Mountmellick

FLOOD RELIEF SCHEME

Hydrology Report

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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 and Tom Sampson of JBA Consulting carried out this work.

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Purpose

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Abbreviations

AEP	Annual Exceedance Probability
AFA	Area of Further Assessment
AMAX	Annual Maximum
ARF	Areal Reduction Factor
ARTDRAIN	Proportion of catchment area mapped as benefitting from arterial drainage schemes
BFI Soil	Soil baseflow index
CFRAM	Catchment Flood Risk Assessment and Management
CWI	Catchment Wetness Index
DDF	Depth Duration Frequency
DRAIND	Drainage Density (m/km^2)
DTM	Digital Terrain Model
EPA	Environmental Protection Agency
FARL	Flood Attenuation from Reservoirs and Lakes
FM	Flood Modeller
FRS	Flood Relief Scheme
FSSR	Flood Studies Supplementary Report
FSU	Flood Studies Update
GC	Growth Curve
GIS	Geographical Information System
GSI	Geological Survey Ireland
HEP	Hydrological Estimation Point
HEFS	High End Future Scenario
HRP	Hydrological Reporting Point
LCC	Laois County Council
LIDAR	Light Detection and Ranging
mOD	Metres above Ordnance Datum
MRFS	Medium Range Forecast Scenario
MSL	Main Stream Length
OPW	Office of Public Works
PCD	Physical Catchment Descriptor
PFRA	Preliminary Flood Risk Assessment
Qmed	50% AEP flow
SAAR	Standard-period Average Annual Rainfall
SECFRAM	South Eastern Catchment Flood Risk Assessment and Management
SFRA	Strategic Flood Risk Assessment
SMD	Soil Moisture Deficit
SPR	Standard Percentage Runoff
SW	Storm Water
TII	Transport Infrastructure Ireland
Tp	Time to Peak
URBEXT	Proportional extent of catchment area mapped as urbanised

1 Introduction

1.1 Overview and purpose of study

Mountmellick town is located in Co Laois within the River Barrow catchment. Several tributaries of the River Barrow flow near and through the town. Historically, the town has been subject to fluvial flooding and as such Mountmellick was part of the Office of Public Works (OPW) Catchment Flood Risk Management (CFRAM) study programme. The Preliminary Options Report from this study concluded that a flood relief scheme would be viable and effective for the local community. The viable scheme option for Mountmellick, as identified in the CFRAM Options Report, included a series of hard defences consisting of flood embankments, walls, and raised roads.

Since the publication of the Preliminary Options Report (June 2016), Mountmellick experienced an extreme flood event (November 2017), and the town has now been prioritised for a flood relief scheme assessment.

The overall purpose of the Mountmellick Flood Relief Scheme (FRS) project is to design and build flood defences that will protect properties and critical infrastructure in future flood events.

1.2 Hydrology Report aims and outline

The aim of the Hydrology Report is to report on the hydrology analysis undertaken as part of the FRS including:

- Review all the available data used in hydrological assessment including the available SECFRAM documentation;
- Perform rating reviews for three key gauges within the study area;
- Assess other key considerations such as joint probability and climate change;
- Provide detail on the development of design event flows;
- Detail inflows for a range of design events.

1.3 Previous studies: South Eastern CFRAM

The South Eastern Catchment Flood Risk Assessment and Management (CFRAM) Study is the most recent and detailed flood risk assessment and mapping study to be carried out in the area. SECFRAM Model 5 includes Mountmellick Area for Further Assessment (AFA) and the upper reaches of the River Barrow and its tributaries. The final reports and flood maps for the Model 5 area were released in 2016, final flood map outputs can be viewed at www.floodinfo.ie.

Refer to Section 4 of this report for a full detailed review of the SECFRAM hydrology methodology for Model 5.

2 Catchment overview

This section gives a basic overview of the study area considered.

2.1 Watercourses

Figure 2-1 shows the watercourses included in the Mountmellick FRS hydraulic model; the SEFRAM model has formed the base dataset for the model development. Following initial modelling and review of data a number of watercourses were extended upstream or added compared to the SECFRAM Model 5 model. This was done to allow greater understanding of upstream cross flow interaction between the Pound and Owenass systems as well as represent additional watercourses not previously considered. The largest watercourse considered is a reach of the River Barrow which flows to the north of the town. All flow within the study area eventually discharges into the Barrow. The key tributaries are the Pound, Owenass and Triogue Rivers with each of these being fed by minor watercourses and drainage channels.

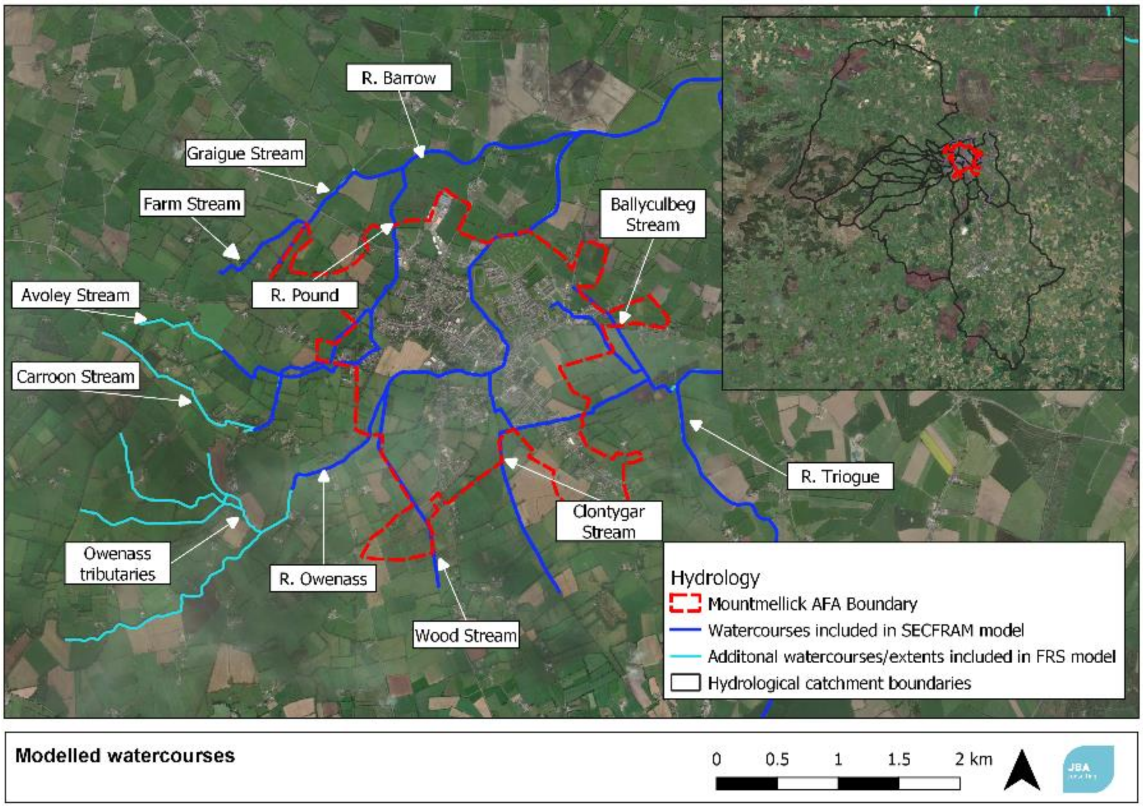

Figure 2-1: Modelled watercourses

2.1.1 River Barrow Drainage Scheme

The study area lies within the River Barrow Drainage district. The watercourses within the study area were previously managed under the Barrow Drainage Scheme. Maintenance under the scheme involved:

- Periodic clearing of vegetation from selected rivers and drainage channels;
- Removal of sediment in some areas but no formal dredging.

The board of the Barrow Drainage board was dissolved as part of the Local Government reforms of 2014, responsibility for maintenance on the Barrow is with the respectively local authorities of Laois, Offaly and Kildare. Maintenance works are still being undertaken by the Local Authorities. This includes intermittent clearing of vegetation from the channels is being carried out by Laois County Council, with a formalised programme of works planned for a three-year cycle.

2.2 Topography

Refer to Figure 2-2 for the study area topography. The catchment is flat and low lying particularly around the River Barrow and its flood plain. The Slieve Bloom Mountains lie to the west resulting in an area of higher ground in the upper reaches of some of the watercourses, namely the Pound and Owenass. Elevation ranges from 65mOD to in excess of 200mOD.

This range of topography is particularly significant when considering the application of rainfall data and river response to that rain. The Pound River and its tributaries rise in the upland parts of the Slieve Bloom Mountains and give a characteristic rapid response, with steep rising and falling limbs to the hydrograph. The Owenass and most of its tributaries rise in the lower slopes of the Slieve Blooms and have a shallower gradient. The resulting hydrograph shows a relatively steep rise, but a more gradual recessional limb. This is explored further in Section 6.2, when the development of a conceptual hydrological model is discussed.

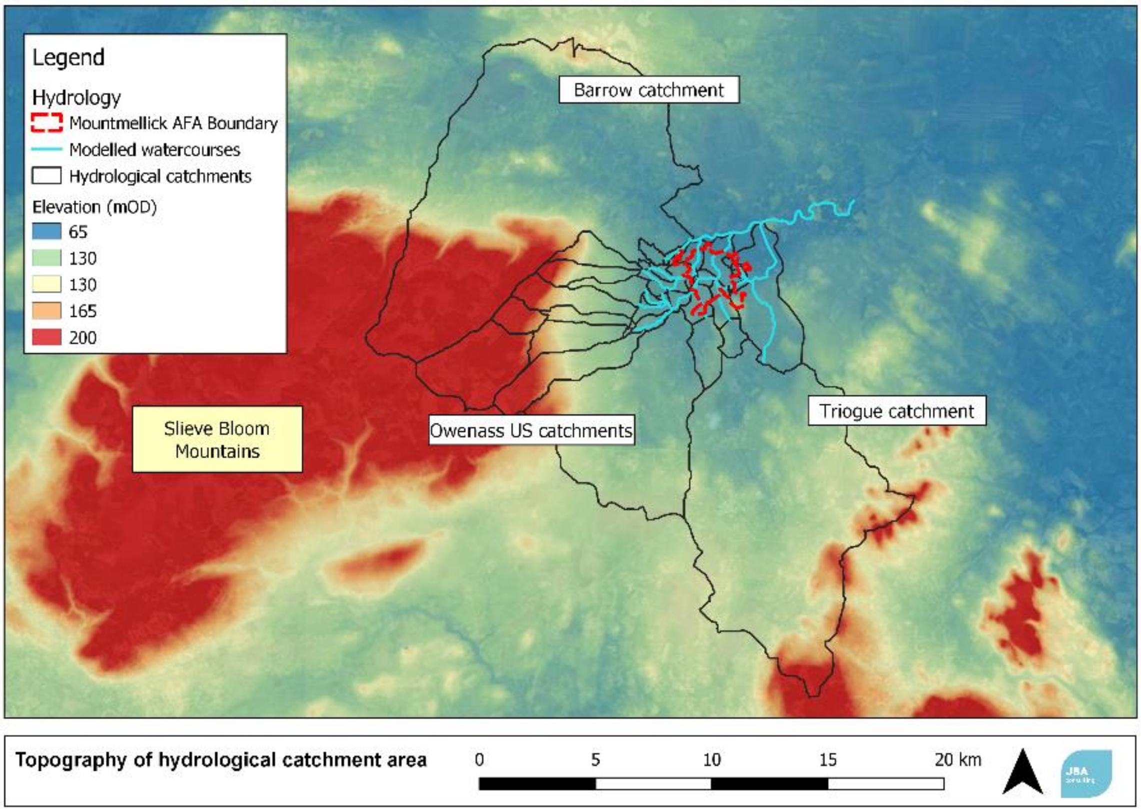

Figure 2-2: Topography of hydrological catchment area

2.3 Land use

Figure 2-3 shows agricultural land and pasture are the main land use types in the catchment; Mountmellick town is the only urban area.

In the Slieve Bloom Mountains to the west there is forestry related land use. Peat bog and moors also cover a significant portion of the Slieve Bloom mountains. These generally damp and waterlogged land use types will influence the amount of rainfall runoff that enters watercourses from these mountainous upper catchment areas.

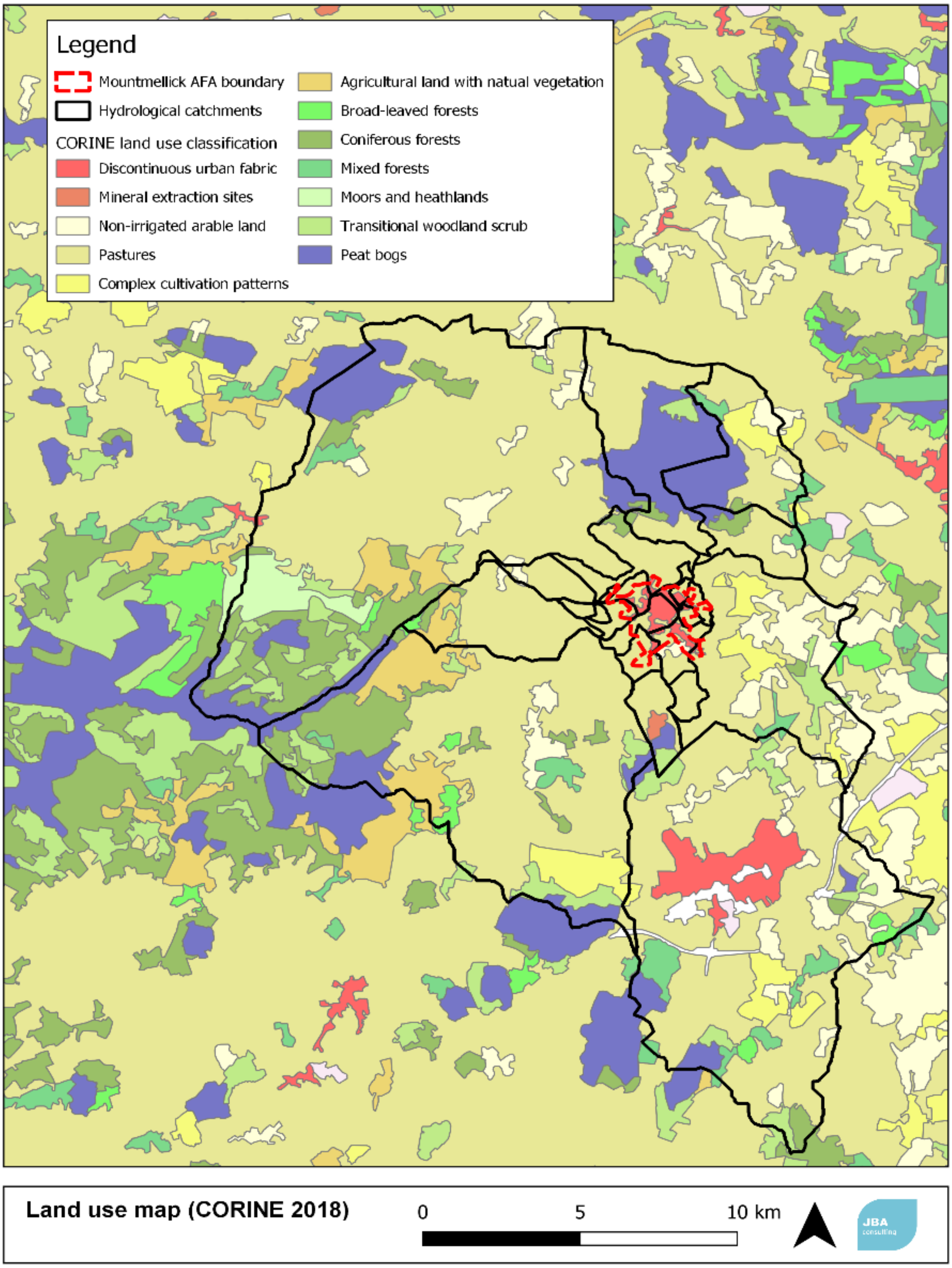

Figure 2-3: Land use map (CORINE 2018)

2.4 Hydrogeological environment

2.4.1 Bedrock geology and quaternary sediments

The bedrock of the hydrological study area consists predominantly of Carboniferous argillaceous dark-grey bioclastic limestone, with some areas having limestone-shale or sandstone bed rock. Figure 2-4 highlights the variety of quaternary sediments. Cut peat and till are the main sediments found in the upper catchment with higher permeability materials like alluvium and gravels found within the flood plain areas.

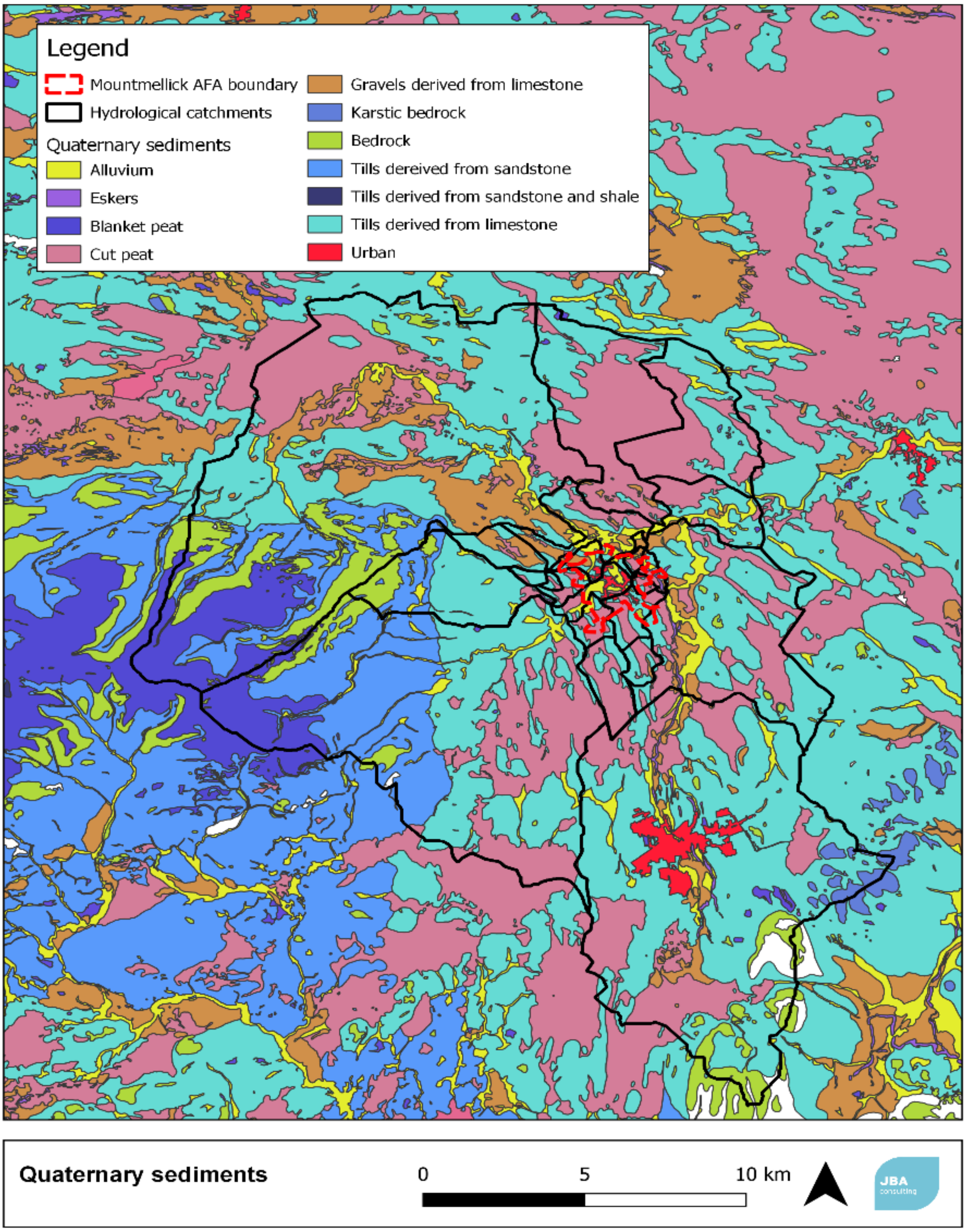

Figure 2-4: Quaternary sediments

2.4.2 Groundwater bodies

Figure 2-5 highlights the aquifer bodies. The limestone bedrock which Mountmellick lies on is classified as a locally important aquifer. The Triogue River flows over a locally important sand and gravel aquifer.

The limestone bedrock aquifer is classified as having an overall 'moderate' vulnerability with areas where bedrock is exposed at surface being more vulnerable. The 'moderate' vulnerability classification indicates that the depth to bedrock is approximately 10m. The subsoil permeability is classified overall as 'moderate.' Estimated groundwater recharge values for the area range from 20mm/yr in areas with peat to 120mm/yr in areas with more permeable subsurface materials. Overall given the depth to bedrock the contribution of groundwater to flood risk within the area is considered minimal.

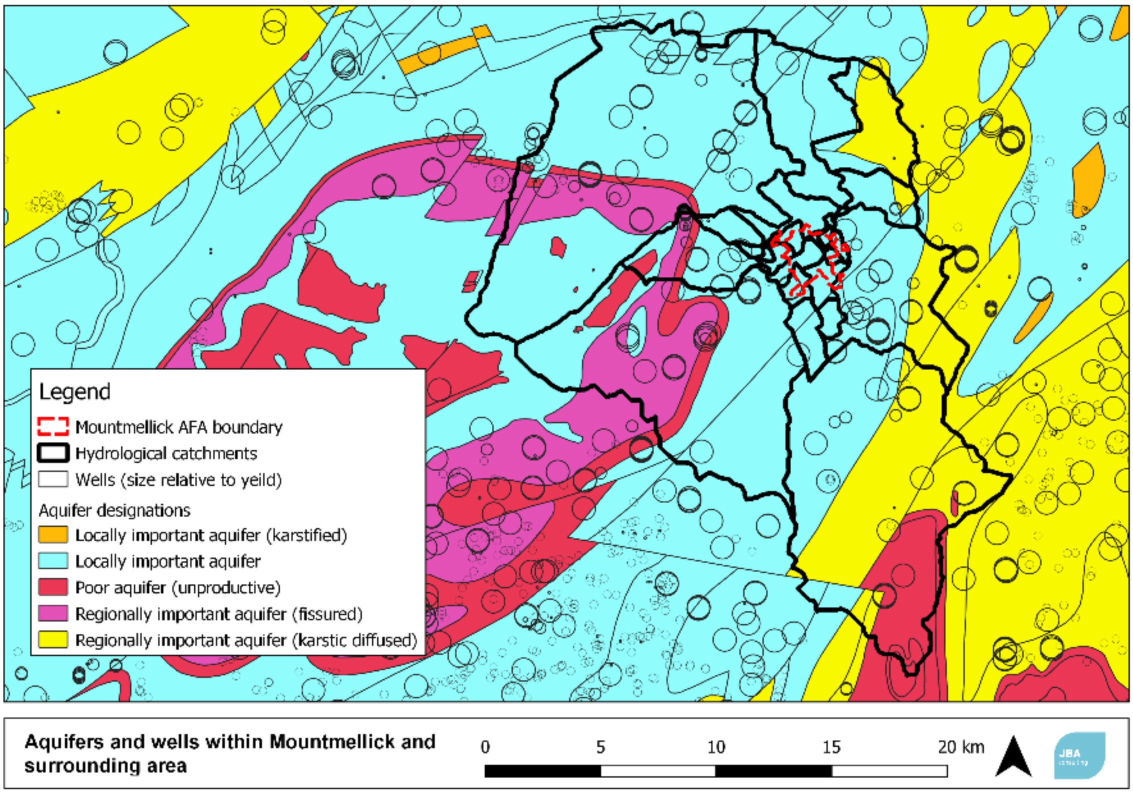

Figure 2-5: Aquifers and wells within Mountmellick and surrounding area

3 Data Review

3.1 Introduction

This section reviews the available data for the project which has been obtained from a variety of sources. Table 3-1 summarises all the data reviewed.

Table 3-1: Summary of available data sources

Type of data	Data relevant to this study?	Data available?	Source of data	Details
Topographic data and mapping	Yes	Yes	OPW, ESRI imagery, OSI mapping, Blue sky	A wide variety of base maps and satellite imagery were available, 1m, 2m, and 5m resolution LIDAR data was also provided
Watercourse extents	Yes	Yes	EPA	Blue line network
Catchment characteristics	Yes	Yes	FSU	FSU catchment database and underlying datasets
Hydrometric Gauge data	Yes	Yes for a number of gauges	EPA/OPW	Data for 5 gauges within the area available (one inactive) and one gauge outside the study area. Gauges subject to rating review. Peak of 2017 event not recorded on the Owenass River.
Historic flood data	Yes	Yes	CFRAM documentation	Flood history assessment pre 2017
			OPW and LCC	2017 and 2020 flood data (records, photographs and reports), OPW historic flood database – 2008 flood event data
			News articles	Various events and sources
			Public consultation	2017, 2008, 1990,1968 event data. Eyewitness accounts and anecdotal information
Rainfall data for events	Yes	Yes	MET Eireann	Rain gauges located within the wider area but not within the study area. Radar imagery for all of Ireland available
Rainfall data for events	Yes	Yes	TII	Rain gauges located within the wider area but not within the study area.
CFRAM study method & outputs	Yes	Yes	CFRAM	SCFRAM HA14 Documentation (inception, hydrology, hydraulics reports), existing model, survey data, GIS data (extents)
Other data or information (e.g. groundwater, channel widths, low flow statistics)	Yes	Yes	LCC	Location of storm water outfalls within Mountmellick town that discharge into watercourses of interest
			GSI	Groundwater information regarding geological materials and permeability available
			Irish Water	Storm water drainage maps of Mountmellick town

3.2 Catchment characteristic data

3.2.1 EPA blueline river network

A review of the blueline network was carried out using the available data (2m LIDAR, topographic maps, and historic maps (sourced from geohive.ie)), through site inspection and as a result of feedback from the topographic surveyors.

Following the identification of the errors and missing channels the blueline network shapefile was manually updated. Figure 3-1 shows the updated blueline network within the study area with changes highlighted. The updated blue line network GIS file accompanies this report.

3.2.2 Catchment descriptors review

Under the SECFRAM, 27 hydrological estimation points (HEPs) were used as locations for flow analysis; in some cases, the HEP catchment area was amended from the FSU catchment based on review of topography. A map of the SECFRAM catchments and catchment descriptors for each SECFRAM HEP can be found in Appendix A.

Following the review of the SECFRAM catchments and the data available, updated catchment boundaries were established to better represent the division of flows across the area and to include new reaches that were not included in the SECFRAM study. In particular, smaller sub catchments were derived within the town area to better represent the distribution of flow across a watercourse.

Updated catchment areas and descriptors were derived from the most up to date available data (e.g. FSU database, recent DTM data, SAAR data etc) and reviewed to ensure they are representative. A map of the catchments and updated catchment descriptors for this study are presented in Appendix B.

The datasets used to derive catchment descriptors were examined to ensure no significant updates or changes had occurred. Refer to Table 3-2 for the findings of the review.

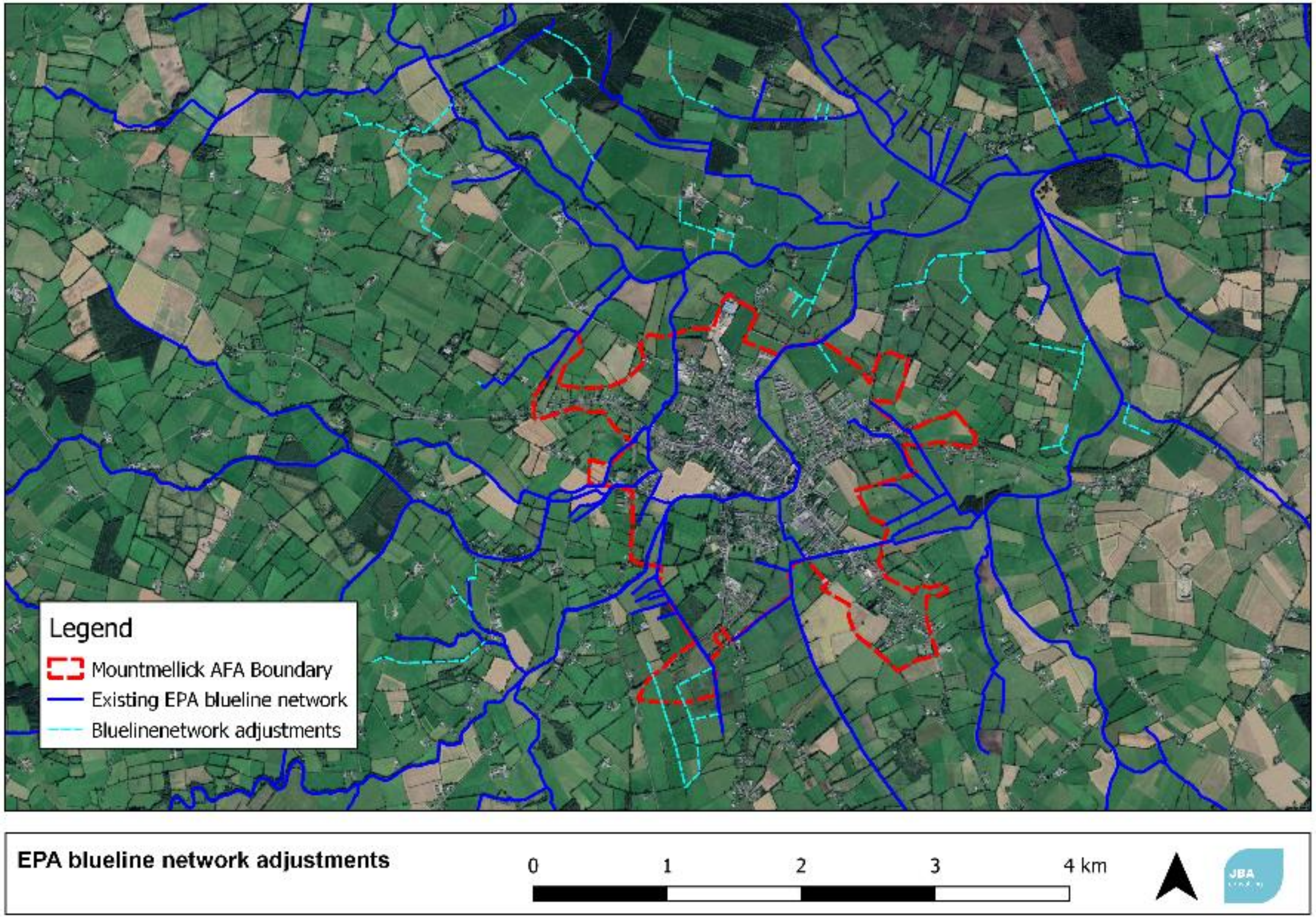

Figure 3-1: EPA blueline network adjustments and additions

Table 3-2: SECFRAM Catchment descriptor review

Descriptor	Data used in original FSU	Updated data set	Need for adjustment?
Area	Catchment areas delineated using a hydrologically adjusted DTM	1m/2m resolution DTM data	Visual inspection of the catchment boundaries carried out to ensure that watersheds and flow paths are properly accounted for, no noticeable errors or issues identified with existing FSU ungauged catchment boundaries or updated boundaries.
SAAR	Gridded annual rainfall data for the period 1961 – 1990 from MET Eireann used to generate catchment SAAR values	Gridded annual rainfall data for the period 1981 – 2010 from MET Eireann now available	Comparison between the two datasets showed a difference reported in SAAR values with lower values being reported in the more recent dataset. All updated catchment SAAR values have been derived from the most recent dataset.
FARL	Waterbodies defined using EPA waterbodies shapefile and the % of catchment area with lakes or reservoirs calculated	No major alterations or adjustments to the initial dataset	There are no reservoirs or lakes within the study area therefore no updates to this descriptor is needed
BFI Soil	Catchment wide value of baseflow index estimated using watercourse data	No change to dataset used	BFI Soil catchment descriptor values obtained from the current dataset.
URBEXT	Corine land cover 2000 dataset used to get % of urban land use within the catchments	Corine land cover 2018 dataset released	No change in URBEXT for upland catchments and minimal changes to URBEXT values for lowland catchments within the Mountmellick townland area, adjustments accounted for in updated catchments.
MSL	Stream length measured from GIS shapefile of watercourses	No update	No changes to MSL (main stream length) within the study area.
S1085	Slope determined using OSi DEM data	Updated topographic datasets (e.g. 2m LiDAR)	Spot check on S1085 values reported in study area are consistent with those estimated using the updated topographic data.
Drain D	Calculated by dividing channel length by catchment area	Updated topographic data available for catchment area review	Following review of catchment areas there was no need to adjust DrainD values.
ArtDrain2	Measured using a GIS line shapefile from the OPW	Updated map layers	No changes in channels affected by arterial drainage, no need for adjustment.

