Mountmellick
FLOOD RELIEF SCHEME

Mountmellick FRS – Hydraulic Modelling Report

2019s1073

Final report

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Contract

This report describes work commissioned by the Office of Public Works (OPW), on behalf of Laois County Council (LCC). Hannah Moore of JBA Consulting carried out this work.

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Purpose

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Abbreviations

AEP	Annual Exceedance Probability
AFA	Area for Further Assessment
DTM	Digital Terrain Model
EPA	Environment Protection Agency
FM	Flood Modeller
FRS	Flood Relief Scheme
FSR 16	Flood Studies report 16
HEFS	High End Future Scenario
HRL	Hydrological Reporting Line
LCC	Laois County Council
LiDAR	Light Detection and Ranging
MBE	Mass Balance Error
MRFS	Medium Range Forecast Scenario
mOD	Metres above Ordnance Datum
OPW	Office of Public Works
OSI	Ordnance Survey Ireland
SECFRAM	South Eastern Catchment Flood Risk Assessment and Management
TUFLOW	Two-Dimensional Unsteady Flow

1 Introduction

This user report aims to provide technical details about the construction and schematisation of the hydraulic model of Mountmellick and the surrounding area used within the development of the Mountmellick Flood Relief Scheme (FRS).

1.1 Project aim

The overall purpose of the Mountmellick FRS project is to design and build flood defences that will protect properties and critical infrastructure in future flood events. This is being done using hydraulic modelling to assess past events and the potential defence options.

1.2 Study area overview

Below is a summary of the study area and catchment details:

- The study catchment area is defined by the downstream extent of the SECFRAM model for the area (Model 5), refer to Section 2.1.
- The largest watercourse in the area is the River Barrow which flows in an easterly direction near the northern boundary of the town. The Owenass, and Pound Rivers, tributaries of the Barrow, flow through Mountmellick town.
- Additional tributaries and drainage channels also contribute flow through the AFA area.
- Elevation over the study area varies on average from about 100mOD to 69mOD over approximately 7km (refer to Figure 1-1).
- Agricultural and pastural land is the main land use type within the model area. Mountmellick town is the only urban area.
- The tributaries of the River Barrow (Owenass and Pound etc) originate in the foothills of the Slieve Bloom Mountains located to the west of the study area, there no reservoirs or other large waterbodies present.

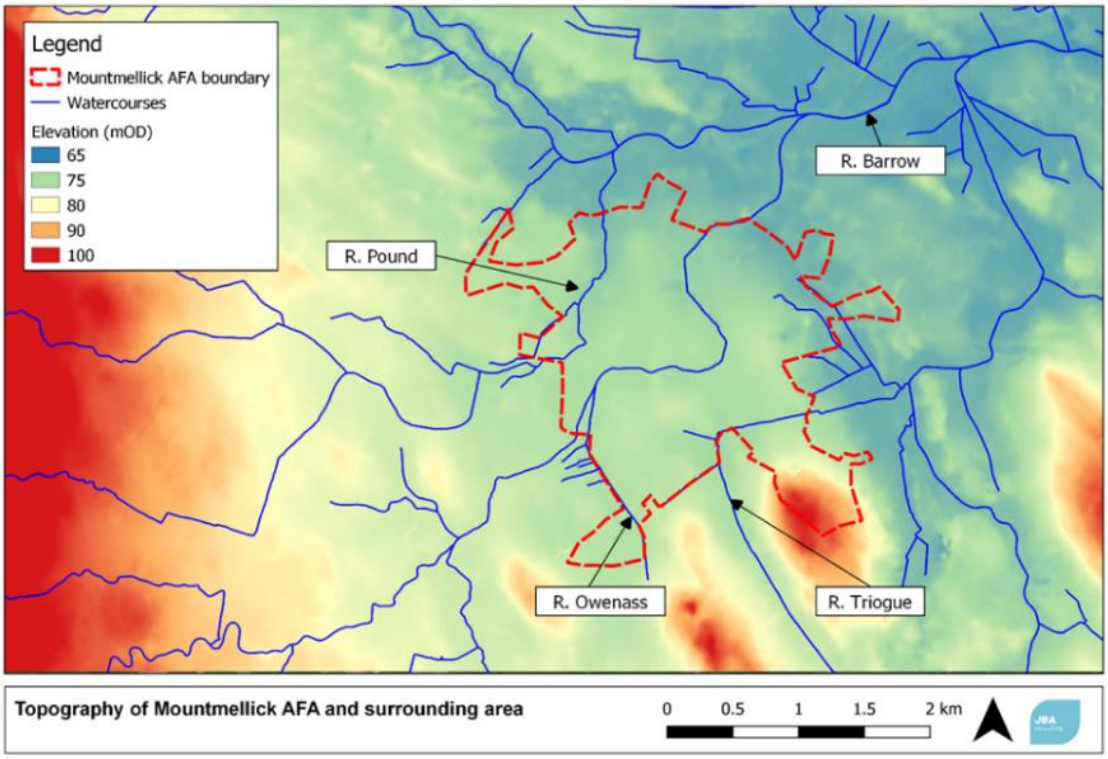


Figure 1-1: Topography of Mountmellick AFA and surrounding area

2 Available data

2.1 Existing models

The previous hydraulic model of Mountmellick's watercourses was constructed under the OPW's CFRAM Study programme:

- **South Eastern Catchment Flood Risk Assessment and Management (SECFRAM) Model 5 (2016)**: This hydraulic model was developed under the national CFRAM study and is the most detailed hydraulic modelling study carried out in the area to date. SECFRAM Model 5 includes Mountmellick town (designated an Area For Further Assessment (AFA)) and the surrounding area. The 1D-2D SECFRAM model was constructed using the MIKE FLOOD software package, full details of the model schematisation and development can be found in the SECFRAM Hydraulic Modelling Report available at floodinfo.ie. The model has been examined to help inform the construction of the flood relief scheme model.

2.2 DTM and Survey data

2.2.1 Available DTM data

Table 2-1 summarises the DTM data that was made available for the study during the time of model construction and development. Figure 2-1 shows the different coverage extents of the data sets.

Table 2-1: DTM data comparison

Source	OSi 5m	OSi 2m	Bluesky	Murphy Survey (DTM)
Date flown	2008	2008	2019	2019
Horizontal resolution	5.00m	2.00m	1.00m	0.15m
Quoted vertical accuracy bound	±500mm	±500mm	±500mm	±150mm
Date data received	16/09/2019	04/10/2019 (1st issue) 03/01/2020 (final issue)	13/03/2020	17/07/2020

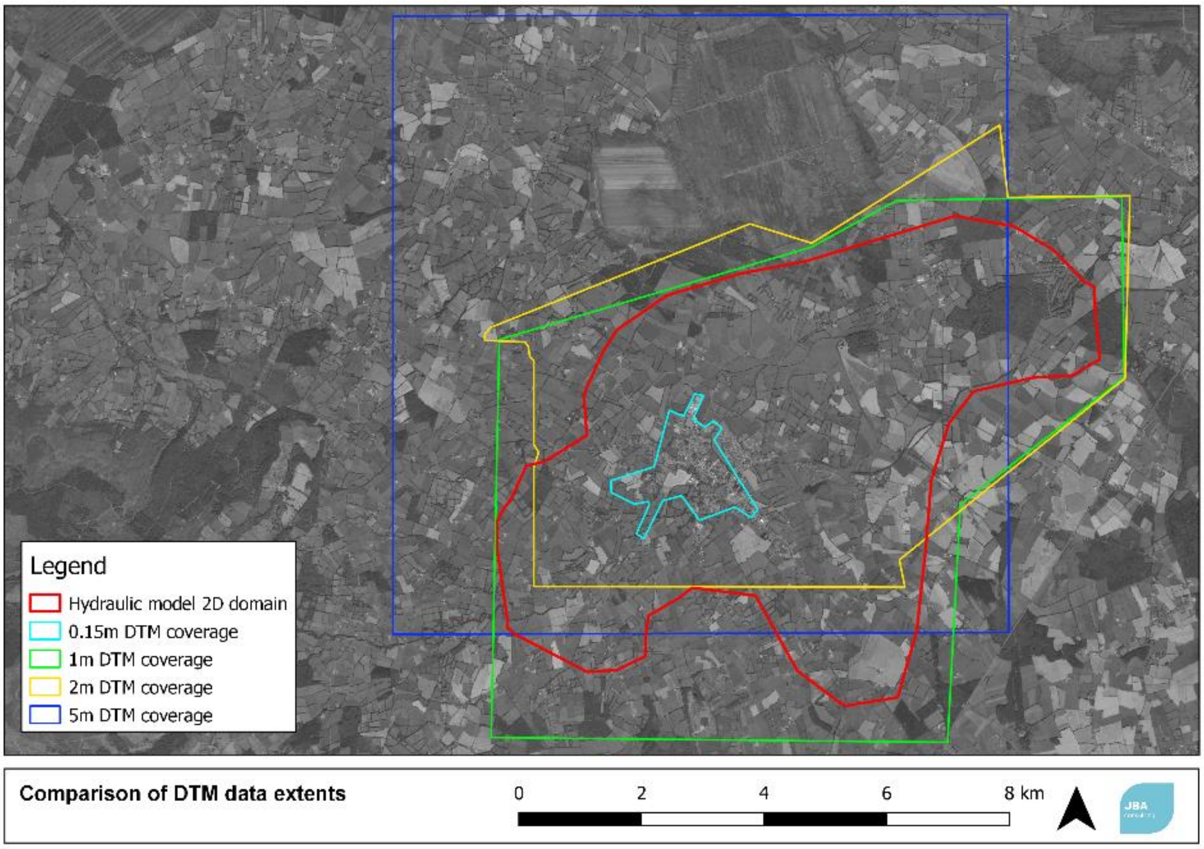


Figure 2-1: Comparison of DTM data coverage

2.2.2 Available Survey data

A number of different sources of survey data were used to build the FRS hydraulic model:

- **SECFRAM topographic survey data (Murphy Surveys 2013):** This cross section topographic survey data was collected for SECFRAM model 5 and has been provided for this project. The survey covers the major watercourses considered. The data has been reviewed and there are no major alterations to the channels since this survey was taken.

- **Additional topographic survey 2019 (Murphy Surveys 2019):** Following review of the SECFRAM model and survey additional survey was collected in December 2019 targeting locations where there were gaps in information or new watercourses to be included. It also included drone survey of a large area around Mountmellick town which was later processed into a DTM and used to cross check and update ground elevations where necessary (supplied 2020).
- **Survey of outlets/inlets to streams and rivers in Mountmellick (Laois Co Co 2019):** A map containing details of all the visible inlets/outlets discharging into the Pound and Owenass rivers was collected and reviewed as part of model construction. In some cases, culvert details are missing or could not be confirmed, of note is the culvert connecting the Manor Court field drain to the Pound River running under a property.
- **Additional river channel survey 2020 (Murphy Surveys 2020):** Following initial testing during model building it was found that there was need to extend a number of watercourses upstream of the SECFRAM modelled and surveyed extent. The additional upstream survey was collected in February 2020.
- **Topographical survey 2020 (Murphy Surveys 2020):** Upstream model extension channel survey and post flood survey was carried out to record wrack marks resulting from Storm Ciara. This data was used in the calibration of the hydraulic and hydrological models.
- **CCTV survey of key culverts (December 2020):** CCTV survey of four culverts within the Mountmellick town area was carried out to gain greater understanding of structure condition, previously unknown dimensions, and hydraulic connection to the system.

All survey data was reviewed to ensure it was fit for purpose, of an appropriate level of accuracy and gave sufficient information.

2.2.3 Comparison between DTM and Survey

2.2.3.1 DTM comparison

A comparison between the Bluesky1m and the OSi 2m and 5m DTM data sets along the Barrow River was carried out when first received (refer to Figure 2-2, Figure 2-3 and Figure 2-4). The Barrow River was chosen for comparison as it was a location where extended survey cross sections were available to allow a better comparison between the survey and DTM values. All other channel survey data available at the time of initial comparison was limited in respect to measurements outside the main river channel.

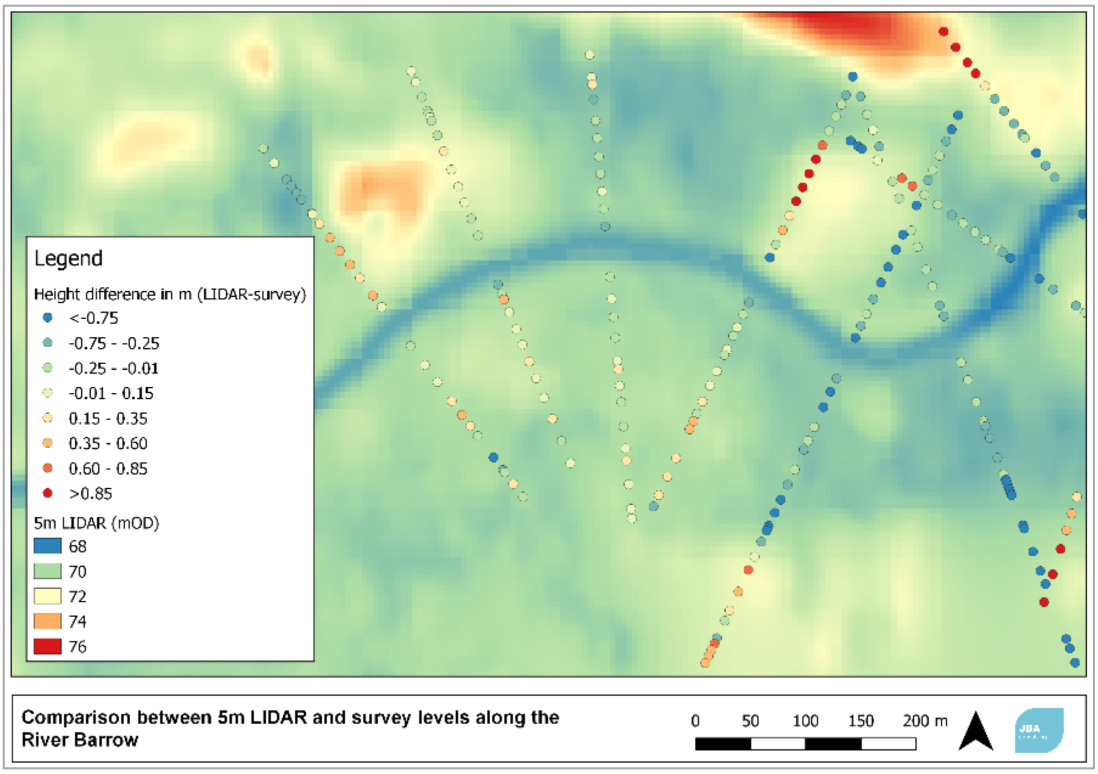


Figure 2-2: Comparison between 5m LIDAR and survey levels along the River Barrow

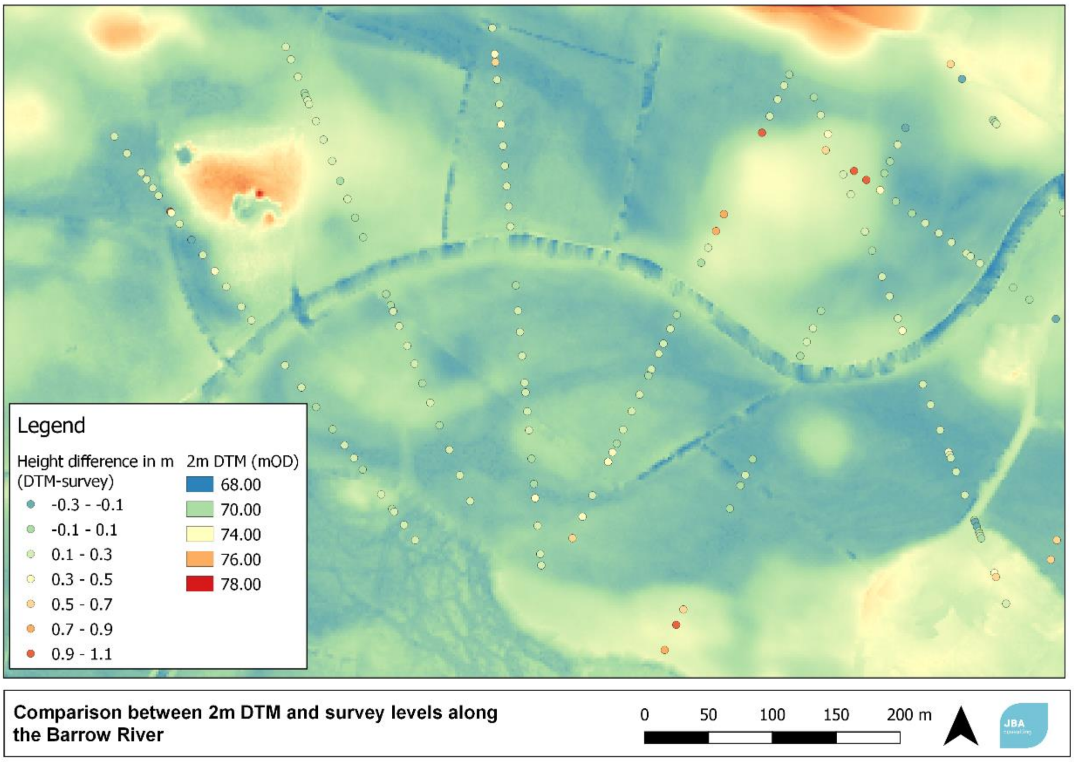


Figure 2-3: Comparison between 2m DTM and survey levels along the River Barrow

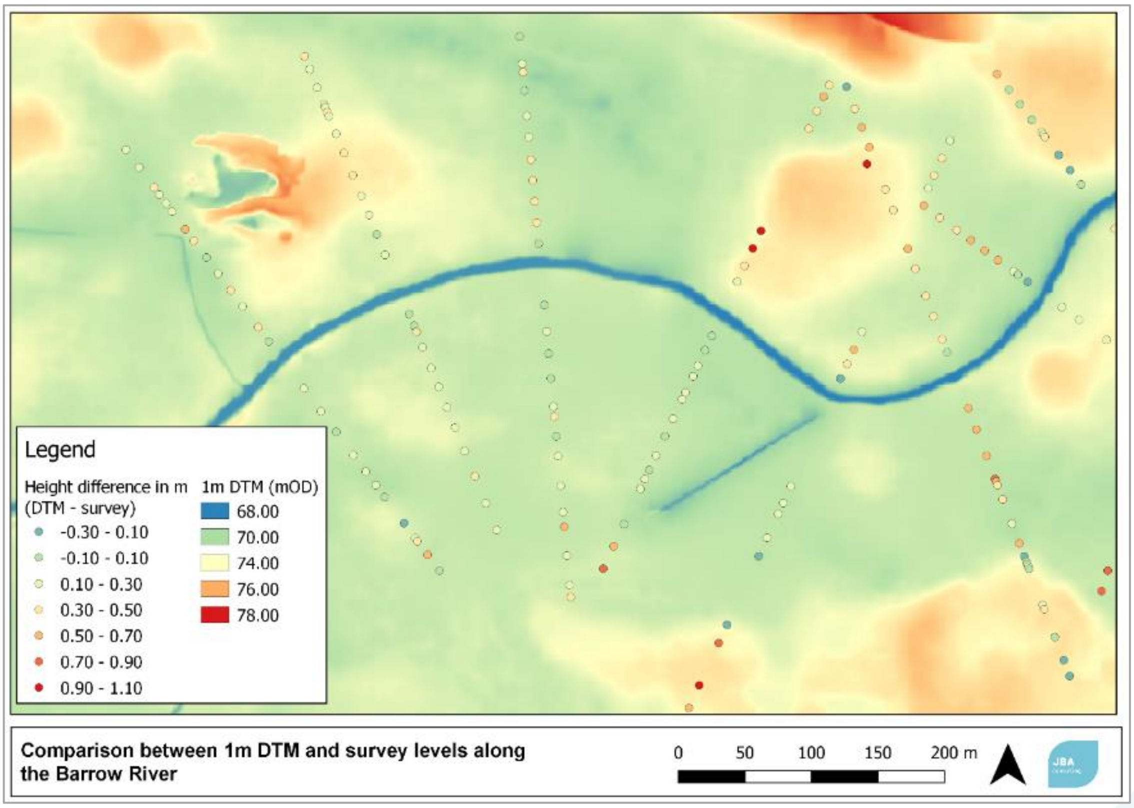


Figure 2-4: Comparison between 1m DTM and survey levels along the River Barrow

From review of the data, it was decided that the OSi 5m DTM was not to be used as it has the lowest horizontal resolution of the data sets available and matched least well with the survey data. It also did not cover the full model extent.

Both the Bluesky 1m and OSi 2m DTM data sets matched the survey data with a similar degree of accuracy. From Figure 2-1 the OSi 2m DTM data set does not cover the entirety of the model area considered and had a filtering issue in which there were 'no-data' stripes within the DTM tiles (refer to Figure 2-5). Discussions back and forth with the OPW and the resending of data to rectify this issue were made but no resolution was found. To rectify the issue a GIS infill tool was used to infill the missing data in the DTM. It is also noted that as it is flown in 2008 the data is now 12 years old at time of writing.

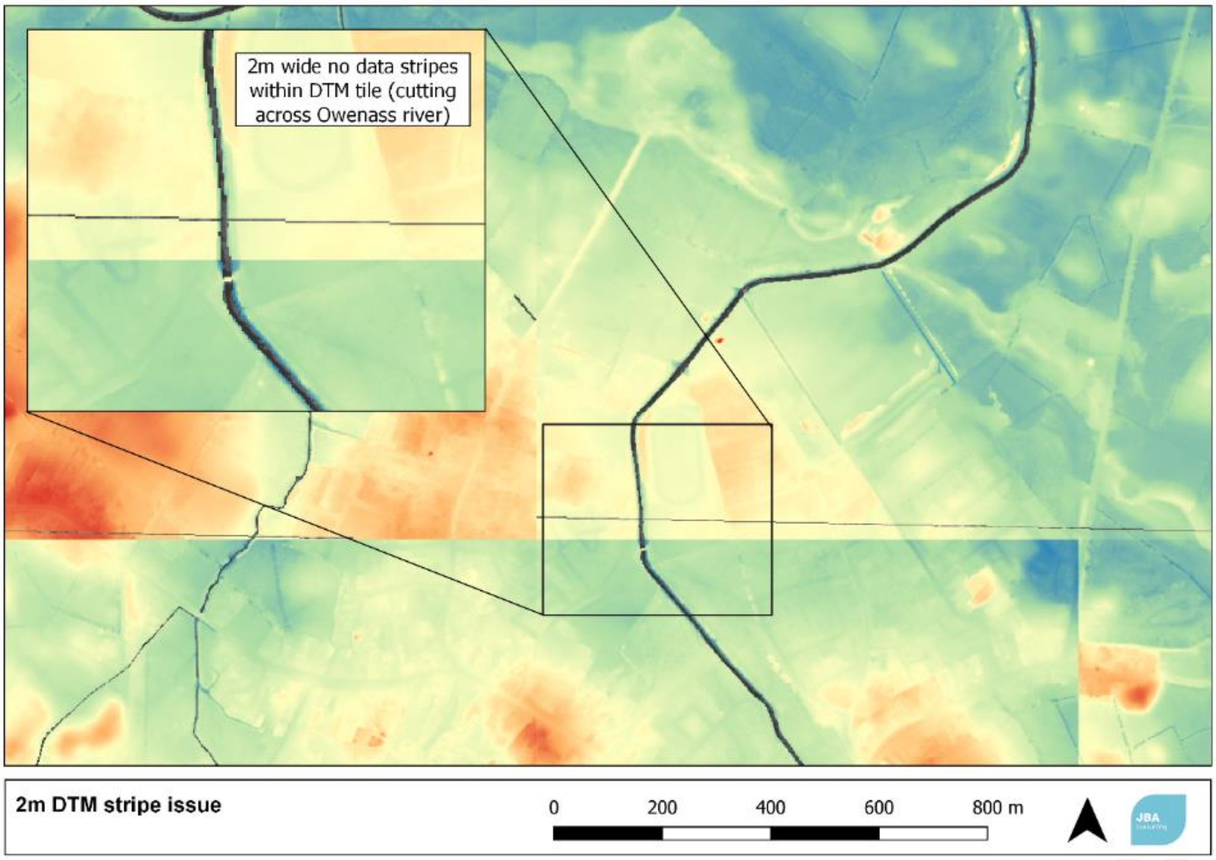


Figure 2-5: 2m DTM stripe issue

In contrast the Bluesky 1m DTM data set is the most recent wider dataset available (flown in 2019). It is the highest horizontal resolution dataset available for the wider catchment area and covers the entirety of the model extent such that the entire area is represented with one dataset of the highest resolution. The 1m DTM also did not have any filtering or processing issues like the stripes in the OSi 2m data set. Given these considerations the Bluesky 1m DTM was initially selected for use to build the 2D domain.

However, during model development, it was found that there were issues in calibrating the model and representation of the urban Mountmellick town area using the Bluesky 1m DTM data. Following extensive review and testing of both the Bluesky 1m and OSi 2m datasets it was found that although an older data set with a lower horizontal resolution the OSi 2m DTM enabled better representation of the observed flooding and flow mechanisms within the flood plain compared to the Bluesky 1m DTM.

Also during model development the 0.15m resolution DTM data from Murphy Surveys which provided the most accurate representation of topographic levels in the town was made available (refer to Figure 2-6 for comparison with surveyed levels within the town). This data set was preferred for representation in the town as it provided the greatest accuracy.

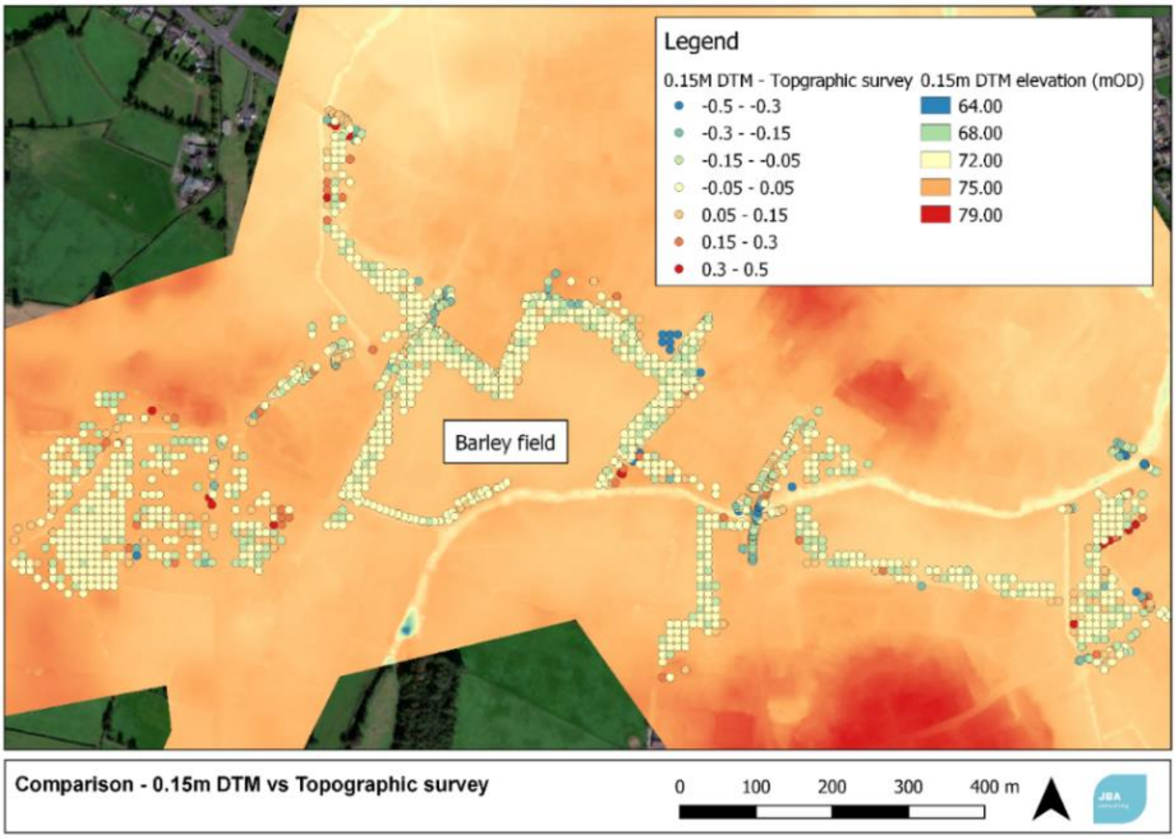


Figure 2-6: Comparison – 0.15m DTM vs Topographic survey

Following the review of the DTM data it was decided that the 2D model domain would be based using a combination of the following DTM datasets:

- Murphy's survey 2020 DTM for Mountmellick town,
- OSI 2m DTM with infilled no data stripes for the wider flood plain areas,
- Bluesky 1m DTM for the areas of the model which the 2m DTM data set does not cover.

This combined DTM approach ensures the data that results in the most realistic representation of flow behaviour has been used to develop the hydraulic model. The 1m DTM is used for areas on the outskirts of the model in areas where there are limited risk receptors and have been modelled to allow flows through the catchment to be represented. These areas are at a distance from where the defences will likely be. The overall risk of using this data on the final impacts and design of the FRS and final levels will not be significant and is outweighed by benefits of better representing water movement through the upper catchments.

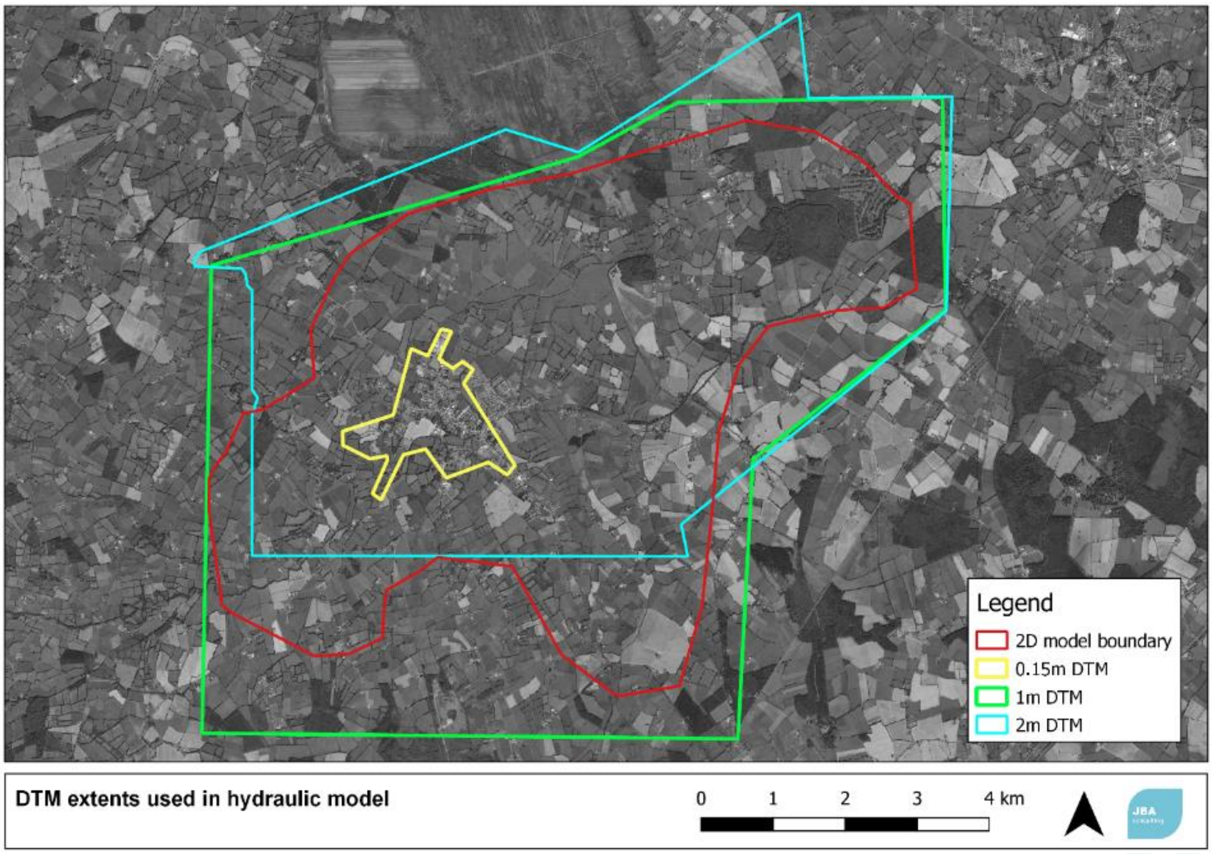


Figure 2-7: DTM extents used in hydraulic model

2.3 Hydrometric gauges

There are four active and one inactive gauges within the study area modelled. Below is a summary of the available gauge data, a full review of the available data for the gauges can be found in the Hydrology Report for this study.

Table 2-2: Hydrometric gauge summary

Gauge name	Gauge number	Operator	Watercourse	Data recorded	Data record
Borness	14003	OPW	Barrow	Water level	1979 – present
Owenass	14033	EPA	Owenass	Water level	1977 – 2013
Mountmellick Mill	14114	EPA	Owenass	Water level	2013 – present
Manor Road	14121	OPW	Pound	Water level	2019 - present
Chapel Street	14120	OPW	Pound	Water level	2019 - present

- Manor Road (14121) and Chapel Street (14120) gauges were only installed on the Pound River in 2019 and therefore have extremely short records. The were both recording at the time of Storm Ciara and Storm Dennis in February 2020.
- The Owenass (14033) EPA gauge was discontinued in 2013 and replaced by the Mountmellick Mill (14114) gauge.
- The Borness (14003) gauge is located downstream of the confluence between the Owenass and Barrow Rivers on the River Barrow.

Gauges 14003, 14033 and 14114 underwent rating reviews as part of the FRS project. Further details of all the gauges and the outcomes of the rating reviews can be found in the Hydrology Report.

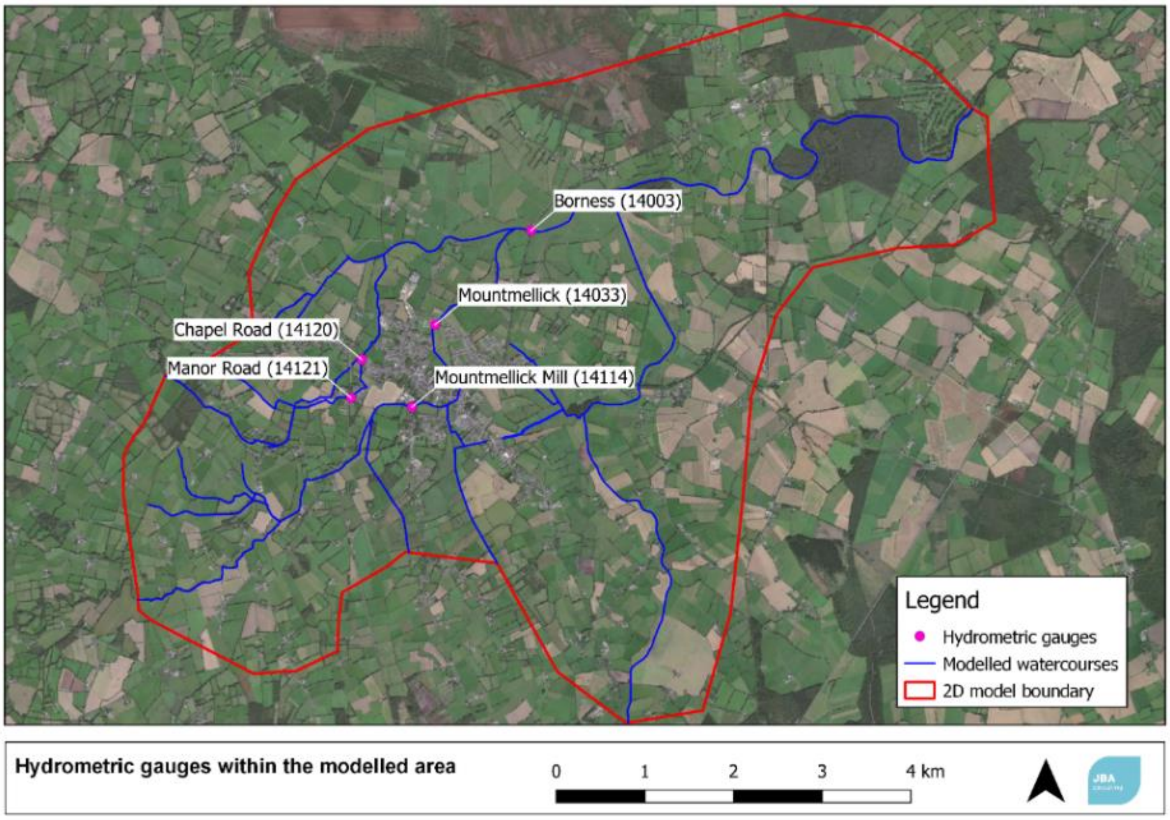


Figure 2-8: Hydrometric gauges

2.4 Flood history

A summary of the key events within Mountmellick's flood history is provided. Refer to the hydrology report for a full flood history review.

Table 2-3: Summary of flood history

Date	Details
October 1954	Limited information but reports of the Barrow bursting its banks
December 1968	Limited information but reports of the Barrow bursting its banks
February 1990	Prolonged heavy rain raised water levels and fluvial flooding from the Barrow, Owenass and Triogue.
August 2008	Heavy rainfall resulted in increased flow. The Barrow is reported to have burst its banks but there is no other mention of any other watercourse in the area bursting its banks.
November 2017	Considered the worst flood event to occur within the town. Following a 9-hour rainstorm over the area the Owenass, Pound, Triogue, and Barrow Rivers all burst their banks resulting in large amounts of overland flow moving through the town and surrounding area. Over 70 properties were impacted in this event.
February 2020	Storm Ciara – Flooding within the town and wider area following intense wind and rain. Out of bank flow from the Owenass River and its tributaries reported. A number of abandoned properties were flooded, and some residents were evacuated over safety concerns. Several roads including the N80 were flooded and closed for a number of hours.

2.5 Hydrological assessment

Refer to the hydrology report for this project for a full description of the methods used to estimate inflows. In summary:

- Inflow hydrographs were developed using FM FSSR 16 inflow units for the upstream inflow points for wall watercourses with considerable upstream catchments.
- Lateral flow hydrographs were also developed using FM FSSR 16 units to represent the overland flow entering the watercourses along the reaches.
- The inflow hydrographs were generated using the necessary catchment descriptors for each individual catchment.
- To further refine and calibrate the estimated flows the parameters of the FSSR units were calibrated using the rainfall recorded and catchment conditions from the November 2017 and February 2020 events. With hydrometric gauge data, photographs and wrack marks used to assess the model's performance (refer to Section 8.1 for hydraulic model calibration).
- Following calibration design event hydrographs were developed using the FSSR derived values for a given return period and duration. The same

storm duration was applied to all catchments to reflect how a single event would impact the entire area due to the nature of large frontal weather systems.

- Three storm durations (5, 11, 21-hour storms) were run for the 1% AEP flow event to assess the impact of storm duration (refer to Section 8.2.3 for further discussion on this). The peak inflows applied for the 1% AEP event are provided in Appendix A.
- It is noted that hydrology and estimated inflows are the greatest source of uncertainty within a hydraulic model and although there are hydrometric gauges present within the model area that allow for comparison it is recommended that a rain gauge be installed within the study area and an additional gauge located upstream on the Owenass watercourse.

3 Model development

3.1 Overview

Table 3-1 provides a summary of general model details. For efficiency two separate models were developed, the Mountmellick model and the Triogue model. The Mountmellick model includes all the watercourses that flow through the town and within the AFA boundary and the Triogue model includes all those watercourses within the Triogue system. This division of the watercourses into two separate models could be done because there is no hydraulic connection between the two.

The schematisation of the 1D and 2D model components are shown in Figure 3-1 and Figure 3-2 respectively. A 4m grid cell size was selected for the 2D domain. This resolution ensured that there was sufficient detail in the model for use in FRS development and that the model run times were not excessive.

Table 3-1: Hydraulic model summary

1D model	Value
Total 1D modelled length	42.78km
Number of modelled structures	52
1D timestep	1 second FM 1 second ESTRY
Number of inflows	40 – 24 upstream inflows (23 FM, 1 ESTRY) 16 lateral inflows (15 FM, 1 TUFLOW 2D)
Number of outflows	1 1D outflow (Height-discharge (HQ) boundary)
2D model	
Total model area	44.65km2 (single 2D domain used)
Model orientation	South-west to north-east
2D grid cell size	4m
2D timestep	2 seconds
Number of inflows	1 2D point inflow (Mountmellick model)
Number of outflows	1 2D outflow (Height-discharge (HQ) boundary)
1D-2D model linkage	Via HX and CN point and lines
Coordinate reference system	TM65 (Irish National Grid)
Average model run time	8 hours

3.2 Software

The model was developed using Flood Modeller and TUFLOW software packages creating a linked 1D-2D model. The majority of the 1D model domain was modelled using Flood Modeller (FM) Pro v4.5. Due to the presence of steep topography and hydraulically complex structures, the Pound and Clontygar B watercourses have been modelled in ESTRY for stability and are linked to the FM 1D watercourses. The 2D domain is represented using TUFLOW Classic 2018-03-AE. These versions were the latest releases at the time of initial model build. The double precision versions of both software were used.

3.3 Schematisation

This section discusses the schematisation of the model and how the different aspects of the model including boundaries have been applied. Figure 3-1 and Figure 3-2 show the 1D and 2D model structure.

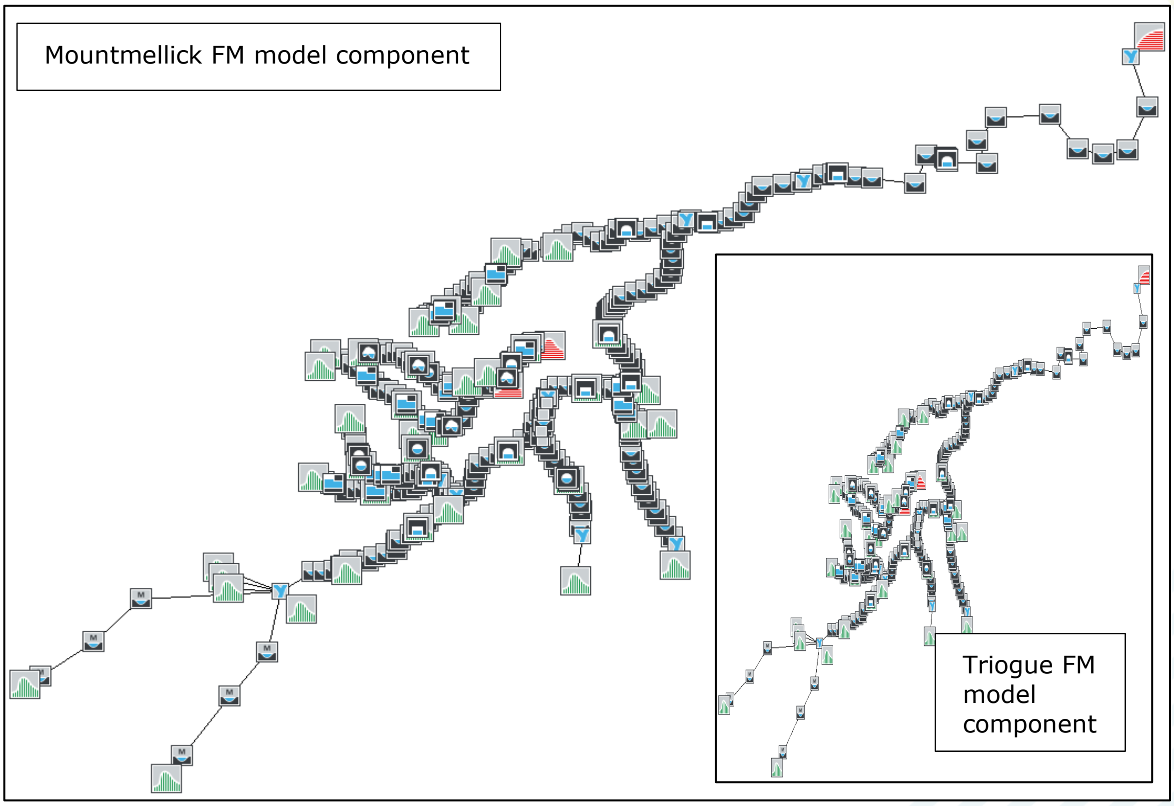


Figure 3-1: 1D Flood modeller model schematisation

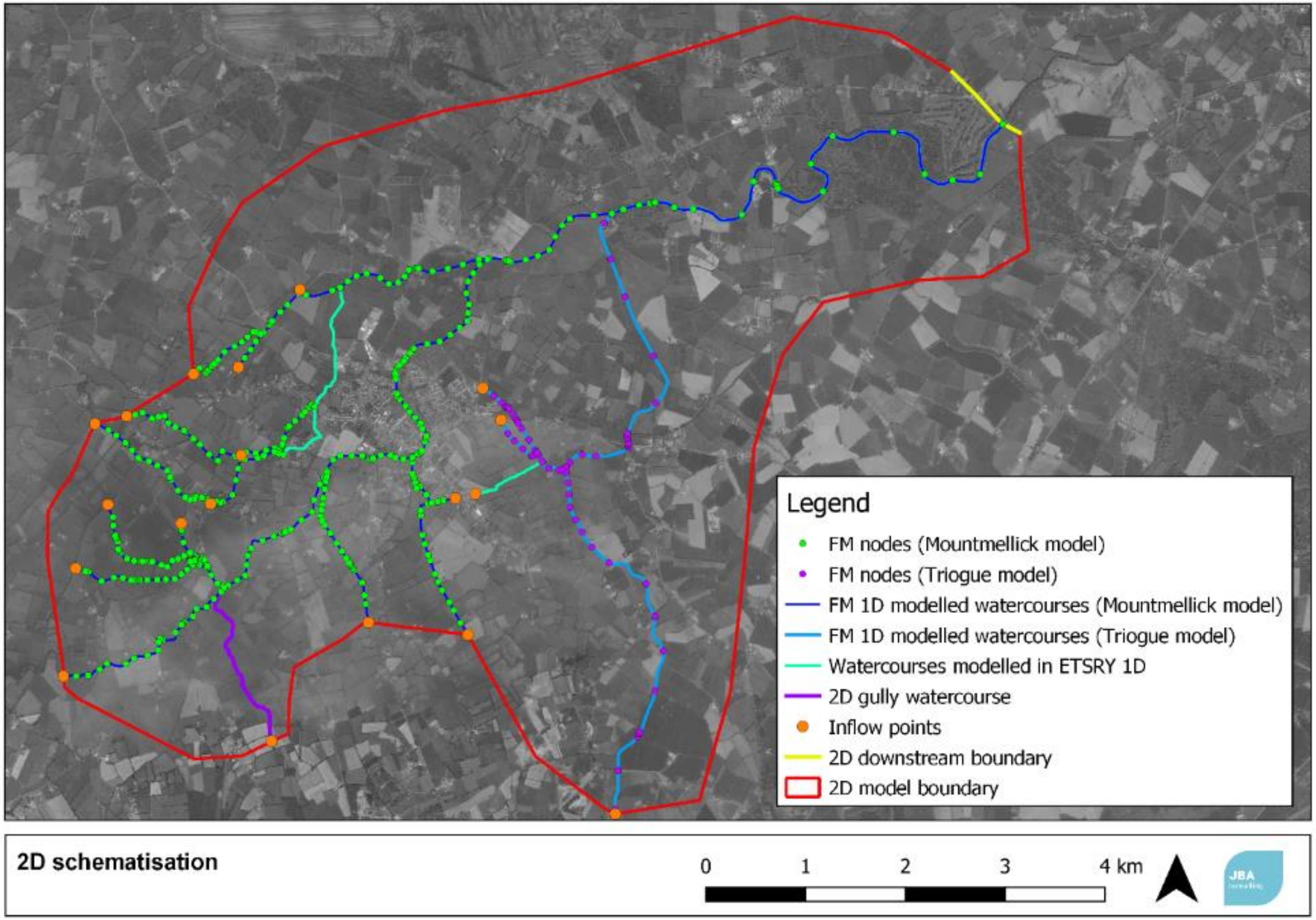


Figure 3-2: 2D model schematisation

3.3.1 Inflow boundaries

Table 3-2 summarises how the various inflow boundaries have been applied in the two models. All inflow hydrographs have been generated using the FSSR16 FM units and then applied to the models. Refer to Section 2.5 and the Mountmellick hydrology report for details on the estimation of the hydrological inflows for this study.

Table 3-2: Model inflows

Inflow boundary type	Mountmellick Model	Triogue Model
FM 1D inflows	19 upstream inflows, 14 laterals	3 upstream inflows, 1 lateral
ESTRY 1D inflows	1 lateral inflow	1 upstream inflow
2D inflows	1 point inflow, 1 lateral inflow	-

The hydrographs and flows calculated for this study were applied in the 1D component of the models. Figure 3-2 shows the location of the point inflows within the model. There are 16 lateral inflows included in the model, 15 applied to the FM 1D model and one 2D lateral flow applied to the downstream reach of the Pound via a 2d_bc polygon.

3.3.2 Outflow boundaries

The same outflow boundaries are applied in both the Mountmellick and Triogue models. An HQ boundary has been used to represent the continuation of flow along the River Barrow which continues downstream of the model extent. An HQ boundary is considered suitable as the downstream boundary is far enough away from the key risk area (Mountmellick town) for a backwater effect to impact results; sensitivity to the Barrow water levels and joint probability have been considered (see Section 8.2).

3.3.3 1D - 2D boundaries

HX lines have been applied at the 1D-2D boundaries within the models, namely at the top of banks (TOB) of the watercourses. The HX line elevations (TOB) were sourced from surveyed data and intermediate points from the underlying 1m LIDAR data. This ensured that the crest levels of the channel in the 1D model were being read into the 2D models. The TOB levels sourced from the LIDAR were reviewed to ensure that they were appropriate and consistent with the surveyed levels. A 2D inactive area was applied to remove the 1D modelled areas from the 2D domain. Figure 3-3 shows an example of the 1D-2D boundaries applied within the models.

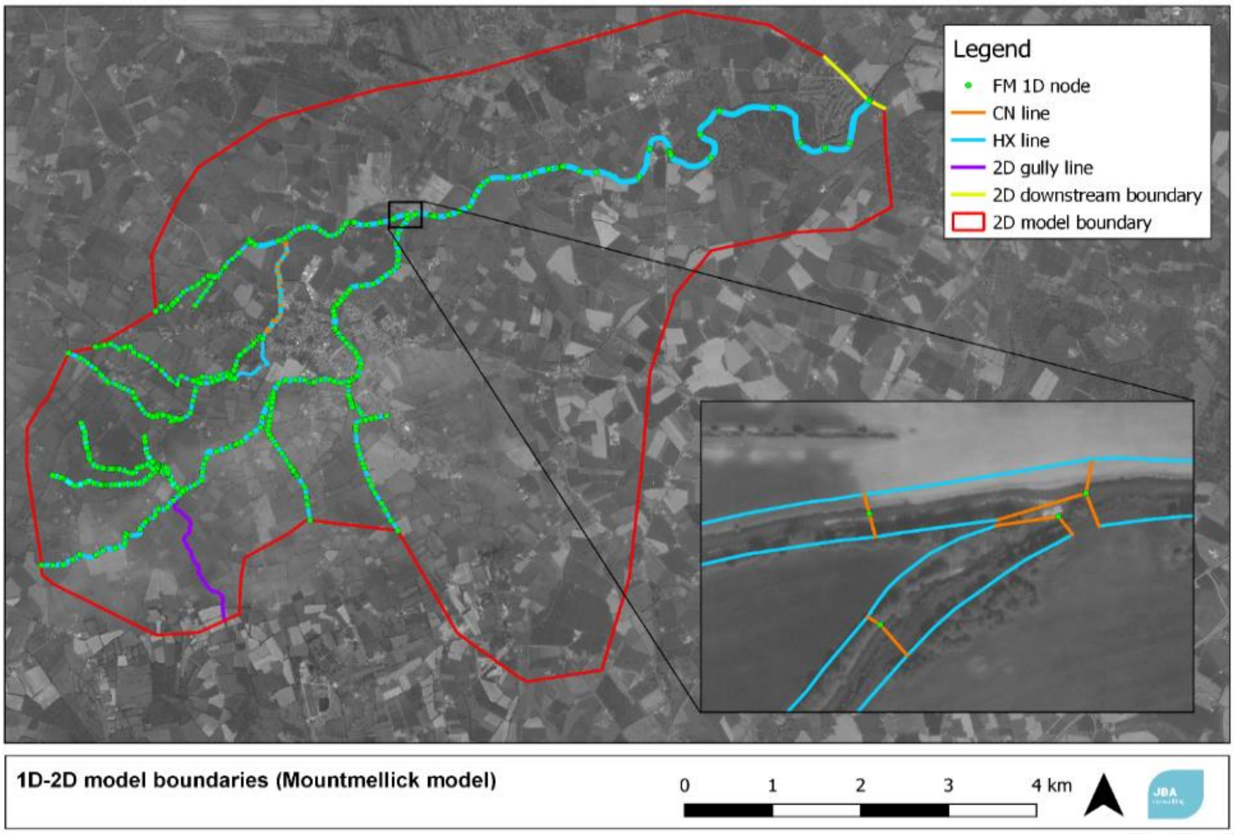


Figure 3-3: 1D-2D model boundaries (Mountmellick model)

3.3.4 ESTRY – FM connections

Two watercourses, the Pound River and the Clontygar Stream B have been modelled using ESTRY 1D rather than FM. These watercourses are connected to the FM 1D model components using:

- An ESTRY X1DH connection point linked to a FM QT boundary unit for flow moving from ESTRY to FM.
- AN ESTRY X1DQ connection point linked to a FM HT boundary unit for flow moving from FM into ESTRY.

Figure 3-4 shows the locations of the connection points between the two 1D channel types.

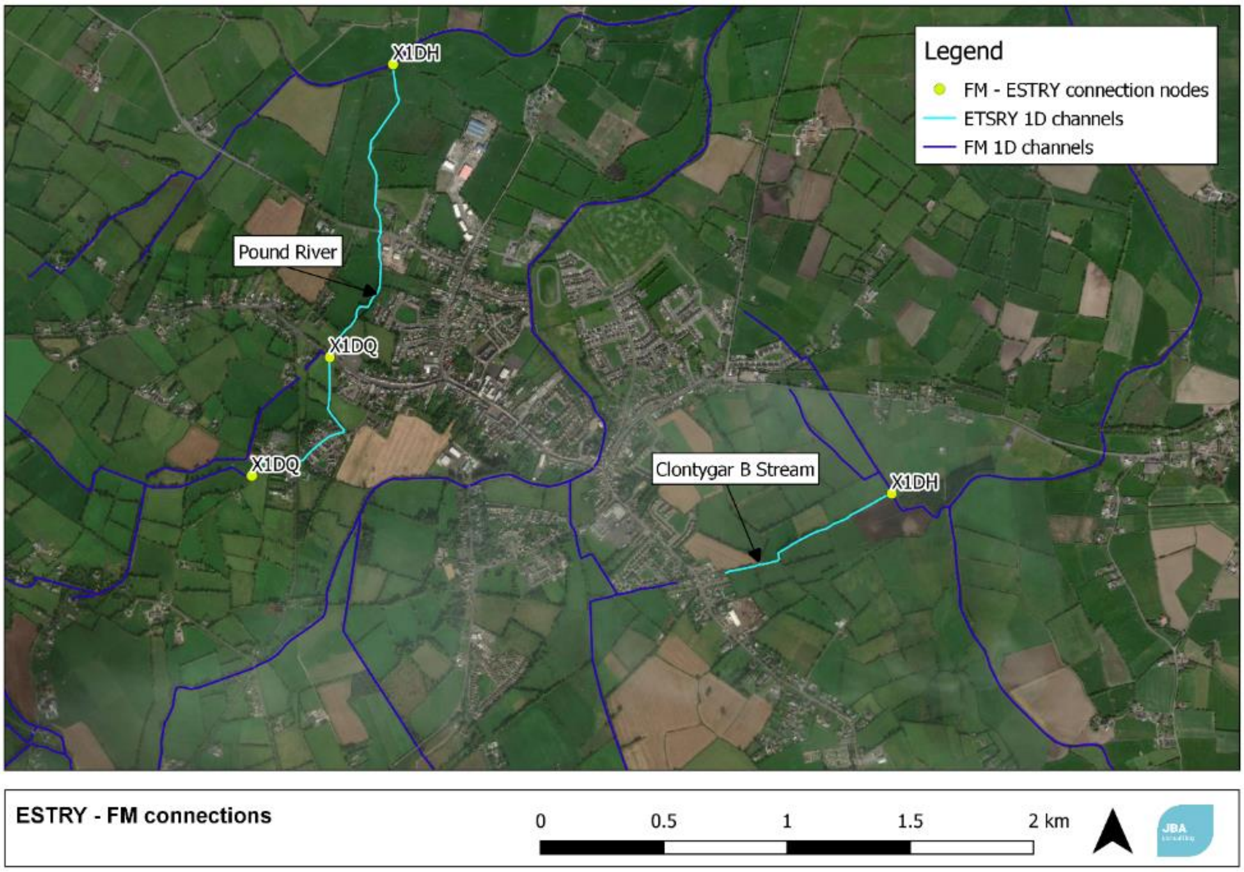


Figure 3-4: ESTRY – FM connections

3.4 Coefficients used

3.4.1 Culvert coefficients

In general, the default culvert inlet and outlet culvert coefficients provided with the FM software and the values recommended in the ESTRY-TUFLOW manual (2018) were applied to the 1D culvert structures within the model. This was considered appropriate as there was no evidence provided to warrant a deviation from the default values such as significant wear and tear on a structure or extreme scouring of channel bed. Any deviations from the generic values or approach for specific structures are recorded in Section 4.

3.4.2 Weir coefficients

While there are no formal weirs within the model area, weir coefficient values were applied to all spill units used to represent overtopping of structures in the 1D model. The coefficients used were reviewed and chosen based on the condition of the surface above the structure and to ensure the value was representative of reality. Refer to Section 4 for values used for individual structures.

3.4.3 Bend losses

Several sharp bends are recorded along some of the open channel modelled watercourses. To ensure the hydraulic effect of the bends is accounted for in the model FM bend loss units were included in the model. The bend loss units were applied to severe bends in watercourses (e.g. sharp 90-degree bends). The losses at each bend were estimated using the following equation:

$$h_o = (2B/R_c) \times (V^2/2g) *$$

Where:
ho = channel bend head loss
B = channel width
V = average flow velocity
g = acceleration due to gravity
Rc = centreline radius of bend
**Equation 9.7 from the Queensland Urban Drainage Manual Professional Edition 2013.*

Figure 3-5 shows the location of where bend losses were applied. Refer to

Table 3-3 for the bend loss values applied, all bends where losses were applied are within the Mountmellick model. Bend losses were not applied to all severe bends as in some cases when the head loss value was estimated it was so small that it would have minimal effect on the flow or the bend loss is incorporated in the entry/exit loss applied to a structure. Refer to Appendix C for any bend losses applied to individual structures.

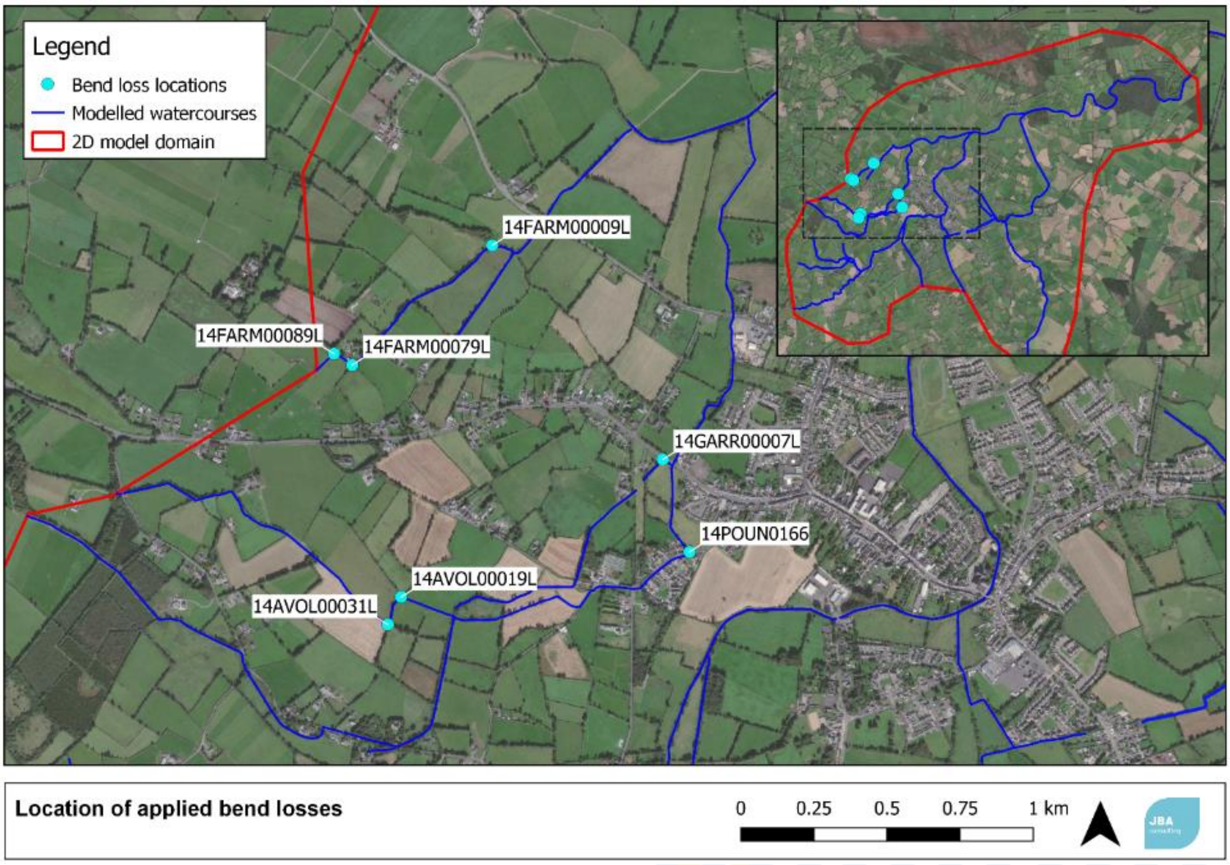


Figure 3-5: Location of open channel bends

Table 3-3: Bend losses applied within the Mountmellick model

Watercourse name	Bend location	Bend loss applied
Garroon stream	Upstream of junction with the Pound River	0.005
Farm stream	Between cross sections 14FARM00089 and 14FARM00079	0.001
	Between cross sections 14FARM00079 and 14FARM00072	0.002

Watercourse name	Bend location	Bend loss applied
	Between cross sections 14FARM00009 and 14FARM00003	0.006
Avoley	Between cross sections 14AVOL00031 and 14AVOL00019	0.026
	At cross section 14AVOL00019	0.002
Pound River	At the entrance of bridge 14POUN00166 (applied at structure)	0.660

3.4.4 Manning's N – Roughness

3.4.4.1 1D channel roughness

Different Manning's N values have been used to represent roughness within the model. The Manning's N values applied have been sourced from a number of sources including Chow 1959, general values applied in hydraulic modelling, site walkover and consultation of photographs and survey notes.

The channel roughness of the Owenass watercourse from Owenass bridge to Mountmellick bridge was also altered after review of panel markers during model calibration on a reach by reach basis. This was done to better represent vegetation present in the channel. Refer to the photographs in Table 3-4 for examples of the different channel roughness values and channel types to which they were applied.

Table 3-4: Examples of Manning's roughness values

Channel description	Chow 1959 channel no.	Manning's N value	Example cross section photograph
Clear wide channel, no encroachment of vegetation.	1.a	0.030	 14BARO15538

Channel description	Chow 1959 channel no.	Manning's N value	Example cross section photograph
Clear wide channel but with increased stones and weeds	1.b	0.040	 14POUN00071
Earth drainage channel with sluggish water, stony bottom and weedy banks	4.b.5 (high end)	0.040	 14GARR00059
Unmaintained channel, dense weeds and slow-moving water	4.e.1	0.080	 14BCBG00071
Unmaintained channel with weeds on banks but clean bottom	4.e.2	0.050	 14OTB200003

3.4.4.2 2D floodplain roughness

Surface roughness including buildings and various land uses within the 2D floodplain have been applied using a 2D materials layer. OSI Prime 2 land use polygon layer data was used to construct the materials layer and the different Manning's N roughness values given to each land use have been based on values from Chow 1959 and general values applied in hydrological modelling. Refer to Figure 3-6 for the modelled land use types and Table 3-5 for the corresponding Manning's roughness values applied.

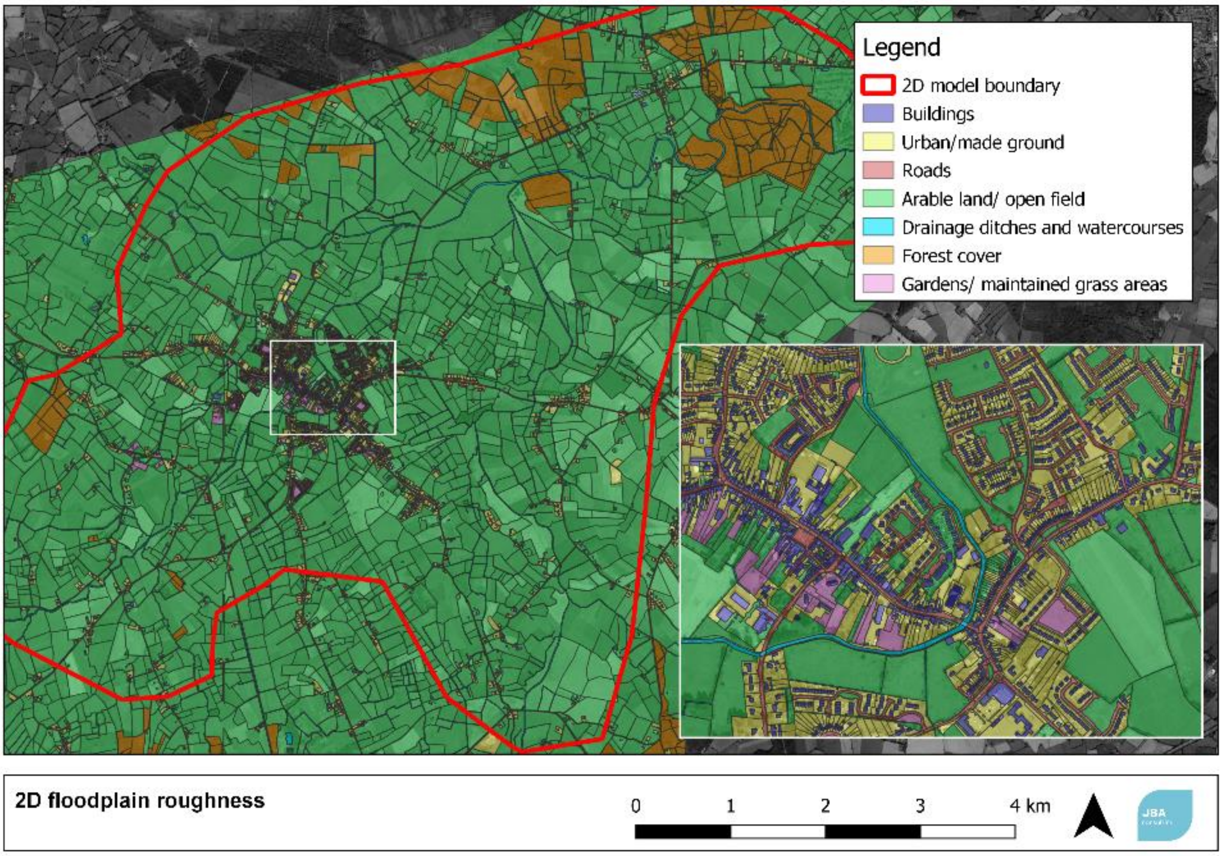


Figure 3-6: 2D floodplain roughness

Table 3-5: Manning's roughness values applied to the 2D floodplain

Surface	Manning's N value applied
Buildings	1.000 (high value ensures water preferentially flows around buildings before moving through them)
Urban/made ground	0.020
Roads	0.030
Fields/arable lands (open fields)	0.045
Gardens/maintained grass areas	0.040
Drainage ditches and rivers	0.050 (Manning's values overwritten by 1D channel values)
Forested areas (deciduous/conifer)	0.080

3.5 Topographic features

3.5.1 Retained walls

In most cases walls have been removed from the model, either from the 1D surveyed cross sections of river channels or not included in the 2D floodplain. This has been done to remove any potential reduction in flooding the walls may cause as they are generally classed as an ineffective defence as there is no guarantee that they will remain in place during a flood event. The removal of walls ensures the flood risk in the worst-case scenario is assessed. The following sections describes locations where walls have been retained and the justification of this in each case. All walls discussed are associated with the Mountmellick model; there are no retained walls in the Triogue model. A sensitivity test has been carried out to assess the impact of walls retained in the design events (refer to Section 8.2.8).

3.5.1.1 Pound River

Walls have been purposefully left in along a portion of the Pound River where the walls on both banks increase channel flow capacity and removing them would result in an unrealistic early onset of fluvial flooding in lower return period events. These walls proved to be effective in both the 2017 flood and Storm Ciara and are included in both the calibration and design runs. However, site investigation is being carried out to determine the structural integrity of the walls for the purposes of including them in the options assessment.

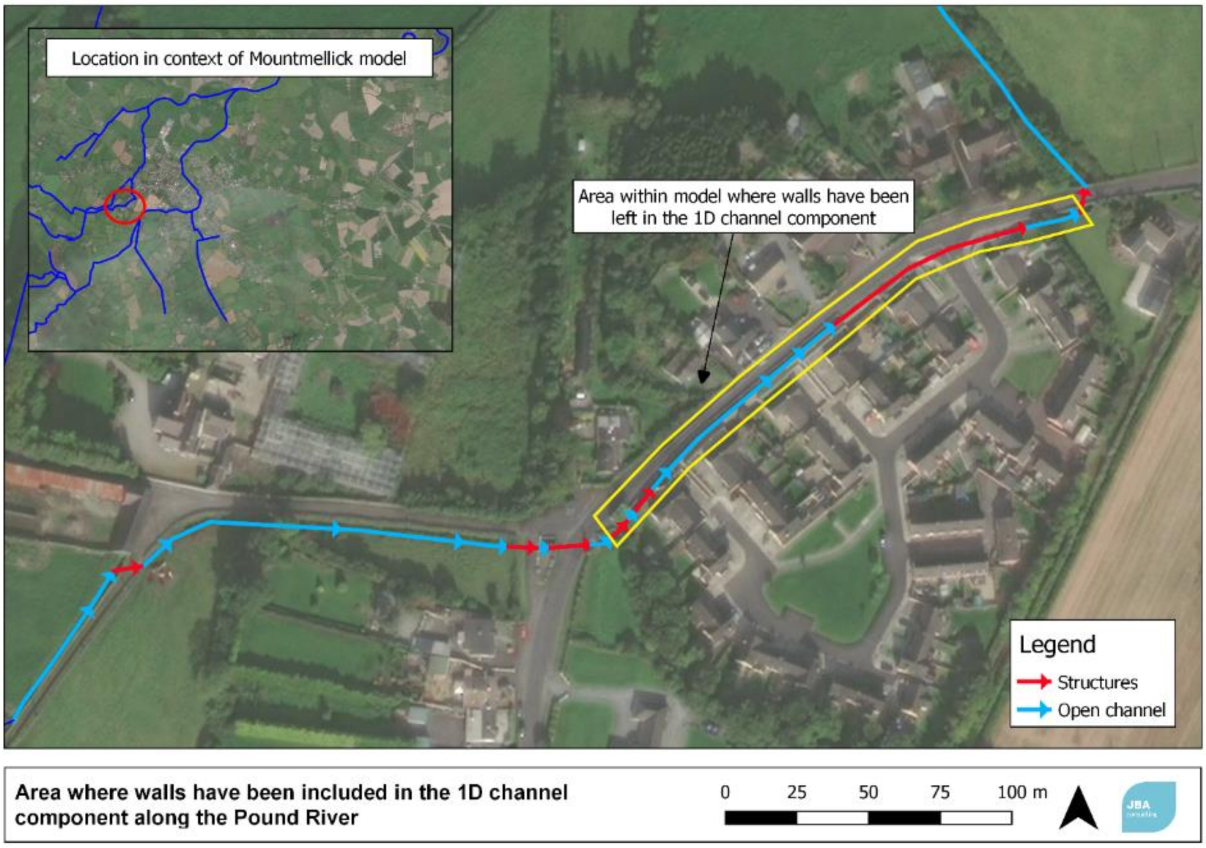


Figure 3-7: Area where walls have been included in the 1D channel component along the Pound River

Figure 3-8: An example of the walls retained on the Pound watercourse (both banks)

3.5.1.2 Wall included along Owenass River

Following review of initial model results it was noted that an area downstream of Convent bridge was being shown as flooded, but this did not match the known flood history for the area. Review of survey data showed an existing wall on the right-hand bank of the watercourse. This was initially removed from the 1D cross section but was reintroduced to ensure that the modelled flooding was realistic. This short section of wall was effective in the calibration runs and higher return period events. Refer to Figure 3-9 for wall location.

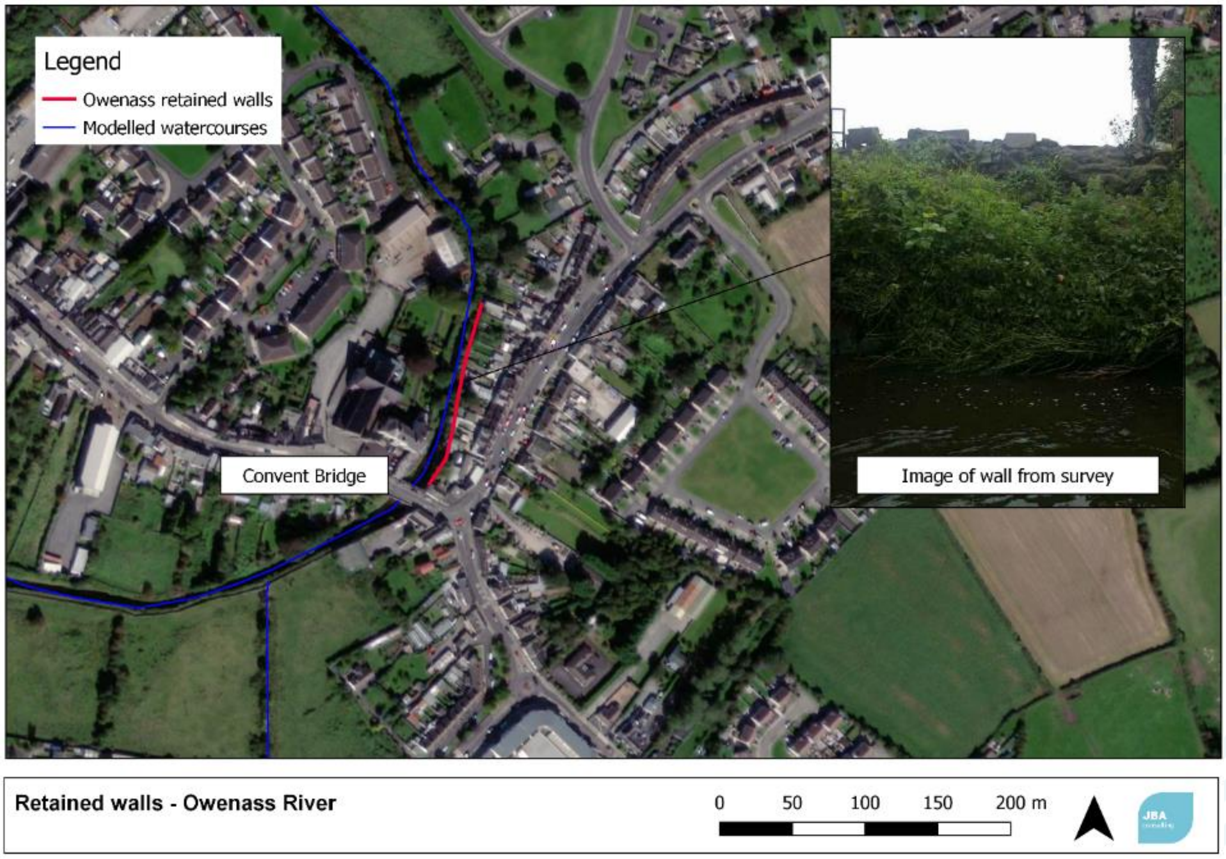


Figure 3-9: Retained walls – Owenass River

3.5.1.3 Walls included in calibration events

Figure 3-10 shows the location of key walls included in the Mountmellick model for the three calibration events examined. The inclusion of the walls for these specific events aided in replicating the observed flooding within Mountmellick. These walls are not included in any of the design event runs to ensure that a worst-case scenario is assessed for flood risk where there is no guarantee of walls being present or withstanding a future event. Wall heights and information for the included walls has been sourced from topographic and channel survey data.

