estimates of flood flows have been updated since the initial options appraisal to take account of recent spot flow gauging and recent flood events. The recent hydrometric data has been used to review the stage-discharge rating relationship at hydrometric gauges and to refine the model calibration.

1.3.2 Hydraulics

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.

1.3.3 Options Appraisal

A number of options for flood alleviation schemes have been hydraulically modelled and appraised. The options are informed by those identified in the Feasibility Report and include containment, dredging, upstream storage, diversion channels and a hybrid approach using a number of elements. The report also documents the testing of flood risk management options using the hydraulic model to simulate design options.

1.4 Available data

1.4.1 Survey data

Cross sectional survey was collected by Murphy Surveys as part of the Western CFRAM Survey Contract No. 2 and was delivered in May 2013. River survey from previous projects has also been used in the Crossmolina Flood Relief Scheme. The OPW provided river survey recorded in January 2009, as well as the 1960s Moy Catchment Arterial Drainage Scheme drawings of the River Deel. The abbreviated version of each watercourse name as represented in the hydraulic models is detailed in Table 1-1.

Table 1-1. Abbreviated watercourse names

Reference	Description
DEEL	River Deel

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 supplied to JBA in 2013, having been flown by FugroBKS in 2012.

Ryan Hanley undertook infill spot surveys of the washlands outside of the LiDAR data coverage.

Habitat mapping of the washlands has been supplied by McCarthy Keville O'Sullivan.

1.4.2 Hydrometric data

A summary of hydrometric data within Crossmolina Town and Environs 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
34007	Ballycarroon	Active recorder (OPW)	Rating review calibrated to gaugings. Primary calibration location.
34051	Crossmolina	Inactive Staff gauge (EPA)	Stage records from Feb. 1993 to July 1999.
34029	Knockdangan	Active recorder (EPA)	Flow and water levels recorded from April 1997 to current day. During high flows, water levels from Lough Conn affect this gauge.
34082	Gortnaraby	Active water level recorder (OPW)	This is the closest WL gauge in Lough Conn. Useful for determining if lake water levels affect levels in Crossmolina.

As part of the study a review of the rating curve at Ballycarroon gauge has been completed. Full details of this review are detailed in Section 3 of this report and are discussed more generally in the Western CFRAM Hydrology Report for UoM 34.

1.4.3 Previous Studies

In January 2012 the OPW published the "Feasibility Report on the Crossmolina Flood Problem", which Mayo County Council had requested in order to investigate feasibility and prepare outline design of a flood relief scheme in Crossmolina town to reduce the flooding problems caused by the River Deel. Flood flow analysis using the Flood Studies Report (FSR) was undertaken, as well as the development of a HEC-RAS 1D model for the feasibility report, which was calibrated using 2006 flood water levels at locations throughout the town. The same water levels were used to calibrate the 1D-2D linked ISIS-TUFLOW model for this study. Three potential solutions were proposed in the OPW feasibility report, which include the do nothing approach; a 2.2km long flood-diversion channel upstream of the town to Lough Conn, which would requires 3 new road bridges and an access bridge; and a flood containment option that includes defence walls, local alleviation measures and underpinning of the Jack Garrett Bridge.

In April 2003 Hydro Environmental Ltd, who were commissioned by Ryan Hanley Consulting Engineers to investigate the hydrological impact of a rock gabion protected sewer pipeline laid downstream of Crossmolina Bridge, produced the report 'Hydraulic impact study of channel encroachment of the River Deel at Crossmolina'. The hydrological study involved collation of relevant hydrometric data, flood flow analysis and the development of a 1D HEC-RAS hydraulic model and performing model runs with and without the sewer pipe and associated work for various return periods and including the 1989 flood event. The key findings of this study show that the sewer pipe encroachment and associated works will increase the upstream flood level at Crossmolina by 0.022m for the 100 year flood event. Under flood conditions the flow depth in the river is large and thus, the reduction of cross-sectional area caused by the sewer encroachment was considered to have a minimal impact.

1.4.4 Flood History

Key flood risk areas have been identified in the OPW Feasibility Report and the CFRAM 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.

Within the Crossmolina, supporting flood history data is available for the 2015, 1989 and 2006 events.

Crossmolina flooded from the River Deel on the 14th November 2015 and on 5th December 2015. Both floods resulted in property flooding, with the December flood being the greatest flood on record in Crossmolina.

The 1989 flood event shows overtopping of the Jack Garrett Bridge with flooding along Church Street, Erris Street and Chapel Street, as well as flooding of the car park on the left bank upstream of the bridge. There seems to be an overland flow route on the left bank upstream of the car park also. On Chapel Street, there are individual houses and a housing estate site (constructed in 2006/ 2007) affected by flood waters.

The 2006 flood event does not overtop the Bridge, but there is significant flooding recorded along Chapel Street, Church Street and Erris Street as well as out of bank water levels in more rural land on the left bank upstream of the Bridge.

2 Hydraulic Modelling

2.1 Overview

A 1D-2D ISIS TUFLOW model has been constructed incorporating the Deel watercourse. This represents the baseline or existing scenario.

The model has been further developed to investigate flood relief options. This includes dredge only, dredge and wall, and diversion options. The dredge and wall options have considered different proposed bridge designs.

The diversion option has been developed as the preferred option and the hydraulic analysis undertaken is detailed in the following sections, along with information on the Baseline Model.

2.2 Model Extent

The 1D element of the model stretches from section 34DEEL01435 to 34DEEL00000, and the linked 1D-2D element covers an area from section 34DEEL01297 to 34DEEL00510A.

The diversion option model has been subject to detailed modelling. Refer to Appendix F - Diversion Channel Model Report for details.

The cross-section nodes and model domain are shown below in Figure 2-1. Note section 34DEEL01224B is an interpolated section between nodes 34DEEL01211 and 34DEEL01185. The final diversion channel option model only includes 1D model nodes and 2D domain for the River Deel downstream of the diversion channel.