3.3 Meteorological data

3.3.1 Gauge data

There are no rain gauges present within the Mountmellick FRS study area, and one within the Triogue catchment. Figure 3-2 shows the closest active gauges and Table 3-3 summarises the data available.

There is also a weather observation website[1], which is hosted by Met Éireann. WOW-IE is the Weather Observations Website of Met Éireann and is part of the global WOW network of crowdsourced weather observations. Although there is an amateur gauge listed at Garrymore, to the north of Mountmellick, contact with the gauge owner revealed potential errors in the record and a lack of calibration, so the data was not used.

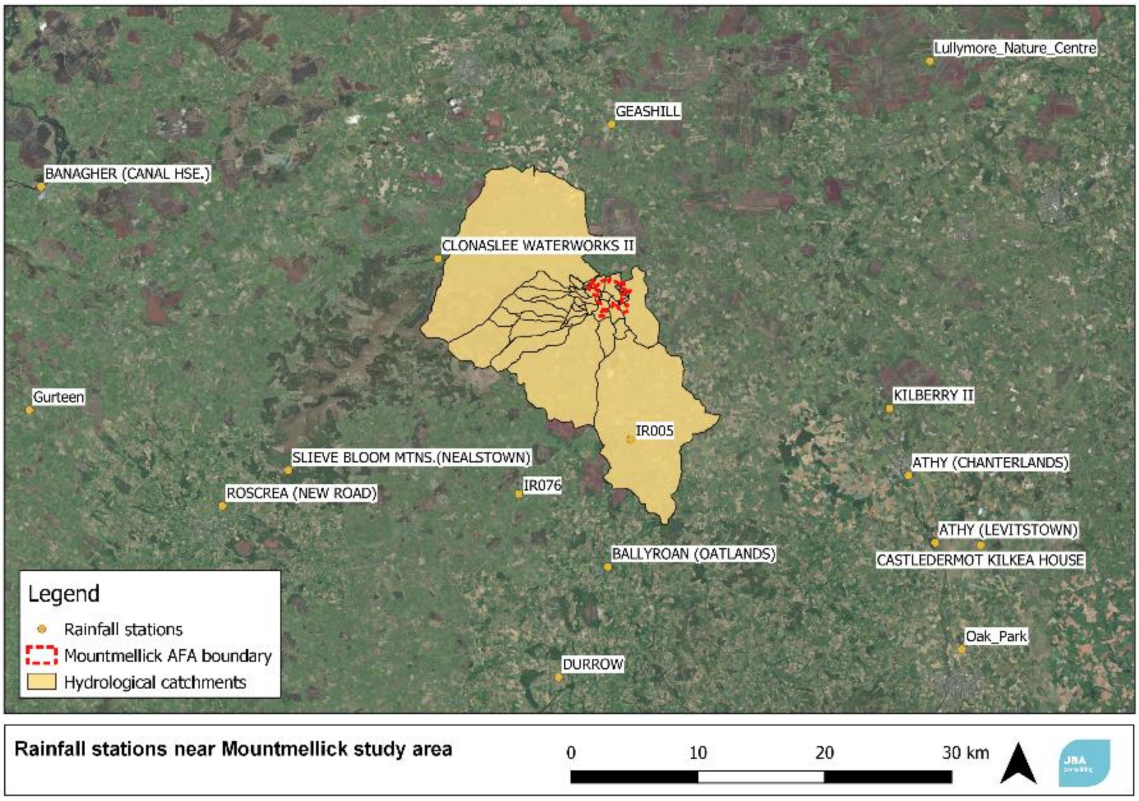

Figure 3-2: Rainfall stations near Mountmellick study area

Table 3-3: Active meteorological gauges

Gauge name	Gauge number	Approximate distance from study area	Rainfall data resolution	Data record
Clonaslee Waterworks*	3222	13.83km	Daily	1985 - present
Geashill	7314	13.50km	Daily	2018 - present

-
-

1 https://wow.met.ie/

Gauge name	Gauge number	Approximate distance from study area	Rainfall data resolution	Data record
Ballyroan (Oatlands)	5313	21.27km	Monthly	2000 – present
Kilberry	6714	23.85km	Monthly	1999 - present
Athy (chanterlands)	6414	27.47km	Daily	1993 - present
Athy (Levistown)	7014	32.14km	Daily	2003 - present
Castledermot Kilkea House	5414	35.21km	Daily	1983 - present
Roscrea (New Road)	6119	34.95km	Daily	1984 - present
Slieve Bloom Mtns (Nealstown)*	3513	29.00km	Daily	1953 - present
Mullingar	875	46.61km	Hourly	2002 – present
Gurteen	1475	46.52km	Hourly	2008 – present
Oak Park	375	39.60km	Hourly	2003 - present
TII gauge (Mountrath)	IR076	16.40km	Sub-Hourly	2015 – present
TII gauge (Portlaoise)	IR005	10.20km	Sub-Hourly	2015 - present
Notes: *Gauges recording upland rainfall.				

3.3.2 MET Eireann Depth Duration Frequency (DDF) data

Rainfall depths for the various return periods and storm durations have been sourced from the MET Eireann Depth Duration Frequency (DDF) dataset. The dataset allows rainfall depths to be assigned to annual exceedance probabilities and was developed using available gauged data. Table 3-4 shows the calculated areal reduction factors (ARFs) and the 1% AEP 9-hour storm rainfall depths for Mountmellick town and the upstream catchment of the larger watercourses. Table 3-5 shows the rainfall depths in mm associated with various durations and AEP events for the Mountmellick area with no reduction factors. The values provided are an approximation of potential pluvial depths.

Table 3-4: Areal reduction factors and rainfall depths for Mountmellick and upstream locations (9-hour 1% AEP storm)

	Mountmellick town	Barrow upstream catchment	Owenass upstream catchment	Pound upstream catchment
Areal reduction factor	NA (point estimate)	0.915	0.925	0.958
Rainfall depth (mm)	56.70	59.20	59.40	59.20

Table 3-5: MET Eireann DDF rainfall depths for various durations and AEP events

	Annual Exceedance Probability (AEP) %					
Duration	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**
30 (mins)	8.60mm	11.70mm	14.00mm	16.50mm	20.40mm	23.80mm
60 (mins)	11.20mm	14.10mm	17.80mm	20.80mm	25.40mm	29.50mm
120 (mins)	14.50mm	18.10mm	22.50mm	26.20mm	31.60mm	36.40mm
240 (mins)	18.80mm	23.20mm	28.50mm	32.90mm	39.40mm	45.00mm
6 (hours)	21.90mm	28.20mm	32.80mm	37.60mm	44.80mm	51.00mm
9 (hours)	25.50mm	32.60mm	37.70mm	43.00mm	50.90mm	57.70mm
12 (hours)	28.40mm	36.10mm	41.60mm	47.30mm	55.80mm	63.00mm
24 (hours)	36.80mm	46.20mm	52.70mm	59.50mm	69.50mm	77.90mm

3.3.3 Meteorological data for the November 2017 event

Figure 3-3 shows the 100km resolution radar data recorded by MET Eireann between the 21st and 22nd of November 2017, the data highlighted a large amount of precipitation occurring over Mountmellick and the surrounding area during the early hours of the 22nd and less intense bands of precipitation passing over during the day. From the radar the key storm event is estimated to have been approximately 9 hours (00:00 – 09:00).

The intense precipitation seen in the radar matches the rainfall records at various rain gauges (refer to Table 3-6). Daily rainfall is recorded at 09.00 the following day therefore rain falling between the hours of 00.00 and 09.00 on the 22nd November is attributed to the 21st November. From Table 3-6 the gauges with the highest recorded rainfall depths (greater than 50mm) for the two days are located in the Slieve Bloom mountains.

Table 3-6: Precipitation recorded for the November 2017 event

Gauge name	Gauge number	Rainfall recorded on 21st November 2017 (mm) (from 09:00 21/11/2017 to 09:00 22/11/2017)	Rainfall recorded on 22nd November 2017 (mm) (from 09:00 22/11/2017 to 09:00 23/11/2017)	Total rainfall recorded over the period (mm)
Daily raingauges				
Clonaslee Waterworks	3222	50.20	15.50	65.70
Athy (Chanterlands)	6414	15.80	12.80	28.60
Athy (Levistown)	7014	14.50	10.40	24.90
Castledermot Kilkea House	5414	5.90	15.30	21.20
Roscrea (New Road)	6119	43.20	9.20	52.40
Slieve Bloom Mtns (Nealstown)	3513	46.50	4.30	50.80

Gauge name	Gauge number	Rainfall recorded on 21st November 2017 (mm) (from 09:00 21/11/2017 to 09:00 22/11/2017)	Rainfall recorded on 22nd November 2017 (mm) (from 09:00 22/11/2017 to 09:00 23/11/2017)	Total rainfall recorded over the period (mm)
Kilminchy water treatment works (Portlaoise)	NA	1.00	39.00	40.00
Hourly rain gauges				
Oak Park	375	13.1	7.6	20.7
Mullingar	875	18.3	5.1	23.4
Gurteen	1475	34.8	4.4	39.2
TII gauge (Mountrath)	IR076	27.1	8.0	35.1
TII gauge (Portlaoise)	IR005	31.9	9.9	41.8

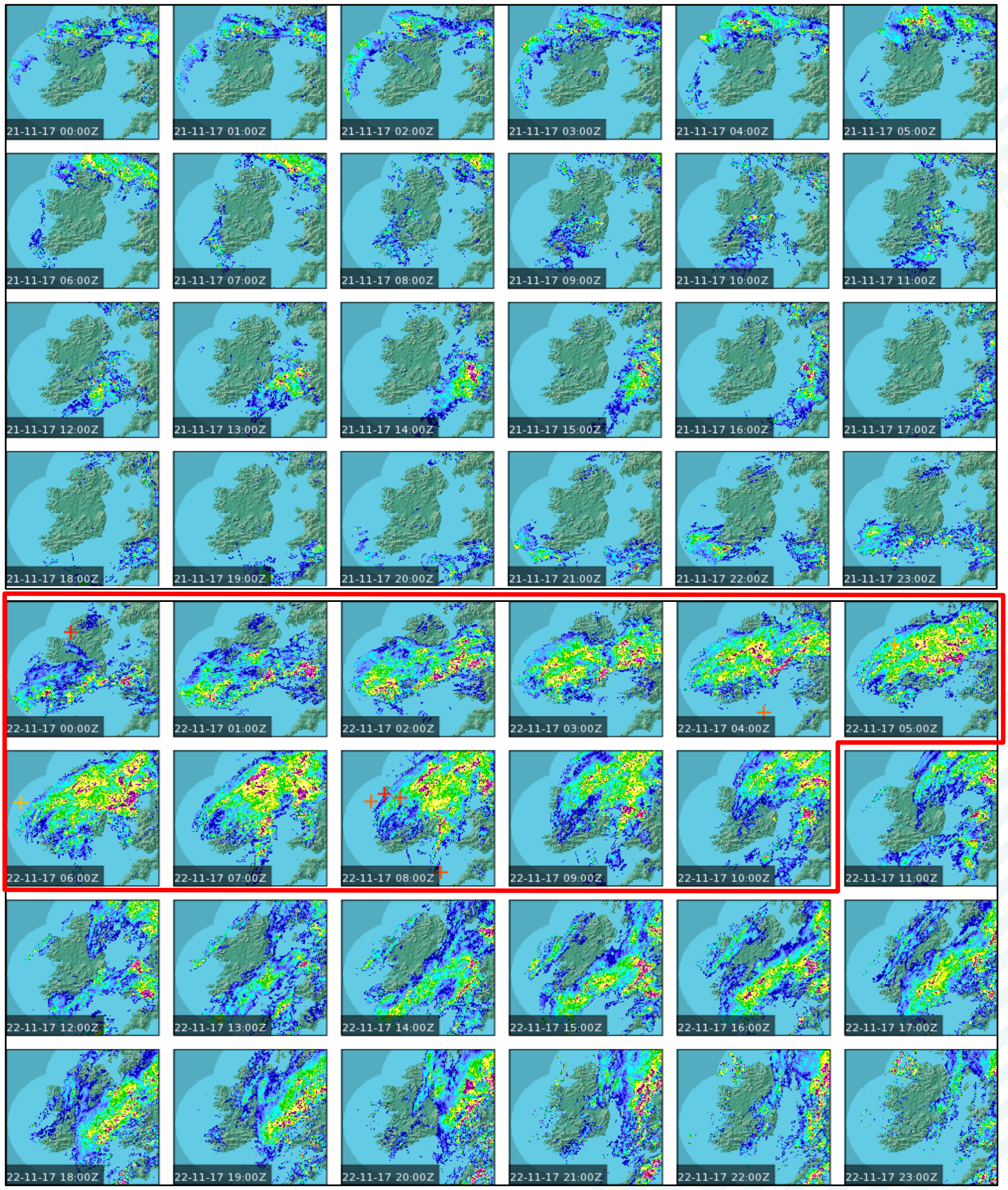

Figure 3-3: Hourly radar images of rainfall for the 21st and 22nd November 2017

3.3.4 Review of hourly precipitation data available for the 2017 event

All the rain gauges listed have either sub-daily, daily, or monthly data resolution. Figure 3-4, Figure 3-5 and Figure 3-6 show the data recorded at the nearest hourly gauges on the 22/11/2017. The location to Mountmellick is also noted on the graphs. The rainfall distribution matches well with the MET Eireann radar imagery with most of the rainfall recorded during the large 9-hour storm event in the morning (refer to Figure 3-3). Hourly radar raster data provided by MET Eireann was also examined however the radar coverage did not include the study area and so could not be used to aid rainfall estimation. Peak rainfall recorded is not the same for the gauges due to their locations and the movement of the storm over time. With reference to the MET Eireann DDF dataset the estimated exceedance probability for the rainfall event in the area at Clonalsee gauge is between 1% - 2% (for a 9-hour storm duration – length of event) or between 10 – 20% (based on a 24 hour record duration), refer to Table 3-4 and Table 3-5.

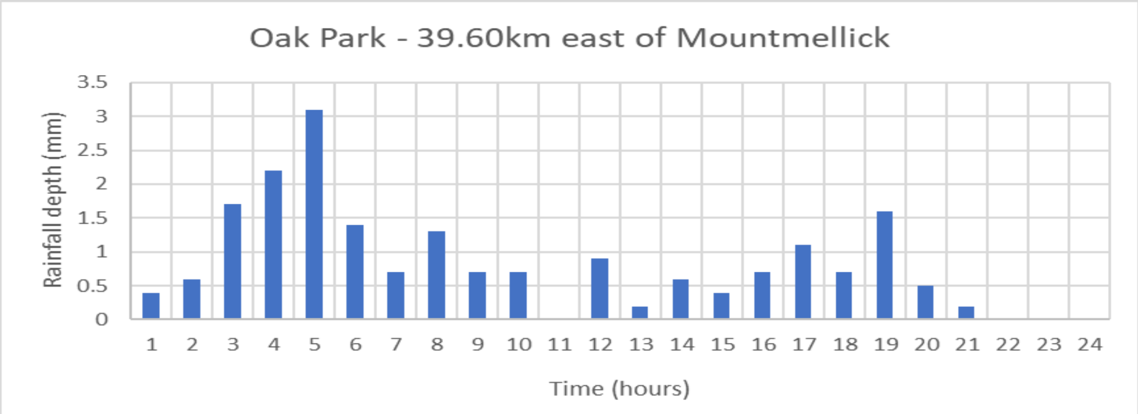

Figure 3-4: Rainfall recorded on the 22/11/2017 at Oak Park gauge

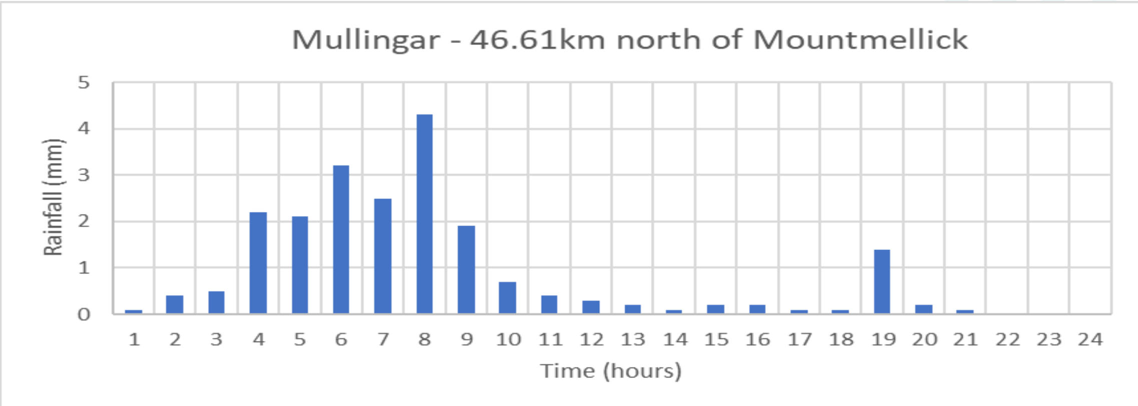

Figure 3-5: Rainfall recorded on the 22/11/2017 at Mullingar gauge

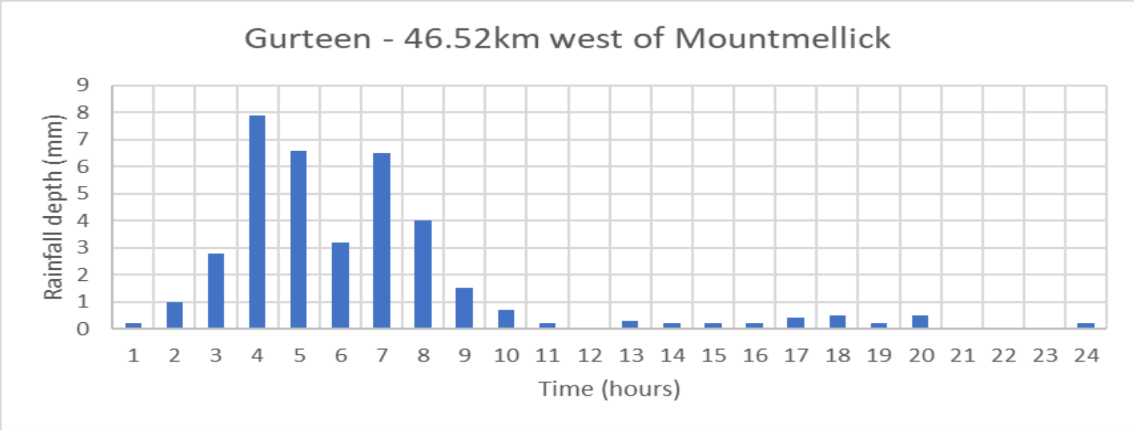

Figure 3-6: Rainfall recorded on the 22/11/2017 at Gurteen gauge

3.4 Soil Moisture Deficit data

Soil Moisture Deficit (SMD) data is available for well, moderately and poorly drained soils from meteorological data at Oak Park. The data gives an indication of catchment saturation conditions. Table 3-7 shows the SMD values recorded for the November 2017 event. The poorly drained soils were draining at/near their maximum capacity on the 21st and 22nd indicating the areas of the catchment were saturated both before and during the event. The moderately drained soils were also draining at their maximum capacity on the day of the event.

Table 3-7: SMD values (in mm) recorded over the November 2017 event

Soil type	20/11/2017	21/11/2017	22/11/207	23/11/2017
Well drained	0.00	0.00	0.00	0.20
Moderately drained	-0.30	-0.40	-10.00	0.20
Poorly drained	-9.70	-9.60	-10.00	-9.30

3.5 Hydrometric data

There are currently 6 active and one inactive hydrometric gauges within the Mountmellick and the surrounding area, refer to Figure 3-7 for the gauge locations. A summary of each gauge is provided in this section. In addition, there is a gauge located on the Triogue River in Portlaoise (EPA number 14014). The catchment descriptors for this gauge were reviewed but found to be too dissimilar to those of the Owenass and Pound catchments to add value to the hydrometric analysis. Reary Valley and Bracknanagh Bridge gauges, although not within the study area, have been included in the hydrometric data review as they provide a better understanding of upstream catchment responses in the Slieve Bloom mountains.

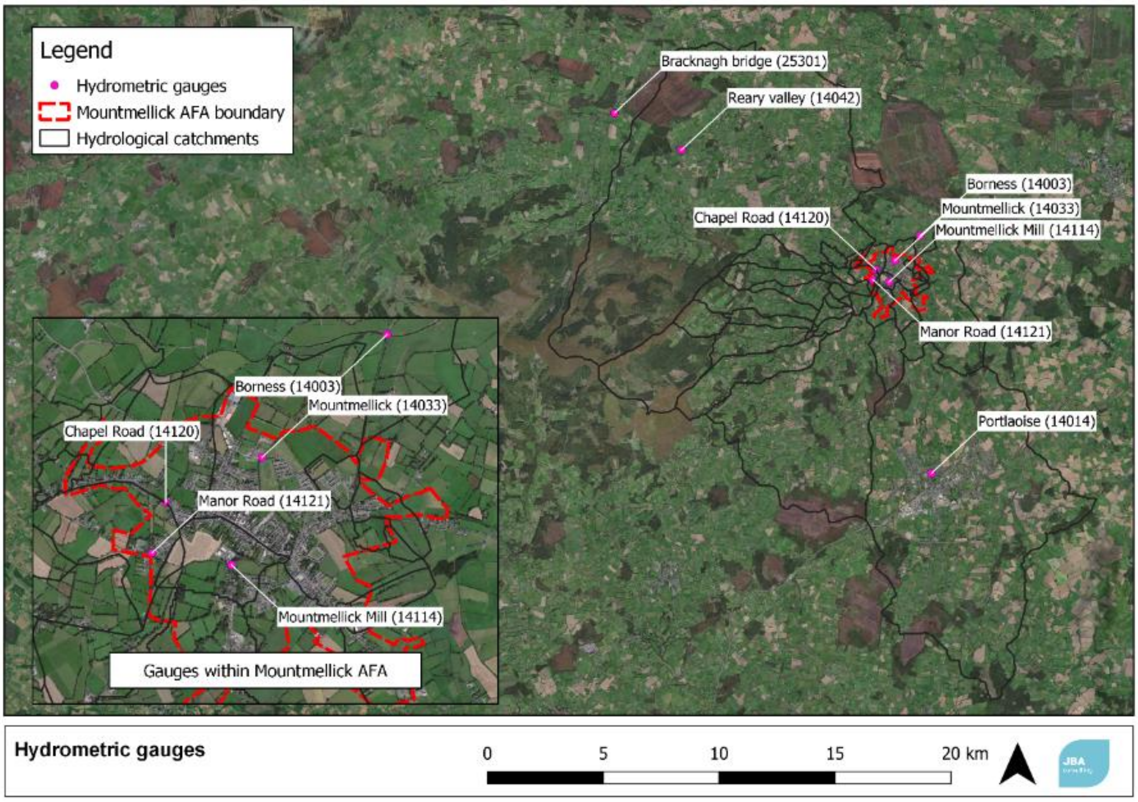

Figure 3-7: Hydrometric gauges

Table 3-8: Gauged catchment summary

	Borness	Mountmellick	Mountmellick Mill	Manor Road	Chapel Road	Reary Valley	Brackanagh Bridge
Gauge Ref	14003	14033	14114	14121	14120	14042	25301
Watercourse	Barrow	Owenass	Owenass	Pound	Pound	Barrow	Clodaigh
Operator	OPW	EPA (discontinued)	EPA	OPW	OPW	EPA	OPW
Catchment Area (km^2)	276.00	78.87	77.99	12.12	12.94	32.60	26.90
BFI soil	0.53	0.45	0.45	0.52	0.52	0.61	0.34
SAAR (mm)	1160.51	1145.00	1147.43	1154.85	1145.71	1146.25	1487.74
FARL	1.00	1.00	1.00	0.99	0.99	1.00	1.00
MSL (km)	31.41	17.57	16.07	8.356	9.12	1.91	13.09
S1085 (m/km)	9.37	11.40	12.65	7.66	6.67	4.95	18.87
ARTDRAIN2	0.00	0.00	0.00	0.00	0.00	0.00	0.18
DRAIND (km/km^2)	1.08	1.10	1.09	1.52	1.51	0.75	0.98
URBEXT	0.01	0.01	0.00	0.00	0.00	0.00	0.01
Gauged Qmed (m^3/s)	34.39	19.33	18.96	NA	NA	29.70	NA
PCD Qmed (m^3/s)	50.94	25.03	24.80	3.93	3.93	18.30	18.83

3.5.1 Borness gauge (active)

Borness Gauge	
Number	14003
Operator	OPW
Watercourse	Barrow
Catchment area	276km^2
Grid reference (NG)	246352 209286
Years active	1979 – present (15-minute data recorded)
Gauge type	Automated level logger
	 Automated logger (looking upstream)  Borness bridge (downstream of logger)
Data available	15-minute water level data (no flow data available online) and gauging report
FSU gauge classification	Not classified under FSU
Rating review carried out?	A rating review was carried out as part of the SECFRAM study. The review used an OPW rating equation as its basis and extended the existing rating curve using the hydraulic model and synthetic rainfall record (SECFRAM NAM model). The reported flow AMAX series below has been generated using the SECFRAM rating curve for the gauge. Within the SECFRAM rating review the hydraulic effect of the bridge on the gauge was highlighted. Details of the rating review can be found in Section 5.1 of this report.