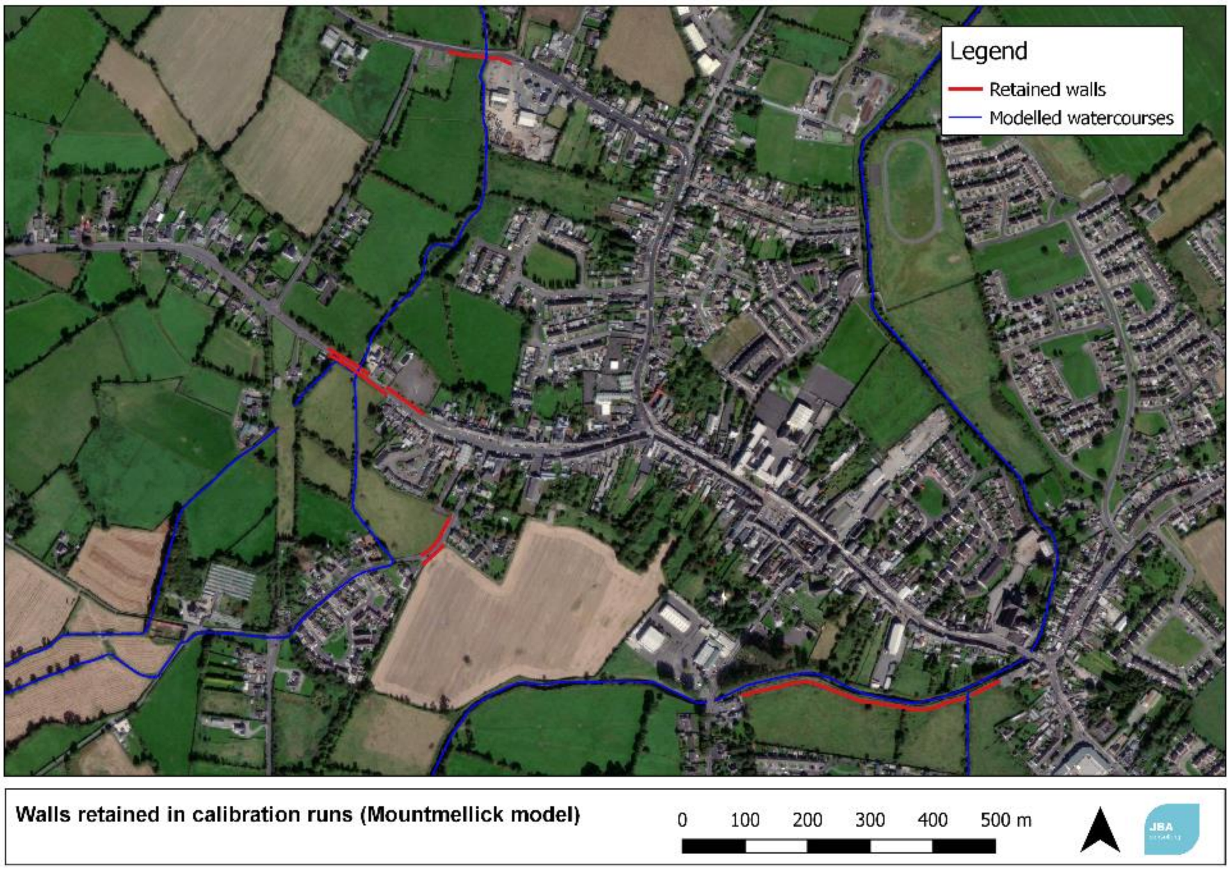


Figure 3-10: Walls retained in calibration runs (Mountmellick model)

3.5.2 Representation of small channels

The 2D model grid sizes has been set to 4m however there are several smaller watercourses that have cross section widths less than this. Figure 3-11 shows an example cross section of one of the smaller watercourses. In this case a single 1D-2D HX line is used to connect the 1D and 2D as the channel is not wide enough to accommodate two HX lines stably (with a gap between active boundary cells). To ensure that the correct levels along the left- and right-hand banks are being applied in the model along the single HX line two Zsh lines were used:

- A width attribute of 4 was applied to the Zsh line running along the side of the cell with the lower bank (thick Zsh line). The height of this zsh line bank level was applied to the entire cell.
- A second Zsh line was applied along the other side of the cell with the higher bank height with no width attribute. The height of this Zsh line was only applied to the cell side.

Using this method, the differing bank heights are represented and ensure that out of bank spill occurs along the smaller watercourses at the correct times and locations. A sensitivity test using a 2m grid cell size has been carried out using the 1% AEP to assess the representation of smaller watercourse and flow pathways.

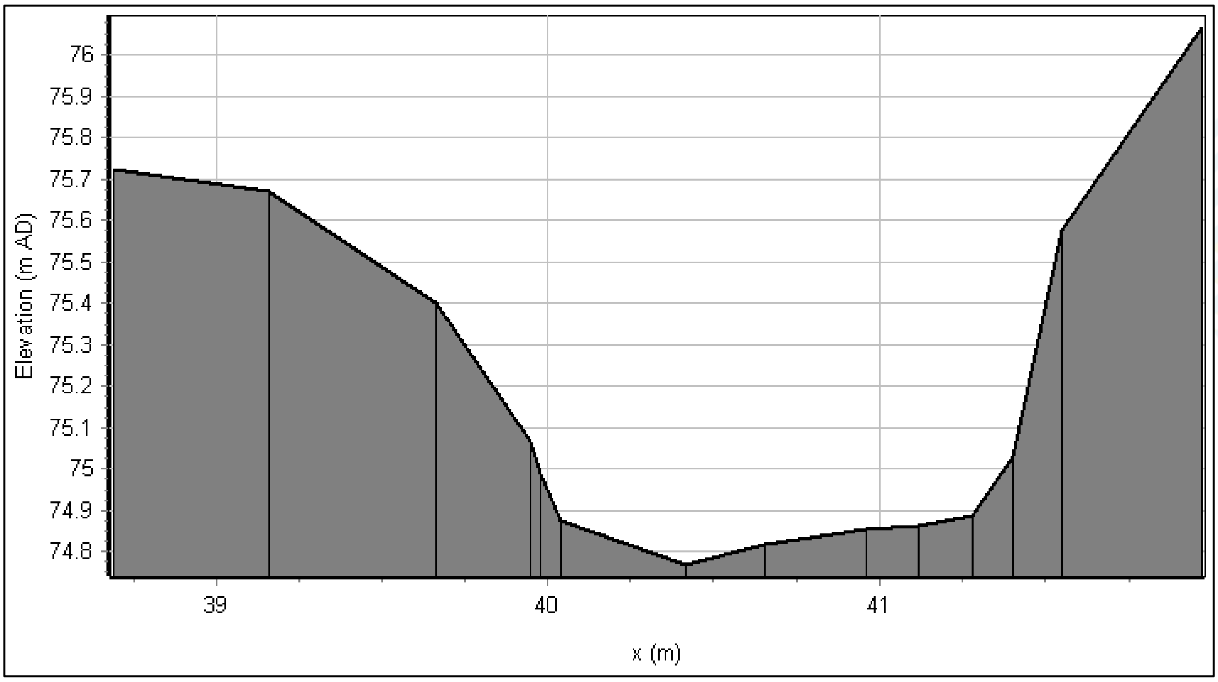


Figure 3-11: 14FARM00060 channel cross section

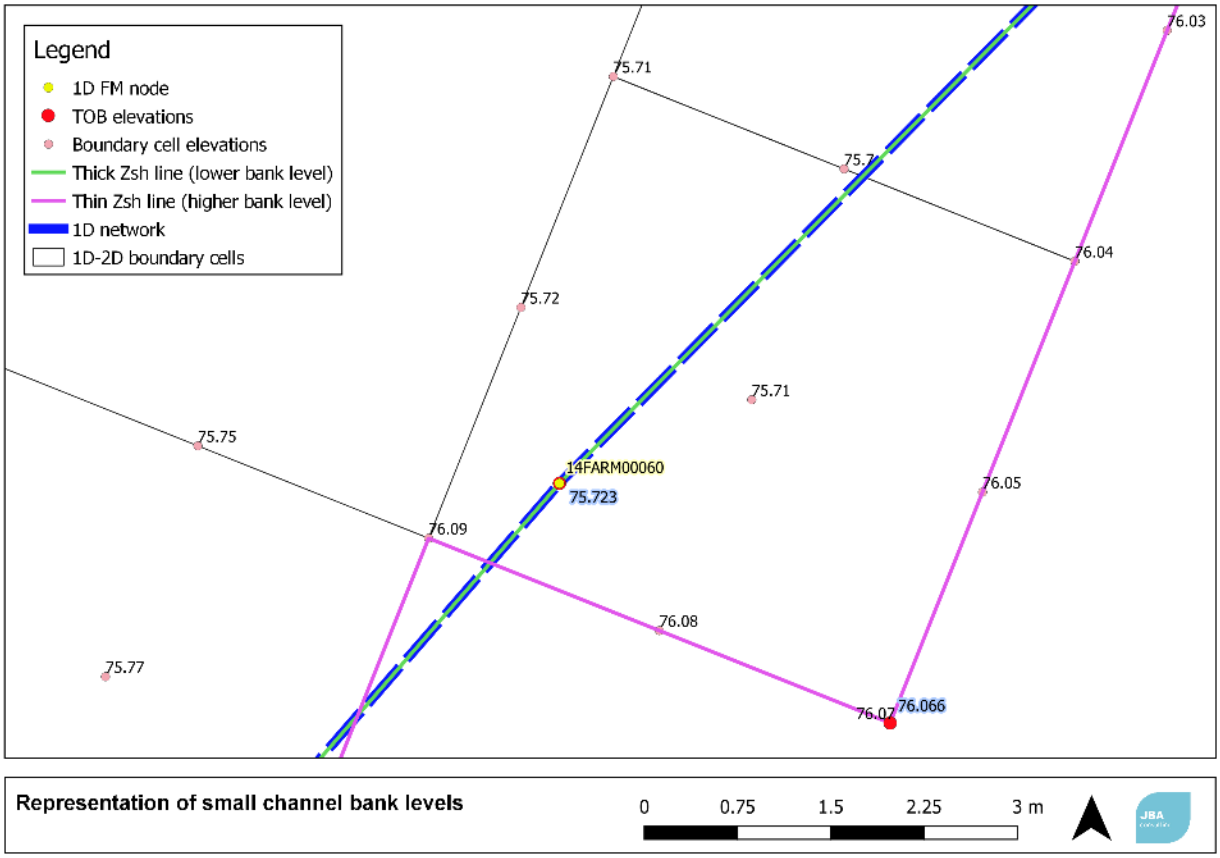


Figure 3-12: Representation of small channel bank levels

3.5.3 Representation of the Blackwater River within the Mountmellick model

The Blackwater watercourse flows into the Owenass River upstream of Mountmellick town within the Mountmellick model. It has not been explicitly modelled and originally flows from this watercourse were included via a point inflow in the FM 1D component as per the CFRAM model. To rectify this the point inflow was moved upstream and applied as a 2D inflow point to a 2d_zsh line with a Gully attribute that follows the watercourse path as seen in the DTM (refer to Figure 3-13).

The top of bank levels at the junction with the Owenass have been altered such that the flow from the 2D channel is able to transfer into the 1D channel but above the actual 1D channel level to ensure there is no premature out of bank spill from the Owenass at this low point in the bank.

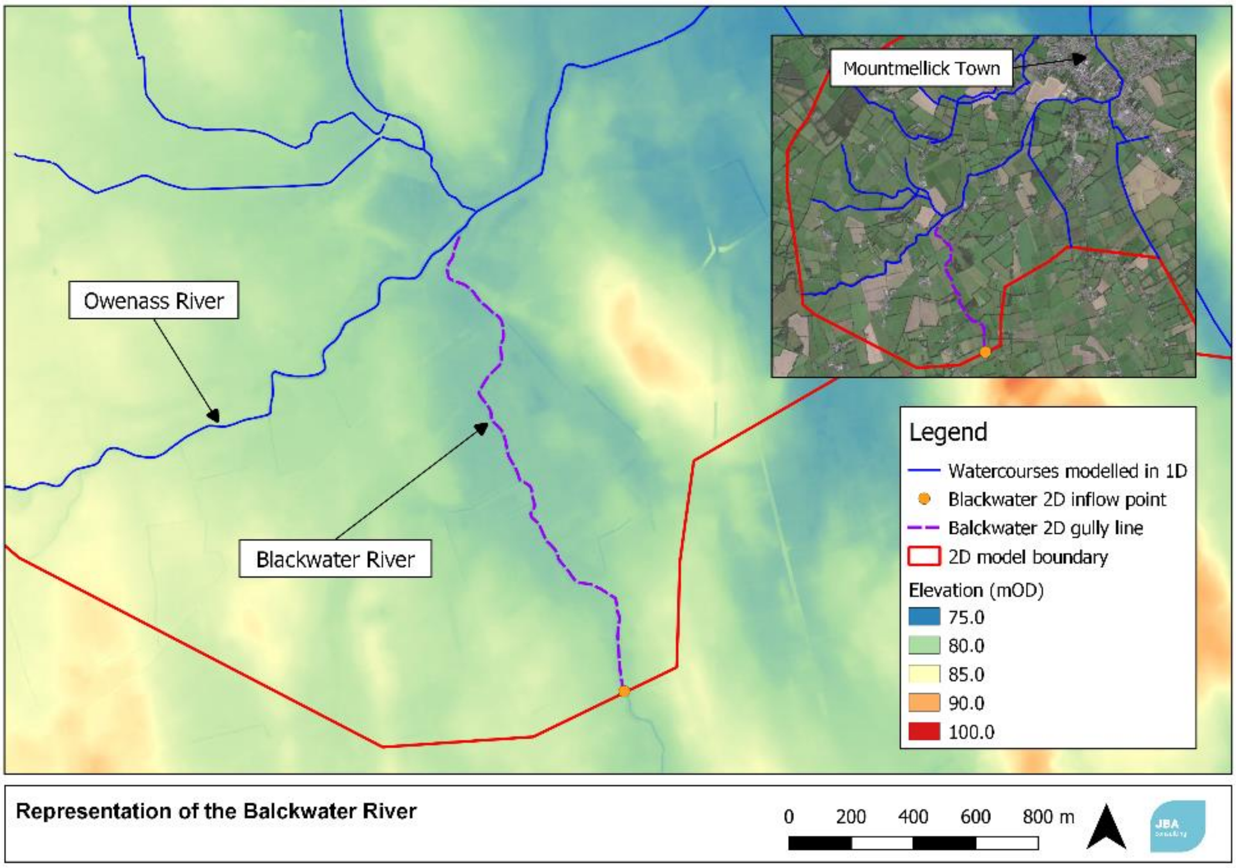


Figure 3-13: Representation of the Blackwater River

3.5.4 Representation of additional reaches

The scope for this project specified an examination of five additional small reaches:

- Additional Reach No. 1 Drain/stream tributary of the Pound River that enters at Pound Bridge on the R422
- Additional Reach No. 2 Drain South of the Manor House
- Additional Reach No. 3 Drains Bakers field running South to North and East to West
- Additional Reach No. 4 Flow path/Old Mill Race Bakers Field
- Additional Reach No. 5 Drain to south side of Owenass River in Healions Field

Figure 3-14 shows their locations. Reach 1 is included in the model as a formal channel (Garroon stream) while reaches 3 and 4 are included as gully channels in the 2D. Reaches 2 and 5 have not been included within the model as they are either too small or were shown to not be formalised ditches/channels. Those reaches represented in the 2D act as flow paths within the floodplain rather than actual channels so no formal inflows have been derived for them.

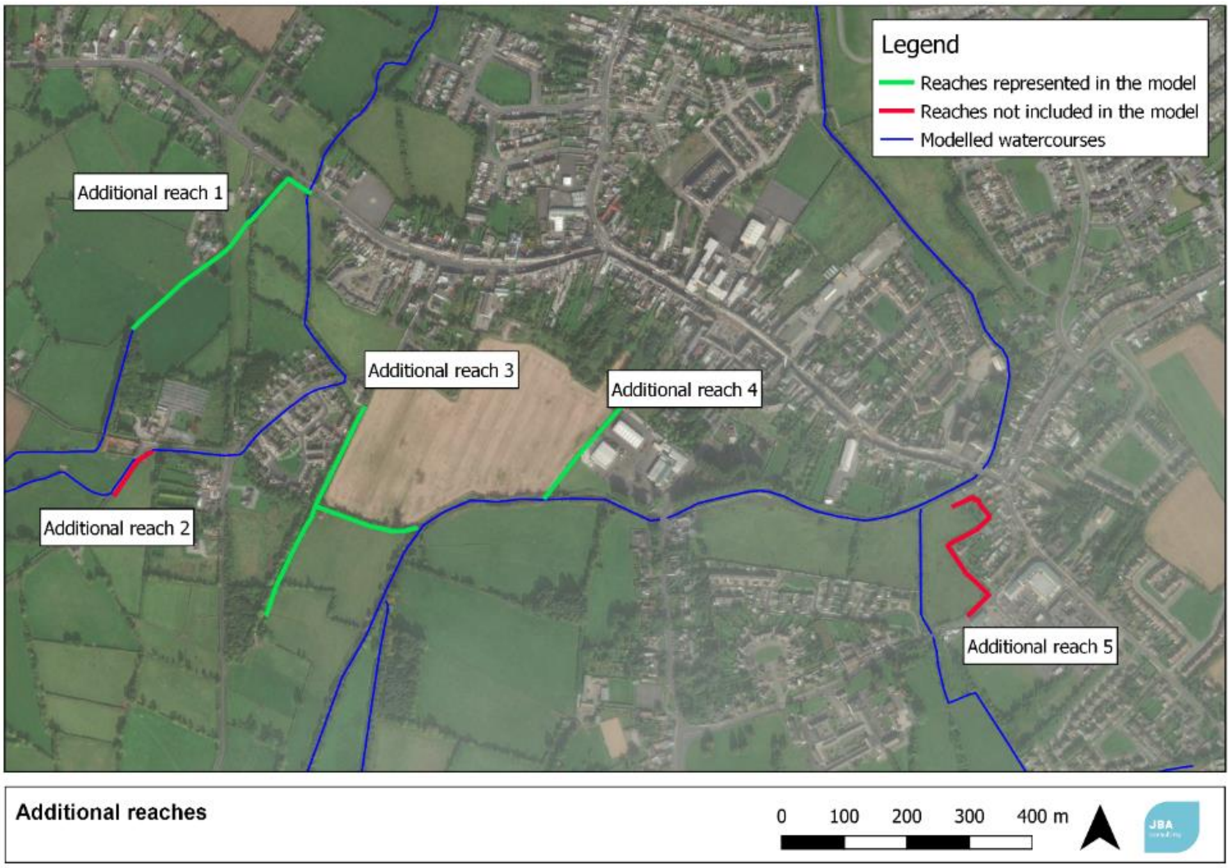


Figure 3-14: Additional reaches

3.5.5 2D Stability patches

Roughness stability patches have been applied to 2D areas within both the Mountmellick and Triogue models. Figure 3-15 and Figure 3-16 show their locations. The patches have been included to provide stability for two different reasons and the Manning's roughness values applied reflect this.

Stability patches with a roughness value of 0.10: Applied to areas where there are short steep slopes which then quickly changed to flatter topography. The change in topography causes a large change in flow velocity over a short space putting stress on the 2D solution scheme. The increased roughness of the stability patches slows the flow and allows a smoother transition of water across the topography.

Stability patches with a roughness value of 0.80: Applied to junctions and areas which are drowned in high flow events to help stability and with the transfer of water between the 1D and 2D solution schemes as the water moves over the area drowning the 1D channels.

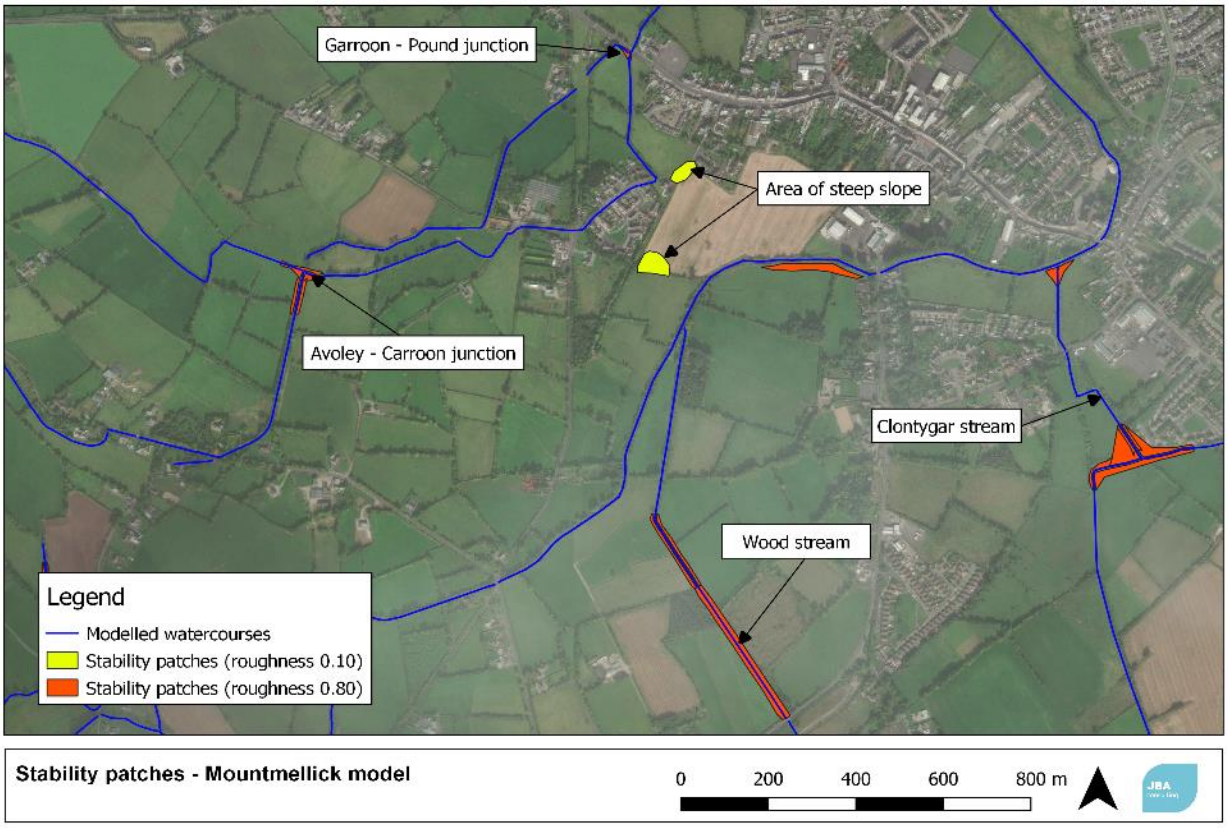


Figure 3-15: Stability patches – Mountmellick model

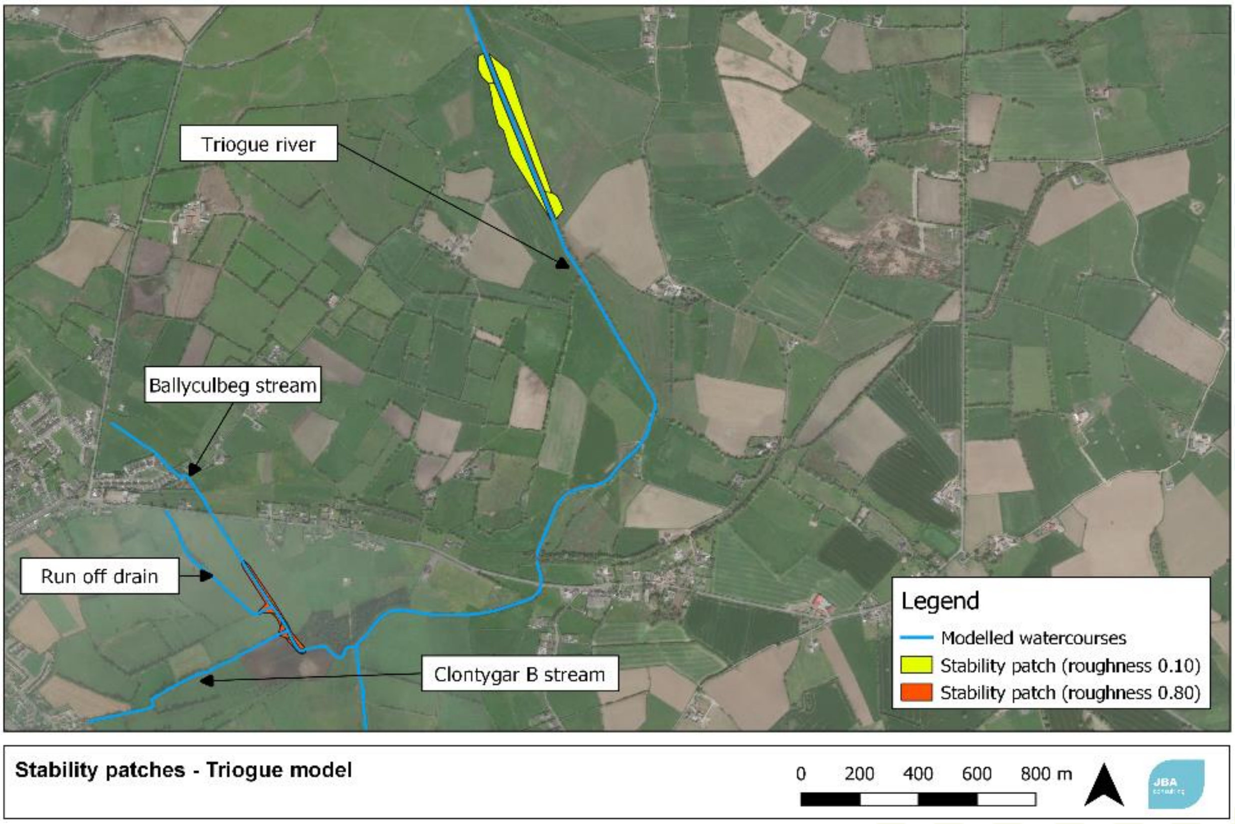


Figure 3-16: Stability patches – Triogue model

3.6 Limitations of modelling method used

Within the modelling process various limitations were identified, this section describes the limitations found and how they were accounted for within the model.

- **Modelling of small channels**: Channels with widths of 4m or less were modelled using a single HX line to connect the 1D and 2D domains. To ensure the banks heights for these smaller watercourses were properly represented two Zsh lines with the left and right-hand bank values were used. Refer to Section 3.5.2 for more detail.
- **Representation of watercourses in ESTRY**: Two watercourses are modelled in 1D using ESTRY not FM – the Pound River and the Clontygar stream B. These watercourses were modelled using ESTRY as they include complex topography (e.g. the Clontygar stream B has an extremely steep slope) or structures (e.g. the Pound River has a high number of small irregular structures) that are modelled more stably in ESTRY. This approach was agreed with the OPW via emails received 14/10/2019 and 16/10/2019 with respect to the modelling method statement. The ESTRY components are linked to the FM 1D channels where necessary.
- **Flood modeller instability during high flow events:** During higher flow events when there is increased volume within the systems large amounts of non-convergence or instability were reported within the Flood modeller component of both models. The instabilities occur when there is increased interaction between flow in the 2D floodplain and in smaller FM 1D watercourses. During high flow events the channels are essentially drowned with 2D flow passing over them. The 1D channels struggle to deal with the large transferral of water from the 2D, into the channel and then back out again which results in a point of non-convergence or instability.

  As this is only associated with larger volumes of water it is not an issue seen in the lower flow events (1% AEP and below). For higher flow events (greater than 1% AEP) the smaller channels where this issue occurs have been removed as 1D channels and replaced with 2D only gullies like the Derrycloney watercourse (refer to Figure 3-17). This removes the 1D-2D interaction across these smaller channels and removes the instabilities associated with increased water level and volume improves model health but does not resolve the issue entirely. Inflow and lateral flow hydrographs are applied to the watercourses in 2D for these higher flow event runs. As the levels and volumes are so large for the higher events this approach does not impact the representation and output of final water levels and extents reported, and this has been thoroughly tested. Refer to Figure 3-18 for comparison of 1D model health between the normal and high flow models.

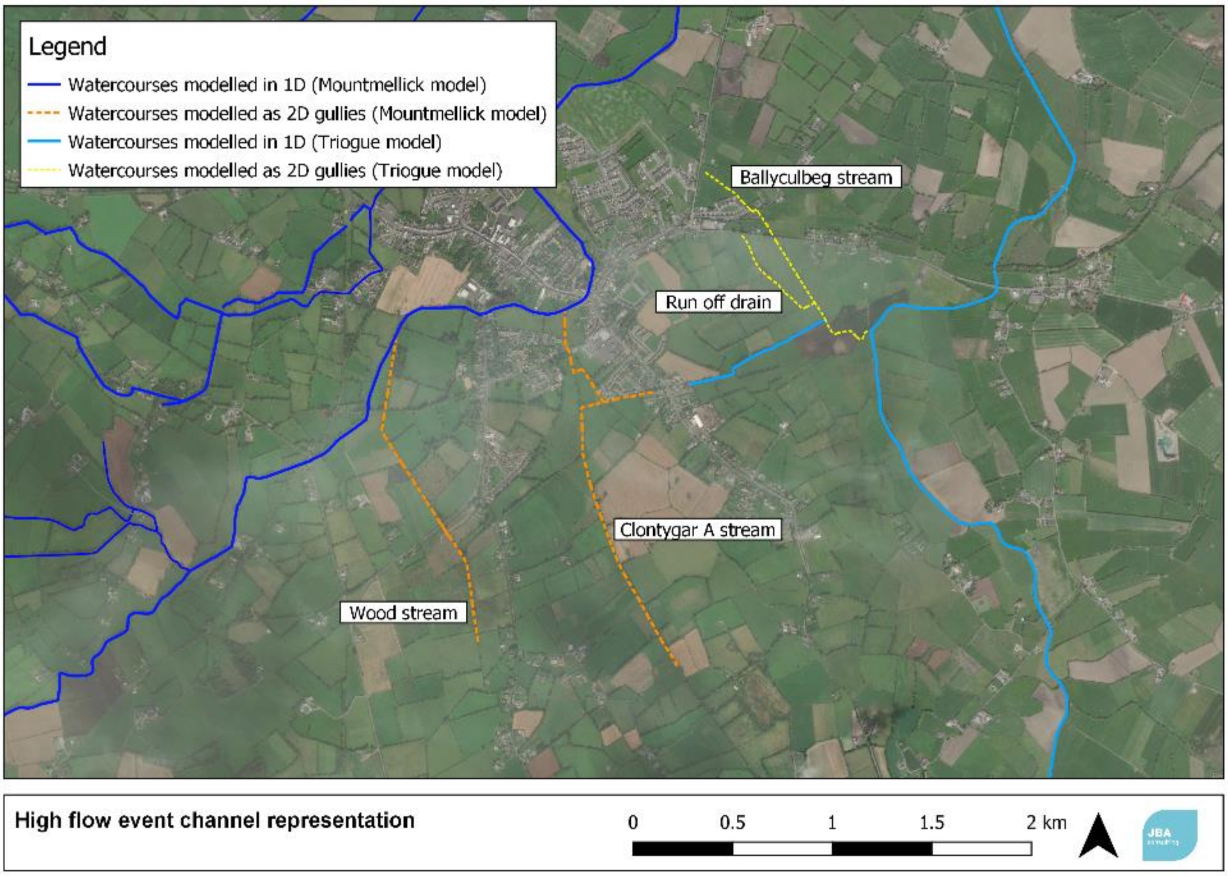


Figure 3-17: High flow event channel representation

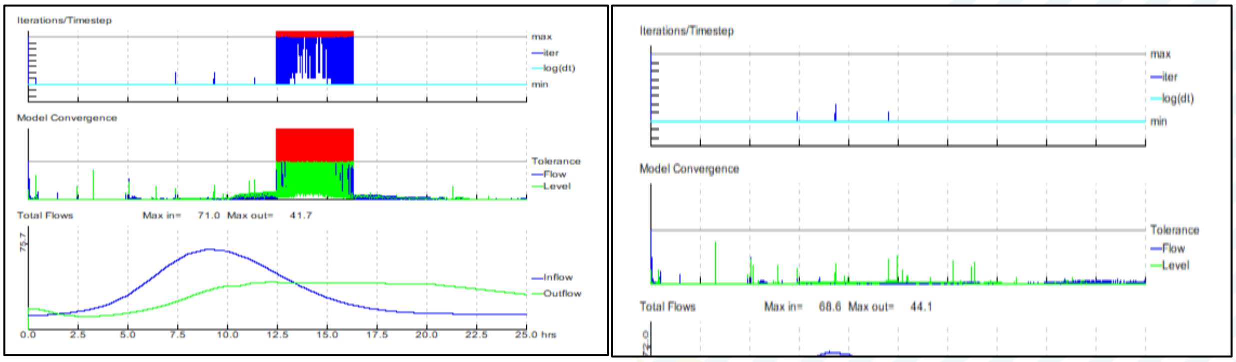


Figure 3-18: Comparison of Mountmellick model 1D stability for the 0.5% AEP event (left – baseline model, right – high flows model)

4 1D Structures

Descriptions of all the structures within the Mountmellick and Triogue models can be found in Appendix C. The performance outputs of the structures have been sourced from the 1% AEP 11-hour flow event. Within the development of the model and review of previous flood history the following structures have been identified as critical within the system and where a blockage could severely impact the flood risk of the surrounding area:

- **Mountmellick Mill bridge (location of gauge 14114)**

  This bridge is directly downstream of a key spill area for the Owenass River, should the bridge become blocked during an event and the conveyance reduced through the bridge reduced it is likely to increase flooding and flow bypass around the gauge increasing flood risk to the surrounding area.

- **Convent Bridge (bridge blocked during the 2017 event)**

  Convent bridge was blocked during the 2017 event which resulted in increased backwater effect along the Owenass between the Mountmellick Mill and Convent bridges and up the Clontygar stream. A more quantified assessment of the impact of blockage at this point in the system on the movement of water downstream towards the Barrow would allow greater certainty of the increased risk blockage has at this location.

- **Railroad culvert (upper most structure along the Manor Court area on the Pound 14POUN00203)**

  This structure is located upstream of the Manor Court area and is the first in a series of structures along the watercourse section. Review of initial results shows that the structure becomes surcharged in larger events resulting in a backwater event and flooding. Should the culvert be blocked this backwater effect and out of bank flooding would be further aggravated and impact the properties in the area hence a blockage assessment at this structure is recommended.

- **Wolfe Tone bridge (downstream of Manor court area)**

  The combined flow of the Pound River and Garroon Stream pass under this structure, as well as flood waters from the Owenass during large flood events with a large volume of water being held upstream of the bridge. Should the structure become blocked levels upstream of the bridge and along the Manor Court area may increase and additional properties could be impacted in a blockage scenario.

It is recommended that a further assessment of the impact of blockage on these structures is carried out.

5 Rain on Grid model

A separate 2D only rain on grid (ROG) model was developed for the urban areas of Mountmellick town. The purpose of this model was to understand and provide indicative contributions of surface water from storm water systems to the watercourses moving through the town by simulating the three most significant rainfall events known for Mountmellick in 2017 and 2020 (Ciara and Dennis). This was done due to difficulties in sourcing information about the storm water system and outfalls within the town. This section details the ROG model. The model was run for the three calibration events and a range of design rainfall storm events. Model overview

Table 5-1 provides a hydraulic summary of the model. The model schematisation is shown in Figure 5-1.

Table 5-1: Hydraulic summary

ROG model	Value
Software	TUFLOW 2018-03-AE-w64
Timestep	2 Seconds
Grid cell size	4m
Model area	8.31km^2
Inflow	Rainfall hyetograph applied over entire area using a 2d_rf polygon
Run time	25 hours for a 24 hour simulation

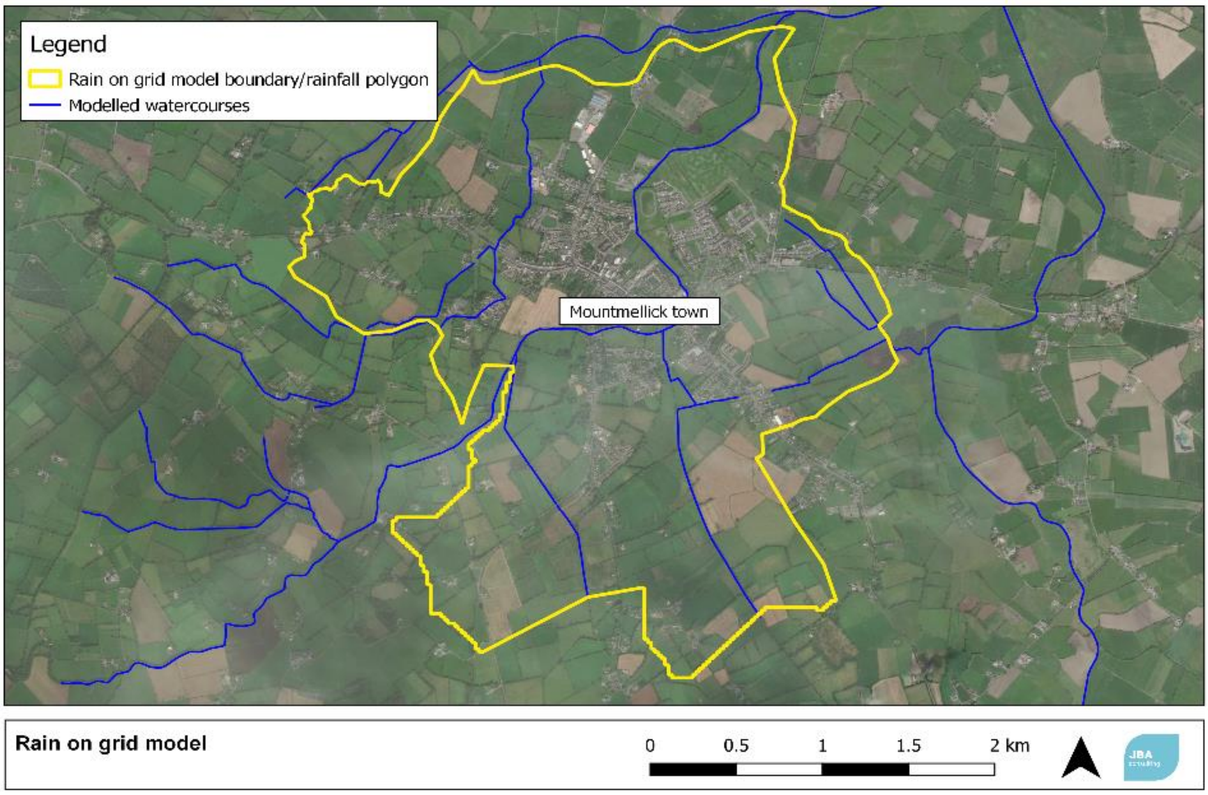


Figure 5-1: Rain on grid model

5.1 Input data

5.1.1 DTM

The same DTM datasets discussed in Section 2.2 was used to define the topography for the ROG model. The DTM has been reviewed and is of sufficient quality for the purpose of the ROG model.

5.1.2 Inflow data – rainfall

Rainfall data for all events was sourced from MET Eireann. For the design events total rainfall depths for a given return period and storm duration were sourced from the MET Eireann Depth Duration Frequency (DDF) dataset. A generic design storm hyetograph shape was then created for a given storm duration.

The ROG model was also run for the November 2017 events used for calibration of the fluvial model. The hyetographs for this event were developed by sourcing the total rainfall from local daily or sub daily rain gauges and applying the total to the recorded hyetograph shape at Gurteen gauge (sub daily rain gauge close to the study area) and scaling as appropriate. The same input hyetographs for the calibration event were used in both the ROG and fluvial models. Refer to Section 8 for more discussion on calibration events and the corresponding hydrology report for further detail on rainfall data.

5.1.3 Roughness and infiltration values

The same 2D roughness layer and values described in Section 3.4.4.2 has been used for this model to define roughness.

Table 5-2 gives the infiltration values applied in the model. The model subtracts the initial loss at the start of the event and then subtracts the continuous loss from the total rainfall falling on a cell for a given time step. The loss values used are the recommended general values for the given material.

Table 5-2: Applied infiltration losses

Material	Initial infiltration loss (mm)	Continuous rainfall infiltration loss (mm/hr)
Buildings	0	2
Urban/made ground	0	2
Roads	0	2
Arable lands/open fields	5	0.2
Drainage ditches	5	0.2
Forest cover	5	0.4

5.2 Model results

Pluvial flood extent maps for the 1% AEP event (1- and 8-hour storm duration) and the November 2017 event are presented in Appendix E. From the modelled extents pluvial flooding is widespread throughout the Mountmellick area.

Topographical depressions within the landscape result in pooled areas of water creating waterlogged areas particularly in wide open areas where there is limited/no drainage (e.g. in Bakers field near the MDA boundary and on the right hand bank of the Owenass between Mountmellick Mill and Convent bridge). This will become more prominent in wetter periods where the ground is saturated, and the falling rain will rest on the ground surface. Standing water in these areas from pluvial sources reduces the potential flood plain storage in fluvial events.

Within the urban areas localised spot pluvial flooding is observed throughout the town area. It is highlighted that much of this spot flooding would be managed within the local stormwater drainage system which is not included in the ROG model. However, review of the modelled extents shows a considerable amount of pluvial flooding reported along Davitt Road and surrounding area. The ROG modelling has identified this area as one more at risk of pluvial flooding. The topography of the area results in stormwater ponding and impacting properties and access routes to a level which may not be managed by the stormwater system. It is noted that this area was subject to flooding in the November 2017 event and there were multiple reported issues relating to the backing up and surcharging of the local stormwater system rather than flooding from a fluvial source which is consistent with the findings of this ROG modelling.

Further to the assessment of localised pluvial flooding in Mountmellick data from the ROG modelling has been used to provide inflows for several smaller, stormwater-fed watercourses within the hydraulic model (refer to the Mountmellick FRS Hydrology Report for more discussion on this).

6 Model Scenarios

A series of model runs were undertaken to meet the objectives of the project. The key model files are outlined in Table 6-1.

Table 6-1: Key model files – Flow events

Key model files – Flow events		
Flood modeller files	IEF	MOUNTMELL_140_XXXX_MOUNT/TRIO
	DAT (events)	MOUNTMELL_130_CB2/ MOUNTMELL_102_TRIO MOUNTMELL_130_HGULLY/ MOUNTMELL_102_TRIO_GULLY (High flow events)
	DAT (sensitivity)	MOUNTMELL_140_MOUNT_MANM/P MOUNTMELL_102_TRIO_MANM/P
	IIC	MOUNTMELL_88_b
	IED	Dependent on event and model
	Results	MOUNTMELL_140_XXXX_MOUNT/TRIO
TUFLOW files	Tcf	MOUNTMELL_~e1~_~e2_~s1~_~s2~_140
	Ecf	MOUNTMELL_140
	Tgc	MOUNTMELL_140
	Tbc	MOUNTMELL_140
	Tef	MOUNTMELL_138
	Tmf	MOUNTMELL_136
Notes	Same TUFLOW files used for both models	

7 Model Performance

This section summarises the general performance of the Mountmellick existing scenario hydraulic model.

- Model runs were run in double precision with a 1 second 1D FM, and ESTRY timestep and a 2 second 2D TUFLOW timestep.
- Average model run time is approximately 8 hours for a 25-hour simulation.

7.1 Model Stability

7.1.1 1D Flood modeller stability

Figure 7-1 and Figure 7-2 shows the 1D FM convergence plots for the 1% AEP 11-hour flow event. FM 1D mass balance is reported as negative due to spilling of water into the 2D domain and so not reflective of the overall model health.

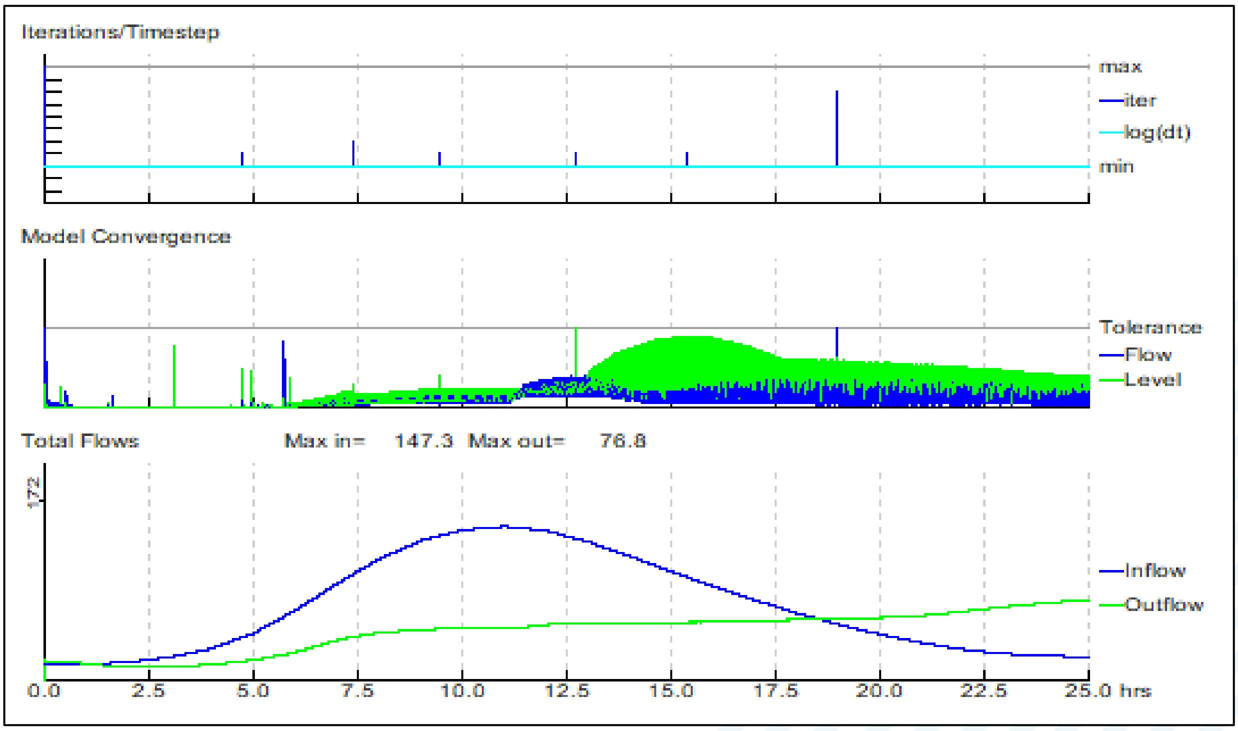


Figure 7-1: FM convergence plots for the 1% AEP 11 hour flow event (Mountmellick model)

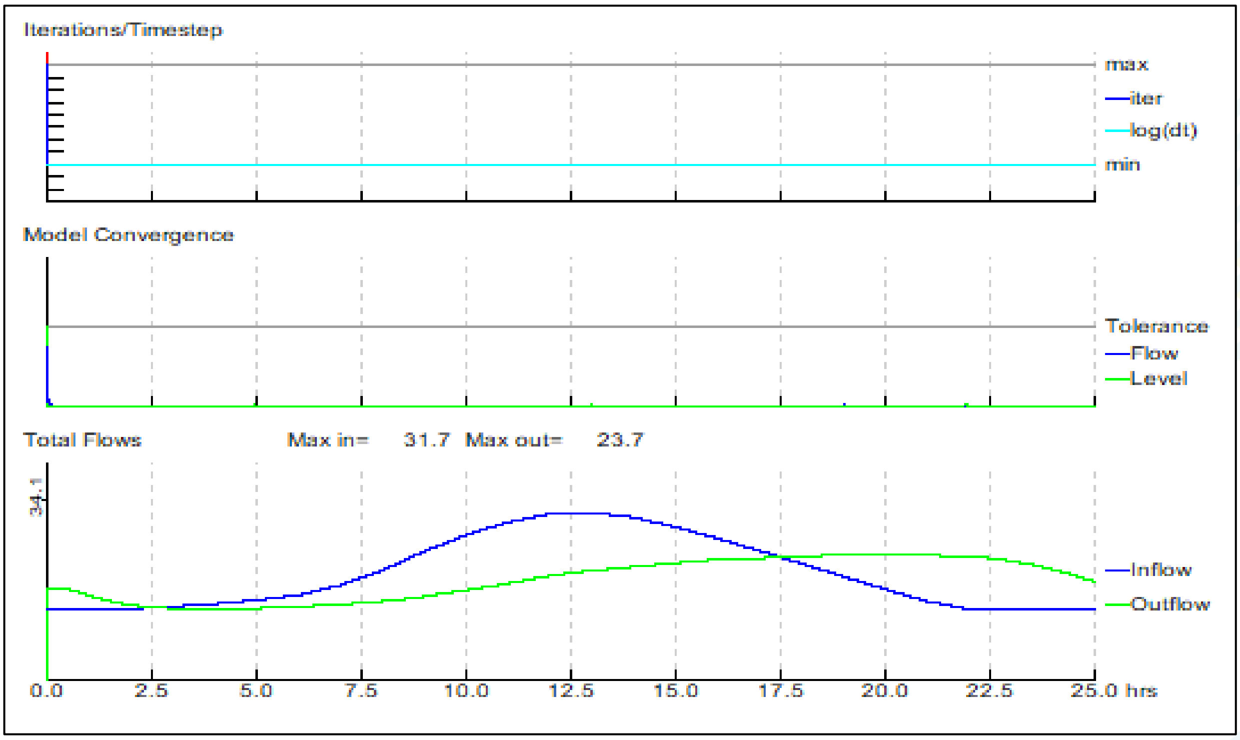


Figure 7-2: FM convergence plots for the 1% AEP 11 hour flow event (Triogue model)

7.1.2 2D TUFLOW stability

Within the 2D domain to ensure that the model is stable and performing adequately three main factors are examined:

- Checks and warnings recorded,
- Number of negative depths,
- Mass balance error (MBE).

7.1.2.1 Checks and warnings

The following checks and warnings occurred prior the start of the model run:

- CHECK 2099 – Ignored repeat application of boundary to 2D cell

  Two HX lines lie within the same 2D cell snapped to a 1D node. This check occurs at watercourse junctions where HX lines meet. As the HX lines are set to the bank heights which are the same at the junction this check is not a concern and does not affect model performance.

- CHECK 1152 – For channel XXX, using centre cross-section and ignoring end cross-section(s)

  This check only occurs along the watercourses modelled in ESTRY where a centre cross section has been used to apply the height width tables to structures, the check refers to the following structure cross sections:

  - POUN00203E
  - POUN00189C
  - POUN00189E
  - POUN00186E

- POUN00186J
- POUN00184E
- POUN00168J
- POUN00166C
- POUN00133B
- POUN000732

This check does not affect model performance.

- CHECK 1034 – No XS line data at downstream and of channel XXX. Using upstream end cross section

  This check occurs where there is no ESTRY downstream cross section due to connection back into the FM 1D model component, this check occurs at downstream extent of the Clontygar B stream and the Pound River. The connections and cross sections at these locations have been reviewed and deemed appropriate.

- CHECK 1393 – Node XX linked to external 1D scheme

  This check occurs where there is a connection between the ESTRY and FM 1D model components and does not affect model performance.

- WARNING 1100 – Structure XXX crest/invert is below bed of primary up/downstream channel XXX

  This check occurs where there is a mismatch between bed and invert levels. All points where this warning occurs the difference in levels is below 5mm, and all inverts have been cross checked with survey data to ensure mismatch does exist.

- WARNING 2218 – Manning's n value of 1.00 for Material 1 is unusually low or high

  Material 1 in the .tmf file refers to buildings which are modelled with a roughness value of 1.00 to replicate flow preferentially moving around properties before moving through them, this warning does not affect model performance.

- WARNING 1036 – Maybe problems with interpolating n values for channel XX. Interpolating n using channel n and downstream XSL n. Check n values. US X-Section n not specified.

  This warning occurs at POUN00071 directly downstream of a bridge modelled as two irregular culverts hence there is no US cross section value applied. Review of the model outputs shows the Manning's value applied is appropriate and the warning does not affect model performance.

7.1.2.2 Negative depths – Triogue model

1D Negative depths occur in the model at a single point along the Clontygar B watercourse modelled in ESTRY in the higher return period events:

- The negative depths appear for a period of approximately 2 hours during the run at the point where there is a significant slope change upstream of an existing culvert.
- At the time the depths appear water level in and out of bank reaches the point at which the slope changes with water travelling upstream but unable to increase due to the slope of the channel and topography.
- This results in the water level at this point fluctuating as water moves back and forth causing instability in the 1D solution scheme and generating negative depths.

As the negative depths occur at a single localised point for a short period of time and their presence can be explained by realistic behaviour within the system, they are not considered to impact the modelled results and flood extents generated within the model. It is also noted that the location of the issue is not within a critical area in relation to flood risk.

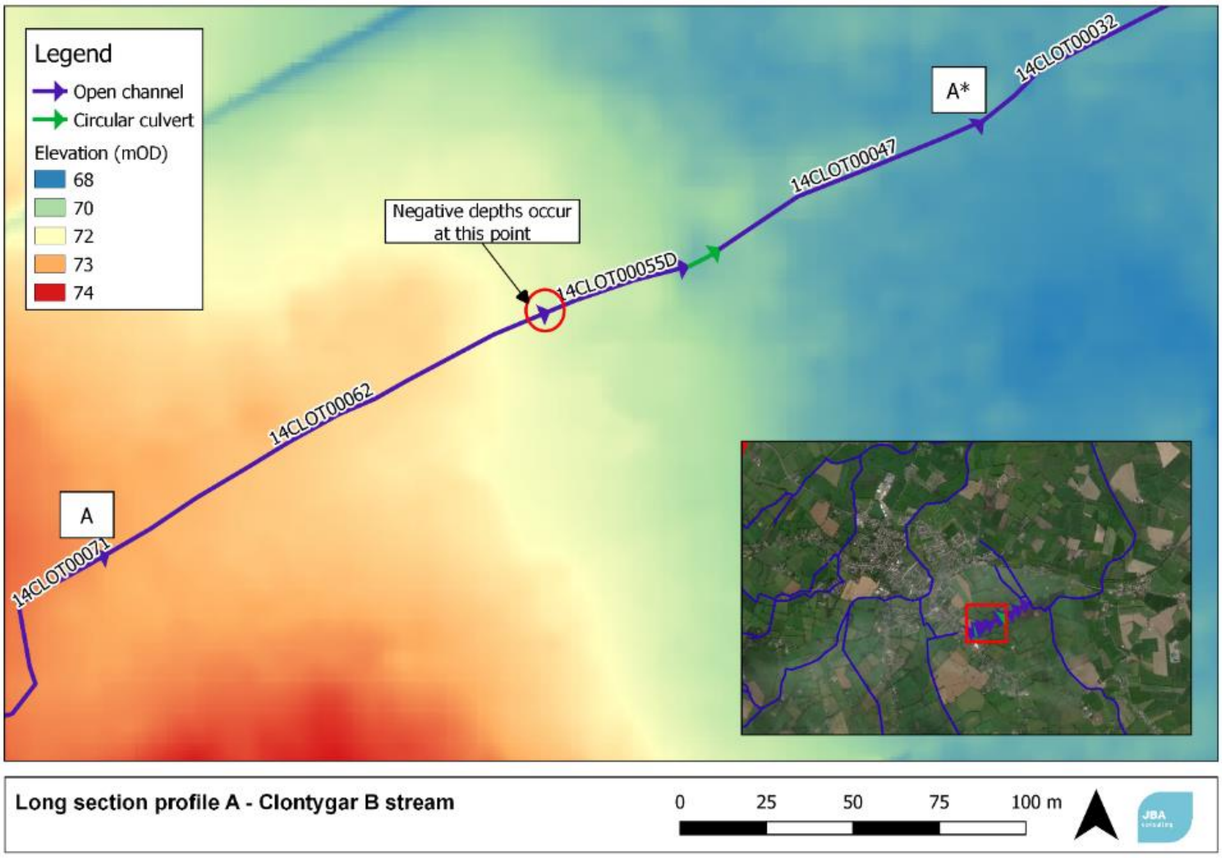


Figure 7-3: Location of long section profile A – Clontygar B stream

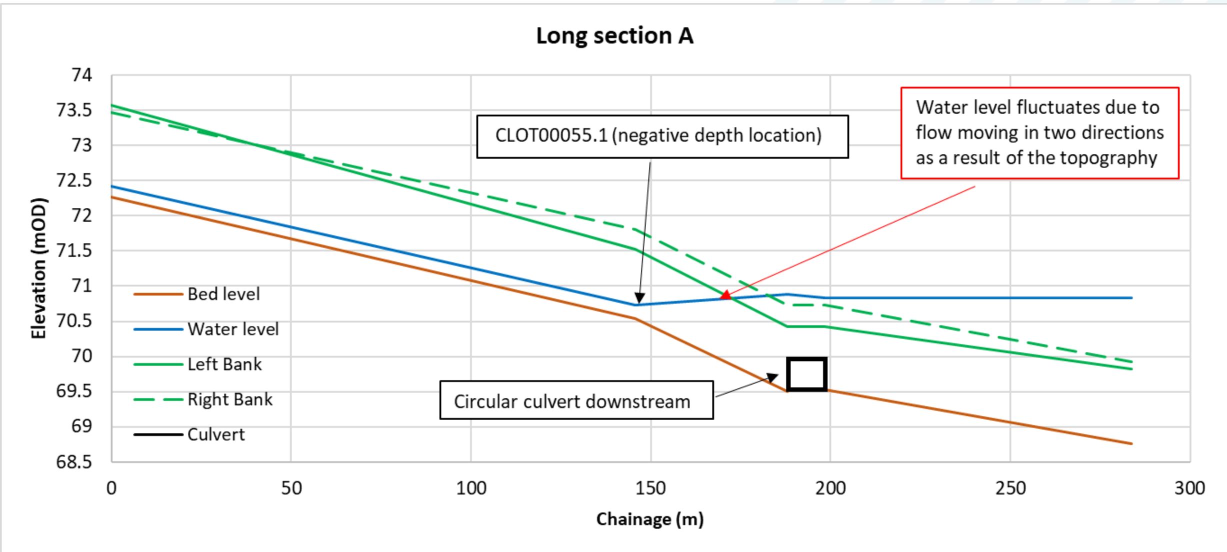


Figure 7-4: Long section A

7.1.2.3 Mass balance error (MBE)

The tolerance limit for MBE is +/- 1.0%. The highest MBE value recorded for the 1%AEP 11-hour design run is -2.35% and -0.25% for the Mountmellick and Triogue models respectively.

The high MBE in the Mountmellick model relates to the representation of the Blackwater watercourse as a 2D gully line and mostly occurs in the wetting up period of the model. MBE along the gully is focused particularly on where right-angle bends occur along the line in relation to the grid cell orientation. This is a result of the 2D grid orientation and how gully lines operate within TUFLOW and cannot be altered. As the Derrycloney watercourse is upstream and away from the key risk receptor area of the model (Mountmellick town) the MBE issue is restricted to this area and the MBE value is not reflective of the whole model (refer to Figure 7-5). Review of the outputs shows this issue does not impact final results/flood outlines generated and the final reported MBE for the run is reported as 0.46%.

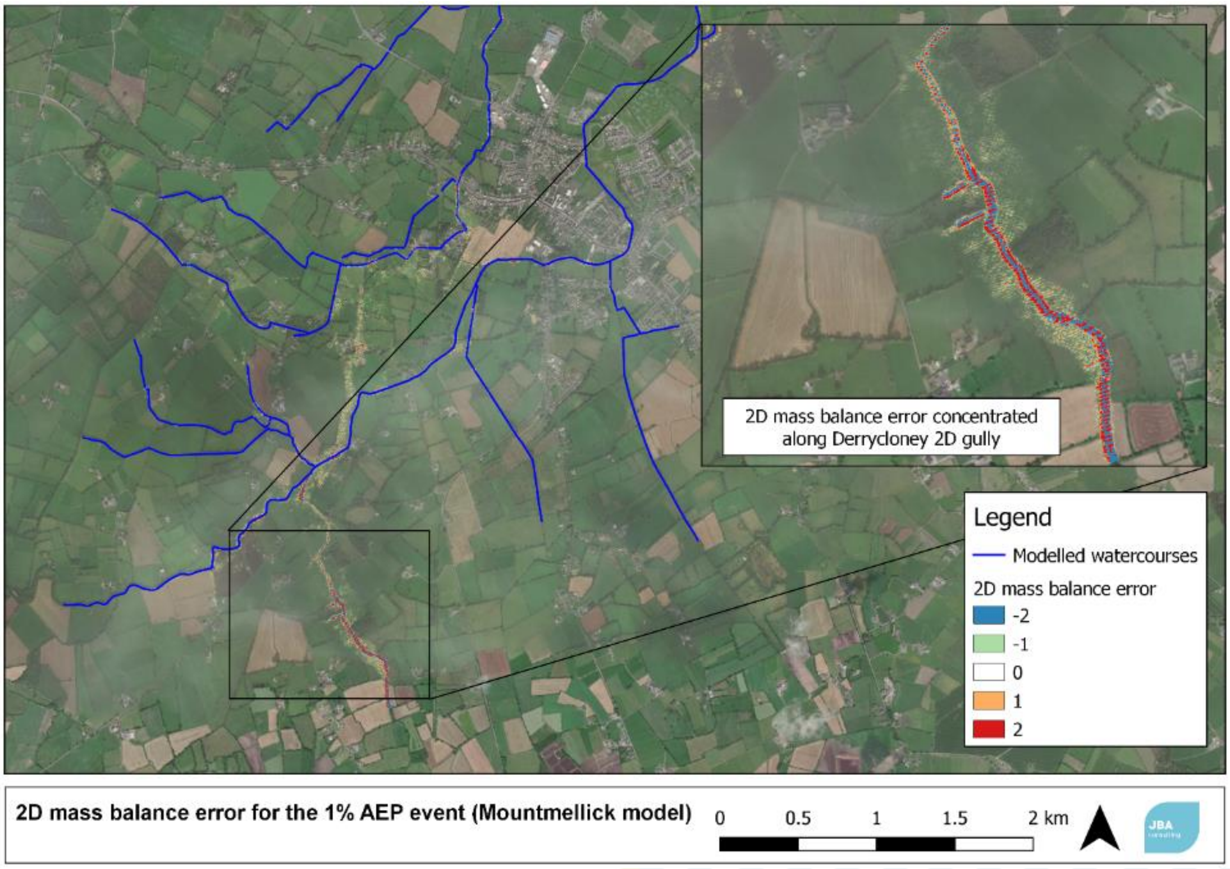


Figure 7-5: 2D mass balance error for the 1% AEP event (Mountmellick model)

8 Model Calibration, and sensitivity testing

8.1 Model calibration

This section describes the calibration of the hydraulic model using data from the 2017 and two 2020 events. All three events have been used as calibration events as different aspects of the system were calibrated within each event. Further descriptions of the flood events can be found in Section 2.4 and the corresponding Hydrology Report. The following data is used in the assessment and calibration of the model:

- 2017 flood event:
  - Aerial photographs and drone footage of flood extents,
  - Eyewitness accounts,
  - Gauge records
- 2020 Storm Ciara flood event:
  - Photographs of flooded areas,
  - Eyewitness accounts,
  - Wrack marks,
  - Gauge records.
- 2020 Storm Dennis event (no flooding):
  - Eyewitness accounts,
  - Gauge records

In relation to the different data provided for calibration, greater weight has been given to those data sets which are considered more reliable, refer to Table 8-1 for the order of preference in calibration data. Hydrologic and hydraulic model calibration was performed simultaneously with adjustments made to inflows and hydraulic aspects in an iterative process to calibrate the models to the observed data. In all events an inflow for the Barrow based on the event rainfall data was derived using the FSSR16 FM unit and applied to allow for completeness in the model despite the Barrow having minimal to no impact on upstream levels (see Section 8.2.1).

Table 8-1: Calibration data confidence ranking

Data set	Calibration confidence ranking	Advantages	Limitations
Gauge 14114 – Mountmellick mill level and flow records	1	This gauge was active in all three calibration events. Using the revised rating curve established in the hydrology report both level and flow can be derived from the gauge record.	Potential issues do arise during high flow events where the recorded level exceeds the rating curve resulting in uncertainty.
Wrack marks	2	Wrack marks surveyed after Storm Ciara along the length of the Owenass provide cross check points for level at points up and downstream of the gauge.	Wrack marks not available for 2017 or Storm Dennis, which was in bank. As marks are taken after the event there is large amounts of uncertainty in whether the marks represent the peak level reached or some interim value. The human judgement on what is/is not a true wrack mark and the error in surveying the correct level must also be considered when using the

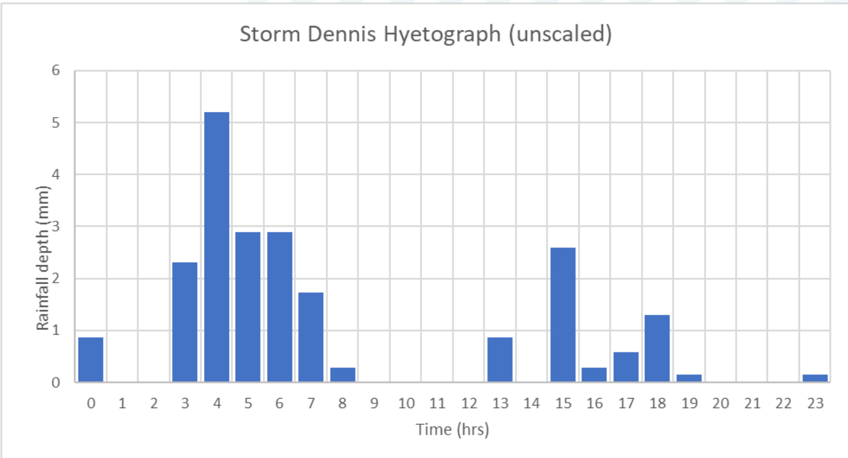
Data set	Calibration confidence ranking	Advantages	Limitations
			data.
Pound gauging station (gauges 14120 and 14121) level and flow records	3	Gauges were active during two of the three events. Both level and flow can be derived from the gauge record.	The gauges have only recently been installed so no rating relationship has been established at time of writing. All flow values from recorded levels are therefore based on modelled results and subject to uncertainty. As the gauges are so new there is also uncertainty as to how the structures up and downstream on the river influence the gauge recordings in relation to backwater effects.
Previous flood extents and eyewitness descriptions	4	Visual comparisons of modelled flood extents and aerial photographs provides confidence of representation of wide scale flooding. Descriptions of the timing of events is useful in matching the timing of flood events within the model.	Unless timestamped it is difficult to determine which point of the flood event is represented in the photographs. Also do not provide any information about depth of water etc. Eyewitness accounts may be subject to human error and estimation of timings compared to gauges which provide more accurate timeframes.

8.1.1 Storm Dennis 2020 event (no flooding)

Storm Dennis occurred a week after Storm Ciara (15th-16th February) and was an in-channel event. This event has been used as a calibration event as it is the only event in which there is no cross flow between the Owenass and Pound systems and is important for understanding how the rivers behave when they are not connected.

Table 8-2 shows the catchment and rainfall data used to derive the Storm Ciara flows.

Table 8-2: Hydrological model – Storm Dennis

Hydrologic model Storm Dennis 2020 event input parameters	
Catchment wetness index	Upland catchments: 135 Lowland catchments: 135
Storm duration (Hrs)	24 hours
Hyetograph	

The following adjustments were made to the hydrological inflows as part of hydrological calibration (refer to the Hydrology Report for more detail):

- The percentage runoff for each inflow was derived from the underlying soil type as per the standard practice of the FSSR method, apart from the Pound watercourse where review of BFI values showed that the PR value should be higher than the soil type estimate.
- The time to peak values for the upper catchment inflows to the Pound watercourse were adjusted by a factor of 1.13 following time to peak and lag analysis (changed from 6.22 to 7 hours).
- A dynamic base flow was applied to both the Owenass and Pound watercourses based on the recorded gauge hydrographs available for the event.

The following adjustments were made in the hydraulic model to calibrate the model:

- The channel roughness of the Owenass watercourse from Owenass bridge to Mountmellick bridge was altered after review of panel markers. Roughness along the channel sides has been altered to reflect the vegetation present in the channel. The same channel conditions used in the calibration of the Storm Ciara event which occurred a week prior have been applied. The channel conditions would not have altered significantly between the events.

Figure 8-1 shows the flood extents for the event and Figure 8-2, Figure 8-3 and Figure 8-4 compare observed and modelled levels at the active hydrometric gauges along the Owenass and Pound watercourses. A larger version of Figure 8-1 can be found in Appendix F. The extents show a small amount of shallow out of bank flooding of fields at upstream reaches and along the Barrow. The small amount of flooding modelled is probable and would not likely have been reported as there are no risk receptors impacted.

Comparing the modelled and recorded levels at the gauges, the model levels are within ± 0.20m and ±0.05m of the reported levels along the Owenass for peaks one and two respectively. Levels are within ±0.10m for both gauges on the Pound. The model produces hydrograph shapes similar to the observed. The timing of the peak of the events is not well correlated and relates to the application of rainfall across the catchment. This is explained further in the Mountmellick Hydrology Report.