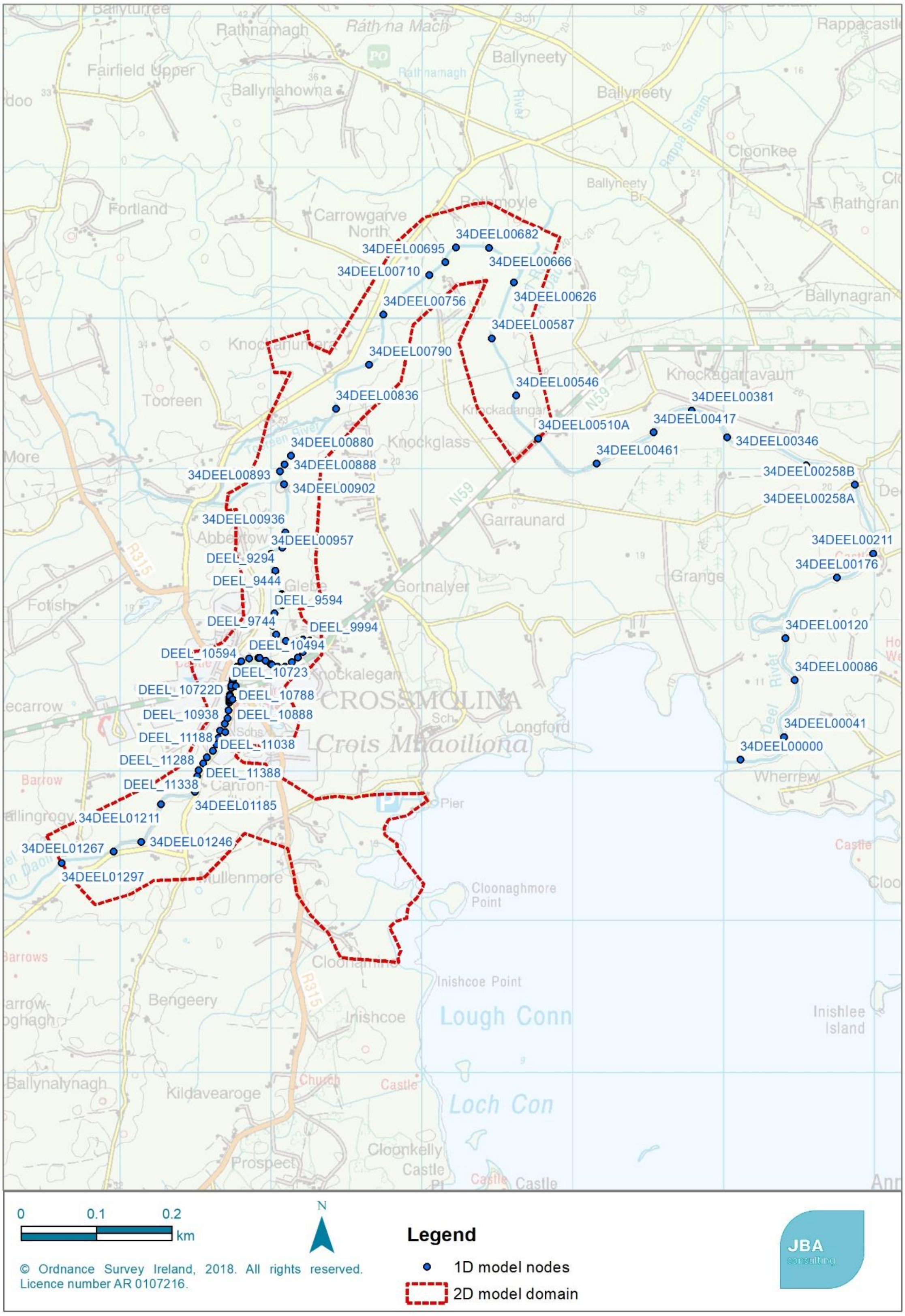


Figure 2-1. Model domain and river model nodes

2.3 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 (Baseline Model)

Structure Name	Description
Jack Garrett Bridge	The Jack Garrett Bridge is a two pier flat deck road bridge, with metal railings - the spill is over the deck level. This is the only road crossing of the River Deel in Crossmolina. The structure has been modelled as a USBPR (a bridge unit with methodology developed by the US Bureau of Public Roads). The 1D spill has been deactivated and it is modelled in the 2D domain.
	
Ford/ weir at Ballycarroon gauge	The stone ford/ weir acts as a control on water levels at the Ballycarroon gauge (34007). It comprises a stone river crossing at low flows with 3 no. 0.8m pipe culverts. This structure has been modelled as a USBPR and a spill with roughness to represent the natural stone crossing. Sensitivity tests have been completed in order to identify the most realistic way of representing this structure.

Structure Name	Description
	

2.4 Hydraulic roughness

Sections of river reach of similar hydraulic roughness have been identified from survey photos, drawings and site visits. In addition, the model has been calibrated against selected significant events (refer Section 3.3.1) and this has informed the roughness assigned to reaches of the modelled watercourse.

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.

2.5 Model boundaries

2.5.1 1D-2D boundary

Bank top survey data has been interpolated between cross section data as a minimum.

Throughout the model, bank top survey between cross sections was collected as part of the topographic survey (both old and new) and has been incorporated into the 1D-2D boundary.

2.5.2 Downstream model boundary

The lake levels at Lough Conn are used as the downstream model boundary and the model was simulated for a number of scenarios as follows.

- The maximum lake level recorded, which occurred in December 2015 and was surveyed at 11.6mOD. This level was obtained by Ryan Hanley following a post flood survey. Due to missing gauge data at Ryan Hanley contacted Irish Water to get a flood level at Wherrew WTP.
- The 95 percentile lake level, which was calculated as 8.536mOD from Gortnaraby gauge data.

The downstream boundary is located approximately 11km downstream of Jack Garrett Bridge. A sensitivity analysis of the downstream boundary confirms that the model results within the key area of interest (Crossmolina Town, Jack Garrett Bridge and location of proposed diversion) are not influenced by the downstream boundary. The baseline model has been simulated for all design events with a 95 percentile lake level as the downstream boundary. The 1% AEP event and climate change event have been included in the design model runs as a check.

2.6 Defences and walls

There are no formal or informal effective flood defences within Crossmolina.

Informal ineffective structures identified with the AFA are detailed in Table 2-2. There is one informal ineffective structure that has been included in the hydraulic model of the town. This structure contains flood waters to the crest of the structure generally, but there are gaps in the wall at certain important locations. These gaps have been included in the 1D-2D model.

2.7 Floodplain

A 2D cells size of 4m has been used so as to incorporate the required level of detail for this study and also to ensure appropriate model run times.

LIDAR was used to define the 2D model's base topography. The available LIDAR was flown in 2012 for the CFRAM project and cover the complete 2D domain for the River Deel Baseline Scenario model.

Additional survey, carried out by Ryan Hanley in August 2016 and March 2017 was incorporated into the model. (This included more detail on the washlands topography where LIDAR was limited or not available and was used primarily to inform the model geometry at the downstream end of the diversion option scenario model).