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<td>Seasonality</td>
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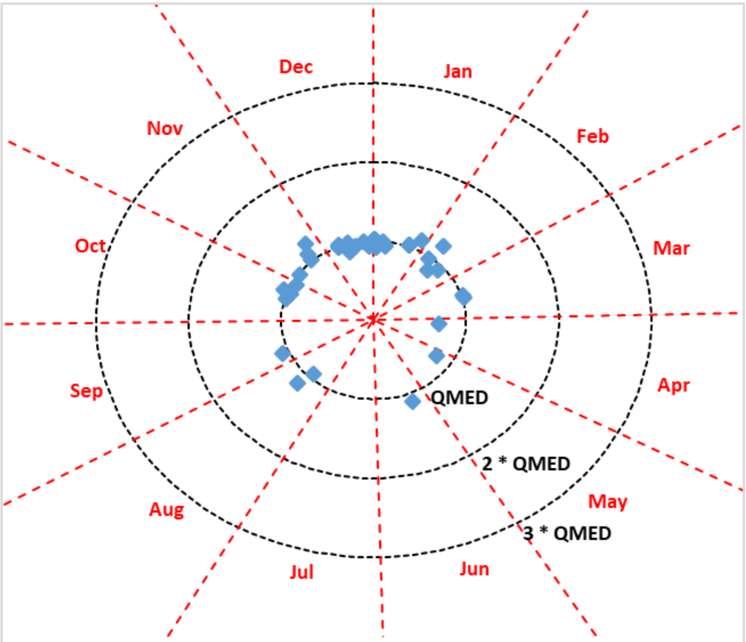

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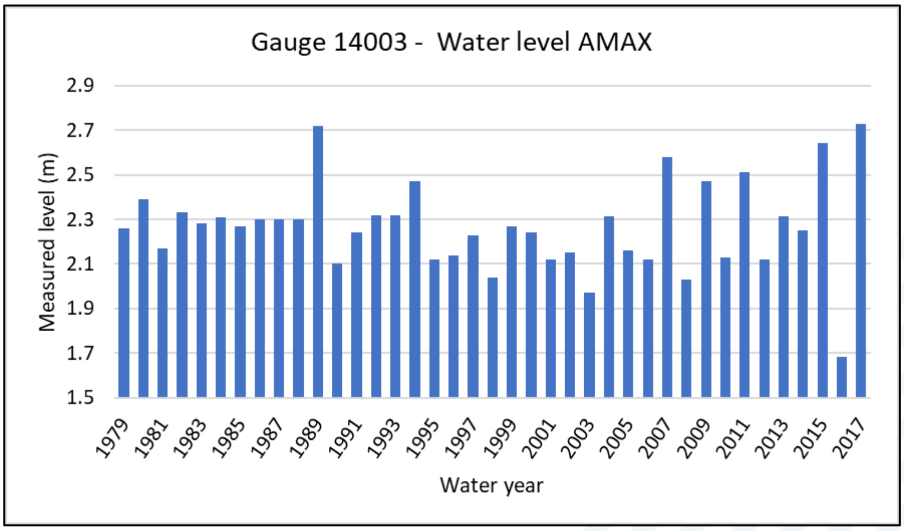

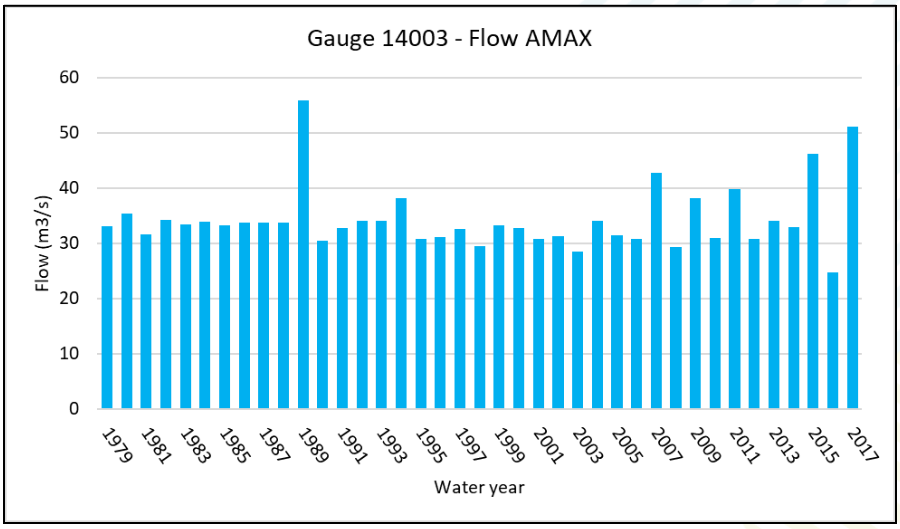

The AMAX series for the gauge extends over 40 years, there are no gaps or missing data within
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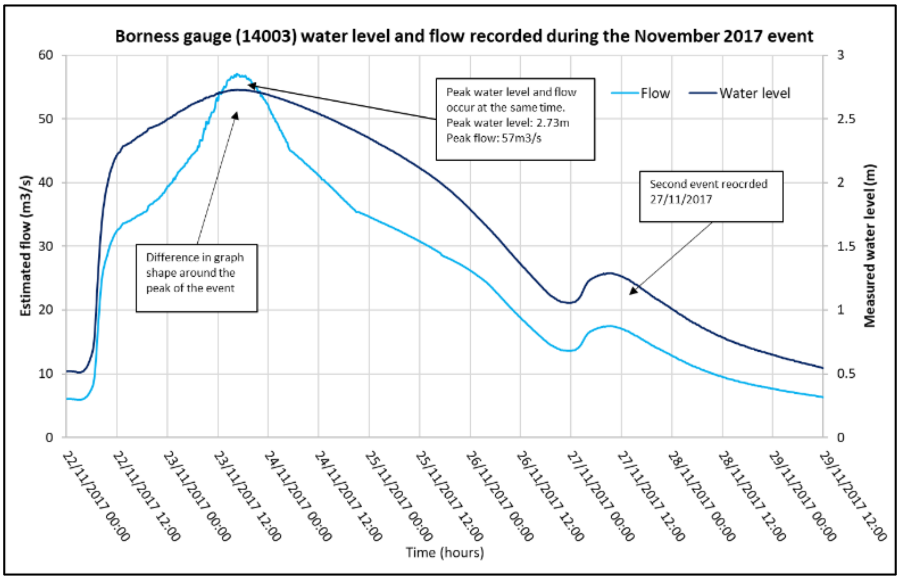
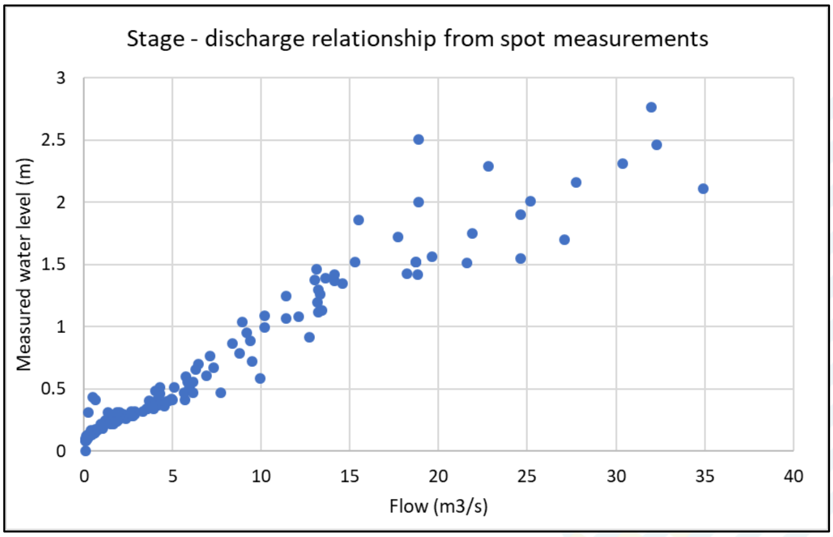
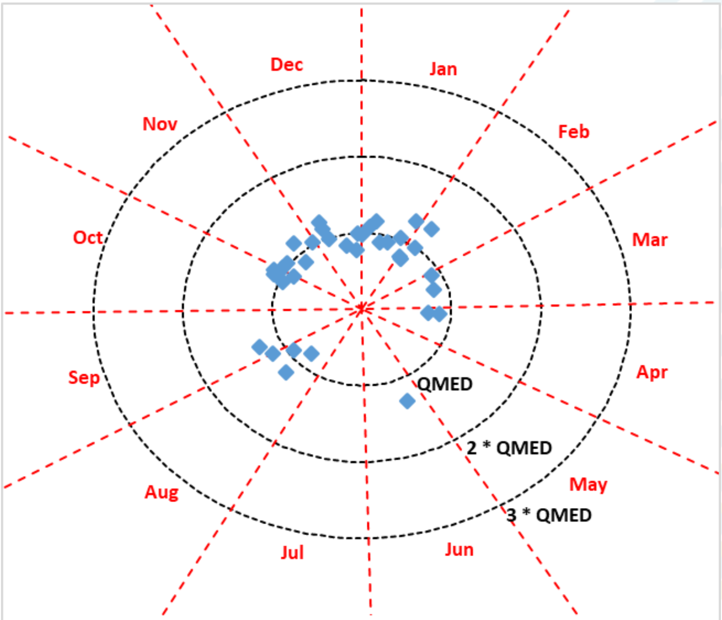
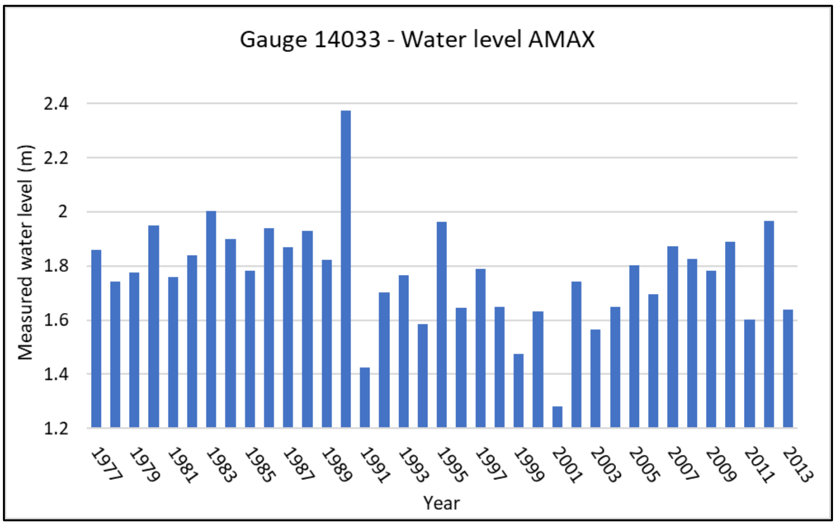
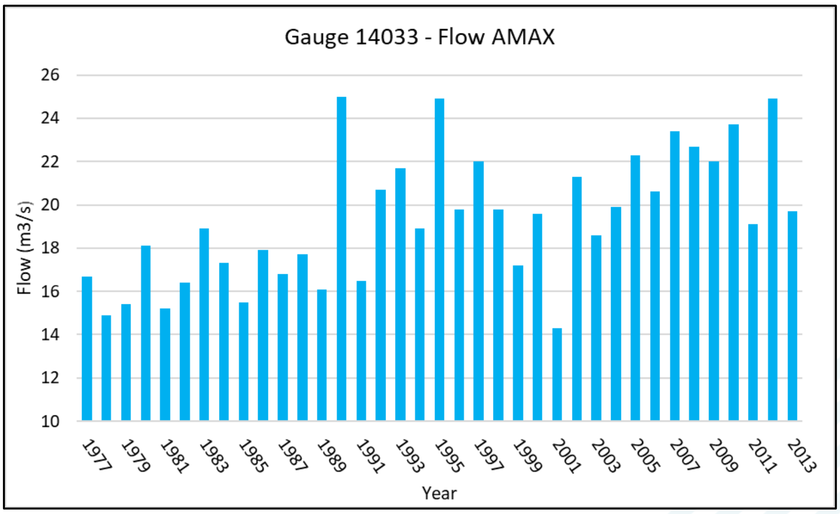
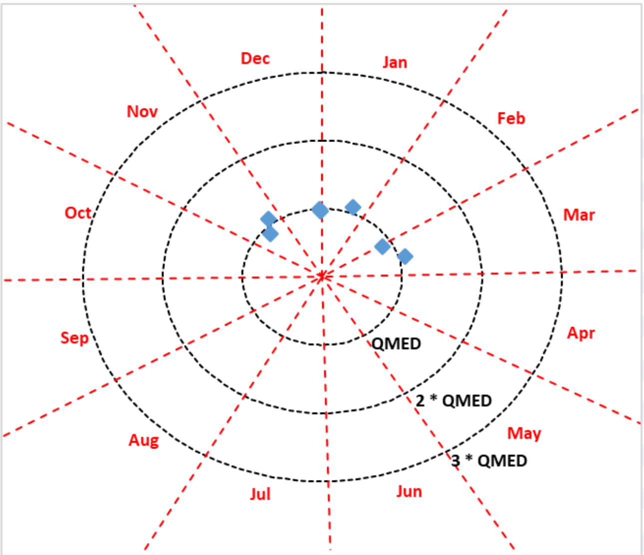
	the records.
2017 data	 The level logger at the gauge operated throughout the entire event recording the peak level on the Barrow. Using the SECFRAM rating curve the flow for the event on the Barrow can also be estimated. The hydrographs show a very steep rising limb at the beginning of the event. The falling limbs of the hydrographs are elongated with the water level and flow returning to the pre event levels approximately 6 days after the peak.
Notes	The gauge underwent a rating review as part of the SECFRAM study and used an OPW rating equation as its basis. However, no rating equation was provided by OPW for this study. The OPW state that their gauge rating is not reliable due to a large amount of scatter within the spot flow data. A gauging report was provided and the spot flow data is plotted below and highlights the scatter. An updated rating review for the gauge is discussed in Section 5. 

3.5.2 Mountmellick gauge (inactive)

Mountmellick Gauge	
Number	14033
Operator	EPA
Watercourse	Owenass
Catchment area	78.90km^2
Grid reference (NG)	245271 208226
Years active	1977 - 2013 (inactive, replaced by gauge 14114)
Gauge type	Velocity area station with level logger
	 Data logger housing and staff gauge
Data available	Water level and flow for 1977 – 2013 (flow estimated using rating curve)
FSU gauge classification	B
Rating review carried out?	NA
Seasonality	

AMAX series review	  The AMAX series is complete for the gauges entire active period. A full rating review has been carried for the gauge as part of this study and is discussed in Section 5
2017 data	Gauge not active during event
Notes	EPA website notes multiple changes to rating equation for the gauge due to works in channel. It is also recorded that the channel was drained in 1990. These changes and the inaccessibility of the gauge were why it was decommissioned and replaced with gauge 14114 in 2013.

3.5.3 Mountmellick Mill gauge (active)

Mountmellick Mill Gauge		
Number	14114	
Operator	EPA	
Watercourse	Owenass	
Catchment area	78.90	
Grid reference (NG)	645130 707411	
Years active	2013 – present	
Gauge type	Velocity area station with level logger (flow estimated using rating curve)	
	 Level logger location at channel edge	 Bridge structure directly upstream of gauge location.
Data available	15-minute water level and flow data	
FSU gauge classification	NA	
Rating review carried out?	NA	
Seasonality		

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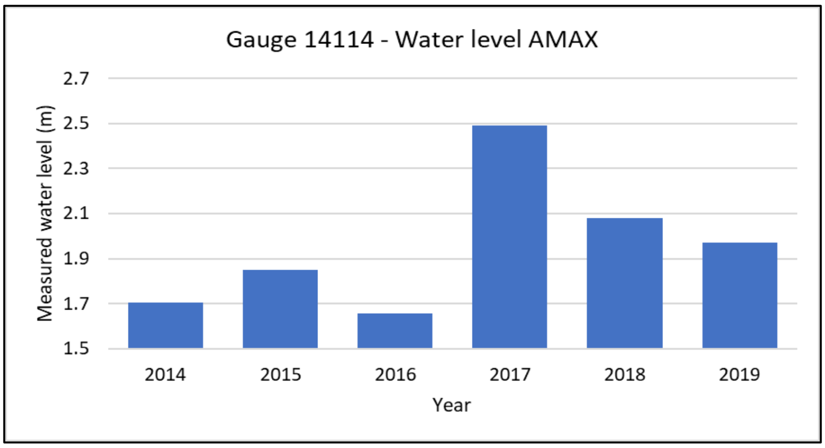

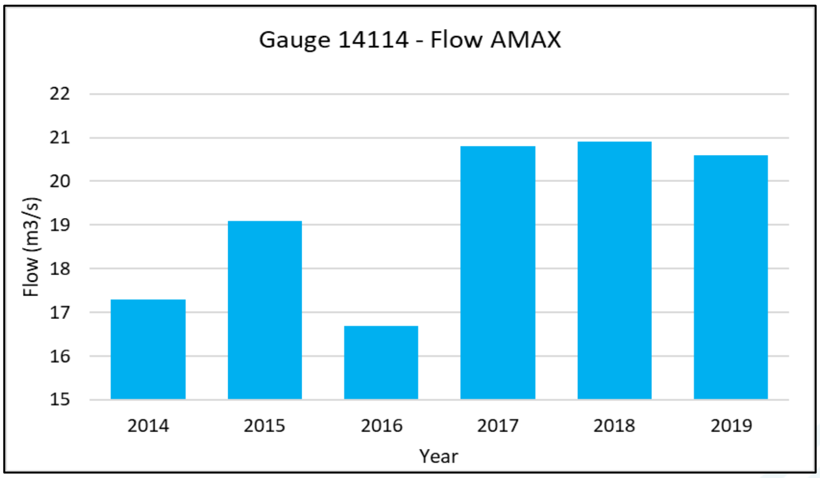

Gauge has only been active for 5 years therefore the AMAX record is short but there is no missing data or noted irregularities. There has been one revision to the rating equation following cleaning of the channel after the 2017 event.
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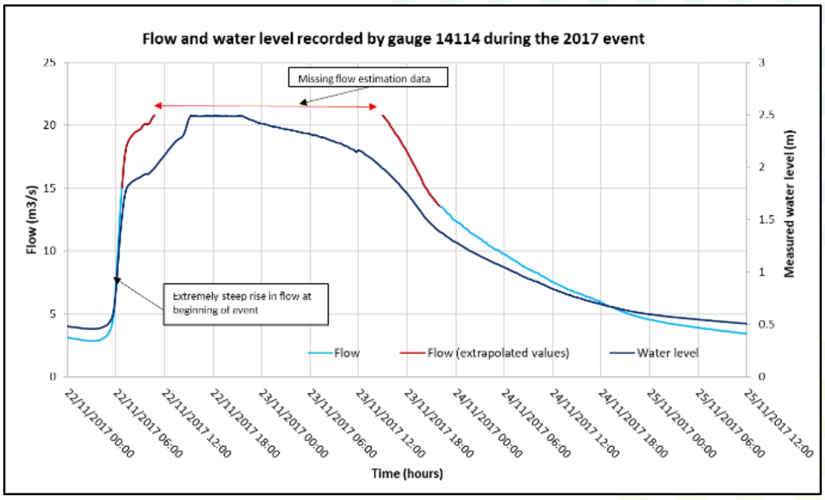
<tr>
<td>2017 data</td>
<td>
The gauge was active during the event however the recorded level at the peak plateaus. Initially it was thought that this was due to a gauge malfunction. However, further investigation and understanding of the hydraulic controls on the system showed this is due to the activation of the flood plain upstream of the gauge with level in channel remaining consistent as any additional flow is directed out of bank upstream. Flow and level at the gauge are restricted by this flood plain activation.
It is noted that the a large portion of the event hydrograph either side of the peak was extrapolated as the level rose higher than the maximum bound of the EPA rating curve (upper bound: 1.385m).


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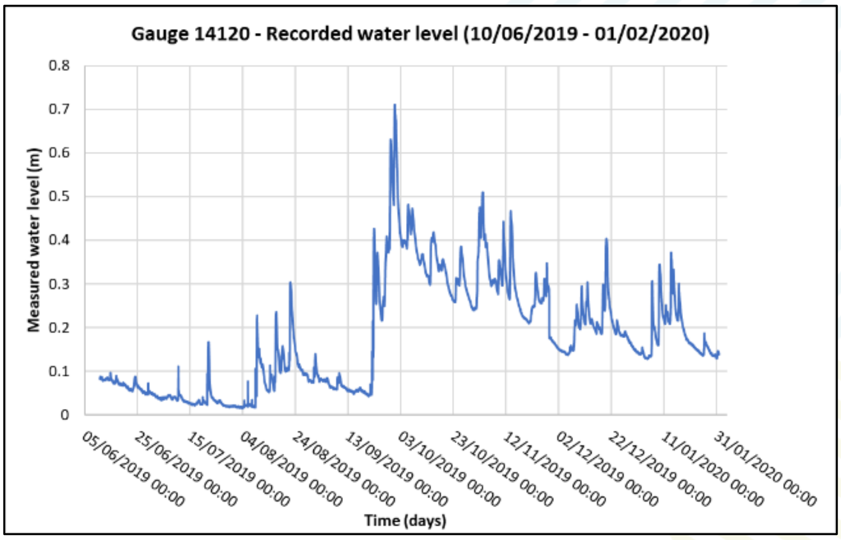
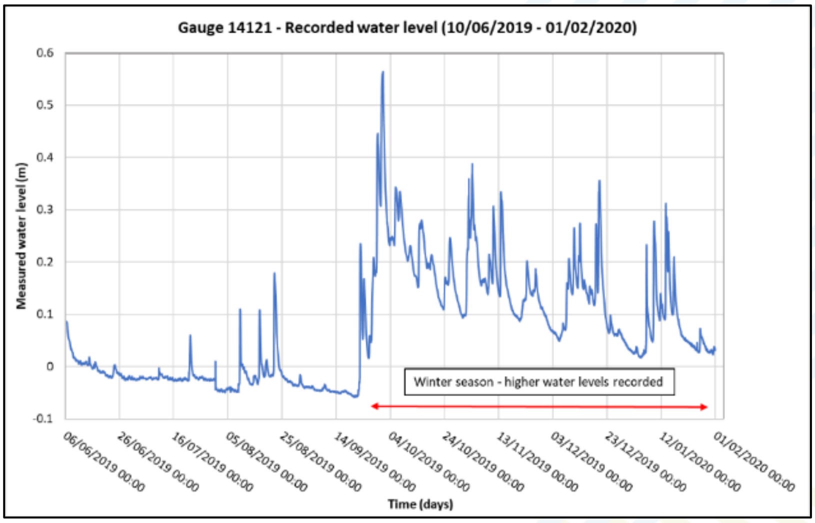
Notes	The gauge is restricted in recording higher flows and levels by the bridge directly upstream and the activation of flood plain during high flow events. It is located approximately 1.3km upstream of the location of inactive gauge 14033.

3.5.4 Chapel Street gauge (active)

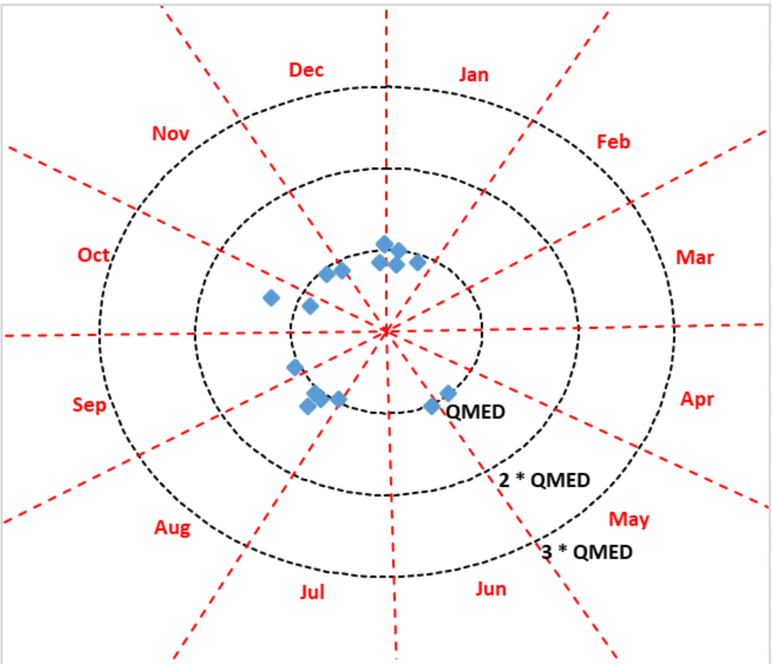
Chapel Street		
Number	14120	
Operator	OPW	
Watercourse	Pound	
Catchment area	12.68km^2	
Grid reference (NG)	644763 707486	
Years active	2019	
Gauge type	 Level logger gauge located on the downstream face of bridge.	 Bridge structure (image take facing upstream looking bridge face gauge is attached to).
Data available	Water level only (no rating curve equation established at time of study)	
FSU gauge classification	NA	
Rating review carried out?	NA	
AMAX series review	No AMAX series available at time of study – gauge too new 	

2017 data	Gauge not active during event
Notes	This gauge has been installed as a response to the 2017 flood event when significant flooding was caused by the Pound River, the watercourse was previously ungauged. The gauge is located on the downstream face of a rectangular bridge structure and upstream of a complex system of engineered channel and culverts.

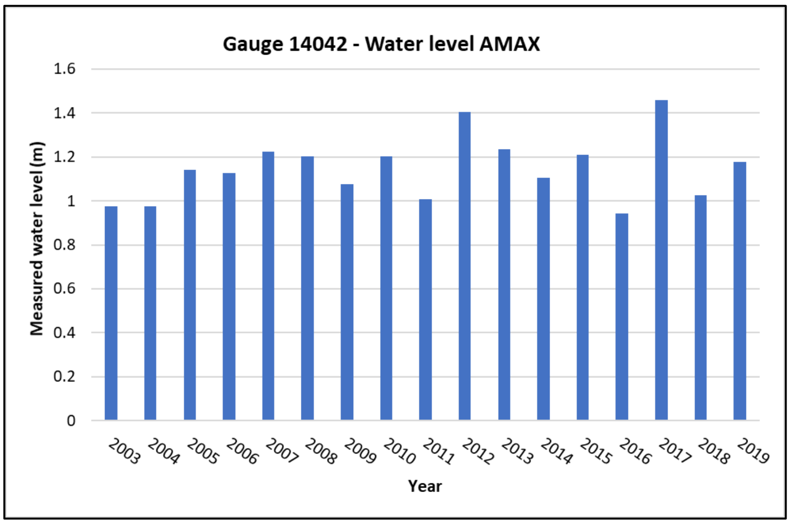
3.5.5 Manor Road gauge (active)

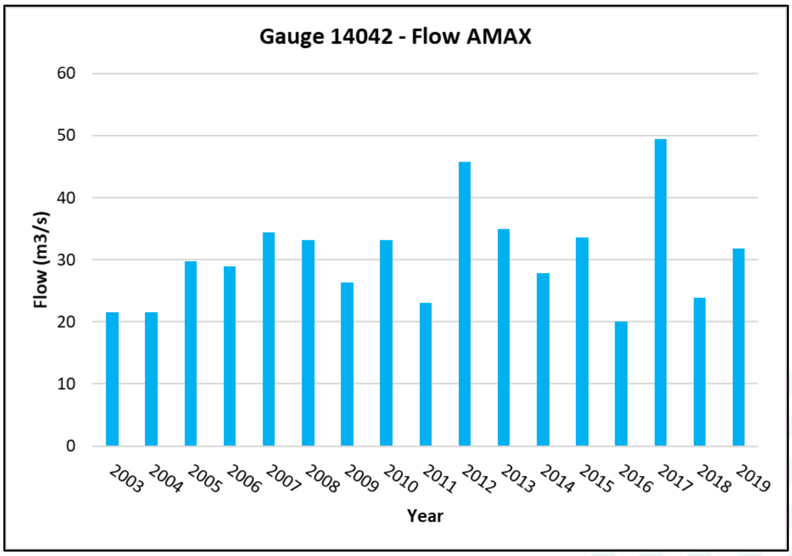
Manor road	
Number	14121
Operator	OPW
Watercourse	Pound
Catchment area	12.12km^2
Grid reference (NG)	244321 207402
Years active	2019
Gauge type	 Level logger gauge (image looking upstream). Gauge is located on the downstream face of bridge.  Bridge structure downstream of gauge (image take facing downstream on bridge gauge is attached to).
Data available	Water level only (no rating curve equation established at time of study)
FSU gauge classification	NA
Rating review carried out?	NA
AMAX series review	No AMAX series available – gauge too new 
2017 data	Gauge not active during event
Notes	Gauge installed as a response to the 2017 flood event, the watercourse was previously ungauged. The gauge is placed at the downstream face of a bridge and the confluence of the Pound and Garoon rivers is directly upstream of this structure.

3.5.6 Reary Valley gauge (active)

Reary valley		
Number	14042	
Operator	EPA	
Watercourse	Barrow	
Catchment area	32.60km2	
Grid reference (NG)	644262 707435	
Years active	2003 - present	
Gauge type	 Bridge at gauge location – looking downstream	 Staff gauge
Data available	15-minute water level and flow data	
FSU gauge classification	NA	
Rating review carried out?	NA	
Seasonality		

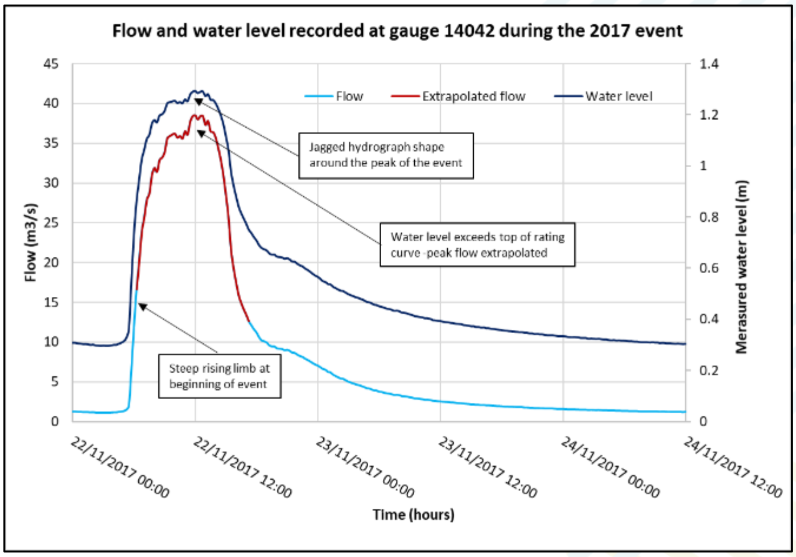
AMAX series review



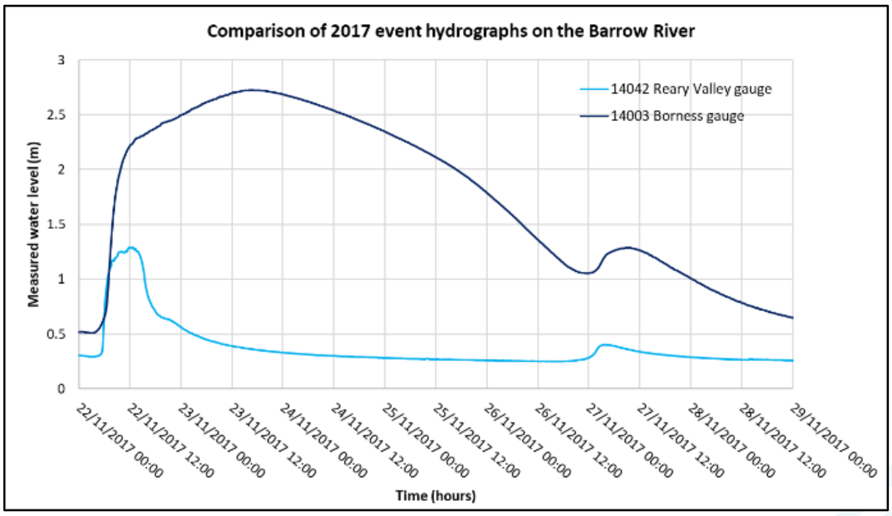


The AMAX series for the gauge is complete with no irregularities.