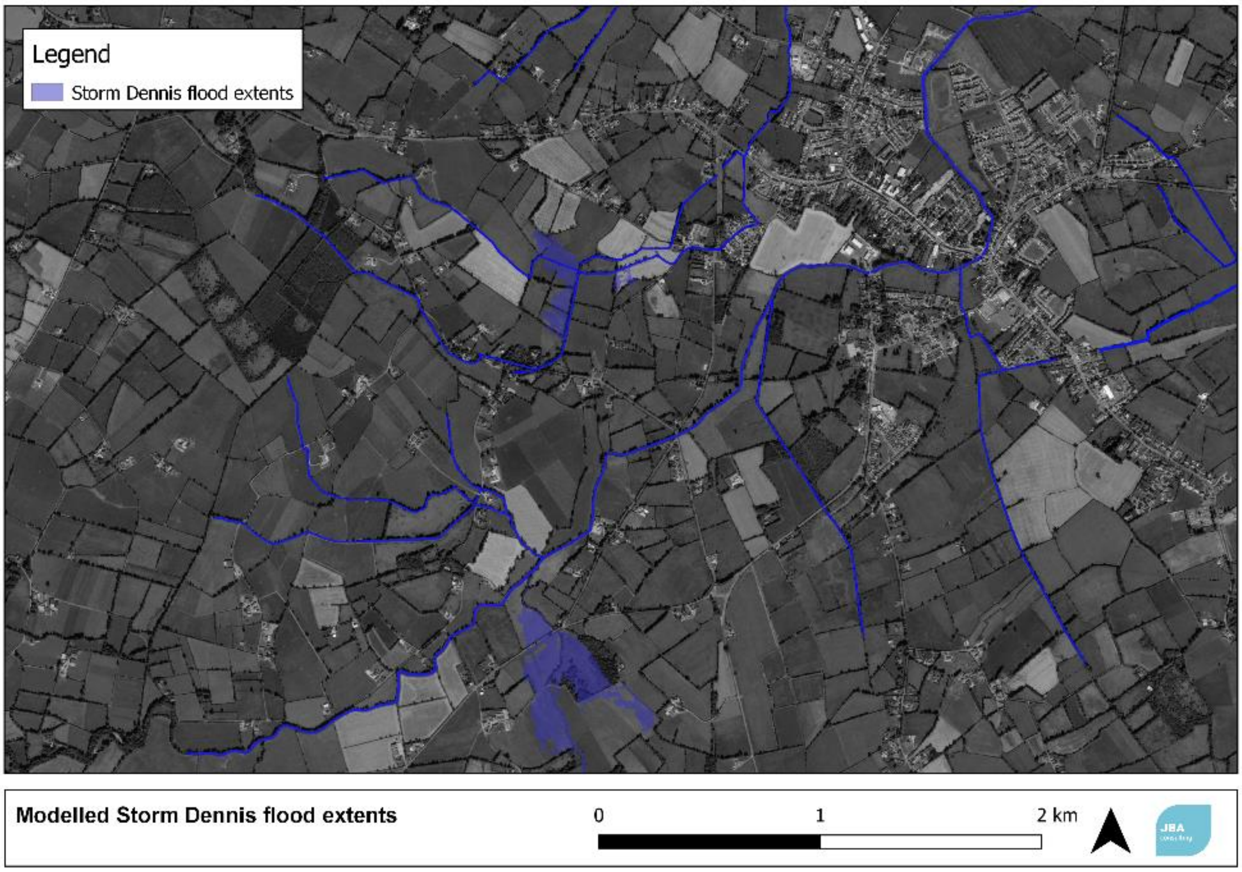


Figure 8-1: Modelled Storm Dennis flood extents

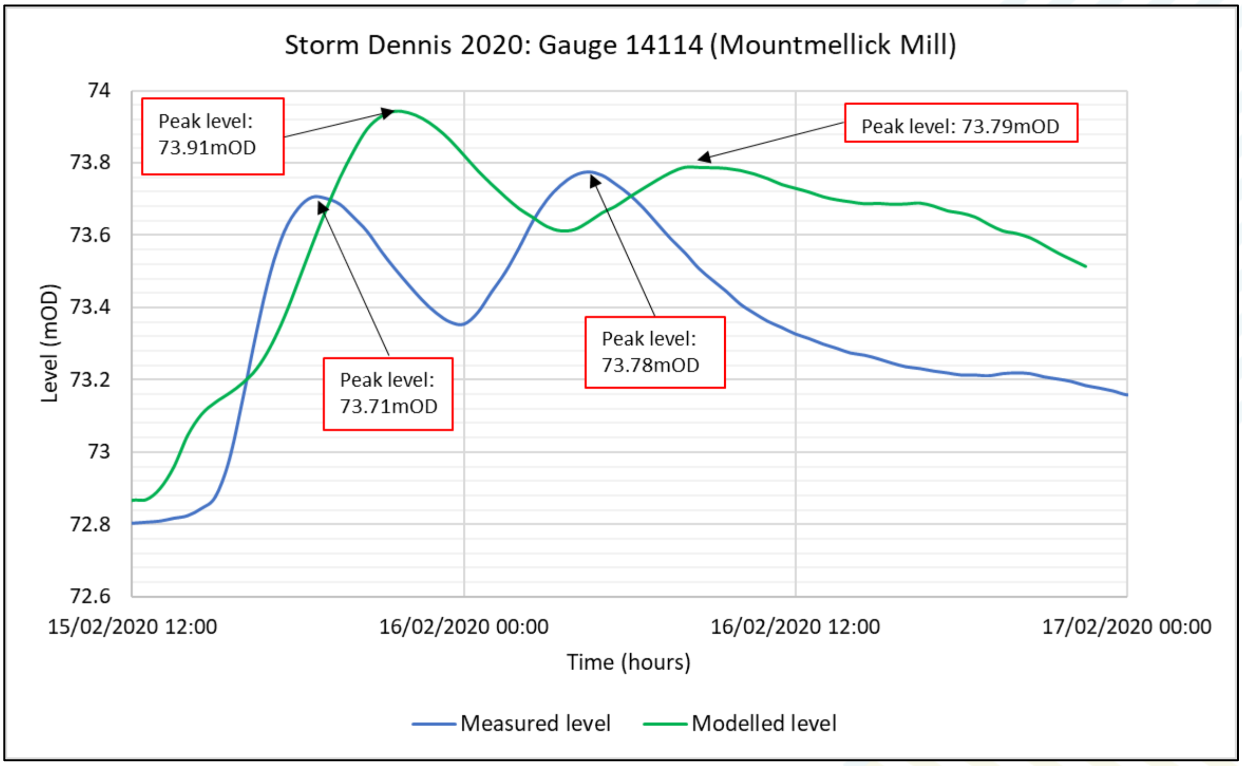


Figure 8-2: Storm Dennis 2020: Gauge 14114 (Mountmellick mill)

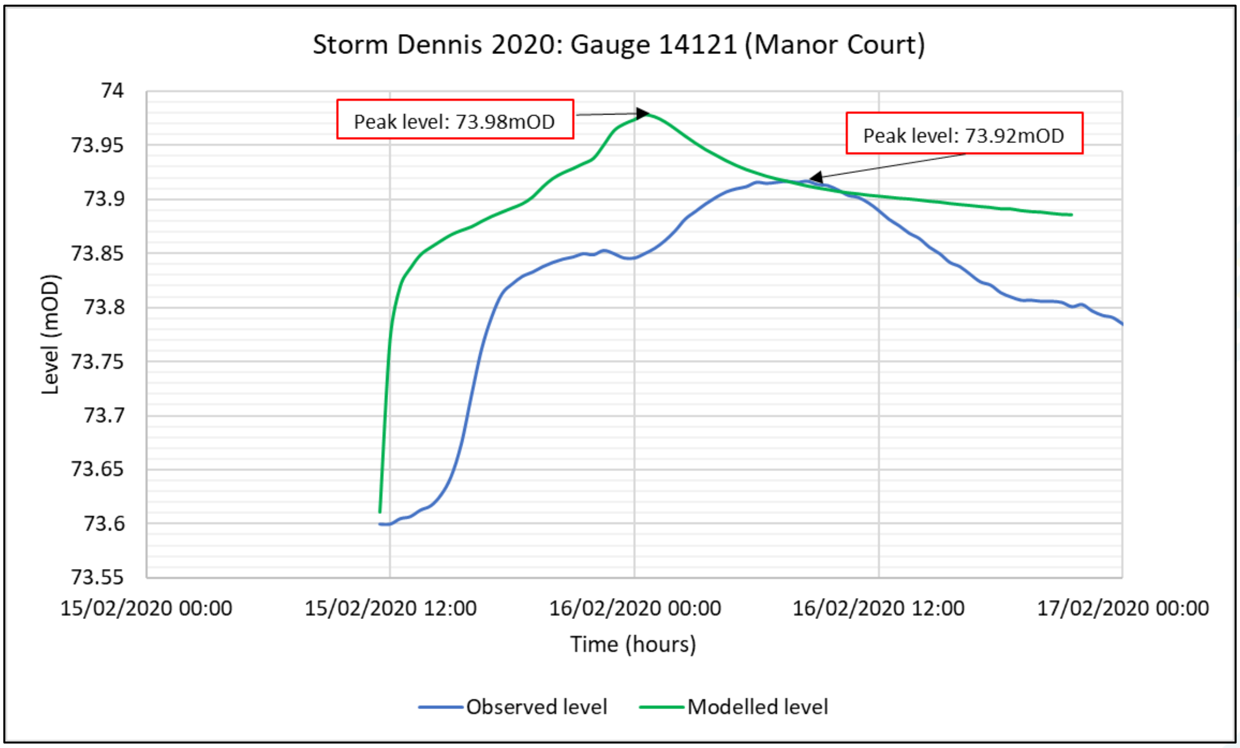


Figure 8-3: Storm Dennis 2020: Gauge 14121 (Manor court)

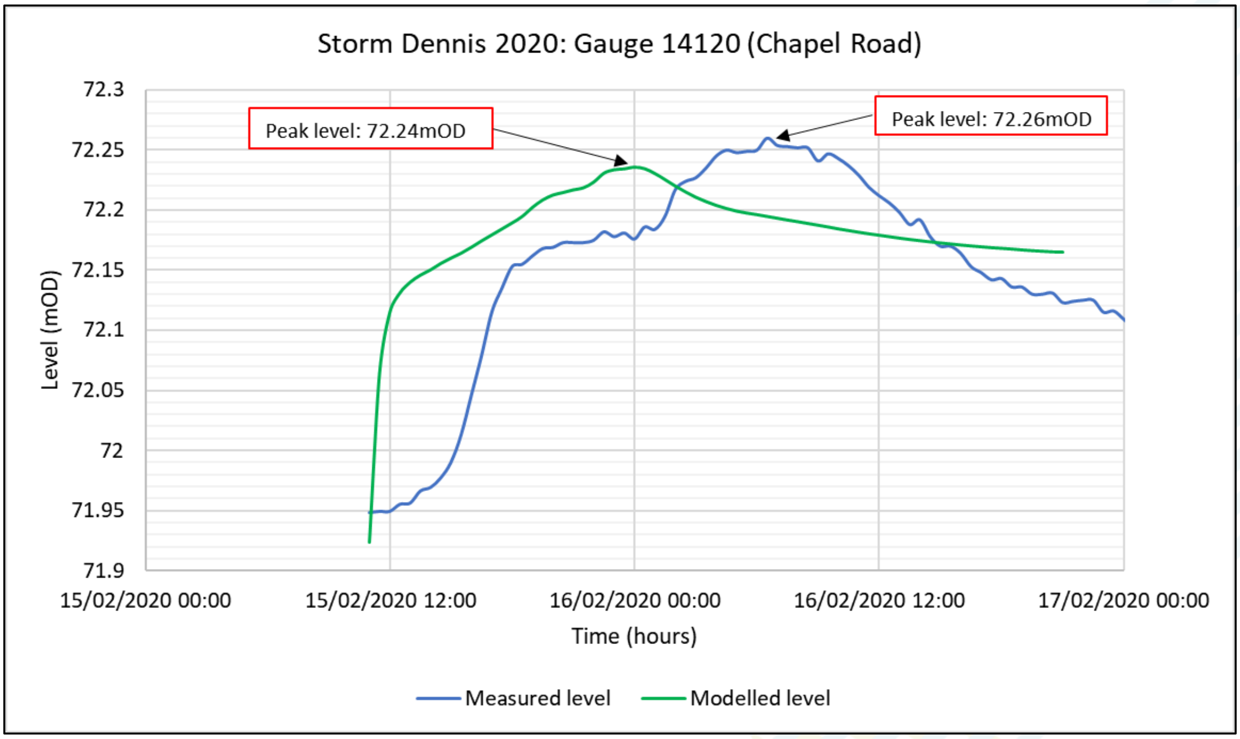


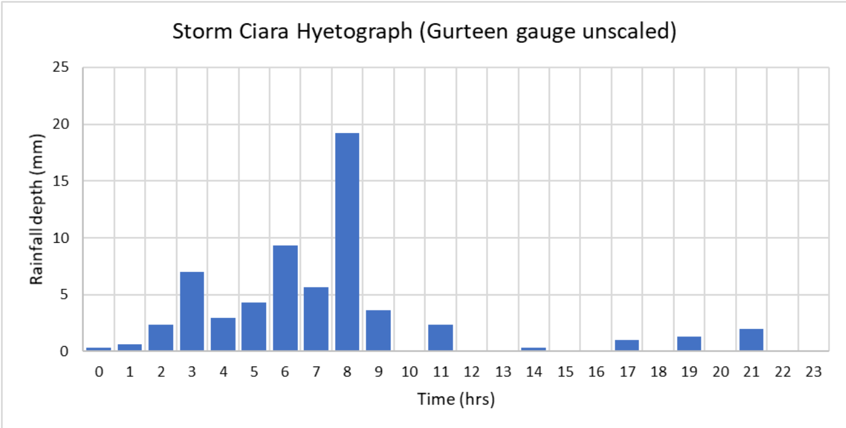
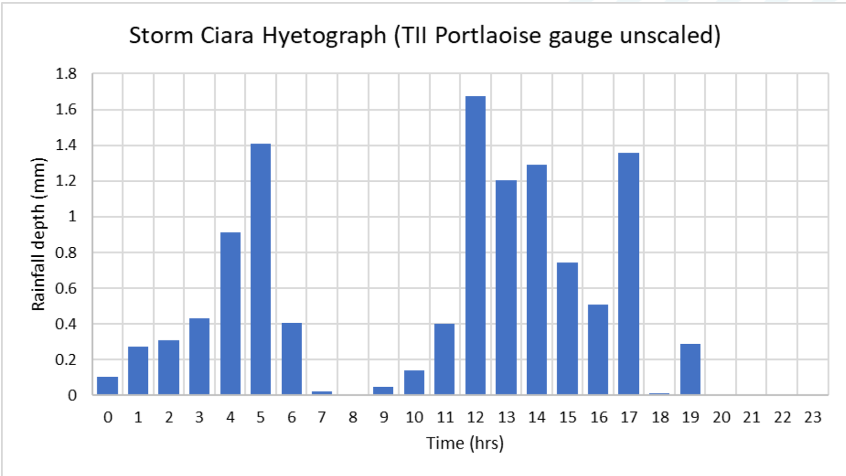
Figure 8-4: Storm Dennis 2020: Gauge 14120 (Chapel road)

8.1.2 Storm Ciara 2020 flood event

Heavy rainfall over the area on the 8th and 9th of February due to Storm Ciara resulted in highwater levels and flooding within Mountmellick. Storm Ciara is the most recent flood event to have occurred which created observed inundation. The extent of flooding is much smaller than the 2017 event. A number of near misses of property flooding were recorded and there were a number of road closures around Manor court due to flood waters.

Table 8-3 shows the catchment and rainfall data used to derive the Storm Ciara flows.

Table 8-3: Hydrological input data – Storm Ciara

Hydrologic model Storm Ciara 2020 event input parameters	
Catchment wetness index	Upland catchments: 135 Lowland catchments: 132.6
Storm duration (Hrs)	24 hours
Hyetographs	 Western catchments  Eastern catchments

The following adjustments were made to the hydrological inflows as part of hydrological calibration (refer to the Hydrology report for more detail):

- The percentage runoff for each inflow was derived from the underlying soil type as per the standard practice of the FSSR method.

- The time to peak values for the upper catchment inflows to the Pound watercourse were adjusted by a factor of 1.13 following time to peak and lag analysis (changed from 6.22 to 7 hours).
- The total rainfall for this event was taken from the Clonaslee daily rain gauge and scaled appropriately; the depths recorded at this gauge gave a better match to observed gauge levels.
- To obtain a better shape hydrograph for the event a number of tests involving hyetograph shapes were carried out. It was found that the best matched to observed hyetograph shape was obtained when the hyetograph shape recorded at the TII Portlaoise gauge was applied to the eastern catchments and the Gurteen hyetograph shape to the western catchments. This division was based on Thiessen polygon analysis of the available gauges in the area (refer to Figure 8-5).
- Base flow was added to Owenass river after examination of the recorded hydrograph.

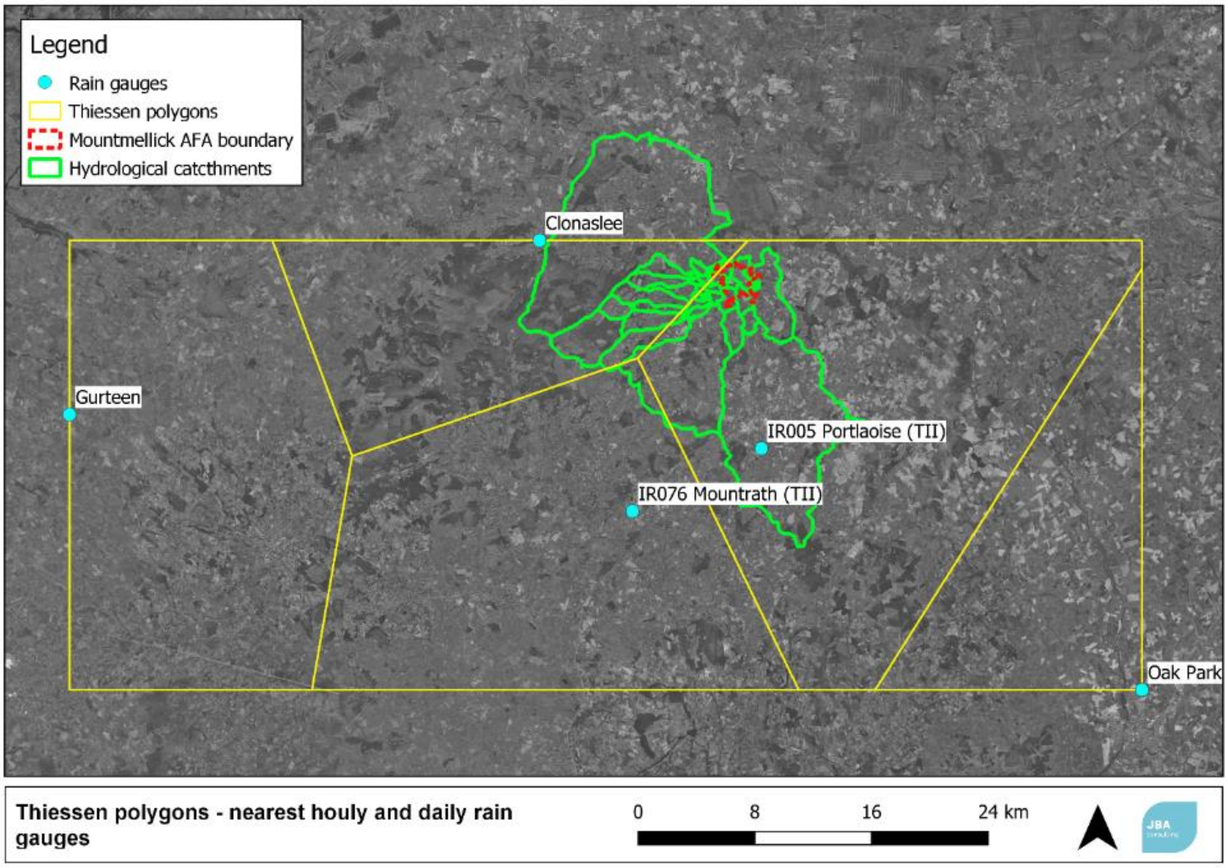


Figure 8-5: Thiessen polygons – nearest hourly and daily rain gauges

Figure 8-6 shows the modelled flood extents for the event, a larger version of this figure can be found in Appendix F. The model replicates much of the observed flooding and the descriptions recorded after the flood event in particular around the upstream area of the Pound River where there were multiple road closures reported and a pre-emptive evacuation of one house. It is noted that while the playground area within Mountmellick town is shown as flooded the model shows smaller extents in this location compared to the descriptions recorded about the event where flood waters from the playground rose up towards the road and near the entrance of the Mountmellick Mill Development Association building on the other side of the road. Post flood levels and gauge data have been used to calibrate the model.

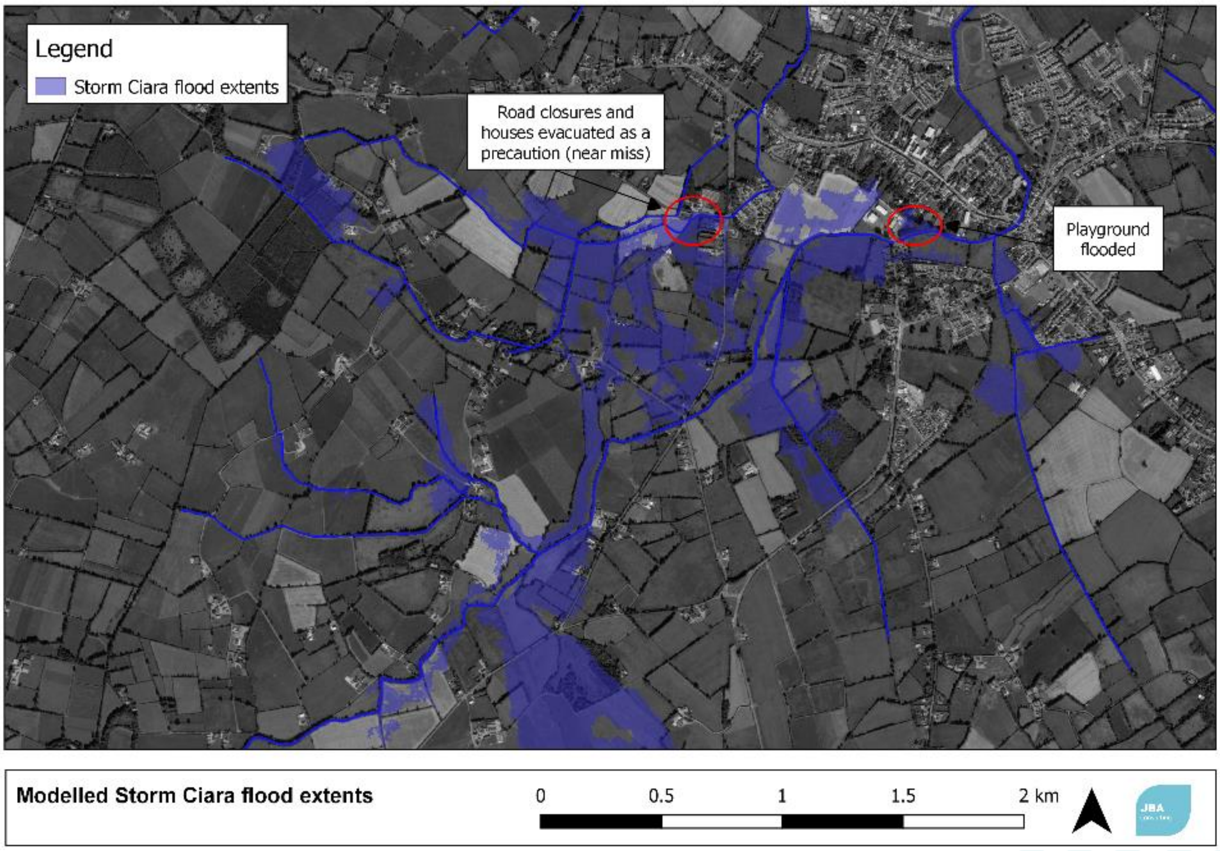


Figure 8-6: Modelled Storm Ciara flood extents

Figure 8-7, Figure 8-8, and Figure 8-9 compare modelled and observed gauge data while Figure 8-10 shows the modelled hydraulic profile in relation to observed wrack mark data. The modelled peak levels at gauges are within ±0.05m of the observed levels. The levels at Mountmellick Mill (14114) and Manor court (14121) are within ±0.15m of the recorded peak levels at these gauges. The shape of the hydrographs modelled on the match reasonably well to the observed gauge levels although the timing of the modelled event is delayed by approximately 3 hours compared to the observed data.

Looking at the peak level in comparison with the surveyed wrack marks the model matches level with some points but not all. In particular it is lower for most wrack marks between the Mountmellick Mill and Convent bridges. While important evidence, it is noted that there is uncertainty associated with wrack mark identification and recording, particularly when they are associated with leaves and other mobile debris.

Of the events assessed, Storm Ciara proved the most difficult to calibrate due to the floodplain cross flow between the Owenass and Pound watercourses. The difficulty in calibrating this event highlights the complexity and sensitivity of the system to flow transfers and floodplain interaction. It is very easy to overwhelm the Pound system by transferring excess flow from the Owenass.

The peak level observed in the Pound gauge records is a result of out of bank spill from the Owenass crossing the floodplain and entering the Pound. Multiple tests examining runoff coefficients, flood plain roughness, time to peak, and rainfall hyetograph shapes and depths were carried out investigating the flood plain flow relationship between the two gauges. The application of the different hyetograph shapes to the western and eastern catchments was found to greatly help establish this flow balance as the timing and intensity of the rainfall generating flow on the Owenass provided the most representative hydrograph shape. The difference in hyetograph shape across the study area applied for this calibration event highlights the uncertainty and changeability of a storm across an area, particularly when the impact of the Slieve Bloom Mountains is considered. However, while the hyetograph shapes differed the rainfall depth recorded at Portlaoise gauge was too low to generate the flows needed again suggesting a high degree of variability within the area during this storm.

In summary, through a wide range of testing the calibrated model matches the observed gauge data well and highlights the importance of understanding the nature of the flow transfer between the two watercourses.

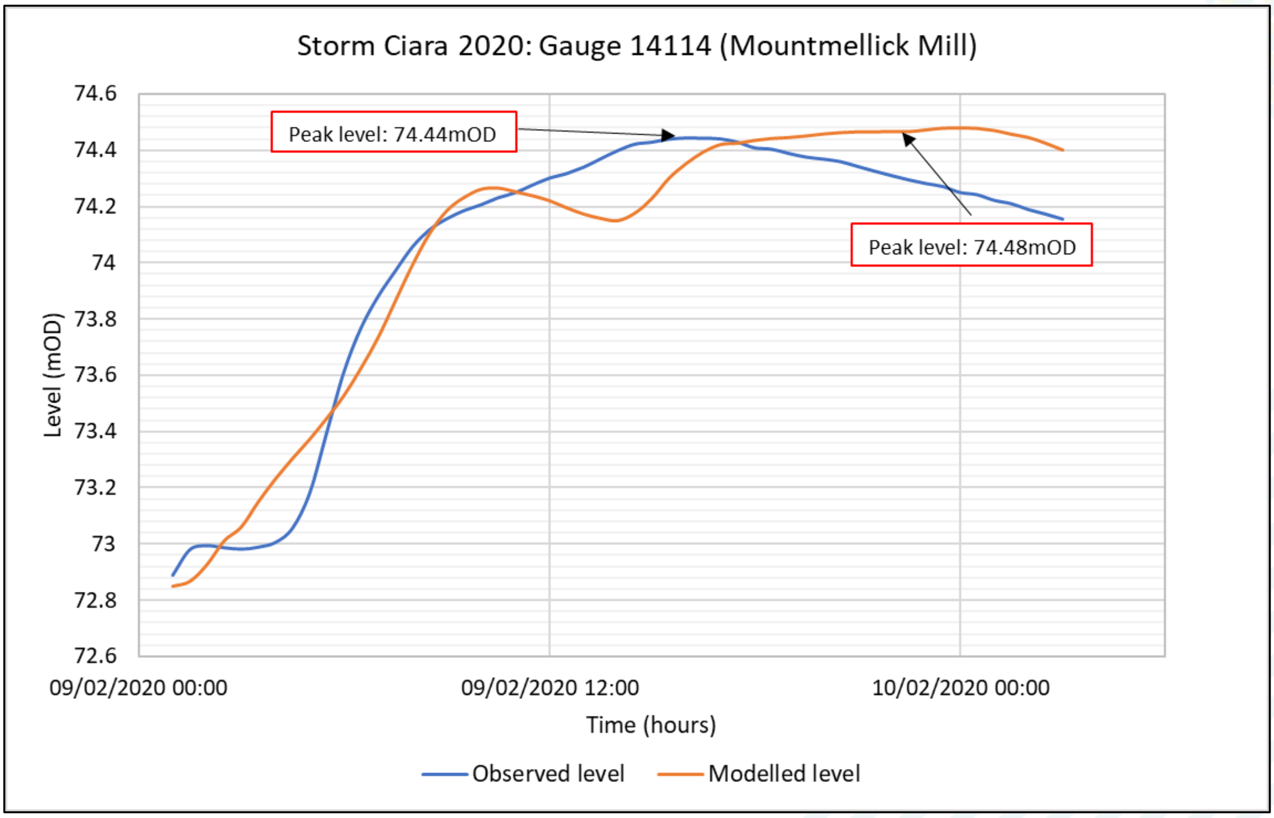


Figure 8-7: Storm Ciara 2020: Gauge 14114 (Mountmellick mill)

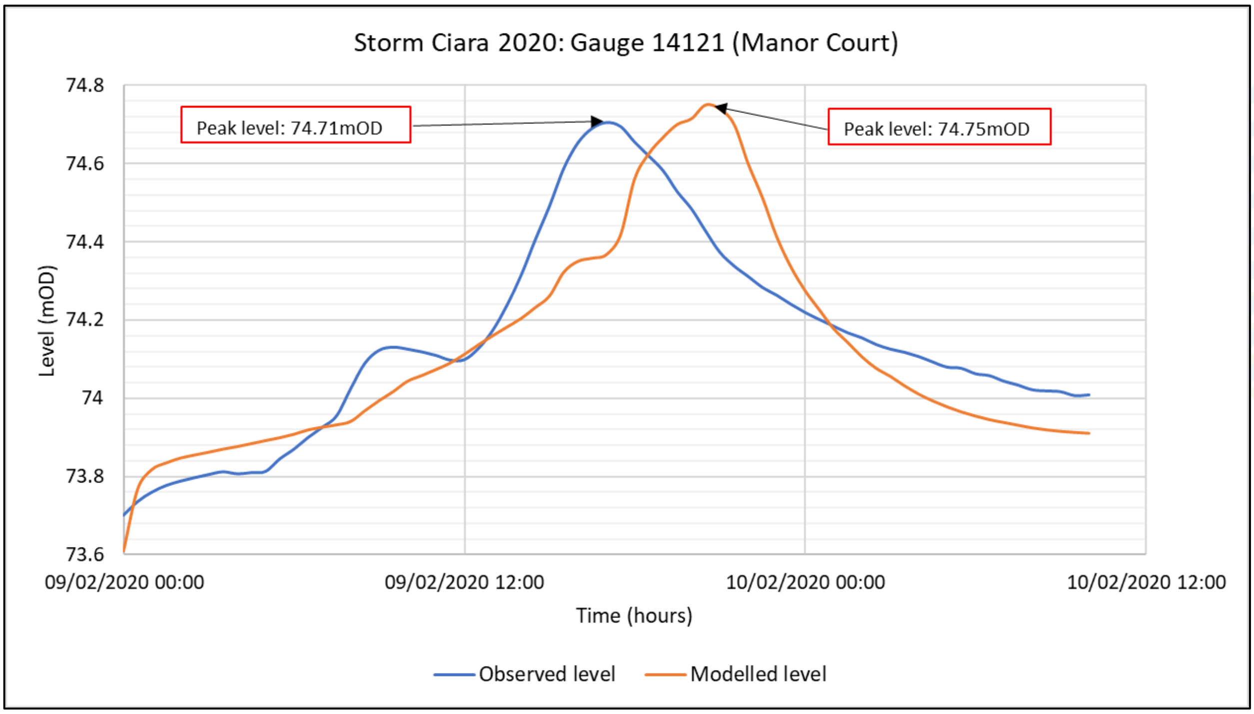


Figure 8-8: Storm Ciara 2020: Gauge 14121 (Manor court)

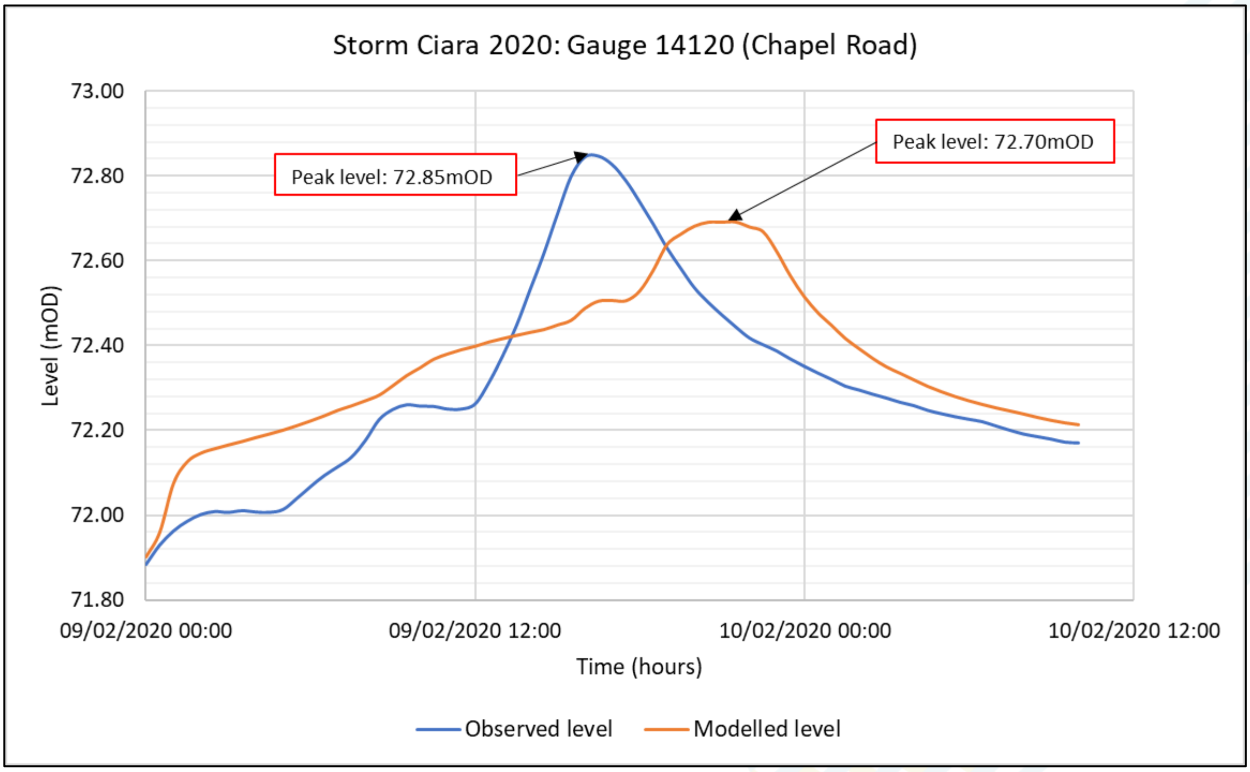


Figure 8-9: Storm Ciara 2020: Gauge 14120 (Chapel road)

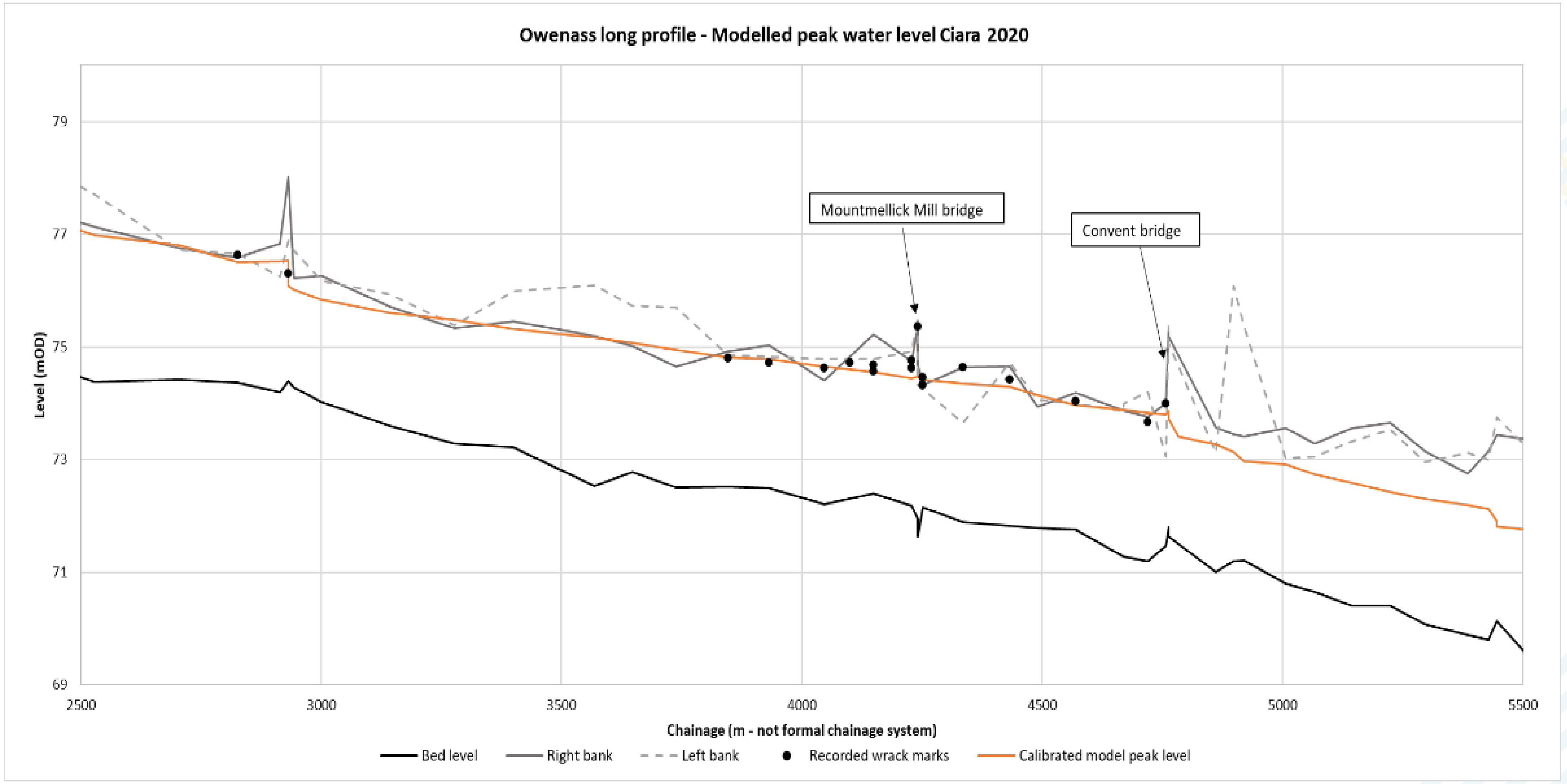


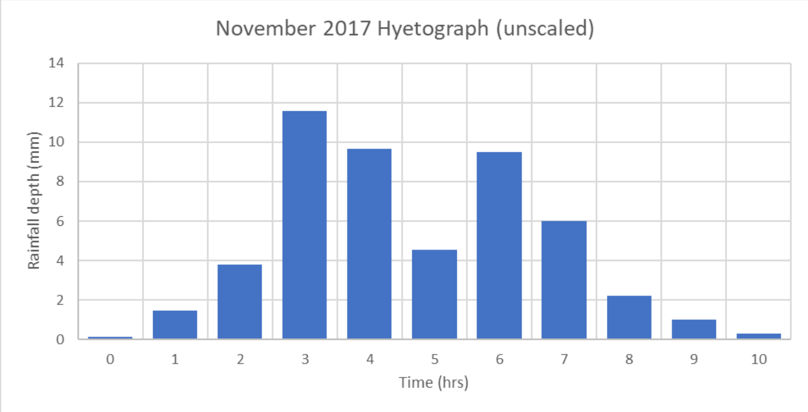
Figure 8-10: Owenass long profile – Modelled peak water level Ciara 2020

8.1.3 November 2017 flood event

The 2017 flood event is noted as the worst flood event to have occurred in Mountmellick in recent history. The land at the time of the event was saturated due to antecedent rainfall in the area. Eyewitnesses mention debris within the channels prior to the event with the Convent bridge noted as being blocked by a tree (Refer to Figure 8-11).

Table 8-4 shows the catchment and rainfall data used to derive the November 2017 flows, the hyetograph shape has been sourced from the Gurteen hourly gauge and scaled to reflect the total daily rainfall recorded at the Clonaslee gauge (closest gauge to the study area).

Table 8-4: Hydrological model – November 2017

Hydrologic model November 2017 event input parameters	
Catchment wetness index	Upland catchments: 137.17 Lowland catchments: 127.97
Storm duration (Hrs)	11 hours
Hyetograph	

The following adjustments were made to the hydrological inflows as part of hydrological calibration (refer to the Hydrology Report for further detail):

- The estimated percentage runoff for all catchments was increased (PR 70% for all catchments).
- The time to peak values for the upper catchment inflows to the Pound watercourse were adjusted by a factor of 1.13 following time to peak and lag analysis (changed from 6.22 to 7 hours).
- A base flow was applied to the Owenass watercourse based on the recorded gauge hydrograph available for the event.

In relation to hydraulic parameters the following aspects were adjusted specifically to reflect the conditions of the November 2017 event:

- No channel maintenance was being undertaken at the time of the event, eyewitness accounts describe the river channels being overgrown and debris travelling down the watercourses. To reflect this the in-channel Manning's roughness of the Owenass was increased from 0.04 for the entirety of the watercourse.

- During the event a large tree was caught on the upstream face of Convent bridge (14OWEN00257B in the model, refer to Figure 8-11) resulting in a blockage of the channel. A 25% blockage has been applied to the bridge in the model to represent this.

Figure 8-11: Tree blocking Convent bridge during the 2017 event

Figure 8-12 shows the modelled flood extents for the November 2017 event (refer to Appendix F for enlarged version of this figure and a map focused on the town). The extents show a good match with the photographs of flooding taken the day after event. The fluvial extents also cover a large proportion of the properties recorded as having flooded. Those that the extents do not cover have been shown to have flooded from pluvial not fluvial sources, for example along Davitt Road to the east of the town (Refer to Figure 8-12). Table 8-5 shows the number of the properties reported as flooding from the model outputs, these numbers are approximate as some properties partially impacted have not been counted as the information point for the property lies on the dry area and not within the extents. Flooding is reported in Manor court estate; however, water was reported as pouring through the wall to the west during the event which is not represented in the model.

Figure 8-13 compares the modelled and recorded stage and flow at gauge 14114 Mountmellick Mill on the Owenass which was active during the event. The peak modelled level is within +/- 0.15m of the recorded level and shows a similar hydrograph shape to the observed data.

Further examination of the hydrograph shape for this event displayed the hydraulic significance of the flood plain in relation to the Mountmellick Mill gauge shape. There is a noted change at approximately 8am in the 22/11/2017 where level plateaus before rising again at the peak of the event where there is again a flattening of the graph. Initially after the event it was assumed that the gauge on the Owenass malfunctioned and failed to record the peak of the event hence the flat top of the observed hydrograph. However, further investigation has found that the level and flow at the gauge is restricted at the upper limit by increased out of bank spill and floodplain flow upstream of the gauge. This sets an upward limit on the amount of flow that can pass through the gauge and into the lower reaches of the Owenass and highlights a hydraulic constraint on the system as well as further highlighting the connectivity between the Pound and Owenass Rivers (refer to Table 8-6).

To further investigate the impact event conditions had on the flood extents a sensitivity test was run in which the 2017 event flows were applied to the design model not the event specific model for 2017 with the increased roughness and blockages. Figure 8-14 shows the difference in water level reported between the runs with the 2017 event model results showing increased levels and flood extents. This test highlights the impact channel clearing and maintenance on the Owenass has on flood risk at higher return period events.

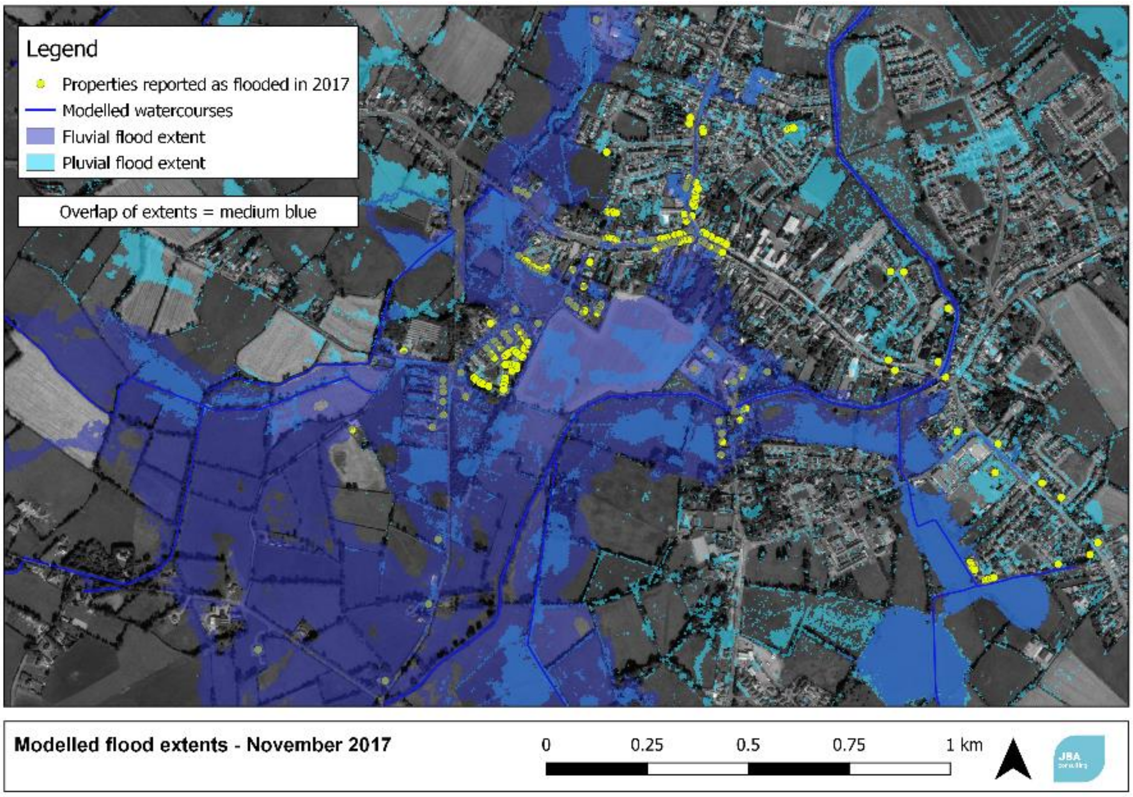


Figure 8-12: Modelled flood extents – November 2017

Table 8-5: Numbers of properties recorded as flooded in modelled extents (point count)

	Properties reported as flooded
Recorded 2017 impacts point layer	196
Recorded as flooded from fluvial sources (modelled extents)	88
Recorded as flooded from pluvial sources (modelled extents)	27
Total recorded as flooded in model run	115

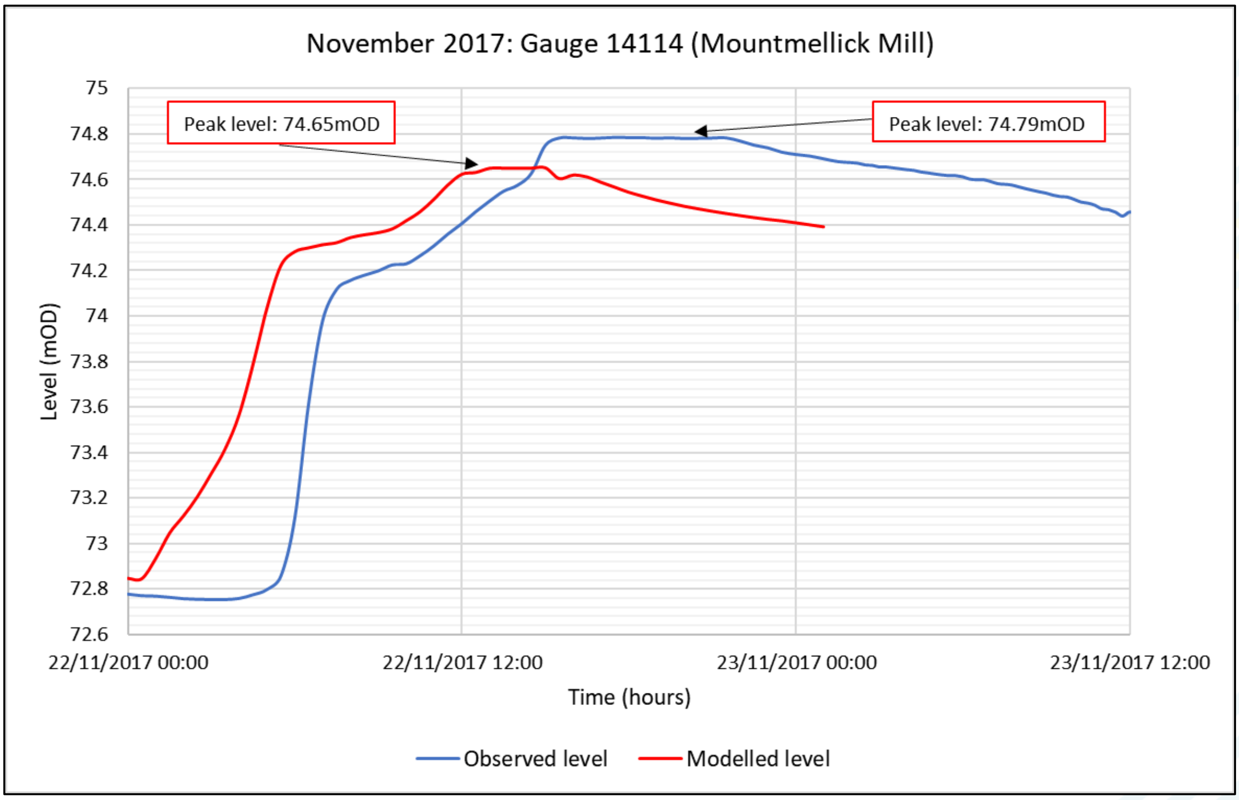
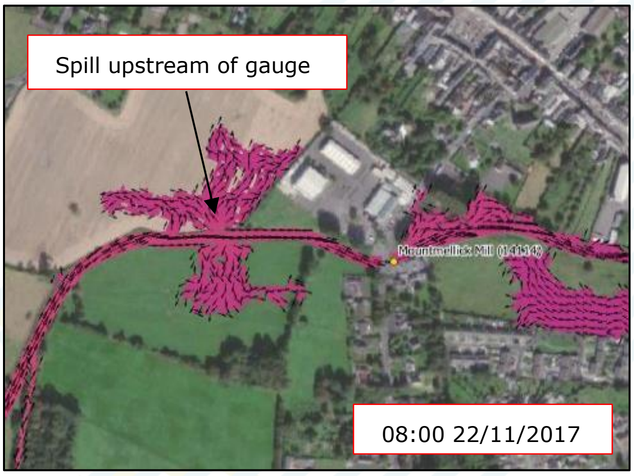
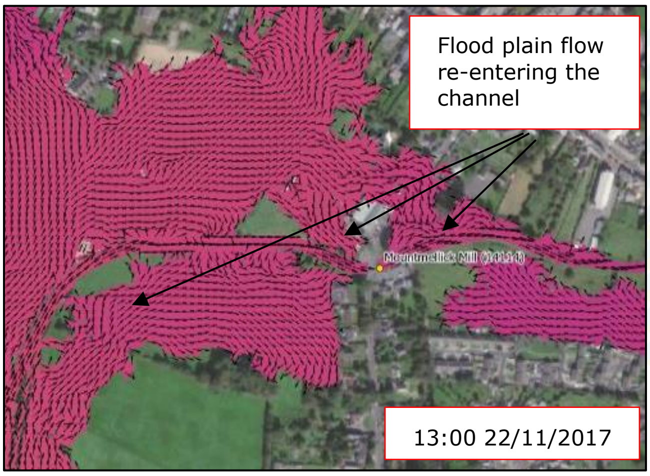


Figure 8-13: November 2017: Gauge 14114 (Mountmellick Mill)

Table 8-6: November 2017 hydraulic mechanisms resulting in response recorded at Gauge 14114

	
Activation of flood plain upstream of the gauge resulting in a plateau of level and flow recorded at the gauge (refer to Figure 8-13)	



Increase in level and flow and then flattening of curve at peak of the event as flood plain flow renters the channel resulting in an increase in recorded levels until the maximum capacity of the channel is reached and flow preferentially stays within the flood plain (refer to Figure 8-13 for gauge response).

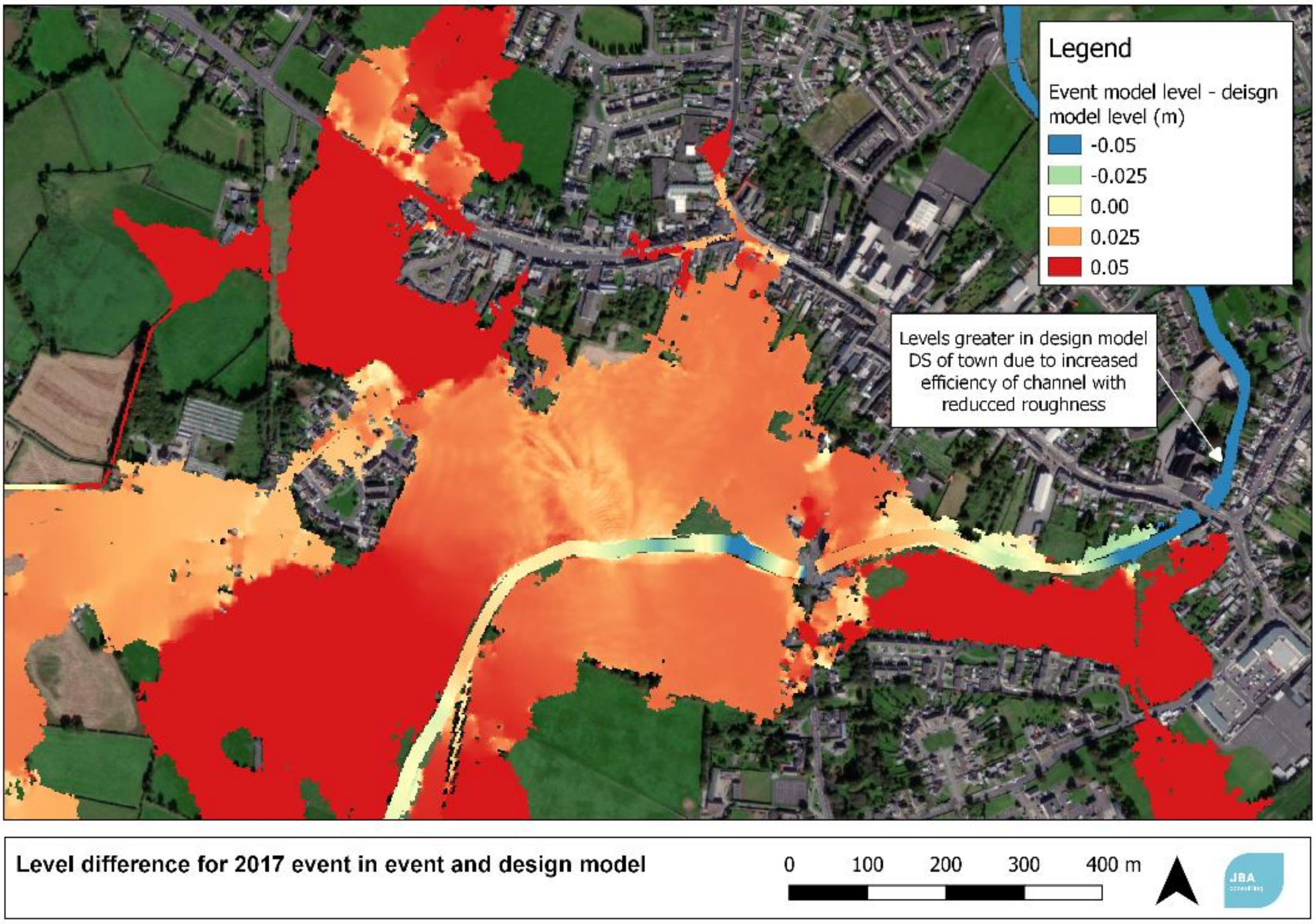


Figure 8-14: Level difference for 2017 event in event and design model

8.1.4 Calibration summary

Overall, the calibrated model satisfactorily replicates the three events. Sensitivity to cross catchment flow and floodplain interaction have been noted. The model calibrated to the 2020 events (Ciara and Dennis) has been used to model the design events with any adjustments to the hydrology and hydraulics mentioned applied. As 2017 had a number of event specific aspects it has been left as a single event validation model.

By examining the past flood events the importance of floodplain flow and upstream interaction has been identified. In higher return period events the flood plain activation upstream of Mountmellick town becomes increasingly important. As highlighted by the gauge records and modelled outputs for Storm Ciara and the November 2017 event, along the Owenass the channel is limited in the amount of water it can pass through the town as any additional flow volume is transferred to the flood plain resulting in wide spread flooding and cross catchment flow. This activation of flood plain is only seen in higher flow events, as demonstrated by the lack of interaction observed in the Storm Dennis event.

8.2 Sensitivity testing

This section describes the various sensitivity tests carried out to examine the performance calibrated model. All sensitivity tests have been carried out using the 1% AEP 11-hour flow event. Results for both models are presented in the same figure unless stated otherwise.

8.2.1 Joint probability screening

The Barrow is the largest watercourse represented, and into which all other watercourses in the model eventually flow. The river is downstream of the key risk receptor area (Mountmellick Town) within a wide low-lying floodplain. The flood history detailed in the Hydrology Report highlights and independence between the two systems, with the Barrow responding slowly to long duration rainfall, whist the Owenass and Pound are much flashier in nature.

To test whether the Barrow influenced flood levels within the town two screening runs were carried out – a high flow (1% AEP) event run on the Owenass and Pound systems, with a high (1% AEP) and low (50% AEP) Barrow flow. Figure 8-15 shows the difference in flood levels between the two tests, the influence of the Barrow is restricted to the floodplain and does not impact levels upstream within the town. Based on this the potential impact of joint probability in connection with the Barrow has been screened out. As a conservative approach for the design events flows for the same return period have been applied to all watercourses in the model including the Barrow.

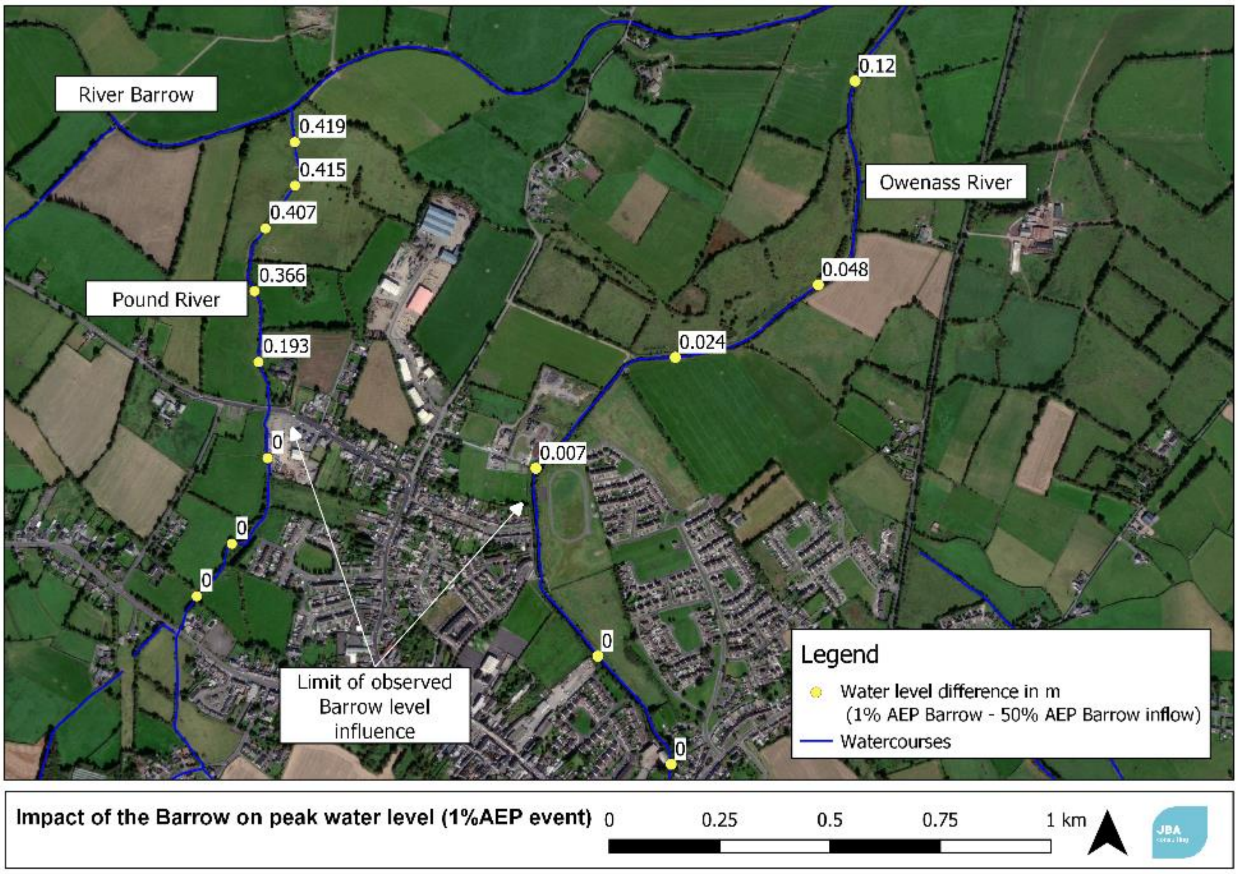


Figure 8-15: Impact of the Barrow on peak water level (1% AEP event)

8.2.2 Cell size sensitivity – 2m 2D grid cell size

All runs have been carried out using a 4m resolution 2D grid as it was felt to appropriately capture all the critical flow paths in the key risk receptor areas. In particular, flows through the passageways between houses on O'Moore Street were represented in the model. In the 4m grid runs a single HX line has been used for some of the smaller watercourses due to channel size as discussed in Section 3.5.2.

Figure 8-16 compares the modelled flood extents between the 4m and 2m cell size runs, a larger version of the figure can be found in Appendix F. The total run time for the 2m grid cell size 1%AEP event was 36 hours which is significantly longer than the 8 hours it takes to run the 4m grid for the same event.

Overall, the 4m grid cell run shows greater flood extents compared to the 2m cell run. This is likely due to increased detail in the 2m grid restricting flow paths with more water being retained on flood plains and not flowing out across areas. A simple point count of properties impacted shows that 84 properties are within the 2m grid extent compared to the 4m grid run (91 properties). Figure 8-17 also shows that the 4m grid cell run produces higher water levels across the floodplain indicating that it is the more conservative approach concerning flood risk. This is likely due to the higher resolution of bank heights in the 2m run holding water within the channel. Given that there is little difference in flood level reported and the 4m cell run produces more conservative extents and levels and has a significantly shorter run time the 4m grid cell size is considered sufficient for the purpose of the model and overall project aim.

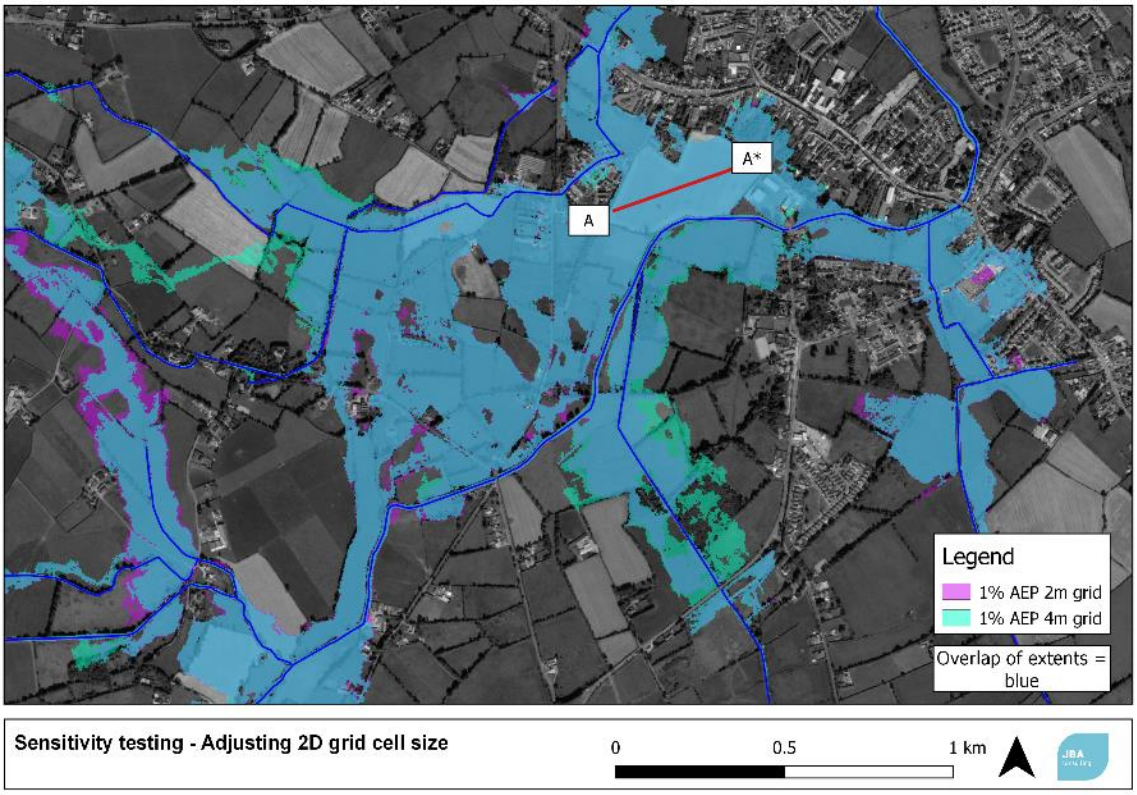


Figure 8-16: Sensitivity testing – Adjusting 2D grid cell size

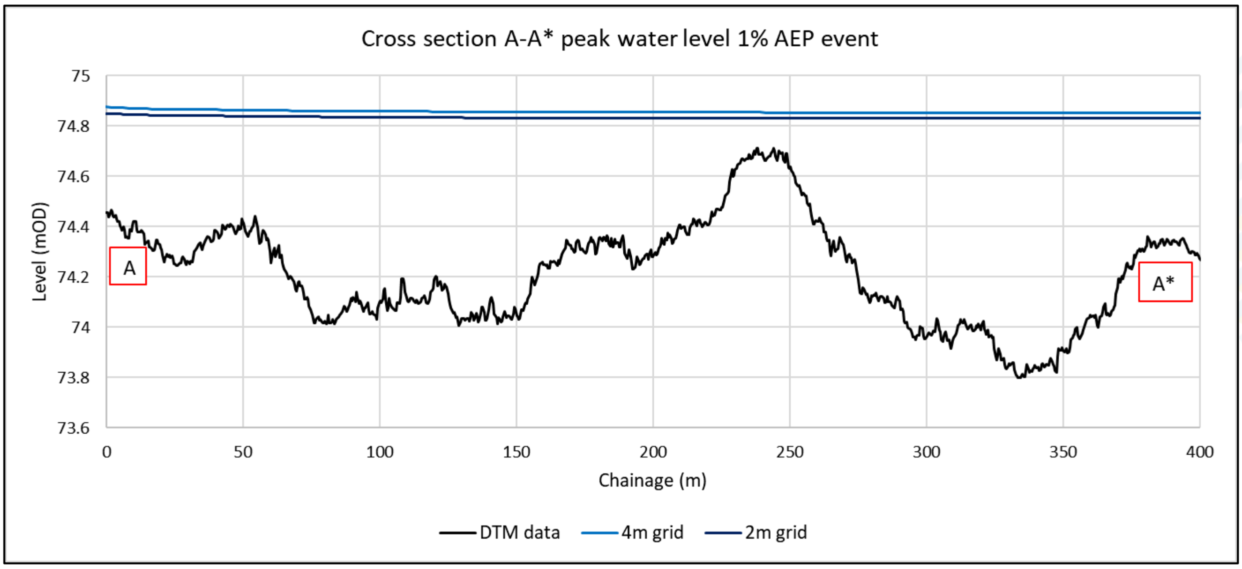


Figure 8-17: Cross section A to A*

8.2.3 Increase/decrease in storm duration

To establish the critical storm duration and test whether the model is more sensitive to volume than flow, the 1% AEP flow event was run using three different rainfall storm durations; 5-, 11- and 21-hour storms, each producing a 1% AEP flow were run through the hydraulic model.

Figure 8-18 compares the flood extents for the various storm durations a larger version of the figure can be found in Appendix F. As expected, the flood extent increases with increasing duration. The 21-hour storm shows increased flooding around the Davitt Road area and within the main town compared to the 11-hour flood extent. A simple count analysis of the geo-directory property points within the flood extents using a GIS tool showed that 19 additional points are within the 21-hour storm flood extent compared to the 11-hour (114 compared with 91) but there is no significant increase in peak level. Figure 8-19 and Figure 8-20 show the modelled level hydrographs at gauge locations along the Owenass and Pound Rivers. The figures show that there is no significant impact on levels along the either watercourse with changing storm duration, but the time to peak increases with storm duration.

It was decided to run the model at the 11-hour storm duration as this gave a significantly greater flood extent than the 5-hour storm, and also tied in with the duration of the 2017 flood event. Using a 21-hour storm duration was felt to be overly conservative and not grounded in the historic data that is available.

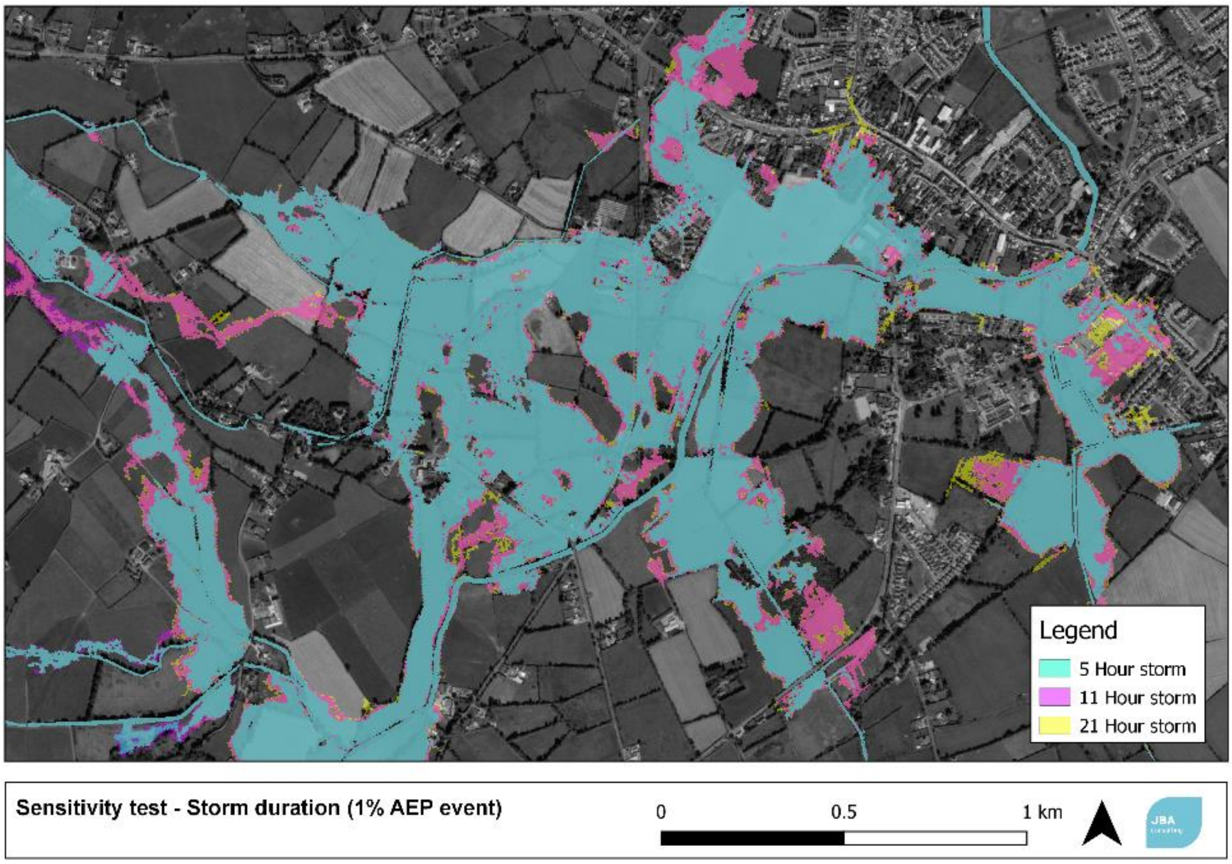


Figure 8-18: Sensitivity test – Storm duration

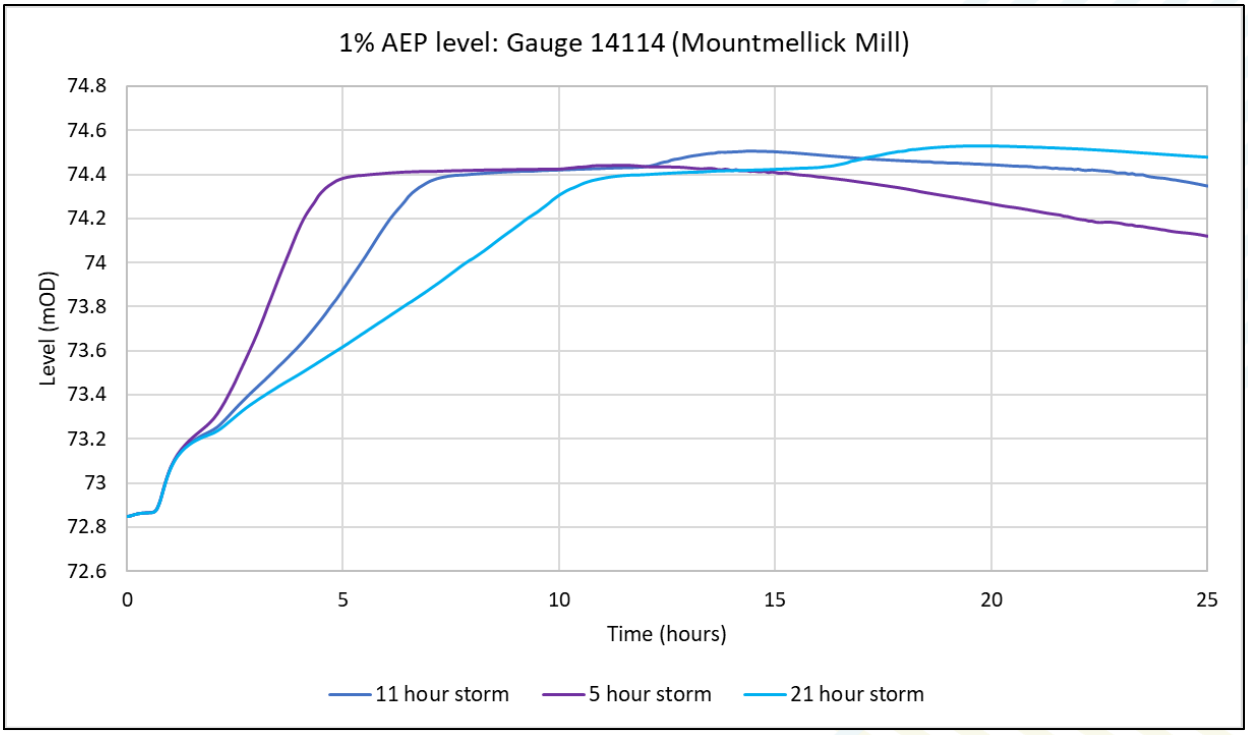


Figure 8-19: 1% AEP modelled hydrographs: Gauge 14114 (Mountmellick Mill)

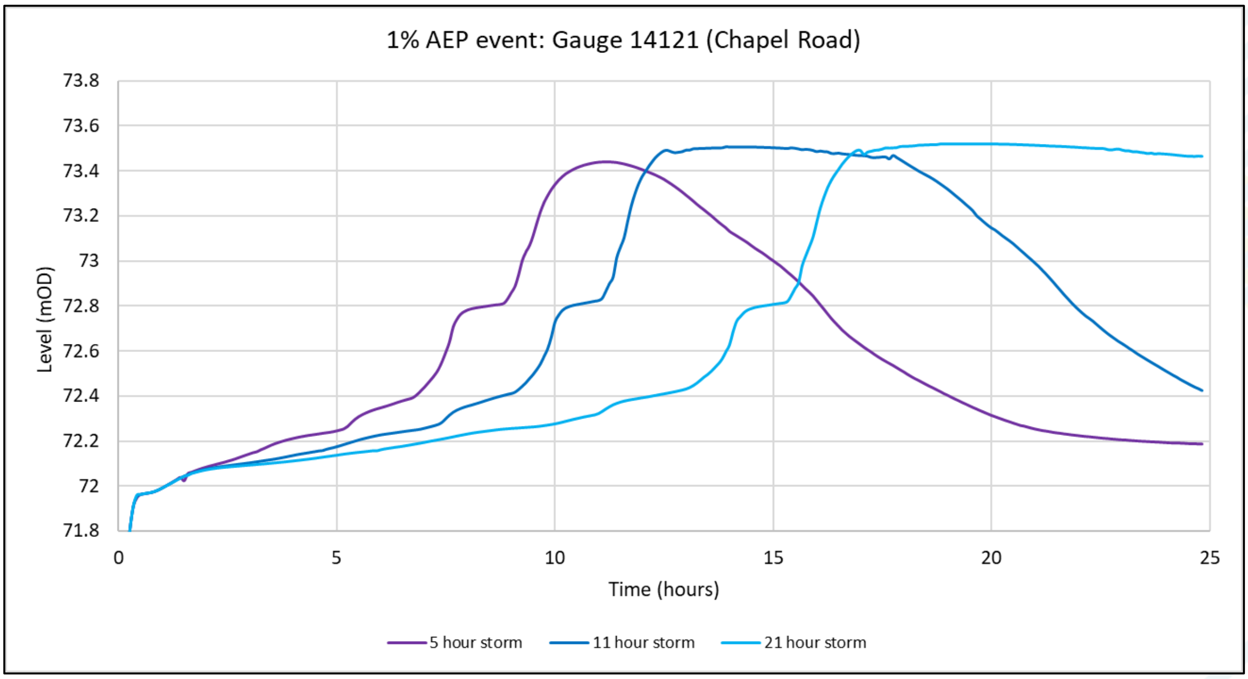


Figure 8-20: 1% AEP modelled hydrographs: Gauge 14121 (Chapel Road)

8.2.4 Increase/decrease in roughness

To fully calibrate and validate the rating curves generated by the model the effect of seasonality was examined by varying the channel roughness values to reflect seasonal changes in vegetation and differences in the maintenance regime. The Manning's N value was calibrated through the design events to give a high level of confidence in this parameter. To further test sensitivity, Manning's N roughness of the 1D channel and the 2D floodplain were increased and decreased by 20% to assess the impacts (refer to Section 3.4.4 for Manning's values used in models).