Table 2-2. Key flood defence structures

Description and Location	Modelling Method	Photograph
This structure is a natural stone wall extending from section 34DEEL01185 to DEEL_10722. There are two gaps in the wall to ground level at sections DEEL_1018 and DEEL_10723.	Gaps incorporated in wall	 Gap in wall at section DEEL_10723  Gap in wall at section DEEL_10818

		 Gap in wall at section DEEL_11038
Wall around public car park. It is unclear whether the wall would offer sufficient flood protection against flooding as it could be overtopped or unable to withstand the pressure of flood waters. An overland flow path for flood water is present in the baseline model and the effect of this wall on the flow path has not been modelled or mapped. It could influence water levels elsewhere.	Not included in model	 

3 Flow Gauging and Rating Review Update

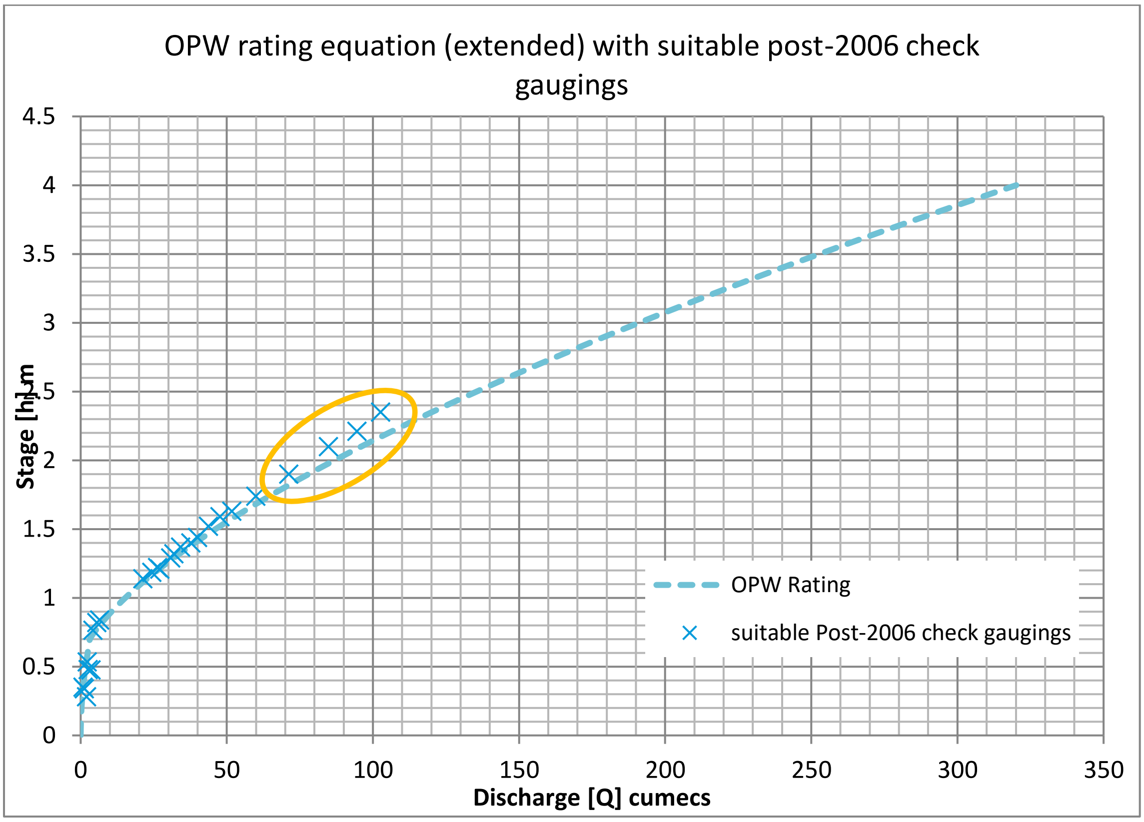
3.1 OPW Flow Gauging

The OPW hydrometric section undertook four flow gaugings at the Ballycarroon gauge (ref. 34007) and recorded the data presented in Table 3-1. An attempt to gauge the flow during the flooding in early December was considered but not possible for safety reasons. All of these flow gaugings are higher than previous flow measurements at the Ballycarroon gauge. Figure 3-1 plots all of the suitable post-2006 flow gaugings against the OPW rating curve for Ballycarroon. Suitable gaugings are defined as those taken at the gauge to provide a reliable reading. The recent flow gaugings are circled in orange and can be seen to be above the current OPW rating curve.

Table 3-1: OPW flow gaugings in 2015

Date	Stage (m above gauge datum)	Calculated Discharge (m^3/s)	OPW comments from database
12/09/2015	1.9	71.255	Recorded at the gauge. 800mm out of bank flow on left bank at gauge - mainly stagnant water and not included in flow gauging
15/11/2015	2.35	102.62	none
15/11/2015	2.21	94.5	none
15/11/2015	2.1	84.78	none

Figure 3-1: Flow gauging and OPW flow rating



3.2 Gauge Datum

Appendix A of the Draft Hydrology and Modelling Report (March 2014) discusses the surveyed levels for the gauge datum. OPW records have the gauge datum at 23.35 mOD Poolbeg. In the previous rating review JBA estimated the gauge datum at 20.65 mOD Malin by subtracting 2.7 from the Poolbeg datum. The topographic river survey carried out in July 2013 surveyed the gauge datum at 20.434 mOD Malin.

Recent correspondence in 2017 with the OPW Hydrometric Section has confirmed that the OPW is in the process of resurveying all stations to OD Malin and the datum for Ballycarroon is 20.569 mOD Malin. This recent survey takes precedence over other previous estimates of the gauge datum and is used in comparisons between the hydraulic models and gauge measurements.

The OPW hydrometric section have also clarified some confusion regarding the two gauge boards at the gauge location. Both are set to an identical datum and so any previous confusion concerning which gauge board was surveyed and which refers to recorded water levels can be dismissed.

3.3 Rating Review

In light of the recent flow measurements, including spot flow gaugings, by the OPW Hydrometric Section and the December 2015 flooding, JBA have revisited the rating review presented in the Draft Report[2]. There are 26 suitable flow gaugings for Ballycarroon gauge since 2006. All flow gaugings at Ballycarroon prior to 2006 are well below QMED and so of limited value in refining the rating curve for flood estimation purposes.

Previously in 2014 the highest gauged stage at Ballycarroon was 1.38m (above gauge datum). The four recent gaugings are all above this stage with the highest now being 2.35m (above gauge datum). Based on the information available at the time, the 2014 flood model calibrated well to the OPW rating curve and so there was no evidence to improve the flow-stage rating relationship. With the new flow measurements there was reason to suggest the OPW rating curve and model was overestimating flood flows (see Figure 3-1).

3.3.1 Model updates

In light of the new information available, JBA have undertaken a thorough review of the flood model and updated the model schematisation around the ford just downstream of the Ballycarroon gauge and adjusted roughness values in the constrained channel downstream of the ford.