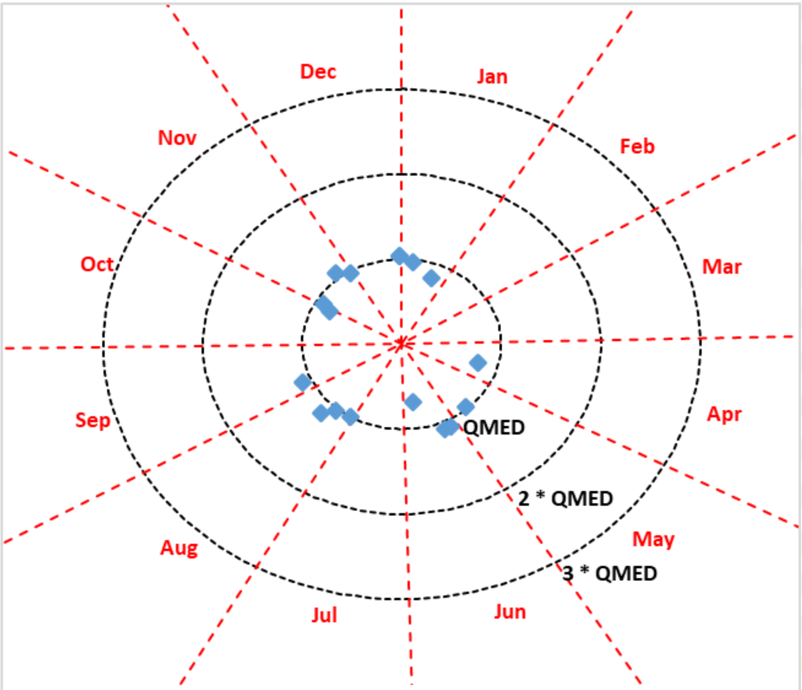
2017 data



The level logger at the gauge operated throughout the entire event recording the peak level on the Barrow upstream of Mountmellick. However, it is worth noting that drone footage and local reports during after the November 2017 event shows Tinnahinch bridge on the Barrow severely blocked with trees. This is likely to have had an impacted

	on the recorded gauge water levels. Like the other active gauges, the hydrographs show a very steep rising limb with water level and flow increasing rapidly at the beginning of the event. The peak water level and flow recorded at the gauge occur at the same time. The hydrographs have a jagged appearance around the peak of the event as water level and flow fluctuate. The water levels recorded in 2017 exceeded the top of the gauge rating curve hence nearly all the hydrograph levels are extrapolated. Comparing the responses of the two gauges on the Barrow, gauge 14042 shows a flashier response to the rainfall event which is reflective of its upper catchment location and smaller catchment size. Gauge 14003 shows a longer hydrograph duration and a larger response due to its location further downstream and significantly larger catchment size. There is little to no difference in timing of the initial river response between the upstream and downstream gauges highlighting the short amount of time it takes rainfall to reach the river. 
Notes	The peak 2017 water level for the gauge was not recorded during the 2017 flood event but during an event in October 2017. There is no reported flood event in Mountmellick associated with this October event. Although no formal gauge rating review has been carried out for this gauge its data record is considered to be of sufficient quality for use as in examining the timing and indicative scale of flood events.

3.5.7 Brackanagh Bridge gauge (active)

Brackanagh		
Number	25301	
Operator	OPW	
Watercourse	Clodiagh (Tullamore)	
Catchment area	27.10km²	
Grid reference (NG)	233163 214580	
Years active	2002 - present	
Gauge type	 Staff gauge with level logger placed on DS face of bridge	 Bridge structure
Data available	15 minute water level records	
FSU gauge classification	NA	
Rating review carried out?	NA	
Seasonality		

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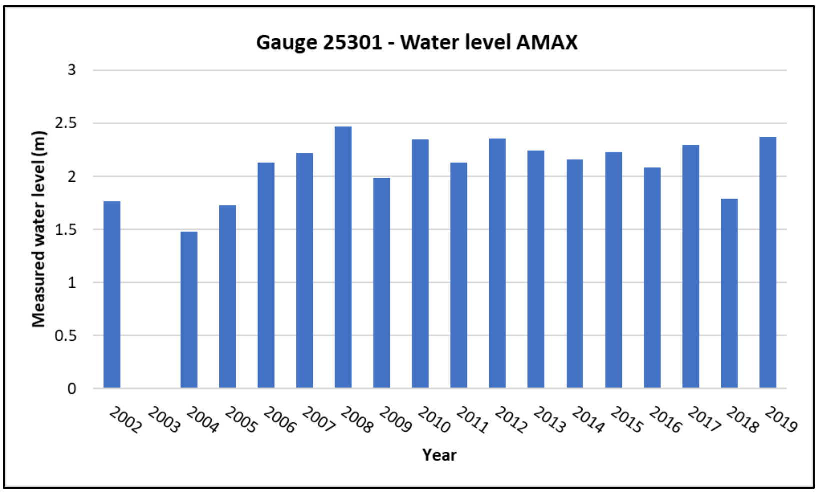
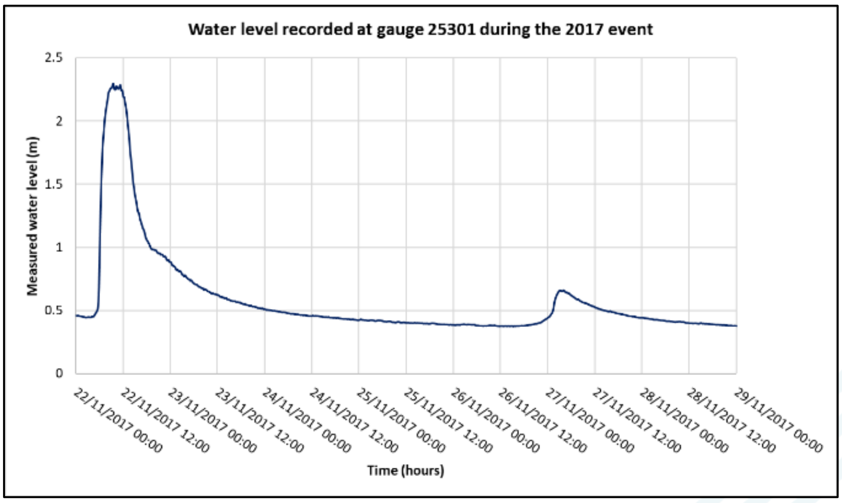


There is one year of missing data in the series (2003) otherwise the AMAX record is complete with no notable irregularities.</td></tr>
<tr><td>2017 data</td><td>


The gauge was active during the November 2017 event. The hydrograph recorded highlights the flashy regime of the gauged catchment. Both the rising and falling limb are steep with the levels returning to normal 24 hours after the start of the event.</td></tr>
<tr><td>Notes</td><td>There is no flow data available for this gauge</td></tr>
</table>

3.5.8 Top five recorded AMAX events

Table 3-9 show the top five recorded water levels for the gauged watercourses near Mountmellick (Barrow and Owenass) from the available AMAX records.

For both the Barrow and Owenass the peak water levels were recorded in 2017. Otherwise there is variation as to when the peak AMAX levels were recorded (note Reary Valley gauge was only established in 2002). From comparing the top 5 AMAX levels at the gauges the following conclusions are drawn:

- The watercourses respond differently to events as highlighted by the fact that the peak levels recorded for each gauge are not for the same event;
- Gauge location influences the response recorded;
- Seasonality is noted within the gauges with most of the AMAX levels being recorded in the Winter months. However, there are a number of AMAX values recorded in August/September – this time of the year is often noted as wet period.

- The presence of seasonality within the record indicates channel roughness and antecedent conditions are important in the consideration of overall flood risk;
- Flood risk is greatest when multiple watercourses are affected by the same storm event indicating that joint probability is a key factor in flood risk (e.g. 1990 and 2017 flood events);

Table 3-9: Top five AMAX water levels recorded at the available gauges

	Borness (14003)		**Reary Valley (14042)**		**Mountmellick – Owenass (14033+14114)**		**Brackanagh Bridge (25301)**	
AMAX rank	Year	Peak (m)	Year	Peak (m)	Year	Peak (m)	Year	Peak (m)
1	2017	2.73	2017	1.46	2017	2.49	2008	2.47
2	1990	2.72	2012	1.41	1990	2.37	2019	2.37
3	2015	2.64	2013	1.23	2018	2.08	2012	2.36
4	2008	2.58	2007	1.23	1983	2.00	2010	2.35
5	1995	2.56	2015	1.21	2012	1.97	2017	2.30

3.6 Groundwater activity

There has been no recorded groundwater flooding. However, a resident of Manor Court has noted that subsidence / potholes have appeared along the road and public spaces following the 2017 flood event, along with cracks appearing on communal walls. These may be indicative of localised groundwater activity.

3.7 Urban drainage

The brief for the FRS does not include for a full survey of the storm drain network. However, it is noted that any flow contribution that it makes to the watercourses is hydrologically relevant, and the scheme will have to take account of any outfalls and overland flow paths or result in surcharging of the drainage system.

It was intended that a review of the pipe network and outfall locations would allow urban catchments to be defined, and the modified rational method to be applied to estimate the urban hydrology for the town. This would then be input into the model and used to understand where the scheme would need to account for linkages into the river system.

Laois County Council provided outfall locations along the Pound and Owenass Rivers which had previously been surveyed by in-house engineers. A total of 24 storm water outfalls discharge into the Pound and Owenass Rivers (refer to Figure 3-8).

LCC also provided pdf copies of Irish Water infrastructure for the town. This included detail of the sewer network and a number of 'unknown' pipes with no obvious outfall / connections. There was no indication of combined or surface water networks on the drawings.

After being in contact with Irish Water to obtain further data with regards to the network systems in Mountmellick, they informed us that they do not hold stormwater data (and had no knowledge of combined systems) and suggested contacting the local authority for the stormwater data.

Follow up with the local authority, found that there is no further information in relation to the stormwater network within Mountmellick.

Any assumptions made in determining outfall and overflow location, coupled with a topographically driven catchment, could have a high degree of uncertainty in the absence of supporting information.

In the absence of certainty over the combined and foul system, including the location of outfalls and overflow points, a scoping rain-on-grid model was developed for Mountmellick. In this model, design rain events were 'poured' onto the DTM with a view to identifying low points, where ponding would occur, and associated overland flow routes. The model was run on the assumption that a certain amount of capacity is available within the piped network, and also with the piped network full. Given the reports of the system backing up at relatively low return period rain events, this latter scenario is probably most realistic. This model run identified flow routes into the river.

The impact of surface water flooding will be investigated in conjunction with the emerging preferred options, with a view to determining where flow paths will be blocked and to give an idea of volumes that will need to be managed through the scheme design. However, management is likely to involve pumping so actual catchments will need to be determined to see what will be intercepted and to appropriately size the pumps. This will need a sewer model, or for the provision of a new SW system in Mountmellick as part of the scheme, which is not part of this initial recommendation.

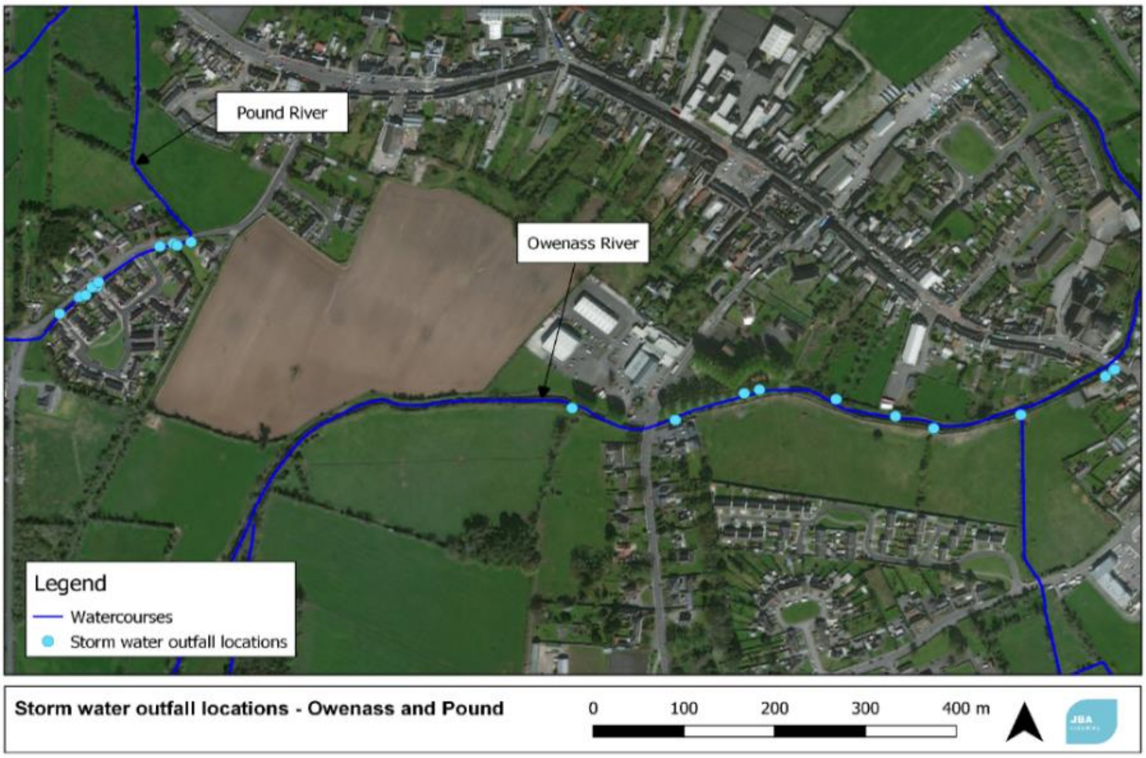


Figure 3-8: Storm water outfall locations – Owenass and Pound

3.8 Flood History

This section reviews the major flood events recorded in Mountmellick up to the time of writing. The events are discussed in chronological order.

3.8.1 October 1954

Records from the Irish Independent state the River Barrow burst its banks resulting in flooding in the Mountmellick area.

3.8.2 December 1968

Flooding recorded when the Barrow burst its banks, the event is remembered as severe by residents with some properties flooded.

3.8.3 February 1990

February 1990 is noted by MET Eireann as a particularly wet and windy period. Several newspaper articles describe flooding in Mountmellick and the surrounding area. There is mention of heavy rainfall occurring in the days prior to the main flood event, indicating wet antecedent conditions. Figure 3-9 shows the hydrographs recorded at the gauges that were active during the event.

There is approximately 24 hours difference between the response times on the Owenass and Barrow. Both rising limbs recorded are steep but high water levels on the Owenass and Barrow were maintained for an extended period after the peak of the event.

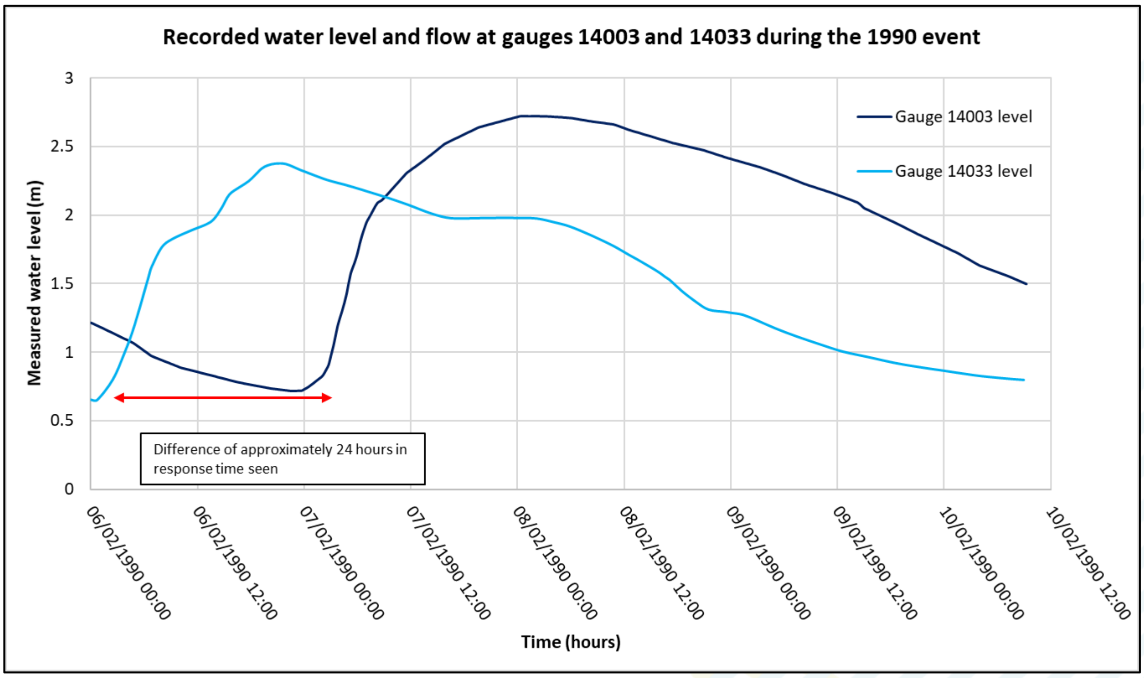


Figure 3-9: Recorded water level and flow at gauges 14003 and 14033 during the 1990 event

3.8.4 August 2008

Flooding of fields north of Mountmellick town occurred due to the River Barrow bursting its banks; Figure 3-10 shows an aerial photograph of the area affected the day after the flood event. No properties were recorded as damaged.

Figure 3-11 and Table 3-10 show the catchment conditions, before, during and after the event in relation to catchment wetness.

Figure 3-12 shows the hydrographs recorded during the event at the active gauges. Peak water level recorded on the Owenass is not exceptionally high compared to other flood events. There is no mention of the Owenass or any other watercourse overtopping during this event indicating that flooding was limited to the Barrow.

Figure 3-10: Aerial image of area affected by the 2008 flood event (source: floodmaps.ie)

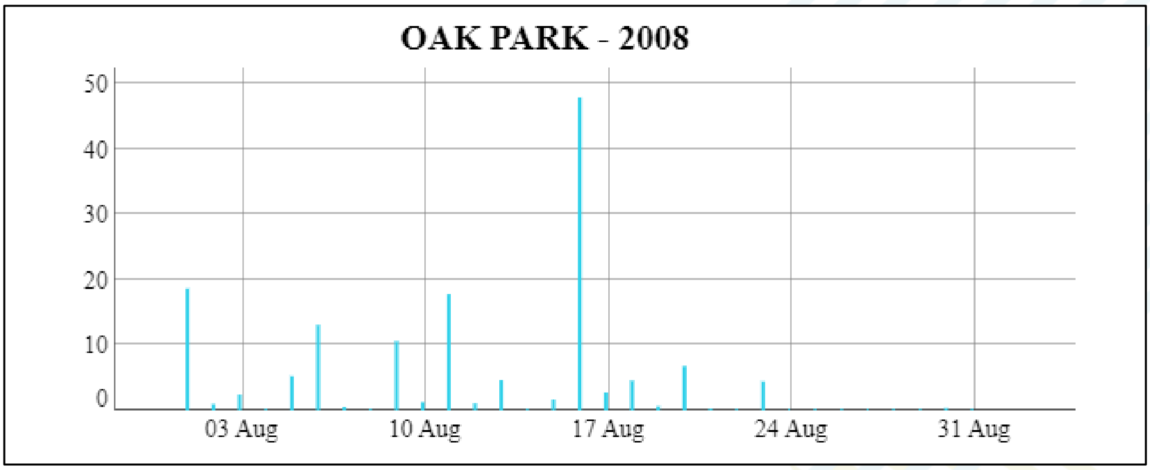


Figure 3-11: Daily rainfall recorded at Oak park weather station – August 2008

Table 3-10: SMD values (in mm) recorded over the August 2008 event

Soil type	14/08/08	15/08/08	16/08/08	17/08/08	18/08/08	19/08/08
Well drained	3.1	3.4	0.0	0.0	0.0	1.6
Moderately drained	3.1	3.4	-10.0	-1.0	-2.7	1.6
Poorly drained	-6.4	-5.7	-10.0	-10.0	-10.0	-7.9

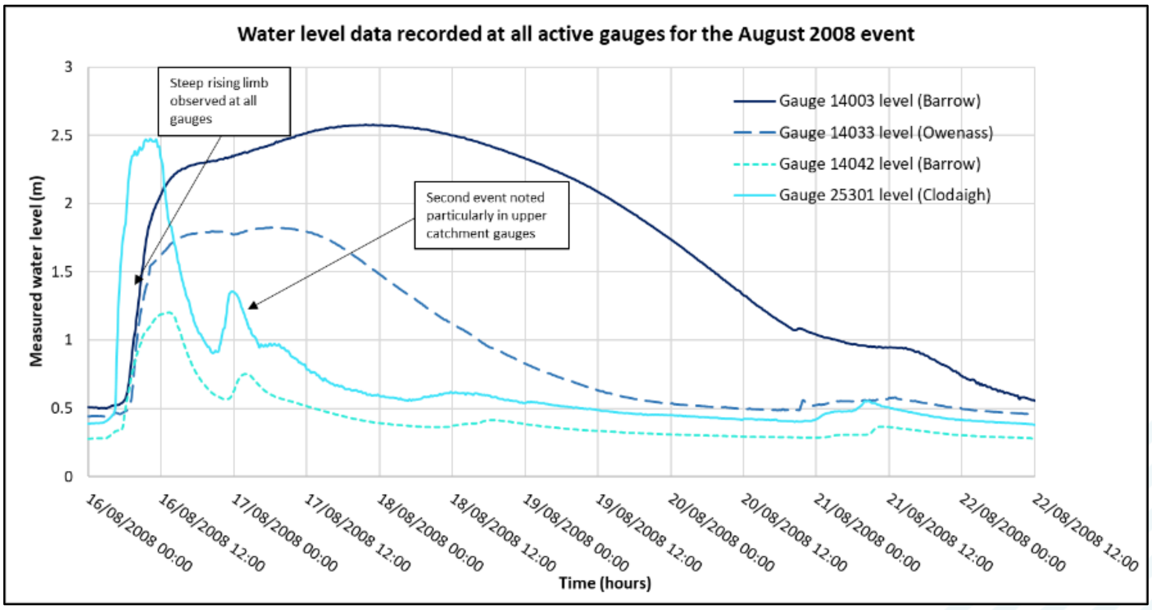


Figure 3-12: Water level data recorded at all active gauges for the August 2008 event

3.8.5 November 2017

Severe flooding was recorded within Mountmellick town and the wider Laois county area on the 22nd November 2017. It is considered the most damaging flood event to have occurred in the area, with over 80 properties affected.

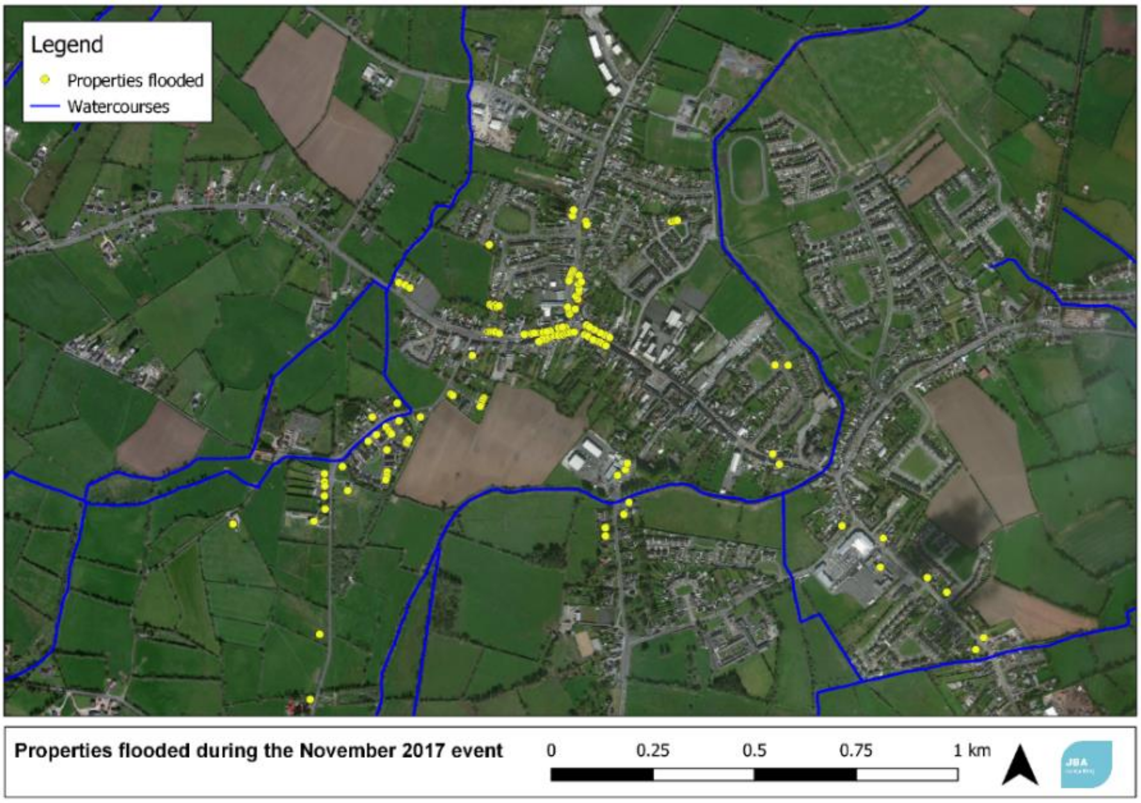


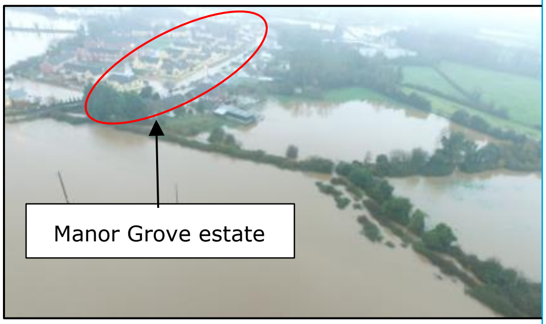
Figure 3-13: Properties flooded during the November 2017 event (source: LCC and OPW)

Following a 9-hour rainstorm over the area, multiple watercourses burst their banks resulting in large amounts of overland flow moving through the town and surrounding area. Eyewitness reports talk of flood levels rising within a short timeframe which is consistent with the data recorded at the gauges within or near the town (refer to Figure 3-15). The Mountmellick Mill gauge (14114) on the Owenass has a flattened hydrograph peak due to increased spill into the flood plain upstream of the gauge resulting what appeared to be a gauge malfunction around the peak of the event. The water levels and extents resulting from the flood event are greater than those predicted in the SECFRAM 0.1% AEP modelled event.

Eyewitness reports detail properties flooding from combined pluvial and fluvial sources and the surcharging of storm water systems. It is recorded that flooding around Davitt Road to the south west of the town was a result of only pluvial sources. Blockage of the Convent Bridge was also reported and is evident in photographs of the event (refer to Figure 6-14).

Figure 3-14 shows images of the affected areas taken on the 22nd and 23rd of November. Water levels were slow to recede with several roads still blocked days after the event.

It appears that the event was reasonably localised; the downstream gauge at Portarlington (14005) rose close to its peak record, but there was only a small rise at Pass Bridge (14006) in Monasterevin.



Nov 22nd (approximately 4pm, around peak of the event). Photograph taken facing south west looking towards flooding in Manor Grove estate (yellow houses)

Nov 22nd (approximately 4pm around peak of the event). Photograph taken facing south looking at flooded fields past Manor Grove estate (Yellow houses)

Nov 23rd (time unknown). Photograph taken facing south east looking at flooding at the HSE Occupational Therapy Store (square white building) and adjacent fields and properties

Nov 23rd (time unknown). Photograph taken facing east looking at flooding of fields and properties within the centre of Mountmellick (St Joseph's Church to the left of the image for reference)

Figure 3-14: Images of areas flooded during the November 2017 event

Figure 3-15 shows the data recorded by the active gauges in the area during the event. The gauges show a quick initial response to the rainfall event. Peak water level on the Barrow at the Borness gauge was recorded approximately 24 hours after the estimated time on the Owenass. Water levels remained high on both watercourses for an extended period of time. Refer to Sections 3.3.3, 3.3.4, and 3.4 for discussion on the precipitation and catchment conditions for the November 2017 event.

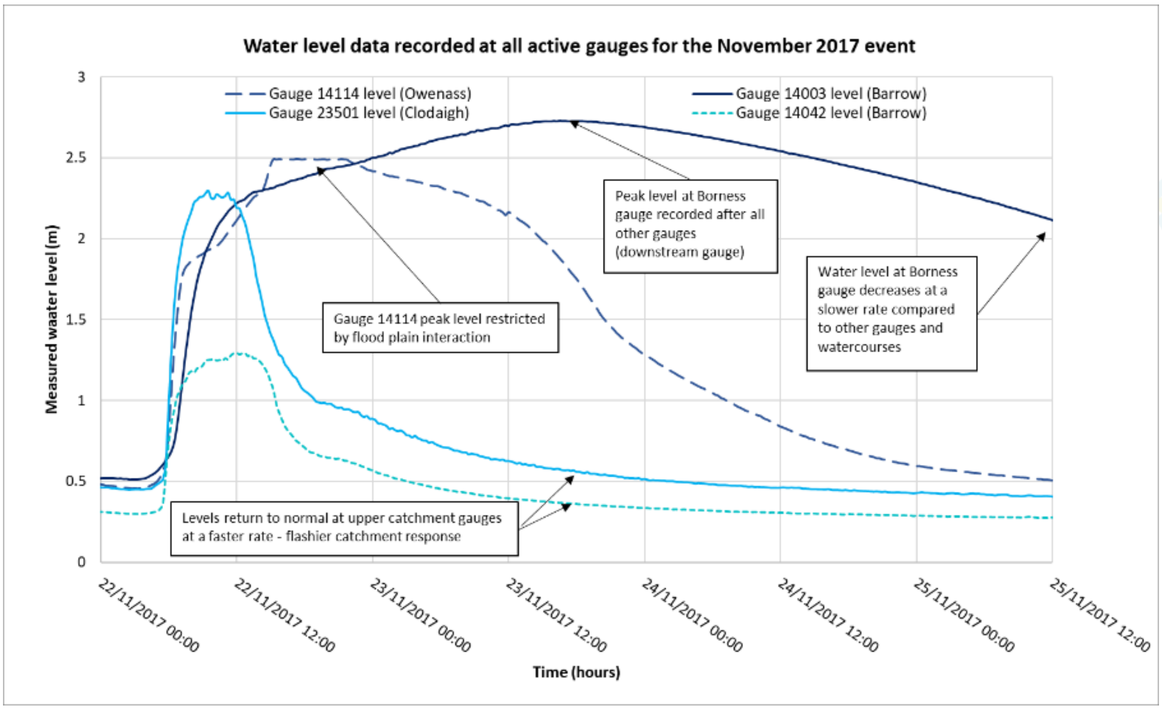


Figure 3-15: Water level data recorded at all active gauges for the November 2017 event

3.8.6 February 2020

3.8.6.1 Storm Ciara (8-9th February)

Flooding was recorded in Mountmellick following strong winds and intense rainfall between the 8-9th February as a result of Storm Ciara, refer to Table 3-11 for rainfall data. Flooding was recorded within Mountmellick town and wider area as well as other locations within Laois county. One derelict property was reported as flooded immediately downstream of the Owenass Bridge, and two properties were evacuated as a precautionary measure. The N80 road was inundated and closed for several hours.