Figure 8-21 compares the flood extents generated for the 1% AEP event with different roughness values, a larger version of this figure can be found in Appendix F. It is noted that the model extents change with variation in roughness with slightly larger flood extents observed when roughness is increased. This is reflected in a simple point count of properties within the extents: 90 in the reduced Manning's extent, 91 in the normal model extent and 121 in the increased Manning's extent. This is expected as increased roughness results in build-up of water within the channel and floodplain. However, the increases in extents are not great, highlighting that seasonality of vegetation growth does not significantly impact potential flood extents. However, Figure 8-22 shows the Q-h relationship at gauge 14114 with varying roughness which varies greatly. The change in Q-h relationship shows that while the floodplain flow is not overly sensitive to roughness the in-channel flow is. The fact that sensitivity to in-channel roughness does not translate to increases in flood extents indicates that the representation of the floodplain has greater influence on the flood outlines. Overall, it is considered that the in channel and flood plain roughness values selected are appropriate and represent the average catchment condition in relation to roughness and were calibrated to recorded events.

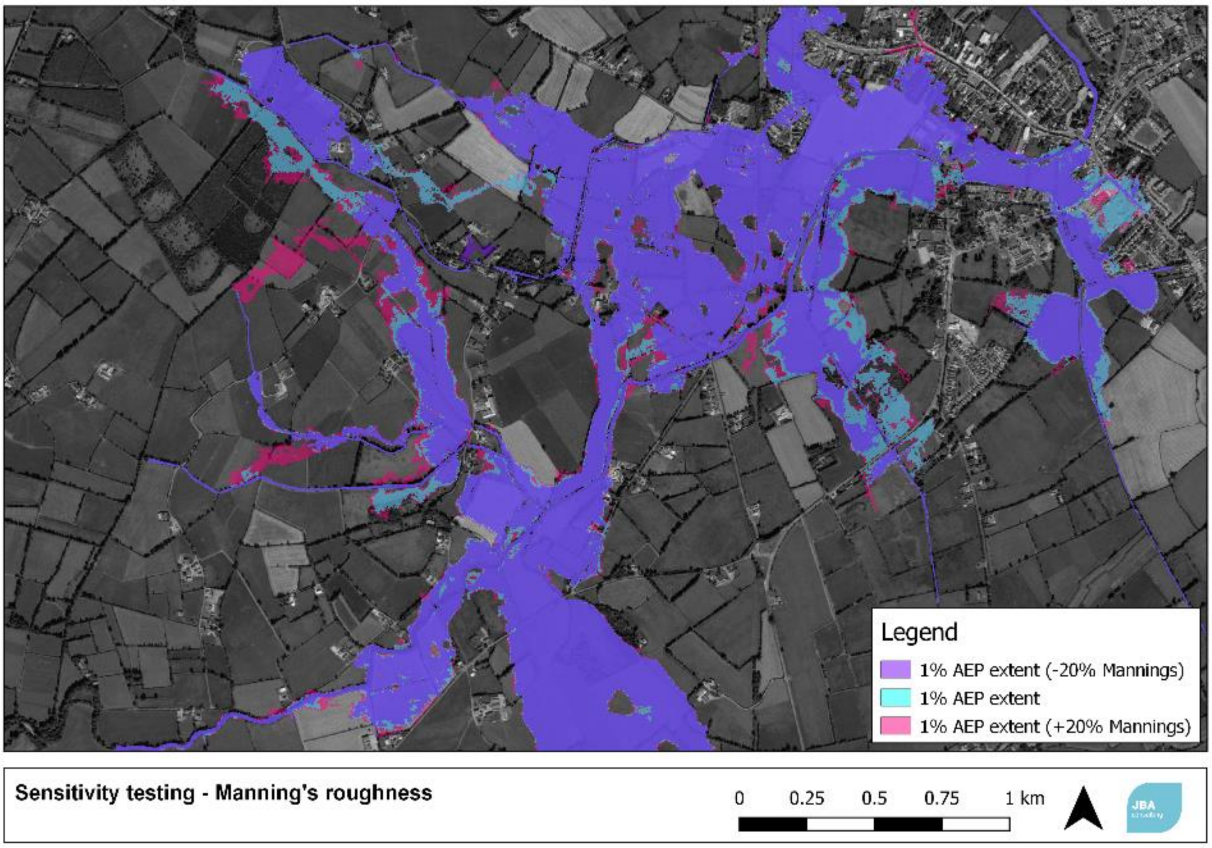


Figure 8-21: Sensitivity testing – Manning's roughness

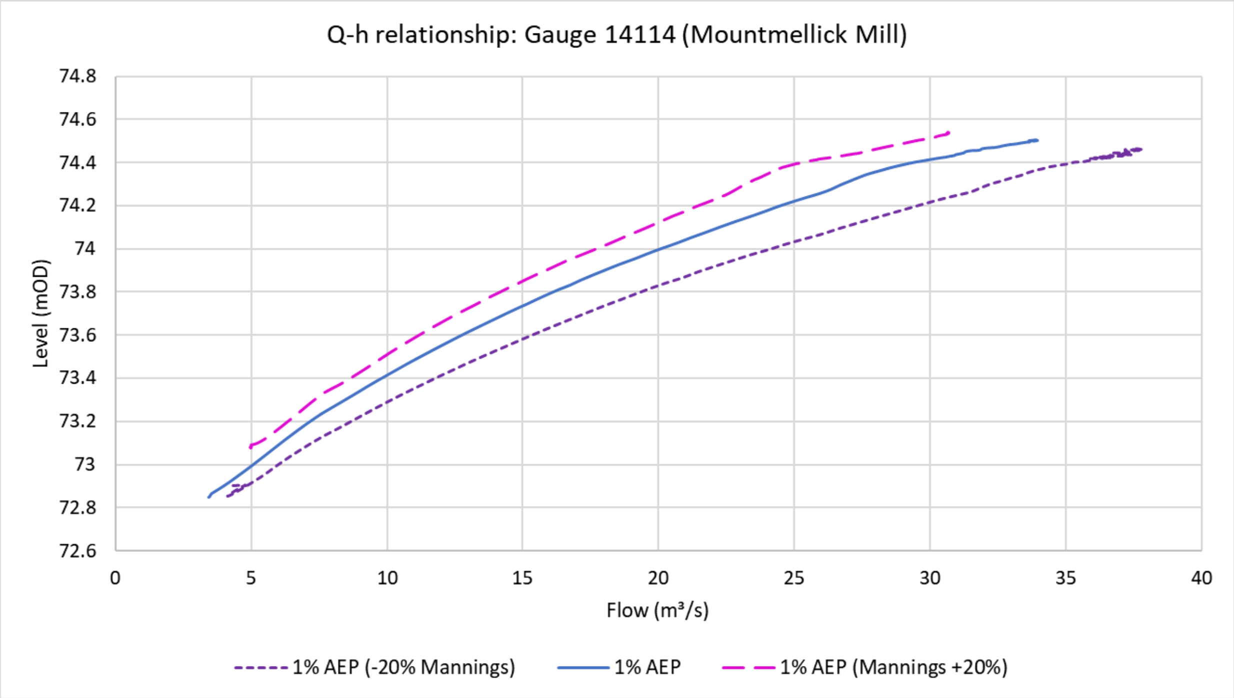


Figure 8-22: Q-h relationship at gauge 14114 (Manning's roughness sensitivity)

8.2.5 Representation of open grated manholes along Manor court culvert

The Pound River is culverted for 75m along the Manor Court estate to allow vehicle access. Along the culvert length there are a number of open grated manholes which allow the access to the culvert for cleaning and maintenance. A sensitivity test was run to understand the impact of including these grates within the model. Figure 8-23 compares the flood extents with and without the grates for the Manor Court area for the 1%AEP event, a larger version of this figure can be found in Appendix F. The grates were modelled using SX pit connections to allow flow between the 1D and 2D domains. There was no increase or change in water level within the culvert when the grates were included but there is a minor variation in extents because of their presence, but no new properties or areas are impacted in the 1% AEP event. As the grates are likely to be more effective in allowing flow out in more extreme events and as levels and connection increases, it is proposed that they are represented in the high flow model (used for greater than 1% AEP events) but are not included for smaller events.

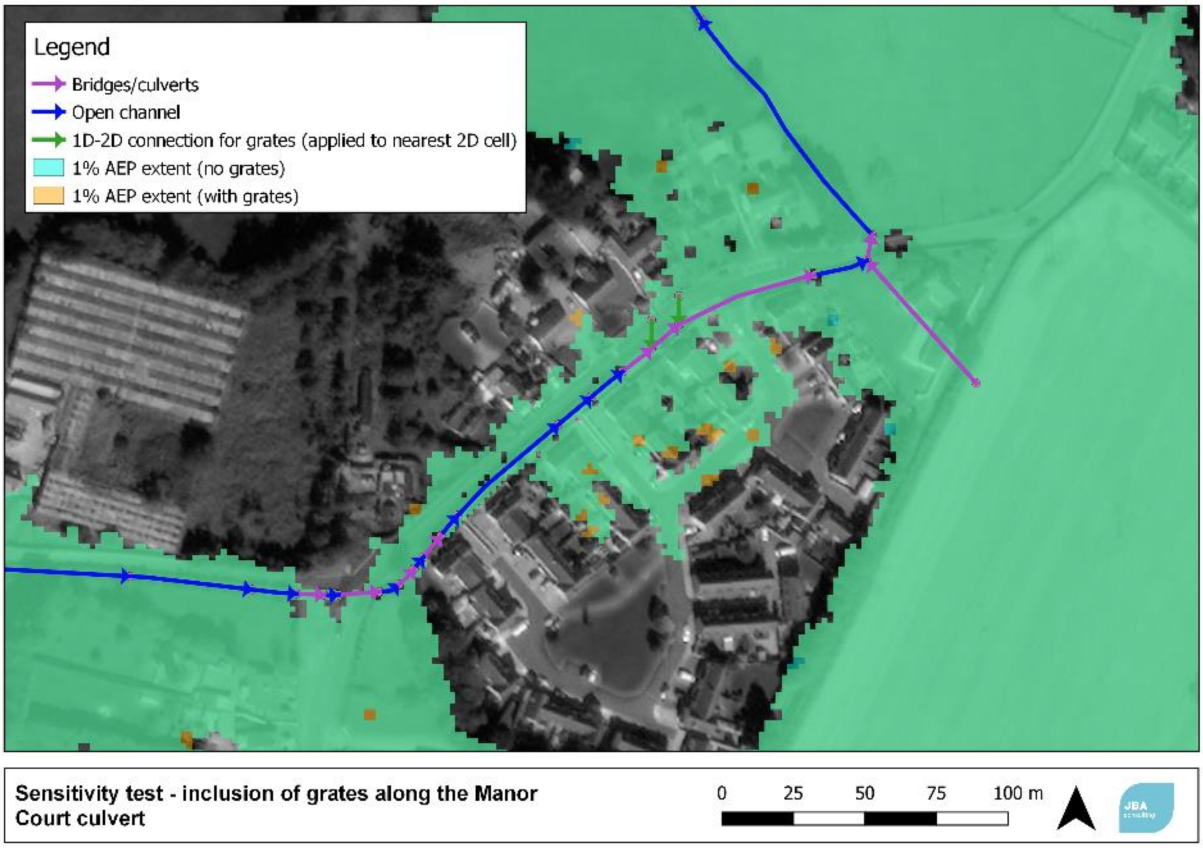


Figure 8-23: Sensitivity test – inclusion of grates along the Manor Court culvert

8.2.6 Testing of structure representation

How each structure within the model is represented is discussed in the structure assessments in Appendix C. In most cases the selection of whether to represent a structure using a bridge or culvert units is justified by looking at the channel width to structure length ratio. For the vast majority of structures, the appropriate choice of representation is clear. Review of the model found 3 structures represented as bridges which could potentially be represented as culverts (length-width ratio reasonably close). These structures are:

- 14OWEN00311B (Mountmellick Mill bridge)
- 14OTB100017B (Owenass tributary 1 bridge)
- 14OTB300036B (Owenass tributary 3 bridge)

To test the impact of changing the representation of these structures a sensitivity test was carried put where they bridges were modelled as culverts. Figure 8-24 compares the flood extents when the structures are modelled as bridges and then culverts, a larger version of the figure can be found in Appendix F. From the outputs there is no change in extents along the Owenass tributaries due to the change. There is a noted increase in the extents due to the change in representation at the Mountmellick Mill bridge. This is due to the change in equations used in conveying the flow. While the culvert representation results in greater flood extents the dimensions of the bridge mean it is more suitable to be represented as a bridge as initially specified and ensures that the flood extents at all return periods are representative at that point (risk of excessive flooding reported at lower return period events is culvert used). Therefore, the representation of all three structures tested is considered suitable.

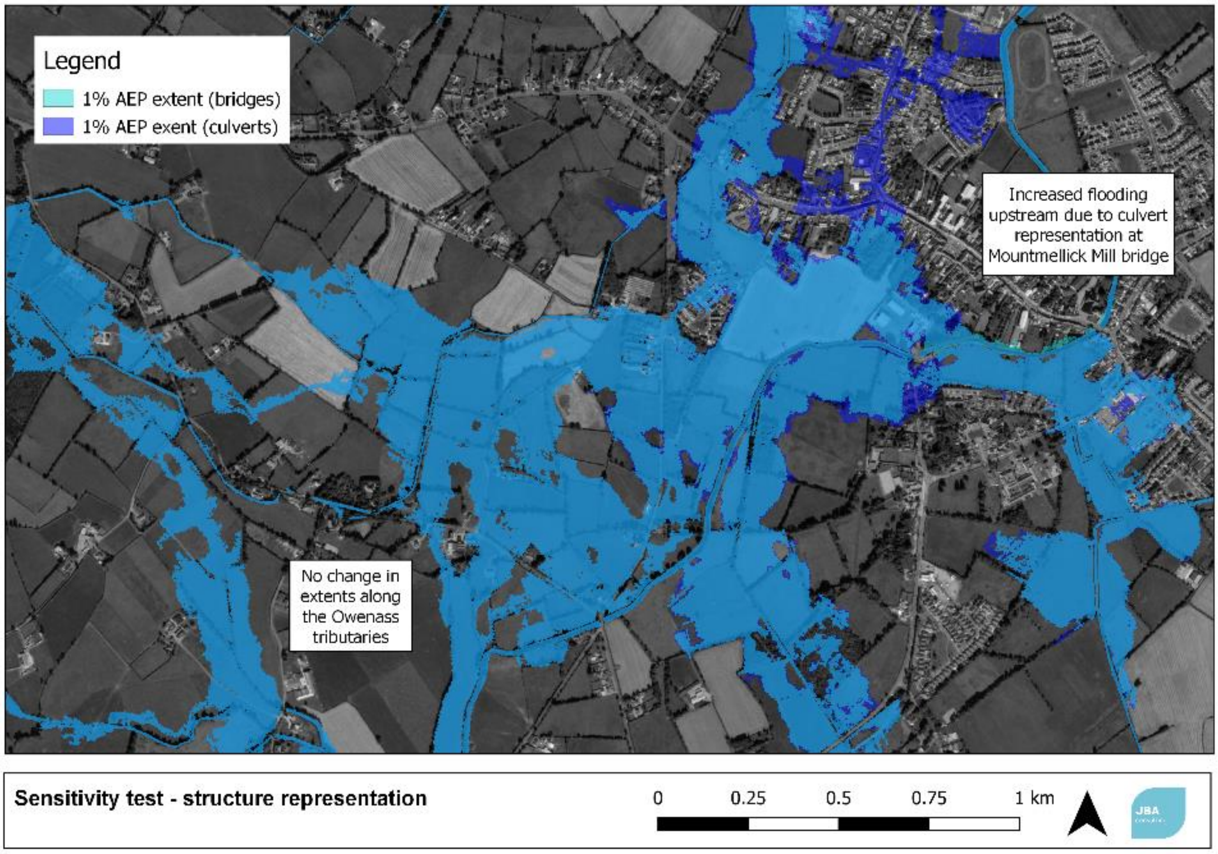


Figure 8-24: Sensitivity test – structure representation

8.2.7 Testing of structure parameters

A sensitivity test was carried out to test the impact of changing parameters for various structures. Parameter changes were carried out on the critical structures highlighted in Section 4. Table 8-7 summarises the parameter changes made, and Figure 8-25 compares the levels for the 1% AEP event with and without the parameter changes. The only area impacted by the change is around Convent bridge where there is an increase in levels by approximately 0.05m. Overall this test highlights that the model is not overly sensitive to parameters except for Convent bridge.

Table 8-7: Parameter changes for sensitivity test

Structure	Parameter change
Mountmellick Mill Bridge	Decreased orifice coefficient to 1.0 from 0.9
Convent Bridge	Decreased orifice coefficient to 1.0 from 0.9
Railroad Culvert	Increased entry and exit losses from 0.5 and 1.0 to 0.6 and 1.1 respectively
Wolfe Tone Bridge	Increased entry and exit losses from 0.5 and 1.0 to 0.6 and 1.1 respectively

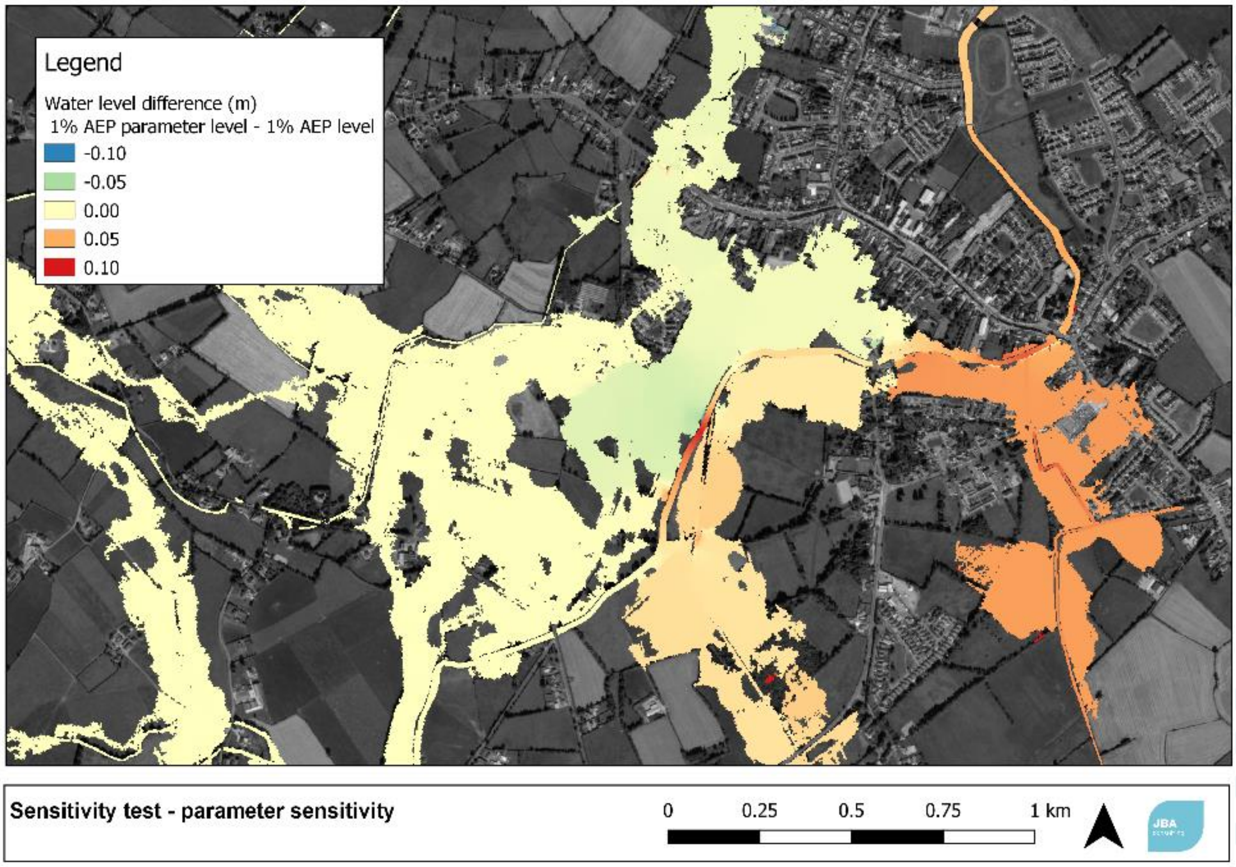


Figure 8-25: Sensitivity test – parameter sensitivity

8.2.8 Testing of retained walls

As discussed in Section 3.5.1 walls are retained in the design scenario in two locations – along Manor Court on the Pound and downstream of Convent Bridge on the Owenass. These were retained to ensure a realistic onset of flooding in these areas was developed. A sensitivity test using the 1% AEP event was run to assess the additional flooding that would occur if the walls were not included. Figure 8-26 compares the modelled extents with and without the walls. A larger version of the figure can be found in Appendix F. From the figure the removal of the walls only impacts the extents local to the wall locations, no new properties are impacted when the walls are removed.

Downstream of convent bridge out of bank spill occurs on the right-hand bank, depth of flooding here is between 0.10-0.20m in the 1% AEP event and impacts back gardens.

The removal of the walls around the Manor Court area results in greater extents and flood depths. By removing the walls additional spill from the channel occurs increasing the flood depths by up to 0.10m within the area (refer to Figure 8-27).

From this test the retained walls in both areas provide an amount of additional protection but the increase in flooding when they are removed is not overly excessive. Therefore, it is considered appropriate to retain the walls in the design events to provide realistic onset of flooding and extents for the area.

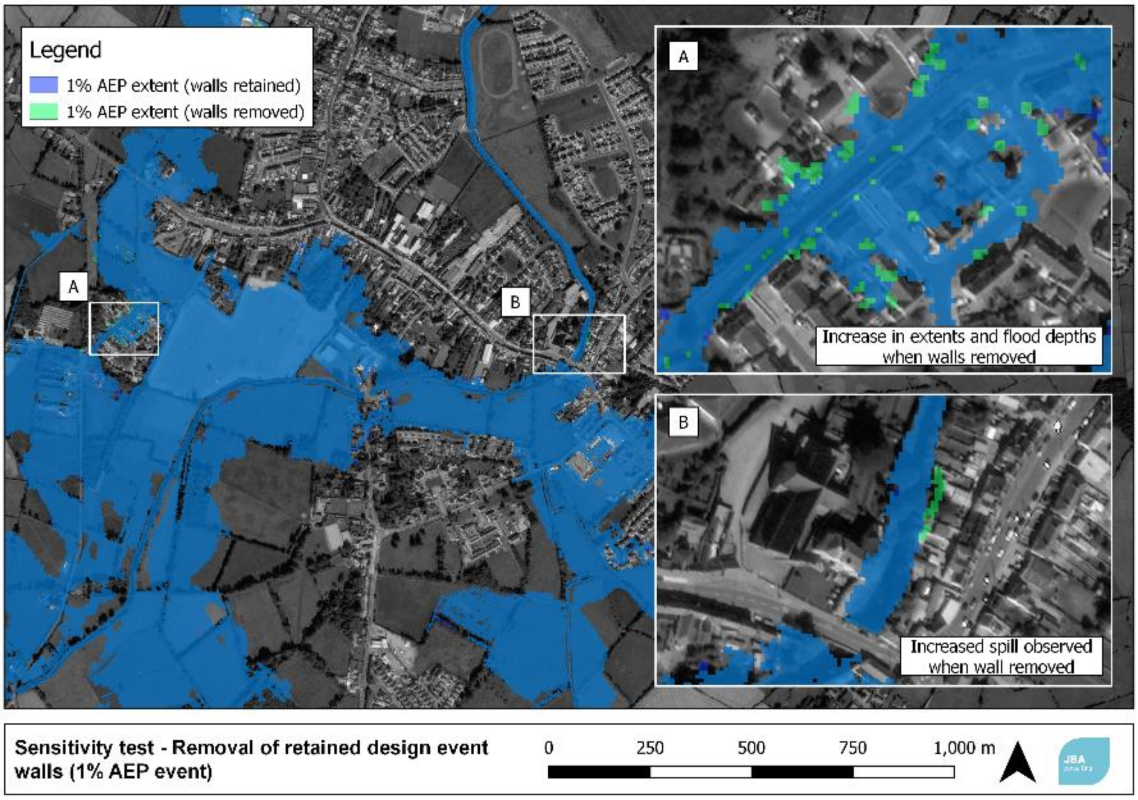


Figure 8-26: Sensitivity test – Removal of retained design event walls (1% AEP event)

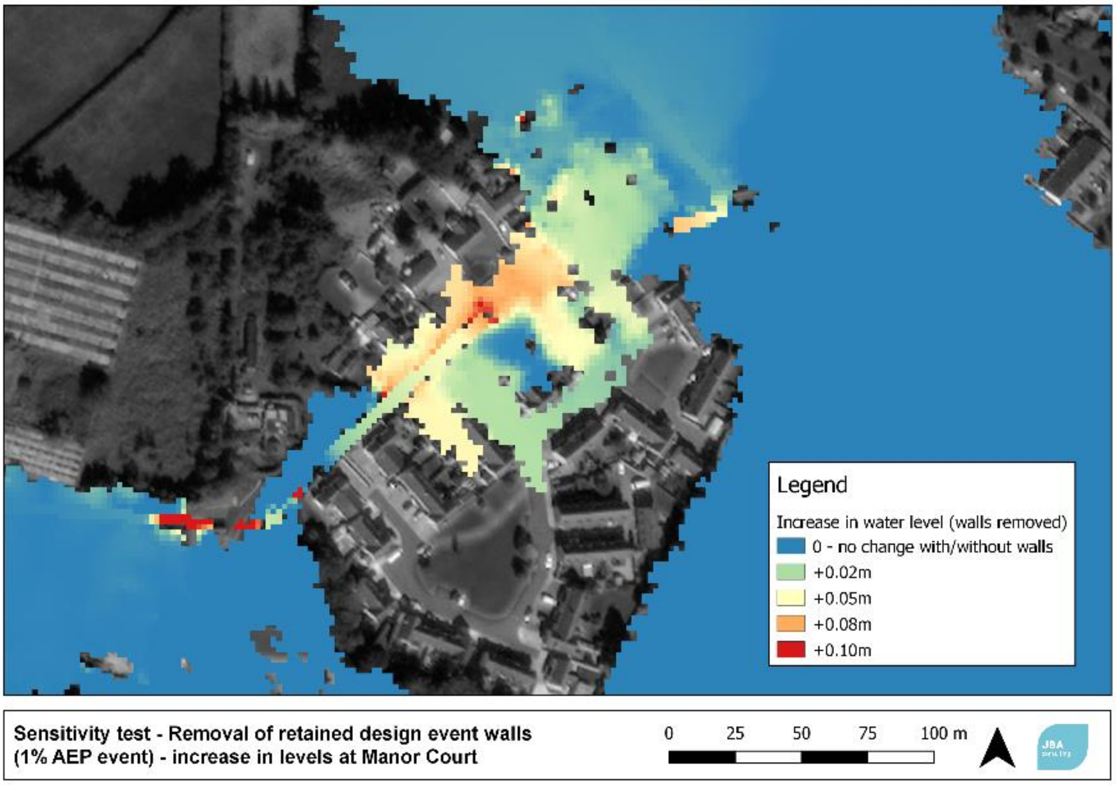


Figure 8-27: Sensitivity test – Removal of retained design event walls (1% AEP event) – In crease in levels at manor Court

8.3 Climate change

Impacts of climate change have been considered in the modelling process. The climate change factors applied for the Medium Range Forecast Scenario (MRFS) and High-End Future Scenario (HEFS) are discussed in the corresponding Hydrology Report. Figure 8-28 and Figure 8-29 compare the 1% AEP flood extents for the current, MRFS and HEFS scenarios. Larger versions of these figures can be found in Appendix F. As expected, there is an increase in flooding with an increase in climate change severity.

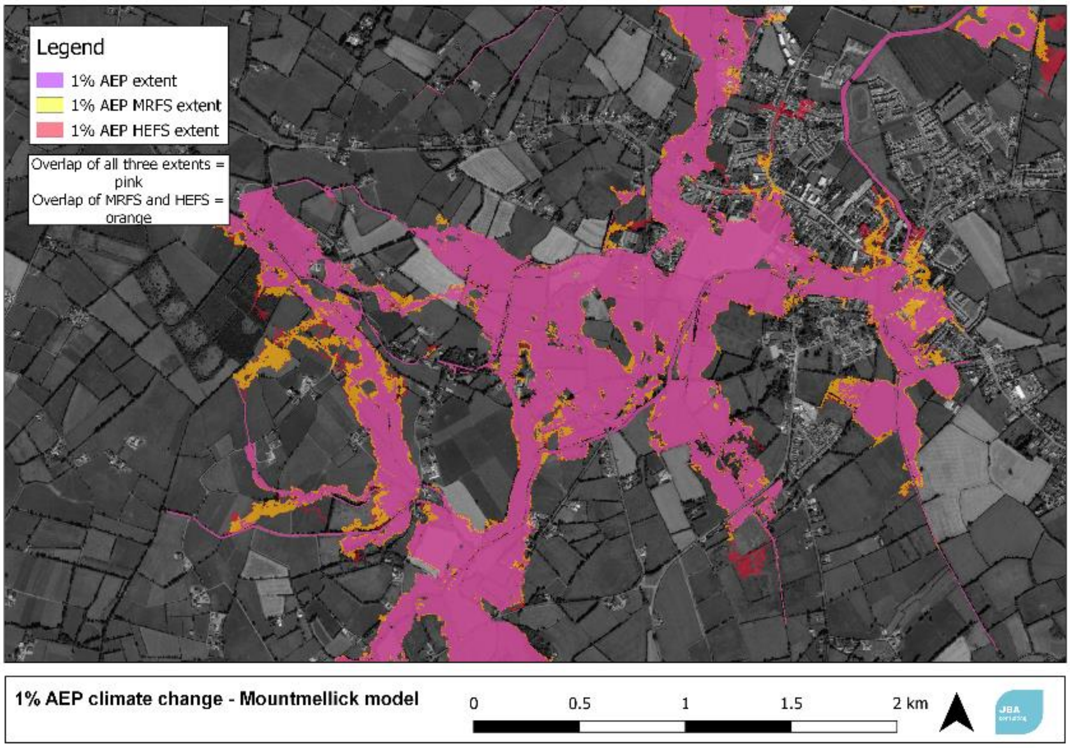


Figure 8-28: 1% AEP climate change – Mountmellick Model

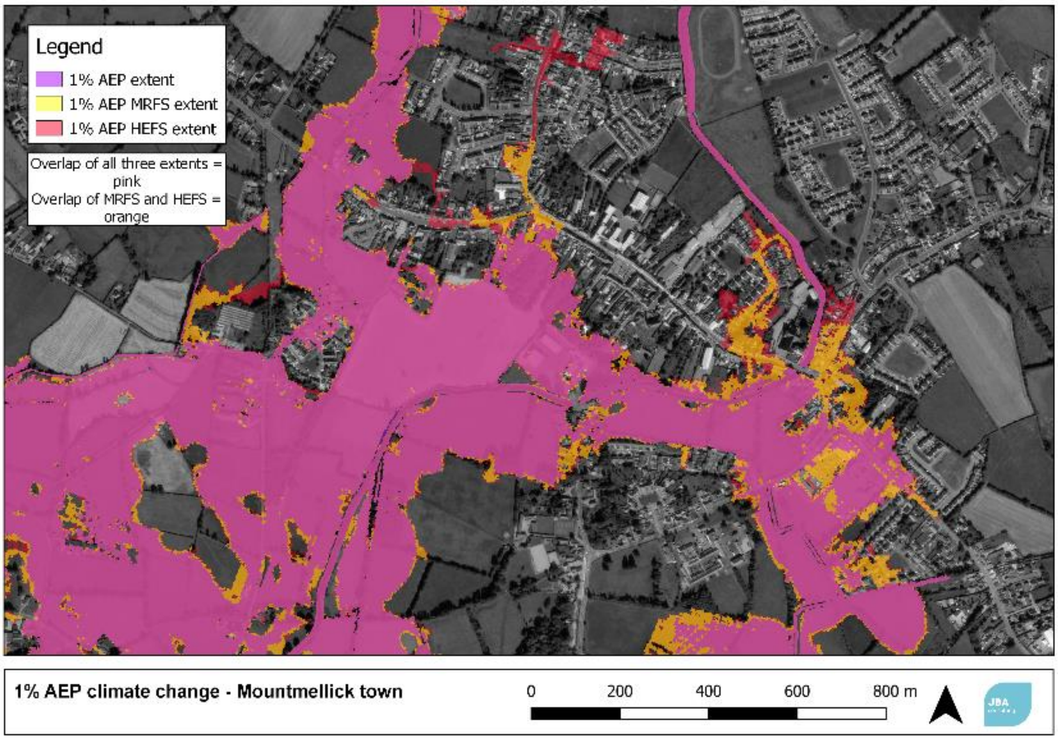


Figure 8-29: 1% AEP climate change – Mountmellick town

9 Hydraulic system summary

From examining the modelled outputs for calibration events and sensitivity tests a number of key hydraulic factors are identified as having an impact on overall flood risk to Mountmellick town and are described in the following sections. Figure 9-1 highlights the key locations discussed.

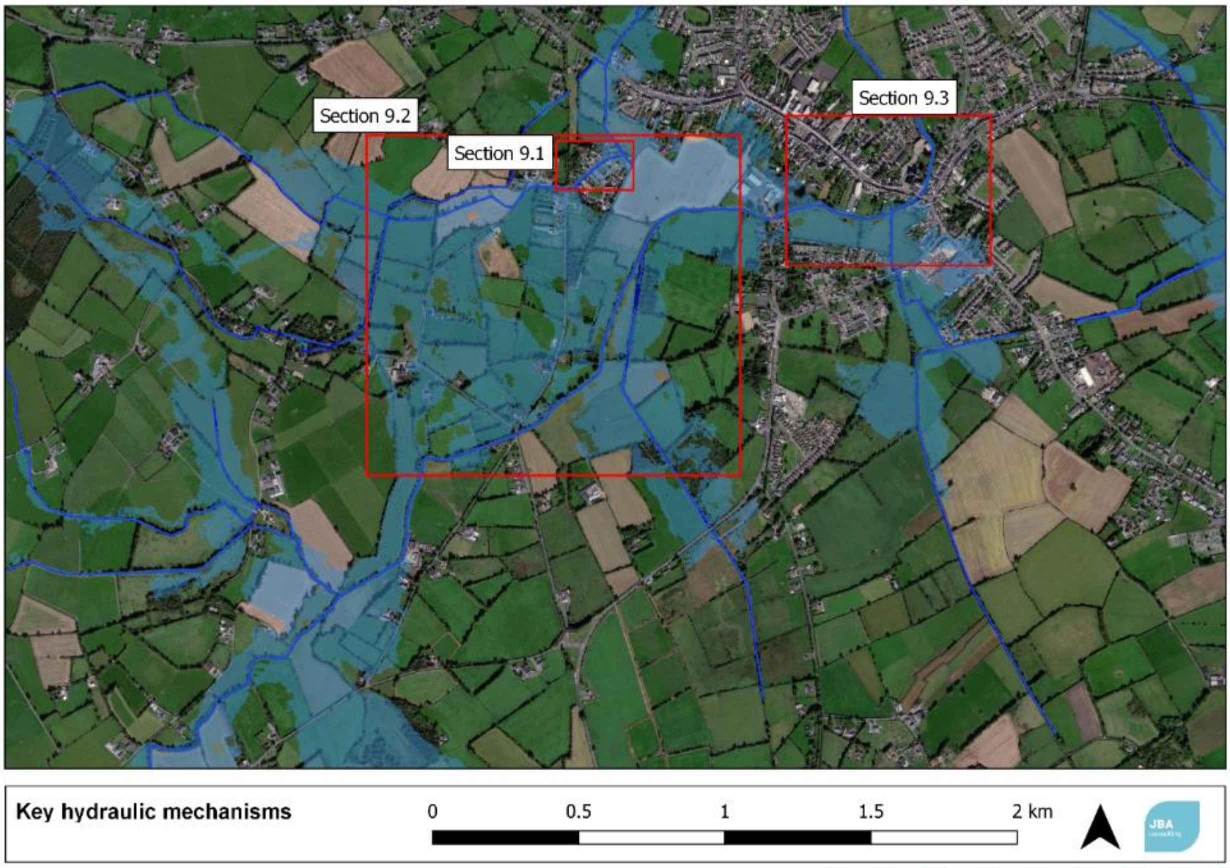


Figure 9-1: Key hydraulic mechanisms

9.1 Constriction of the Pound at Manor Court

Along Manor Road the Pound is confined to a narrow concrete channel with several small bridges and culverts present along the reach, as well as a 75m long culvert (refer to Figure 9-2). In higher frequency events, the Pound can convey flows through this engineered reach. In lower frequency events, with the addition of cross flow from the Owenass and cumulative backwater effects from these structures, the conveyance capacity of this reach is exceeded, with the culverts and bridges surcharging. This results in out-of-bank spill emerging from the short sections of open channel between culverts and bridges, flowing down the road, into Manor Court estate and around the estate across the Owenass-Pound flood plain.

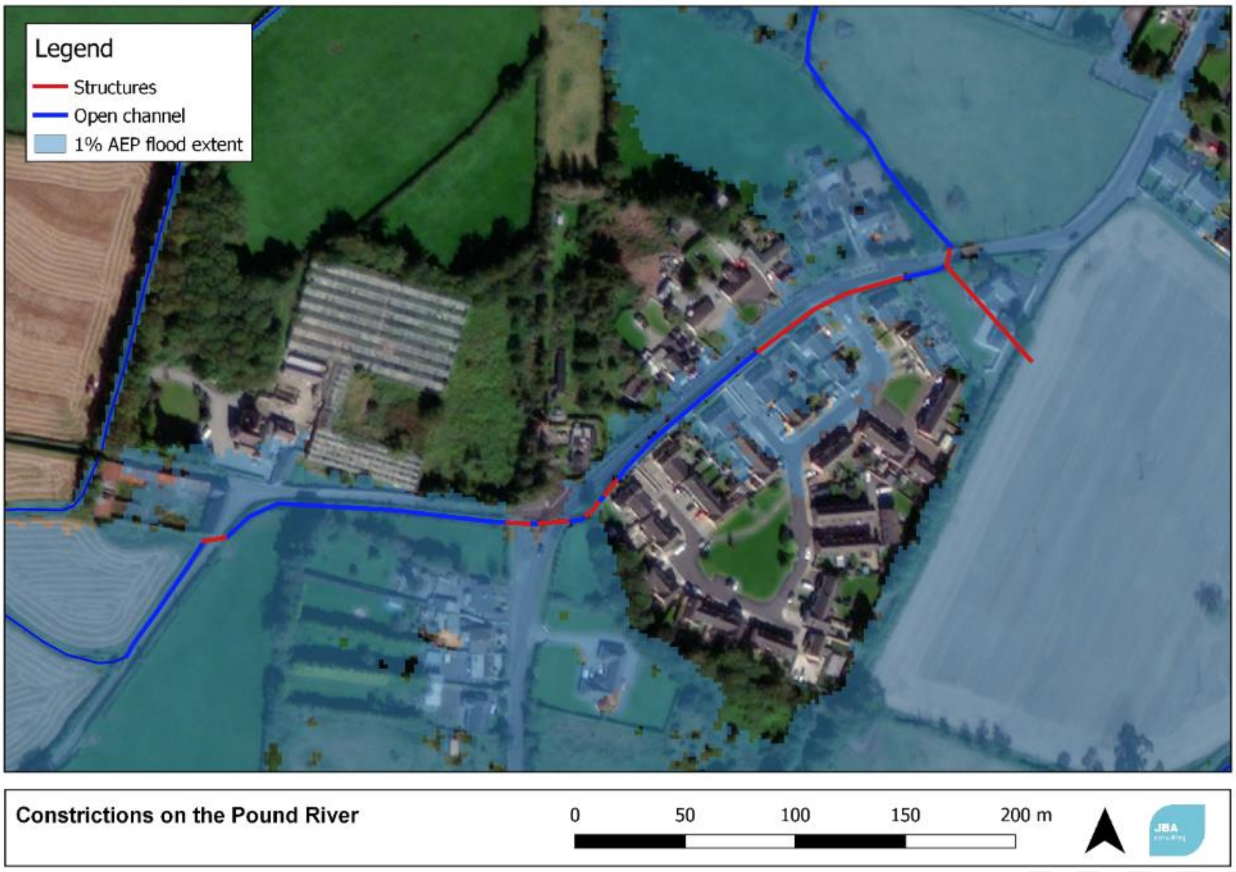


Figure 9-2: Constrictions on the Pound River

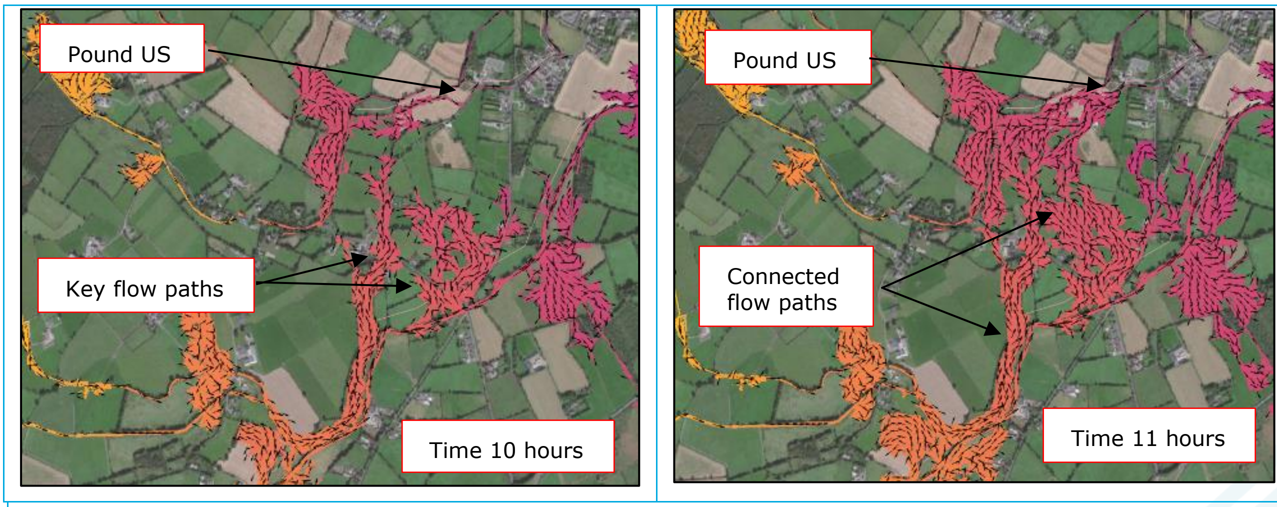
9.2 Cross catchment flow between the Owenass and Pound Rivers

As noted, calibrating the model cross-catchment flow between the Owenass and Pound watercourses is crucial for understanding the behaviour of flood waters within the system. Review of the higher flow event modelled outputs shows the direction of flow transfer between the watercourses changes throughout the event and as you move down through the system. However, the dominant flow transfer direction is from the Owenass to the Pound.

Initially, out of bank flow from the Owenass spills upstream of Mountmellick town and moves across the flood plain towards the Pound upstream of Manor Court via topographical low points and pathways within the flood plain (refer to Figure 9-3). The impact of the additional flow from the Owenass in the Pound is shown by the sharp increase in level observed in the hydrographs along the Pound watercourse (Figure 9-4). The Pound, an already constricted channel due to the presence of multiple structures previously highlighted, becomes overwhelmed by the flow volume. Increased out of bank spill occurs upstream of Manor Court. This spill, now a combination of flow from the Owenass and Pound, moves across the flood plain in a south-easterly direction around Manor Court into Baker's field. A large proportion of this flow returns to the Pound watercourse downstream of Manor Court passing through Baker's field gate and across the road while some enters back into the Owenass highlighting the transfer of water back and forth between the two systems.

Directly upstream of Mountmellick Mill bridge another flow transfer pathway from the Owenass to the Pound is activated with a portion of the out of bank flow at this point moving across the Baker's field and into the Pound via the same flow path while the rest fills up the flood plain upstream of the main town (Figure 9-3). The impact of these first and second flow contributions from the Owenass into the Pound are shown in the hydrographs at the upstream and downstream flow entry points on the Pound (Figure 9-4), the total additional flow to the Pound is estimated to be approximately 13m3/s in the 1%AEP event (Figure 9-5). It is also noted that hedges and ditches within the flood plain have not been explicitly modelled within the flood plain.

This back and forth transfer of flow between the watercourses, the limited capacity of the Pound upstream and the activation and filling of the flood plain between the two rivers is the main driver of flooding with the town and wider area.



Establishment of upstream flow connection between Pound and Owenass

Establishment of second downstream flow connection between Pound and Owenass, also note movement of flow back into Owenass towards the south of the images

Figure 9-3: Establishment of Owenass and Pound flow connections

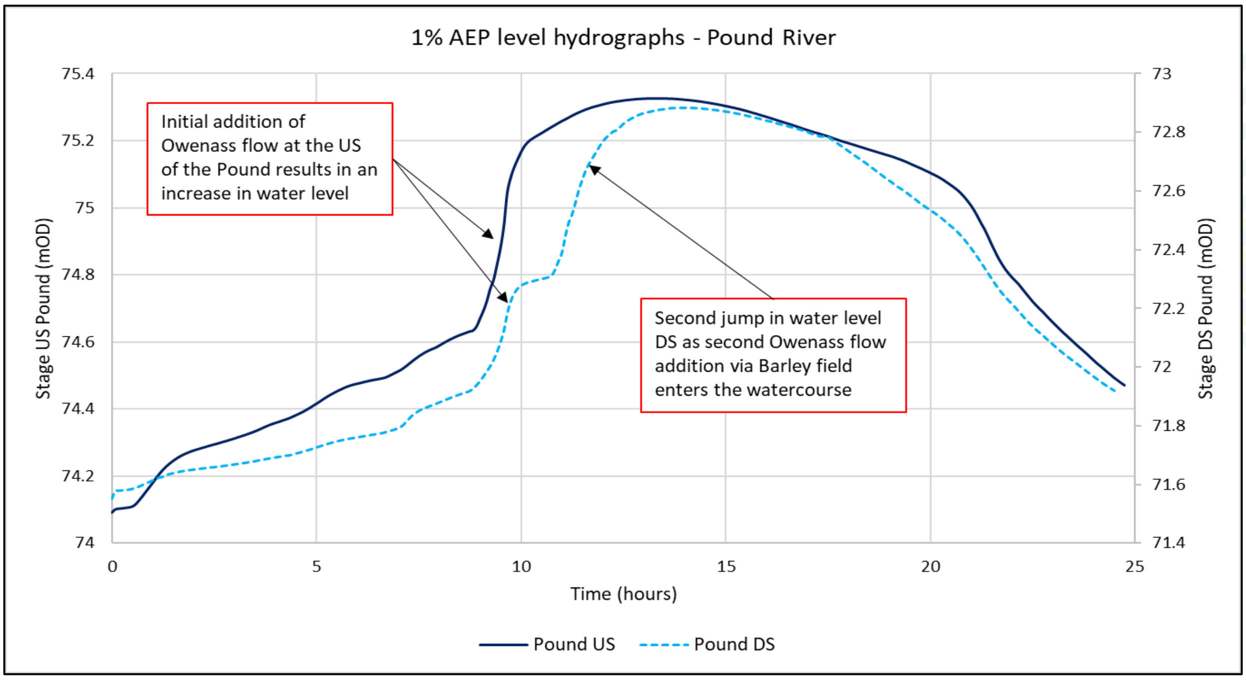


Figure 9-4: 1% AEP level hydrographs – Pound River

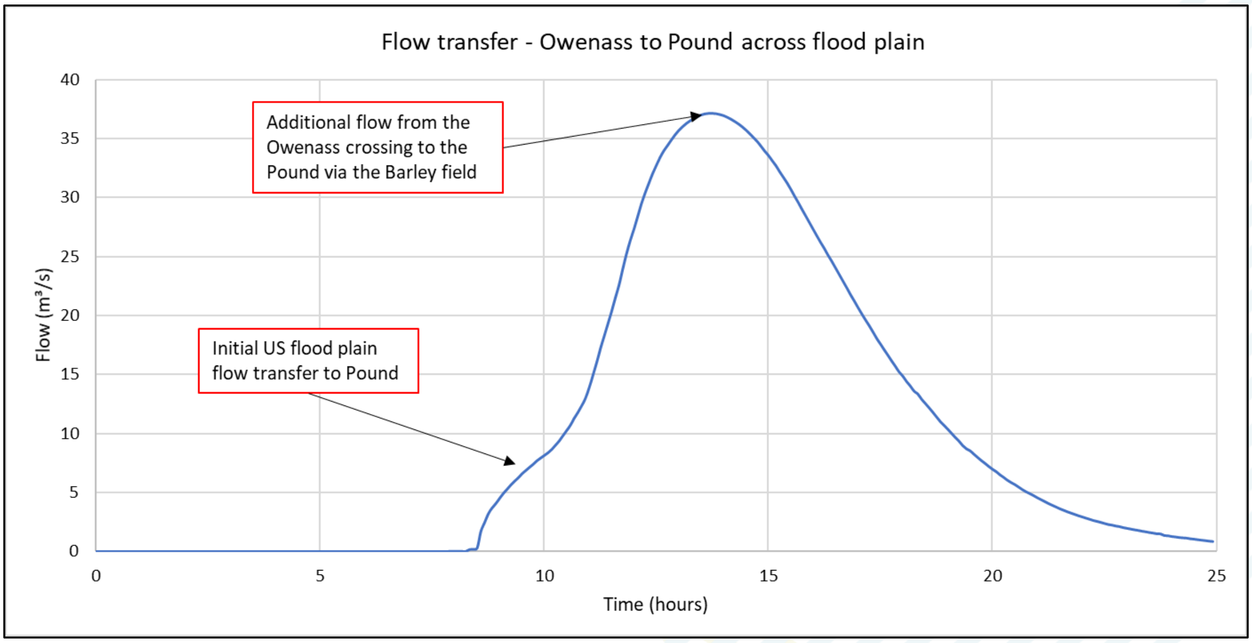


Figure 9-5: Flow transfer – Owenass to Pound across flood plain

9.3 Restriction of flow downstream of Convent bridge

From the modelled outputs and anecdotal evidence there is no flooding downstream of Convent bridge. This is a result of the increased activation of the Owenass floodplain upstream of Mountmellick Mill gauge with increasing return period, coupled with an oversize channel as a result of arterial drainage maintenance activity. The action of the floodplain upstream results in a limit to the amount of flow travelling downstream in channel and explains the flattened hydrograph peaks at Mountmellick Mill gauge; any additional inflow is temporarily lost to the floodplain, resulting in increased flood depths and extents upstream of Mountmellick Mill gauge and Convent bridge but no increased risk downstream of the town flood plain.

10 Summary

This Hydraulic Model Report describes the methods and steps carried out to develop two linked 1D-2D hydraulic models for the Mountmellick area. 18 watercourses have been modelled. Review of the available data and flood history for the area has been carried out and used to construct the new hydraulic model.

Flood Modeller Pro and TUFLOW software packages were used to build the 1D and 2D model components respectively. All structures were modelled in 1D and details of each and its representation recorded. Two sections of the watercourses were modelled in ESTRY 1D rather than Flood Modeller due to channel complexities. The Blackwater River was modelled in 2D only. TUFLOW was used to model the flood plain and wider area.

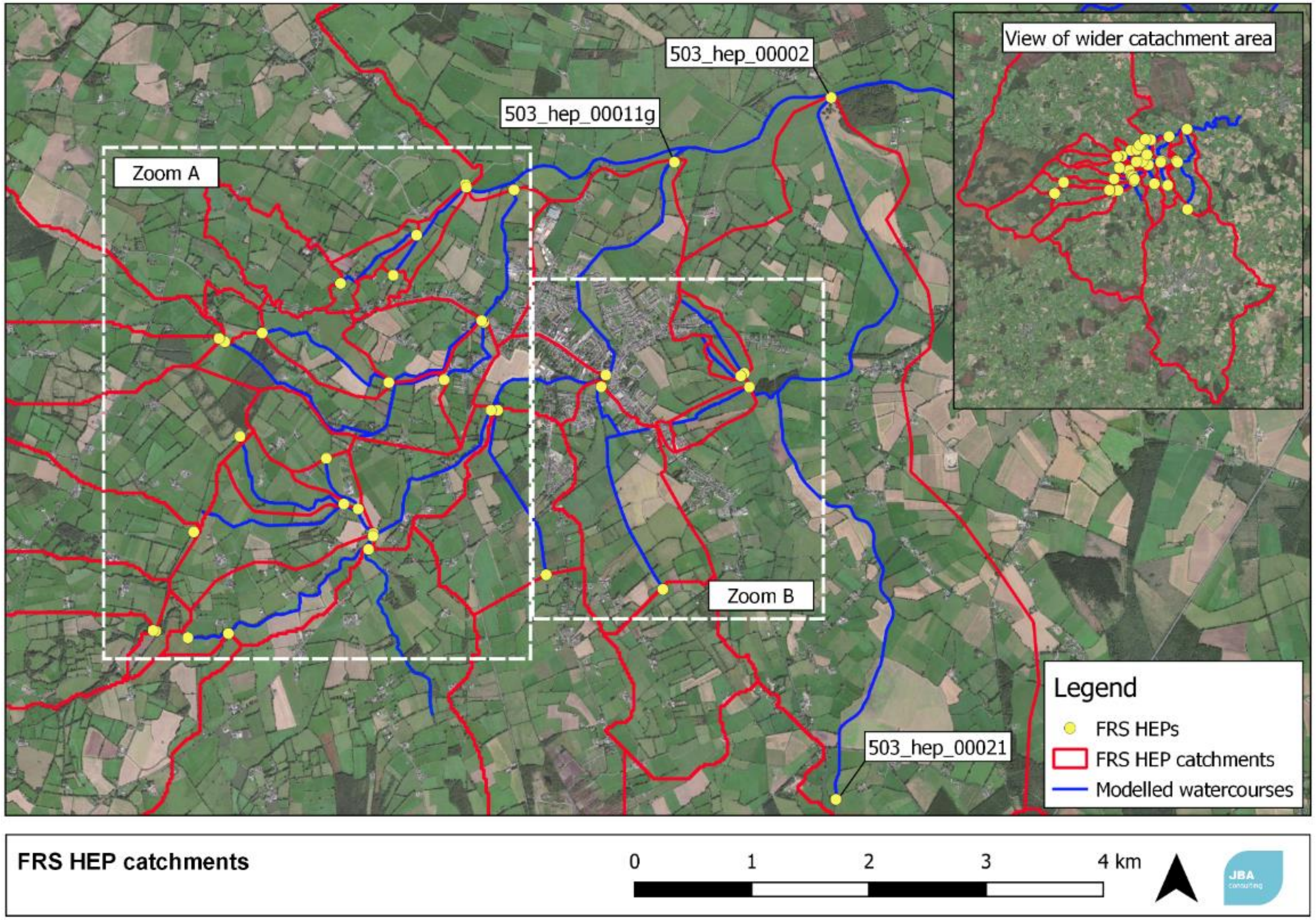
Limitations of the modelling method have been highlighted, and measures to overcome these limitations discussed. These include the use of single HX lines to represent small channels, and the representation of portions of the model in ESTRY rather than Flood Modeller due to complexity. A key limitation identified was the model's inability to deal with large volumes of water resulting in issues with 1D-2D flow transfer in channels where there is a lot of out of bank flooding. To address this separate high flow event models where smaller watercourses have modelled in 2D only have been used to help with model stability for these higher events and minimise the impact of this issue.

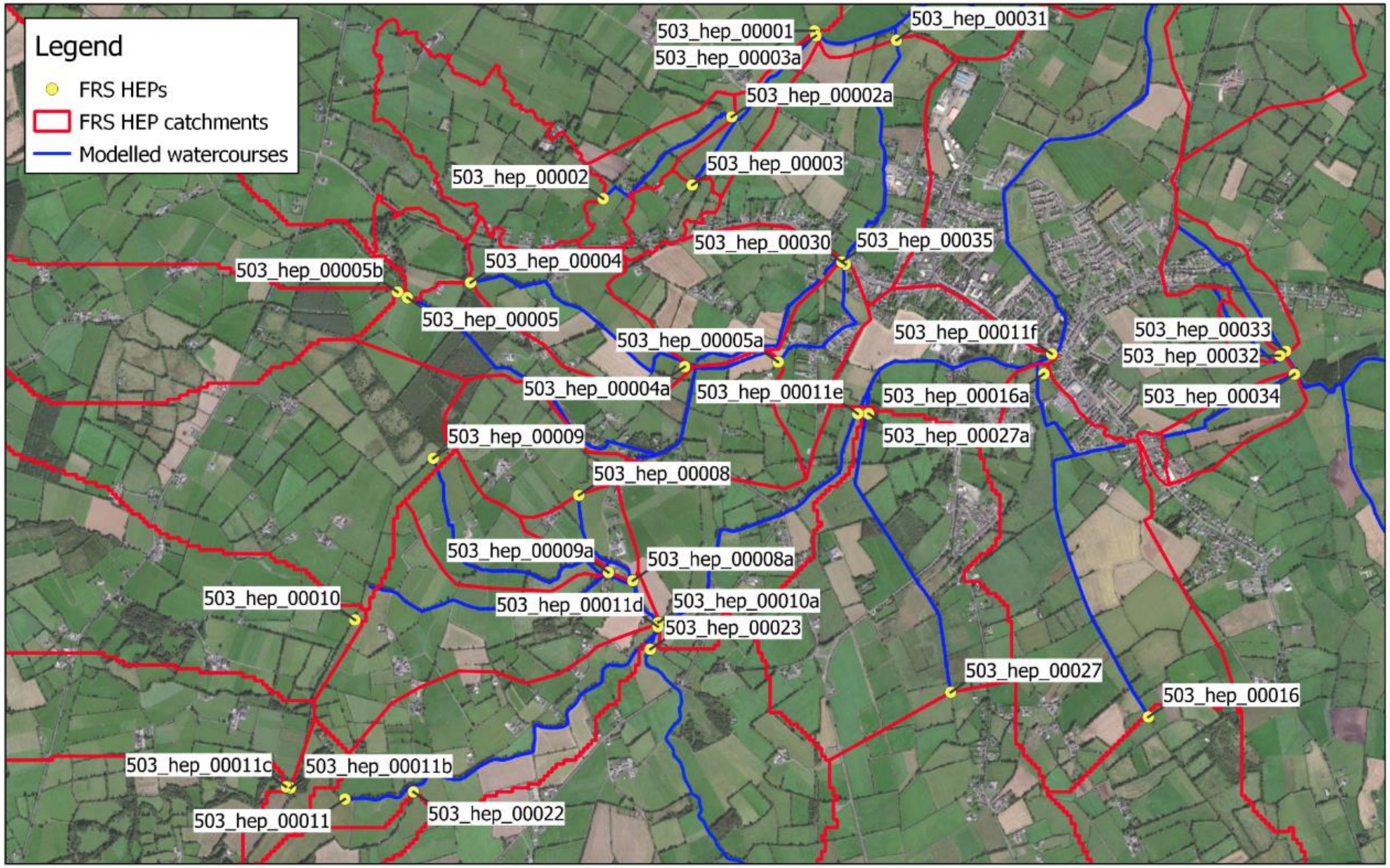
The model was calibrated using data from three recorded flood events. A range of sensitivity tests were carried out. A number of hydraulic constraints and features have been identified from the calibration and sensitivity outputs. The critical feature is the cross-catchment flow from the Pound into the Owenass, and then around Manor Court how that reverses.

The main calibration point at Mountmellick Mill gauging station provides limited ability to improve the calibration of the model, as it is at the downstream end of a complex heavily attenuated system. Coupled with the lack of hourly raingauge data within the catchment and no watercourse gauges upstream of the cross-flow locations calibration has been a challenge. However, both the hydrological and hydraulic models are replicating observed flooding extents and depths that give confidence in using these models for assessment of the Flood Relief Scheme options.

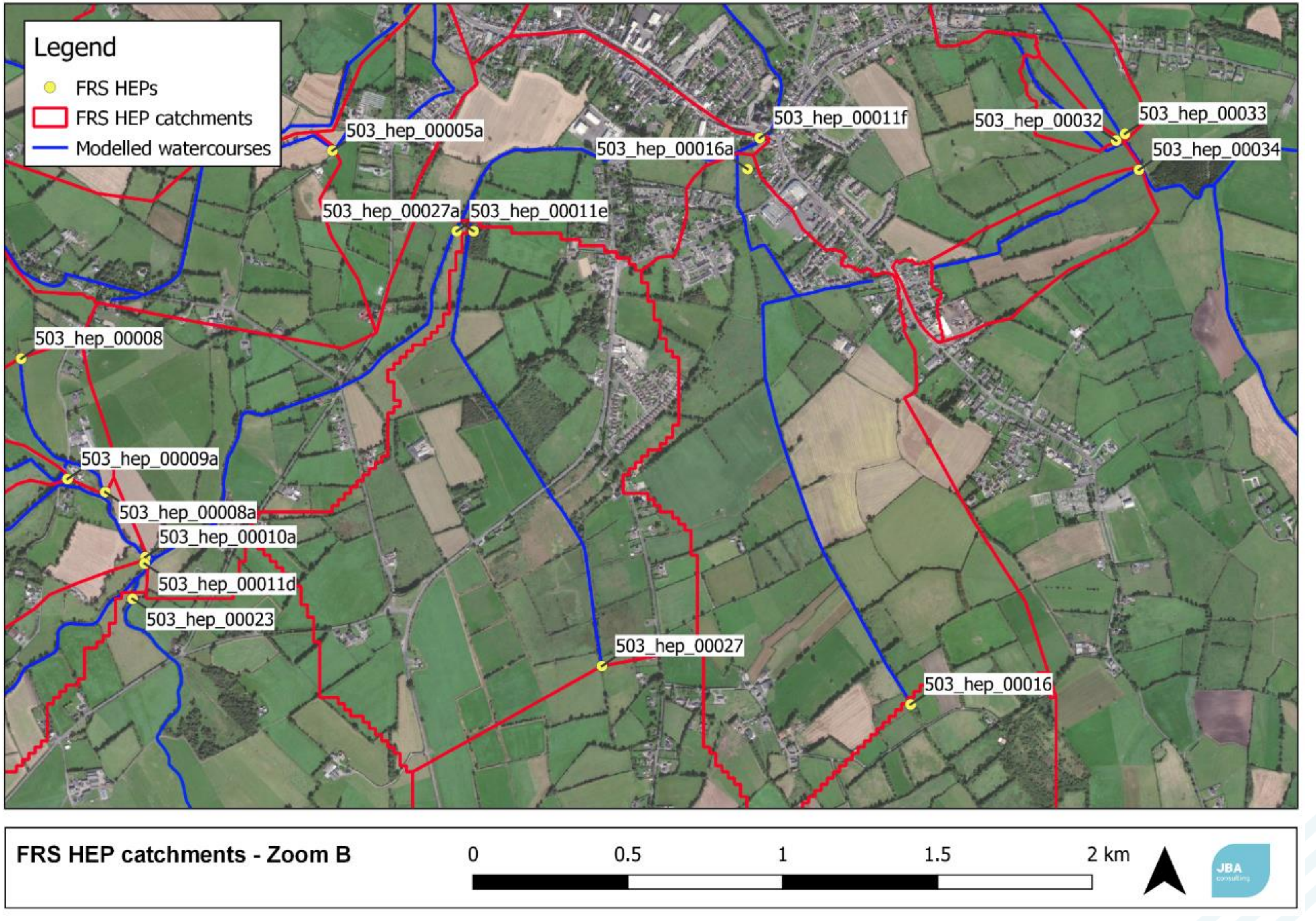
A 1% AEP peak inflows

A.1 Catchment areas





FRS HEP catchments - Zoom A


Legend
FRS HEPs
FRS HEP catchments
Modelled watercourses
503_hep_00005a
503_hep_00016a
503_hep_00011f
503_hep_00032
503_hep_00033
503_hep_00034
503_hep_00027a
503_hep_00011e
503_hep_00008
503_hep_00009a
503_hep_00008a
503_hep_00010a
503_hep_00011d
503_hep_00023
503_hep_00027
503_hep_00016
FRS HEP catchments - Zoom B
0
0.5
1
1.5
2 km

A.2 1% AEP peak inflows

Key		
Point inflow	Lateral inflow	Storm water point inflow

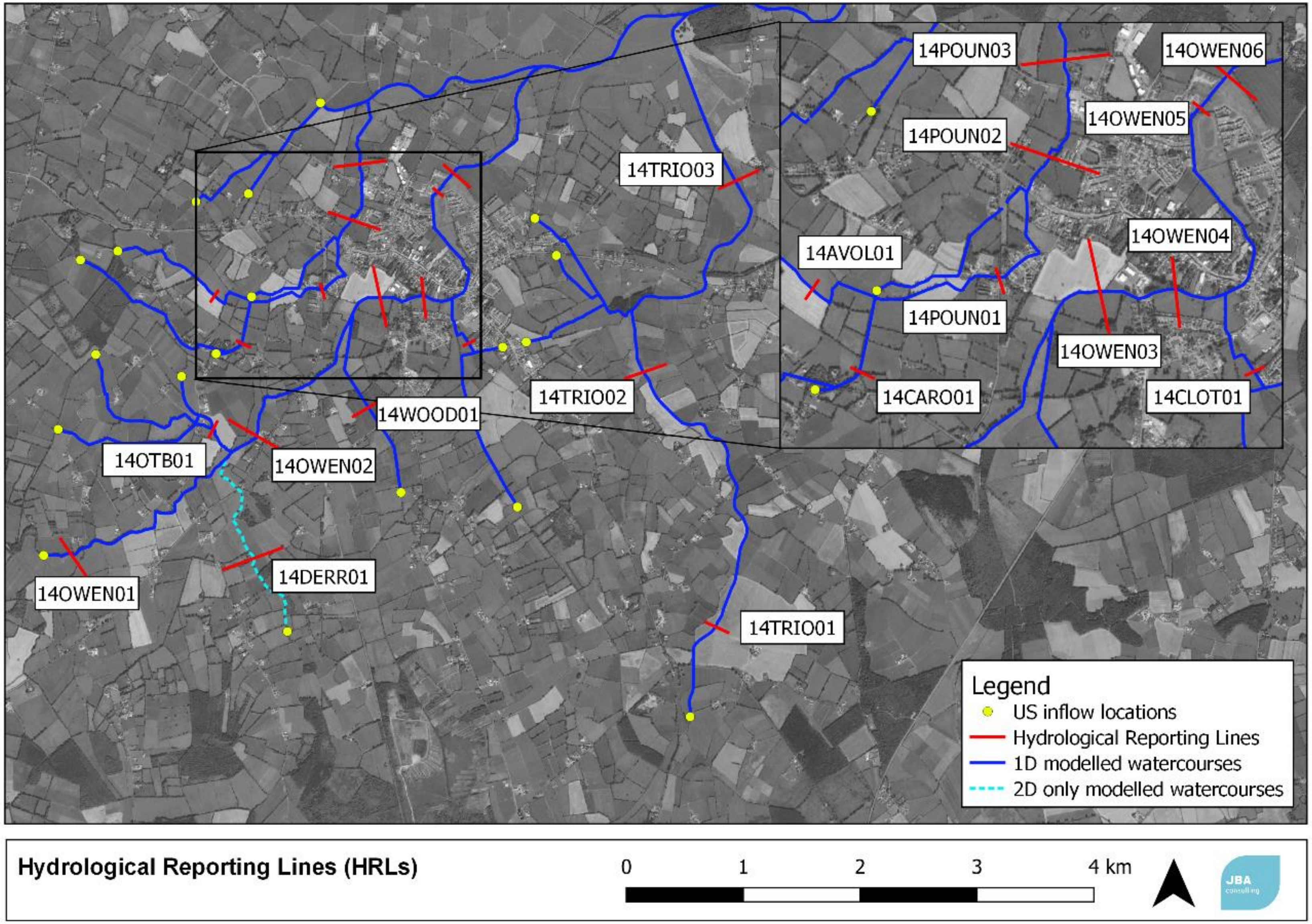
HEP	Watercourse	1% AEP Peak flow (m³/s)
503_hep_00001	Barrow	88.28
503_hep_00002	Farm	0.56
503_hep_00002a	Farm	0.28
503_hep_00003	Graigue	0.11
503_hep_00003a	Graigue	0.05
503_hep_00004	Avoley	0.20
503_hep_00004a	Avoley	0.61
503_hep_00005	Carroon	2.84
503_hep_00005a	Carroon	0.80
503_hep_00005b	Carroon	3.08
503_hep_00008	Owenass trib1	0.38
503_hep_00008a	Owenass trib1	0.19
503_hep_00009	Owenass trib2	2.16
503_hep_00009a	Owenass trib2	0.39
503_hep_000010	Owenass trib3	6.28
503_hep_00010a	Owenass trib3	0.86
503_hep_00011	Owenass	0.23
503_hep_00011b	Owenass	2.00
503_hep_00011c	Owenass	5.66
503_hep_00011d	Owenass	0.98
503_hep_00011e	Owenass	0.67
503_hep_00011f	Owenass	0.49
503_hep_00011g	Owenass	2.05
503_hep_00016	Clontygar A	0.45
503_hep_00016a	Clontygar A	2.07
503_hep_00021	Triogue	24.14
503_hep_00021a	Triogue	3.75
503_hep_00022	Owenass south	8.50
503_hep_00023	Blackwater	24.90
503_hep_00025	Owenass	4.66
503_hep_00026	Owenass	20.57
503_hep_00027	Wood	0.73
503_hep_00027a	Wood	0.81
503_hep_00030	Garroon/Pound	0.22
503_hep_00031	Pound	0.99
503_hep_00032	Run off drain	0.03

HEP	Watercourse	1% AEP Peak flow (m³/s)
503_hep_00001	Barrow	88.28
503_hep_00033	Ballyculbeg	1.30
503_hep_00034	Clontygar B	1.18
503_hep_00035	Garroon	0.46

B Hydrological Reporting Line 1% AEP flows

A network of hydrological reporting lines (HRLs) was proposed in the Mountmellick FRS Hydrology report. The location of the HRLs and reported total flow (1D and 2D flow) for the 1% AEP event are presented in this Appendix.

B.1 HRL locations



B.2 HRL 1% AEP reported flows

Hydrological Reporting Line	Peak 1% AEP flow (m3/s)
14OWEN01	36.763
14OWEN02	57.245
14OWEN03	40.162
14OWEN04	36.171
14OWEN05	35.697
14OWEN06	35.697
14OTB01	9.195
14DERR01	20.85
14WOOD01	1.778
14CARO01	4.57
14AVOL01	2.985
14POUN01	5.848
14POUN02	27.124
14POUN03	25.542
14CLOT01	1.638
14TIRO01	23.574
14TIRO02	24.358
14TIRO03	18.953

C 1D Structures

Details of all structures are provided in this Appendix. Photographs, survey data and modelled outputs are provided to give general overall indication of structure and performance and so are not intended to convey numerical information, therefore numbers and labels within the tables may not be readable.

C.1 River Barrow structures (Mountmellick model)

C.1.1 Weirs

There are no weirs along the portion of the River Barrow modelled.

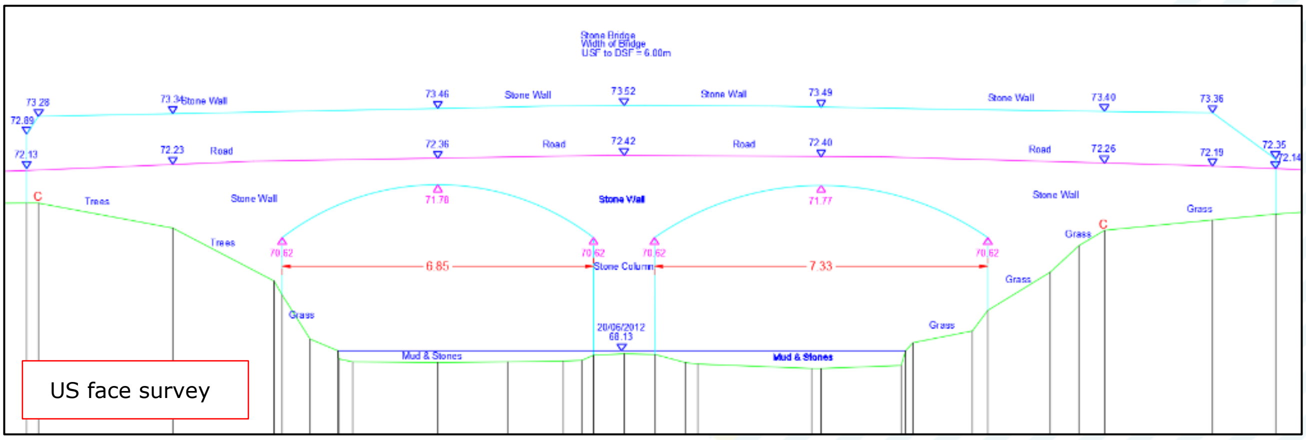
C.1.2 Culverts

There are no culverts along the portion of the River Barrow modelled.