The flow-stage rating relationship at Ballycarroon under flood conditions is controlled by the downstream channel geometry and its vegetated and rocky nature. The ford and pipe culverts through the ford are completely drowned out in flood conditions. Additional model cross sections were added to improve the resolution of the model in the vicinity of the ford following the photographs provided by OPW on the dead zones upstream of the gauged location. This change also resulted in a better representation of the river bed gradient between the gauge and the ford. The previous interpolated section resulted in a gradual slope in the river bed between the gauge location and the ford, which in reality is more of step change in bed level at the ford.

Manning's roughness values have been increased from the previous model to reflect the vegetation growth on the channel banks and rocky bed downstream and that the channel around the gauge is not maintained. The roughness values have been adjusted to result in a good fit to the recent flow measurements at Ballycarroon.

The flood model has been calibrated to match the measured flow and stage and average flow velocity across each model cross section. The hydraulic model does not explicitly model the inactive flow area but represents its influence through the calibration of the model.

Further downstream through the town of Crossmolina Manning's roughness values have also been increased to reflect the vegetation growth and lack of maintenance. The adjustments are based on recent observations during site visits by JBA for this and other projects. All roughness values remain within expected range of values for the vegetation and channel type.

Table 3-2 presents the previous and updated Manning's Roughness values for the whole model.

2 JBA (2014) Draft Hydrology and Modelling Report v4

Table 3-2: Previous and updated Manning's Roughness Values

Upstream and Downstream Cross Section	Roughness Values (Manning's n) and materials		Photograph
	Previous	Updated Model	
34DEEL01435 to 34DEEL01185	Bed - 0.045 Rock/ Boulders/ Gravel Left & Right Bank - 0.08 Dense trees/ grass	Bed - 0.06 Bank/ channel margin - 0.09 Bank - 0.11	 Looking upstream from section 34DEEL01391
DEEL_11388 to DEEL_10838	Bed - 0.04 Rock/ gravel Left & Right Bank - 0.08 Dense trees/ grass	Bed - 0.05 Bank - 0.11	 Looking upstream from section 34DEEL01267
DEEL_10828 to DEEL_10594	Bed - 0.04 Rock/ gravel Left & Right Bank - 0.06 Scrub/ Long Grass/ Trees	Bed - 0.045 Bank & Walls - 0.06 Bank trees/ overgrowth - 0.11	 Looking downstream (To next section) from section 34DEEL01185

Upstream and Downstream Cross Section	Roughness Values (Manning's n) and materials		Photograph
	Previous	Updated Model	
DEEL_10544 to DEEL_9294	Bed - 0.04 Rock/ gravel Left & Right Bank - 0.08 Dense trees/ grass	Bed - 0.045 Bank & Walls - 0.06 Bank trees/ overgrowth - 0.11	 Looking downstream from section 34DEEL01098
34DEEL000967 to 34DEEL00710	Bed - 0.04 Rock/ gravel Left & Right Bank - 0.06 Scrub/ Long Grass/ Trees NO CHANGE		 Looking downstream from section 34DEEL00940
34DEEL00695 to 34DEEL00381	Bed - 0.035 Gravel/ Mud Left & Right Bank - 0.06 Scrub/ Long Grass/ Trees NO CHANGE		 Looking upstream from section 34DEEL00587

Upstream and Downstream Cross Section	Roughness Values (Manning's n) and materials		Photograph
	Previous	Updated Model	
34DEEL00346 to 34DEEL00000	Bed - 0.03 Mud Left & Right Bank - 0.055 Long Grass/ Scrub NO CHANGE		 Looking upstream from section 34DEEL00000

3.3.2 New flow rating

A revised stage-flow rating curve has been developed to fit both the flow gaugings and also the model outputs at the Ballycarroon gauge location. The model outputs in mOD to Malin datum have been converted to the gauge datum using the OPW surveyed gauge datum of 20.569 mOD Malin. Model outputs have only been used to inform the rating curve for stages above 1.5m. This is to place sufficient weight on the number of suitable gaugings for lower flows. Figure 3-2 shows the rating curve with suitable flow gaugings and model results above 1.5m. Table 3-3 contains the rating curve parameters.

Figure 3-3 shows the comparison between the new and old rating relationships. It confirms the new flow rating is a better match to the recent flow gaugings and should be adopted. All previous ratings are based upon flow measurements below Qmed. The new rating has four flow measurements close to, or greater than Qmed and so is based on relevant evidence which was not previously available. Further the flood model has now been calibrated to higher level and flow measurements which has reduced model uncertainty. The previous model had no information at which to calibrate higher flows and levels and so, as there was no data available it was accept that the flood model results matched the extension of the old flow rating. Due to the higher flow levels used in the calibration the model it is now appropriate for use in extending the rating curve beyond the highest flow gauging. There is no better data or information available and so this flow rating relationship should be adopted.

Table 3-3. New rating curve parameters

Limb No.	c	a	b	Stage (m)		Flow	
				Min	Max	Min	Max
1	6.3000	-0.0300	2.0800	0.0000	0.6920	0.00	3.20
2	48.7	0.573478	1.51527	0.692	1.6	1.92	50.67
3	55.80054	0.676934	1.215037	1.600	2.900	50.63	147.30
4	57.4741	0.801376	1.276505	2.900	3.800	148.06	233.49
$Q = c(h-a)^b$							