Table 3-11: Recorded rainfall (in mm) from the nearest sub-daily gauges during the Storm Ciara 2020 event

	07/02/2020	08/02/2020	09/02/2020	10/02/2020	11/02/2020
Oak park	0.8mm	13.9mm	23.0mm	13.5mm	7.0mm
Mullingar	1.8mm	4.1mm	26.2mm	4.1mm	7.6mm
Gurteen	1.3mm	8.6mm	37.6mm	11.7mm	4.8mm
TII Portlaoise	0.0mm	0.4mm	9.9mm	8.7mm	5.8mm
TII Mountrath	0.0mm	1.0mm	7.6mm	12.2mm	0.4mm

Refer to Figure 3-16 for the recorded data for the relevant hydrometric gauges for the event. It is noted that the water levels prior to the event were lower than what would generally be expected during February and had the water levels been higher before the event flooding of properties would have occurred.

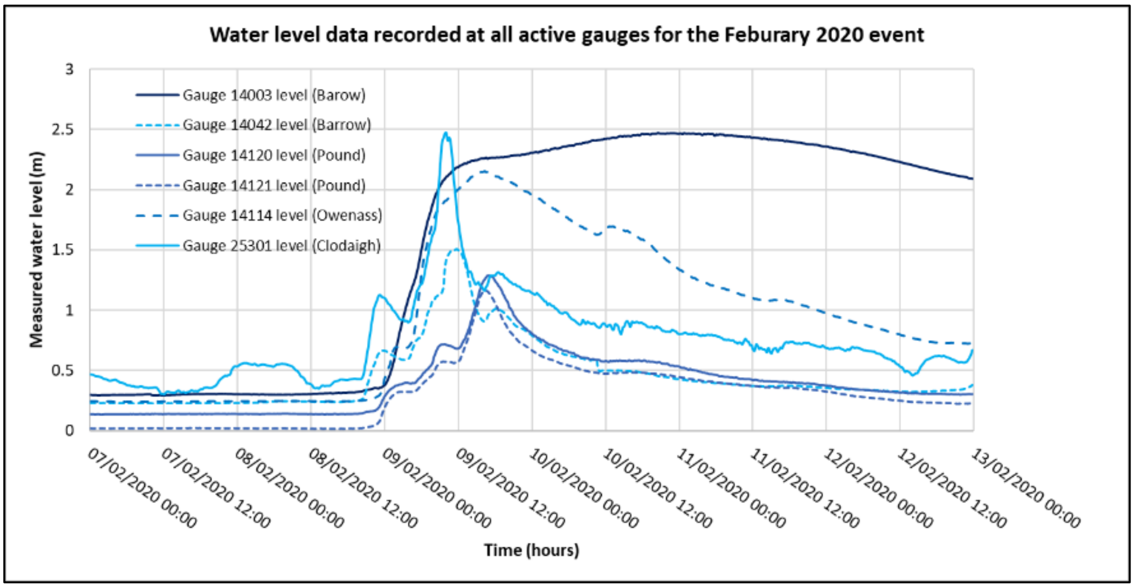


Figure 3-16: Water level data recorded at all active gauges for the Strom Ciara

3.8.6.2 Other February storm events

Two other storm events of note occurred during February 2020, Storm Dennis (15th-17th) and Storm Jorge (29th). While neither of these events resulted in any reported flooding within Mountmellick or the surrounding area, high water levels were recorded at all active gauges. Eyewitness reports describe the river levels being dangerously close to spilling with property level protection (sandbags etc) being deployed as a cautionary measure.

3.8.7 Summary of flood history

From review of the flood history the following observations have been noted:

- Wet antecedent conditions appear to be a critical factor with most flood events coinciding with prolonged periods of rainfall.
- In some events only the River Barrow is recorded to have flooded while in others multiple rivers were affected. Those events where multiple rivers are involved are shown to be the most severe in Mountmellick.
- Some of the highest peak water levels and flows recorded in the available gauge AMAX records are not recorded as significant flood events (e.g. 1995 and 2010 – refer to Table 3-9).
- The gauged watercourses in the area respond rapidly with steep rising hydrograph limbs seen for all major flood events where records are available.

Using the Gringorten Flood Frequency Analysis formula the following return periods for events:

- October 1954: Estimated to be between a 25% and 33% AEP event
- December 1968: Greater than 4% AEP event
- February 1990: Estimated to be between a 2% and 1%AEP event
- November 2017: Greater than a 1% AEP event
- February 2020 (Storm Ciara): Greater than 4% AEP event

The August 2008 event was not included as it was a Barrow only event.

3.9 Recommendations

3.9.1 Sub-daily rain gauge

At the start of this study, there was no raingauge within Mountmellick or the immediate catchment. In recent months, a gauge has been installed at the fire station, but it has limited maintenance requirements, and the long term quality assurance system is unknown.

It is recommended that the fire station rain gauge be formalised and a QA regime be implemented to ensure the data recorded is of suitable quality. In addition, two new gauges are recommended in the upper catchment areas of the Pound and Owenass systems to improve the rain gauge network in the area and allow the relationship between rainfall and flood response to be measured and understood.

The sites must be level and the surrounding ground should be uniform. The ground should preferably be grassed or loose earth. No object such as another instrument, building or trees should be closer than four times their height. Very exposed sites, such as on the top of a hill, should be avoided. For very exposed sites without any natural shelter rain gauge shields are sometimes used. The rain gauge should be firmly mounted on a concrete base. The rim of the rain gauge must always be horizontal. The site must also be secure and accessible. Figure 3-17 shows recommended locations for the additional raingauges and potential existing secure lands where they could be placed. However final placement of the gauges is dependent on land availability, landowner engagement, and security.

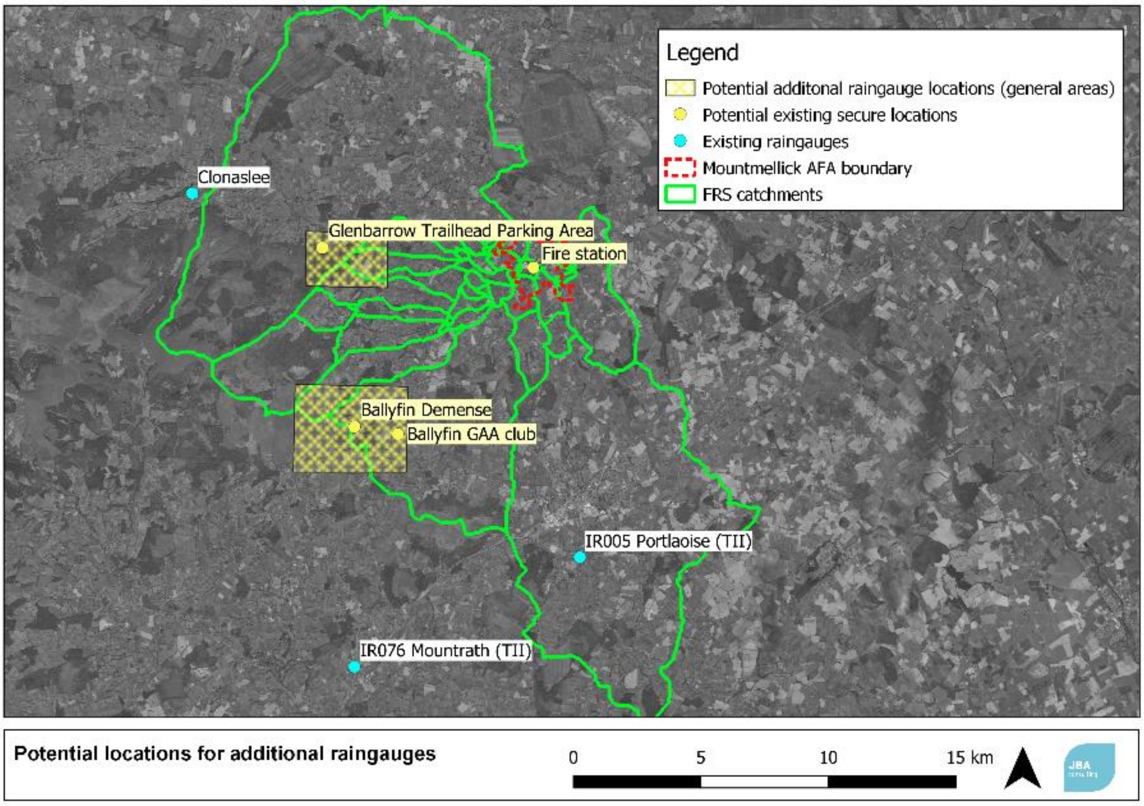


Figure 3-17: Potential locations for additional raingauges

3.9.2 River Owenass flow gauge

As has been shown in both the 2017 and 2020 event, the Mountmellick Mill (14114) gauge is not appropriately located. It is located immediately downstream of a bridge and at a point downstream of where considerable spill occurs into the floodplain resulting in a flattening at the top of the recorded hydrographs. Further, it is considered that there is interaction and cross-channel flow between the Owenass and Pound rivers, which is indicated on the flow record of the gauges on the Pound, but not picked up on gauge 14114. An additional gauge, located further upstream in the catchment, would be helpful in assessing flow splits and monitoring this interaction. A location close to but somewhat upstream of the Owenass Bridge is suggested so the hydraulic impact of the bridge does not impact the gauge readings (minimum distance of 600m upstream recommended to ensure no backwater impacts).

4 Review of SECFRAM Hydrology

4.1 Overview

The first draft of the SECFRAM Hydrology Report was released in 2013 with the final report and flood maps released in 2016. This section reviews the SECFRAM hydrology and highlights new information available or changes in the catchment that have occurred since its completion.

4.2 Flow Estimation Methods – Qmed Estimation

Flow estimation was carried out for 27 Hydrological Estimation Points (HEPs) in the SECFRAM Model 5 area.

Of the 27 HEPs 9 were created for the SECFRAM study all others were sourced from the FSU ungauged location node database which was the source of the catchment descriptor data. Refer to Appendix A for the HEP catchment descriptors.

AEP event flows were calculated for each HEP; Figure 4-1 shows the SECFRAM Qmed values. The Flood Studies Update catchment descriptor-based equation (FSU PCD) was used as the estimation method for all but four HEPs. Nodes 14_880_Trib and 14_1547_2 are both minor flow check points and 14033_RPS and 14003_RPS refer to gauges.

The FSU PCD method was the recommended approach for Qmed estimation in all ungauged catchments for the CFRAM studies (refer to Guidance Note 21 - CFRAM guidance note on flood estimation for ungauged catchments).

Two gauges were operational in the Model 5 area during the SECFRAM study; the Borness gauge (14003) and the Mountmellick gauge (14033) on the Barrow and Owenass respectively. Only the Borness gauge underwent rating review in the study.

According to the SECFRAM documentation the estimated Qmed values were adjusted using adjustment factors derived from the available gauges where appropriate. However, there is no mention of which HEPs were adjusted.

Node ID_CFRAMS	AREA (km^2)	Q_{med} (m^3/s)	Preferred Estimation Methodology
14_871_U	2.79	0.75	FSU
14_872_U	0.09	0.03	FSU
14_872_1	0.16	0.06	FSU
14_1037_2_RPS	104.29	16.84	FSU
14_1845_3_RPS	11.17	2.56	FSU
14_445_U	0.46	0.18	FSU
14_445_1	0.72	0.28	FSU
14_1701_1_RPS	12.22	2.62	FSU
14_1038_1_RPS	12.94	2.69	FSU
14_1038_4_RPS	13.97	2.85	FSU
14_273_2_RPS	72.71	26.91	FSU
14_1495_U	3.46	0.3	FSU
14_1495_2_RPS	4.95	0.45	FSU
14_1547_2	1.38	0.12	
14_880_Trib	3.18	0.31	
14033_RPS	82.65	29.70	Gauge
14_1718_9_RPS	83.07	28.27	FSU
14003_RPS	209.50	34.39	NAM
14_1024_2_RPS	19.20	2.19	FSU
14_1018_1_RPS	83.79	10.69	FSU
14_1498_U	0.35	0.07	FSU
14_1729_U	0.02	0.00	FSU
14_859_1	0.40	0.08	FSU
14_855_1	1.43	0.08	FSU
14_1014_2_RPS	1.84	0.4	FSU
14_1028_2_RPS	112.78	13.43	FSU
14_286_3_RPS	347.02	47.79	FSU

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input flows

Figure 4-1: SECFRAM HEP Qmed values (source: SECFRAMs Hydrology Report pg. 53. F03)

4.2.1 Review of SECFRAM Qmed estimation methods

Review of the documentation has shown the estimation of Qmed has been carried out appropriately given the proposed methods and guidance for the CFRAM programme.

Given the size of the study area and the aim of the SECFRAM study to give an assessment of flood risk over the entire area the spacing of the HEPs is considered appropriate.

The Qmed for all but four HEPs was estimated using the FSU PCD method. The FSU PCD method is recommended for catchments with areas greater than 25km^2. 19 of the 27 HEP catchments are less than 20km^2 with 14 catchments being less than 5km^2. It is not recommended to use the equation for catchments it is not designed for and in these cases alternative approaches may be appropriate. Table 4-1 shows a comparison of Qmed values generated using other methods designed for small catchments. Although the FSU PCD method was the recommended approach within the appropriateness of the method for the smaller catchments needs to be considered.

Table 4-1: Comparison of small catchment method Qmed estimations

HEP node	Catchment area	SECFRAM FSU	FSU Small Catchments	IH124	FSR RR (uncalibrated regression)
14_1547_2	1.38	0.12	0.50	0.30	0.21

4.3 SECFRAM rating review – Borness gauge (14003)

The Borness gauge on the River Barrow was the only gauge within Model 5 to undergo a rating review as part of SECFRAM. A rainfall runoff model was used to generate inflows. The input rainfall data was calculated using an area weighting of hourly rain data from the closest rain gauges.

Figure 4-2 shows the rating equation values generated by the SECFRAM rating review. The updated curve extends the existing OPW rating curve available at the time. The SECFRAM Hydrology Report mentions the bridge at the gauge location causes a significant hysteresis effect. The stage-discharge curve indicates a change in rating behaviour when water levels reach around 2.40m (approximately 0.40m below bridge soffit level).

Section	Min Stage (m)	Max Stage (m)	C	a	b
1	0.040	0.378	38.30	-0.040	1.996
2	0.378	1.650	9.00	0.250	1.540
3	1.650	1.955	30.68	-1.210	0.290
4	1.955	2.400	8.00	0.520	1.390
5	2.400	2.635	8.00	-0.430	2.190
6	2.635	2.780	8.00	-1.070	3.880
7	2.780	2.860	8.00	-1.380	6.200

Where: $Q = C(h+a)^b$ and h = stage readings (metres)

Note: Sections 1 and 2 are existing OPW rating curve segments. The maximum stage value for section 2 has been adjusted from 0.945m to 1.650m.

Figure 4-2: SECFRAM rating curve equations (source: SECFRAM Hydrology Report Appendix C pg. 3)[2]

From the rating review, the updated rating curve was applied to the available AMAX series giving an AMAX Qmed value of 33.14m^3/s and a gauged Qmed value of 34.39m^3/s. This value is approximately 15m^3/s lower than the predicted Qmed value for the catchment generated by the FSU physical catchment descriptor equation estimation (50.94m^3/s). Figure 4-3 compares the pre and post rating review AMAX flow series from 1979 – 2010. It is noted that the previous OPW rating curve equations used to generate flows are no longer being released due to uncertainty within the rating.

2 The note below the table is taken directly from the CFRAM report and the reason for the adjustment is not provided within the CFRAM.

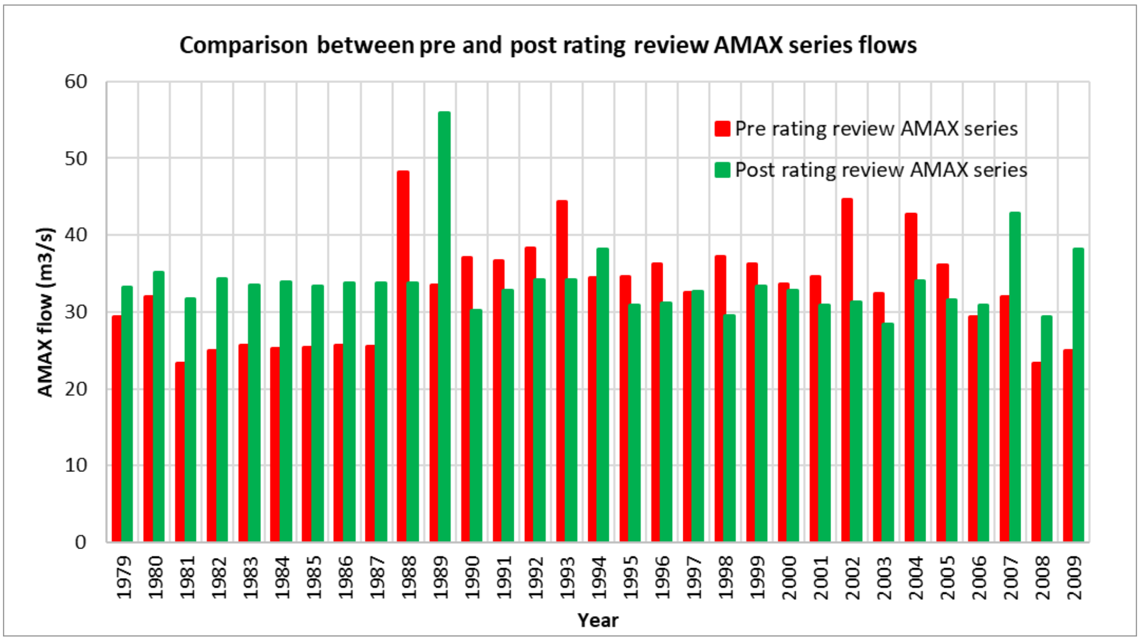


Figure 4-3: Comparison between pre and post rating review AMAX series at Borness Bridge

4.3.1 Review of SECFRAM rating review

Overall the SECFRAM rating review for the Borness gauge (14003) has been carried out appropriately given the guidelines and aims of the CFRAM programme. However, there are issues with the gauge location and data gathered that affect the reliability of the generated curve. The effect of the bridge and spill into the floodplain on the stage discharge relationship is highlighted in the SECFRAM and issues with significant scatter in the OPW spot flow records. This is discussed further in Section 5 as part of the rating review carried out for this study.

4.4 Growth curve generation

The growth curves (GCs) for the SECFRAM study were developed in accordance with the FSU guidance. A total of 92 hydrometric gauges were used in SECFRAM pooling group development, all located in the eastern and south-eastern regions of Ireland. A total of 3336 AMAX station years are considered in the pooling group, including 569 AMAX years sourced from the 16 gauges along the River Barrow. Table 4-2 shows a statistical summary of the SECFRAM pooling group. Review of the data from the 92 gauges found that a General Logarithmic (GLO) distribution fit the pooling group data and was used for the development of the GCs.

Table 4-2: Statistical summary of SECFRAM pooling group (source: SECFRAMs Hydrology Report pg.87)

Parameters	Minimum	Maximum	Average	Median
Record length (years)	9.00	71.00	37.00	35.00
Mean flow (m^3/s)	0.49	303.45	56.56	27.16
Median flow (m^3/s)	0.47	299.32	53.83	25.42
L-CV	0.052	0.415	0.198	0.182
L-skewness	-0.181	0.488	0.166	0.163
L-kurtosis	-0.127	0.426	0.155	0.139

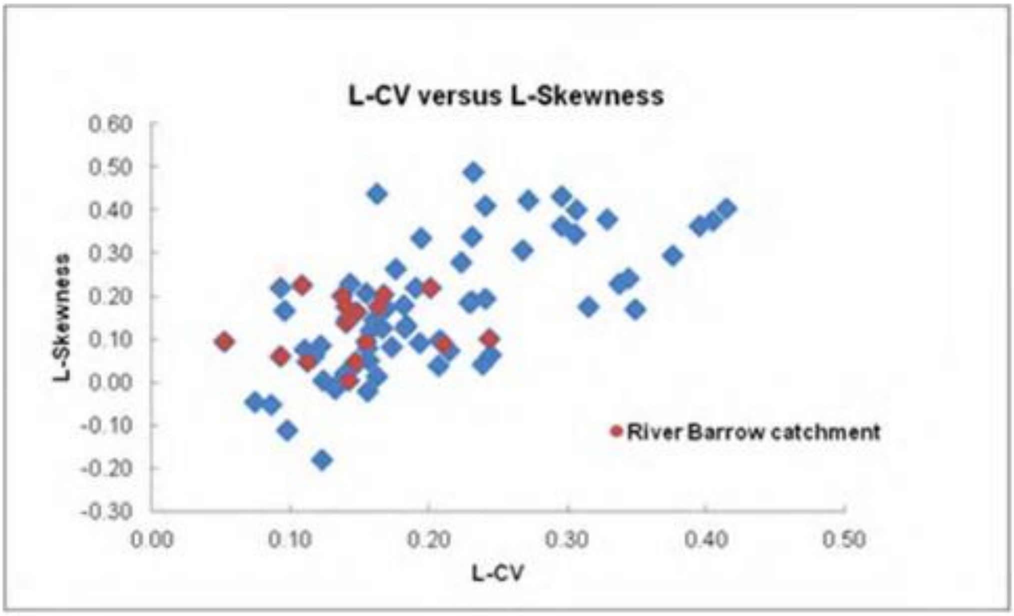


Figure 4-4: SECFRAM pooling group statistical summary plot (source: SECFRAMs Hydrology Report pg.87)

A GC was developed for each HEP in the SECFRAM study area (217 HEPs). To simplify the process 6 GCs based on catchment size were created. The variation in growth factor for catchment sizes between 10 and 200km^2 was found to be large indicating a single growth curve would not be appropriate. Instead individual growth curves developed for catchments within this size range were used. Figure 4-5 shows the final 6 GC groups. Approximately 95% of the SECFRAM pooling group gauges had catchments greater than 5km^2, and as a result the pooling group for HEP catchments less than 5km^2 was not homogeneous. To minimise the potential error from this the same GC (GC1) was applied to all HEP catchments less than 10km^2 in size.

GC Group No.	Catchment size range	GLO - Growth factors									
		AEP 50%	AEP 20%	AEP 10%	AEP 5%	AEP 4%	AEP 2%	AEP 1%	AEP 0.5%	AEP 0.2%	AEP 0.1%
1	AREA<=10km^2	1.000	1.448	1.793	2.176	2.31	2.771	3.31	3.945	4.962	5.896
2	10 < AREA <= 200 km^2	1.000	1.233 to 1.456	1.394 to 1.807	1.561 to 2.200	1.618 to 2.339	1.802 to 2.818	2.005 to 3.383	2.228 to 4.051	2.561 to 5.132	2.845 to 6.132
3	200 < AREA < = 400 km^2	1.000	1.255	1.422	1.589	1.644	1.820	2.011	2.223	2.522	2.766
4	400 < AREA < = 800 km^2	1.000	1.213	1.352	1.489	1.534	1.679	1.831	1.992	2.222	2.410
5	800 < AREA < = 1200 km^2	1.000	1.248	1.413	1.578	1.633	1.809	1.997	2.198	2.490	2.731
6	AREA> 1200 km^2	1.000	1.248	1.413	1.580	1.635	1.814	2.005	2.211	2.510	2.758

Figure 4-5: SECFRAM GC groups (source: SECFRAMs Hydrology Report pg.88)

To ensure that the GC groups were appropriate comparison between the relevant group GC and site-specific GC for the 13 gauges along SECFRAM modelled watercourses was carried out. This SECFRAM review found that the single site GC for gauge 14033 Mountmellick Mill was more appropriate than the recommended group GC as the observed flood values plotted above the recommended GC. The growth factors from the GCs have been applied to the estimated Qmed values to generate the peak flow estimates at each HEP for larger AEP events.

4.4.1 Review of growth curve methodology

For the overall SECFRAM study the GCs generated are reasonable. Within Model 5 specifically there are some considerations. Of the 27 HEP catchments in the study area 14 have areas less than $10km^2$ and therefore the GC group 1 curve was applied to all of these.

The general $10km^2$ catchment GC applied in the SECFRAM is steep. However, in Model 5 the topography of the small catchments particularly near the town and River Barrow, is flat. With so many small catchments present in Model 5 review of individual or other generalised growth curves is recommended. As an example, for illustrative purposes, Figure 4-6 compares the different growth curves for SECRAM HEP 14_1547_2 which has a catchment area of $1.38km^2$ and a S1085 value of 0.10m/km. In this case the steep SECFRAM growth curve is not reflective of the catchment and one of the other growth curves considered would be more representative.

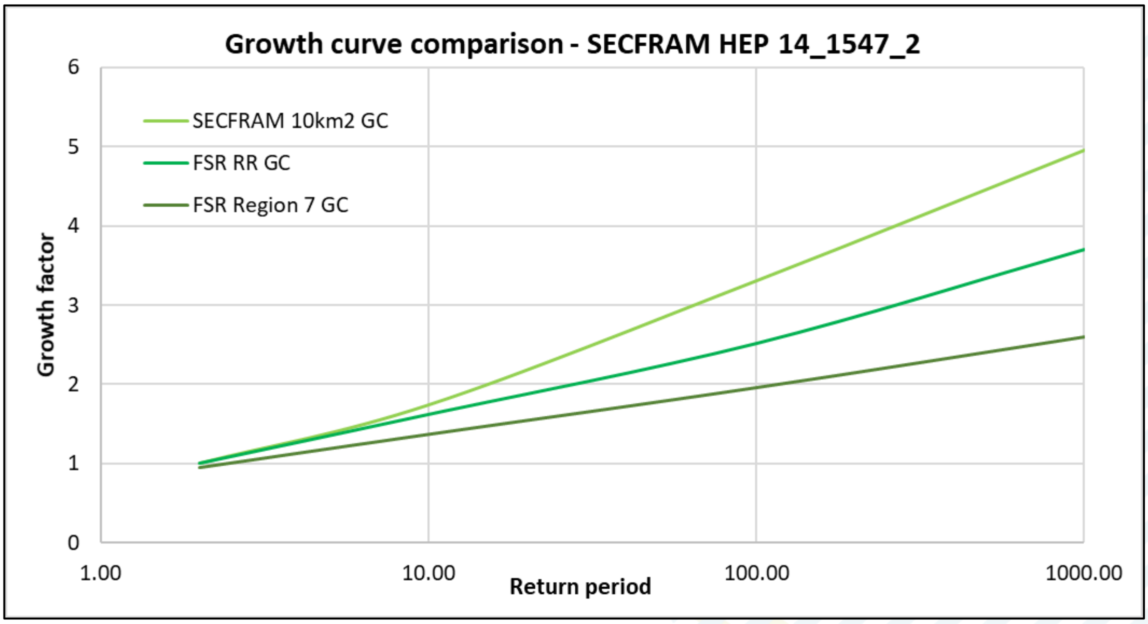


Figure 4-6: Growth curve comparison – SECFRAM HEP 14_1547_2

4.5 Joint probability

The Owenass and Triogue Rivers join with the River Barrow but joint probability (JP) analysis was not considered for these confluences under SECFRAM. As the confluences occur downstream of the AFA the risk of joint events was not considered significant enough to warrant in-depth analysis. These confluences, as well as all others were instead checked and adjusted iteratively by the hydraulic modeller to ensure the flow downstream of the join was consistent.

4.6 Summary

Review of the SECFRAM hydrology documentation shows that overall, the hydrology estimations for the Model 5 area were carried out according to the appropriate guidelines, using logical methods under the CFRAM programme, however the needs of this FRS differ. The following points are noted following the review:

- The FSU method was used for the estimation of Qmed for all but 4 HEPs, this was done as per the CFRAM guidelines provided, but further investigation into other small catchment methods is recommended.
- Only one gauge underwent rating review as part of SECFRAM. The Borness gauge has a number of known issues, therefore this gauge and two others have been reviewed as part of this study (refer to section 5).
- A single steep growth curve was applied to all catchments under $10km^2$ in the SECFRAM study. Review of the catchment characteristics within the study area highlight that this growth curve is not appropriate for the flat catchments within the area and individual growth curves would be more representative.
- Joint probability was not considered in detail for the Model 5 area.

New information that has become available since the completion of the SECFRAM study and is summarised in Table 4-3.

Table 4-3: New information available since SECFRAM completion

Data	Description	New information
Hydrometric gauges 14114, 14120, 14121	Three new hydrometric gauges installed	Gauge 14114 on the Owenass has been recording since 2013 (replaced gauge 14033) and was active during the 2017 event. Gauges 14120 and 14121 were installed in 2019 and mean that data is now being recorded on the Pound River.
14033 rating equation data	Full record of the 14033 rating curve and equations available	With all the data available a full rating review of the gauge can be carried out.
Extended AMAX records	Additional years of water level and flow data available	All water level data from the years following SECFRAM have been added to the AMAX record increasing record length.
2017 event	Large flood event occurred in November 2017	Largest flood event recorded in the area, four active gauges recording during the event, large amounts of photographs and video records as well and eyewitness accounts.
2020 event	Flood event occurred in February 2020	Six active gauges recording during the event, photographs, wrack marks and eyewitness accounts available.
Detailed flood history	Updated flood history specifically for the Mountmellick area	Includes events that happened after the SECFRAM study

Data	Description	New information
Updated DTM data	2m and 1m resolution LIDAR data of area available	Allows more accurate representation of topography and flow paths within the hydraulic model
Additional channel and detailed topographic survey	Additional survey taken in 2019	Allows more accurate representation of watercourses within the hydraulic model

5 Hydrometric gauge rating reviews

Rating reviews have been carried out for three gauges as part of this study and are detailed in this section.

The rating reviews have been carried out using a fully connected existing scenario 1D-2D hydraulic model of the study area. The use of the full model with connected 2D flood plain ensured that the effect of storage on gauge readings could be examined. Refer to Appendix C for details on the hydraulic model and flows used in assessment.

All rating curve equations are presented in the following format:

$$Q = c \times (h-a)\ b$$

5.1 14003 – Borness gauge

The Borness gauge is located along the Barrow River, 5m upstream of the Borness Bridge. Table 5-1 summarises the gauge details while Figure 5-1 and Figure 5-2 show photographs and survey of the gauge. This is the only gauge of the three to have undergone a rating review under SECFRAM.

This gauge was examined during the method statement phase and, as detailed below, it was found that a reliable Q-h relationship could not be established as the gauge is highly sensitive to parameters such as storm duration and roughness and is also subject to hysteresis due to the presence of the bridge directly downstream. The gauge was therefore screened out at method statement stage and the associated modelling has not been re-run as the model has been progressed.