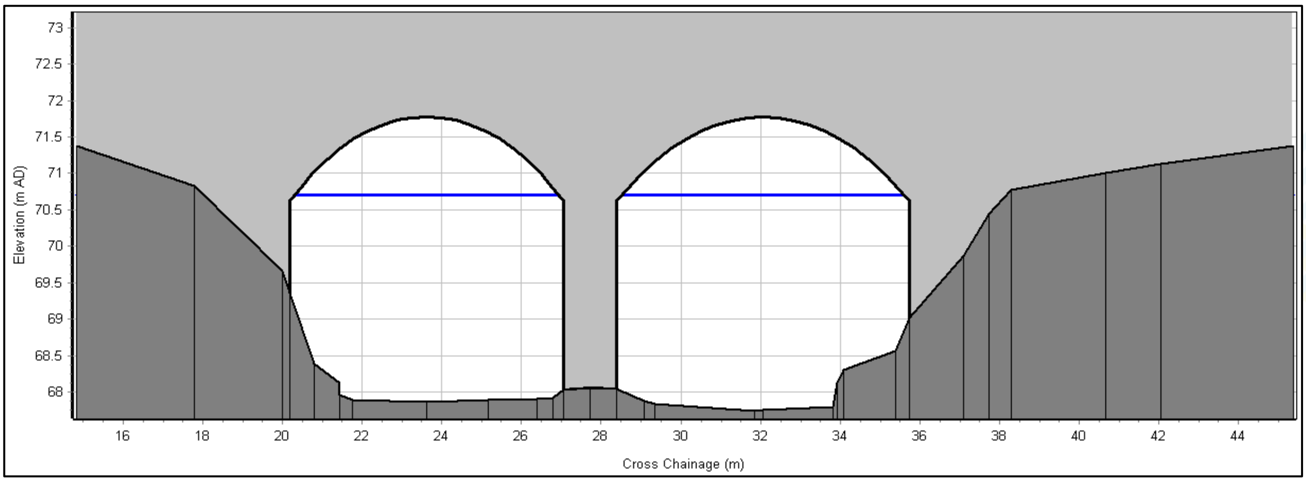
C.1.3 Bridges

BARO1553B – DOUBLE ARCH BRIDGE			
Width	Arch 1: 6.85m Arch 2: 7.326m	**Length**	6.00m
Soffit	Arch 1: 71.78mOD Arch 2: 71.77mOD	**Springing height**	70.62mOD for both arches
Coefficients	Channel roughness: 0.04 Spill weir coefficient: 1.40	**Present in model?**	Yes via 1D arched bridge unit
Skew	NA	**Overtopping**	1D spill unit set to height of stone wall (minimum height 73.28mOD)
Orifice Eqtn used	Yes	**Transition distance**	0.10m

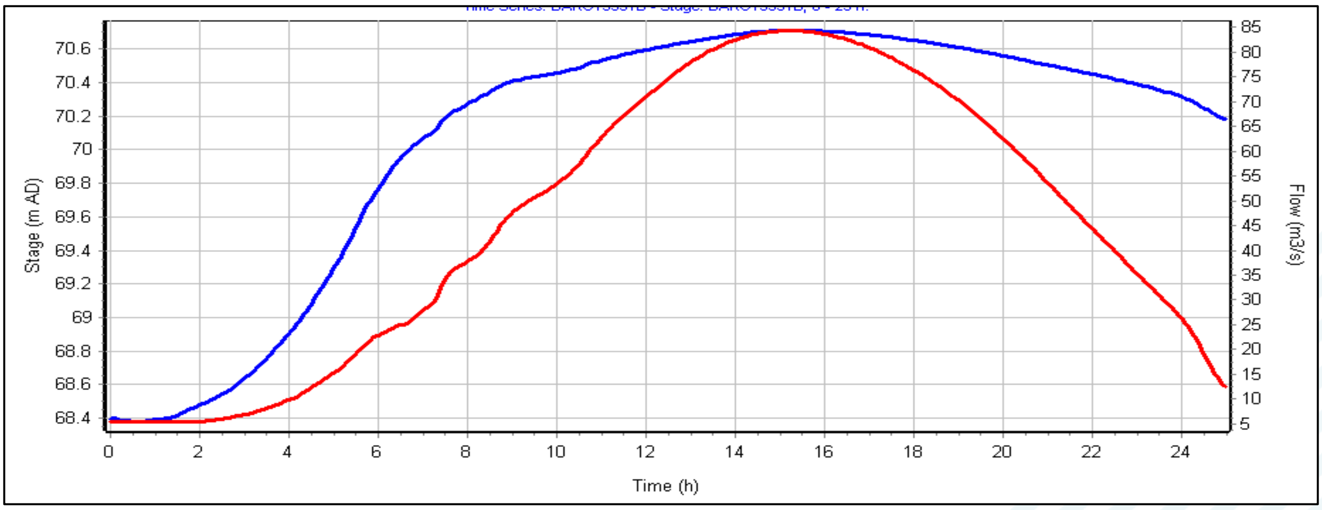

US face



US face survey

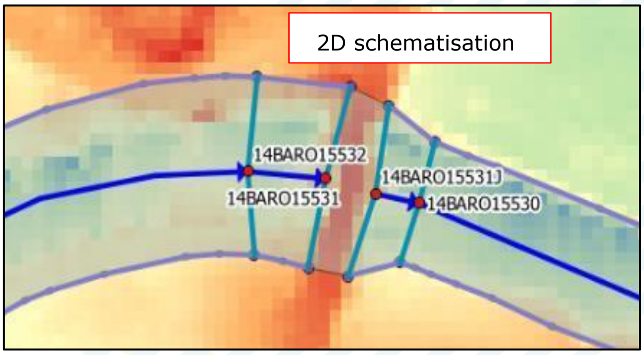


Maximum water level

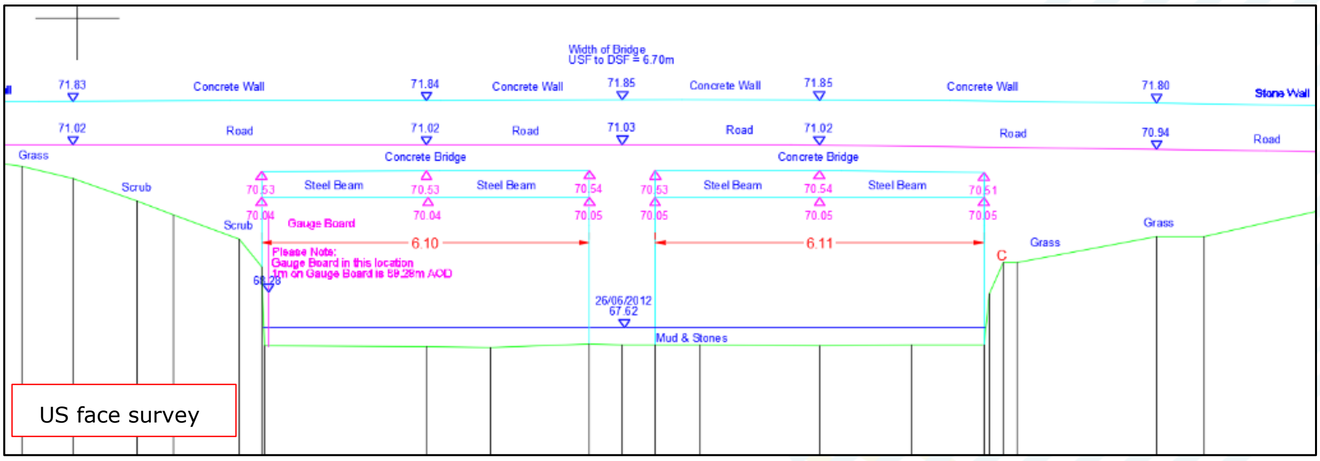


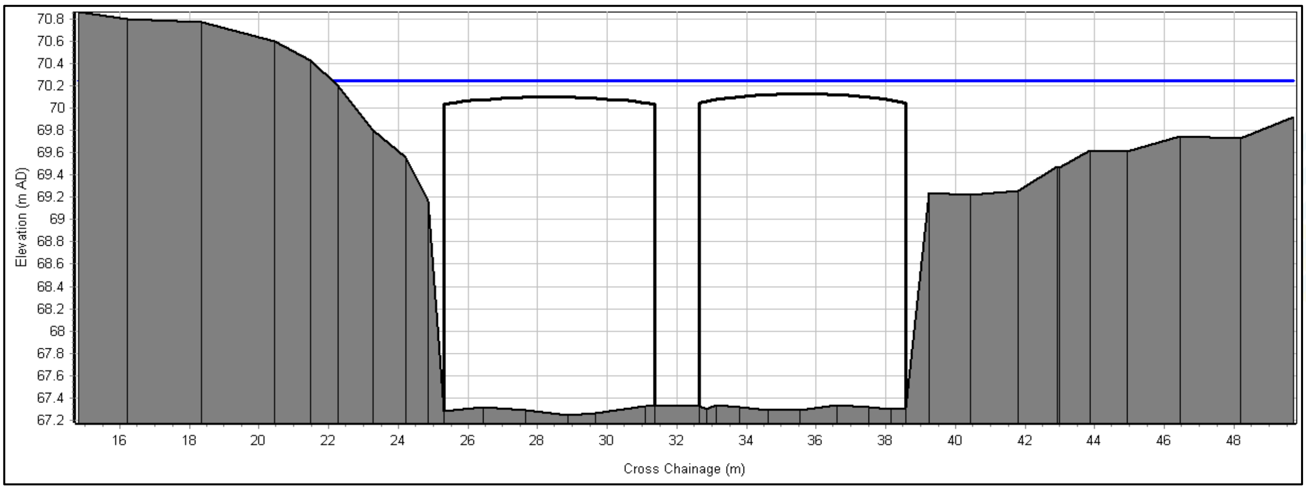
Level (blue) and flow (red) through bridge

Bridge operates normally through event. Stage increases faster than flow due to flood plain interaction and large volumes of flow on the flood plain.

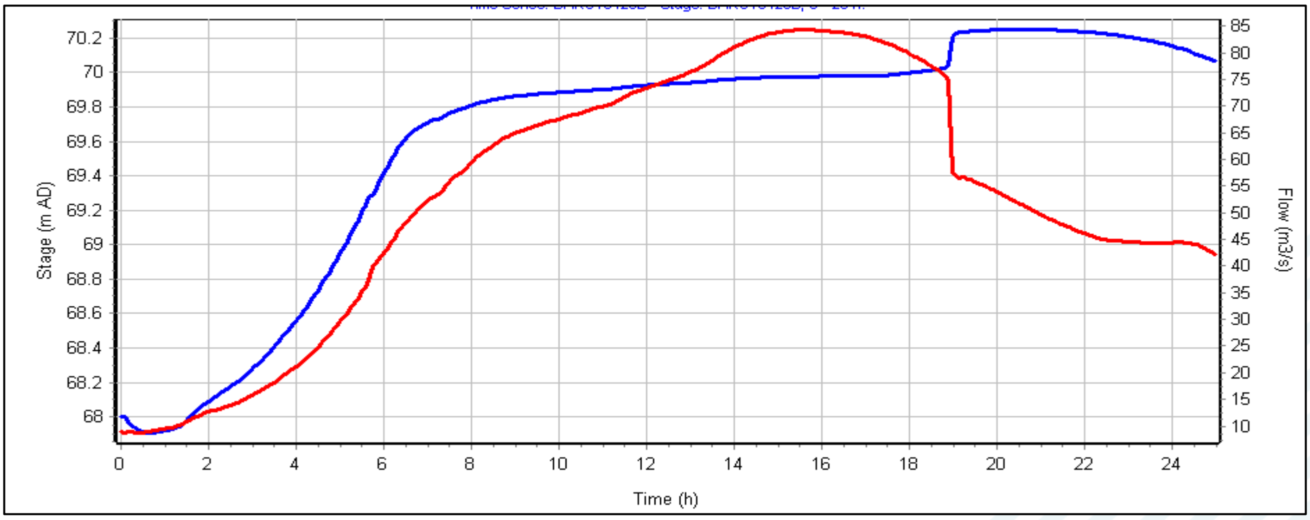


BARO15423B – DOUBLE RECTANGULAR BRIDGE			
Width	Opening 1: 6.102m Opening 2: 6.109m	**Length**	6.70m
Soffit	70.05mOD for both openings	**Springing height**	70.05mOD for both openings
Coefficients	Channel roughness: 0.04, Bank roughness 0.06, Spill weir coefficient: 1.40	**Present in model?**	Yes via 1D USBPR bridge unit
Skew	NA	**Overtopping**	1D spill unit set to height of stone wall (minimum height 71.68mOD)
Orifice equation used	Yes	**Transition distance**	0.10m
Notes		The Borness gauge (no. 140003) is located at US face of the bridge.	



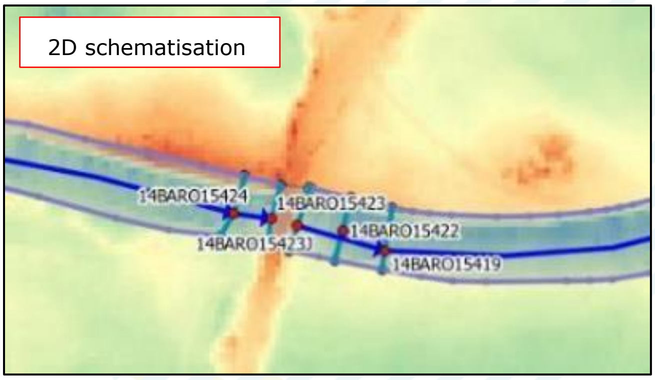


Maximum water level

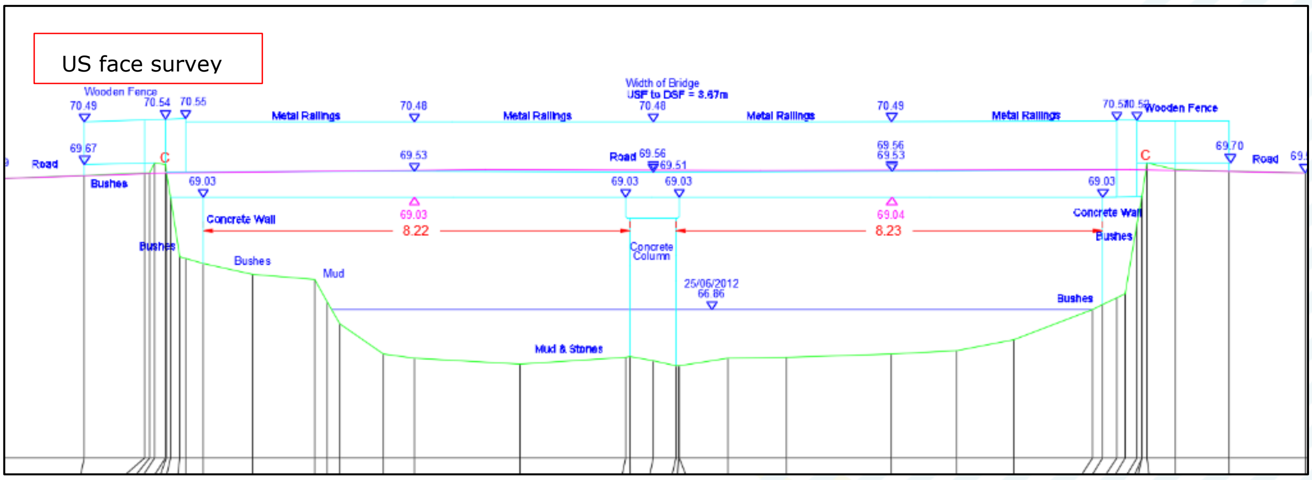


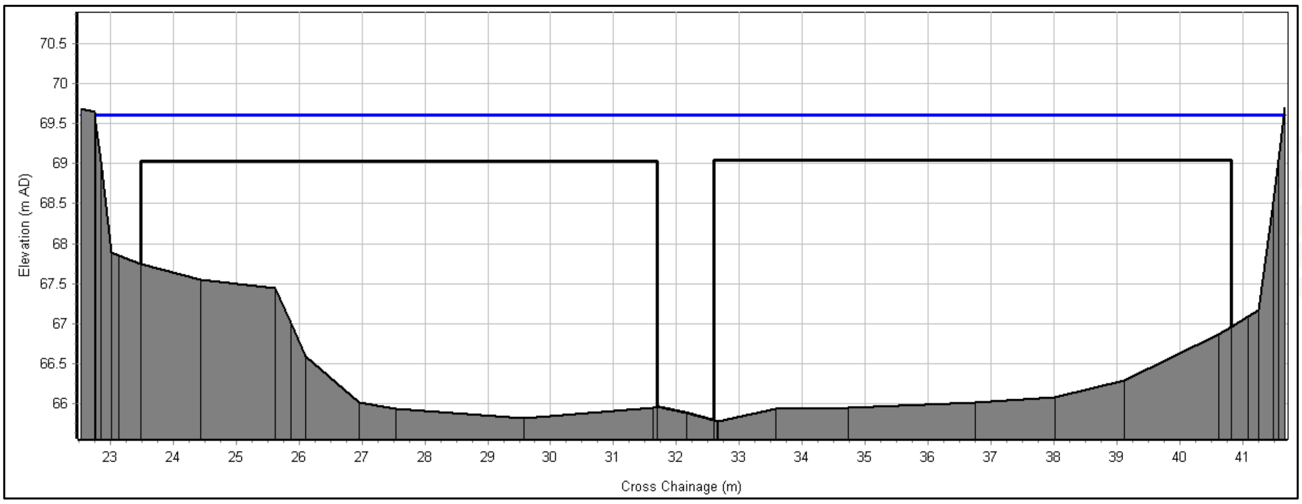
Level (blue) and flow (red) through structure

Structure operating as expected. Flow reduces as flood plain interaction increases as indicated by the increase in level.

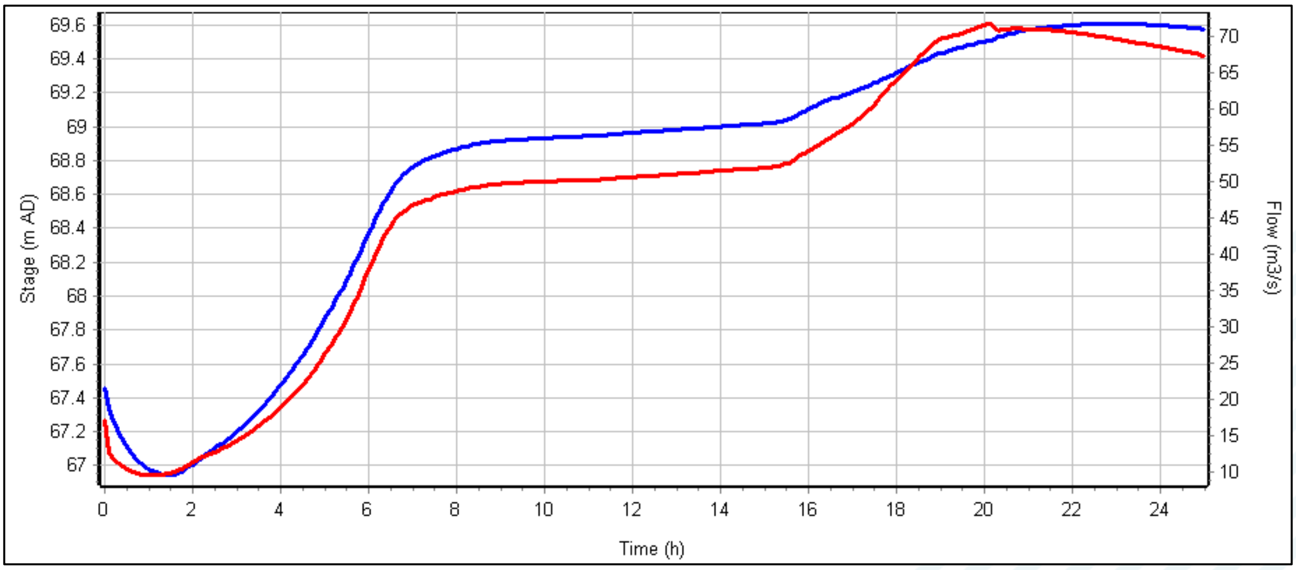


BARO15356B – DOUBLE RECTANGULAR BRIDGE			
Width	Opening 1: 6.102m Opening 2: 6.109m	**Length**	3.67m
Soffit	Opening 1: 69.03mOD Opening 2: 69.04mOD	**Springing height**	Opening 1: 69.03mOD Opening 2: 69.04mOD
Coefficients	Channel roughness: 0.04, Bank roughness 0.06, Spill weir coefficient: 1.40	**Present in model?**	Yes via 1D USBPR bridge unit
Skew	NA	**Overtopping**	1D spill unit set to height of stone wall (minimum height 69.53mOD)
Orifice equation used	Yes	**Transition distance**	0.10m
Notes			



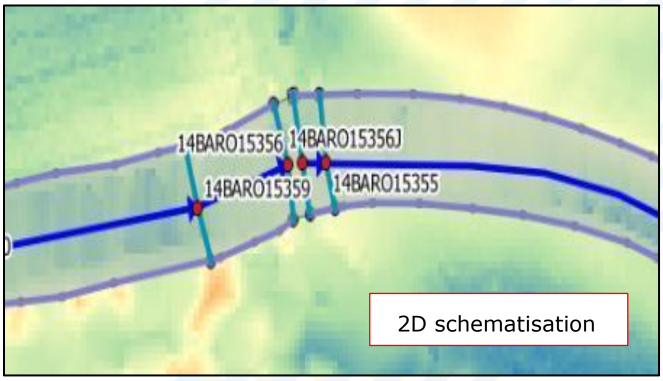


Maximum water level



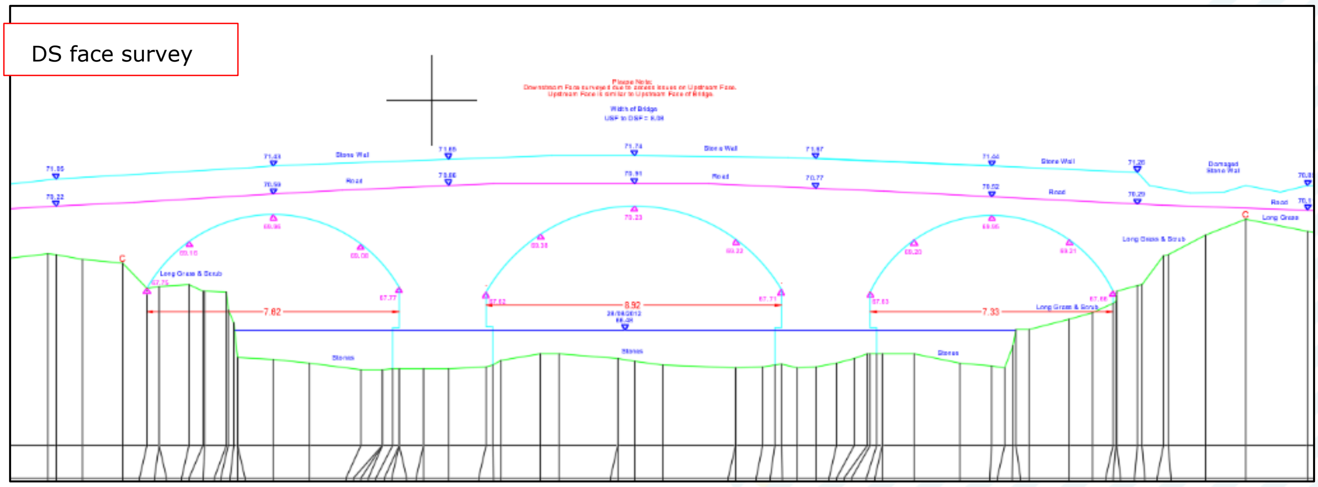
Level (blue) and flow (red) through the bridge

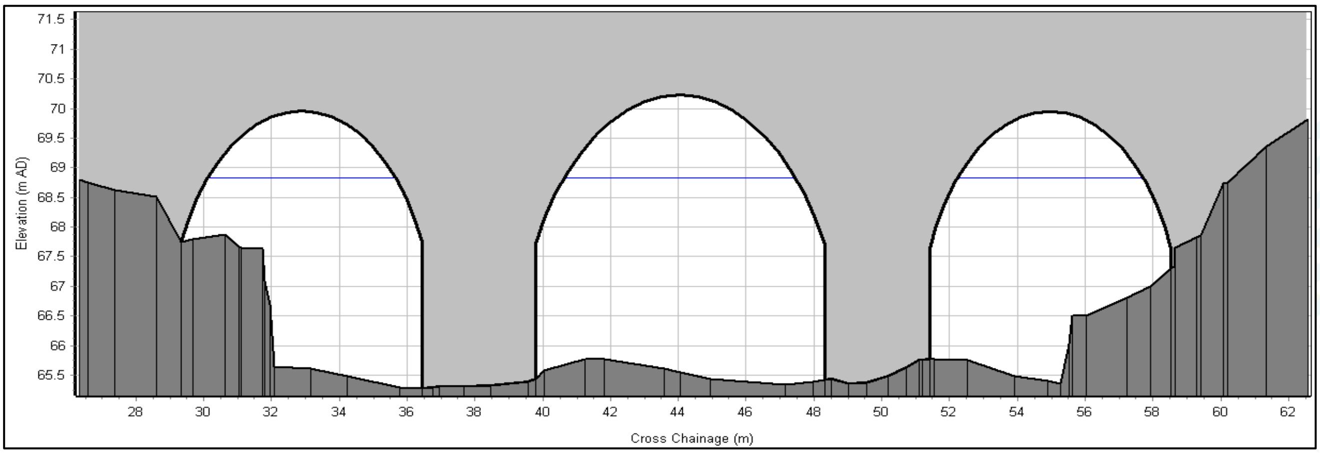
Bridge operating as normal



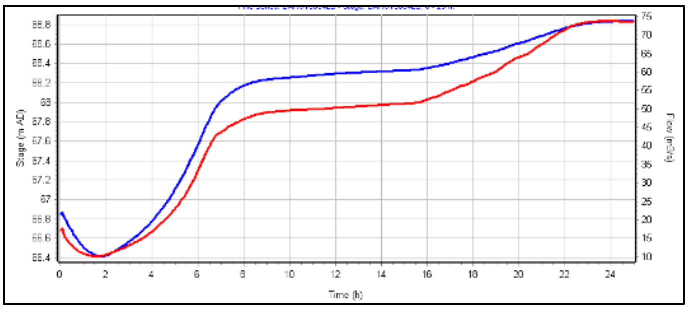
BARO15094EB – TRIPLE ARCHED BRIDGE			
Width	Opening 1: 7.12m Opening 2: 8.526m Opening 3: 7.13m	**Length**	8.08m
Soffit	Opening 1: 66.96mOD Opening 2: 70.23mOD Opening 3: 69.95mOD	**Springing height**	Opening 1: 67.77mOD Opening 2: 67.62mOD Opening 3: 67.63mOD
Coefficients	Channel roughness: 0.04, Bank roughness 0.06, Spill weir coefficient: 1.40	**Present in model?**	Yes via 1D arched bridge unit
Skew	NA	**Overtopping**	1D spill unit set to height of stone wall (minimum height 71.74mOD)
Orifice equation used	Yes	**Transition distance**	0.10m
Notes			

DS face survey

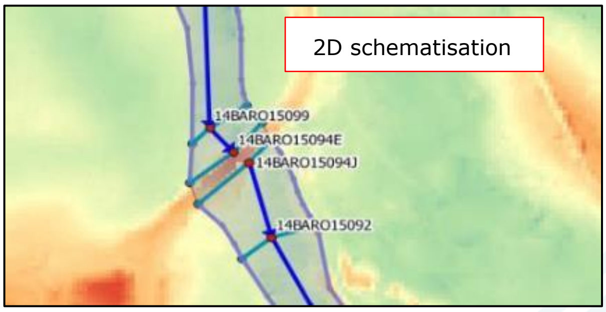




Maximum water level



Level (blue) and flow (red) through bridge



Bridge operating normally during event and is large enough to convey flow.

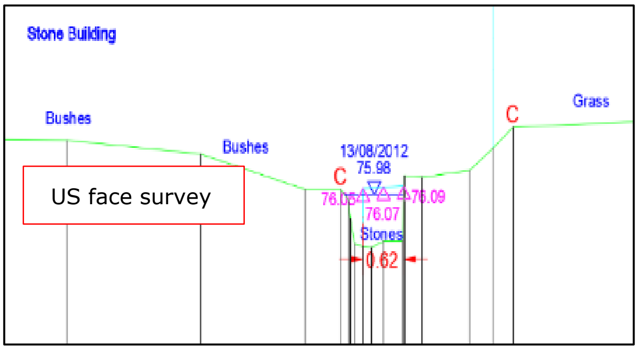
C.2 Farm Stream structures (Mountmellick model)

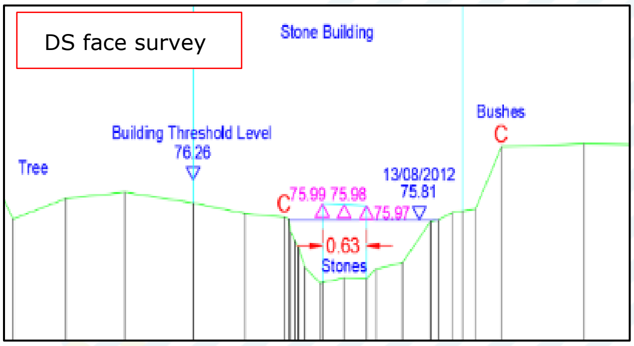
C.2.1 Weirs

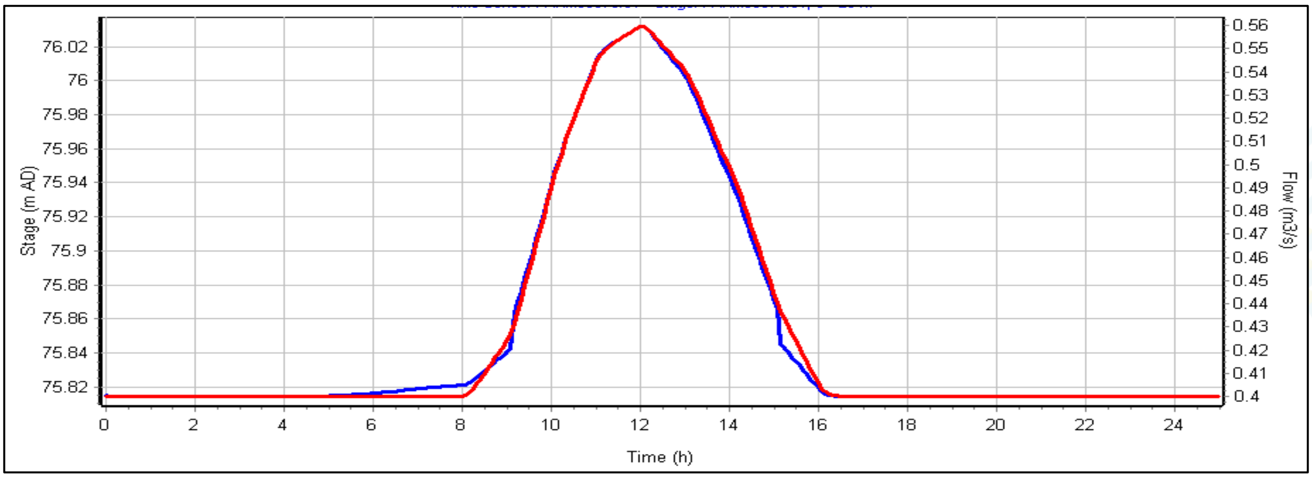
There are no weirs present along the Farm stream watercourse

C.2.2 Culverts

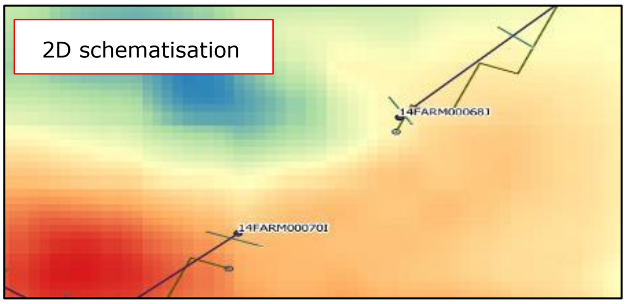
14FARM00070I-14FARM00068J – RECTANGULAR CULVERT			
US Invert	75.38mOD	**DS invert**	75.10mOD
Diameter	Width: 0.62m Height: 0.67m	**Length**	22.66m
Coefficients	Roughness: 0.02 Spill weir coefficient: 1.30	**Present in model?**	Yes, represented in 1D using rectangular culvert unit
Skew	NA	**Overtopping**	2D spill via HX lines set at building threshold (76.78mOD)
Notes			







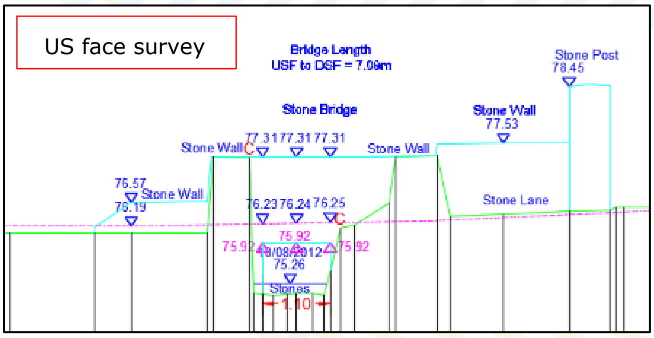
Level (blue) and flow (red) through culvert

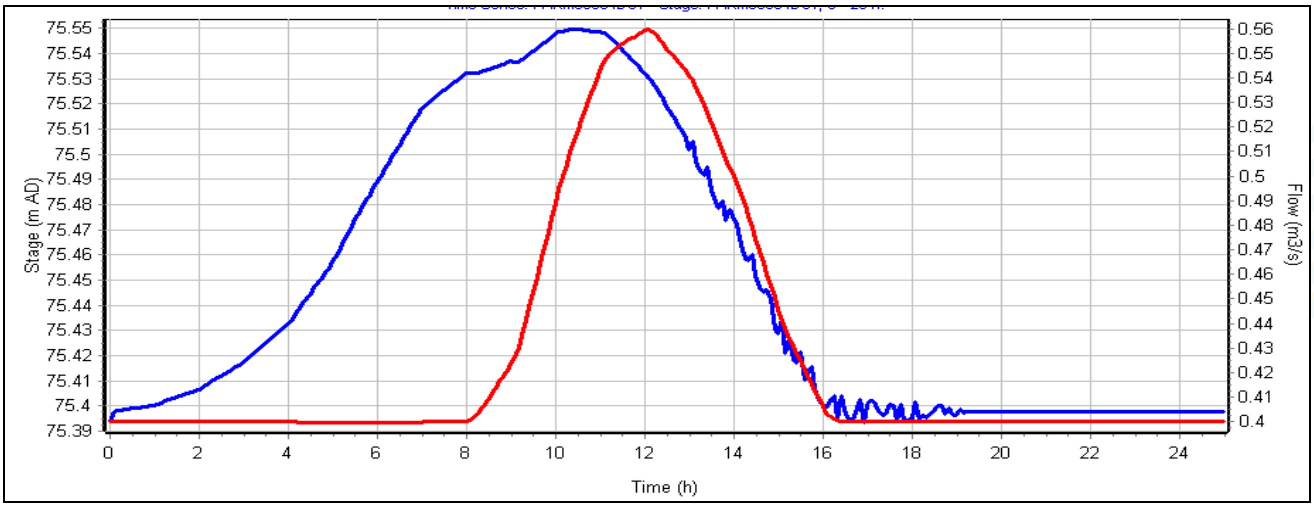


Culvert operates normally and can convey peak flow.

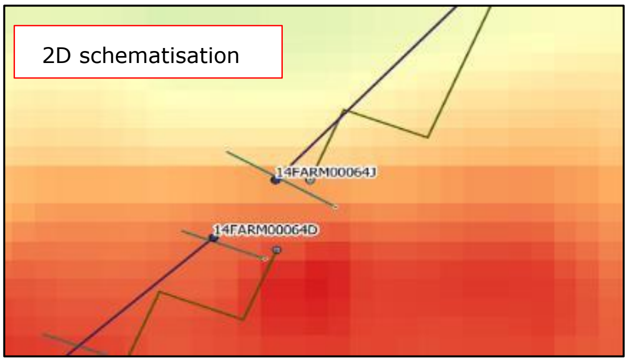
C.2.3 Bridges

14FARM00064D – RECTANGULAR BRIDGE			
US Invert	75.07mOD	**DS invert**	74.90mOD
Diameter	Width: 1.10m Height: 0.85m	**Length**	7.09m
Coefficients	Roughness: 0.02 Spill weir coefficient: 1.40	**Present in model?**	Yes, represented in 1D using rectangular culvert unit due to length width ratio of channel and structure
Notes		Overtopping of culvert represented in the 1D via a spill unit set to height of stone wall (77.31mOD).	





Level (blue) and flow (red) through culvert



Culvert is able to convey peak flow, peak level occurs before peak flow due to presence on lateral inflow downstream of culvert increasing water level before main inflow hydrograph. Fluctuations of level on falling limb a result of backwater effect from the Barrow.

C.3 Graigue Stream structures (Mountmellick model)

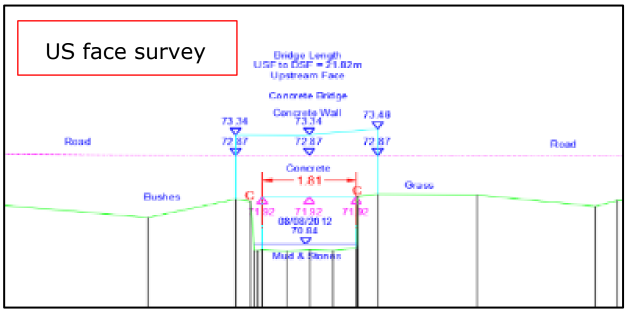
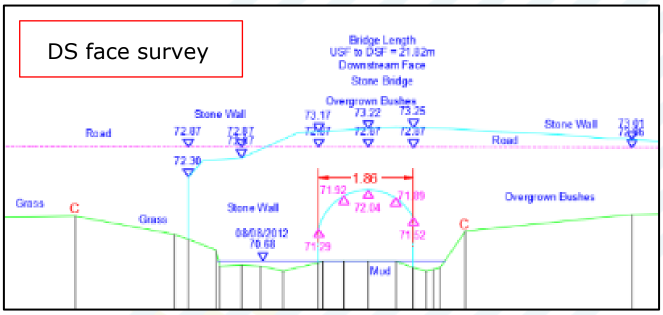
C.3.1 Weirs

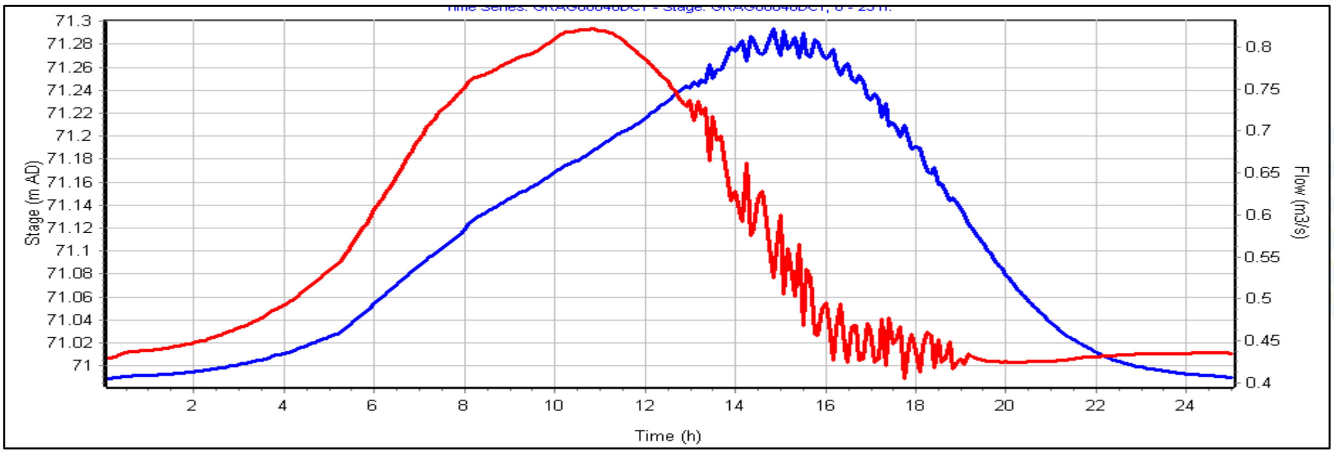
There are no weirs along the Graigue watercourse.

C.3.2 Culverts

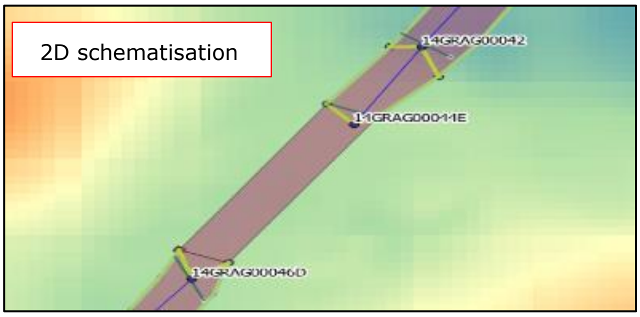
There are no bridges along the Graigue watercourse.

C.3.3 Bridges

14GRAG00046D-14GRAG00044E – RECTANGULAR BRIDGE			
US Invert	70.69mOD	DS invert	70.67mOD
Diameter	Width: 1.81m Height: 1.23m	Length	21.82m
Coefficients	Roughness: 0.02 Spill weir coefficient: 1.40	Present in model?	Yes, represented in 1D using rectangular culvert unit due to length width ratio of channel and structure
Skew	NA	Overtopping	2D spill via HX lines set to height of wall on US face (73.34mOD)
Notes	US and DS face different – Using US face details as it is smaller and the hydraulic control for the structure. This allows a conservative approach to be taken in the modelling.		
			
			



Level (blue) and flow (red) through bridge



Peak flow occurs before peak level as backwater effect from Barrow impacts levels and flow at the downstream of the structure at a later time (Barrow slower to respond compared to Graigue).

C.4 Avoley Stream Structures (Mountmellick model)

C.4.1 Weirs

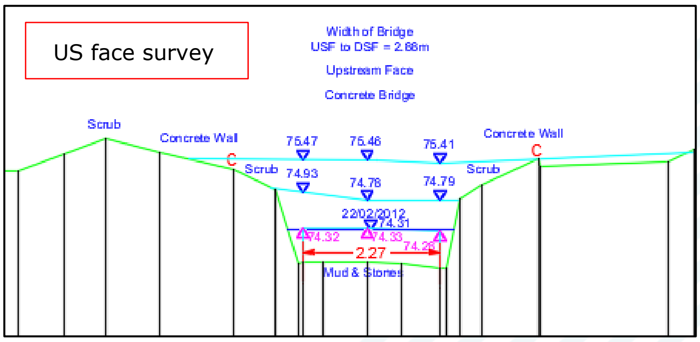
There are no weirs along the Avoley watercourse.

C.4.2 Culverts

There are no culverts along the Avoley watercourse.

C.4.3 Bridges

14AVOL00000D – RECTANGULAR BRIDGE			
US Invert	73.67mOD	**DS invert**	73.67mOD
Diameter	Width: 2.27m Height: 0.66m	**Length**	2.88m
Coefficients	NA	**Present in model?**	No
Notes	Structure initially included in model as culvert but proved to be highly unstable in relation to FM backflow through structures. Structure is small and not within a critical area in the model in relation to flood risk therefore removed.		

C.5 Garroon Stream structures (Mountmellick model)

C.5.1 Weirs

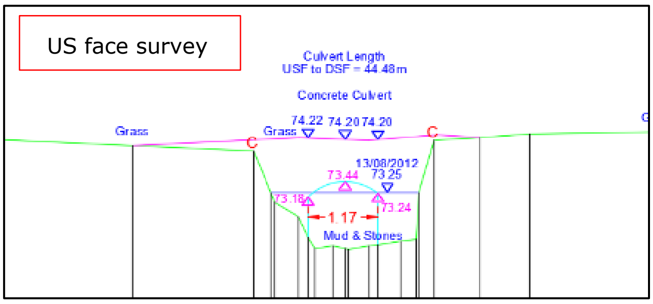
There are no weirs along the Garroon watercourse.

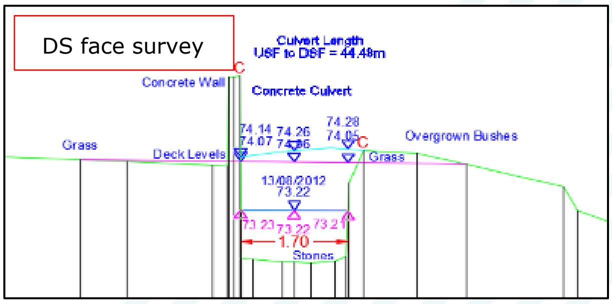
C.5.2 Culverts

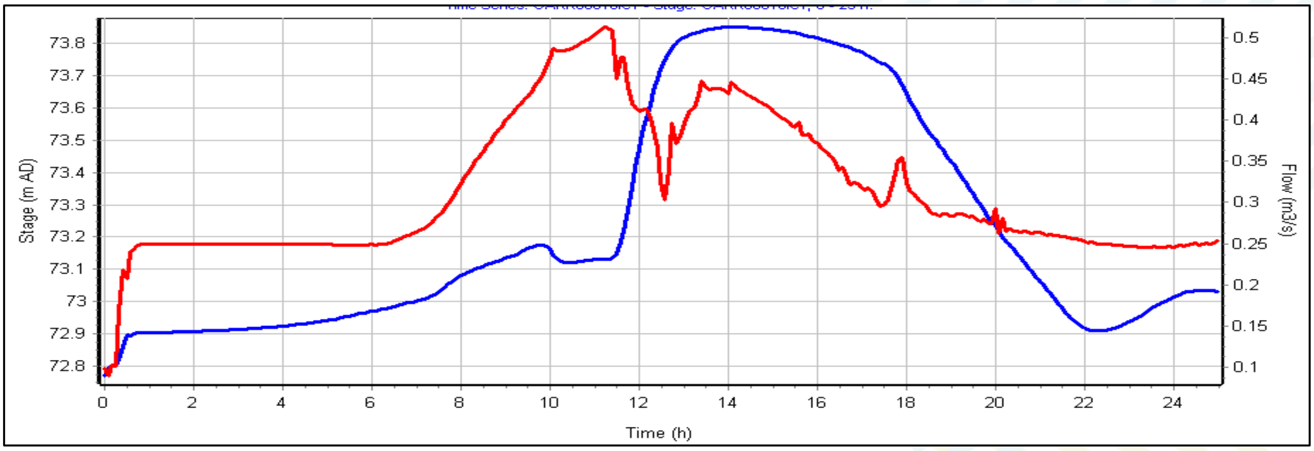
14GARR00018I-14GARR00013J – RECTANGULAR CULVERT			
US Invert	72.250mOD	DS invert	72.31mOD
Diameter	Width: 1.70m Height: 0.91m	Length	44.48m
Coefficients	Roughness: 0.02 Spill weir coefficient: 1.40	Present in model?	Yes, represented in 1D using rectangular culvert unit.
Skew	NA	Overtopping	2D spill via HX lines set to height of field (74.22mOD)
Notes	Culvert modelled as rectangular to reflect DS face of culvert which has smaller flow conveyance hence is more conservative to use.		


US face

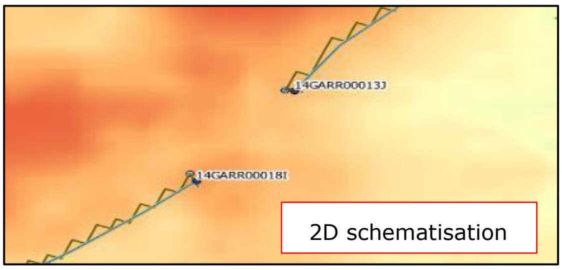

DS face


US face survey


DS face survey



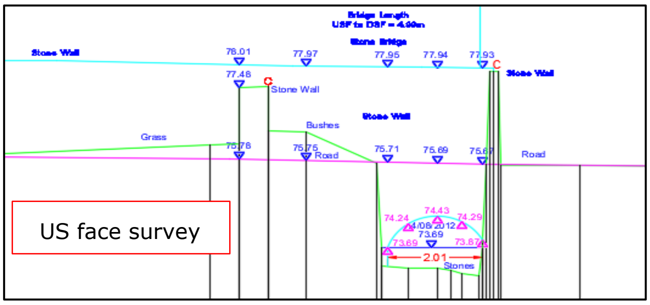
Level (blue) and flow (red) through culvert

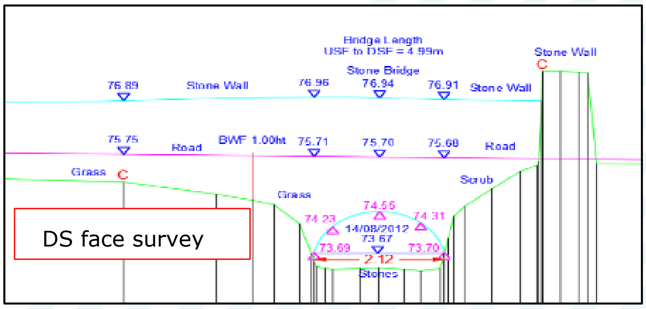


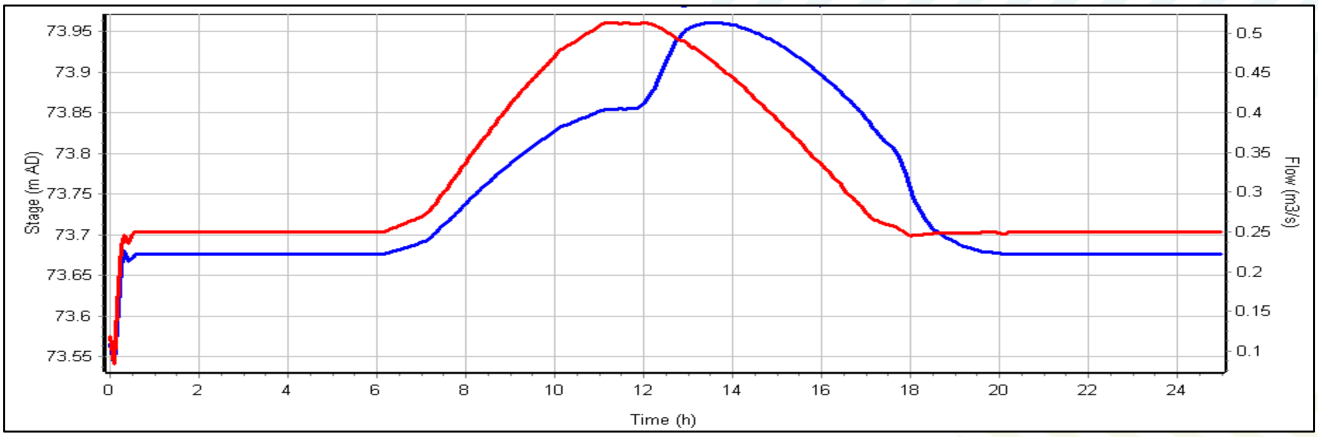
Culvert impacted by flooding downstream and backwater effect as shown in hydrographs.

C.5.3 Bridges

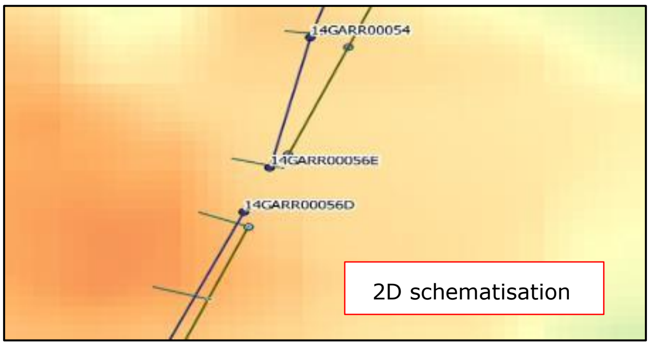
14GARR00056D – ARCH BRIDGE			
US Invert	73.01mOD	DS invert	73.01mOD
Diameter	Width: 2.11m Height: 1.42m	Length	4.99m
Coefficients	Roughness: 0.02 Spill weir coefficient: 1.40	Present in model?	Yes, represented in 1D using irregular culvert units.
Skew	NA	Overtopping	1D spill unit set at height of stone wall on US face (77.97mOD)
Notes	Walls either side of bridge removed in 1D cross sections.		





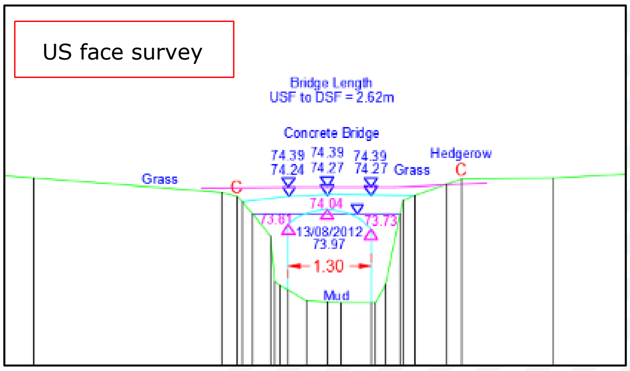


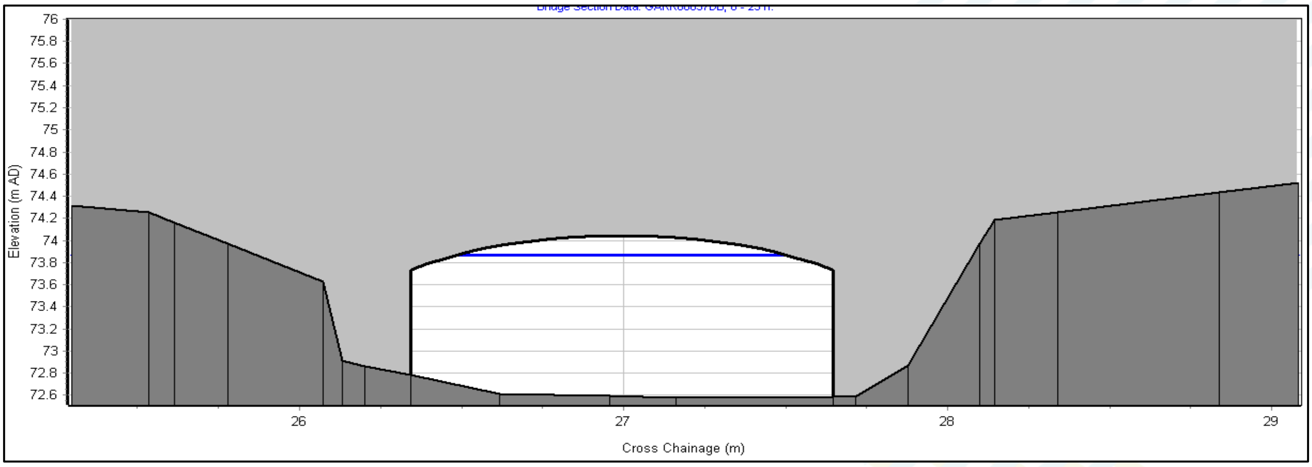
Level (blue) and flow (red) through bridge



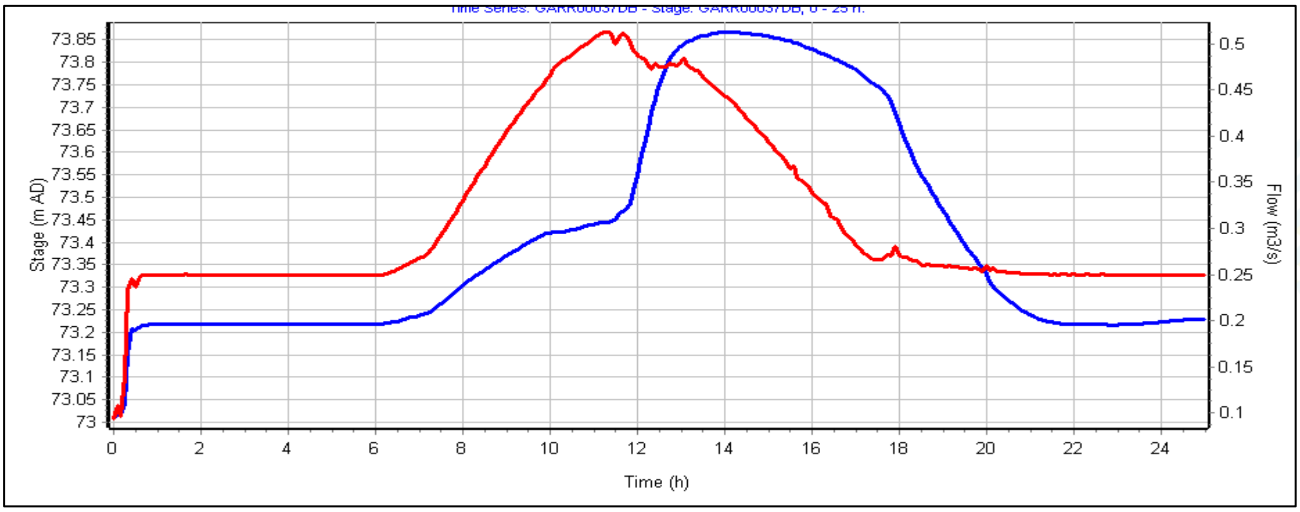
Model flow shows bridge behaving as expected and can convey peak flow.

14GARR00037D - ARCHED BRIDGE			
Width	1.30m	Length	2.62m
Soffit	74.04mOD	Springing height	73.73mOD
Coefficients	Channel roughness: 0.04 Spill weir coefficient: 1.40	Present in model?	Yes via 1D arched bridge unit
Skew	NA	Overtopping	1D spill unit set at height of bridge surface (74.39mOD)
Orifice Eqtn used	Yes	Transition distance	0.10m
Notes			

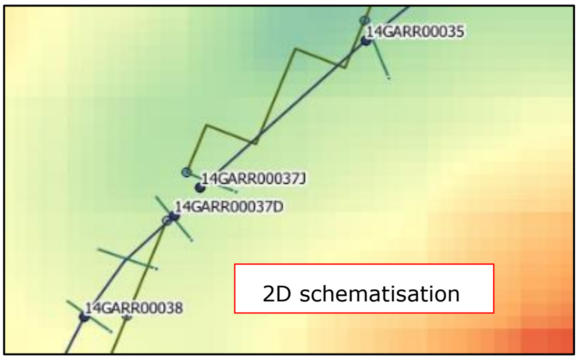




Maximum water level



Level (blue) and flow (red) through bridge



Peak level corresponds with the lower flow, flow and level at this structure dictated by influx of flow and flooding downstream creating a back-water effect rather than the upstream inflow of the watercourse.

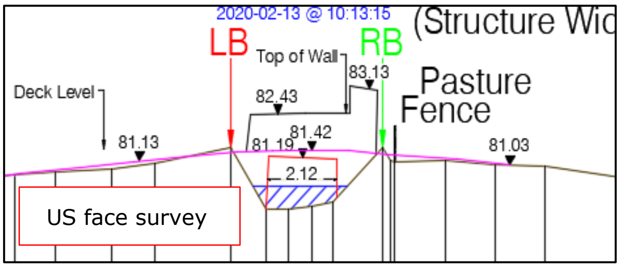
C.6 Carroon Stream structures (Mountmellick model)

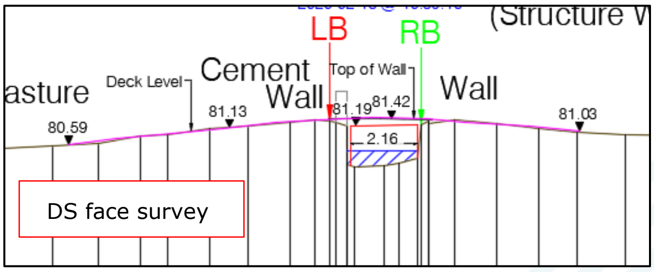
C.6.1 Weirs

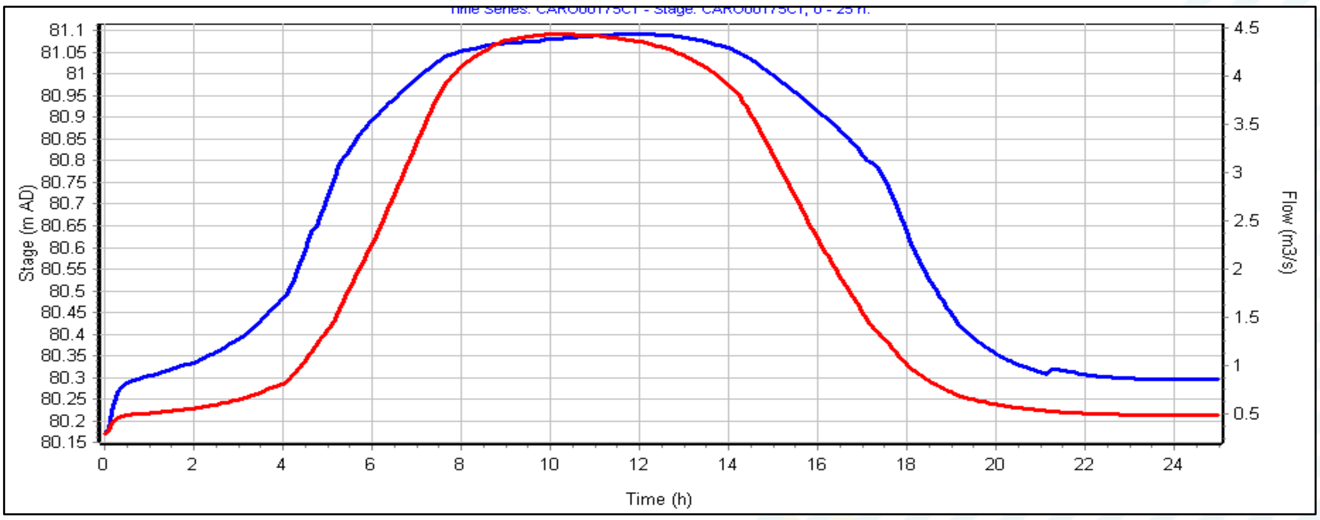
There are no weirs along the Carroon watercourse.

C.6.2 Culverts

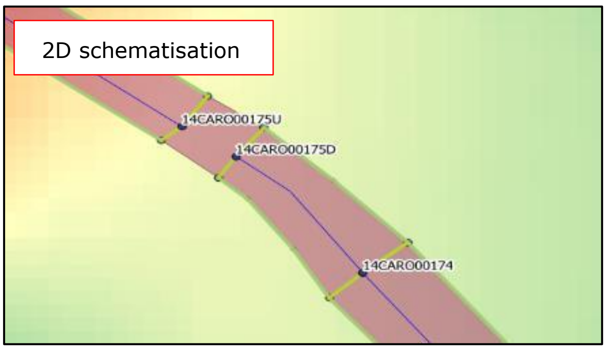
14CARO0175U-14CARO00175D – RECTANGULAR CULVERT			
US Invert	79.76mOD	DS invert	79.91mOD
Diameter	Width: 2.12m Height: 1.43m	Length	4.20m
Coefficients	Roughness: 0.02 Spill weir coefficient: 1.55	Present in model?	Yes, represented in 1D using rectangular culvert unit
Skew	NA	Overtopping	1D spill unit set to height of stone wall (81.42mOD)
Notes			



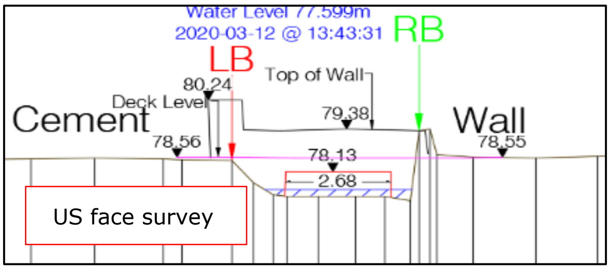
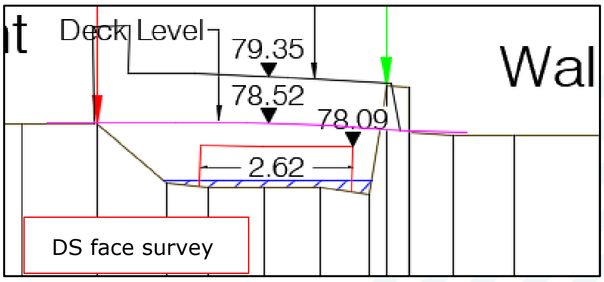
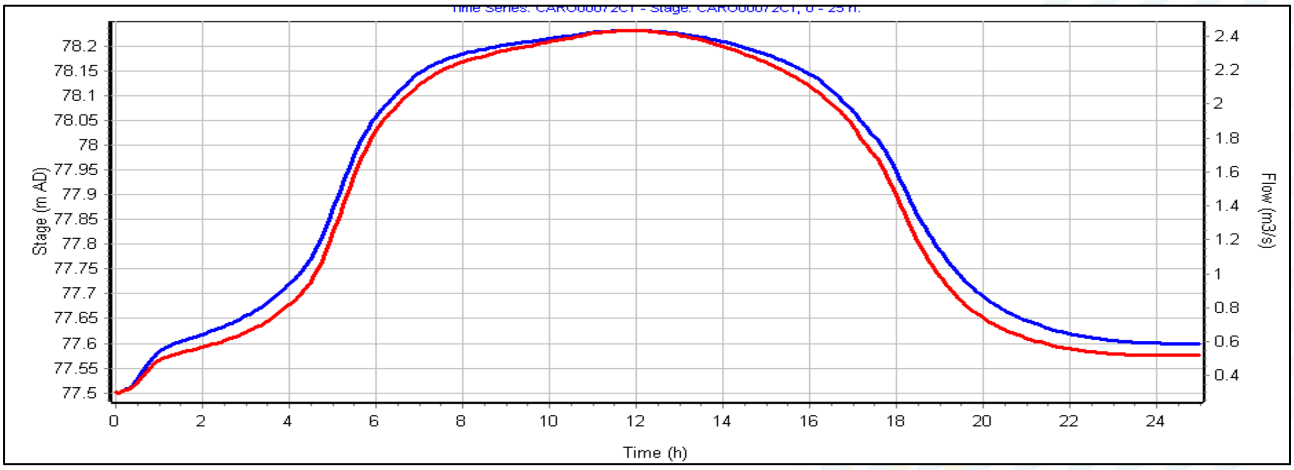


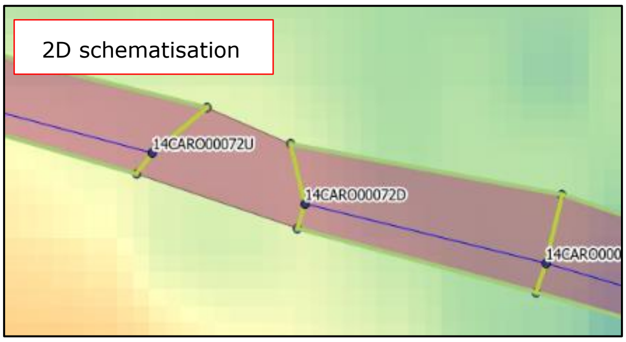


Level (blue) and flow (red) through culvert

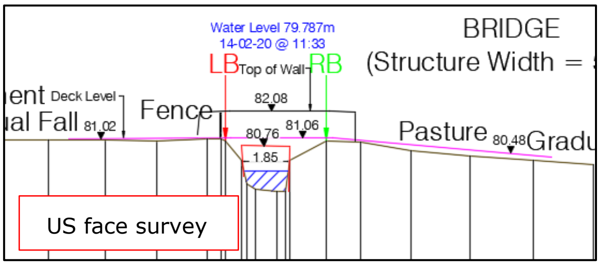
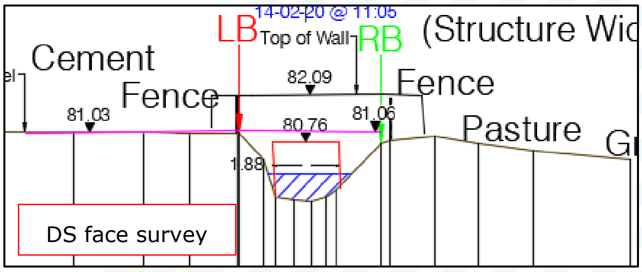


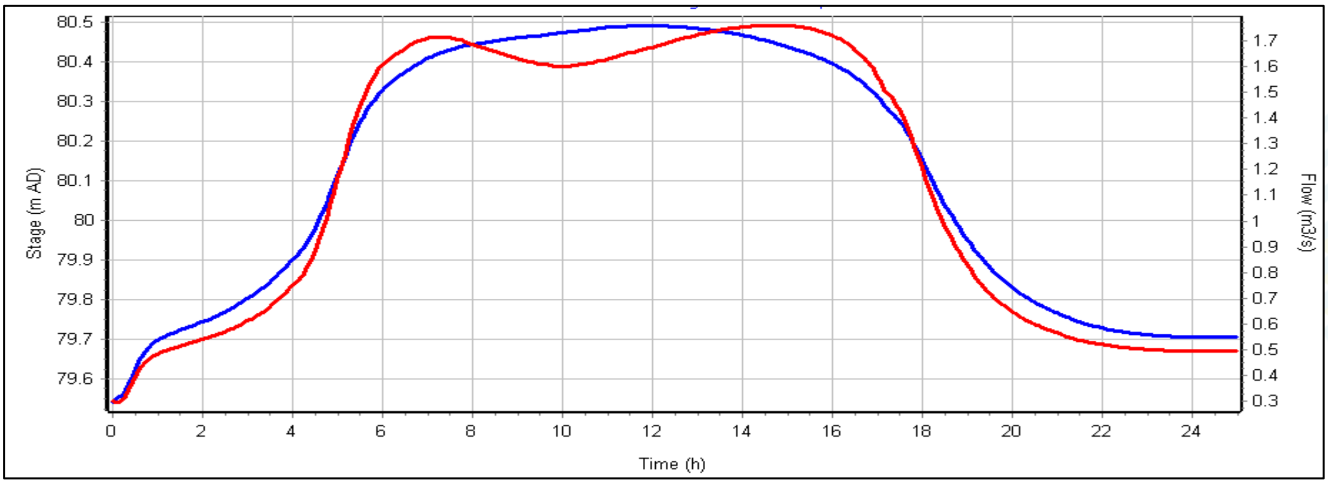
Culvert conveys flow but out of bank spill occurs up and directly downstream and a distance upstream of the culvert.

14CARO0072U-14CARO00072D – RECTANGULAR CULVERT			
US Invert	77.28mOD	DS invert	77.24mOD
Diameter	Width: 2.68m Height: 0.85m	Length	8.60m
Coefficients	Roughness: 0.02 Spill weir coefficient: 1.55	Present in model?	Yes, represented in 1D using rectangular culvert unit
Skew	40 degrees	Overtopping	2D spill via HX lines set to height of stone wall (80.70mOD)
Notes	Skew angle applied to US and DS face cross sections		
			
			
 Level (blue) and flow (red) through culvert			

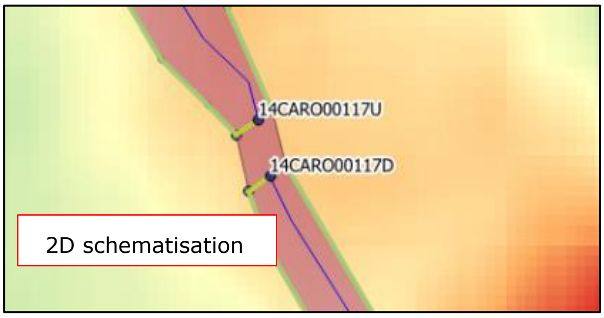
	Culvert is surcharged but conveys flows, water level goes above soffit but does not reach height of 2D spill.

C.6.3 Bridges

14CARO00117U – 14CARO00117D – RECTANGULAR BRIDGE			
US Invert	79.008mOD	DS invert	79.008mOD
Dimensions	Width: 1.85m Height: 1.75m	Length	5.316m
Coefficients	Channel roughness: 0.04 Spill weir coefficient: 1.55	Present in model?	Yes, represented in 1D using a rectangular culvert unit due to length width ratio of channel and structure.
Skew	NA	Overtopping	1D spill unit set to height of stone wall (82.02mOD)
Notes			
			
			

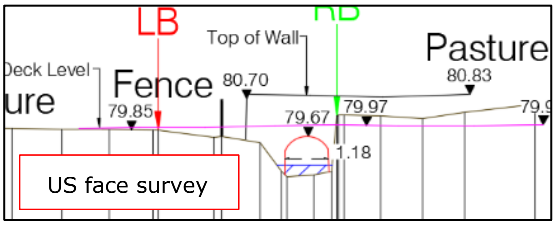


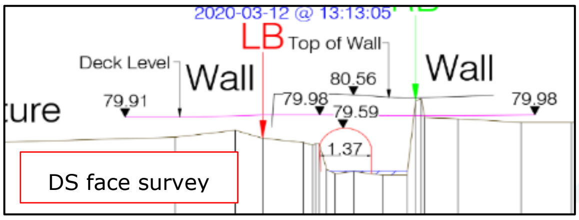
Level (blue) and flow (red) through bridge

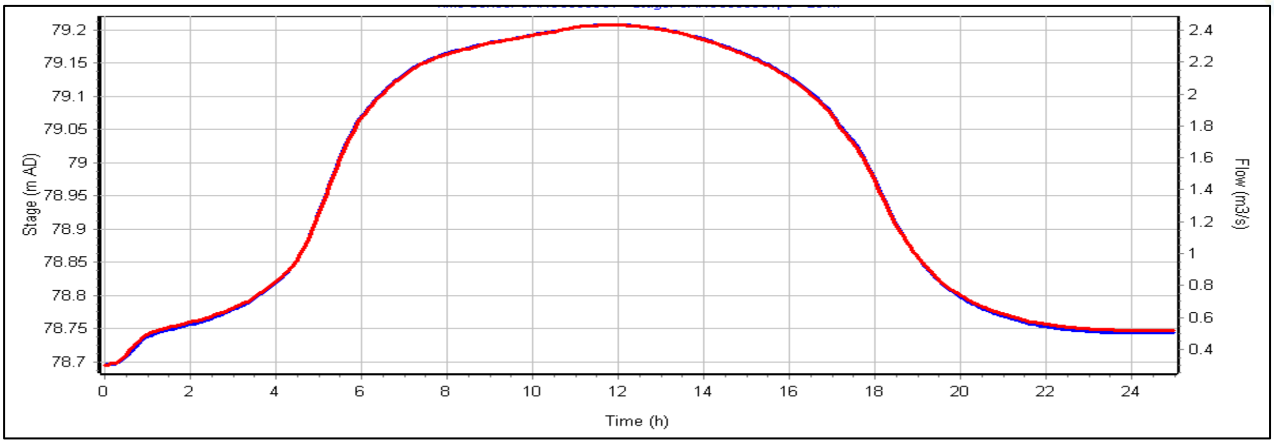


Bridge conveys peak flow, drop in flow observed around peak due to spill upstream of bridge into the 2D.

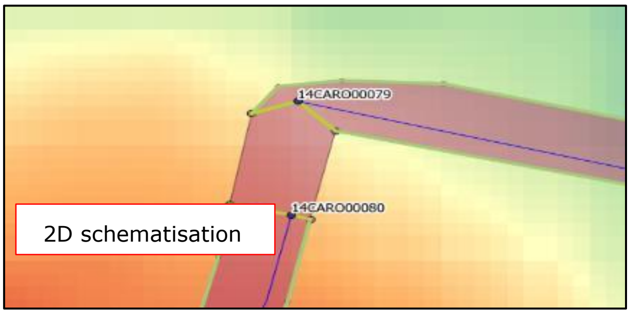
14CARO00080 – 14CARO00079 – ARCHED BRIDGE			
US Invert	78.570mOD	DS invert	78.217mOD
Dimensions	Width: 1.18m Height: 1.15m	Length	8.80m
Coefficients	Channel roughness: 0.04 Spill weir coefficient: 1.55	Present in model?	Yes, represented in 1D using irregular culvert unit due to length width ratio of channel and structure.
Skew	11 degrees	Overtopping	2D spill via HX line set to height of stone wall (79.38mOD)
Notes	Skew angle not applied – considered too small to have any significant impact		





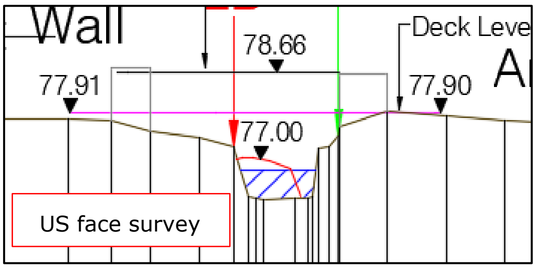


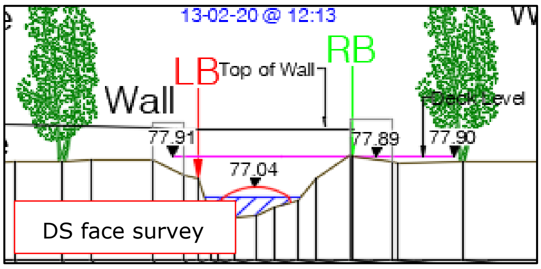
Level (blue) and flow (red) through bridge

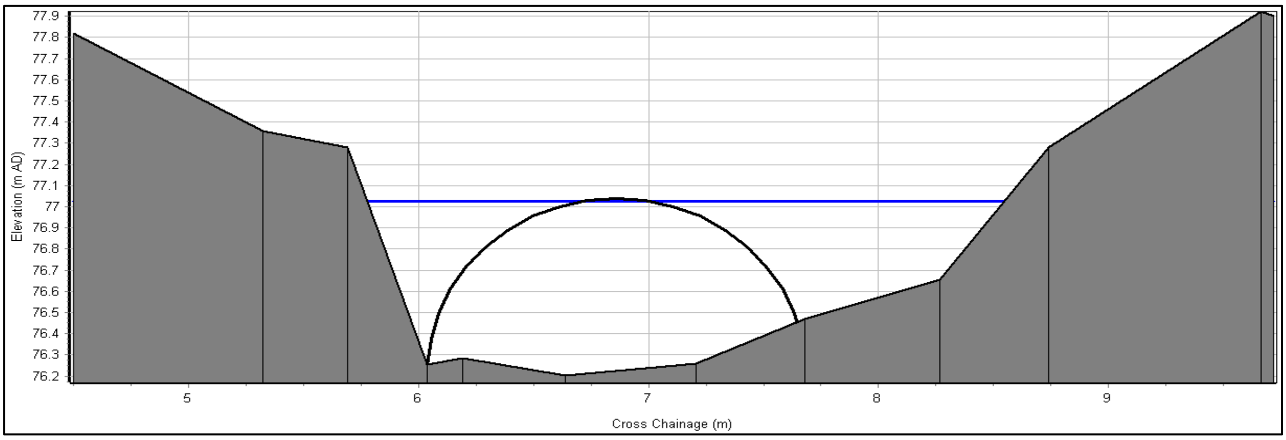


Bridge conveys peak flows with no noted issues, water level at upstream of bridge exceeds soffit resulting in backwater effect.