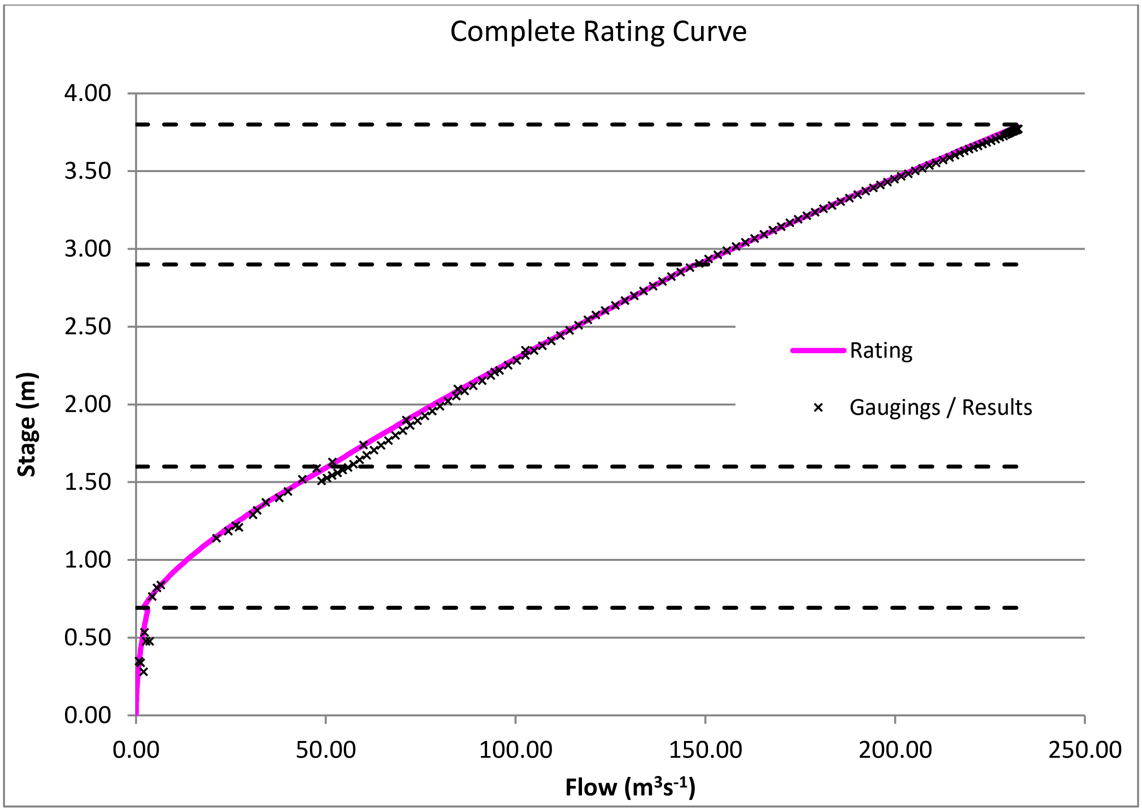


Figure 3-2: New rating curve (see figure 2-4 below for difference between gaugings and model outputs)

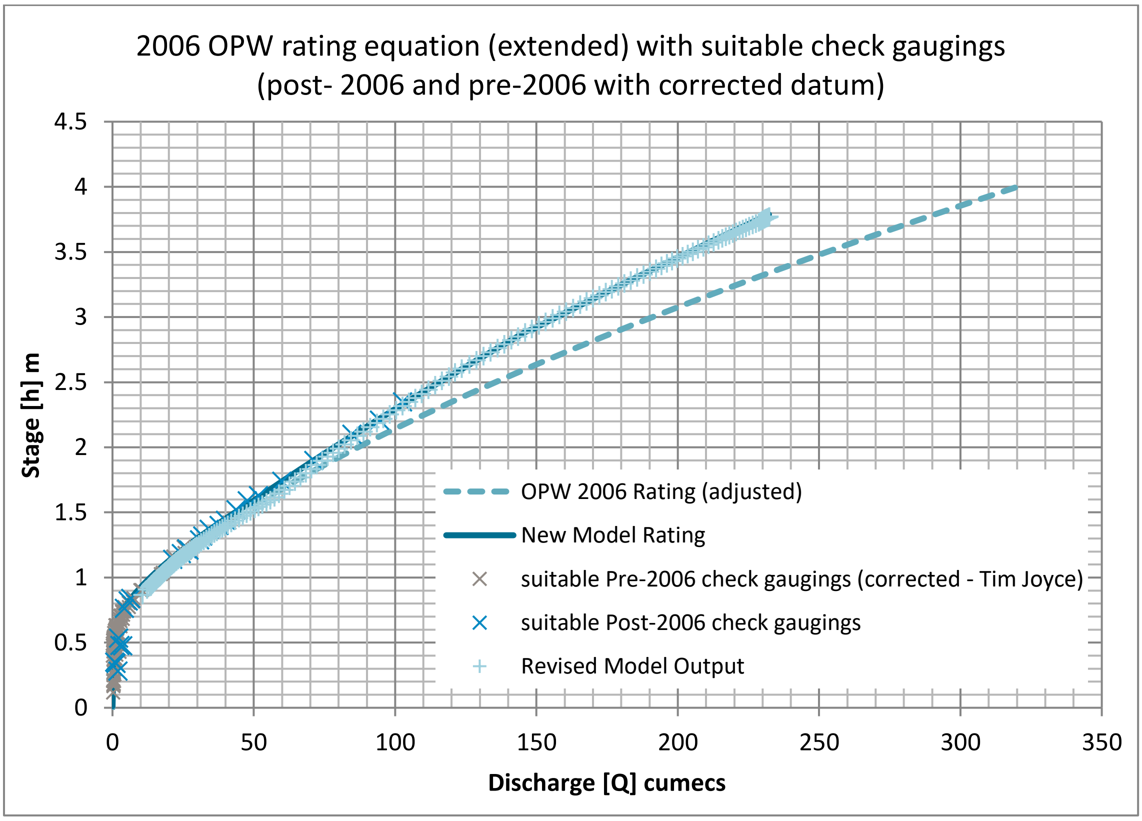


Figure 3-3: Comparison of new and old rating curve

4 Model Calibration

The hydraulic model upstream boundary is upstream of Ballycarroon. The previous model calibration determined that it was appropriate to apply Ballycarroon flows to the model inflow and not adjust the inflows to take account of the greater catchment area at Crossmolina. With the recent flood model updates the calibration exercise has found that a better calibration match can be obtained when increasing the model inflows by 3% to account for the 3% increase in catchment area from Ballycarroon to Crossmolina.

The hydraulic model does not account for overland runoff of surface water before it enters the river channel. There is evidence of surface water flooding during the November and December 2015 flood events, as documented in the flood event reports, and these events have shown that surface water and fluvial sources are causing the extents seen on the ground. The increase in flows to account for catchment area address some of these concerns although do not explicitly model the backing up of drains and surface water flooding.

4.1 Revisit 1989 and 2006 with revised flow estimates

4.1.1 Amending inflows for calibration events

The draft Hydrology and Modelling Report documented calibration model runs for the 1989 and 2006 flood events. The inflows for these have been amended to reflect the new flow rating relationship which has been applied to the 15 minute level data recorded at Ballycarroon gauge for each event. No changes have been made to the downstream boundary conditions. The revised inflows have been run through the updated model used to derive the revised rating relationship which has been calibrated to flow gaugings at Ballycarroon.

4.1.2 Calibration results

The previous calibration exercise presented maps of the calibration model run and the observed flood extent. For both the 1989 and 2006 event the previous model runs overestimated the flood extent but had a close match to recorded flood levels.

4.1.3 October 1989

The revised calibration event model runs provide a very close match to the 1989 flood extent and better than the previous calibration attempt (Figure 4-1).