The Borness gauge has little contribution to the hydrological estimates on the Owenass River, and because of the ungauged element of the Barrow upstream this gauge cannot be used a calibration point for the hydraulic modelling of the Owenass.

Table 5-1: Borness gauge summary

Borness gauge			
Number	14003	**Gauge type**	Staff gauge with water level logger (water level only)
Operator	OPW	**Sensor type**	OTT SDI-12 Pressure level sensor
Years active	1979 – present	**Staff gauge zero level**	70.05mAOD Poolbeg (67.35mAOD Malin)
Maximum recorded water level	72.778mAOD Poolbeg (70.08mAOD Malin). Recorded in 2017		
SECFRAM AMAX Qmed	34.39		
FSU descriptor equation Qmed	50.94		

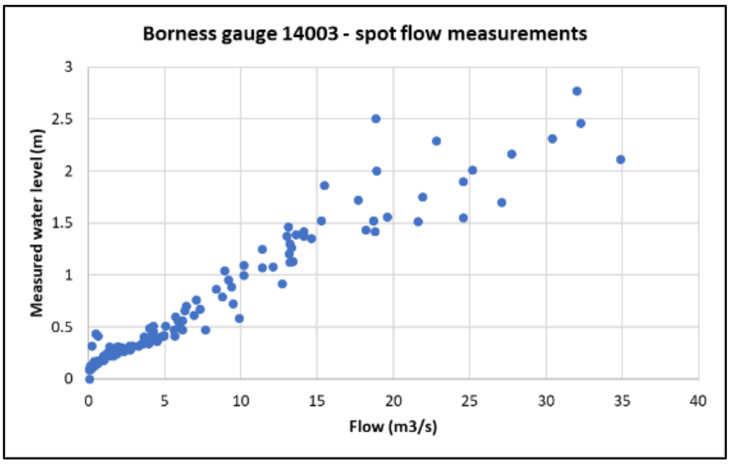
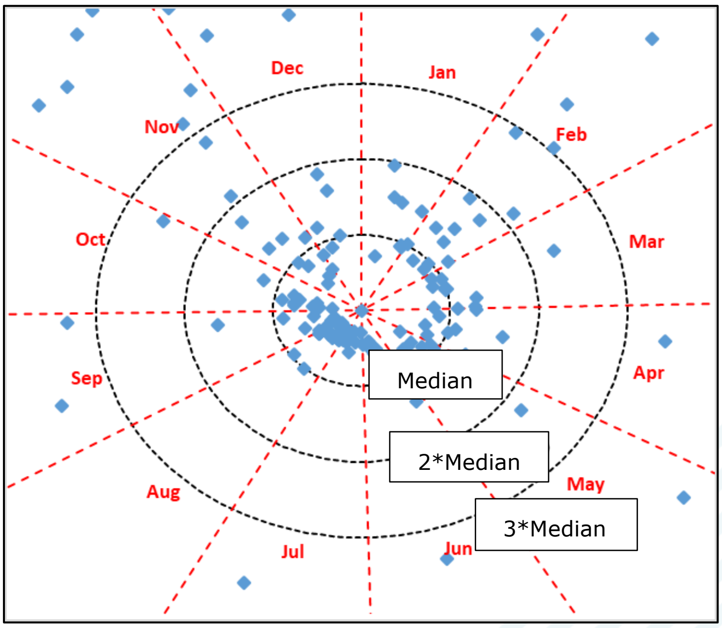
Spot flow measurements	
Spot flow measurements: seasonality	
Losses and coefficients applied in hydraulic model	Manning's roughness: 0.03 Orifice discharge coefficient: 1.00 Spill weir coefficient: 1.40
Notes	Significant scatter recorded in the OPW spot flow measurement record.

Figure 5-1: Photographs of gauge location facing upstream (left) and looking across the river

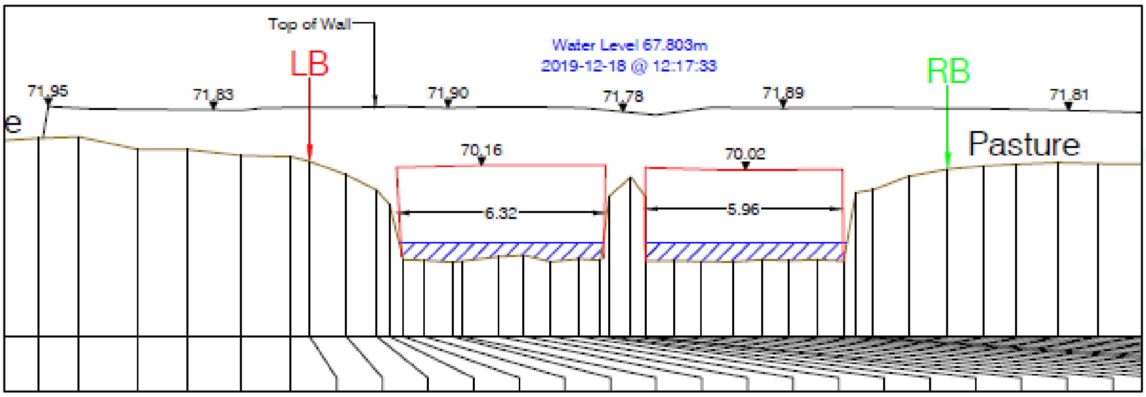


Figure 5-2: Surveyed cross section

Figure 5-3 shows the stage discharge (Q-h) relationship at the gauge. A prominent hysteresis effect caused by the bridge is noted; the water levels recorded on the falling limb of the hydrograph are higher for a given flow than the rising limb. A notable plateau on the rising limb curve at indicates the point at which the channel shape changes and expands to incorporate an area of flood plain.

Sensitivity testing within the hydraulic model found that the gauge is sensitive to a number of factors such as roughness and storm duration (volume of flow) and is also subject to hysteresis due to the presence of the bridge directly downstream. These sensitivities and the significant scatter in the OPW spot flow data (Figure 5-4) highlights that there are issues with the gauge which affect its ability to reliably estimate flows from a given level. The analysis was carried out as to whether the scatter was only present for certain portions of the spot flow data but it has shown to be consistent even for the most recent data recorded.

Based on these findings it is recommended that the levels recorded at the Borness gauge are not used to derive a stage discharge relationship due to the associated uncertainty and not be used in the estimation of flows. The development of a rating curve and associated equations has therefore not been carried out.

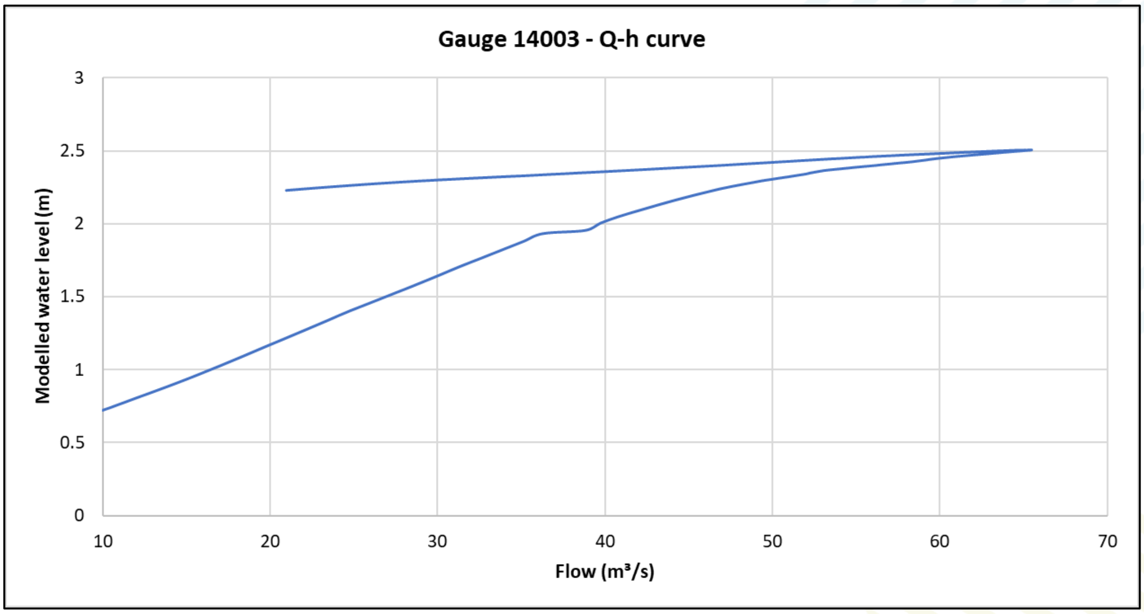


Figure 5-3: Gauge 14003 modelled Q-h relationship

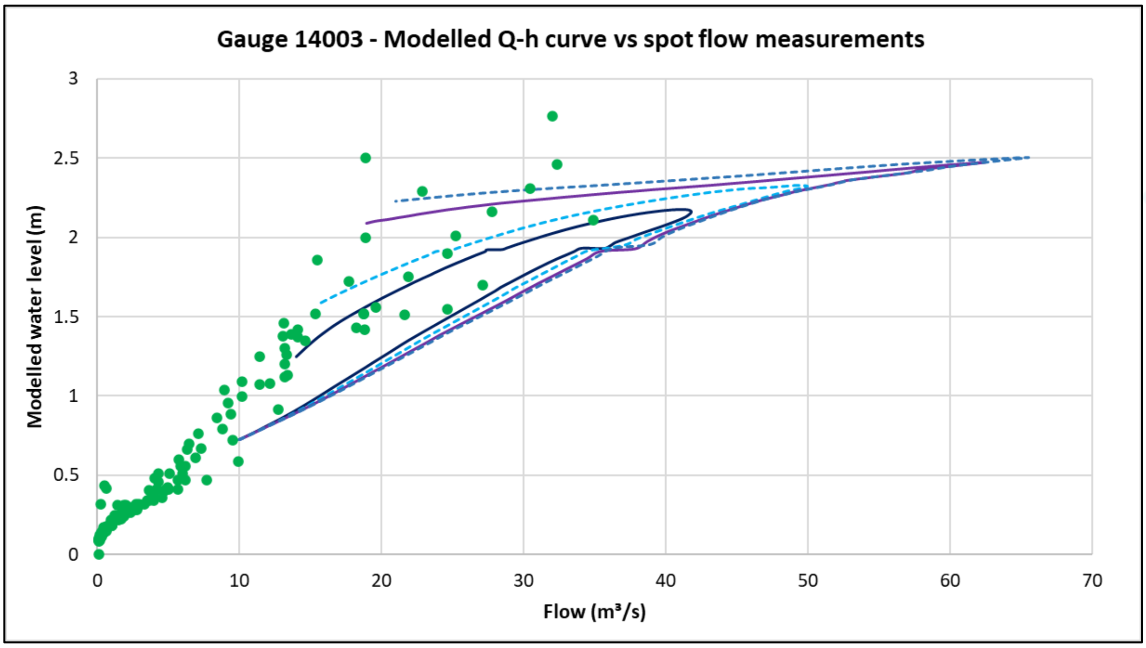
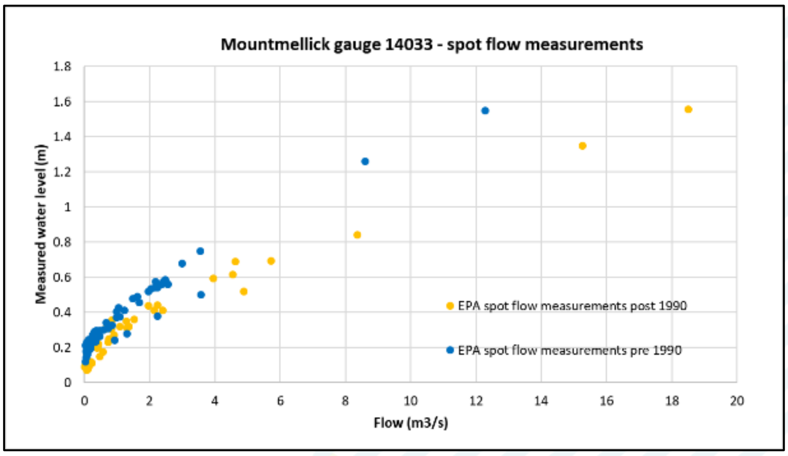


Figure 5-4: Comparison of modelled Q-h curves for a range of flows with OPW spot flow measurements

5.2 14033 - Mountmellick gauge (inactive)

The Mountmellick gauge was located along the Owenass River on a section of open channel. Table 5-2 summarises the gauge details while Figure 5-5 and Figure 5-6 provide visual detail of the former gauge location. Due to multiple adjustments within the river channel and difficulty with access, this gauge was discontinued in 2013 and replaced with gauge 14114 upstream.

Table 5-2: Mountmellick gauge summary

Mountmellick gauge			
Number	14033	**Operator**	EPA
Gauge type	Staff gauge with water level logger	**Sensor type**	Water level data from 1977 to 17/05/1999 recorded using an autographic recorder with float and counterweight. Water level data recorded using a digital data recorder, float and counterweight from 23/03/2000 to the end of records.
Years active	1977 – 2013 (replaced by gauge 14114)	**Staff gauge zero level**	72.06mAOD Poolbeg (69.36mAOD Malin)
Maximum recorded water level	74.43mAOD Poolbeg (71.73mAOD Malin). Recorded in 1990.		
EPA AMAX Qmed	19.33		
FSU descriptor equation Qmed (unadjusted)	25.03		
Spot flow measurements Note, the spot measurements have been divided into pre- and post-1990 to reflect the impact of the draining of the watercourse in 1990.			

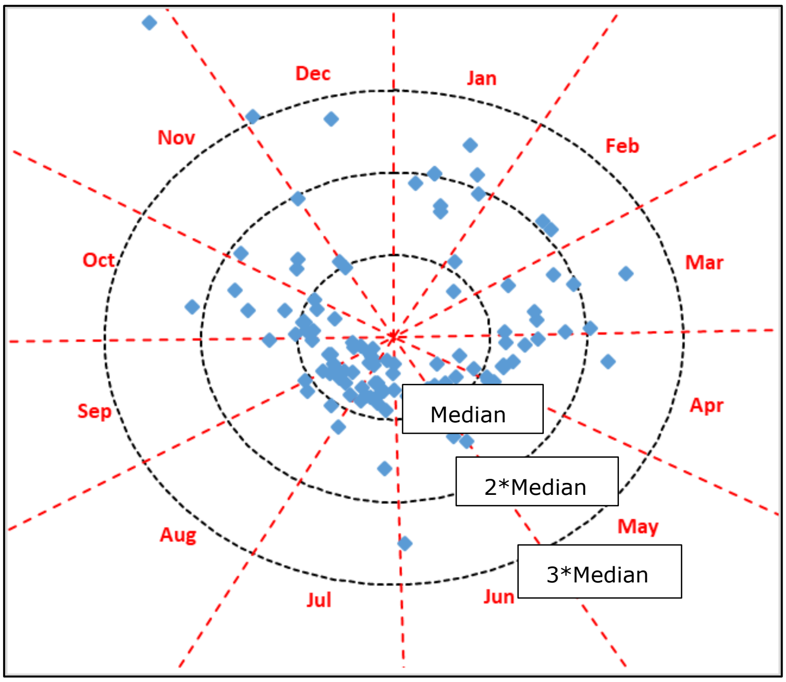
Spot flow measurements: seasonality	
Losses and coefficients applied in hydraulic model	Manning's roughness: 0.03 Orifice discharge coefficient: 1.00
Notes	It is noted that the watercourse was drained in 1990 – EPA rating equations change for this gauge at this point.

Figure 5-5: Photographs of former gauge location facing up and downstream

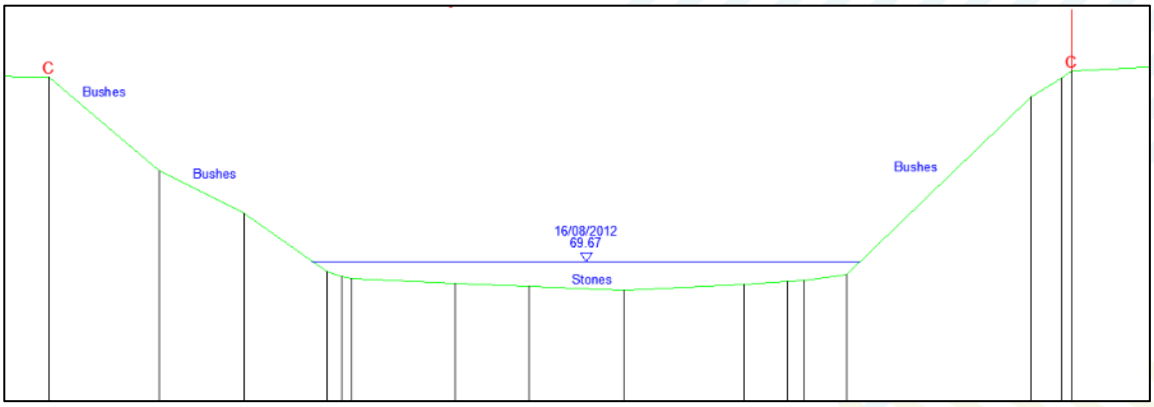


Figure 5-6: Surveyed cross section

Figure 5-7 shows a modelled Q-h curve generated by the hydraulic model compared to the spot flow measurements. The draining of the river channel recorded in 1990 would have changed the flow regime of the watercourse significantly and therefore only the AMAX data and EPA rating curve post 1990 have been assessed as they are more reflective of the watercourse immediately prior to the gauge being discontinued. The modelled outputs show good correlation with the measured values indicating the model successfully replicates the channel behaviour and the gauge data is suitable for use in hydrological analysis. The gauge operates normally under all flow conditions with flow contained in channel, although it is noted that there is significant overland flow upstream of the gauge location. Sensitivity testing of the modelled gauge location highlighted that the Q-h relationship is somewhat sensitive to roughness.

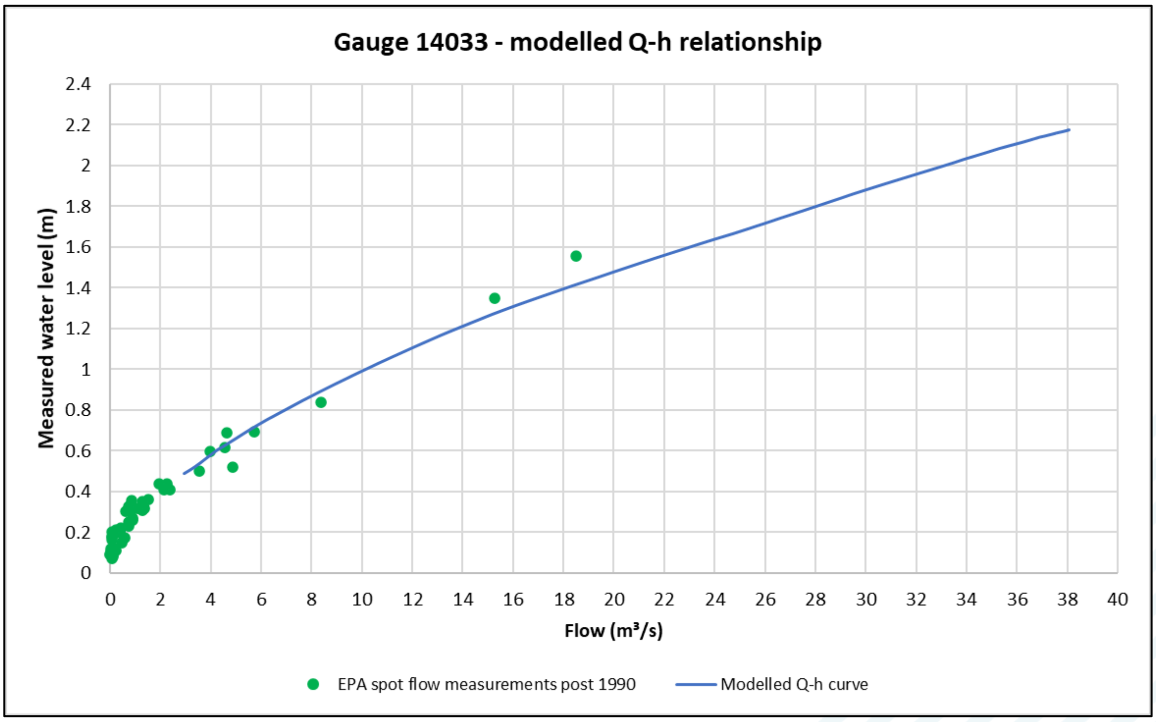


Figure 5-7: Gauge 14033 – Modelled Q-h relationship

Table 5-3 and Table 5-4 show the most recent EPA, and the new rating curve equations established using the modelled data. Figure 5-8 compares the modelled outputs and the EPA and new rating curves. The updated curve shows a better match to the modelled outputs and the recorded spot flow measurements. The upper limit of the new curve is 0.40m higher than the EPA curve. The lower range of the curve is 0.15m higher than the EPA rating curve however the c parameter used in the EPA curve for limb 1 is exceptionally high (over 5000) and highlights potential issues with flow estimations at the lower curve extent. Based on these considerations it is recommended that the updated rating curve be used for any hydrological analysis carried out. Table 5-5 and Figure 5-9 shows the revised AMAX series for the gauge.

Table 5-3: EPA rating curve (2003)

Limb no.	c	a	b	Stage min (m)	Stage max (m)
1	5218.62	0	6.33761	0.165	0.220
2	12.449	0	2.34806	0.220	0.848
3	10.4468	0	1.28506	0.848	1.555

Table 5-4: Updated rating curve

Limb no.	c	a	b	Stage min (m)	Stage max (m)
1	10.48	0	1.77	0.10	0.60
2	10.11	0	1.71	0.60	1.35
3	10.18	0	1.72	1.35	2.00

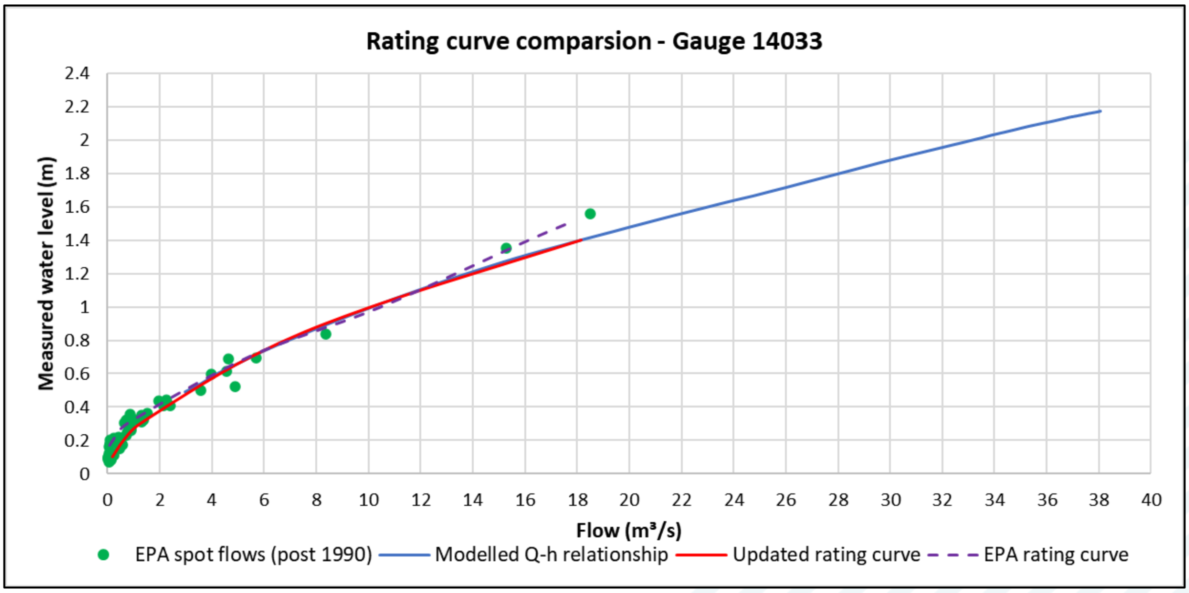


Figure 5-8: Gauge 14033 – Rating curve comparison

Table 5-5: Gauge 14033 AMAX record with EPA and modelled rating

Year	Measured water level (m)	Flow (EPA rating) (m^3/s)	Flow (Updated rating) (m^3/s)	Difference in flow (m^3/s)
1991	1.43	16.50	18.83	+2.33
1992	1.70	20.70	25.35	+4.65
1993	1.77	21.70	27.17	+5.47
1994	1.59	18.90	22.60	+3.70
1995*	1.96	24.90	32.37	+7.47
1996	1.65	19.80	24.08	+4.28
1997	1.79	22.00	27.70	+5.70
1998	1.65	19.80	24.08	+4.28
1999	1.48	17.20	19.98	+2.78

Year	Measured water level (m)	Flow (EPA rating) (m^3/s)	Flow (Updated rating) (m^3/s)	Difference in flow (m^3/s)
2000	1.63	19.60	23.58	+3.98
2001	1.28	14.30	15.42	+1.12
2002	1.74	21.30	26.38	+5.08
2003*	1.57	18.60	22.11	+3.51
2004	1.65	19.90	24.08	+4.18
2005	1.80	22.30	27.97	+5.67
2006	1.70	20.60	25.35	+4.75
2007	1.87	23.40	29.86	+6.46
2008	1.83	22.70	28.77	+6.07
2009	1.78	22.00	27.43	+5.43
2010	1.89	24.90	30.41	+5.51
2011	1.60	19.10	22.84	+3.74
2012	1.97	24.90	32.66	+7.76
2013	1.64	19.70	23.83	+4.13
AMAX Qmed		20.60	25.34	+4.74
*denotes point at which EPA rating equation changes				

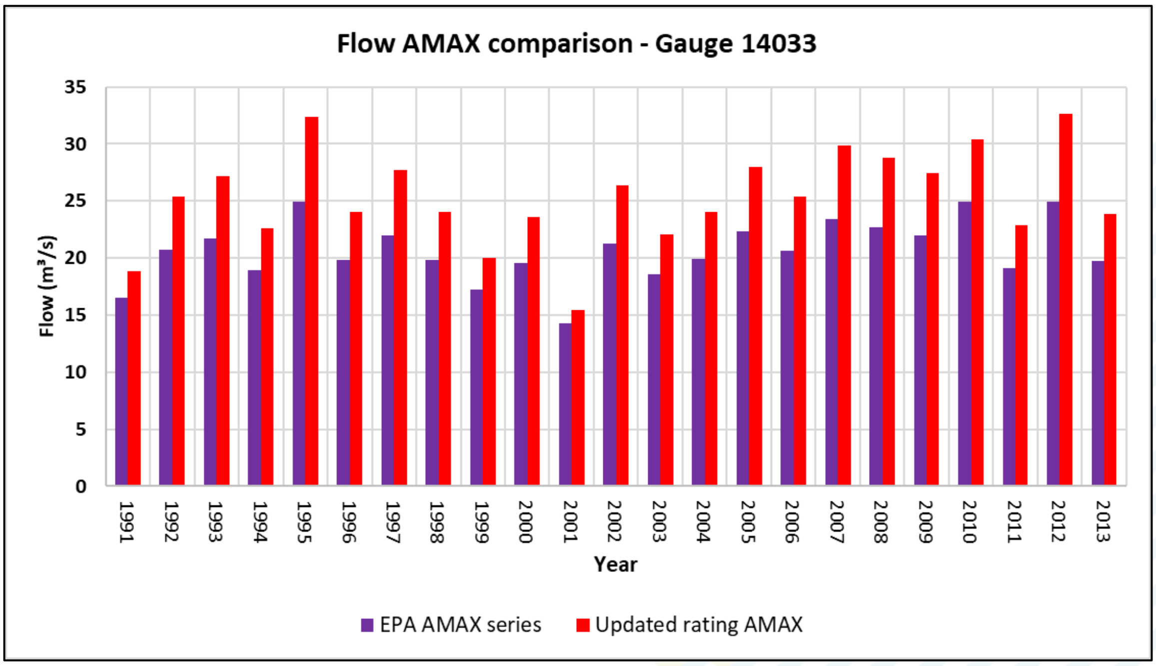
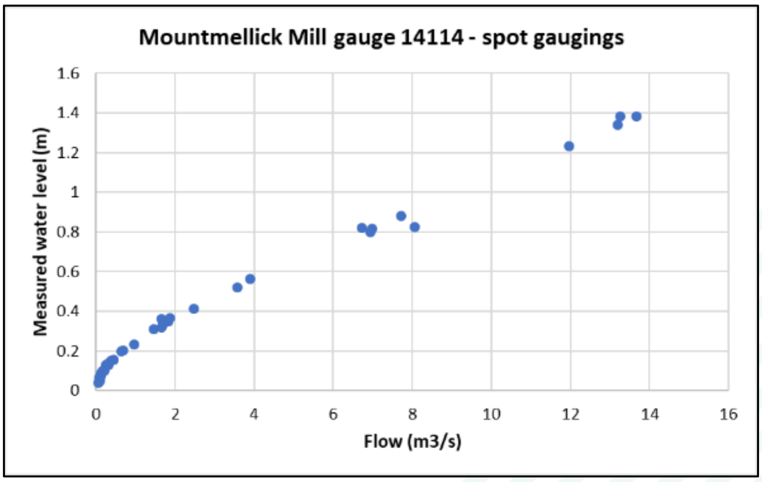


Figure 5-9: Flow AMAX comparison – Gauge 14033

5.3 14114 – Mountmellick Mill gauge

The Mountmellick Mill gauge is located along the Owenass River approximately 5m downstream from the face of a rectangular bridge. Table 5-6 summarises the gauge details with photographs of the gauge location and cross section profile are shown in Figure 5-10 and Figure 5-11. This gauge was established as a replacement for gauge 14033.