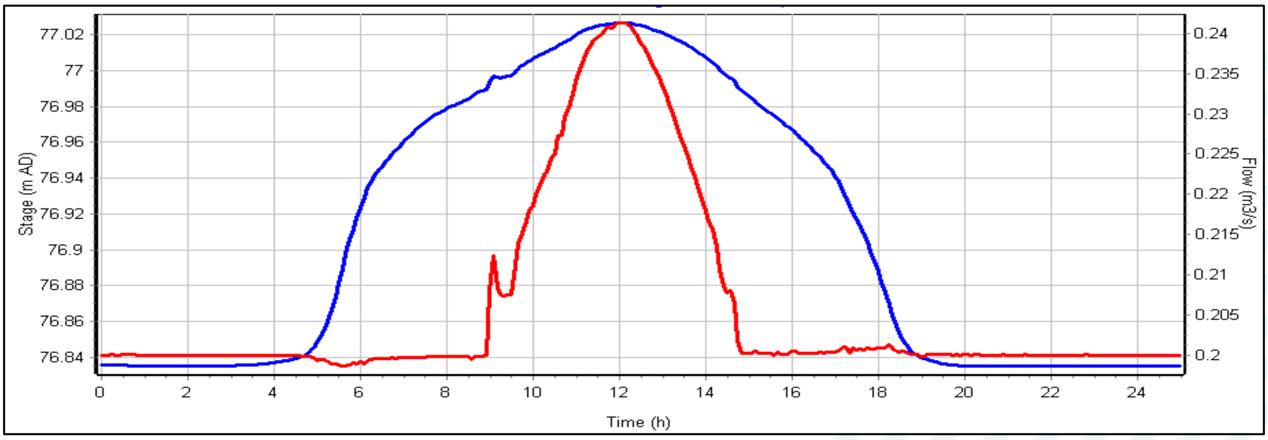
14CARO0099U -14CARO00099D - ARCHED BRIDGE (CARO2)			
Width	1.65m	Length	4.60m
Soffit	77.04mOD	Springing height	76.52mOD
Coefficients	Channel roughness: 0.05 Spill weir coefficient: 1.55	Present in model?	Yes via 1D arched bridge unit
Skew	15 degrees	Overtopping	1D spill unit set at height of bridge surface (78.66mOD)
Orifice Eqtn used	Yes	Transition distance	0.10m
Notes	Skew angle applied. DS face used for bridge as has smaller conveyance area (conservative approach)		



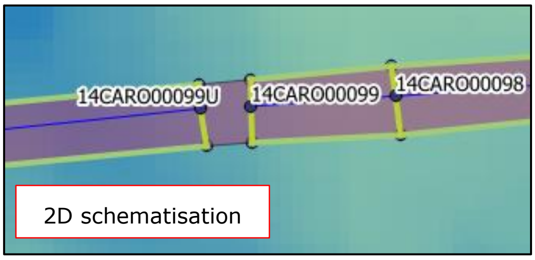




Maximum water level

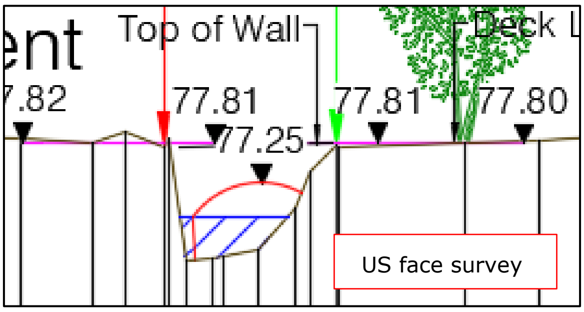


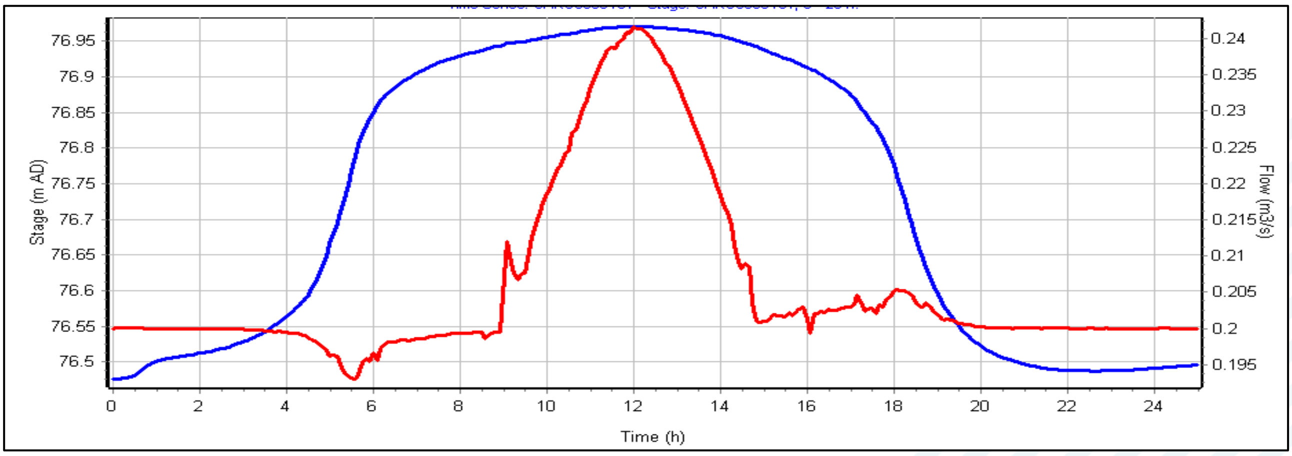
Level (blue) and flow (red) through bridge



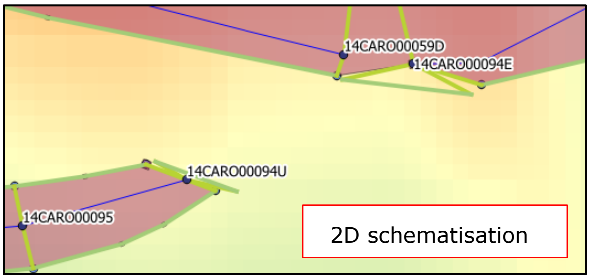
Bridge is able to convey the peak flow

14CARO000094E – ARCHED BRIDGE (CARO2)			
US Invert	75.90mOD	**DS invert**	75.90mOD
Dimensions	Width max: 1.91m Height max: 0.98m	**Length**	15.30m
Coefficients	Channel roughness: 0.02	**Present in model?**	Yes, represented in 1D using irregular culvert unit due to length width ratio of channel and structure.
Skew	22 degrees	**Overtopping**	2D spill via HX lines set to height of stone wall (77.81mOD)
Notes	Skew angle not applied – considered too small to have any significant impact.		





Level (blue) and flow (red) through bridge



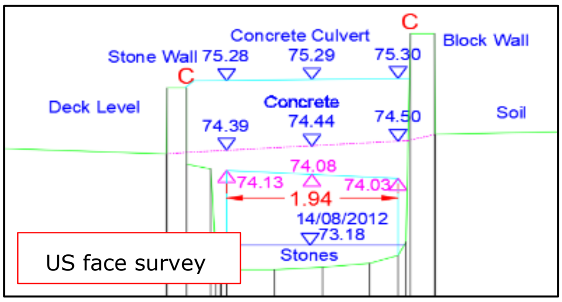
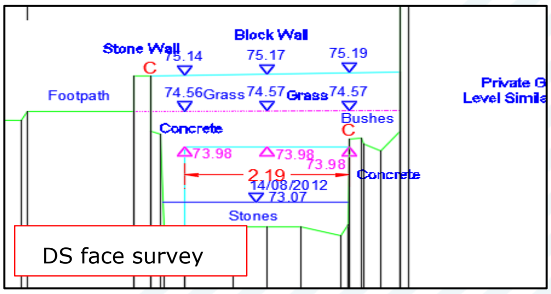
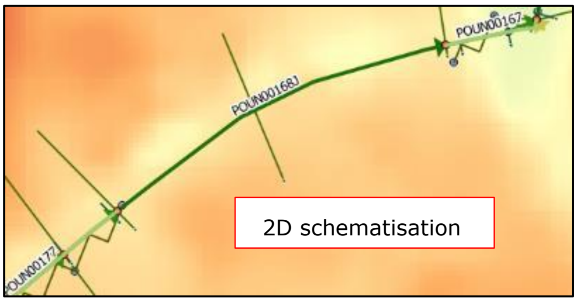
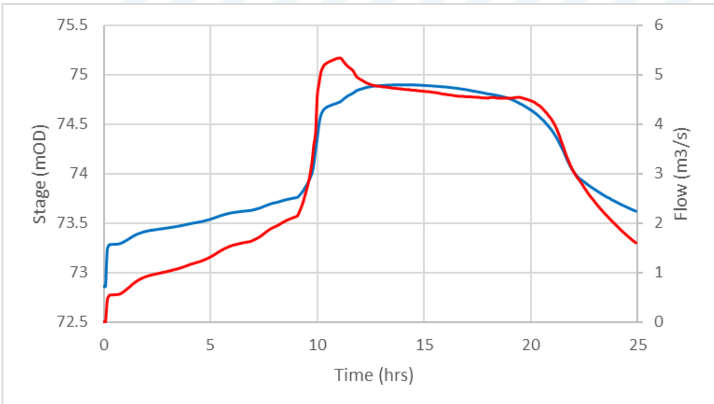
Bridge is able to convey the peak flow.

C.7 Pound River structures (Mountmellick model)

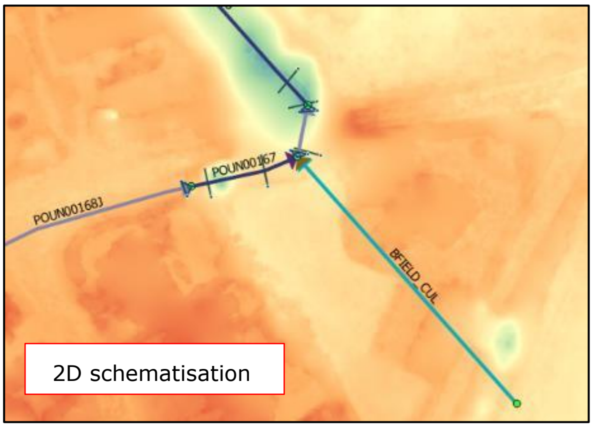
C.7.1 Weirs

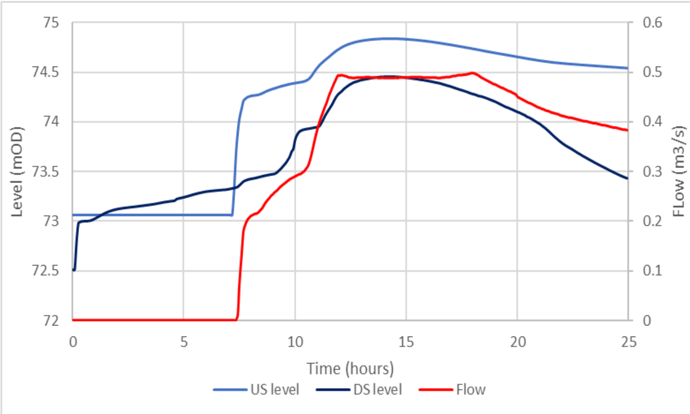
There are no weirs along the Pound watercourse.

C.7.2 Culverts

14POUN00176I-14POUN00168J – RECTANGULAR CULVERT			
US Invert	72.86mOD	DS invert	72.53mOD
Dimensions	Width: 1.94m Height: 1.27m	Length	75.02m
Coefficients	Structure roughness: 0.02	Present in model?	Yes, represented in 1D using irregular culvert unit in ESTRY due to variation of channel bed making shape irregular.
Skew	NA	Overtopping	2D via HX zsh points set to concrete wall height (75.29mOD).
Notes	Grated manholes are located along the length of the culvert. Culvert reach is curved. Bend is only minor therefore no bend losses are applied as the impact is considered to be minimal.		
			
			
		 Level (blue) and Flow (red) through culvert	
Flow decreases due to spill upstream of structure			

BFIELD – RECTANGULAR CULVERT			
US Invert	73.06mOD	DS invert	73.85mOD
Dimensions	Width:0.60m Height: 1.00m	Length	60m
Coefficients	Structure roughness: 0.02	Present in model?	Yes, represented in 1D using a rectangular culvert unit in ESTRY
Skew	NA	Overtopping	Culvert connected to 2D domain via US invert level SX
Notes	Culvert connected to Pound watercourse immediately US of bridge and at bend in watercourse. No survey of culvert available		

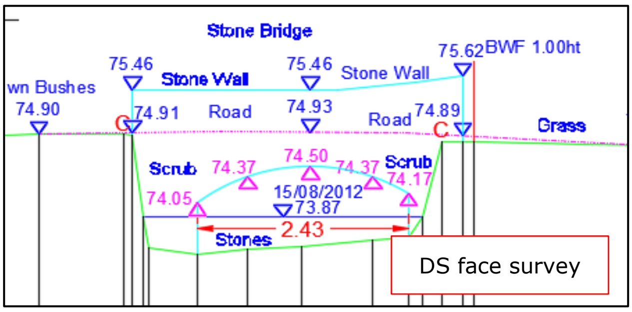


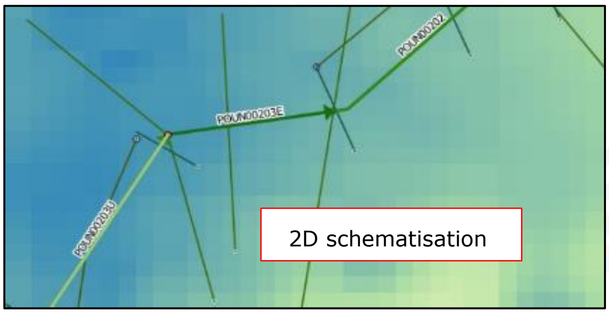


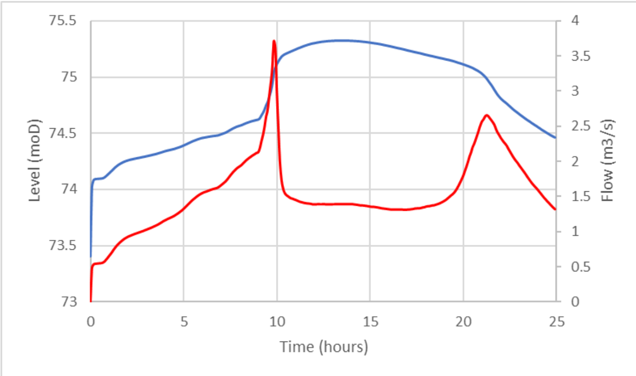
Culvert is impacted by floodplain flow at its US extent and backwater from the Pound at its DS extent. Flow through the culvert plateaus at the peak of the event as the culvert is drowned and there is not a sufficient gradient to promote flow.

C.7.3 Bridges

14POUN203E – ARCHED BRIDGE			
US Invert	75.90mOD	DS invert	75.90mOD
Dimensions	Width: 2.43m Height: 0.99m	Length	7.31m
Coefficients	Structure roughness: 0.02	Present in model?	Yes, represented in 1D using irregular culvert unit in ESTRY due to length width ratio of channel and structure.
Skew	NA	Overtopping	2D spill via zsh points set to concrete wall height (75.46mOD)
Notes	Only DS face surveyed		



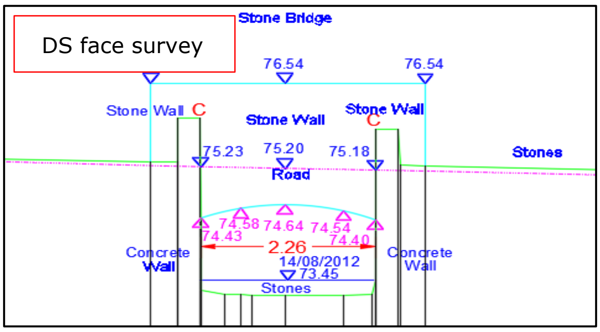


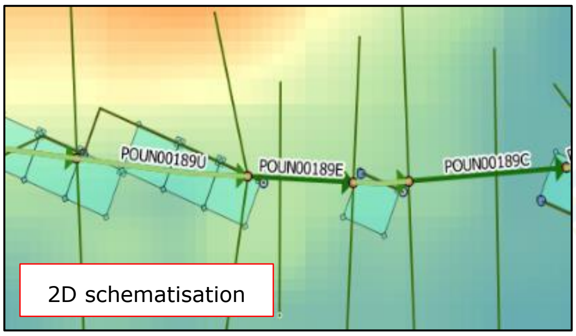


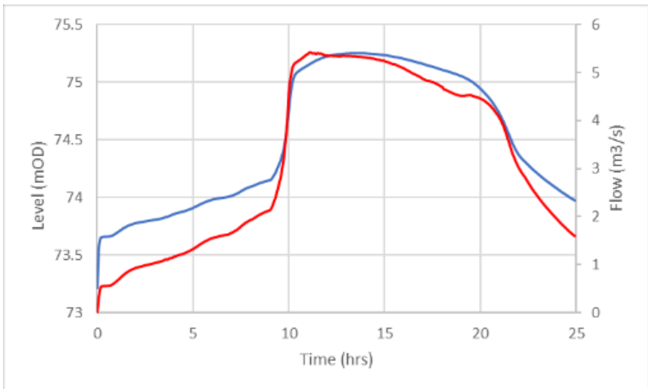
Level (blue) and flow (red) through bridge

Bridge is completely drowned at the peak of the event with flow moving through the 2D floodplain. Flow drops within the structure as the water level plateaus.

14POUN00189E – ARCHED BRIDGE			
US Invert	73.25mOD	**DS invert**	73.20mOD
Dimensions	Width: 2.26m Height: 1.42m	**Length**	9.06m
Coefficients	Structure roughness: 0.02	**Present in model?**	Yes, represented in 1D using irregular culvert unit in ESTRY due to length width ratio of channel and structure.
Skew	NA	**Overtopping**	2D spill via Zsh points set to concrete wall height (76.54mOD)
Notes	Only DS face surveyed		



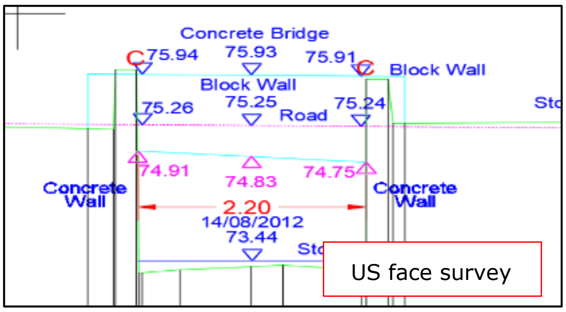


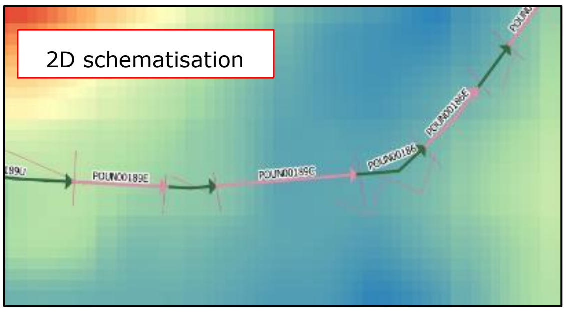


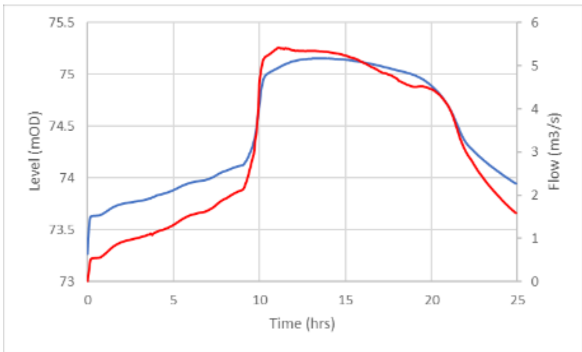
Level (blue) and flow (red) through bridge

Flow and level appear smooth through the structure – level exceeds bridge soffit but does not reach the spill height over the bridge. Large amounts of out of bank spill occur up and downstream of the structure

14POUN00189C – IRREGULAR SHAPED BRIDGE			
US Invert	73.27mOD	**DS invert**	73.00mOD
Dimensions	Width: 2.20m Height: 1.64m	**Length**	14.88.m
Coefficients	Structure roughness: 0.02	**Present in model?**	Yes, represented in 1D using irregular culvert unit in ESTRY due to length width ratio of channel and structure.
Skew	NA	**Over topping**	Represented in the 2D via Zsh points/lines set to concrete wall height (75.93mOD).
Notes			



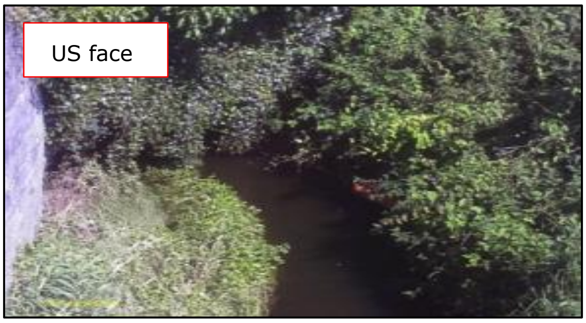


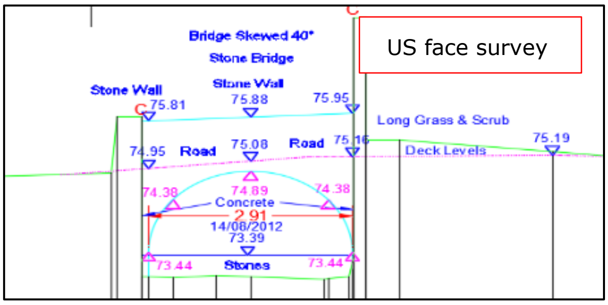


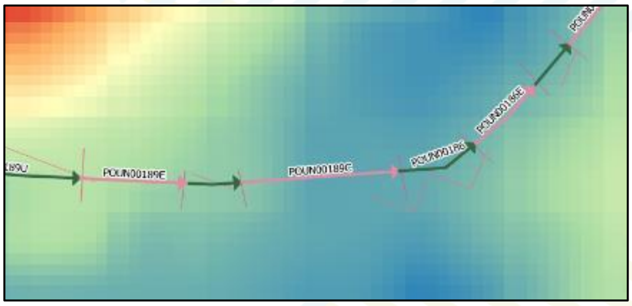
Level (blue) and flow (red) through bridge

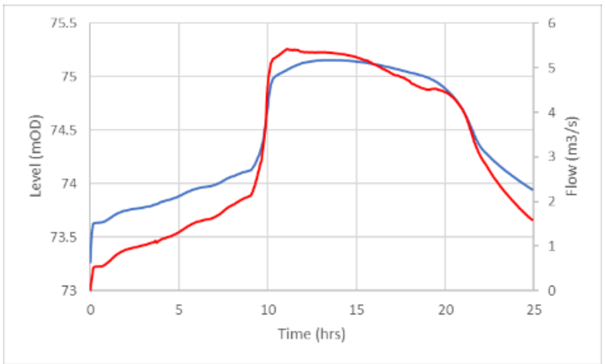
Spill occurs at the downstream end of the bridge as a result of interactions downstream.

14POUN00186D – ARCHED BRIDGE			
US Invert	73.00mOD	**DS invert**	72.97mOD
Dimensions	Width: 2.91m Height: 1.92m	**Length**	7.08m
Coefficients	Structure roughness: 0.02	**Present in model?**	Yes, represented in 1D using irregular culvert unit in ESTRY due to length width ratio of channel and structure.
Skew	40 degrees	**Overtopping**	Represented in the 2D via Zsh points/lines set to concrete wall height (75.86mOD).
Notes	Skew angle applied to US cross section		

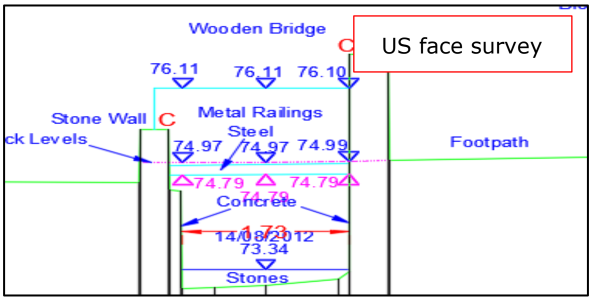


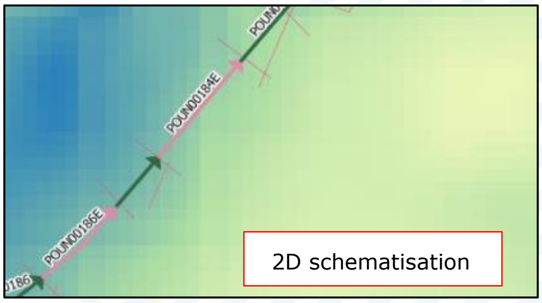


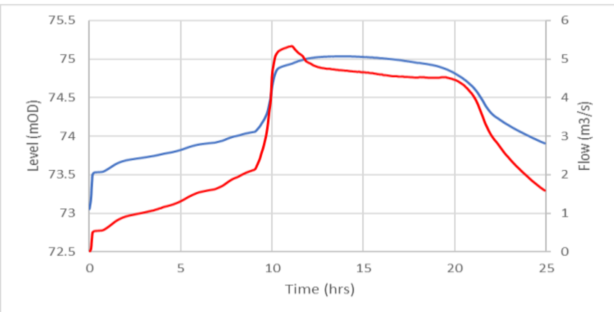


 Level (blue) and flow (red) through bridge	Spill occurs at the upstream of the culvert where water level reaches above soffit resulting in a drop in flow as water moves into the 2D.

14POUN00186E-14POUN00184E – RECTANGULAR BRIDGE			
US Invert	73.06mOD	DS invert	73.05mOD
Diameter	Width: 2.29m Height: 1.68m	Length	9.71m
Coefficients	Structure roughness: 0.02	Present in model?	Yes, represented in 1D using irregular culvert unit in ESTRY due to length width ratio of channel and structure.
Skew	NA	Overtopping	Represented in the 2D via Zsh points/lines set to bridge deck height (74.97mOD).



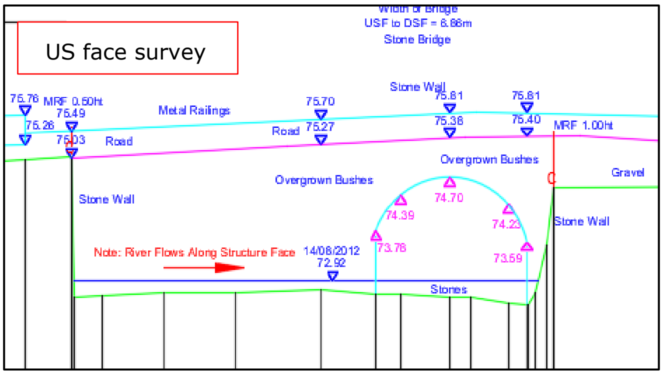


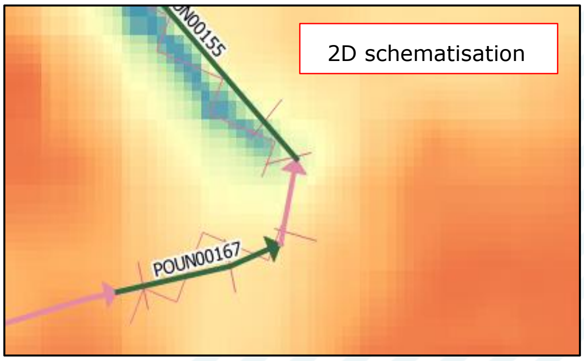


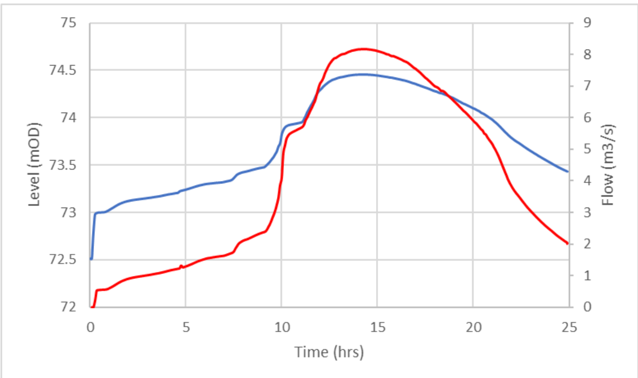
Level (blue) and flow (red) through bridge

Spill results in decreased flow at peak and plateau of water level as water spills over the structure and the water gradient diminishes.

14POUN00166D – ARCHED BRIDGE			
US Invert	72.52mOD	**DS invert**	72.51mOD
Diameter	Width: 2.78m Height: 2.27m	**Length**	6.86m
Coefficients	Structure roughness: 0.02 Inlet loss: 1.66	**Present in model?**	Yes, represented in 1D using irregular culvert unit in ESTRY due to length width ratio of channel and structure.
Skew	90 degrees	**Overtopping**	Represented in the 2D via Zsh points/lines set to concrete wall height (75.81mOD).
Notes	US face cross section adjusted to reflect actual conveyance of channel. Loss due to bend applied at US of structure (1.66 loss)		





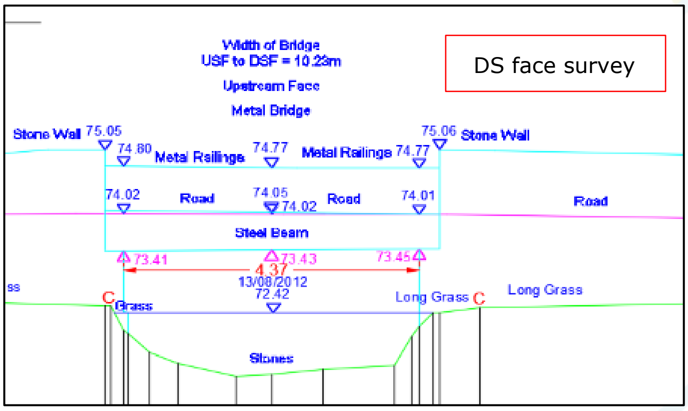


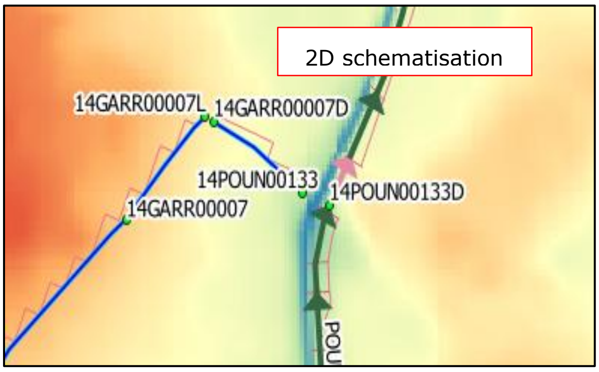
Level (blue) and flow (red) through structure

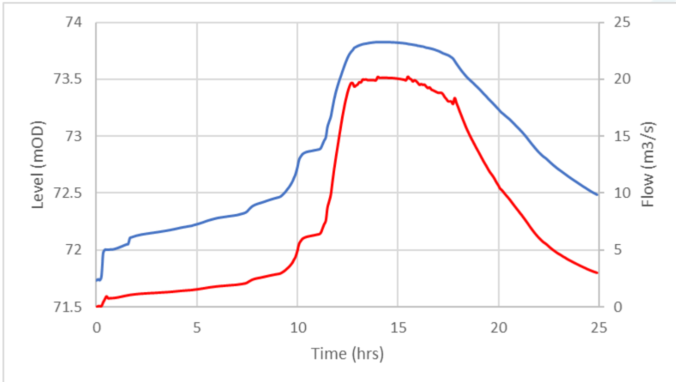
The bridge can convey peak flow and level however there is a considerable amount of floodplain flow that is moving in and around the structure.

14POUN00133D – RECTANGULAR BRIDGE

US Invert	71.39mOD	**DS invert**	71.38mOD
Diameter	Width: 4.37m Height: 2.06m	**Length**	10.23m
Coefficients	Structure roughness: 0.02	**Present in model?**	Yes, represented in 1D using irregular culvert unit in ESTRY due to length width ratio of channel and structure.
Skew	NA	**Overtopping**	Represented in the 2D via Zsh points/lines set to bridge deck height (74.05mOD).
Notes	Hydrometric gauge 14120 is located on the DS face of this structure		



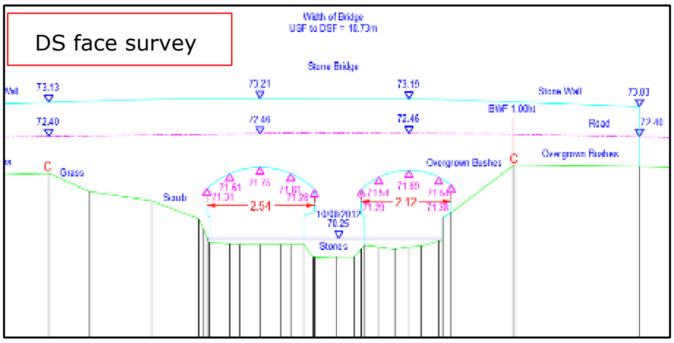


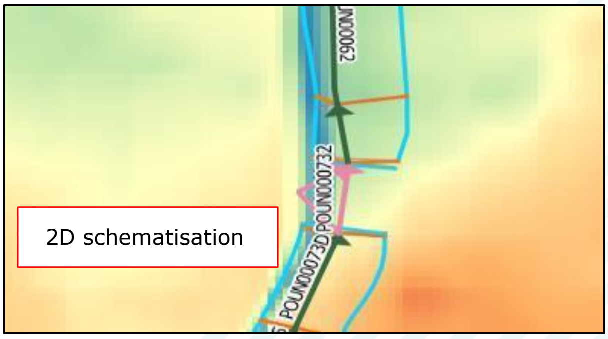


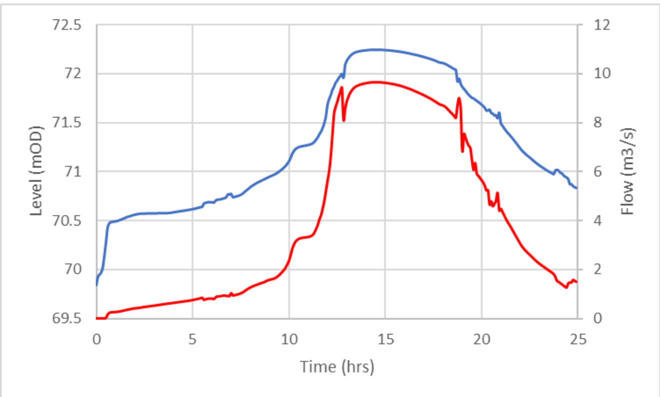
Stage (blue) and Flow (red) through bridge

Structure is drowned at peak with large amounts of overland flow entering the system upstream

14POUN00073D – ARCHED BRIDGE			
US Invert	Arch 1: 70.11mOD Arch 2: 70.03mOD	DS invert	Arch 1: 70.10mOD Arch 2: 70.02mOD
Diameter	Width: arch 1 = 2.54m arch 2 = 2.12m Height: arch 1 = 1.64m arch 2 = 1.69m	Length	10.73m
Coefficients	Structure roughness: 0.02	Present in model?	Yes, each arch opening represented in 1D using irregular culvert unit in ESTRY due to length width ratio of channel and structure.
Skew	NA	Overtopping	Represented in the 2D via Zsh points/lines set to stone wall height (73.19mOD).
Notes			







Level (blue) and flow (red) through bridge

Bridge is surcharged at US face at peak with large amounts of floodplain spill occurring up and downstream of structure.

C.8 Owenass River structures (Mountmellick Mill model)

C.8.1 Weirs

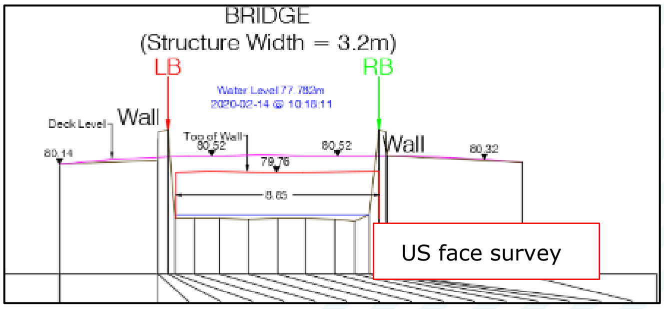
There are no weirs along the Owenass watercourse.

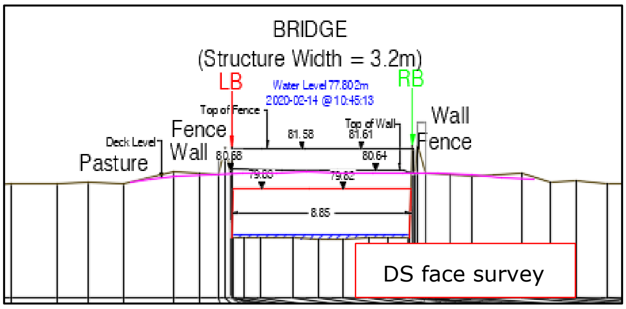
C.8.2 Culverts

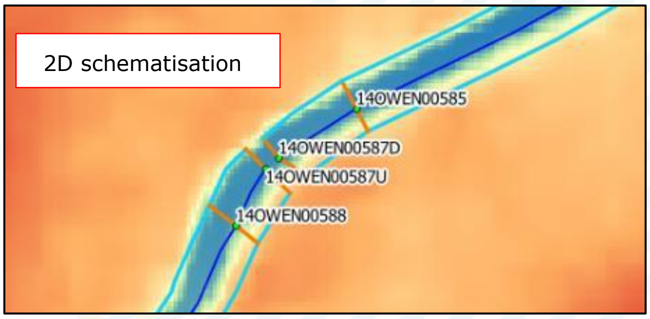
There are no culverts along the Owenass watercourse.

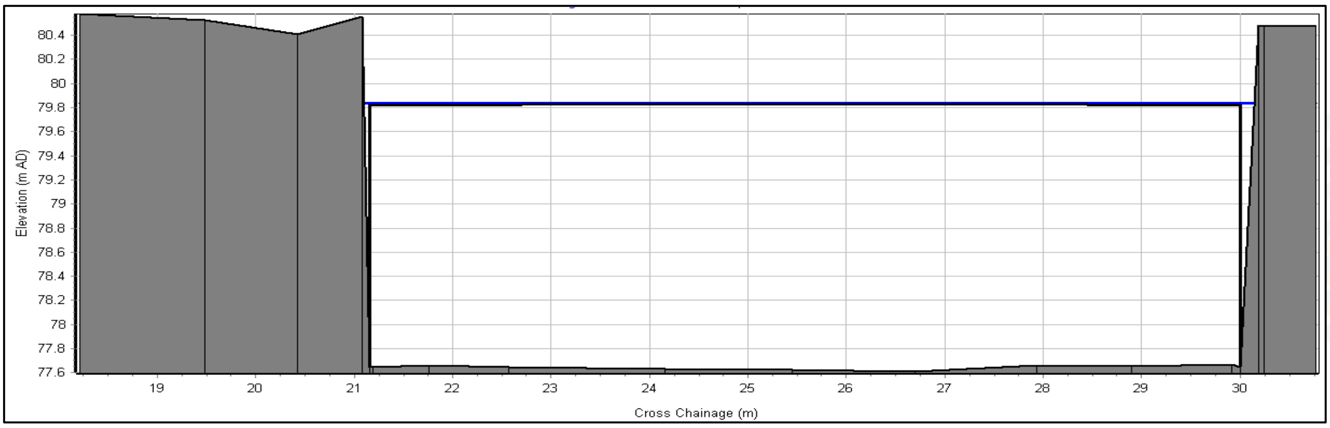
C.8.3 Bridges

14OWEN00587B – RECTANGULAR BRIDGE			
Width	8.85m	Length	3.20m
Soffit	78.83mOD	Springing height	78.82mOD
Coefficients	Channel: 0.040 Spill weir coefficient: 1.55	Present in model?	Yes via 1D USBPR bridge unit
Skew	NA	Overtopping	1D spill unit set to height of deck (minimum height - 80.64mOD).
Orifice equation used	Yes	Transition distance	0.10m
Notes	Stone wall on LHB and RHB removed.		

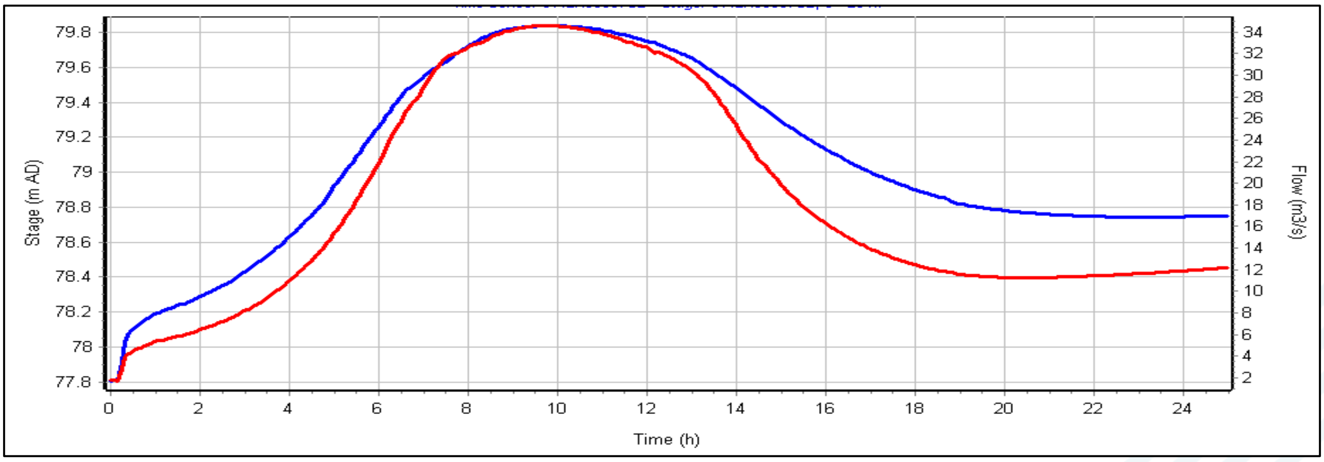








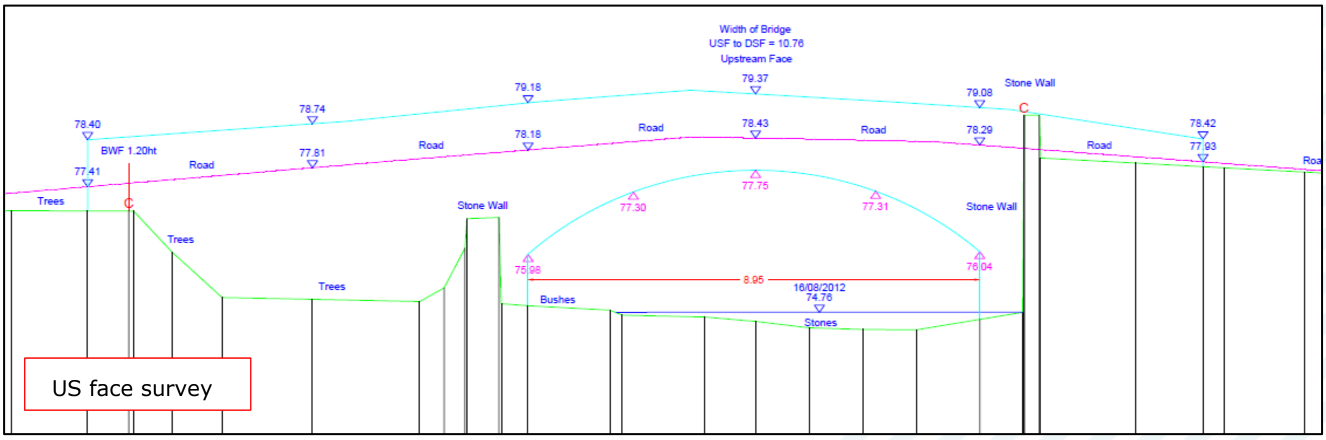
Maximum water level

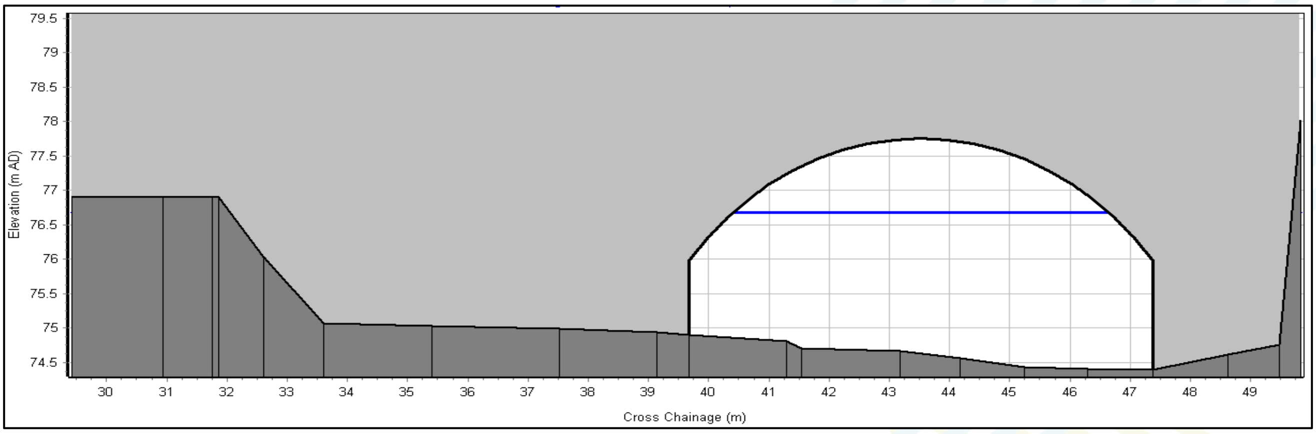


Level (blue) and flow (red) through bridge

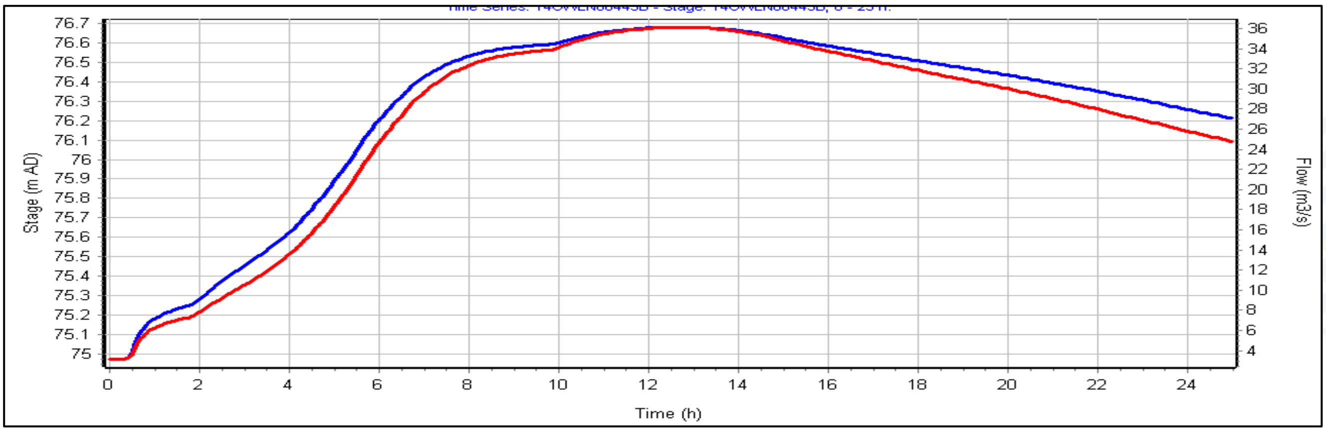
Bridge conveys peak flow, large amount of spill upstream which bypasses bridge via the floodplain.

14OWEN00443B – ARCH BRIDGE			
Width	8.95m	Length	10.76m
Soffit	77.75mOD	Springing height	75.98mOD
Coefficients	Channel: 0.035 Spill weir coefficient: 1.40	Present in model?	Yes via 1D arch bridge unit
Skew	NA	Overtopping	1D spill unit set to height of stone wall (minimum height -78.40mOD).
Orifice equation used	Yes	Transition distance	0.10m
Notes	Stone wall on LHB removed.		

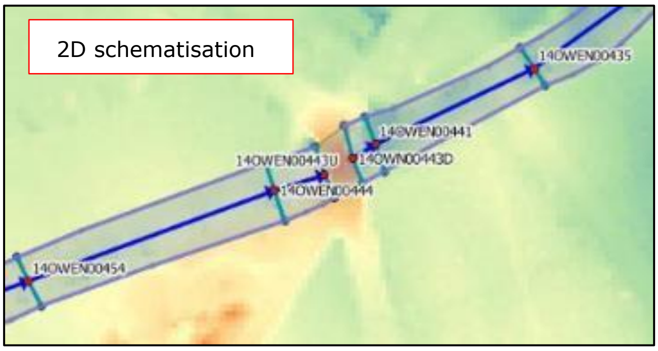




Maximum water level

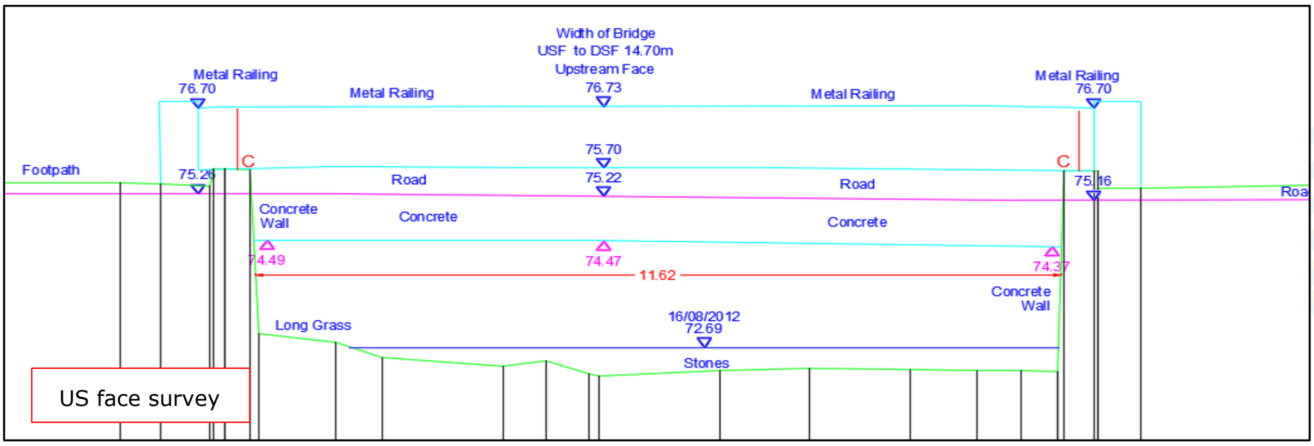


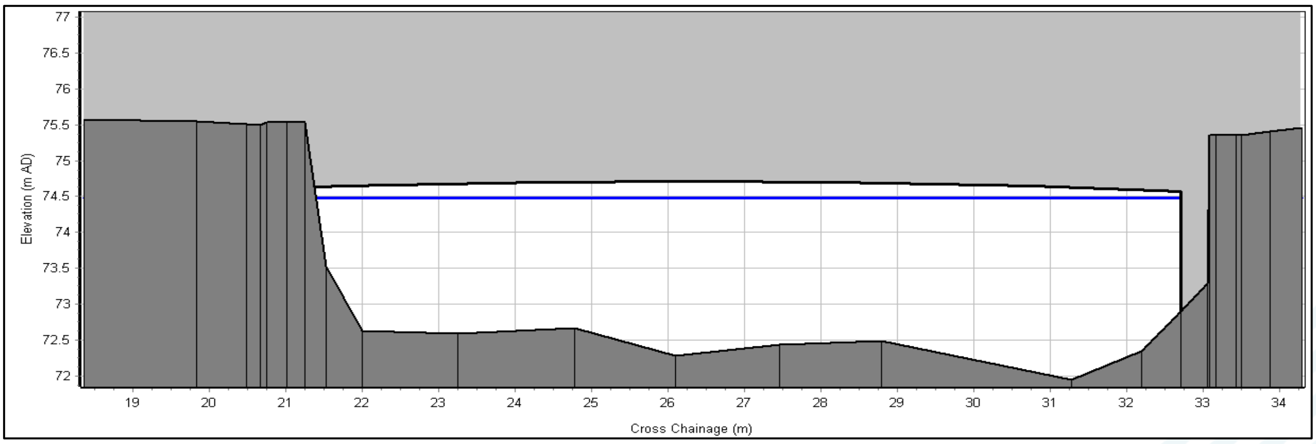
Level (blue) and flow (red) through bridge



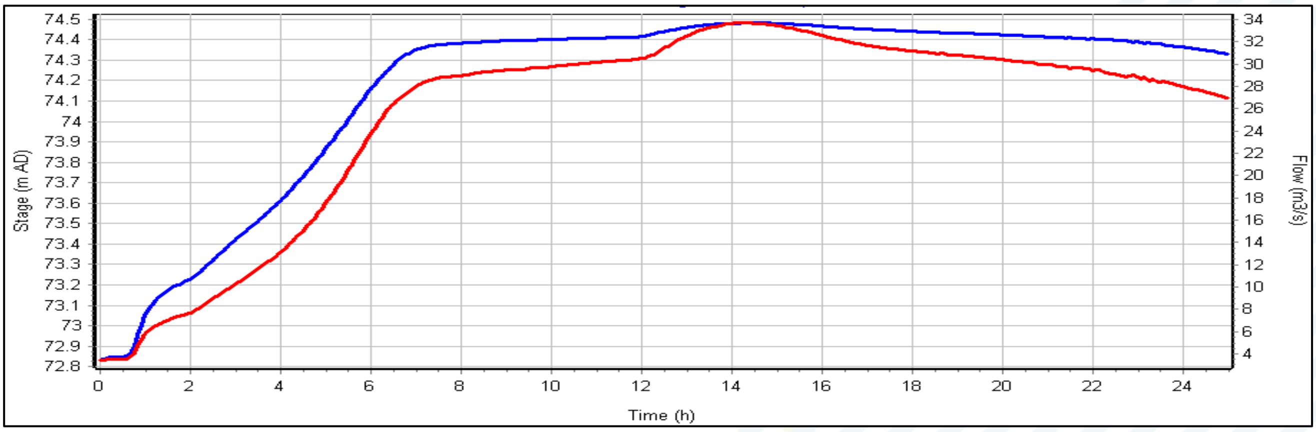
Bridge is able to convey peak flow but there is a large amount of flow bypassing due to spill upstream.

14OWEN00311D – RECTANGULAR BRIDGE			
Width	11.62m	**Length**	14.70m
Soffit	74.47mOD	**Springing height**	74.37mOD
Coefficients	Channel: 0.035 Spill weir coefficient: 1.40	**Present in model?**	Yes via 1D USBPR bridge unit
Skew	44.39 degrees	**Overtopping**	1D spill unit set at height of concrete lip of bridge (minimum height 75.70mOD)
Orifice equation used	Yes	**Transition distance**	0.10m
Notes	Mountmellick gauge (14114) lies directly DS of bridge.		

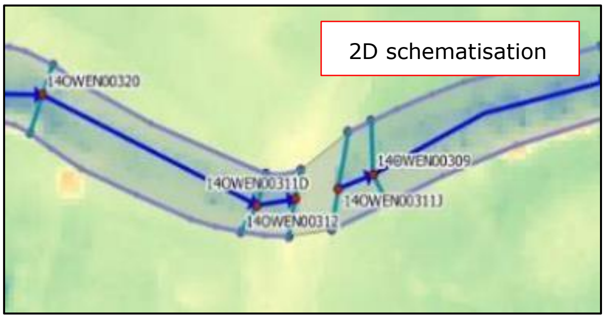




Maximum water level



Level (blue) and flow (red) through bridge

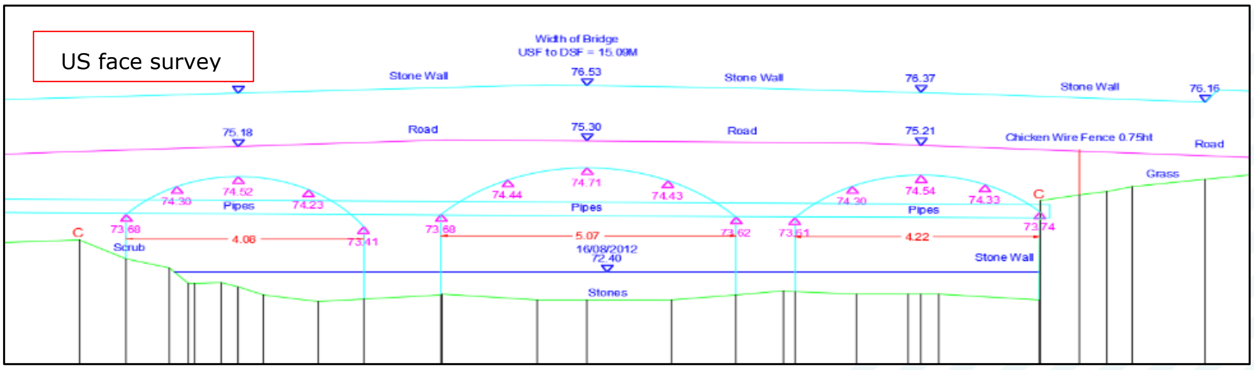


Peak level nears soffit of bridge but does not exceed it. Lots of flow bypassing occurring as out of bank flow enters the floodplain upstream of the bridge.

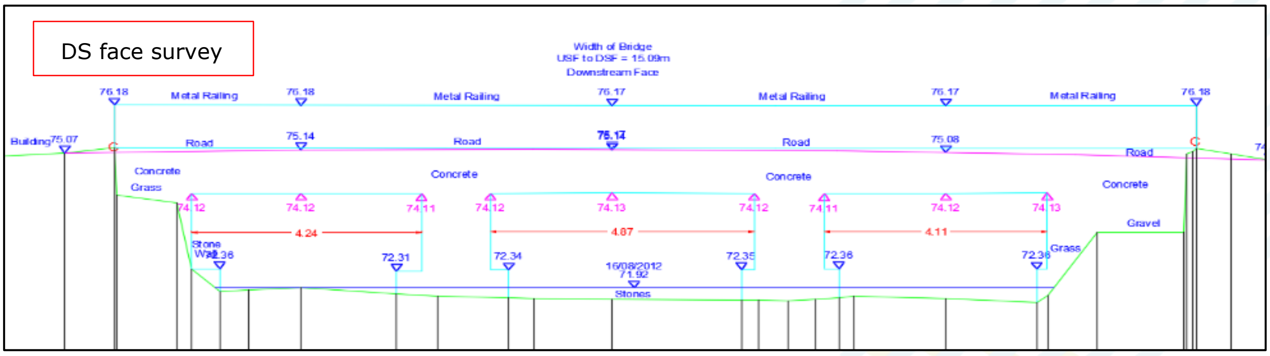
14OWEN00257D – RECTANGULAR BRIDGE			
Width	Opening 1: 4.08m Opening 2: 5.07m Opening 3: 4.22m	Length	15.09m
Soffit	Opening 1: 74.52mOD Opening 2: 74.71mOD Opening 3: 74.54mOD	Min Springing height	Opening 1: 73.41mOD Opening 2: 73.62mOD Opening 3: 73.61mOD
Coefficients	Channel: 0.037 Spill weir coefficient: 1.40	Present in model?	Yes via 1D USBPR bridge unit with three openings.
Skew	NA	Overtopping	1D spill unit set to stone wall height (minimum height 76.37mOD)
Orifice equation used	Yes	Transition distance	0.10m
Notes	DS face modelled as it has smallest conveyance area (conservative approach). Ducts on US face not modelled but would be a concern for blockage impact.		


US face

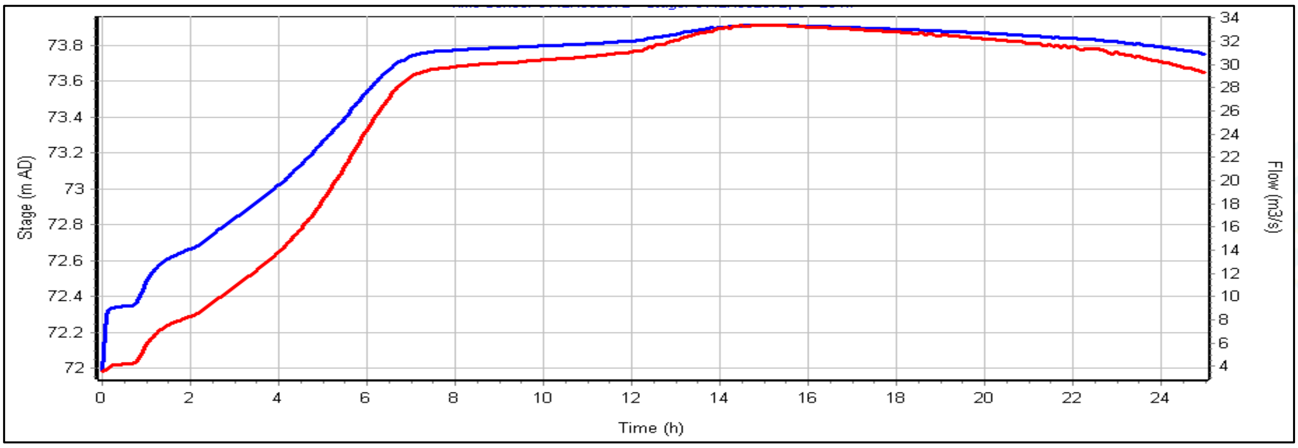

Images through arches US and DS face

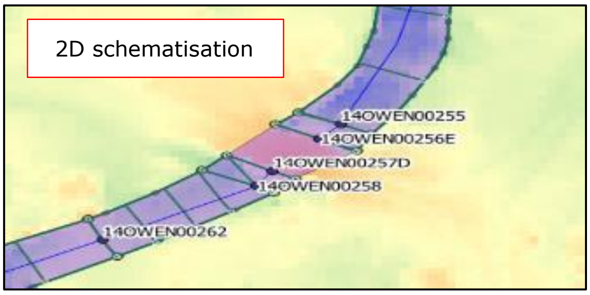


US face survey



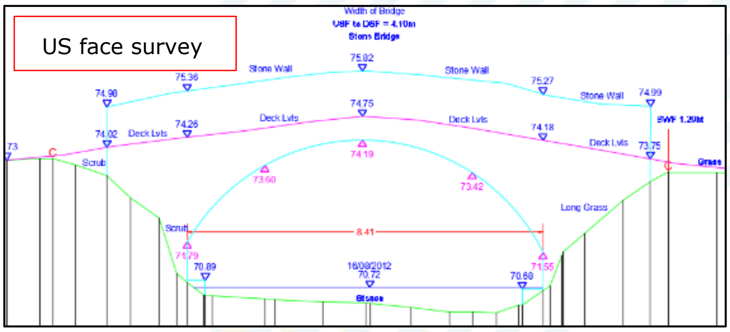
DS face survey

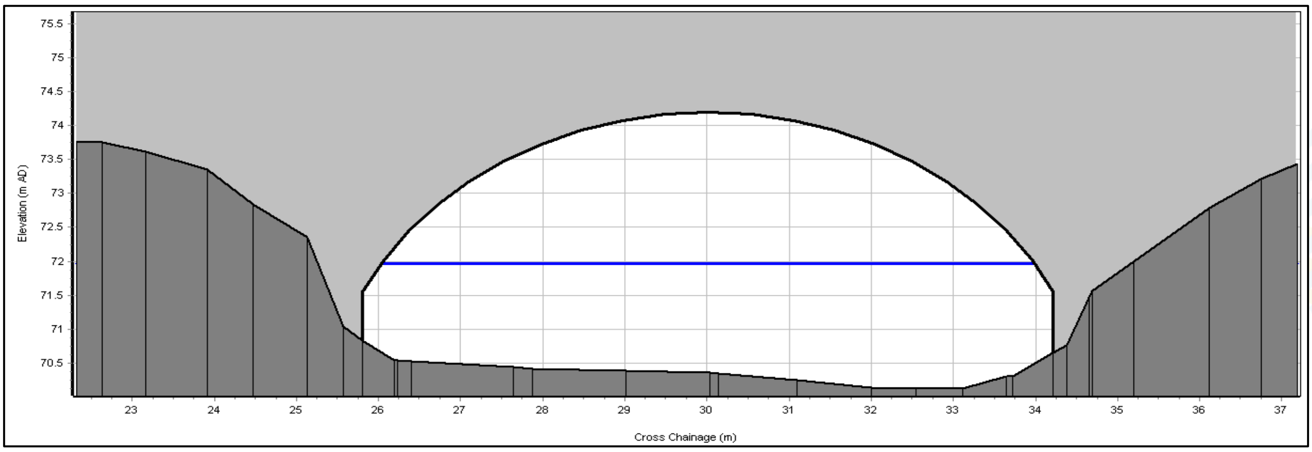




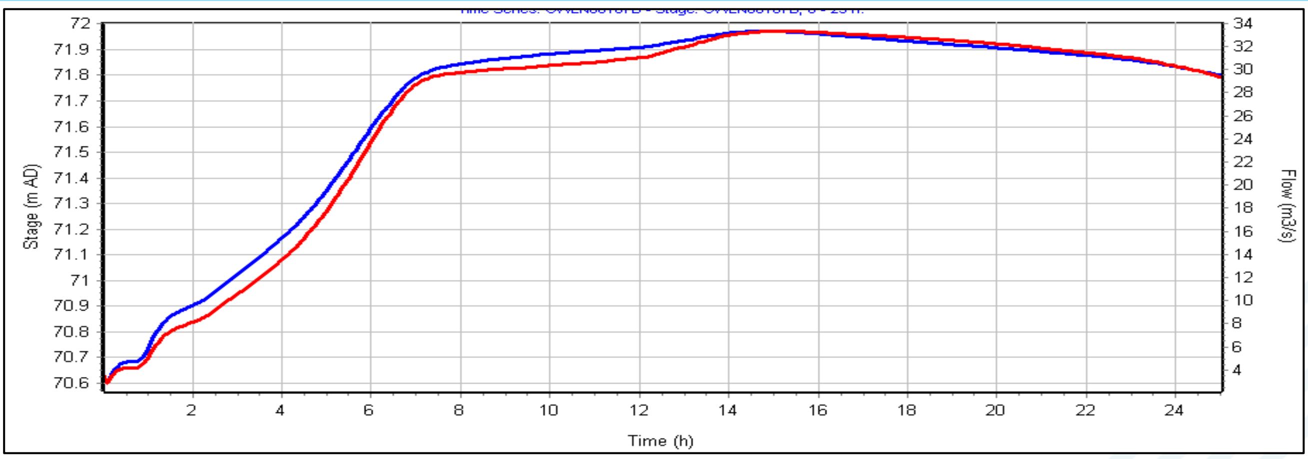
Bridge is able to convey flows, large amount of flood hydrograph spills into the floodplain upstream of the structure. Structure did become partially blocked in the November 2017 event. ESB ducts run across the upstream face of the structure and could potentially capture debris in high flow events.

14OWEN00187D – ARCH BRIDGE			
Width	8.41m	Length	4.10m
Soffit	74.19mOD	Springing height	71.55mOD
Coefficients	Channel: 0.035 Spill weir coefficient: 1.40	Present in model?	Yes via 1D arched bridge unit
Skew	NA	Overtopping	1D spill unit set to height of stone wall (minimum height 74.98mOD)
Orifice equation used	Yes	Transition distance	0.10m
Notes			

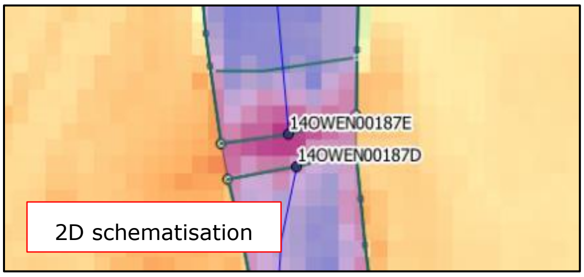




Maximum water level



Level (blue) and flow (red) through bridge



Bridge operating normally during event. Flow contained in channel at this point.

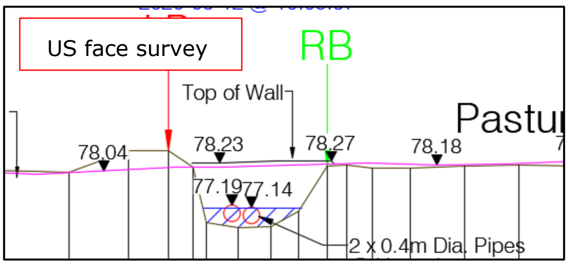
C.9 Owenass Tributary 1 structures (Mountmellick model)

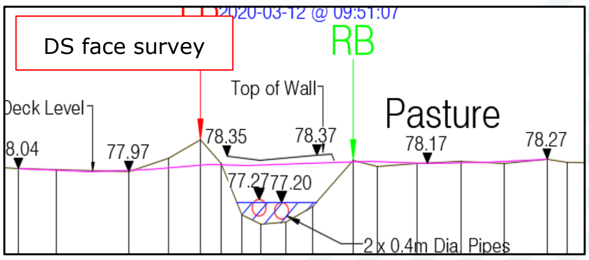
C.9.1 Weirs

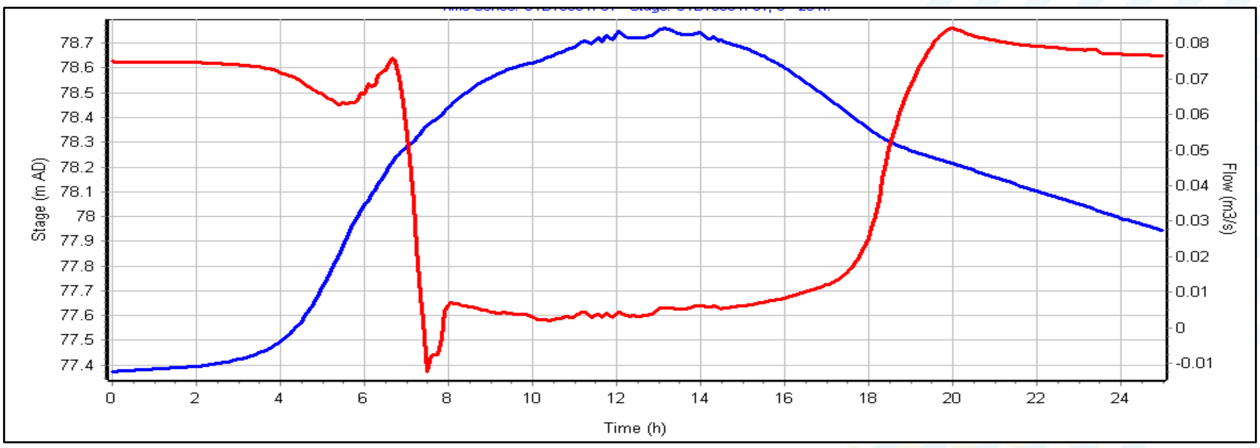
There are no weirs along the Owenass Tributary watercourse.

C.9.2 Culverts

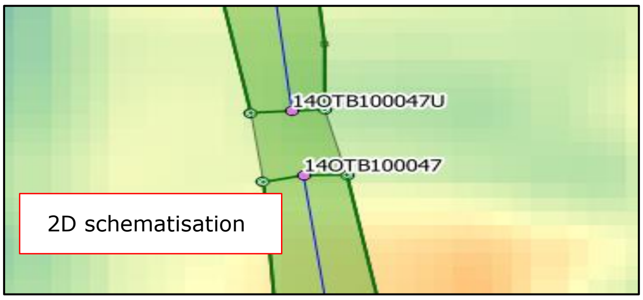
14OTB100047 – DOUBLE CIRCULAR CULVERT			
US Invert	CUL1: 76.89mOD CUL2: 76.84mOD	DS invert	CUL1: 76.80mOD CUL2: 76.78mOD
Dimensions	Both 0.40m diameter	Length	4.79m
Coefficients	Roughness: 0.02 Spill coefficient: 1.55	Present in model?	Represented in FM 1D using circular culvert units
Skew	NA	Overtopping	1D spill unit set to height of wall (78.23mOD)
Notes			







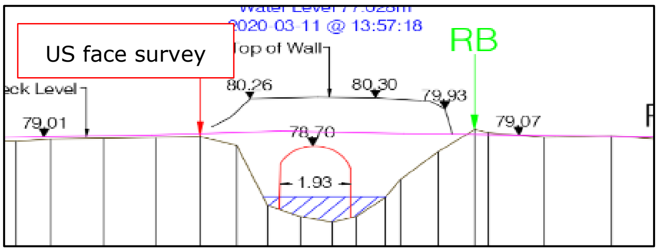
Level (blue) and flow (red) through bridge

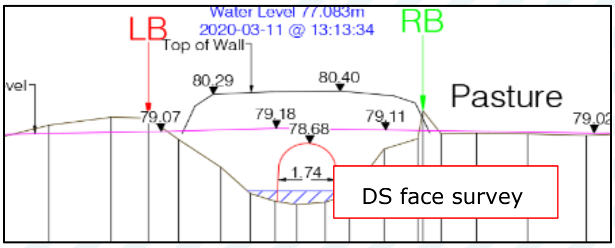


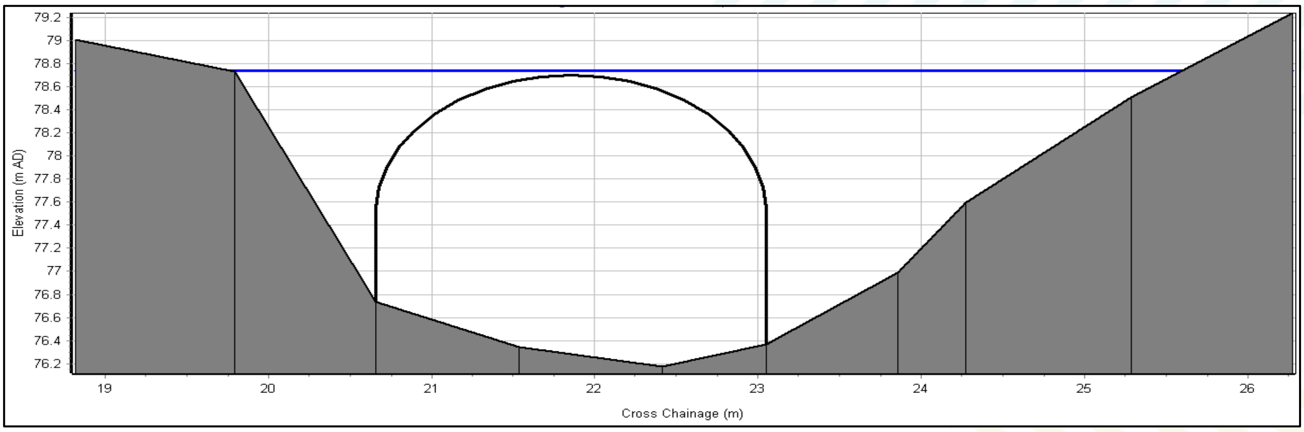
Culverts are drowned at the peak of the event due to cross flow from other areas entering the system. Flow decreases at the peak but is fairly constant (max difference in flow is 0.09m3/s).