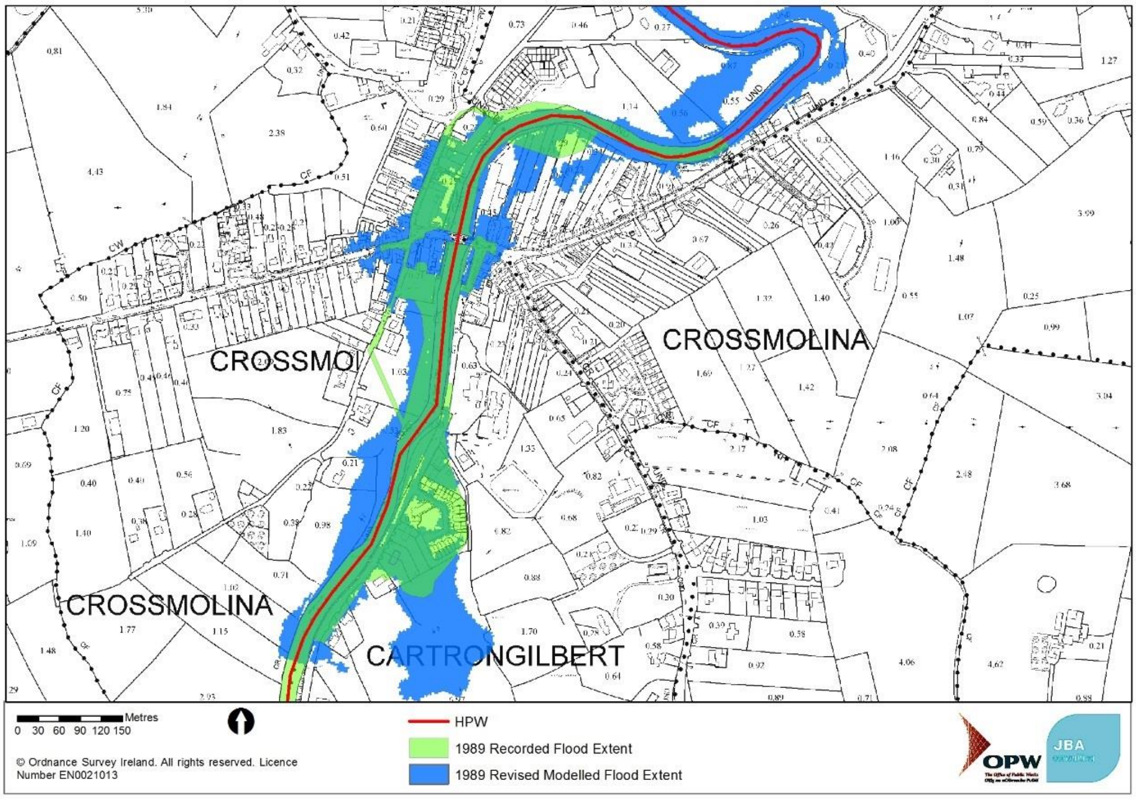


Figure 4-1. October 1989 modelled flood extent

4.1.4 December 2006

The flood model is a good match to the 2006 flood extent in Crossmolina with some overestimation to the south. (Figure 4-2). The flood levels reported in the Draft Hydrology and Modelling Report (Table 4-1 and Figure 4-3 of the draft report) have been used as a comparison. These flood levels are all recorded in the floodplain at properties and so may not be a true representation of river channel levels. The new calibration run flood levels are within an acceptable tolerance of +/- 300mm for calibration runs. The observed levels are a useful guide to calibrating the flood model but care needs to be taken when comparing these floodplain levels to in-channel river levels, especially where overland flow routes may be from bank overtopping upstream, surface water and drainage flood sources. Potential underestimates can be explained by the likely impact of high wrack marks from traffic and surface water may have upon the observed flood levels.

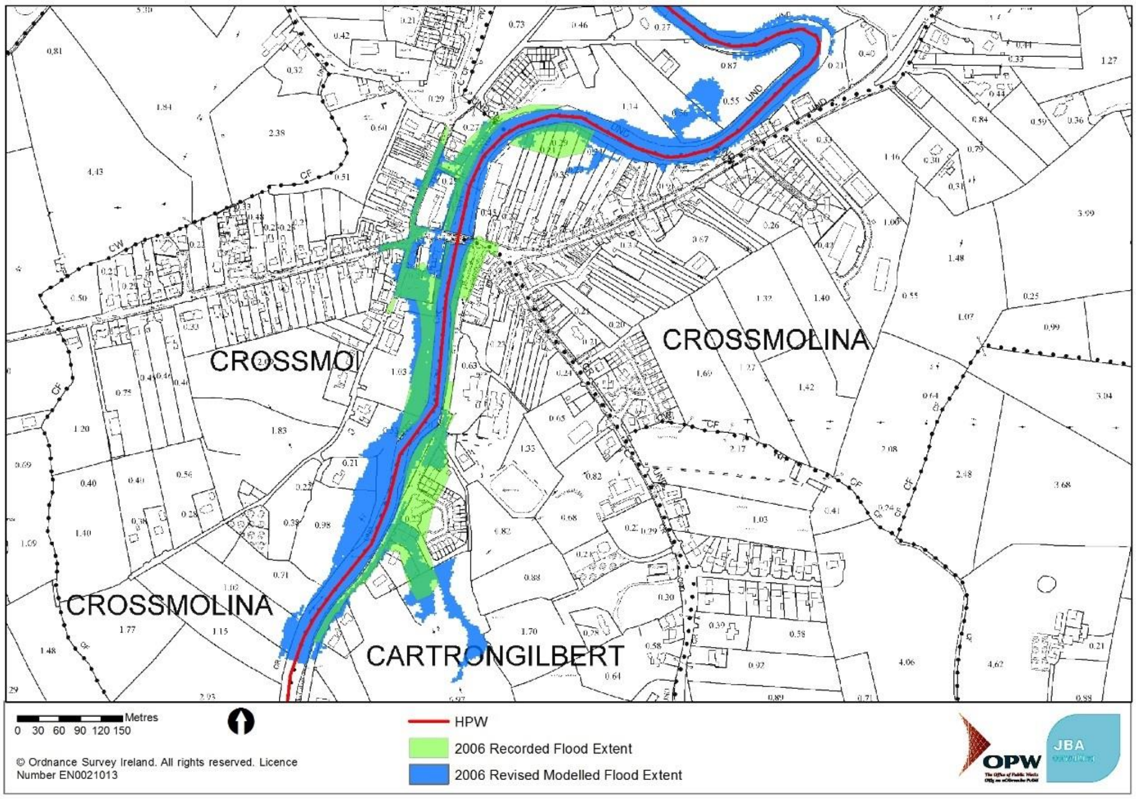


Figure 4-2. December 2006 modelled flood extent

4.2 New calibration events

4.2.1 November 2015

The Ryan Hanley post flood survey for 15th November 2015 identified a total of 18 properties flooded. The flood mechanisms were a combination of fluvial flooding as river levels exceeded the height of walls and from storm drains backing up through gullies in the drainage network. A level survey of wrack marks and homeowner observations of flood levels was carried out and a comparison to the model outputs is presented in Table 4-1. The observed flood extent has been mapped by Ryan Hanley and is compared to the modelled flood extent in Figure 4-3. The model extent and levels are a close match to the flow routes with some underestimate at Chapel Road where floodwater will have flowed through buildings and drains backed up. Some of the underestimate in flood extent at Chapel Street could be due to the contribution of surface water runoff and the backing up of drains.