Table 5-6: Mountmellick mill gauge summary

Mountmellick Mill gauge			
Number	14114	**Operator**	EPA
Gauge type	Staff gauge with water level logger	**Sensor type**	OTT Orpheus Mini pressure transducer water level recorder
Years active	2013 - present	**Staff gauge zero level**	72.296mAOD Malin
Maximum recorded water level	74.788mOD Malin. Recorded in 2017		
EPA AMAX Qmed	18.96		
FSU descriptor equation Qmed (unadjusted)	24.80		
Spot flow measurements			

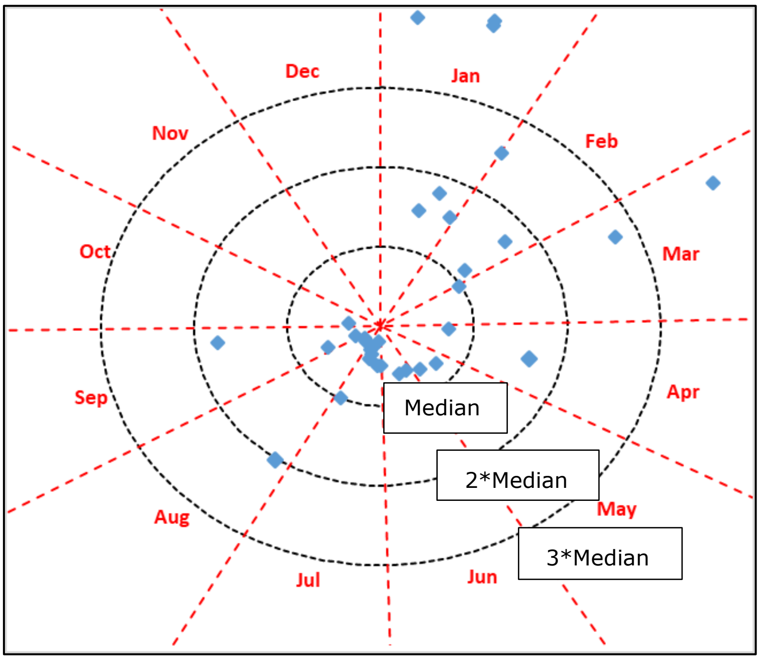
Spot flow measurements: seasonality	
Losses and coefficients applied in hydraulic model	Manning's roughness for channel bed: 0.03 Orifice discharge coefficient: 1.00 Spill weir coefficient: 1.40

Figure 5-10: Photographs of gauge location facing up and downstream

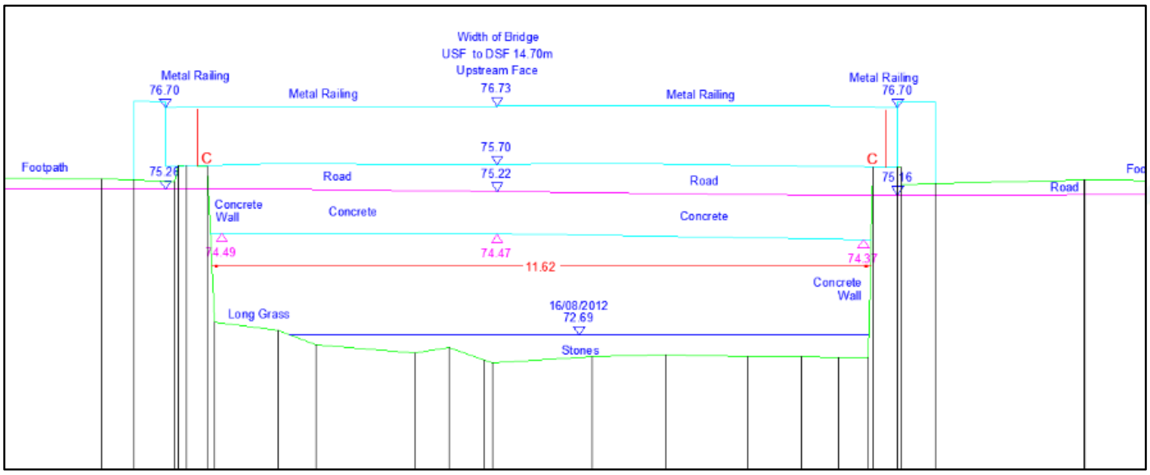


Figure 5-11: Surveyed cross section

Figure 5-12 shows a modelled Q-h curve at the gauge. The modelled outputs show good correlation with the measured values indicating the model successfully replicates the channel behaviour and the gauge data is suitable for use in hydrological analysis.

During sensitivity testing it was found that the gauge was sensitive to changes in roughness, this is important to note as the relationship at the gauge will change seasonally. It is also noted that out of bank spill occurs upstream of the gauge therefore the level and flow recorded at the gauge is not the total peak flow that occurs. This is highlighted by the observed flat hydrograph top recorded by the gauge during high flow events (e.g. 2017). The level at which out of bank flow upstream occurs is approximately soffit level of the upstream bridge (74.47mOD - 2.17m above gauge datum). This limits the validity with which the gauge can capture total peak flows for higher AEP events accurately.

Based on this analysis, a rating curve for the gauge can be established. However, the upper extent of the curve and estimation of peak flow at this location is limited to the level before bridge soffit height. After this point due to the spill upstream bypassing the gauge limiting the amount of flow passing through the channel it is not reflective of the potential total flows (in channel and on flood plain) moving down the system. Refer to the hydraulics report for more detail of the hydraulic mechanisms.

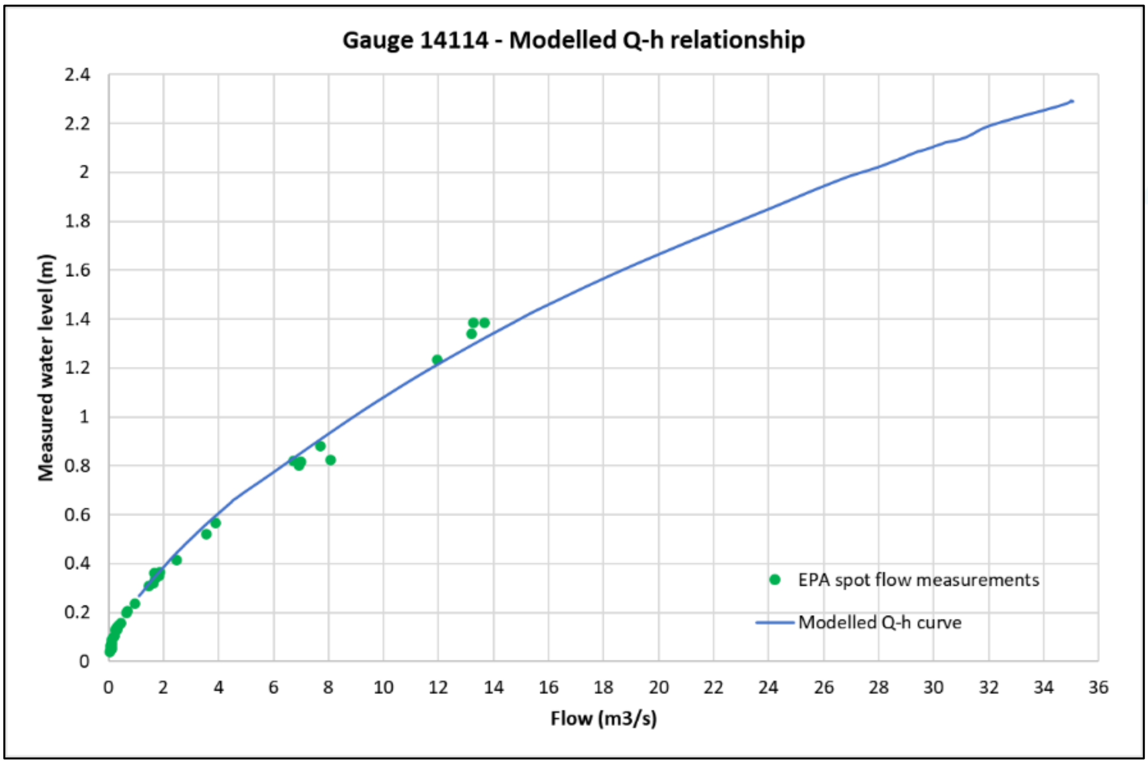


Figure 5-12: Gauge 14114 modelled Q-h relationship

Table 5-7 and Table 5-8 show the most recent EPA rating and the new rating curve equations established using the modelled data. Figure 5-13 compares the modelled outputs and the EPA and new rating curves. The updated curve shows a better match to the modelled outputs and the recorded spot flow measurements. The EPA curve extrapolated also shows a steeper Q-h relationship than recorded by the hydraulic model. The upper limit of the new curve is 0.615m higher than the EPA curve while the lower limit is 0.25m compared to the EPA lower limit of 0.04m. Based on these results it is recommended that the updated rating curve be used for the gauge, but the lowest limb of the EPA rating curve be retained to allow a wider range of certainty for flow estimation at the gauge. Table 5-9 and Figure 5-14 shows the revised AMAX series for the gauge It is noted that all AMAX water levels exceed the EPA curve upper limit. The 2017 and 2018 levels also exceed the updated rating curve upper limit.

Table 5-7: EPA rating curve

Limb no.	c	a	b	Stage min (m)	Stage max (m)
1	5.53798	0	1.37772	0.040	0.158
2	11.2418	0	1.76123	0.158	0.715
3	9.24651	0	1.17789	0.715	1.385

Table 5-8: Updated rating curve

Limb no.	c	a	b	Stage min (m)	Stage max (m)
1	5.54	0	1.38	0.04	0.25
2	8.54	0	1.53	0.25	0.75
3	8.68	0	1.59	0.75	1.40
4	8.25	0	1.74	1.40	2.00
5	8.25	0	1.74	2.00	2.49[3]

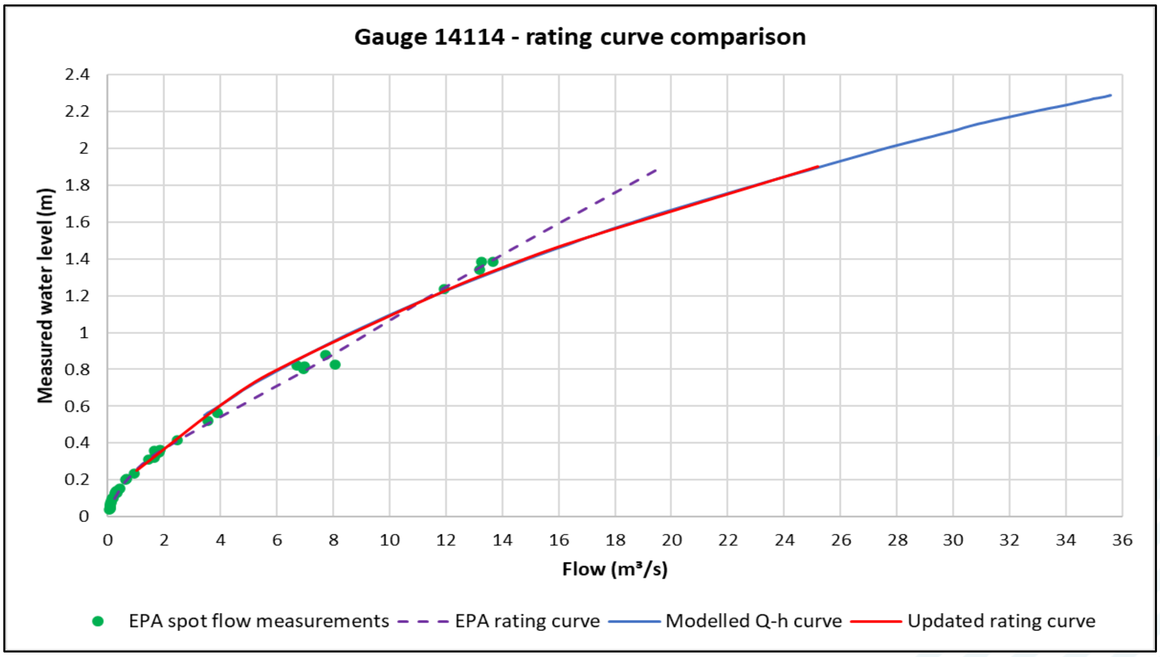


Figure 5-13: Gauge 14114 rating curve

Table 5-9: Mountmellick Mill gauge AMAX record with EPA and updated rating

AMAX year	Measured water level (m)	Flow (EPA rating) (m^3/s)	Flow (Updated rating) (m^3/s)	Difference (m^3/s)
2014	1.703	17.31	20.83	+3.52
2015	1.849	19.07	24.03	+4.96
2016	1.655	16.74	19.82	+3.08
2017	2.492[4]	27.11	40.39	+13.28
2018	2.081	21.92	29.52	+7.60
AMAX Qmed		20.43	26.92	+6.49

3 Limb 5 extends the curve up to the highest gauge record however it is noted that the rating is uncertain for this upper limit greater than 2.00m due to upstream flood plain interaction and the impact of the bridge directly upstream.

4 This level is influenced by the interaction of the increased flood level, flood plain flow and bridge soffit interaction at the upstream face of the bridge the gauge is located on. Refer to Section 6.3.5 and the Hydraulics Report for more detail on flood mechanisms.

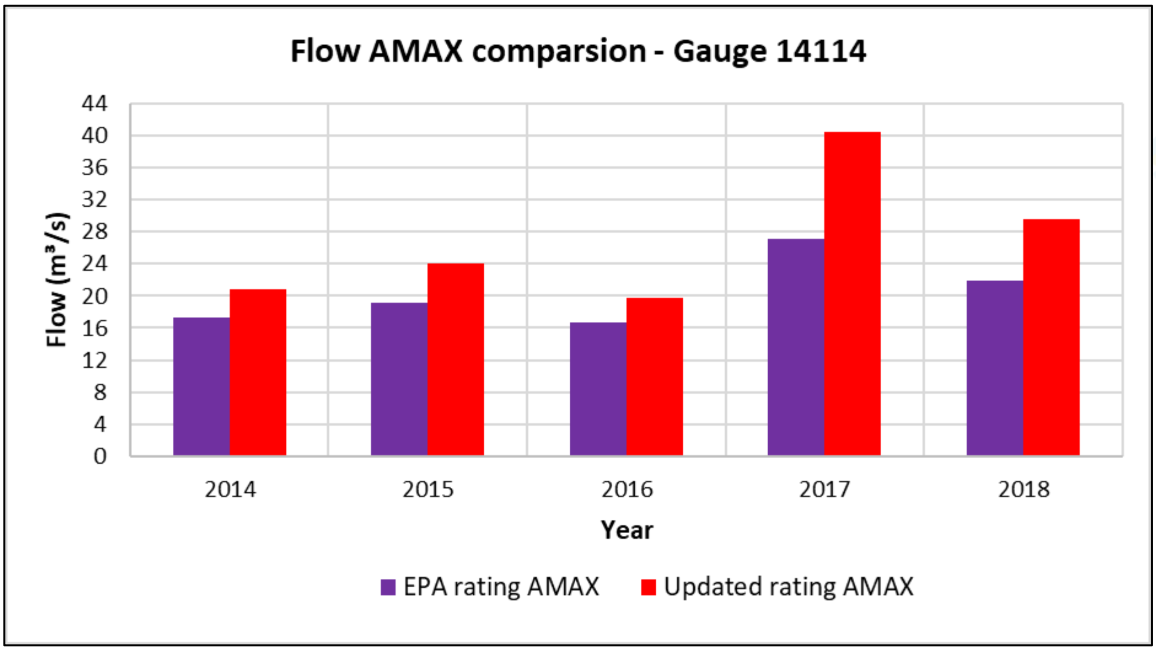


Figure 5-14: Flow AMAX comparison – gauge 14114

5.4 Comparison of updated rating equations and EPA rating curves

It is noted that the revised rating curves for the active and inactive Owenass gauges show the channel to be more efficient than the EPA curves. This difference is likely a result of changing maintenance of the watercourse with more regular clearing occurring at present. This change in channel condition is reflected in the roughness values applied in the channel for the Owenass. As discussed in the Hydraulics Report, channel roughness values were applied based on the available survey photographs and site visit observations of the channel's current condition. Therefore, there is a difference in the current channel conditions as represented within the model and compared with when the check gaugings were recorded. A thorough review of all roughness values along the channel bed and sides was carried out and given the available data are considered appropriate. Based on this information the increase in channel efficiency is considered to be a result of the updated rating curves reflecting the current, more maintained channel condition.

5.5 Provisional rating curves for the Pound River gauges

While out of the scope of works for this project provisional rating curves have been derived using the hydraulic model for gauges 14121 and 14120 along the Pound watercourse to allow comparison of flows for calibration purposes. Figure 5-15 and Figure 5-16 show the shape of the rating curves developed for the gauges. These curves are for comparison purposes only as they cannot be validated due to lack of data for the gauges (too new). At time of writing there are no available check flow gaugings to allow comparison. The provisional rating curves highlight the size difference between the Owenass and Pound watercourses with the Pound curves reporting significantly less flow for a given water level compared to the Mountmellick Mill (14114) rating curve.

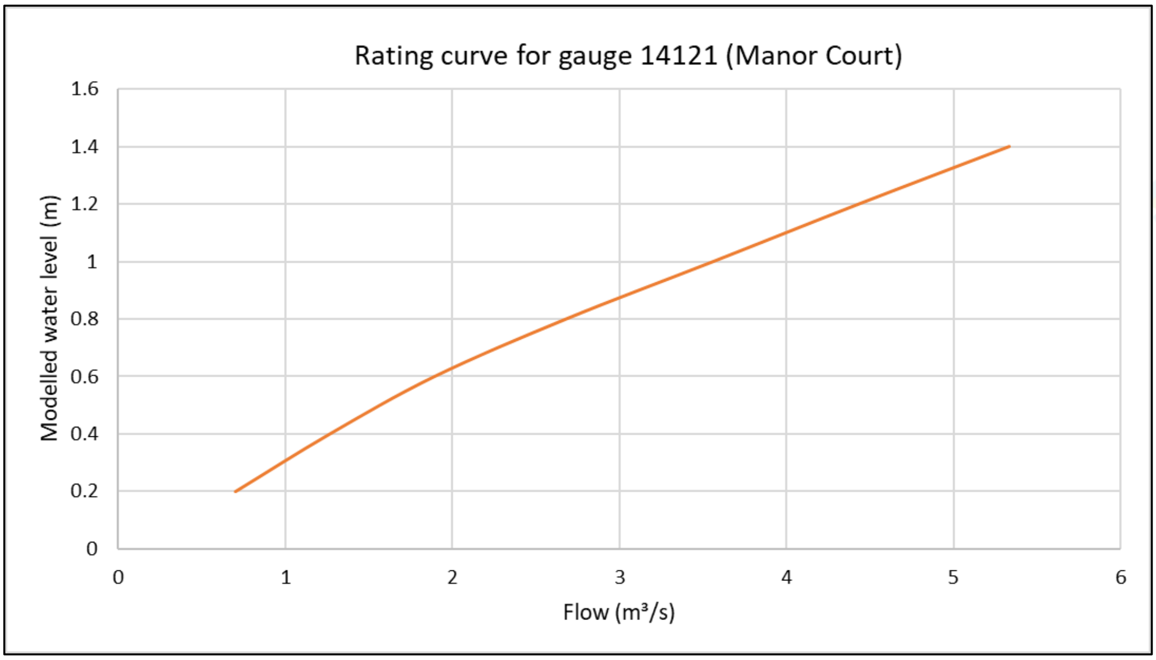


Figure 5-15: Rating curve for gauge 14121 (Manor Court)

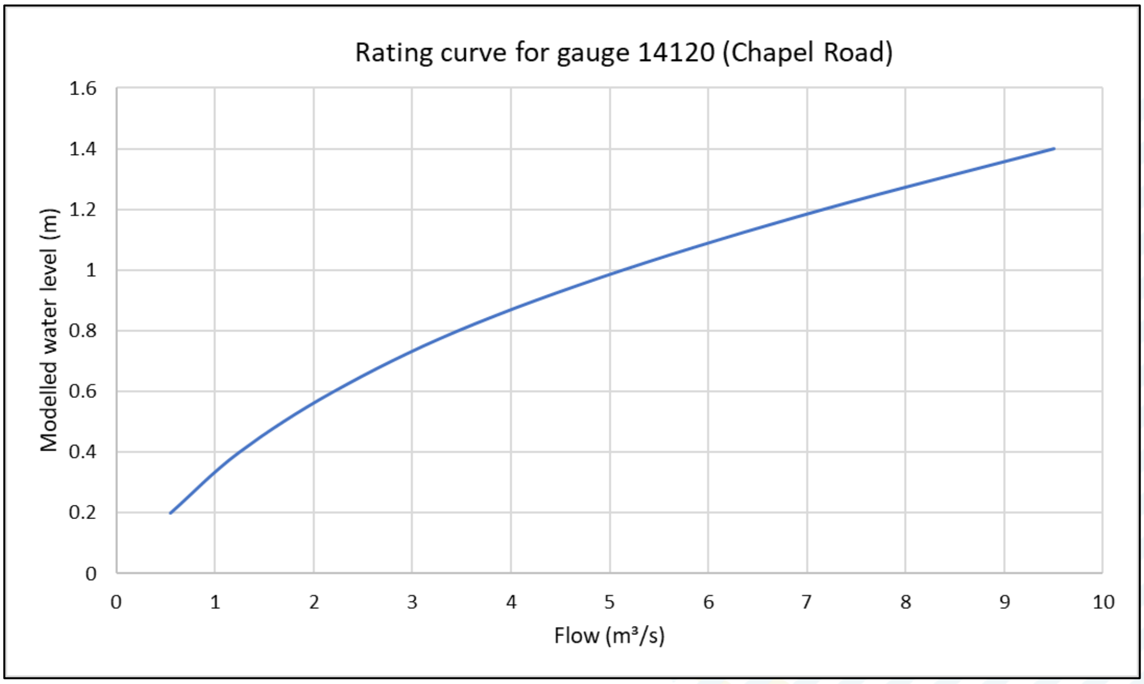


Figure 5-16: Rating curve for gauge 14120 (Chapel Road)

6 Rainfall Runoff Modelling

6.1 Introduction

The flow recorded at Mountmellick Mill Gauging Station (GS) is heavily attenuated by the floodplains upstream. More critically there are known cross flows between the Owenass and Pound catchments. This limits the use that can be made of the observed gauge data, despite the combined record length. Whatever AMAX value determined at the GS a significant grossing up of the hydrograph is required to produce the recorded flow downstream if the flow is simply inserted in the upper part of the model. This phenomenon and the varied responses in the upstream catchments due to topography, soils and arterial drainage creates too much uncertainty in the ability of FSU methods to derive representative inflows for calibration and design events in the traditional HEP estimation approach. Therefore, the Flood Studies Supplementary Report no.16 (FSSR16) rainfall-runoff method has been used to estimate inflow hydrographs for the hydraulic model.

A distributed rainfall-runoff model of the wider catchment area was developed within Flood Modeller. The upland Slieve Bloom rainfall runoff models have been constructed in Flood Modeller and include separate FSSR16 units for each main sub-catchment. Hydrological Routing units transfer upland flows from the foot of the Slieve Bloom to the upstream boundary of the hydraulic model. This hydrological model has been incorporated into the main hydraulic model along with additional FM FSSR16 inflow units that have been used to derive the hydrographs for all necessary inflows in the FRS hydraulic model.

The Rainfall-runoff method was selected for flow estimation due to the following:

- Unlike the HEP approach it can take into account the cross flow between catchments.
- It provides volumetrically consistent method to producing an inflow hydrograph upstream of the floodplains protecting Mountmellick.
- It makes good use of the available rainfall and hydrometric gauges (especially for February 2020), which have been used in the calibration of the models.
- The ability to test the potential effect of upstream catchment change such as changes in land management practises, forest cover and operations, and measures to slow the response to rainfall in the Slieve Bloom mountains on flow response.

An initial conceptual model was developed to provide a base understanding of the catchment responses to rain events. The hydrological model was calibrated using three events (November 2017, and Storm Ciara and Dennis) with any adjustments made during calibration applied in design flow estimation. This calibration is discussed in Section 6.3 and in the corresponding Hydraulics Report.

6.2 Conceptual hydrological model

As mentioned previously, there are distinct differences in the catchments of the Pound and Owenass Rivers, with the Pound tributaries generally having steeper profiles and higher SAAR values compared to many of the tributaries of the Owenass and the Triogue. Table 6-1 compares different descriptor values for locations within the wider catchment area (refer to Figure 6-1 for locations). Given the known hydraulic mechanisms in the catchment, and the lack of gauge data for the 2017 event, the response of the upstream sub-catchments has been investigated further using a FSSR16 rainfall runoff model and with reference to neighbouring and hydrologically similar gauged catchments.

Table 6-1: Comparison of descriptor values from different catchment locations

Gauge/FSU node	14003 (Borness)	14_1043_4	14_1718_8	14114 (Mountmellick mill)	14_272_2	14_300_3	14121 (Manor court)	14042 (Reary Valley)	25301 (Bracknagh Bridge)
Watercourse	Barrow	Barrow (US Owenass)	Owenass (US of Barrow)	Owenass	Owenass (US Mountmellick)	Owenass (DS Slieve Bloom)	Pound	Barrow	Clodaigh
AMAX years	40	-	-	43 (Extended)	-	-	-	17	17
Qmed Stat (m^3/s) (median AMAX Qmed)	-	-	-	19.47	-	-	-	29.70	-
Qmed ratio Stat/AREA	-	-	-	0.25	-	-	-	0.92	-
Qmed PCD (m^3/s) (Physical catchment descriptors)	50.81	30.16	24.27	24.80	24.62	8.27	3.93	18.27	18.49
Qmed ratio PCD/AREA	0.25	0.24	0.30	0.32	0.36	0.72	0.32	0.32	0.56
Area (km^2)	206.00	125.19	79.71	78.26	68.06	11.55	12.12	32.80	27.1
BFIsoil	0.53	0.57	0.45	0.45	0.46	0.31	0.52	0.41	0.34
SAAR	1160	1174	1143	1146	1163	1462	1154	1458	1487
FARL	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
MSL (km)	31.91	31.32	19.07	16.57	13.83	6.49	8.56	15.78	13.09
S1085 (m/km)	9.22	9.33	10.24	12.16	15.28	21.22	7.66	22.37	18.87
ARTDRAIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DRAIND (km/km^2)	1.09	1.05	1.11	1.10	1.15	0.87	1.52	1.05	0.98
URBEXT	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01

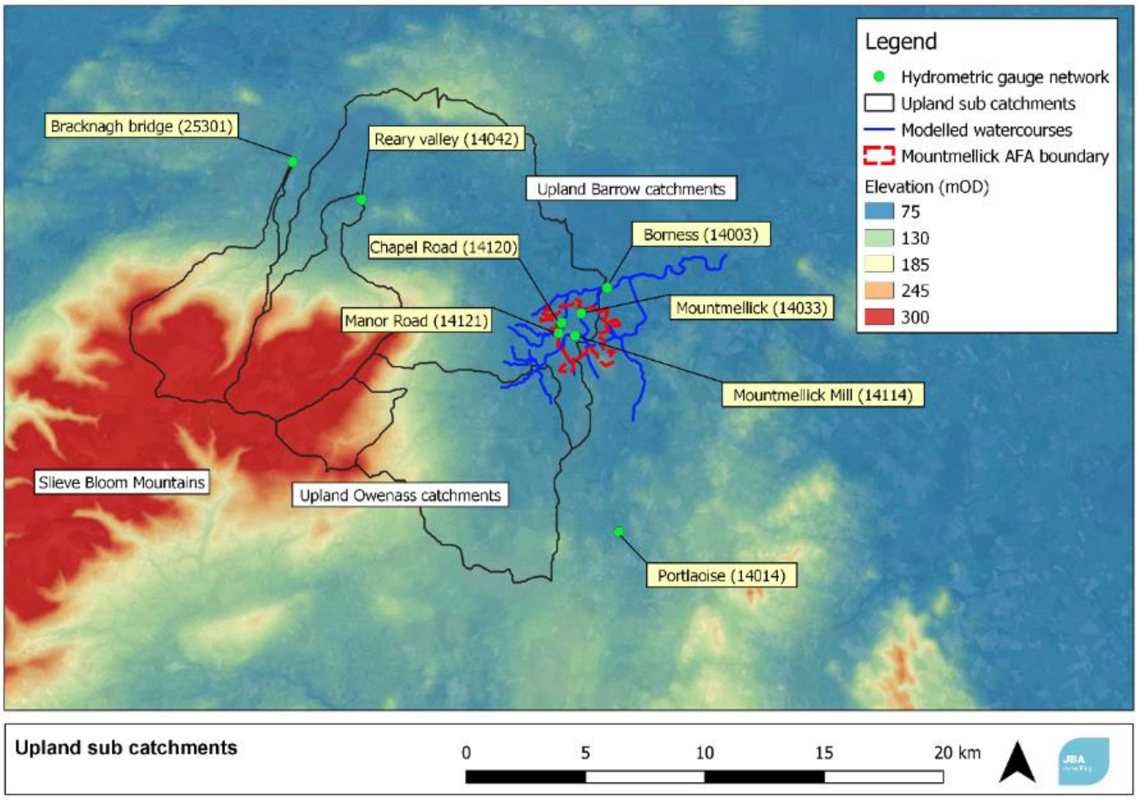


Figure 6-1: Upland sub catchments

Of particular significance is the Reary Valley gauge (14042) which is on the upper reach of the Barrow, and to a lesser extent the Bracknagh Bridge gauge on the Clodiagh River, downstream of Clonaslee. These gauges share similar catchment characteristics to the upper reach of the Owenass. The conceptual model was therefore developed to investigate the suitability of using the Reary Valley gauge to calibrate the rainfall runoff model for the inflows into the Owenass and to demonstrate the validity of the rainfall runoff method. There is sufficient data to calibrate an FSSR16 rainfall-runoff model of the 2017 event response with the Catchment Wetness Index (CWI), Time to peak (Tp) and PR parameters transferred to the Owenass catchments.

For this initial examination, an hourly rainfall hyetograph has been derived for the 2017 event using the hourly rainfall profile of the Gurteen rain gauge to proportion the daily rainfall total from the Clonsee gauge for the rainfall recorded over the 24-hour interval from 21/11/2017 09:00 to 22/11/2017 09:00.

Figure 6-2 shows the gauged flow hydrograph, the cumulative flow and the cumulative rainfall at the Borness, Mountmellick and Reary Valley (as a substitute for the Pound) gauges for the 2017 event. The plot assumes uniform rainfall across the catchments and only the one 9-hour storm is included. This graph shows three types of response; the Barrow is very slow to respond and the cumulative flow plot shows a continued slow increase as the falling limb slowly recedes. The Owenass also responds quickly but has a long, slow, high volume response. By contrast, the Reary Valley gauge is typically fast responding, with flows running off a steep catchment with the cumulative flow plot showing a rapid levelling off. It recedes quickly before the main peak is reached at the Borness gauge. There is only a small difference between the flow and rainfall volumes which suggests a high percentage runoff (PR). The distinctly different hydrograph shapes suggest that the upstream sub-catchments respond differently to the low-lying catchment. This effect is also observed on the neighbouring Clodiagh catchment at the Bracknagh Bridge gauge.