C.9.3 Bridges

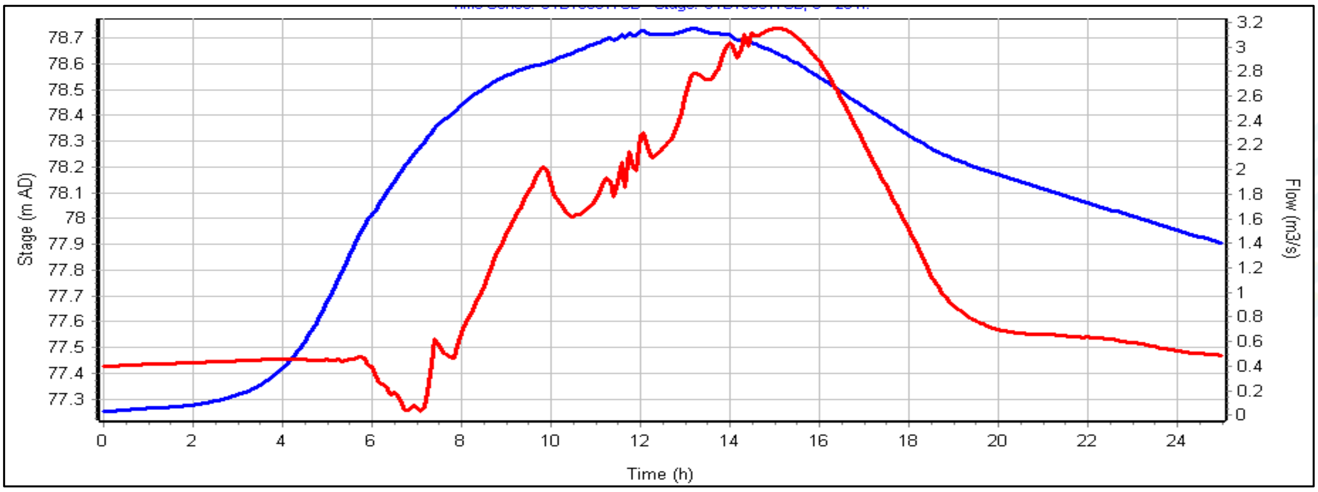
14OTB00017 – ARCH BRIDGE			
Width	1.93m	Length	5.70m
Soffit	78.70mOD	Springing height	77.55mOD
Coefficients	Channel roughness 0.05 Spill coefficient: 1.55	Present in model?	Represented in FM 1D using arche bridge unit
Skew	NA	Overtopping	1D spill unit set at wall height (80.26mOD)
Orifice equation used	Yes	Transition distance	0.10m
Notes	Junction with OTB2 occurs at the US face of the bridge.		



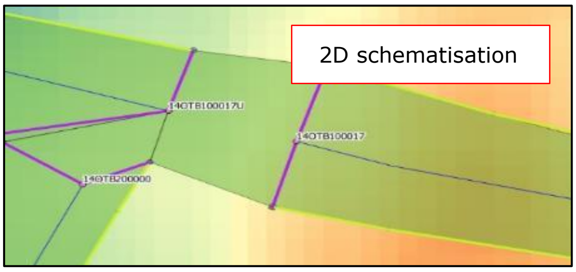




Maximum water level



Level (blue) and flow (red) through bridge



Peak water level just above soffit height, peak flow after peak level due to spill upstream. Initial flow variation due to backwater effect from flow downstream.

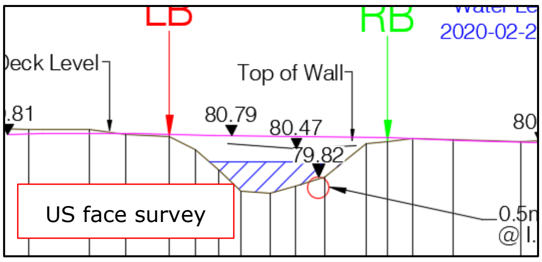
C.10 Owenass Tributary 2 structures (Mountmellick model)

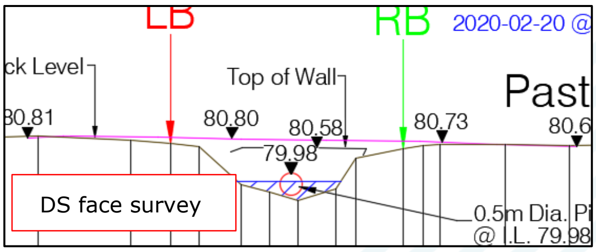
C.10.1 Weirs

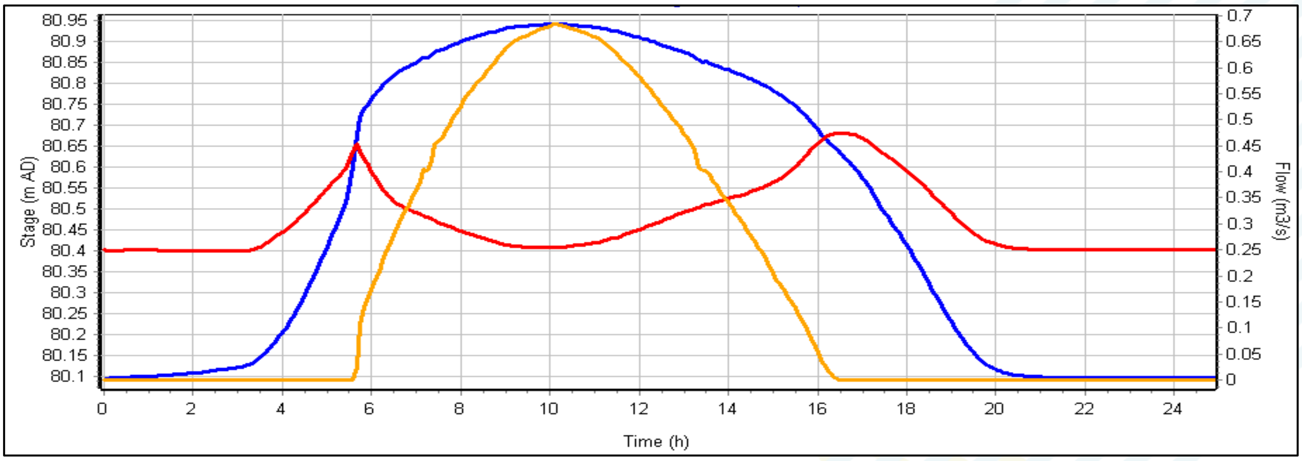
There are no weirs along the Owenass Tributary 2 watercourse.

C.10.2 Culverts

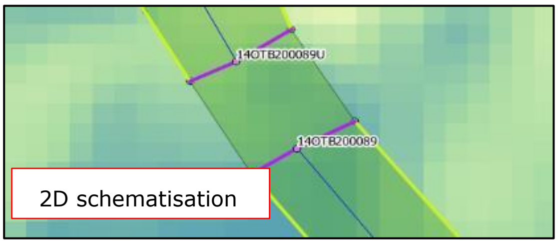
14OTB200089 – CIRCULAR CULVERT			
US Invert	79.32mOD	DS invert	79.48mOD
Dimensions	0.50m	Length	5.34m
Coefficients	Roughness: 0.02 Spill coefficient: 1.55	Present in model?	Represented in FM 1D using circular culvert units
Skew	NA	Overtopping	1D spill unit set to deck level (80.79mOD)
Notes			





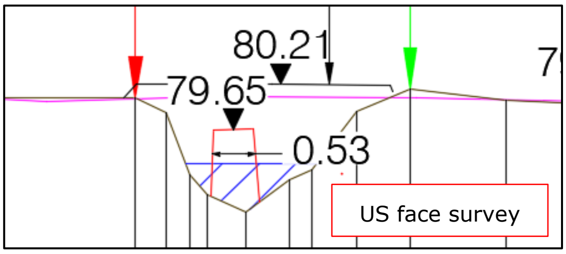


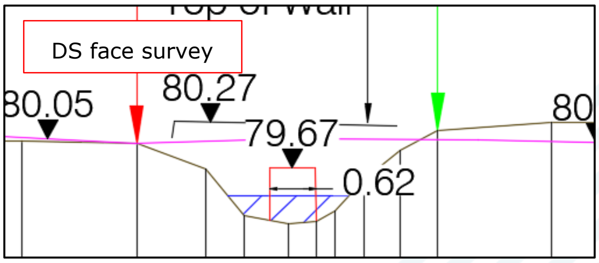
Level (blue) and flow through (red) and over (orange) culvert

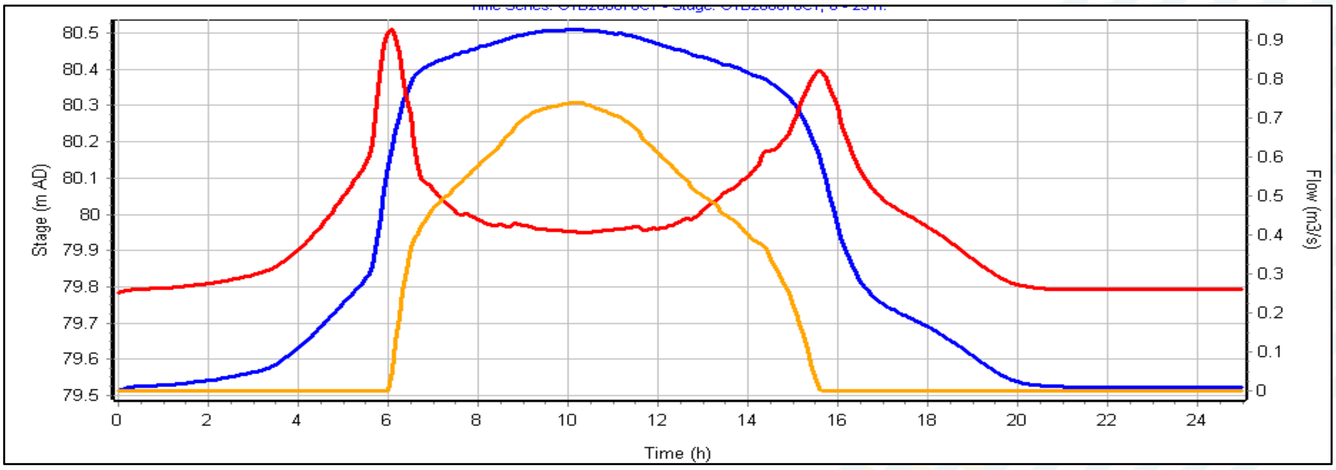


Water level exceeds soffit but flow over the structure is included in the spill unit and in 2D.

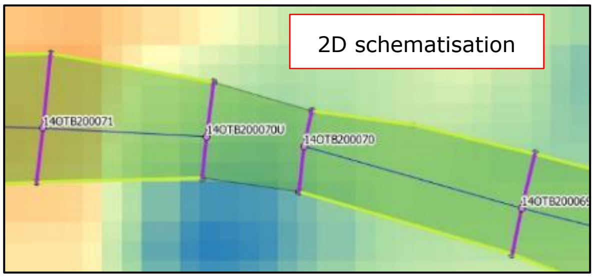
14OTB200070 – RECTANGULAR CULVERT			
US Invert	78.64mOD	DS invert	78.94mOD
Dimensions	Width: 0.53m Height: 1.00m	Length	4.86m
Coefficients	Roughness: 0.02 Spill coefficient: 1.55	Present in model?	Represented in FM 1D using rectangular culvert units
Skew	NA	Overtopping	1D spill unit set to wall level (80.21mOD)
Notes			





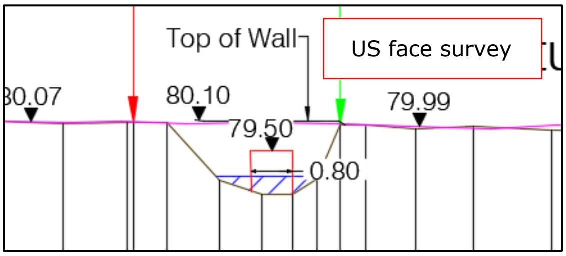


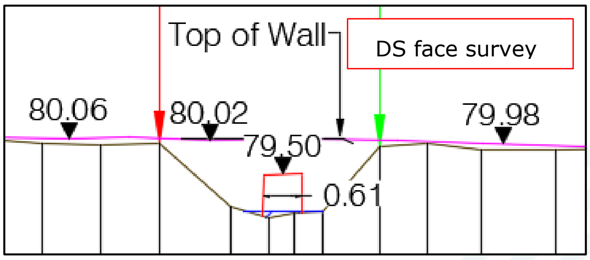
Level (blue) and flow through (red) and over (orange) culvert

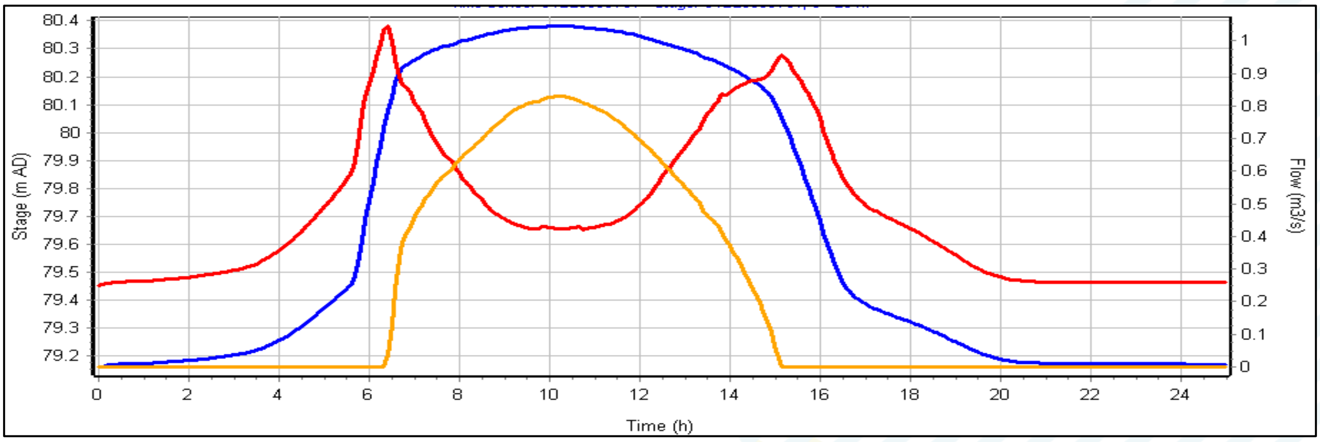


Culvert is surcharged during the peak of the event. Out of bank spill occurs upstream and flow is conveyed over the structure via the spill.

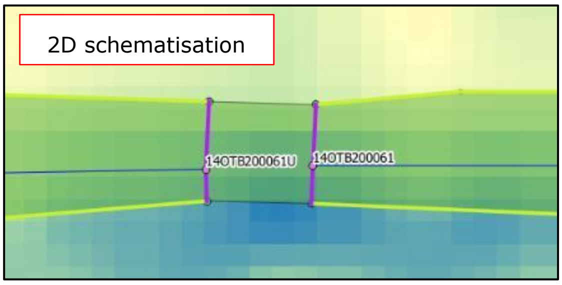
14OTB200061 – RECTANGULAR CULVERT			
US Invert	78.66mOD	DS invert	78.80mOD
Dimensions	Width: 0.800m Height: 0.85m	Length	4.57m
Coefficients	Roughness: 0.02 Spill coefficient: 1.55	Present in model?	Represented in FM 1D using rectangular culvert units
Skew	NA	Overtopping	1D spill unit set to wall level (80.10mOD)
Notes			





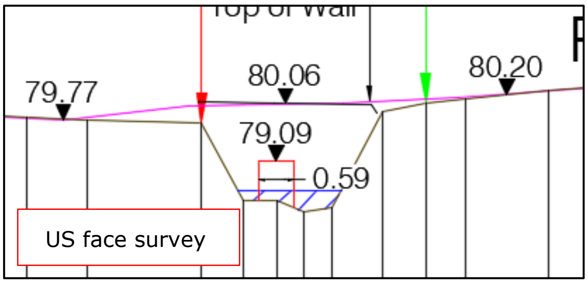


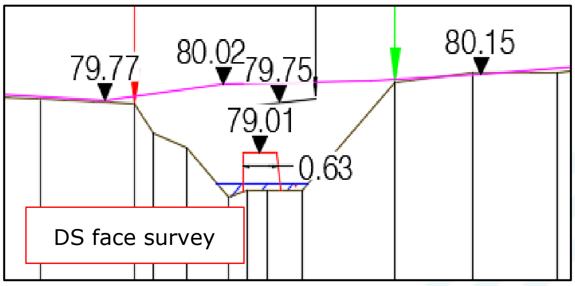
Level (blue) and flow through (red) and over (orange) culvert

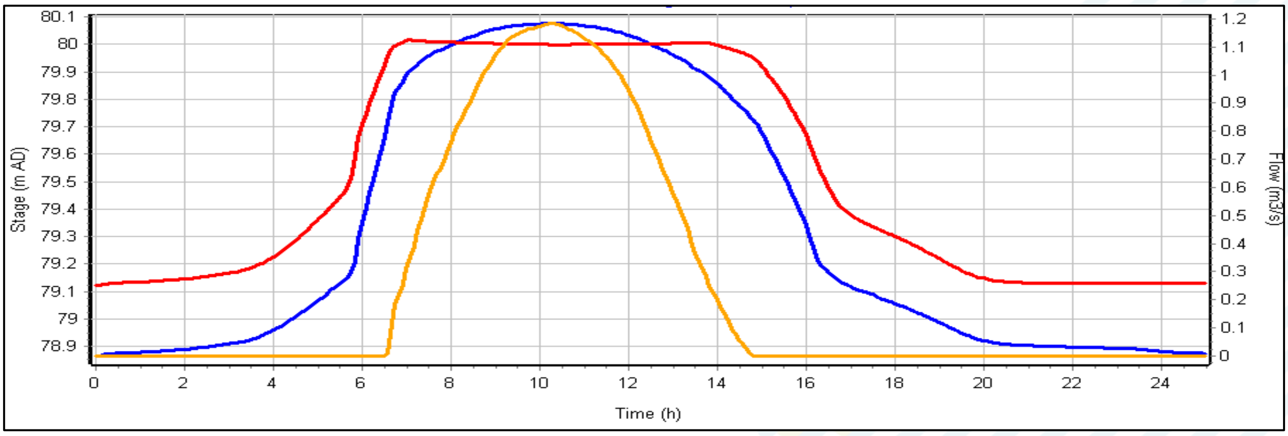


Culvert is surcharged at peak of event some out of bank spill observed upstream and flow over structure conveyed by spill and in the 2D.

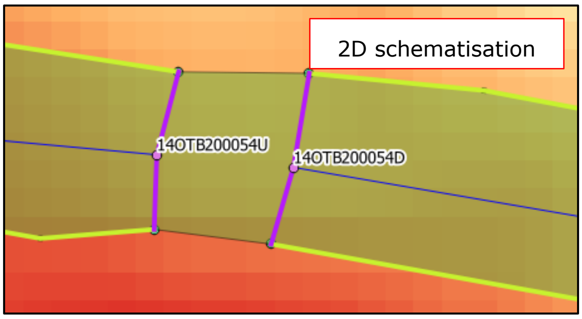
14OTB200054 – RECTANGULAR CULVERT			
US Invert	78.41mOD	DS invert	78.46mOD
Dimensions	Width: 0.53m Height: 0.68m	Length	4.75m
Coefficients	Roughness: 0.02 Spill coefficient: 1.55	Present in model?	Represented in FM 1D using rectangular culvert units
Skew	NA	Overtopping	1D spill unit set to deck level (80.02mOD)
Notes			





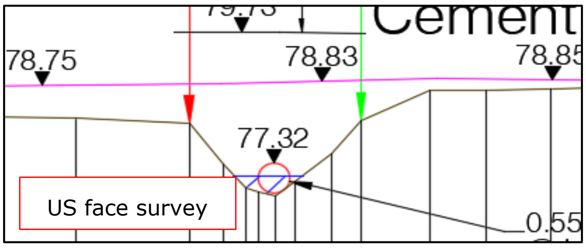


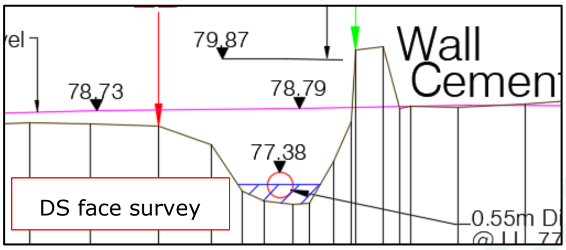
Level (blue) and flow through (red) and over (orange) culvert

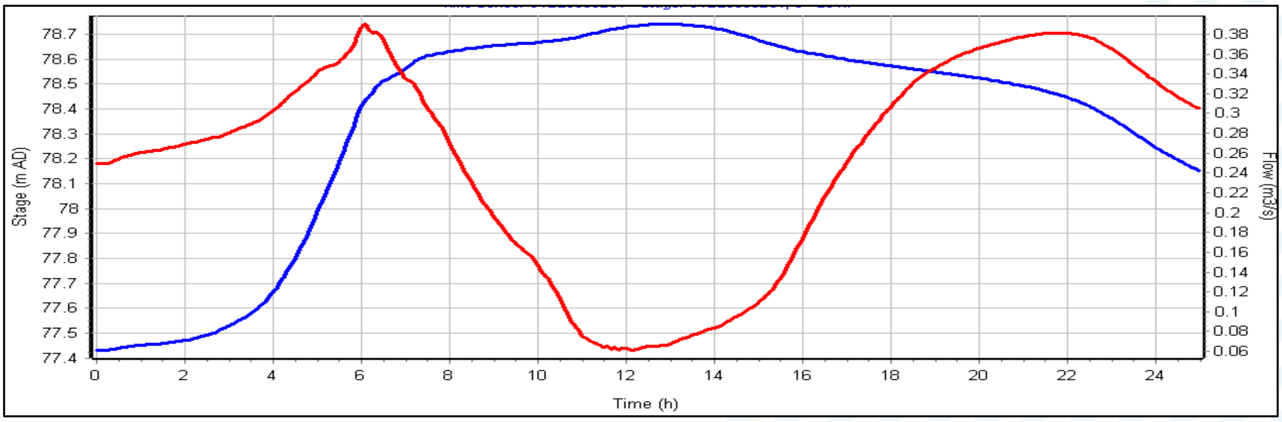


Culvert surcharged causing backwater effect activate spill unit over structure.

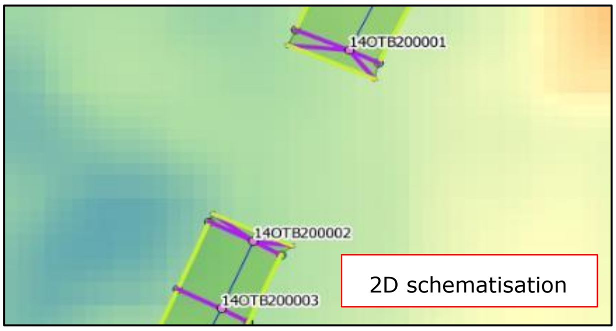
14OTB200002 – CIRCULAR CULVERT			
US Invert	76.77mOD	DS invert	78.83mOD
Dimensions	0.55m diameter	Length	17.46m
Coefficients	Roughness: 0.02 Spill coefficient: 1.55	Present in model?	Represented in FM 1D using circular culvert units
Skew	NA	Overtopping	2D spill via HX lines set to deck level (79.83mOD)
Notes	Wall and DS LHB removed		







Level (blue) and flow (red) through culvert



Culvert is surcharged at peak, out of bank flow occurs upstream and overall flow variations are minimal (max difference 0.32m3/s).

C.10.3 Bridges

There are no bridges along the Owenass Tributary 2 watercourse.

C.11 Owenass Tributary 3 structures (Mountmellick model)

C.11.1 Weirs

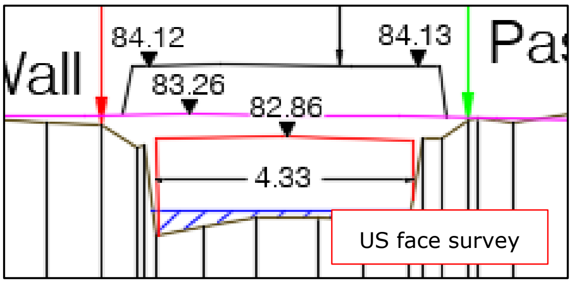
There are no weirs along the Owenass Tributary 3 watercourse.

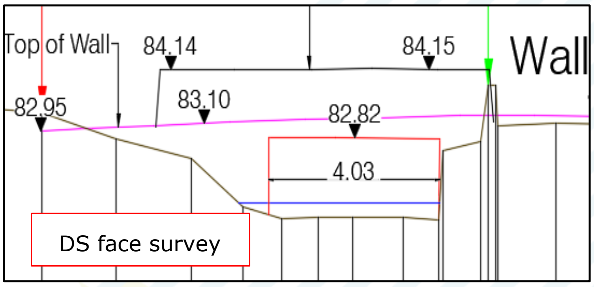
C.11.2 Culverts

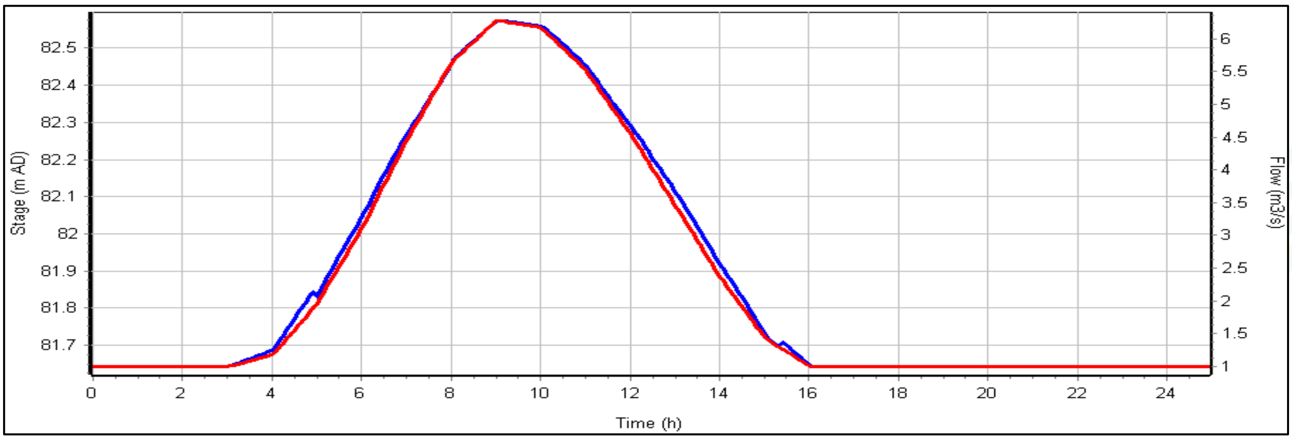
There are no culverts along the Owenass Tributary 3 watercourse.

C.11.3 Bridges

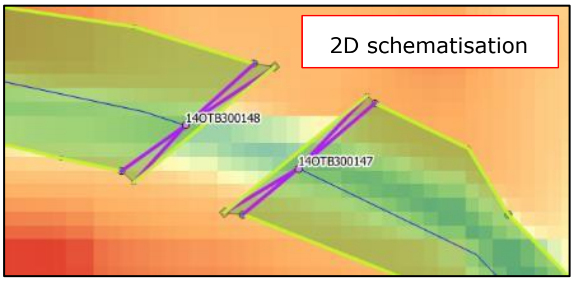
14OTB300148 – RECTANGULAR BRIDGE			
US Invert	81.09mOD	**DS invert**	81.22mOD
Dimensions	Width: 0.4.03m Height: 1.60m	**Length**	8.98m
Coefficients	Roughness: 0.02 Spill coefficient: 1.55	**Present in model?**	Represented in FM 1D using rectangular culvert units due to width length ratio
Skew	NA	**Overtopping**	2D spill via HX lines set to wall level (84.14mOD)
Notes			





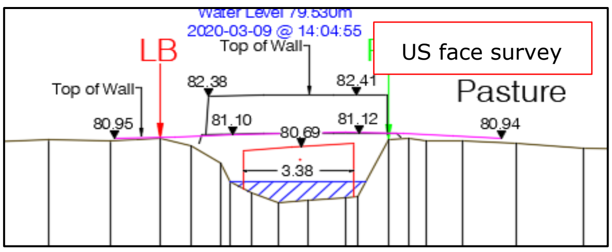


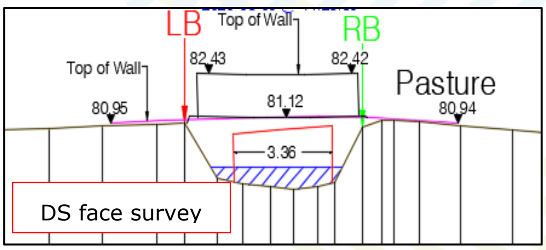
Level (blue) and flow (red) through bridge

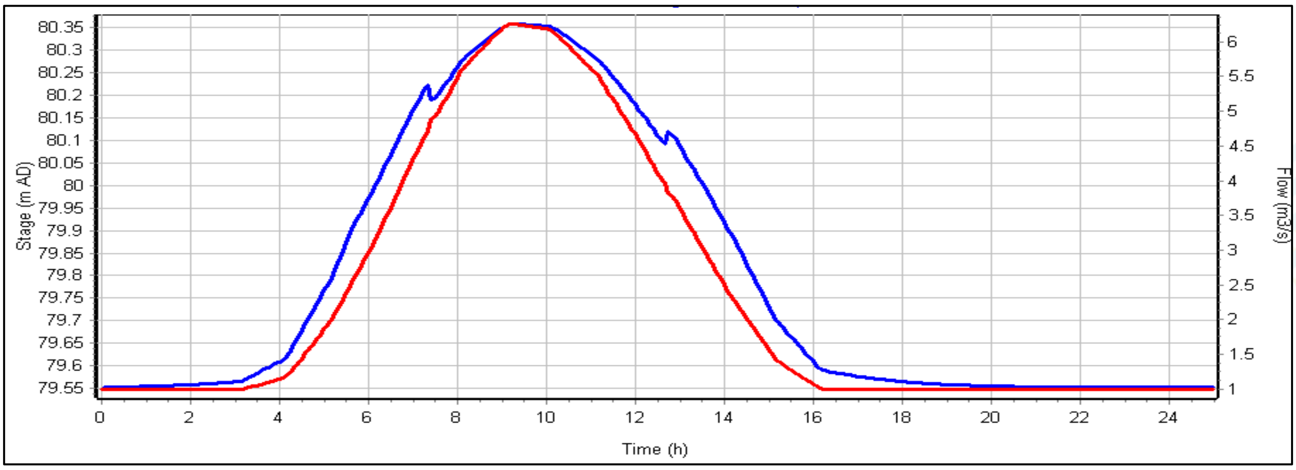


Structure can convey peak flow with no issues.

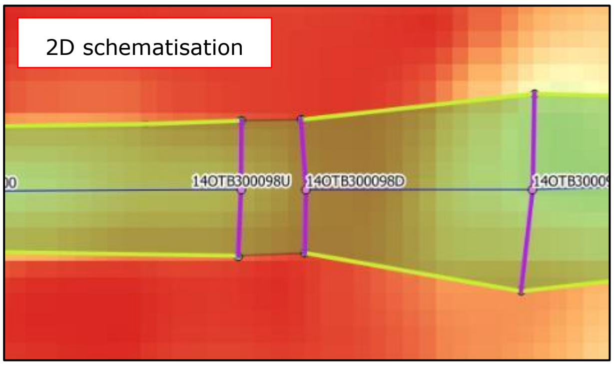
14OTB300098 – RECATANGULAR BRIDGE			
US Invert	78.83mOD	DS invert	78.97mOD
Dimensions	Width: 3.38m Height: 1.86m	Length	3.88m
Coefficients	Roughness: 0.02 Spill weir coefficient: 1.55	Present in model?	Yes, represented in 1D using rectangular culvert units due to length width ratio
Skew	NA	Overtopping	1D spill unit set at deck level (82.12mOD)
Notes			





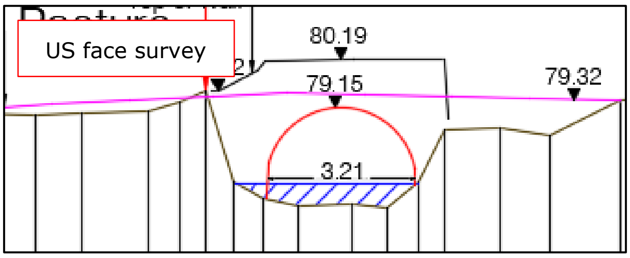


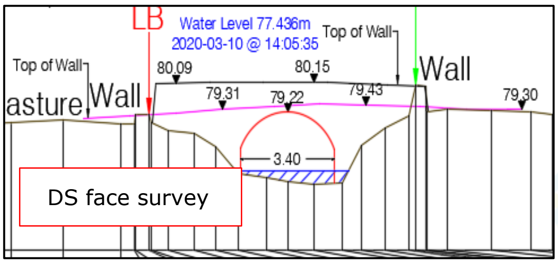
Level (blue) and flow (red) through bridge

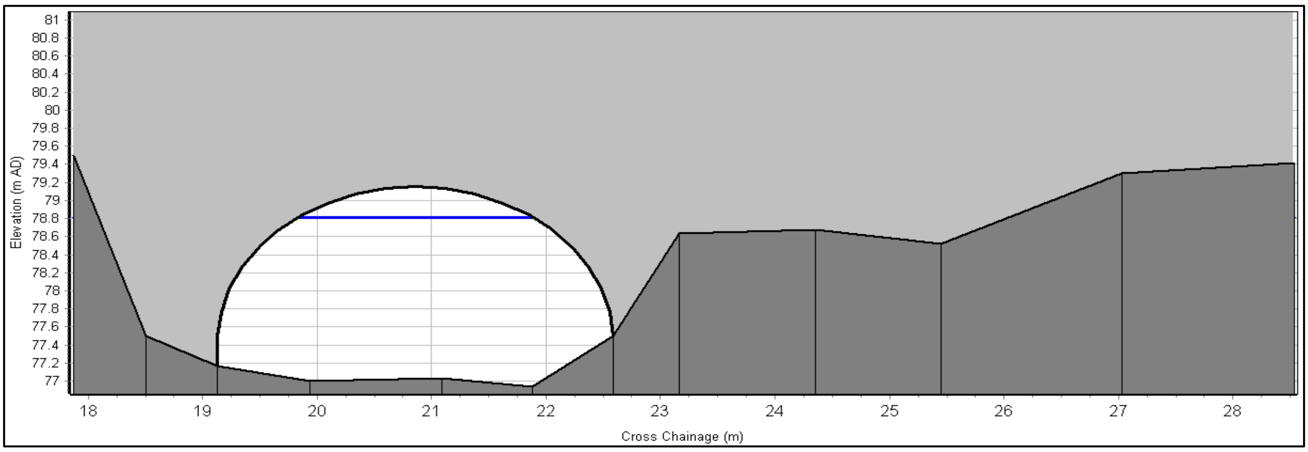


Bridge can convey peak flow.

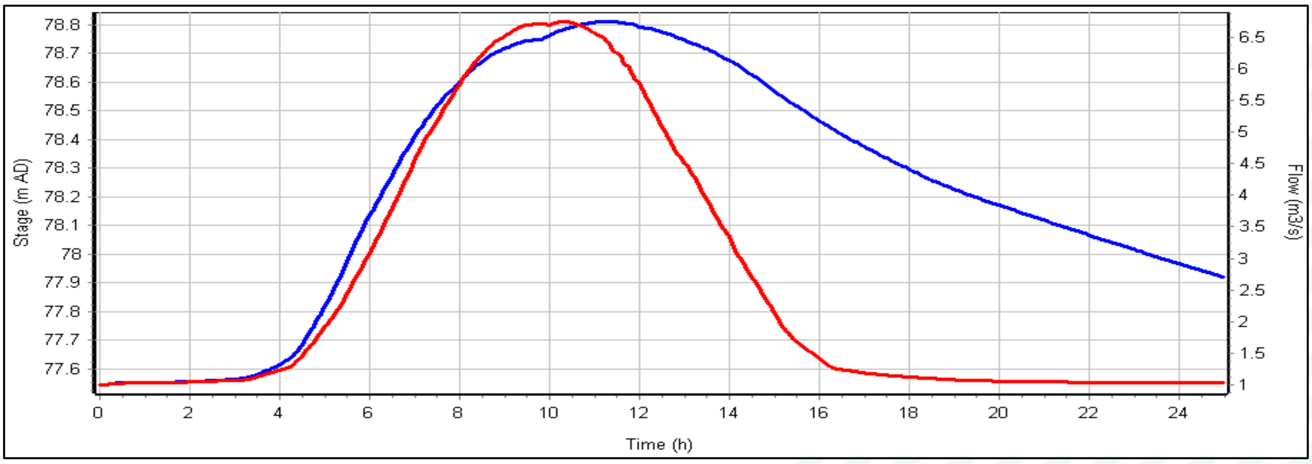
14OTB300036 – ARCH BRIDGE			
Width	3.40m	Length	5.90m
Soffit	79.15mOD	Springing height	77.50mOD
Coefficients	Channel: 0.05 Spill weir coefficient: 1.55	Present in model?	Yes via 1D arch bridge unit
Skew	31.02 degrees	Overtopping	1D spill unit set to wall height (80.09mOD).
Orifice equation used	Yes	Transition distance	0.10m
Notes			



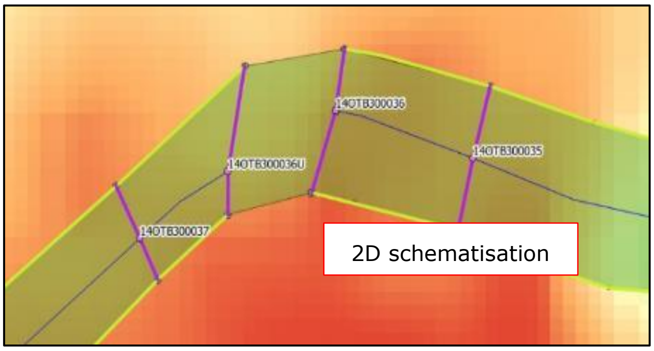




Maximum water level



Level (blue) and flow (red) through bridge



Bridge can convey peak flow with no issues.

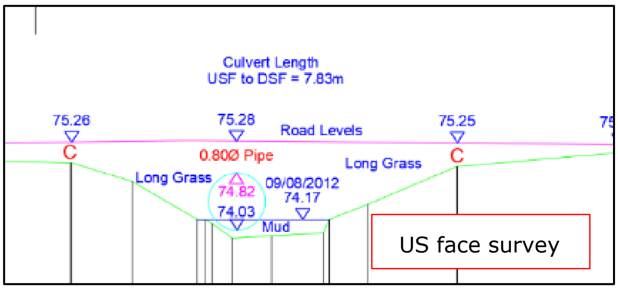
C.12 Wood Stream structures (Mountmellick model)

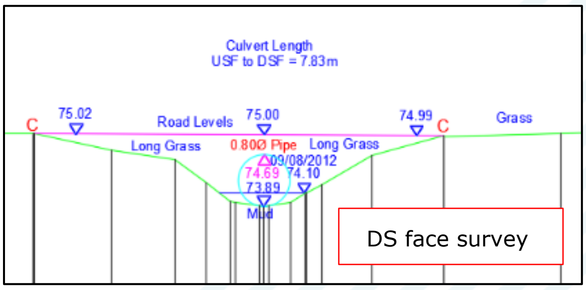
C.12.1 Weirs

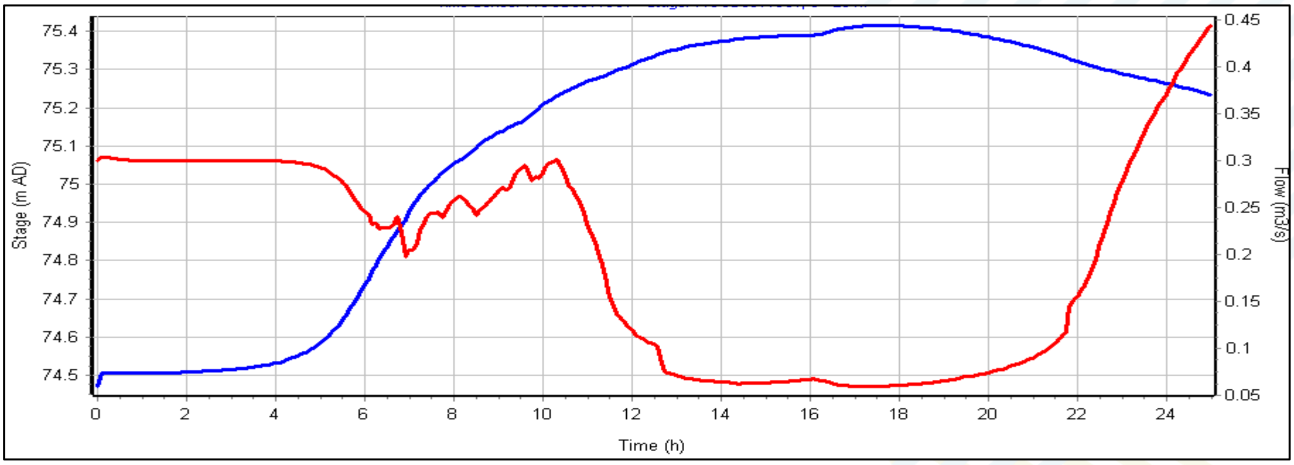
There are no weirs present along the Wood watercourse.

C.12.2 Culverts

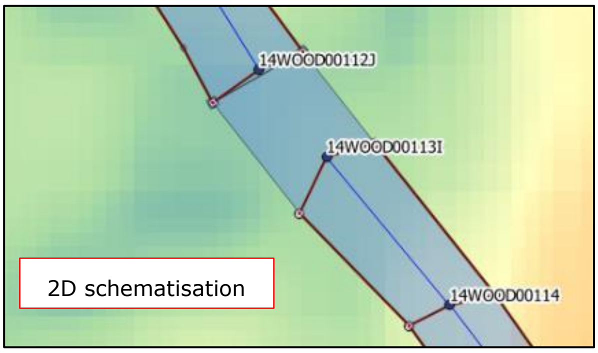
14WOOD00113I-14WOOD00112J – CIRCULAR CULVERT			
US Invert	74.03mOD	DS invert	73.89mOD
Dimensions	0.80m diameter	Length	7.83m
Coefficients	Roughness: 0.02 Spill weir coefficient: 1.40	Present in model?	Yes, represented in 1D using circular culvert unit
Skew	NA	Overtopping	1D spill unit set to road level (75.19mOD)
Notes			





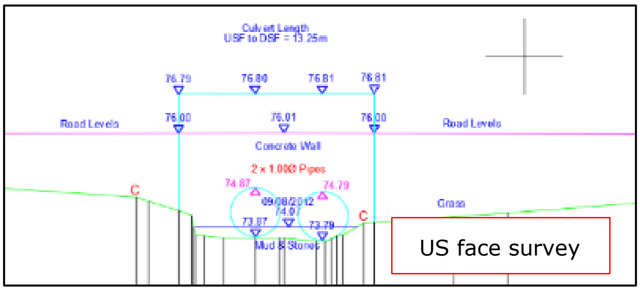


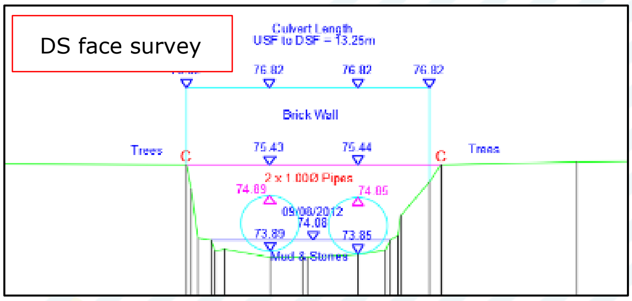
Level (blue) and flow (red) through culvert

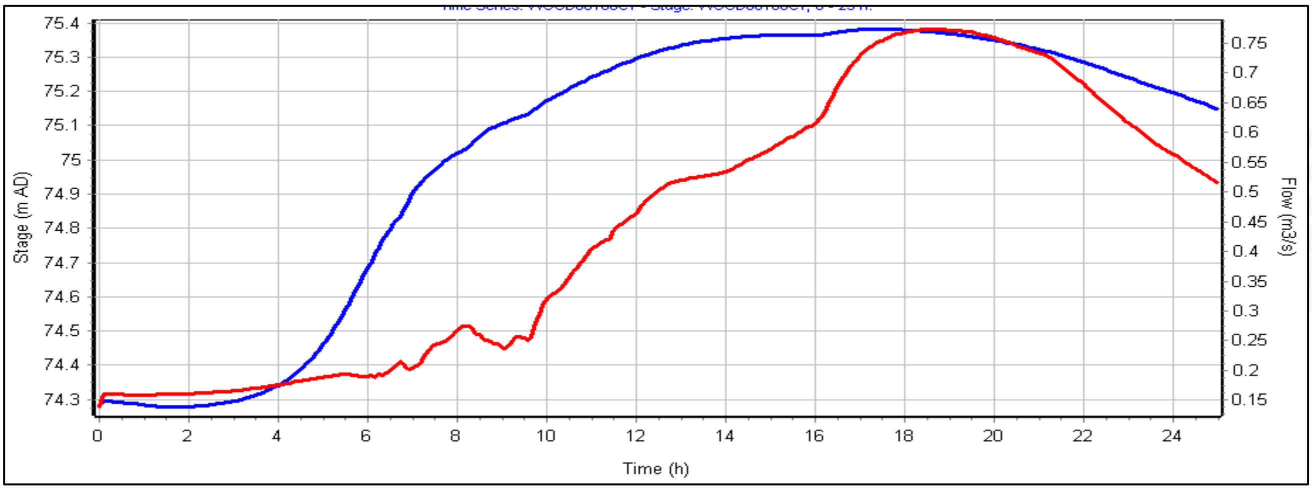


Culvert is drowned at peak – flow essentially drops to zero at peak due to lack of headloss across the structure

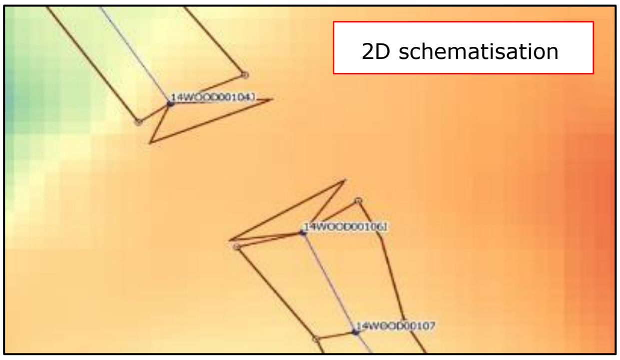
14WOOD00106I-14WOOD00104C – DOUBLE CIRCULAR CULVERT			
US Invert	(C1) 73.87mOD, (C2)73.79mOD	**DS invert**	(C1) 73.89mOD, (C2)73.85mOD
Diameter	1.00m diameter each	**Length**	13.25m
Coefficients	Roughness: 0.02 Spill weir coefficient: 1.40	**Present in model?**	Yes represented in 1D using circular culvert units
Skew	NA	**Overtopping**	2D spill via HX lines set to height of wall (76.80mOD)
Notes			







Level (blue) and flow (red) through culvert



Culvert is drowned at peak. The flow hydrograph on the rising limb is not completely smooth as a result of small changes in the relatively minor head loss across the culvert.

C.12.3 Bridges

There are no bridges present along the Wood watercourse.

C.13 Clontygar A Stream structures (Mountmellick model)

C.13.1 Weirs

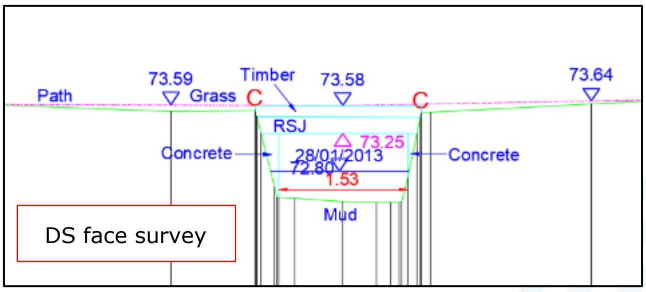
There are no weirs along the Clontygar A watercourse.

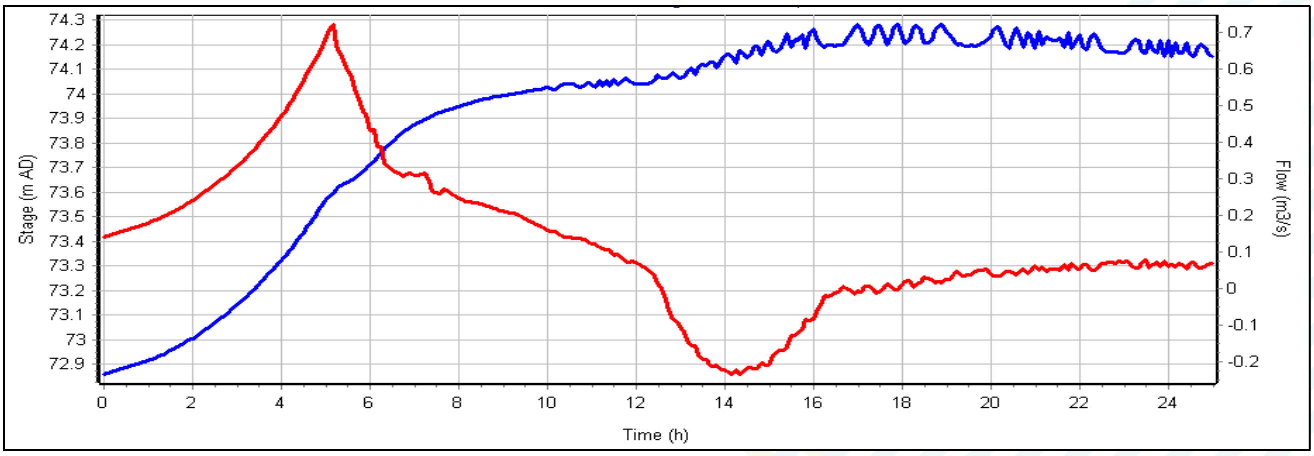
C.13.2 Culverts

There are no culverts along the Clontygar A watercourse.

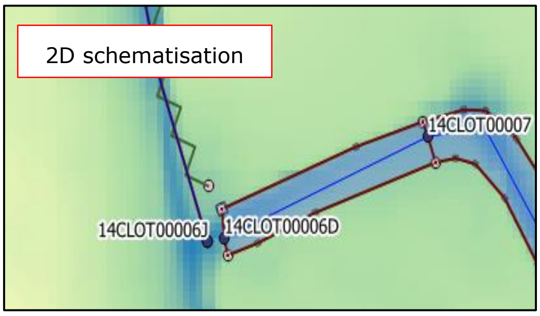
C.13.3 Bridges

14CLOT00006D – RECTANGULAR BRIDGE			
US Invert	72.44mOD	**DS invert**	72.44mOD
Dimensions	Width: 1.53m, Height: 0.81m	**Length**	3.47m
Coefficients	Roughness: 0.02 Spill weir coefficient: 1.40	**Present in model?**	Yes represented in 1D using rectangular culvert units due to length width ratio of structure
Skew	NA	**Overtopping**	1D spill unit set at bridge deck level (73.58mOD)
Notes			



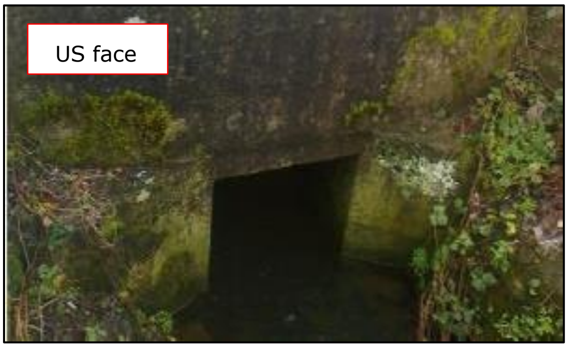


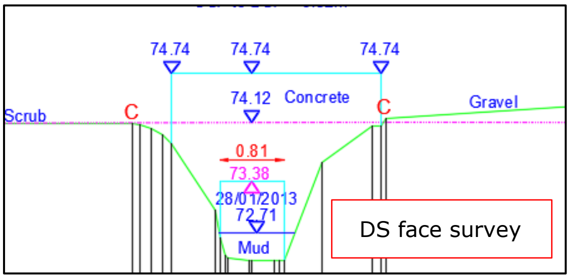
Level (blue) and flow (red) through bridge

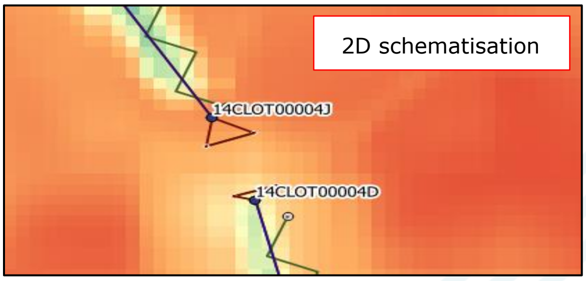


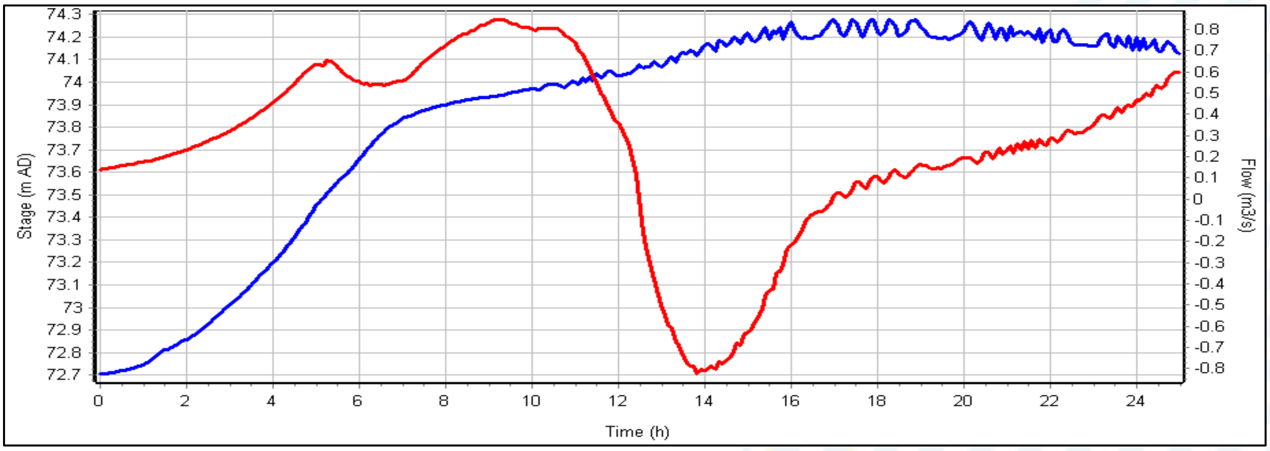
Bridge is completely drowned at the peak due to influx of water from the floodplain. Flow through the structure drops as water increases above the bridge reducing the head difference, water level fluctuates as the flood waters move through the area.

14CLOT00004D – RECTANGULAR BRIDGE			
US Invert	72.35mOD	**DS invert**	72.35mOD
Dimensions	Width: 0.81m, Height: 1.03m	**Length**	9.32m
Coefficients	Roughness: 0.02 Spill weir coefficient: 1.40	**Present in model?**	Yes represented in 1D using rectangular culvert units due to length width ratio of structure
Skew	NA	**Overtopping**	2D spill via HX lines set to wall height (74.74mOD)
Notes	Only DS face surveyed		





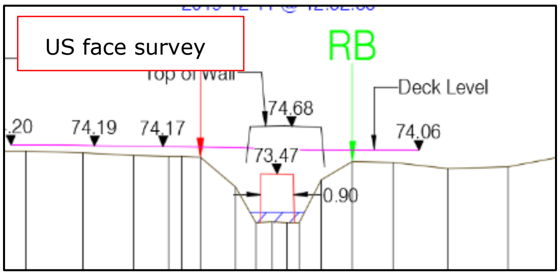


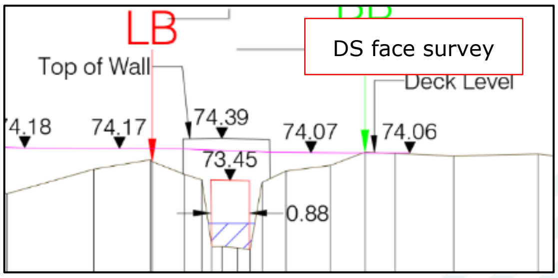


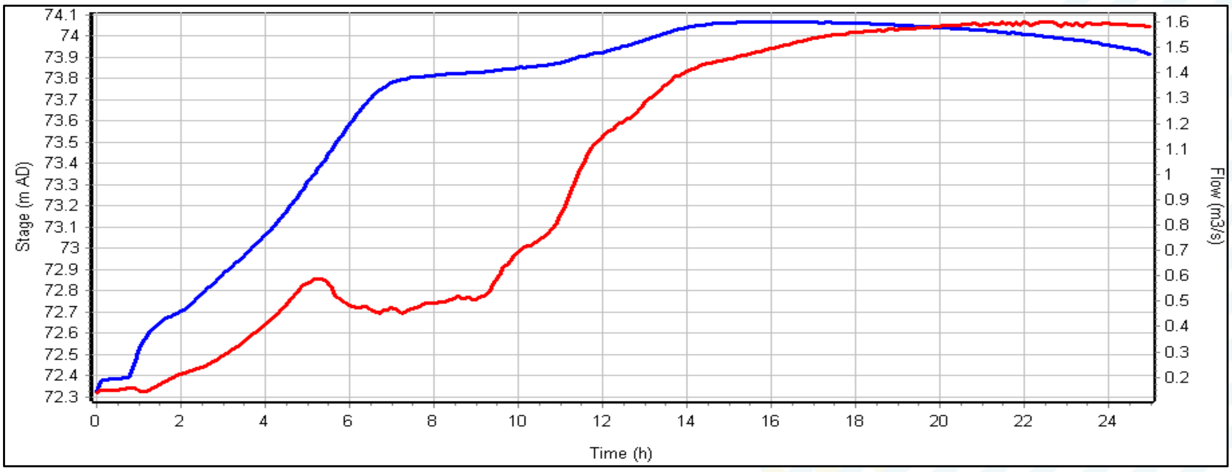
Level (blue) and flow (red) through bridge

Bridge is completely drowned at peak of the event. Flow decreases as flood waters from the Owenass back up the channel and over the floodplain. Level fluctuates as water flows across the structure and area.

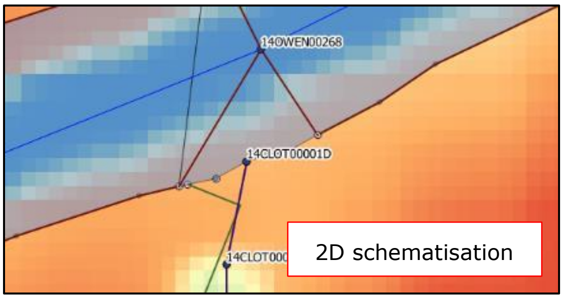
14CLOT00001D – RECTANGULAR BRIDGE			
US Invert	72.22mOD	**DS invert**	71.94mOD
Dimensions	Width: 0.9m Height: 1.25m	**Length**	7.70m
Coefficients	Roughness: 0.02 Spill weir coefficient: 1.55	**Present in model?**	Represented in 1D using rectangular culvert units
Skew	NA	**Overtopping**	1D spill set to deck level (74.07mOD)
Notes	General loss unit applied at DS of culvert instead of culvert outlet unit to help with backflow and stability. Loss applied: 1.00. Wooden planks on US face not included (not in survey data).		







Level (blue) and flow (red) through bridge



Bridge is submerged at peak – flow shows some minor fluctuations as water from the Owenass enters the Clontygar system.

C.14 Clontygar Stream B structures (Triogue model)

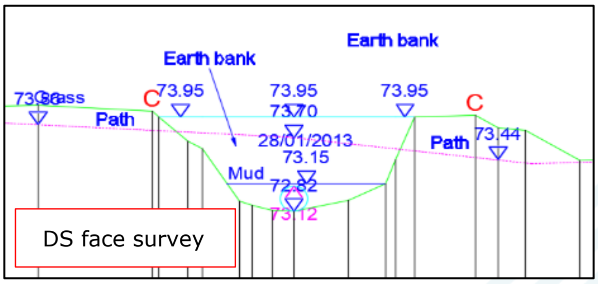
The Clontygar stream watercourse has been modelled in ESTRY (1D TUFLOW component) due to the steep channel gradient is more stable when modelled in ESTRY than FM.

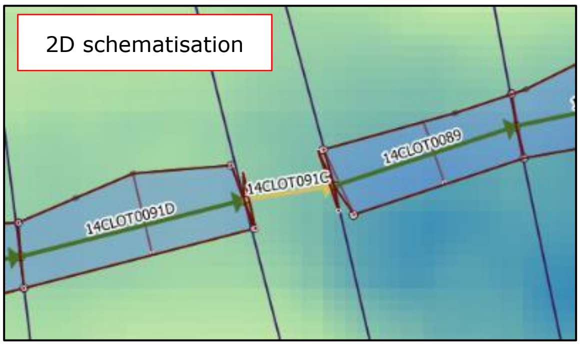
C.14.1 Weirs

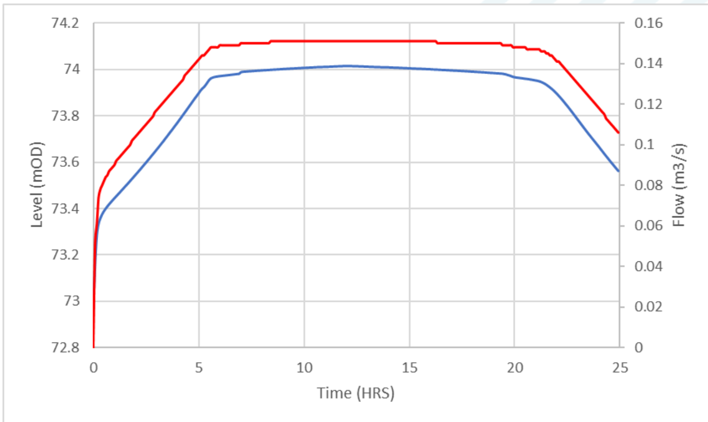
There are no weirs along the Clontygar B watercourse.

C.14.2 Culverts

14CLOT00091D – CIRCULAR CULVERT			
US Invert	72.82mOD	**DS invert**	72.82mOD
Dimensions	0.30m diameter	**Length**	4.68m
Coefficients	Roughness: 0.02	**Present in model?**	Yes, represented in ESTRY 1D using circular culvert unit
Skew	NA	**Overtopping**	2D spill via HX points/line set to deck level (73.95mOD)
Notes			



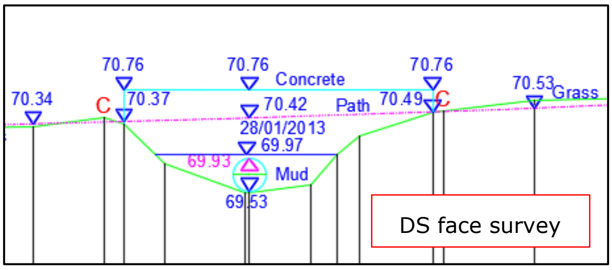


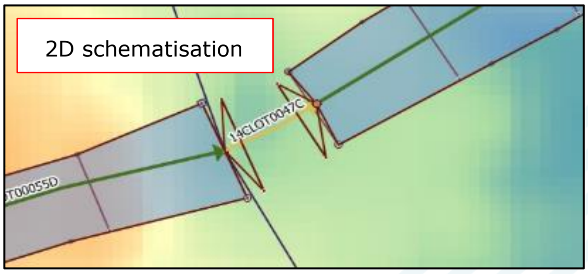


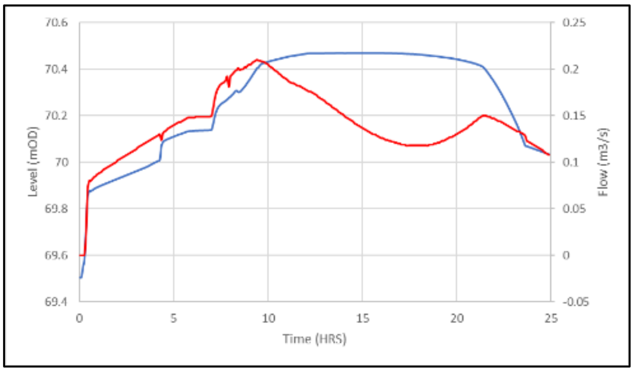
Stage (blue) and Flow (red) through culvert

Culvert is drowned at peak of event – watercourse subject to backwater effect from flooding downstream

14CLOT00055D – CIRCULAR CULVERT			
US Invert	72.82mOD	**DS invert**	72.82mOD
Dimensions	0.40m diameter	**Length**	3.96m
Coefficients	Roughness: 0.02	**Present in model?**	Yes, represented in ESTRY 1D using circular culvert unit
Skew	NA	**Overtopping**	2D spill via HX points/lines set to height of wall (7076mOD)
Notes	US and DS face recorded as the same.		







Culvert is drowned at peak of event. Level and flow instabilities also noted and appear to relate to change in slope at upstream extent of structure.

C.14.3 Bridges

There are no bridges along the Clontygar B watercourse.

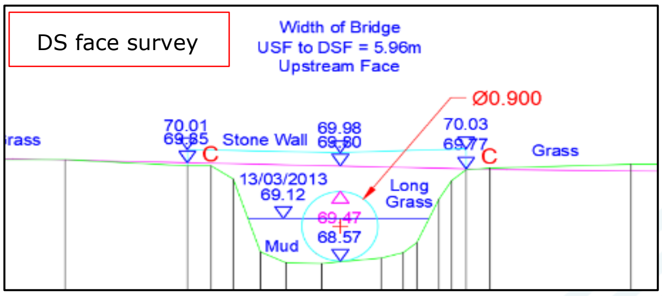
C.15 Run off drain structures (Triogue model)

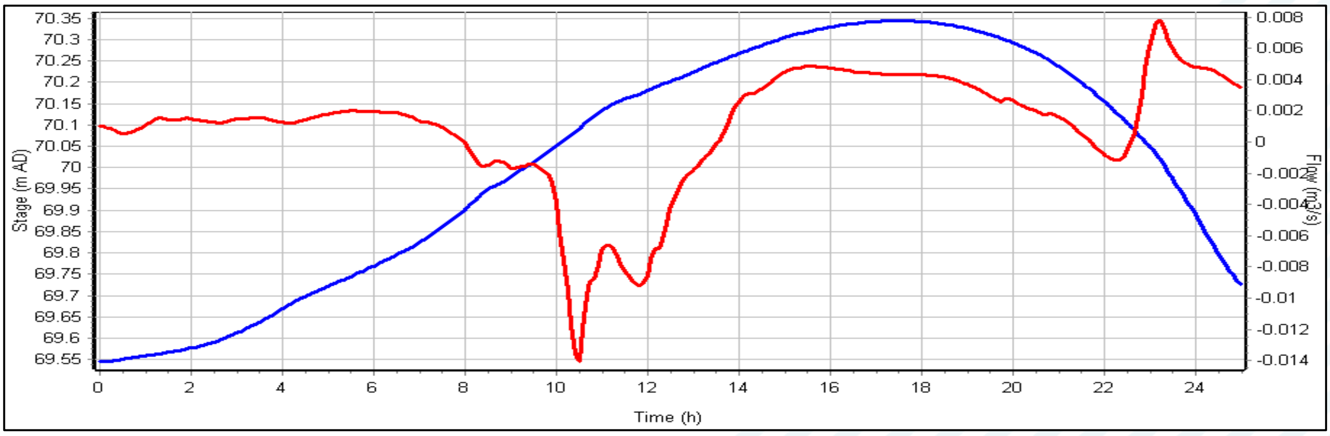
C.15.1 Weirs

There are no weirs along the Run off drain watercourse.

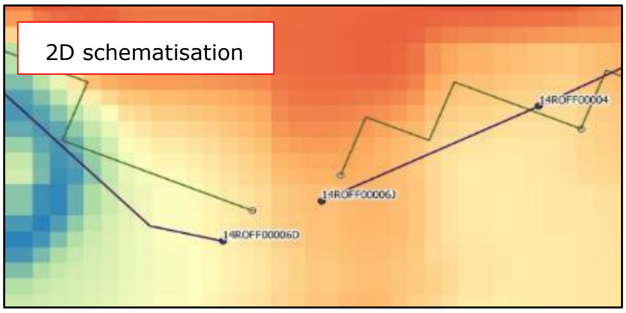
C.15.2 Culverts

14ROFF00006D – CIRCULAR CULVERT			
US Invert	68.57mOD	**DS invert**	68.48mOD
Dimensions	0.90m diameter	**Length**	5.96m
Coefficients	Roughness: 0.02 Spill weir coefficient: 1.60	**Present in model?**	Yes, represented in FM 1D using circular culvert units
Skew	NA	**Overtopping**	1D spill unit set at height of stone wall (69.98mOD)
Notes	Only DS face surveyed General loss applied instead of culvert inlet/outlet units to help with stability and back flow. US loss = 0.50, DS loss = 1.00		





Level (blue) and flow (red) through culvert



Culvert is drowned during the peak of the event due to flood waters ponding in the area. Flow variation is minimal (maximum flow difference is 0.022m3/s)

C.15.3 Bridges

There are no bridges present along the Run off drain watercourse.

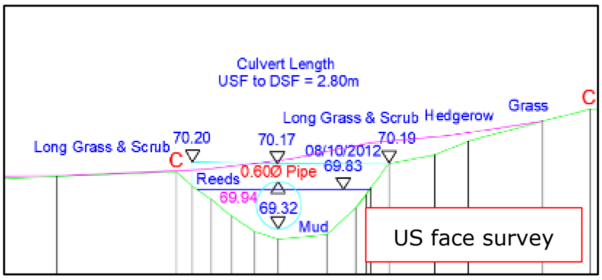
C.16 Ballyculbeg Stream structures (Triogue model)

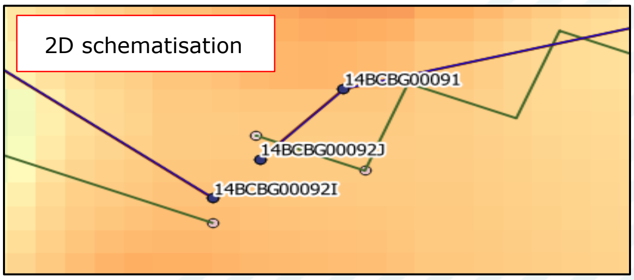
C.16.1 Weirs

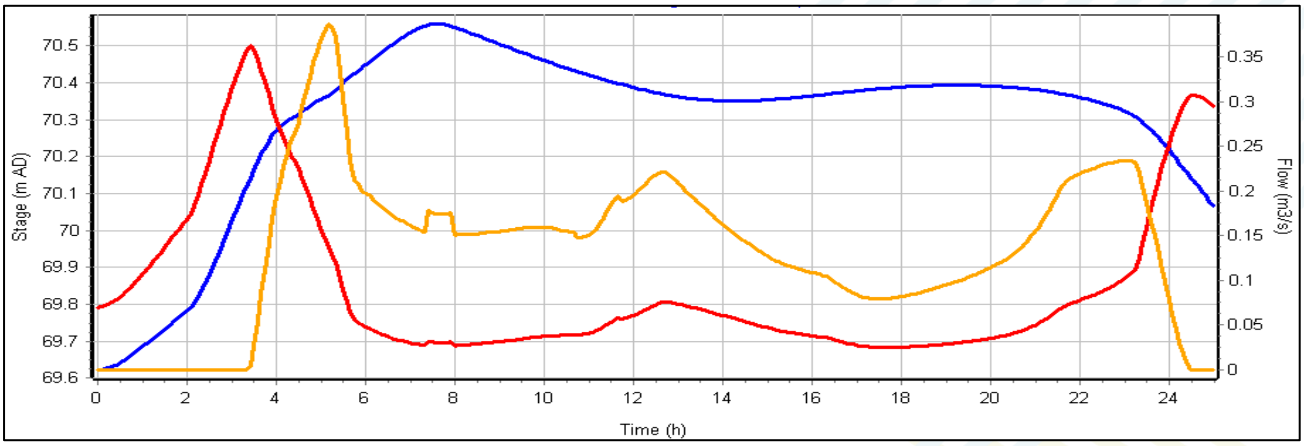
There are no weirs along the Ballyculbeg watercourse.