Table 4-1. Recorded and modelled flood levels for November 2015

Ref	Water Level (mOD)	Location	Source	Modelled level (mOD)	Cross section or 2D domain
1	18.58	Tolan's Butcher	Info from Owner	18.45	DEEL_10722A (upstream face of bride)
2	18.29	Steps beside butchers - rack mark from river	Rack mark		
3	18.63	Moffatt's thatch pub - outside level	Info from Owner		
3	18.43	Moffatt's thatch pub - inside level	Info from Owner		
4	18.46	Jack Garret Bridge	rack mark [Estimated]	18.45	DEEL_10722A (upstream face of bride)

Ref	Water Level (mOD)	Location	Source	Modelled level (mOD)	Cross section or 2D domain
5	18.35	Hiney's Londis Supermarket	Info from Owner	18.37	2D model grid cell
6	18.41	Hiney's Pub	Info from Owner		
7	18.25	Ringbuoy (photos) downstream of bridge [Estimated]	Rack Mark	18.22	DEEL_10704 (18m downstream of bridge)
8	18.41	House on Church Street	Info from Local Fire Brigade	n/a	Outside of model extent (possibly surface water flooding)
9	19.28	John Garrett's house - front door	Info from Owner	19.04	DEEL_11138 (no out of bank flooding in model)
10	19.28	John Garrett's house - back door	Info from Owner		
11	19.26	Heffernan's house - front porch	Info from Owner		

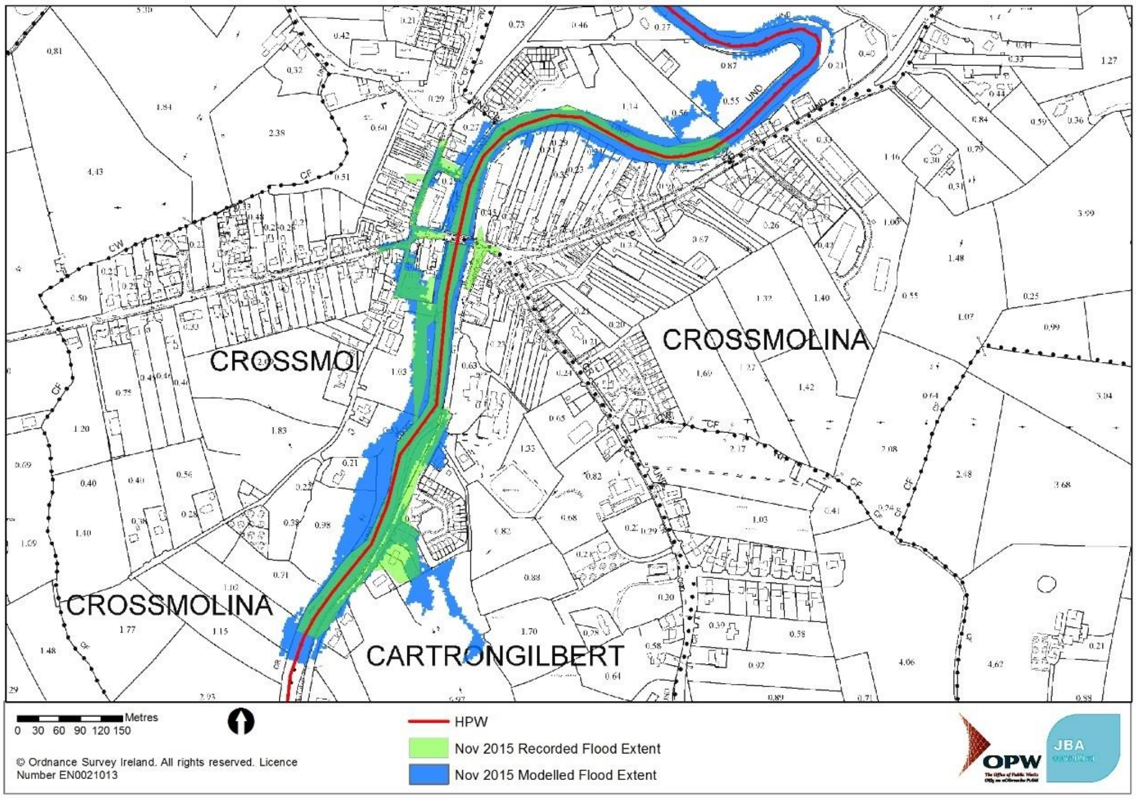


Figure 4-3. November 2015 observed and modelled flood extent

4.2.2 December 2015 flood event

The Ryan Hanley post flood survey for 5th December 2015 identified a total of 119 properties flooded. The flood mechanisms were a combination of fluvial flooding as river levels exceeded the height of walls and from storm drains backing up through gullies in the drainage network. Water levels exceeded the deck of the Jack Garrett Bridge. A level survey of wrack marks and homeowner observations of flood levels was carried out and a comparison to the model outputs is presented in Table 4-2. Where overland flow routes dominate the flood mechanism at the property the maximum flood level 2D model grid cell has been used. The observed flood extent has been mapped by Ryan Hanley and is compared to the modelled flood extent in Figure 4-4. The model is an extremely close match to the observed flood extent, which is remarkable for such a high magnitude flood event where flow recordings are likely to be more uncertain. The flood model represents buildings as high roughness values and does not raise building footprints or include building and garden walls, windows and doors in buildings which will locally influence water levels and depths around the properties.

Table 4-2. Recorded and modelled flood levels for December 2015

Ref	Location	Water Level (mOD)	Source	Modelled level (mOD)	Cross section or 2D domain
1	Tolan's Butchers	19.36	Pumped water mark from site visit	19.28	DEEL_10722A (upstream face of bridge)
2	Crossmolina Vet	19.12	Info from owner	19.16	DEEL_10738 (15m upstream of bridge)
3	Moffatt's Pub	19.29	Info from staff member	19.16	DEEL_10728
5	No. 20 Chapel View	19.63	Info from resident	19.70	DEEL_11088
10	Paddy Heffernan	19.56	Info from resident	19.75	DEEL_11188
13	Stick's Bar (Back)	18.95	Info from owner	18.97	2D model grid cell
14	Munnelly's Centra (front)	19.15	Info from owner	18.99	2D model grid cell
15	Medical Centre	19.08	Info from owner (water mark)	18.93	2D model grid cell
17	Hiney's Pub	19.04	Water mark from site visit	19.08	2D model grid cell
19	Shop at bridge	19.06	Info from owner (water mark)	19.28	DEEL_10722A (upstream face of bridge)
20	Phil Munnelly's Hardware Shop - Pumped	18.95	Info from owner (pumped water mark)	19.20	2D model grid cell
26	Bernie Gardiner	18.78	Info from resident	18.80	2D model grid cell
28	Catherine Gilvarry (House on The Boreen)	19.07	Info from resident (water mark)	19.26	2D model grid cell

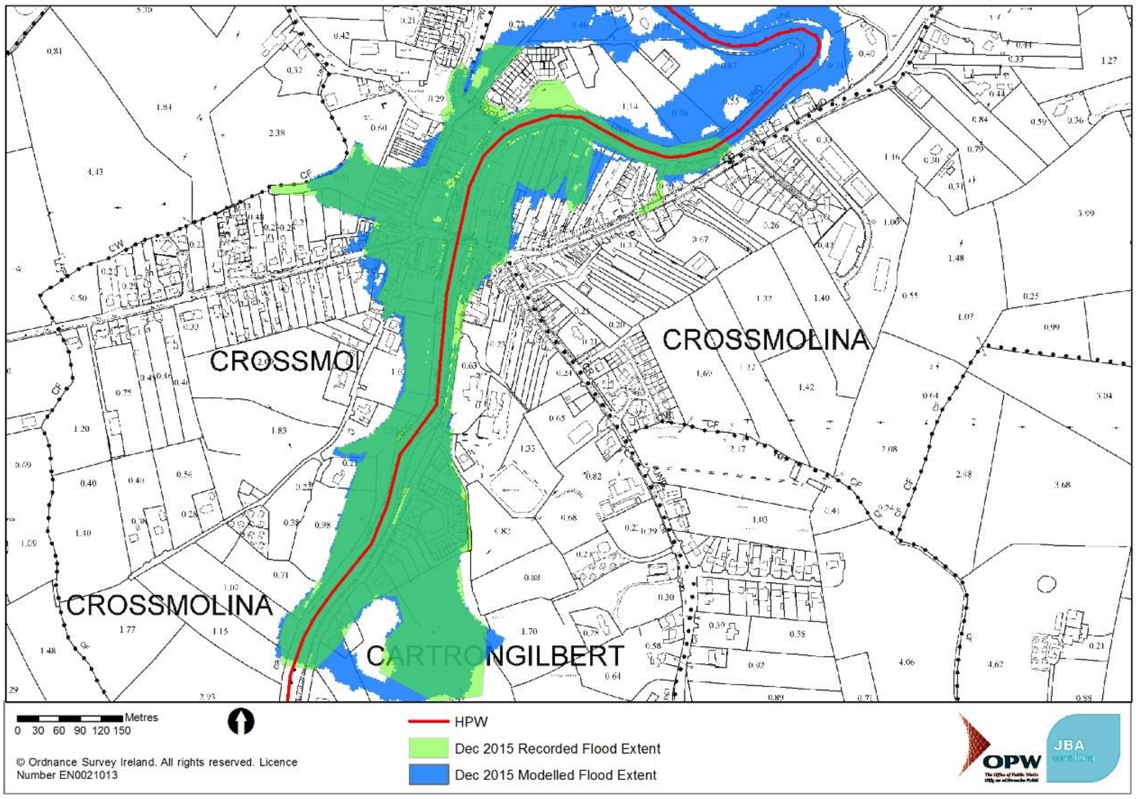


Figure 4-4. December 2015 observed and modelled flood extent

4.3 Calibration conclusions

The calibration events show a very close match to the larger flood events in 1989 and December 2015 and a good match to the November 2015 and 2006 flood events. This does not necessarily mean that the model is better calibrated for higher or lower magnitude flood events. This could potentially be due to the more notable influence of flooding from surface water drains in these events. There may have been greater vegetation overgrowth prior to the November 2015 flood which was cleared by the high flow in advance of the December 2015 flood which could influence the calibration. The 3% increase in the Ballycarroon flows to account for the increase in catchment area to Crossmolina should be applied to the design event flows.

5 Sensitivity Analysis - Baseline Model

5.1 Sensitivity testing

This section provides details on Sensitivity Testing on the Crossmolina baseline hydraulic model, which has been undertaken on a number of model parameters in order to test the robustness of the model estimates. The sensitivity tests have been carried out by running the 1% AEP design hydrograph through the 4m grid, defended test model.

The sensitivity of the fluvial models to the following parameters was tested:

- 2D Cell size
- Channel and floodplain roughness
- Model boundaries (in particular downstream boundary)
- Hydraulic parameters, such as weir coefficients
- Flow

Detailed modelling results of the model sensitivities analysis was undertaken for this study and includes testing on cell size, upstream and downstream model boundaries, river channel and floodplain roughness and flow uncertainties. In summary, the modelled flood risk within Crossmolina Town has been found to be:

- Relatively insensitive to the 2D cell size, downstream and upstream boundaries.
- Quite sensitive to both the channel and floodplain roughness, flow and weir parameters for the ford at Ballycarroon gauge.
- Flow estimation remains uncertain and accounts for the greatest level of uncertainty.

Sensitivity testing for the following parameters has also been carried out on the Diversion Option model:

- Roughness
- Downstream boundary
- Flow

Results from the sensitivity testing have been used to inform the Freeboard Analysis, which is discussed in Section 10.

5.2 Model limitations

For the Crossmolina model, the results are subject to uncertainties relating to the key model inputs (e.g. flows, topography), modelling parameters (e.g. roughness), modelling software used, model stability and the nature of the assumptions used in the modelling. A suitably detailed model has been used to inform the conclusions drawn from this assessment, however uncertainty remains in the model interpretation of flow mechanics including:

- Sub-grid scale mechanisms
- Energy loss at bends and structures
- Vertical mixing of flow
- Horizontal mixing of flow in one dimensional channels.

The model is shown to be fit for purpose through calibration/validation of historic flood events. Further accuracies are only available following detailed monitoring/calibration of afflux at structures, local detailed cross section survey and locally specific hydrometric gauging.

The strengths of this model are the use of the detailed bank crest level data through Crossmolina town and that the model appears capable of simulating the 2006 event, the 1989 and both 2015 events to a reasonable level of accuracy, providing a comprehensive and well calibrated model for the existing condition.

Significant further limitations arise through the use of the 1D in-channel model and available survey and hydrometric data for testing of the diversion channel option. The high level of uncertainty in the representation of local hydraulics at the location of the diversion channel offtake needs to be considered in design of proposed scheme options.

Uncertainties are taken in account by means of Freeboard allowance, as discussed in Section 10.