C.16.2 Culverts

14BCBG00092I – CIRCULAR CULVERT			
US Invert	69.32mOD	DS invert	69.32mOD
Dimensions	0.60m diameter	Length	2.80m
Coefficients	Roughness: 0.02 Spill weir coefficient: 1.60	Present in model?	Yes, represented in 1D using circular culvert unit
Skew	NA	Overtopping	1D spill unit set at deck level (70.17mOD)
Notes	Only US face surveyed. General loss unit applied at US and DS of culvert instead of culvert inlet/outlet unit to help with backflow and stability. Loss applied: US 0.5, DS 1.00		



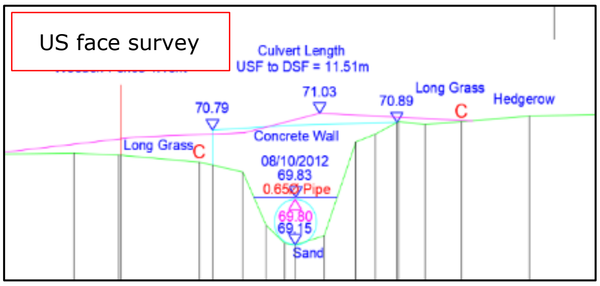


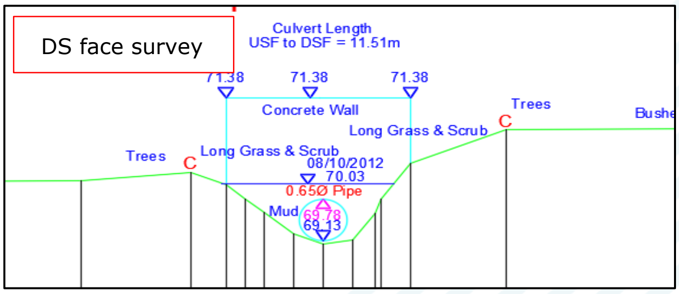


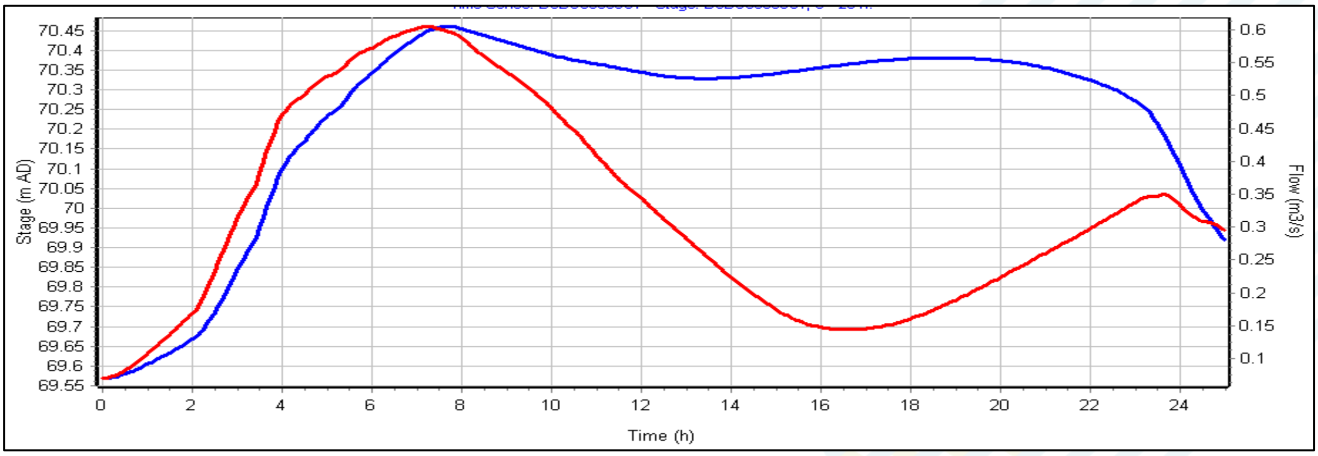
Level (blue) and flow through (red) and over (orange) the culvert

Culvert is drowned at peak of the event with large amounts of spill occurring up and downstream of the structure. Flow drops as the culvert is drowned and the flow gradient decreases.

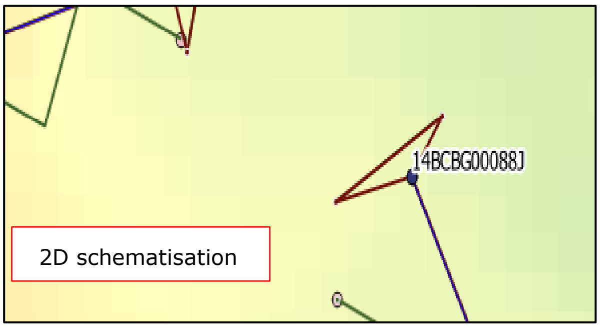
14BCBG00089I-14BCBG00088J – CIRCULAR CULVERT			
US Invert	69.15mOD	**DS invert**	69.13mOD
Dimensions	0.65m diameter	**Length**	11.51m
Coefficients	Roughness: 0.02	**Present in model?**	Yes, represented in 1D using circular culvert unit
Skew	NA	**Overtopping**	2D spill via HX lines set at height of stone wall (71.38mOD)
Notes	General loss unit applied at US and DS of culvert instead of culvert inlet/outlet unit to help with backflow and stability. Loss applied: US 0.5, DS 1.00		





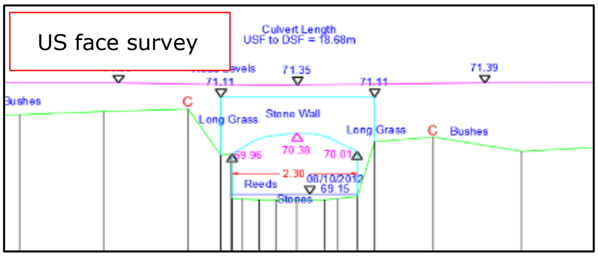


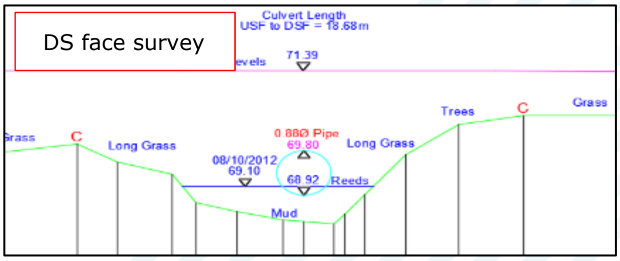
Level (blue) and flow (red) through culvert

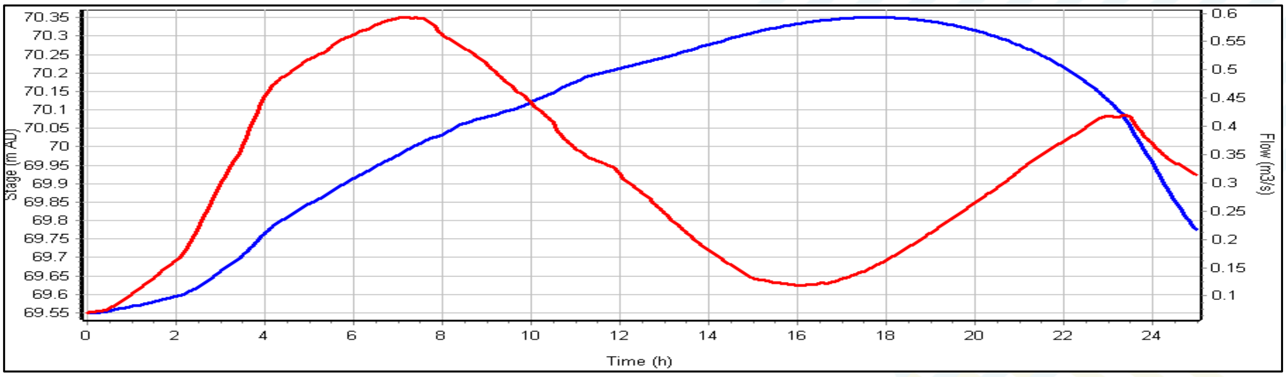


Culvert is drowned at peak of the event. Flow through culvert is drops due to drowning and backwater impacts from the Triogue.

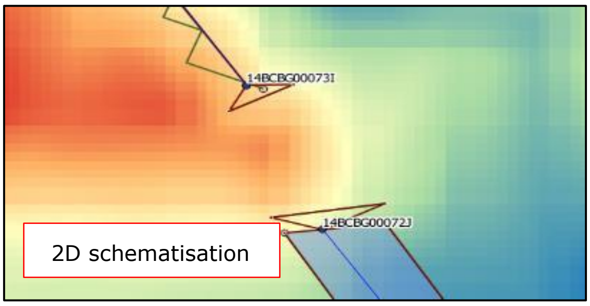
14BCBG00073I-14BCBG00072J – CIRCULAR CULVERT			
US Invert	69.03mOD	**DS invert**	68.92mOD
Dimensions	0.88m diameter	**Length**	18.68m
Coefficients	Roughness: 0.02	**Present in model?**	Yes, represented in 1D using circular culvert unit
Skew	NA	**Overtopping**	2D spill via HX lines set at height of wall (71.38mOD)
Notes	US and DS face of culvert different – used DS face as it has smaller conveyance area and will control flow through the structure. General loss unit applied at US and DS of culvert instead of culvert inlet/outlet unit to help with backflow and stability. Loss applied: US 0.5, DS 1.00		







Level (blue) and flow (red) through culvert

	Culvert is drowned at the peak of the event; flow drops at peak due to backwater flow from the Triogue travelling up the watercourse. Culvert is inundated with flood water from the 2D floodplain as well.

C.16.3 Bridges

There are no bridges present on the Ballyculbeg watercourse.

C.17 Triogue River structures (Triogue model)

C.17.1 Weirs

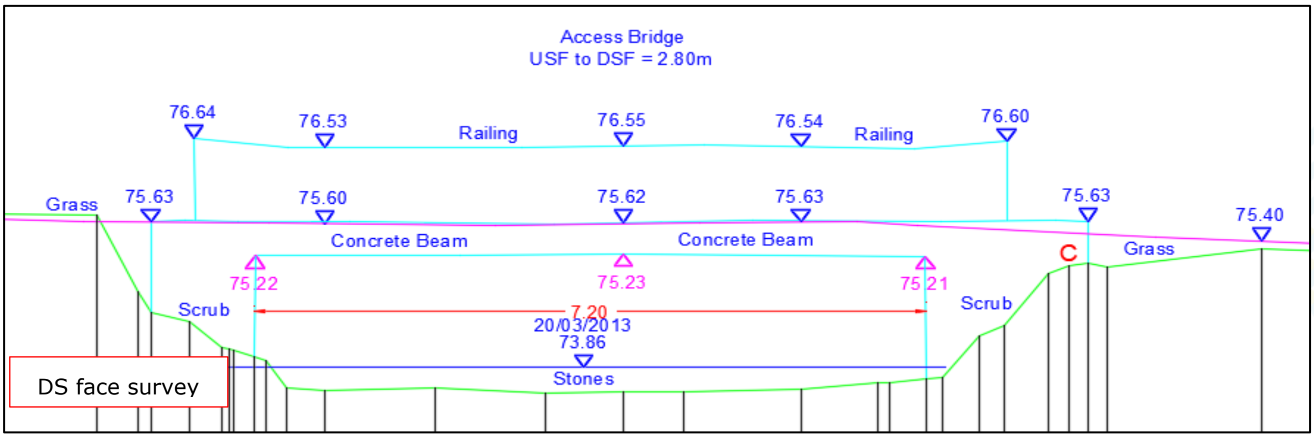
There are no weirs along the Triogue watercourse.

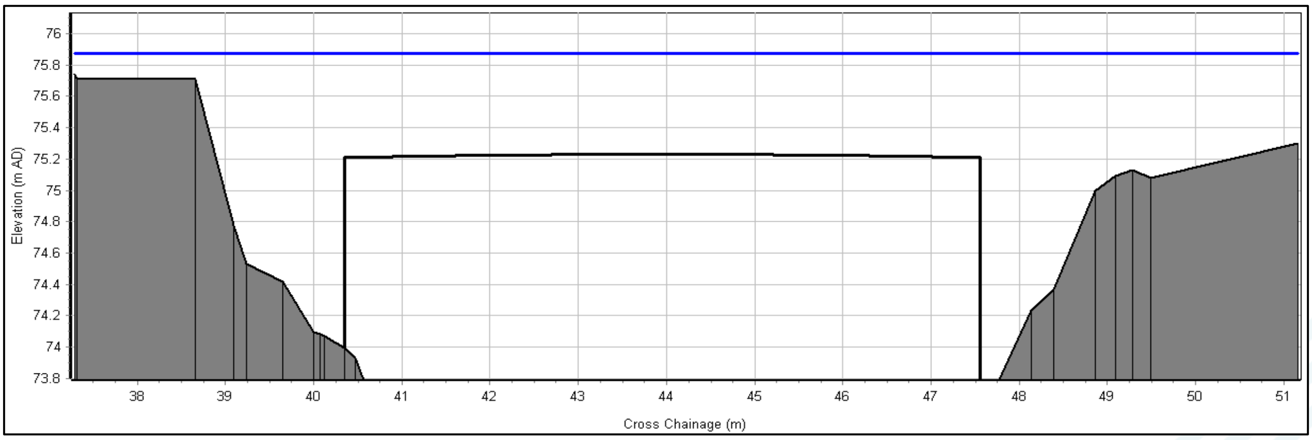
C.17.2 Culverts

There are no culverts along the Triogue watercourse.

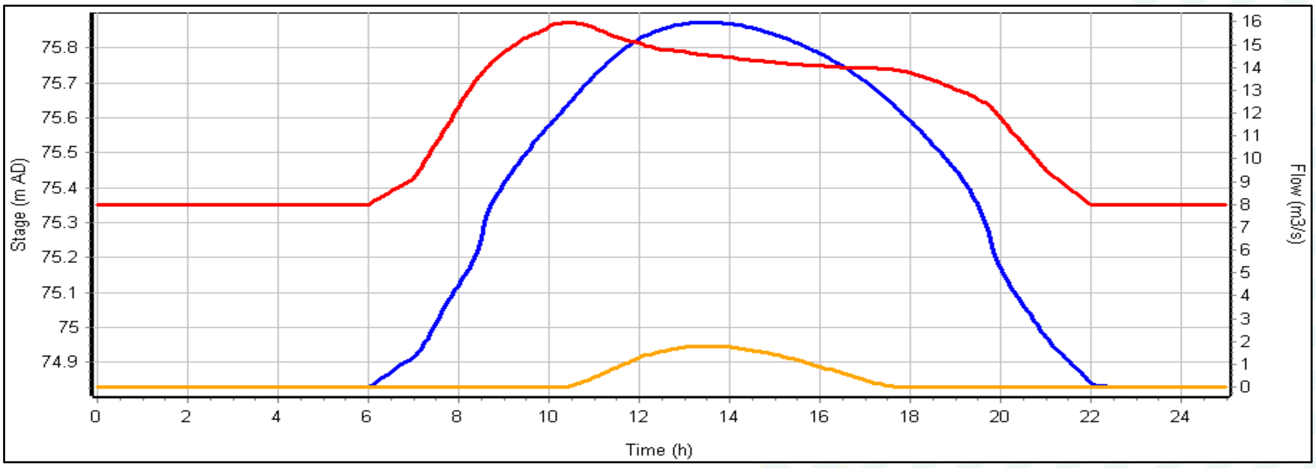
C.17.3 Bridges

14TRIO00746D –RECTANGULAR BRIDGE			
Width	7.20m	**Length**	2.80m
Soffit	75.23mOD	**Springing height**	75.21mOD
Coefficients	Channel roughness: 0.04, Spill weir coefficient: 1.55	**Present in model?**	Yes via 1D rectangular bridge unit
Skew	NA	**Overtopping**	1D spill set at deck level (75.36mOD)
Orifice Eqtn used	Yes	**Transition distance**	0.10m
Notes	Only DS face surveyed		
			

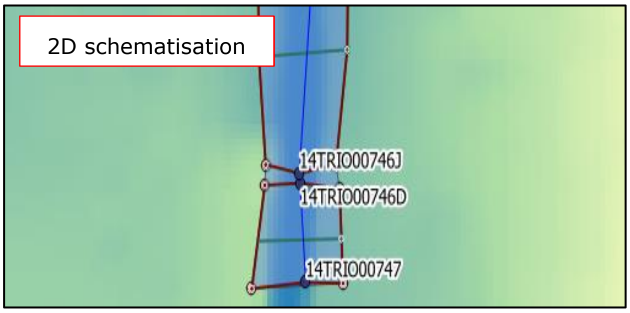




Maximum water level

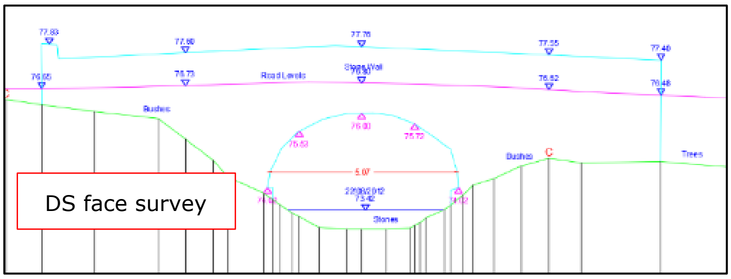


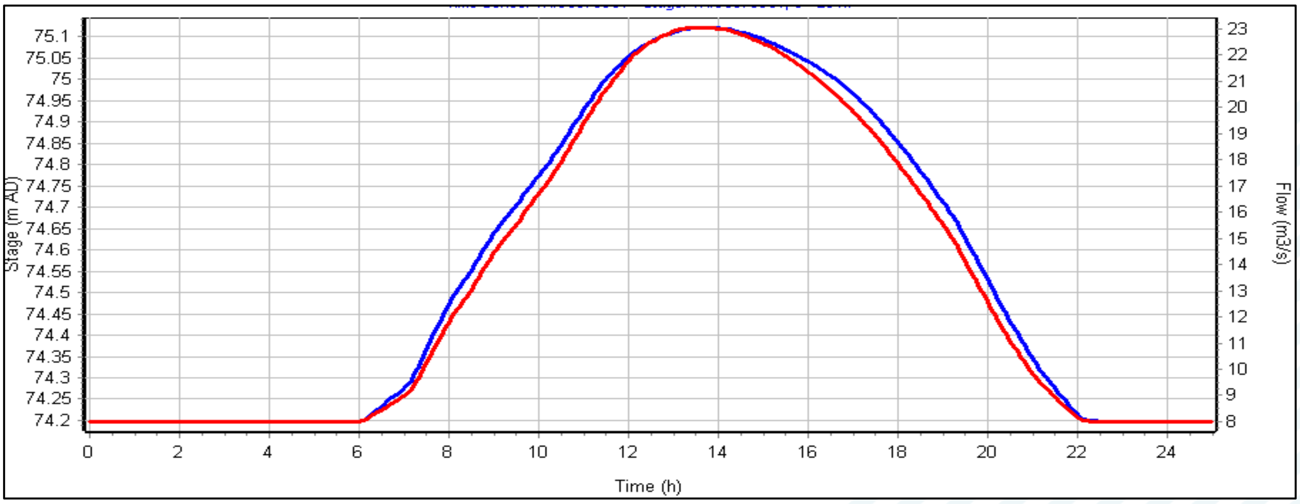
Level (blue) and flow through (red) and over (orange) bridge



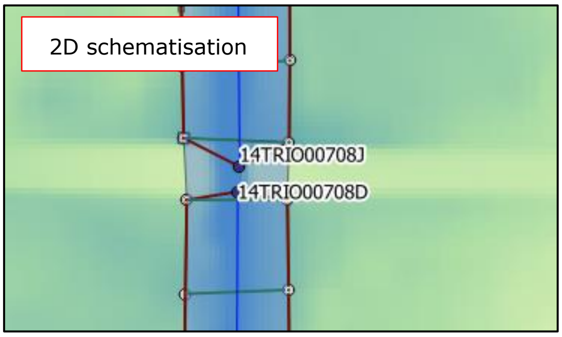
Bridge is overtopped during the peak of the event and flow bypassing is occurring as water in the floodplain circles around the bridge.

14BCBG00708D – ARCHED BRIDGE			
US Invert	72.91mOD	**DS invert**	72.91mOD
Dimensions	Max width: 5.07m Max height: 3.10m	**Length**	8.21m
Coefficients	Roughness: 0.02 Spill weir coefficient: 1.55	**Present in model?**	Yes, represented in 1D using irregular culvert unit due to length width ratio of channel and structure
Skew	NA	**Overtopping**	1D spill set to height of stone wall (min height 77.55mOD)
Notes	Only DS face surveyed		



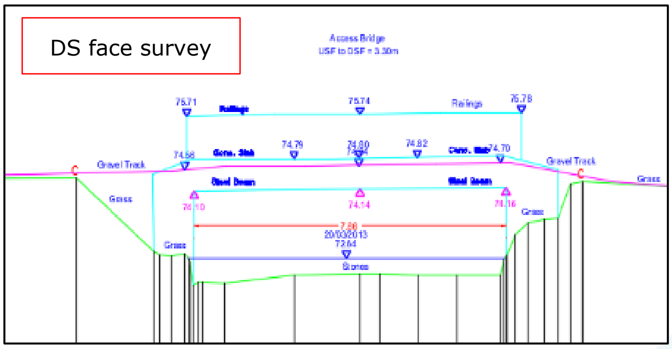


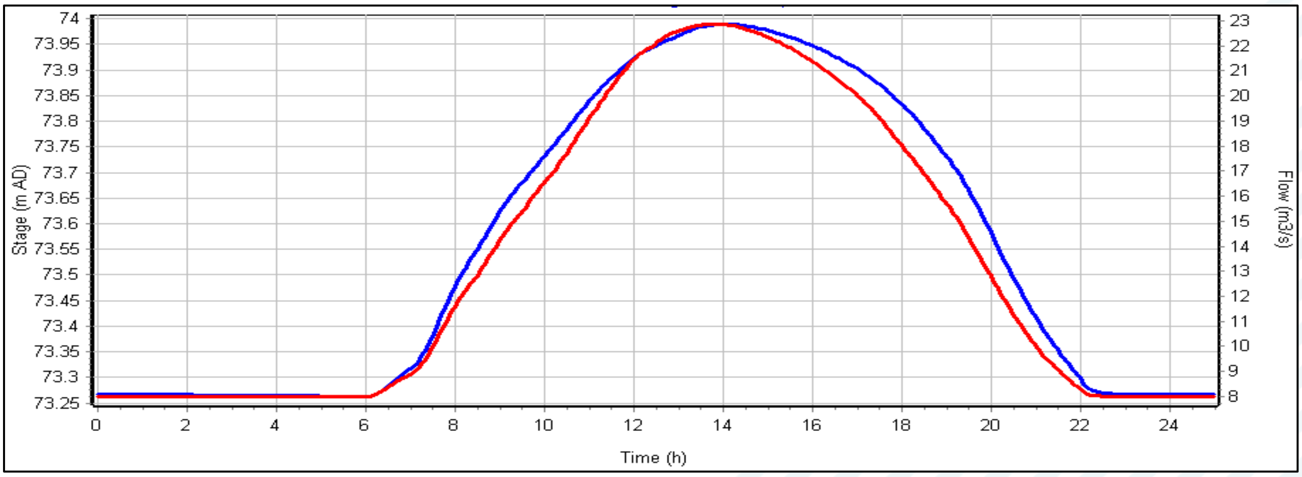
Level (blue) and flow (red) through bridge



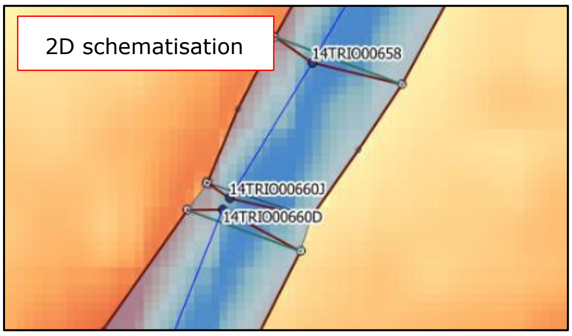
Bridge can convey flow however spill upstream results in flow bypassing the structure, so the total peak flow does not pass through the bridge.

14TRIO00660D – RECTANGULAR BRIDGE			
Width	7.66m	Length	3.30m
Soffit	74.16mOD	Springing height	74.10mOD
Coefficients	Channel roughness: 0.04, Spill weir coefficient: 1.40	Present in model?	Yes via 1D rectangular bridge unit
Skew	NA	Overtopping	1D spill unit set to deck level (74.38mOD)
Orifice Eqtn used	Yes	Transition distance	0.10m
Notes	Only DS face surveyed		



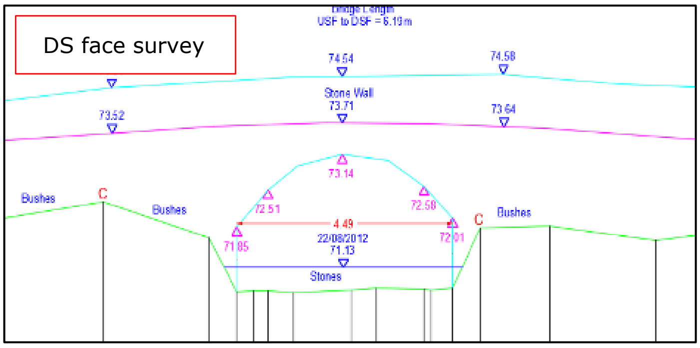


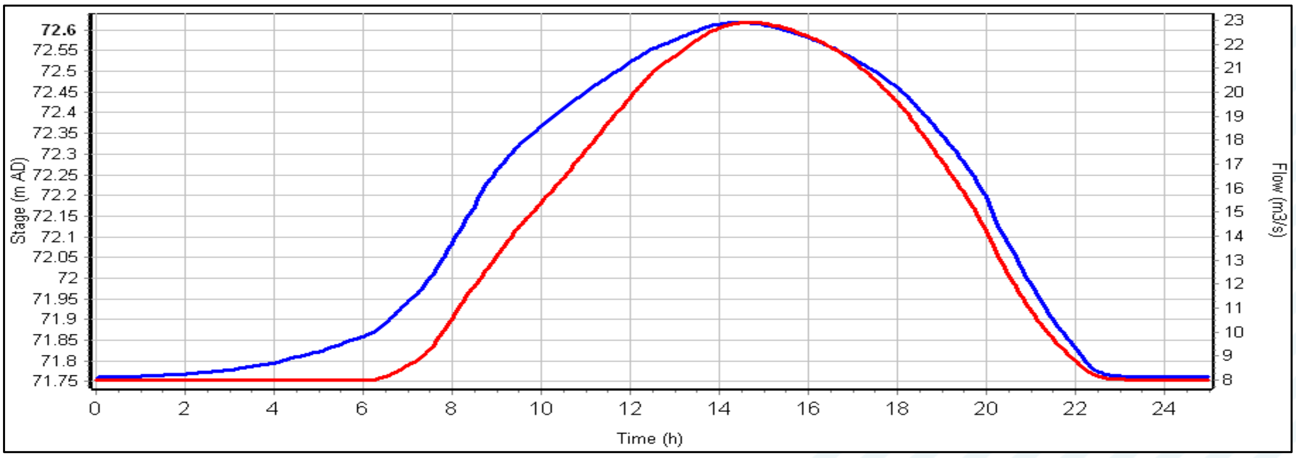
Level (blue) and flow (red) through bridge



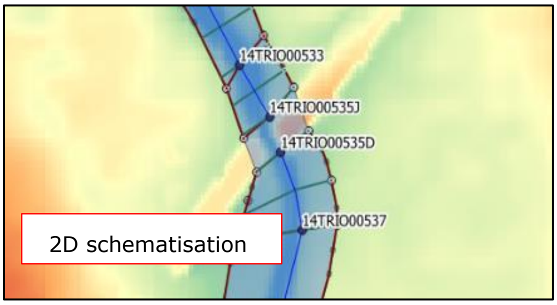
Bridge can convey peak flow.

14TRIO00535D – ARCHED BRIDGE			
Width	4.49m	**Length**	6.19m
Soffit	73.14mOD	**Springing height**	71.85mOD
Coefficients	Channel roughness: 0.04, Spill weir coefficient: 1.40	**Present in model?**	Yes via 1D arched bridge unit
Skew	NA	**Overtopping**	1D spill unit set to height of stone wall (73.57mOD)
Orifice Eqtn used	Yes	**Transition distance**	0.10m
Notes	Only DS face surveyed		



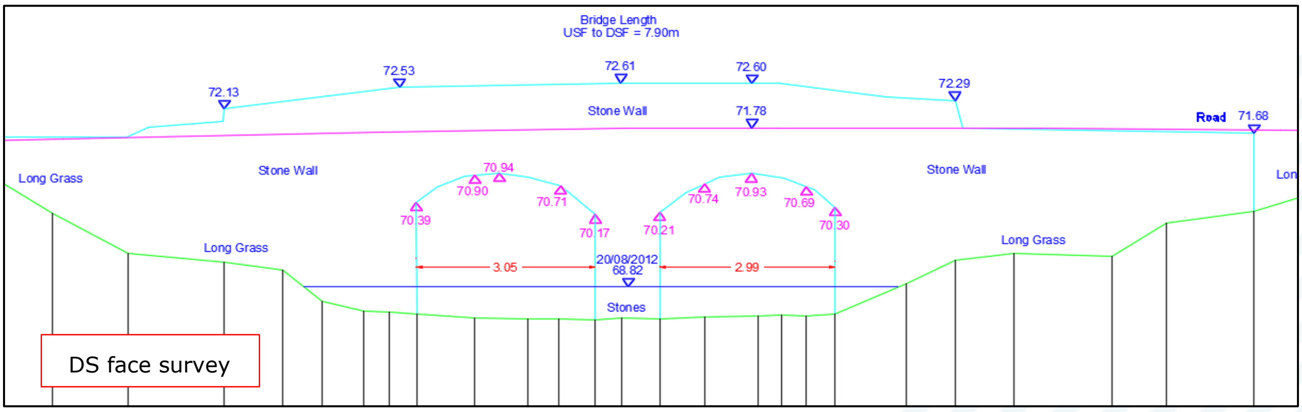


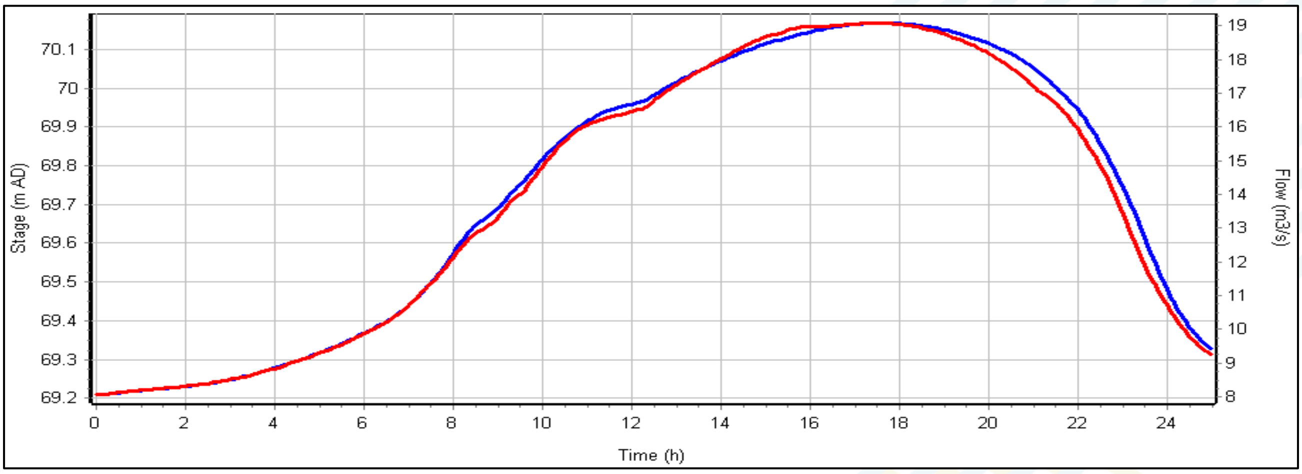
Level (blue) and flow (red) through bridge



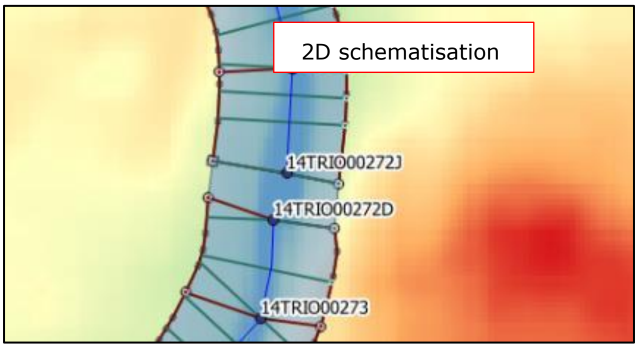
Flow is conveyed through bridge. Out of bank flow occurs up and downstream of structure resulting in flow bypassing bridge.

14TRIO00272D – ARCHED BRIDGE			
Width	Opening 1: 3.05m Opening 2: 2.99m	**Length**	7.90m
Soffit	Opening 1: 70.94mOD Opening 2: 70.93mOD	**Springing height**	Opening 1: 70.17mOD Opening 2: 70.21mOD
Coefficients	Channel roughness: 0.04, Spill weir coefficient: 1.40	**Present in model?**	Yes via 1D arched bridge unit
Skew	NA	**Overtopping**	1D spill unit set at height of stone wall and road (min height 71.43mOD)
Notes	Only DS face surveyed.		



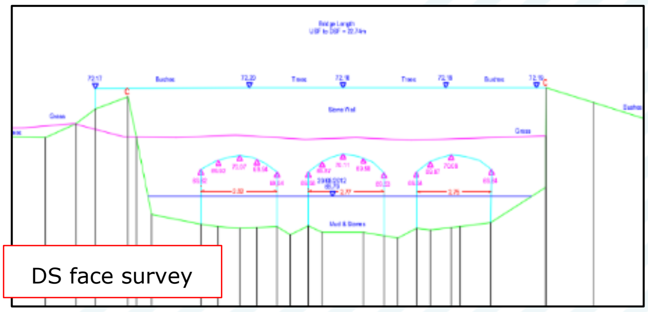


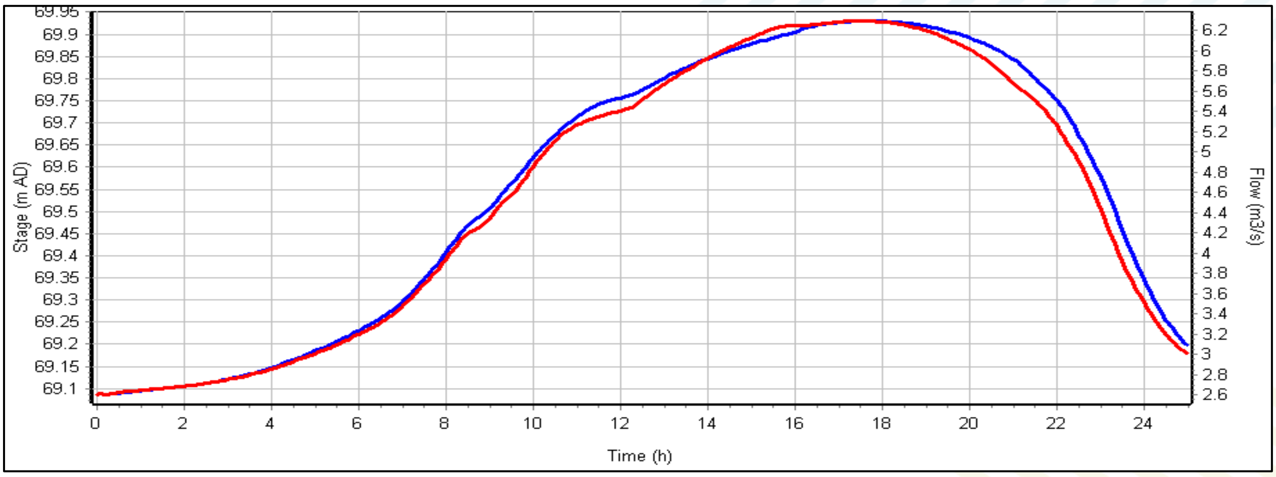
Level (blue) and flow (red) through bridge

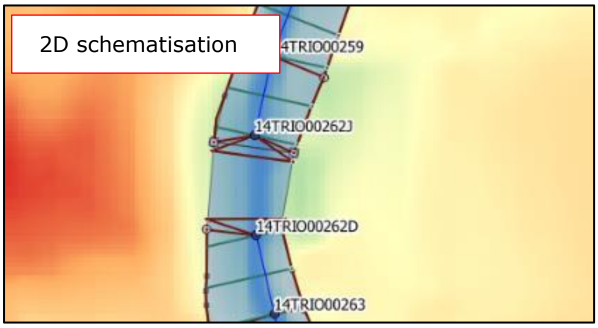


Bridge can convey flow but due to spill occurring upstream and bypassing the structure total peak flow does not pass through structure

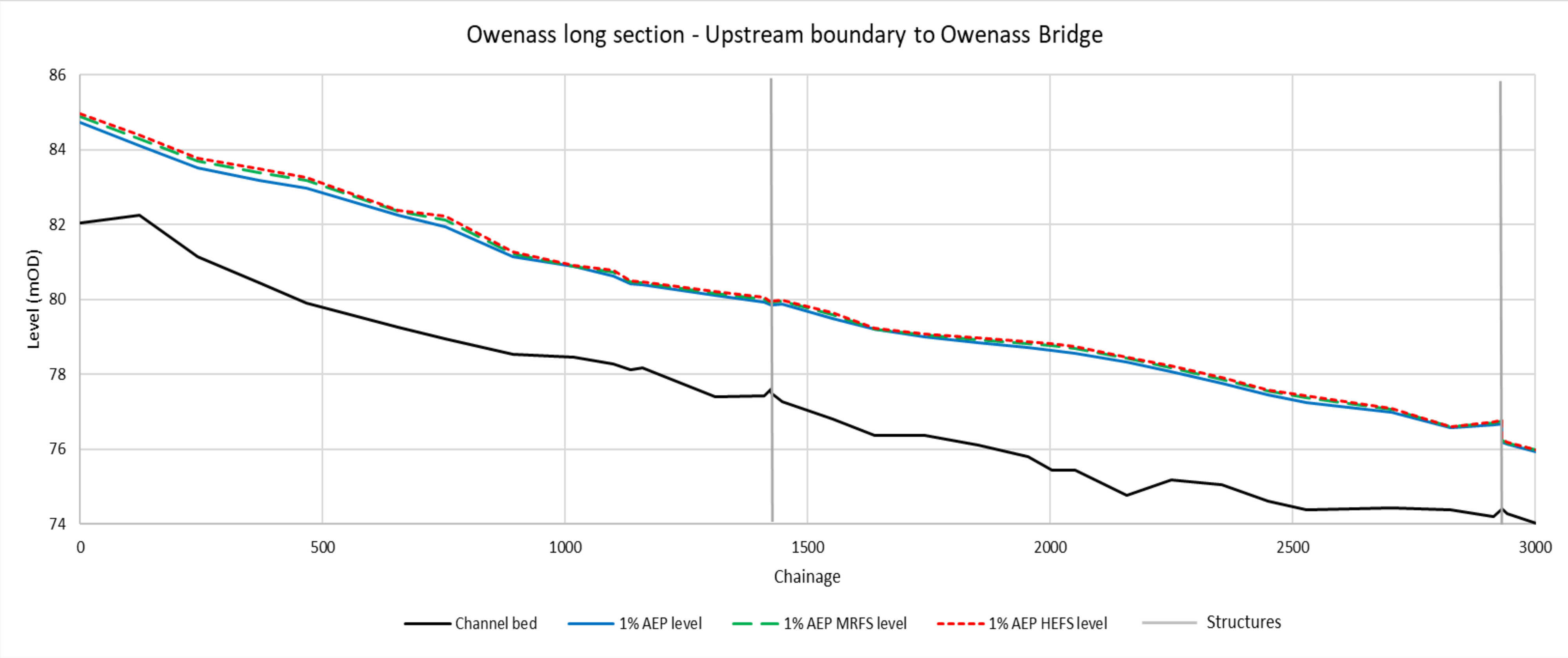
14TRIO00262D – ARCHED BRIDGE			
US Invert	Opening 1: 67.80mOD Opening 2: 69.53mOD Opening 3: 69.64mOD	**DS invert**	Opening 1: 67.80mOD Opening 2: 69.53mOD Opening 3: 69.64mOD
Dimensions	Opening 1: Width = 2.82m Height = 2.27m Opening 2: Width = 2.77m Height = 2.45m Opening 3: Width = 2.75m Height = 2.34m	**Length**	22.74m
Coefficients	Channel roughness: 0.04,	**Present in model?**	Yes in 1D using three asymmetrical culvert units due to length width ration of structure.
Skew	NA	**Overtopping**	2D spill via HX lines set at height of wall (72.17mOD)
Notes	General loss units applied instead of culvert inlet/outlet units to help with stability and backflow through structure. US loss 0.5, DS loss = 1.00		

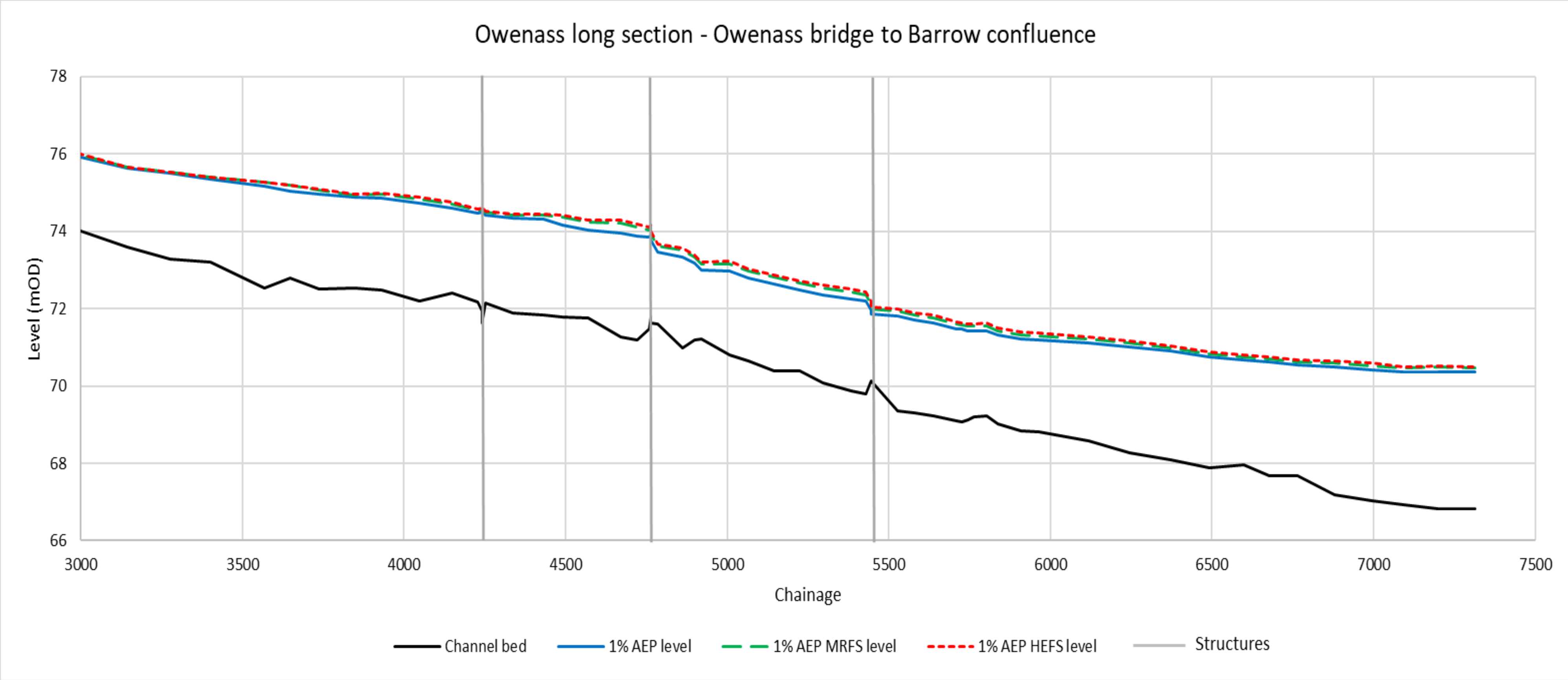




Level (blue) and flow (red) through one arch of bridge	
	Bridge soffit exceeded during peak of the event but level not high enough to activate the 2D spill.

D 1% AEP climate change long section – Owenass River





Owenass long section - Owenass bridge to Barrow confluence
Level (mOD)
78
76
74
72
70
68
66
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
Chainage
Channel bed
1% AEP level
1% AEP MRFS level
1% AEP HEFS level
Structures

E Rain on Grid model results maps

F Calibration and sensitivity results maps

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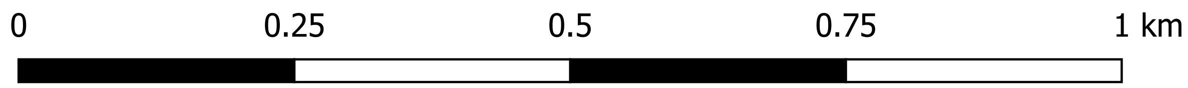
Modelled pluvial flood extents - 1% AEP 1 hour storm

Modelled pluvial flood extents - 1% AEP 8 hour storm

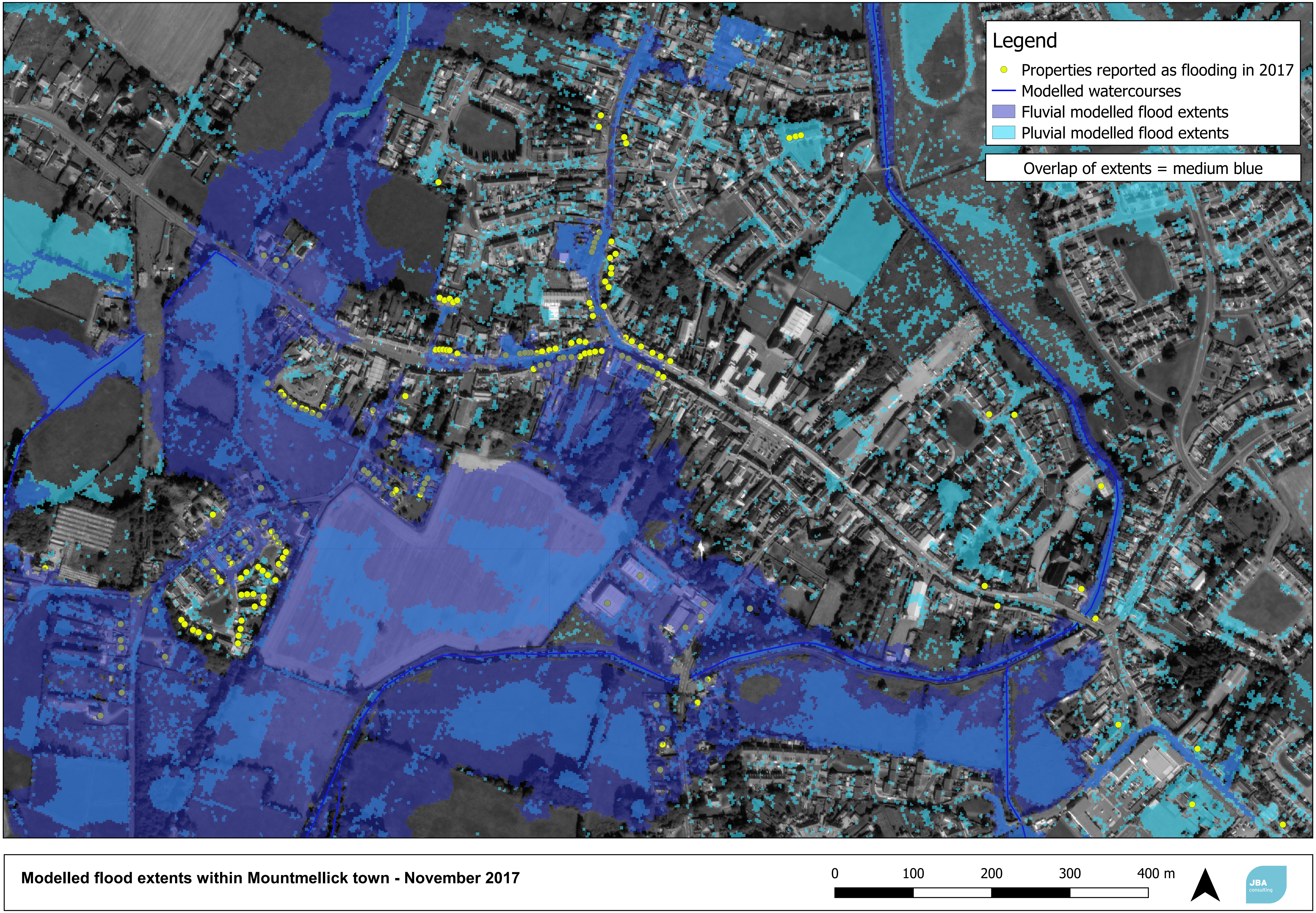
Modelled pluvial flood extents - November 2017



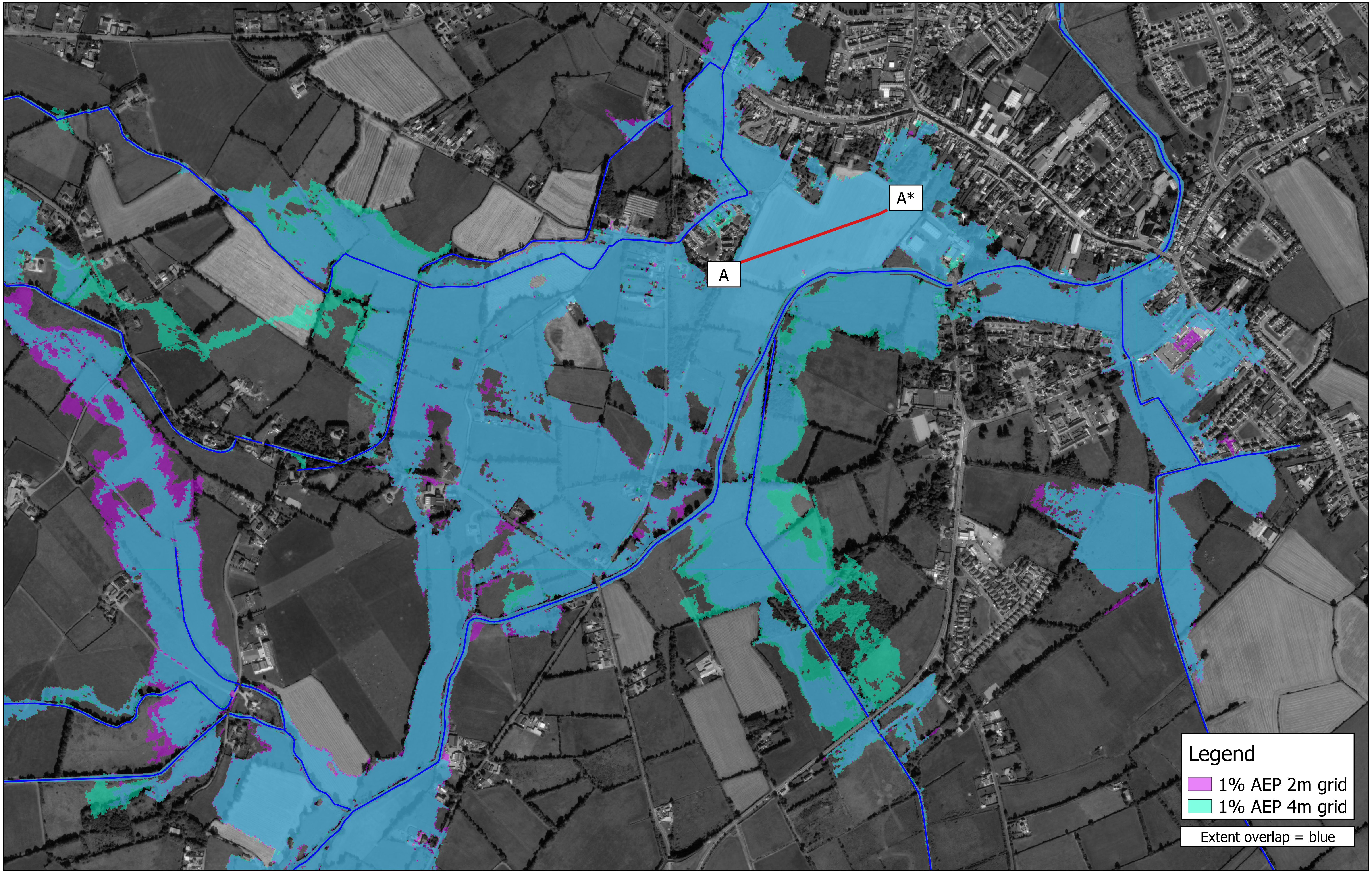
Modelled Storm Dennis flood extents

Modelled Storm Ciara flood extents

Modelled flood extents - November 2017

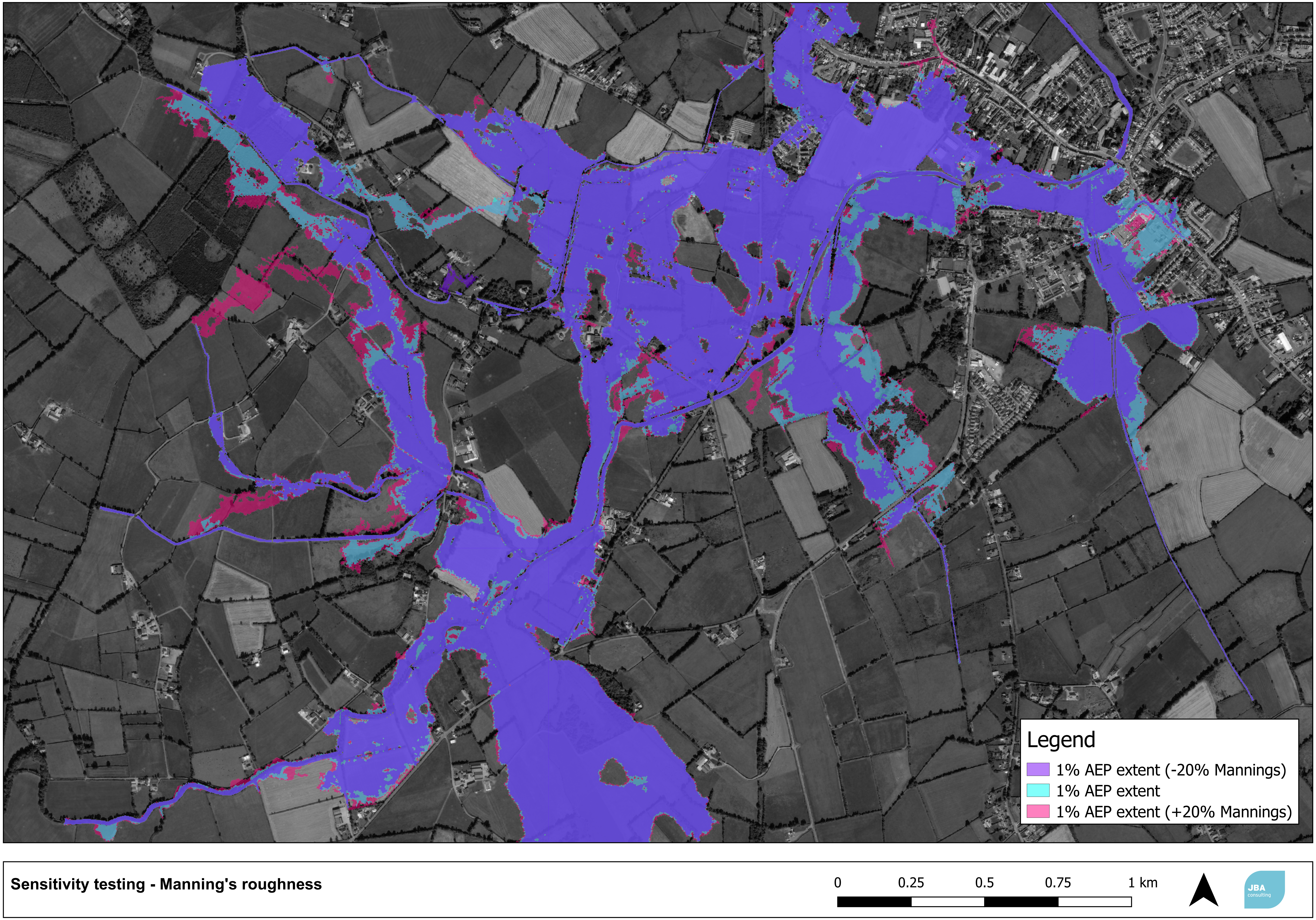


Modelled flood extents within Mountmellick town - November 2017



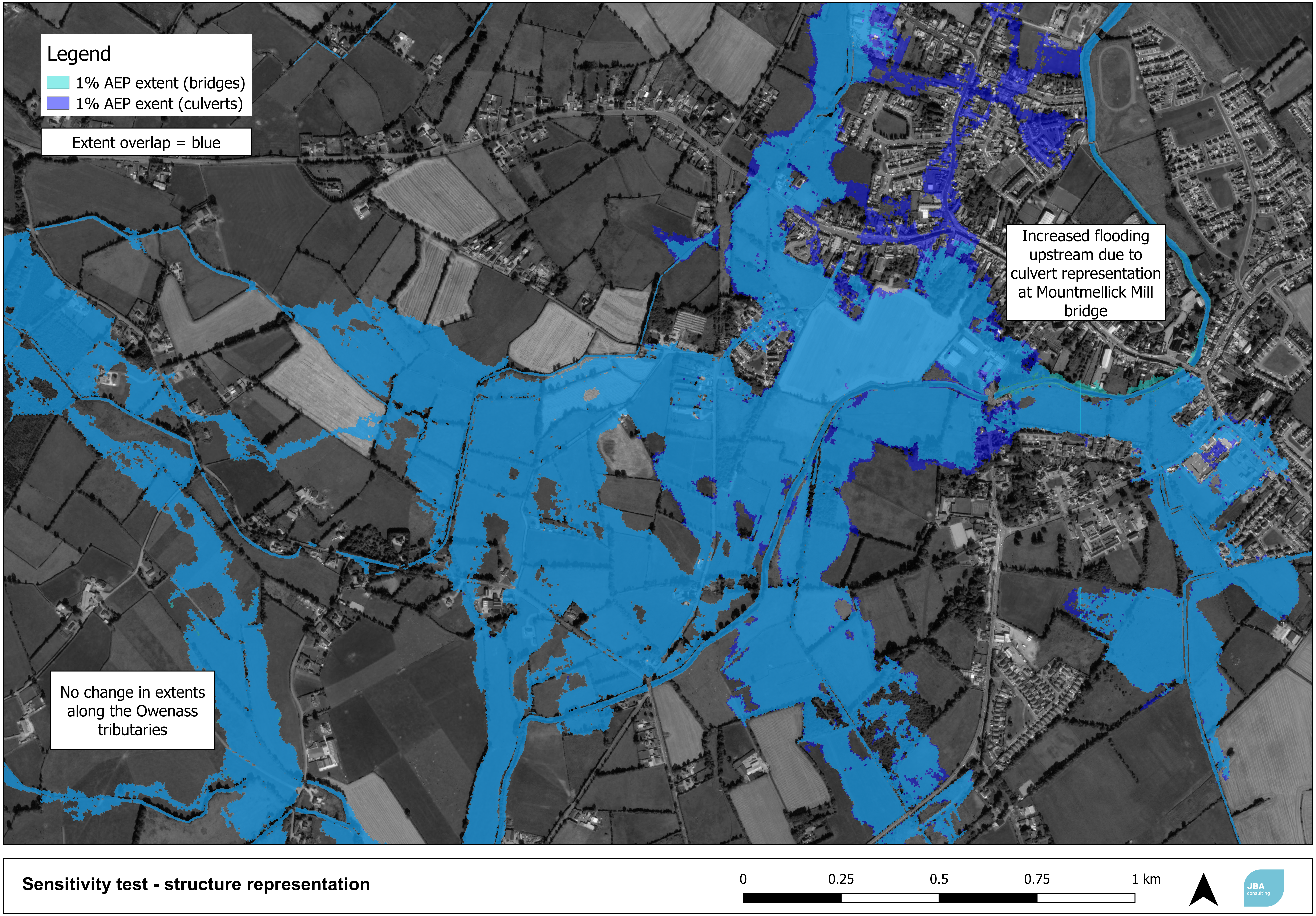
Sensitivity testing - Adjusting 2D grid cell size

Sensitivity test - inclusion of grates along the Manor Court culvert

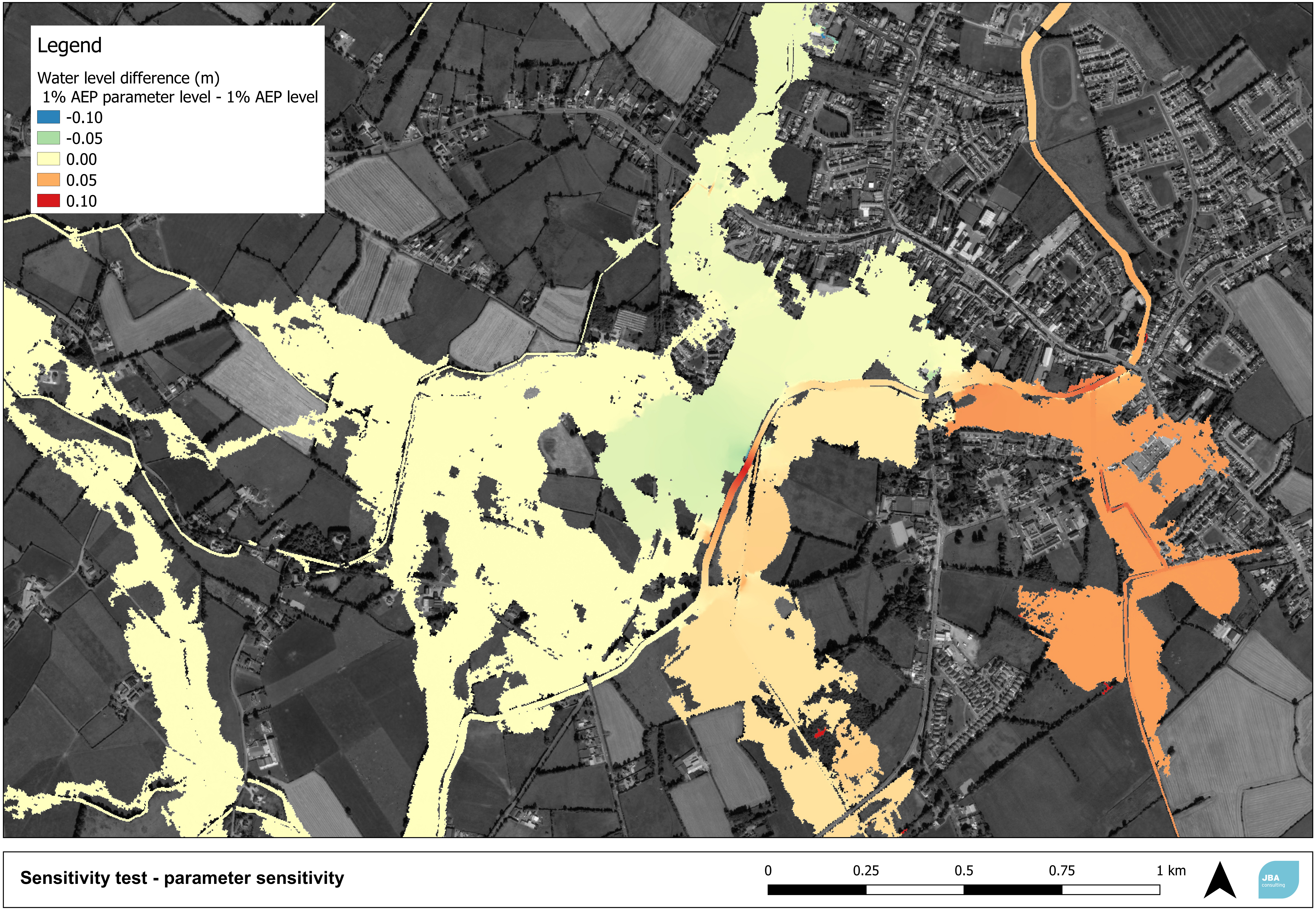


Sensitivity testing - Manning's roughness

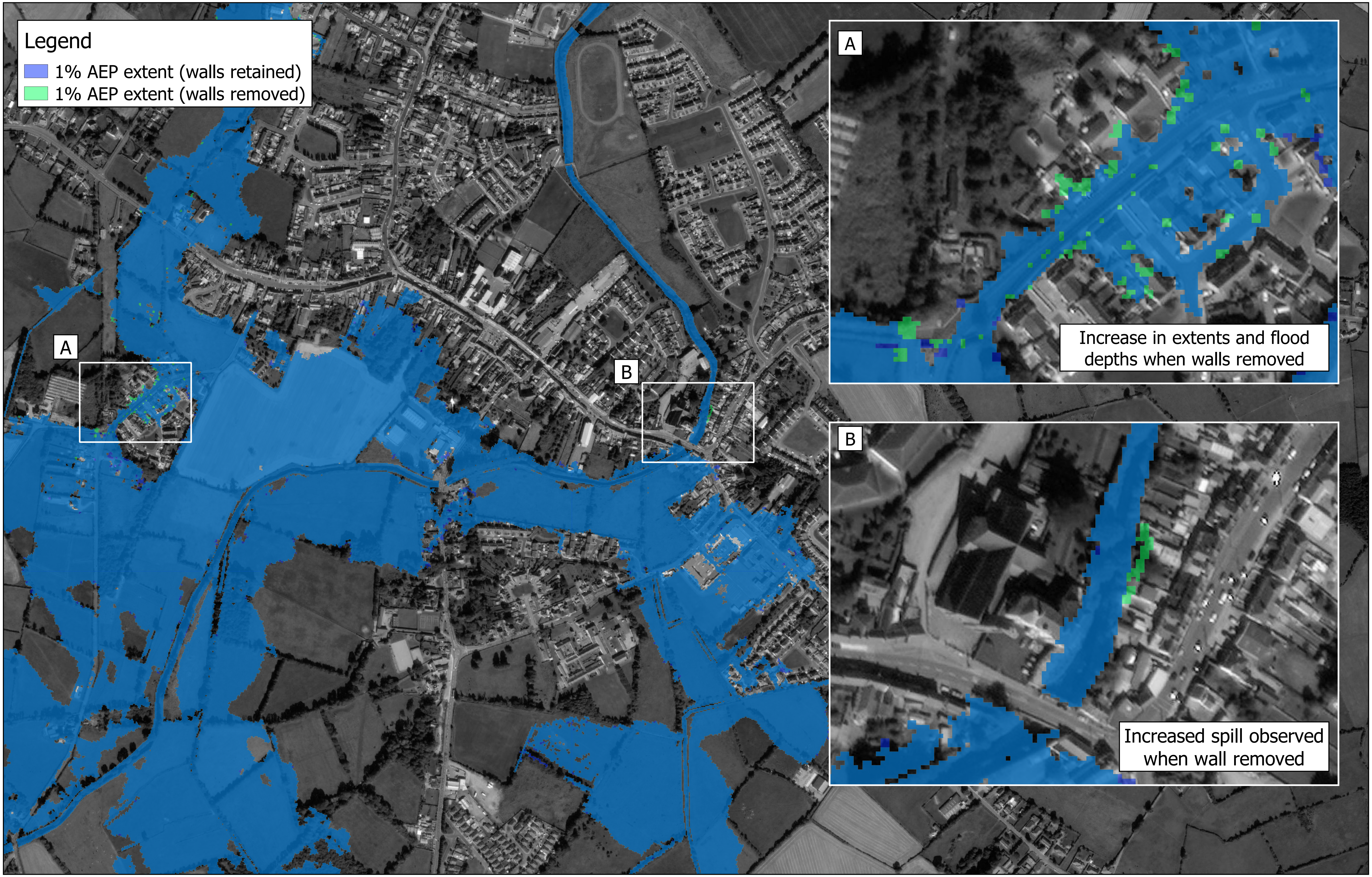
Sensitivity test - Storm duration (1% AEP event)



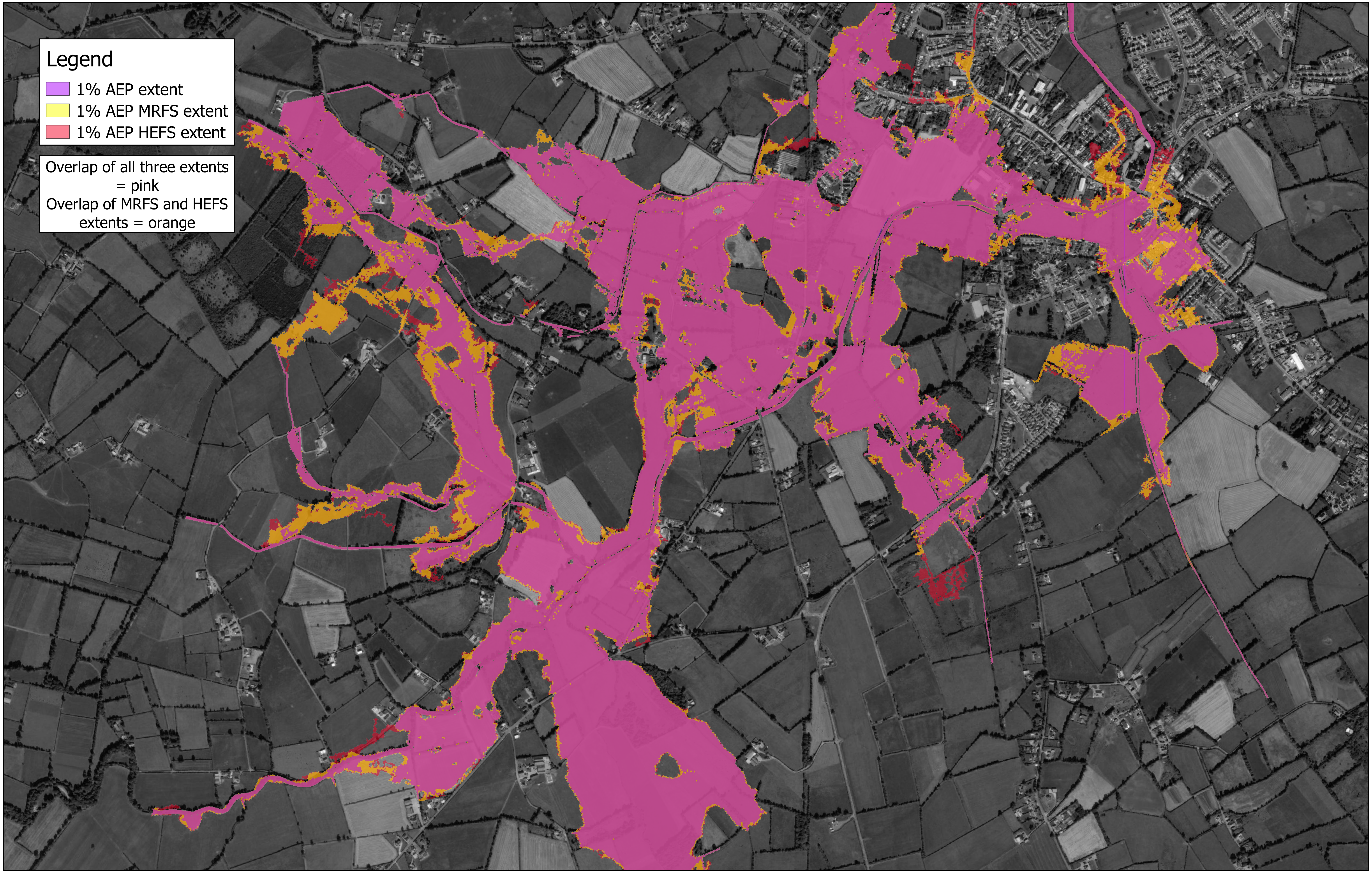
Sensitivity test - structure representation



Sensitivity test - parameter sensitivity

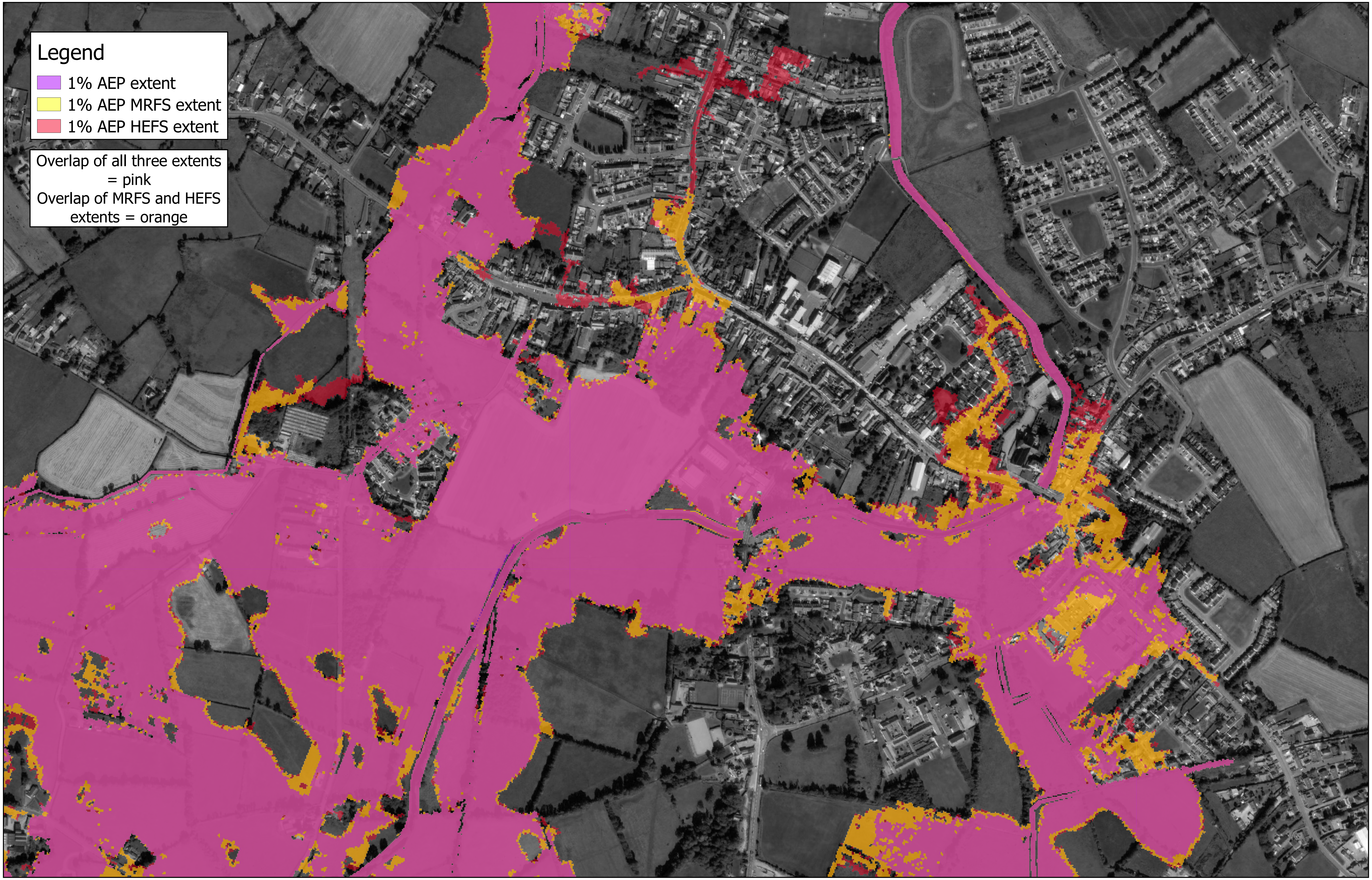


Sensitivity test - Removal of retained design event walls (1% AEP event)



1% AEP climate change - Mountmellick model

0 0.5 1 1.5 2 km



1% AEP climate change - Mountmellick town