Initial development of FSSR16 rainfall runoff models show that a good calibration can be achieved to the 2017 gauged flow at Reary Valley which has a reasonable transfer to the Owenass at the foot of the Slieve Bloom hills.

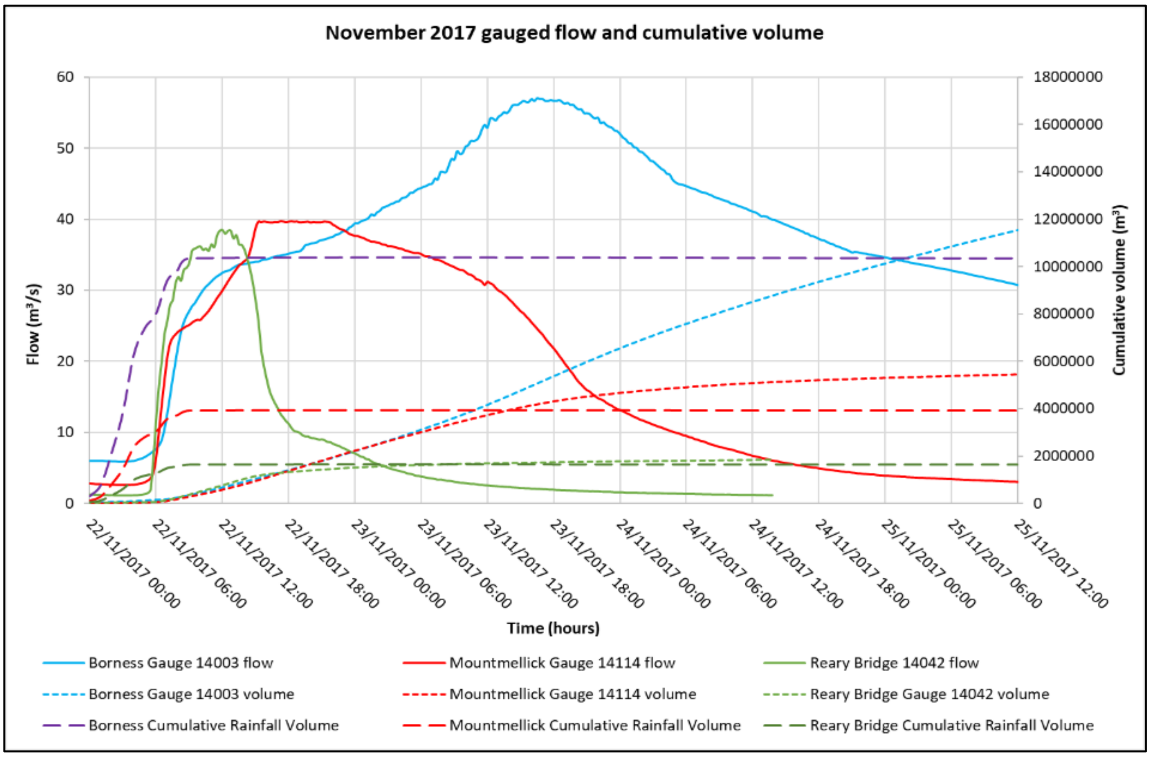


Figure 6-2: November 2017 gauged flow and cumulative volume

6.3 Hydrological model calibration

Both the hydraulic and hydrologic models were calibrated simultaneously as the floodplain and cross catchment flow within the system meant that the two are closely connected. This was carried out in a step wise manner. Firstly, the hydrological calibration was undertaken, looking at shape and volumes at the available gauging stations. This involved looking at the two key components of a rainfall runoff model, namely Time to Peak (Tp) and Percentage Runoff (PR). Due to the lack of reliable rainfall data within the catchment, Percentage Runoff and timing were found to be heavily impacted by which raingauge was adopted for hyteograph shape and volume.

A further test was performed to calibrate the hydraulic components, where the shape changes in the gauge station level data etc. The latter process also gives further confidence in the hydrological calibration.

Three events were used to calibrate and validate the hydrologic and hydraulic models used in this study:

- Storm Dennis 2020 (in channel event)
- Storm Ciara 2020 (mid-range flood event)
- November 2017 (large flood event)

In each event the hydrological parameters such as rainfall, Percentage Runoff and Time to Peak within the FSSR16 FM units were altered to reflect the data recorded, or to match the recorded level data at the gauging stations. Rainfall data was the most critical input and for these events was sourced from the nearest meteorological gauges:

- Clonaslee waterworks daily rain gauge (nearest daily rain gauge to study area).

- Gurteen gauge and weather station (hourly rain gauge to the west of the study area and within the Slieve Bloom mountains).
- TII Gauge IR005 at Portlaoise (ten-minute rain gauge within the Triogue catchment. It is also noted that the TII gauges, while closer to the study area, do not undergo the same level of data quality checking compared to the MET Eireann gauge data.)

6.3.1 Variability in rainfall

Rainfall is the most critical input for the FSSR method for hydrological calibration. To hydrologically calibrate the model, testing was carried out on all three calibration events to determine the combination of available rainfall data that would best replicate the recorded responses in the gauges.

The study area and wider contributing catchments span a large area and therefore the rainfall impacting the area will vary spatially in relation to both rainfall depth falling and the timing of that rainfall. The storm systems that affect Mountmellick are not only impacted by the natural variability across large storm systems but also by the orographic effect from the Slieve Bloom mountains which impacts storm intensity as the system moves from west to east across the area.

The spatial variability is shown by comparing the recorded hyetographs and depths for the four closest sub-daily gauges for a single storm event (Ciara 2020) in Figure 6-3. The impact of applying various rainfall hyetographs and rainfall depth combinations results in varying responses at the gauges within the hydraulic model. Figure 6-4 shows a selection of the modelled responses on the Owenass for various combinations of hyetograph shape and rainfall depths examined for Storm Ciara. Different combinations of depth and hyetograph shape data were tested for all three calibration events.

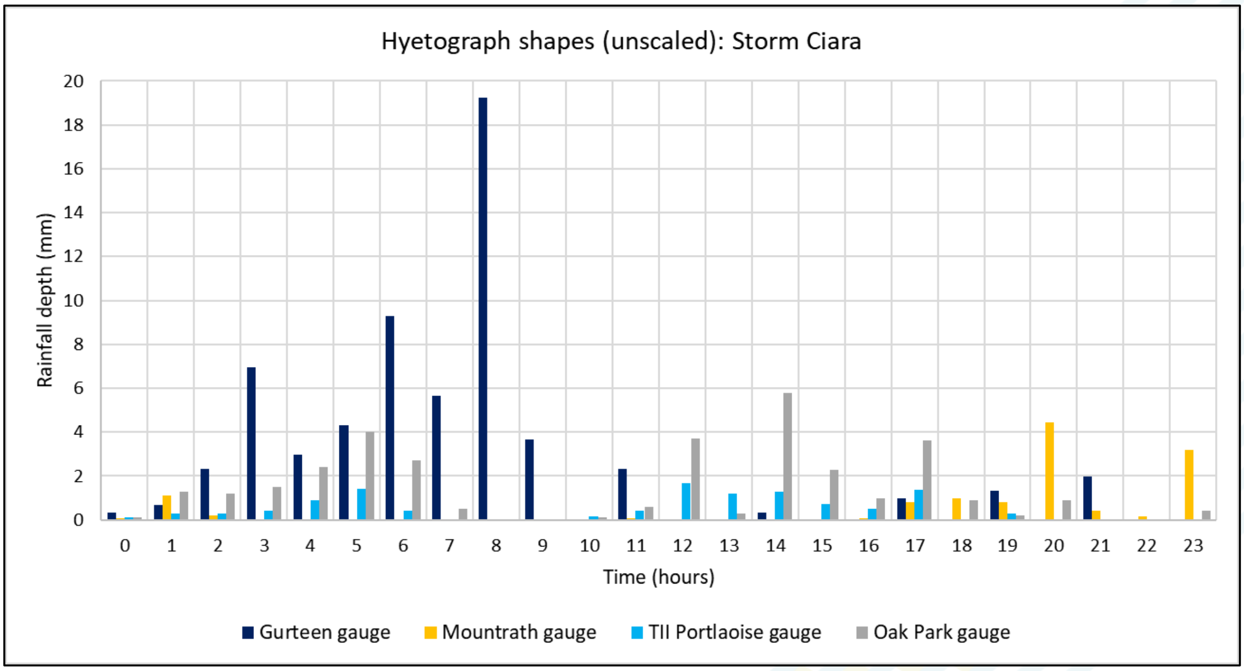


Figure 6-3: Hyetograph shape (unscaled): Storm Ciara

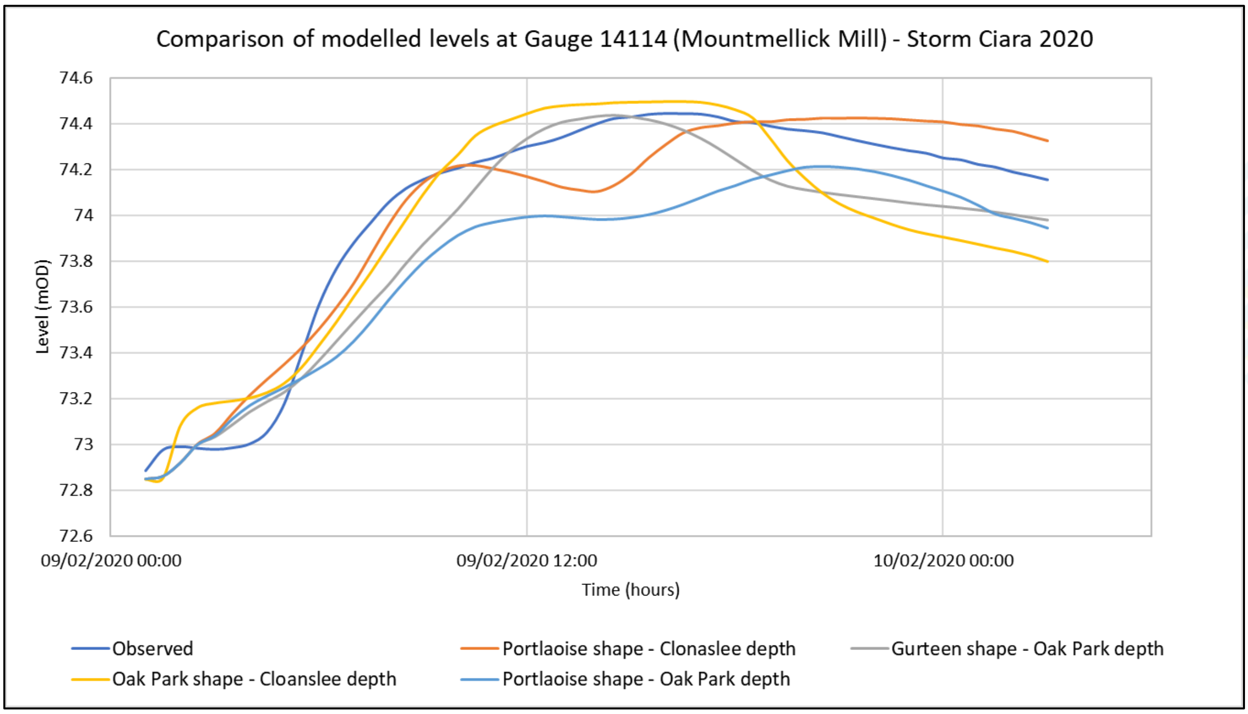


Figure 6-4: Comparison of modelled levels at Gauge 14114 (Mountmellick Mill) – Storm Ciara 2020

Through testing the combination of hyetograph shape and rainfall depth that provided the best overall calibration for each calibration event was found. The following combinations were selected for use in the calibration events:

- Storm Dennis: Gurteen hyetograph shape with scaled rainfall depths from Clonaslee daily gauge.
- Storm Ciara: Gurteen hyetograph used for western catchments and TII Portlaoise hyetograph shape for eastern catchments (including the Owenass) with scaled rainfall depths from Clonaslee gauge applied to all catchments. Division of hyetographs based on Theissen polygons shown in Figure 6-5.
- November 2017: Gurteen hyetograph shape with scaled rainfall depths from Clonaslee daily gauge.

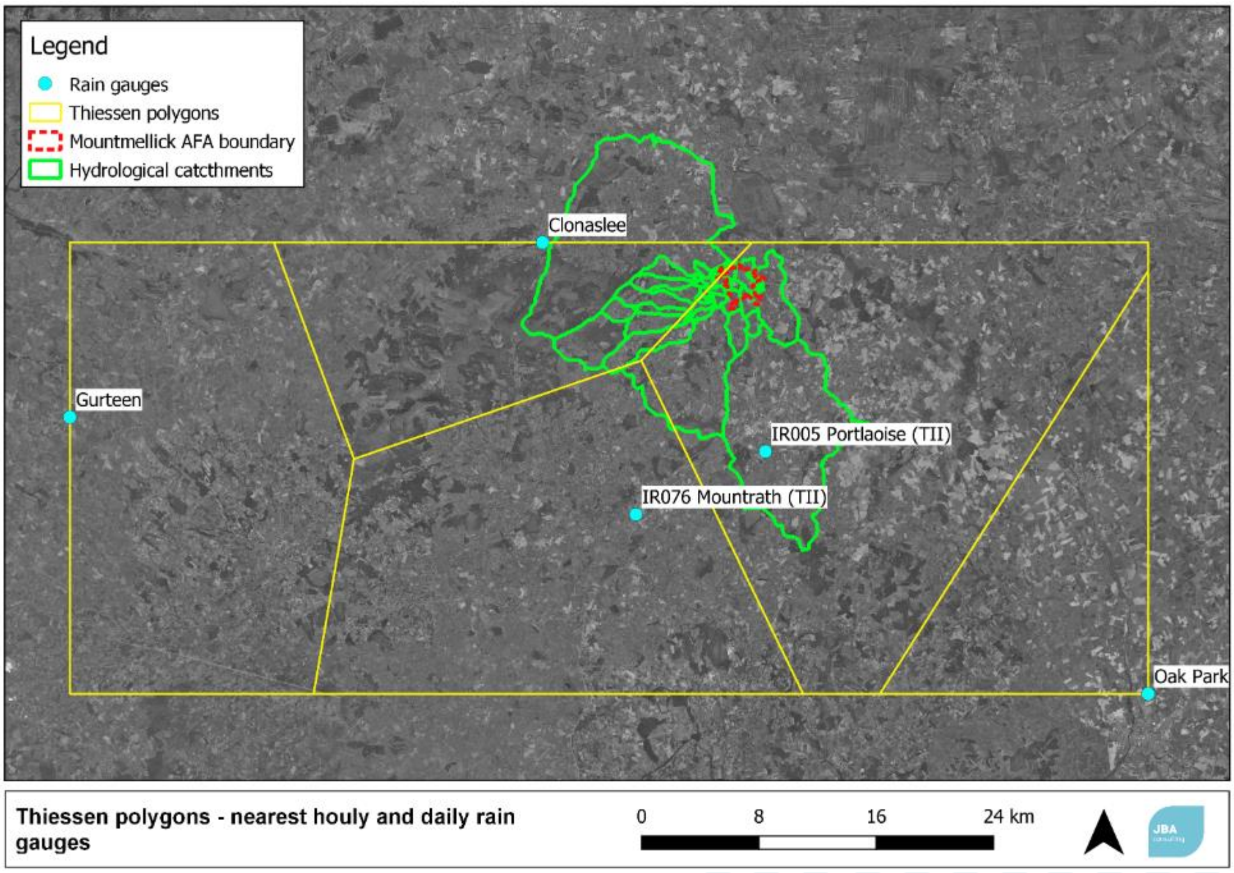


Figure 6-5: Theissen polygons – nearest hourly and daily rain gauges

The scaling of the Clonaslee daily rainfall values has been carried out to account for the additional variability if orographic effects in the recorded rainfall. An inspection of the SAAR values, which are representative of the orographic effects of the Slieve Bloom, shows a significant variation (Figure 6-6) which is also not truly represented in the available rainfall data due to the sparse gauge network available. To account for this, the total rainfall values recorded at Clonaslee gauge were scaled relative to the SAAR values for each sub-catchment This was to account for the impact of the Slieve Bloom mountains and the varying topography in relation to the proportion of rainfall that would fall over a given area.

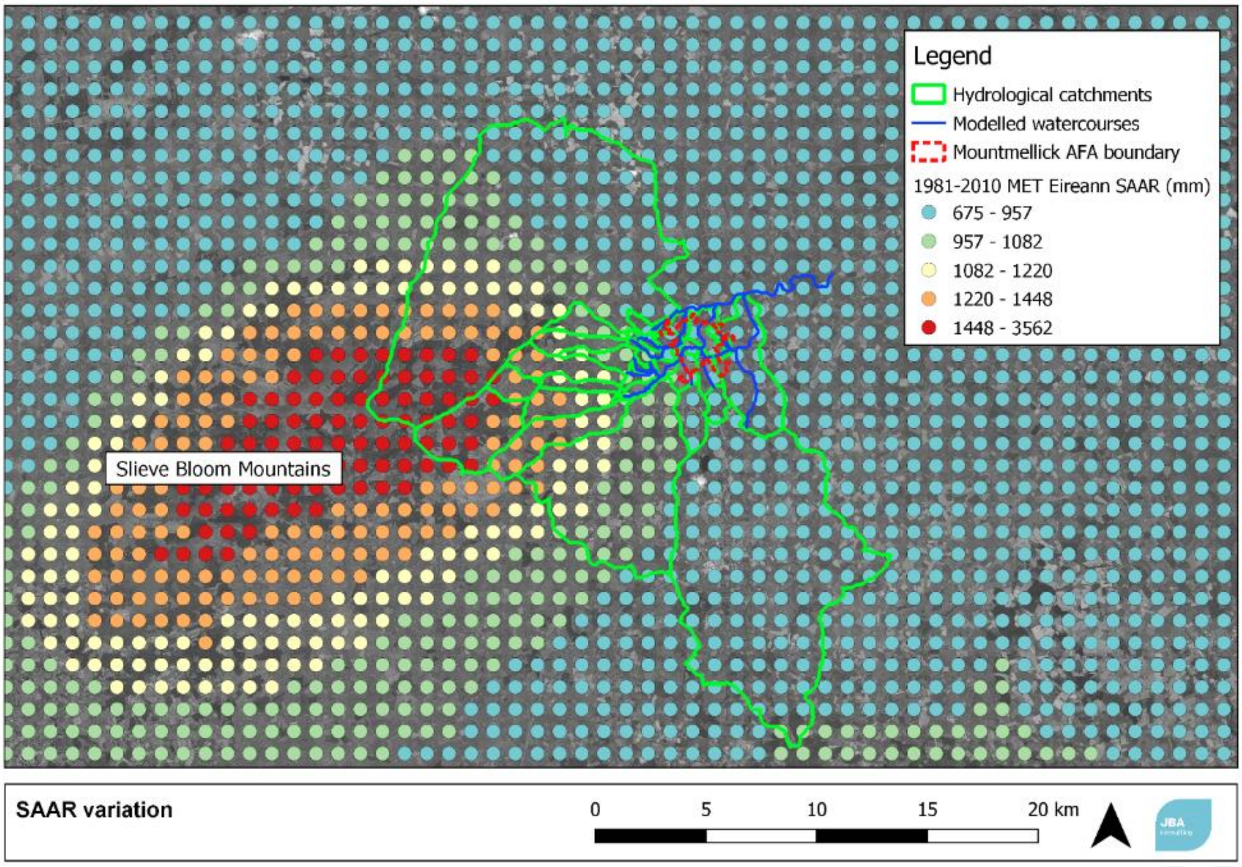


Figure 6-6: SAAR variation

In summary every effort has been made using the data available to account for the variability of rainfall within the system however it is noted that due to the lack of a more complete gauge network a full understanding of this variation cannot be gleaned. This gap of data and understanding is highlighted by the fact that although a good calibration of levels has been achieved for all three events on all gauges there is a noted mismatch of timing between the modelled and observed gauge hydrographs in each event. With no additional data within the main study area, no further meaningful adjustments can be made to the hydrological model to improve this offset and it remains a limitation of the data and the hydrological model used.

6.3.2 Pound and Owenass River Time to Peak (Tp) analysis

The FSSR method estimates a Time to Peak (Tp) for each inflow. As both the Owenass and Pound watercourses are gauged, an assessment as to whether the FSSR Tp values matched the observed data could be made. Given the increased interaction between the two watercourses with increased flow Tp analysis could only be carried out using the Storm Dennis data in which no cross flow occurs.

To carry out this assessment the time delay (or lag) between peak rainfall and peak level recorded at the active gauges was measured. Using the lag time, Tp was estimated using the following equation:

$$Tp\ (0) = 0.604 \times LAG^{1.144}$$

(equation sourced from Flood Studies Report 16)

Comparing the FSSR16 estimated Tp to Tp estimated from observed data it was found that the estimated Tp value for the Owenass matched well, but the Tp for the Pound watercourse was underestimated (FSSR16 Tp: 6.22 hours Observed Tp: 7 hours). To account for this, a Tp adjustment factor of 1.13 was applied to the inflows along the Pound system upstream of gauge 14121, increasing the Tp in the hydrograph estimation for all calibration and design events (refer to Figure 6-7 for difference in timing). While this Tp adjustment analysis has been carried out it is noted that it is also subject to uncertainty and limited by the raingauge data available and the variability across the catchment. The significance and impact these Tp changes have on results are also limited due to the wider variability and limitations in the available hydrological data discussed in Section 6.3.1.

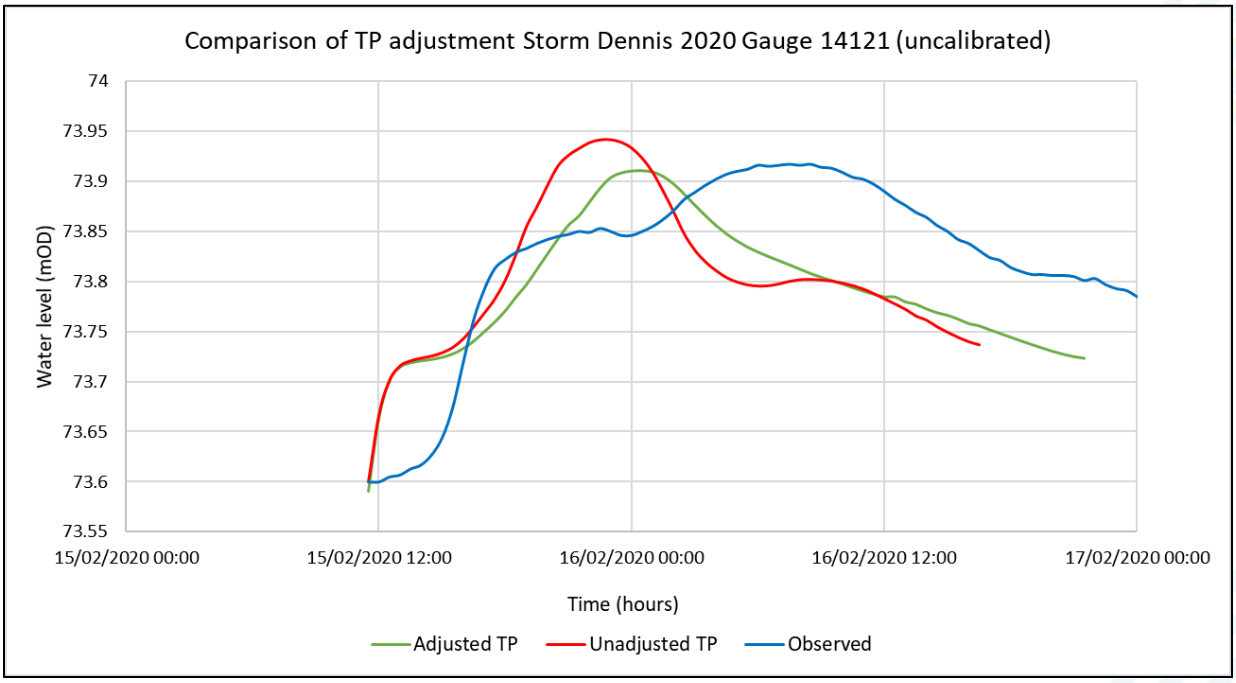


Figure 6-7: Comparison of TP adjustment Storm Dennis 2020 Gauge 14121 (uncalibrated)

6.3.3 Storm Dennis 2020

Storm Dennis occurred one week after the Storm Ciara flood event. Rainfall over a wet catchment resulted in water levels rising, but no flooding was reported. This event is of importance as no cross flow occurred between any of the watercourses during the event so each watercourse can be assessed individually. Table 6-2 shows the event input values used in the FSSR16 method.

Table 6-2: Hydrological input data: Storm Dennis

Parameter	
Storm duration	24 hours
Catchment wetness index	Upland catchments: 135.00 Lowland catchments: 135.00
Soil Moisture Deficit (from Gurteen gauge)	Well drained: 0 Moderately drained: -10 Poorly drained: -10
Percentage runoff	Based on SOIL class (as per normal FSSR16 procedure). Range 30-50%
Total rainfall recorded at Clonaslee gauge for event	Clonaslee: 22.10mm

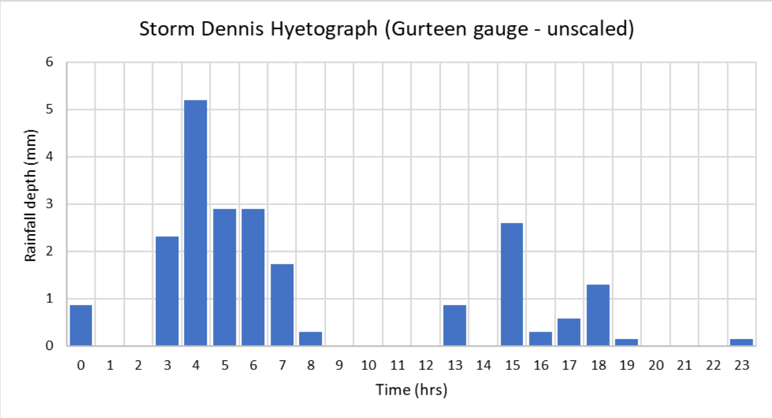
Total rainfall values applied, scaled by SAAR	Low SAAR catchment: 15.69mm Medium SAAR catchment: 21.22mm High SAAR catchment: 26.77mm
Hyetograph shape	
Base flow	Dynamic base flow was applied to the Owenass and Pound watercourses based on the observed gauge hydrographs.

Figure 6-8, Figure 6-9, and Figure 6-10 compare the modelled and observed flows and levels at the gauges active during the event on the Owenass and the Pound. The flows have been estimated using a curve derived from modelled outputs which has not been validated and is subject to uncertainty but enabled a comparison to be made (refer to Section 5.4).

On the Owenass there is a difference of 3.69m^3/s between peak observed and modelled flows and levels are within ±0.20m of the observed for the first peak and a difference of 0.56m^3/s and levels within ±0.05m for the second peak. Along the Pound there is a maximum difference of 0.22m^3/s between peak modelled and observed flows and levels are within ±0.10m of the observed. The observed hydrograph shapes are also replicated in all cases although the timing of the modelled peaks is offset from the observed timing by approximately 4-5 hours. The adjustment of Tp on the Pound system has resulted in a better alignment of timing of peaks at the two gauges compared to no adjustment but there is still a timing issue due to the wider variability of rainfall within the area (refer to Sections 6.3.1 and 6.3.2). Overall, the modelled outputs highlight that both the hydrological and hydraulic model components calibrated reasonably well to this in channel event.

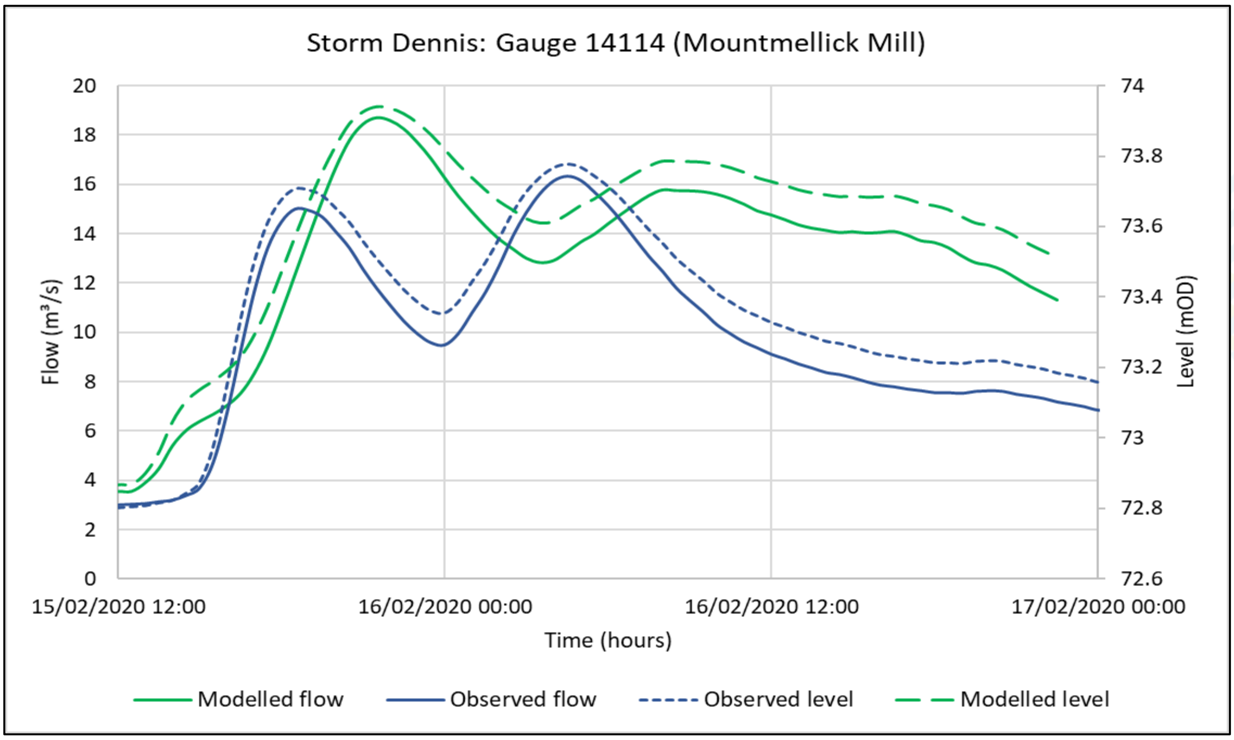


Figure 6-8: Storm Dennis: Gauge 14114 (Mountmellick Mill)

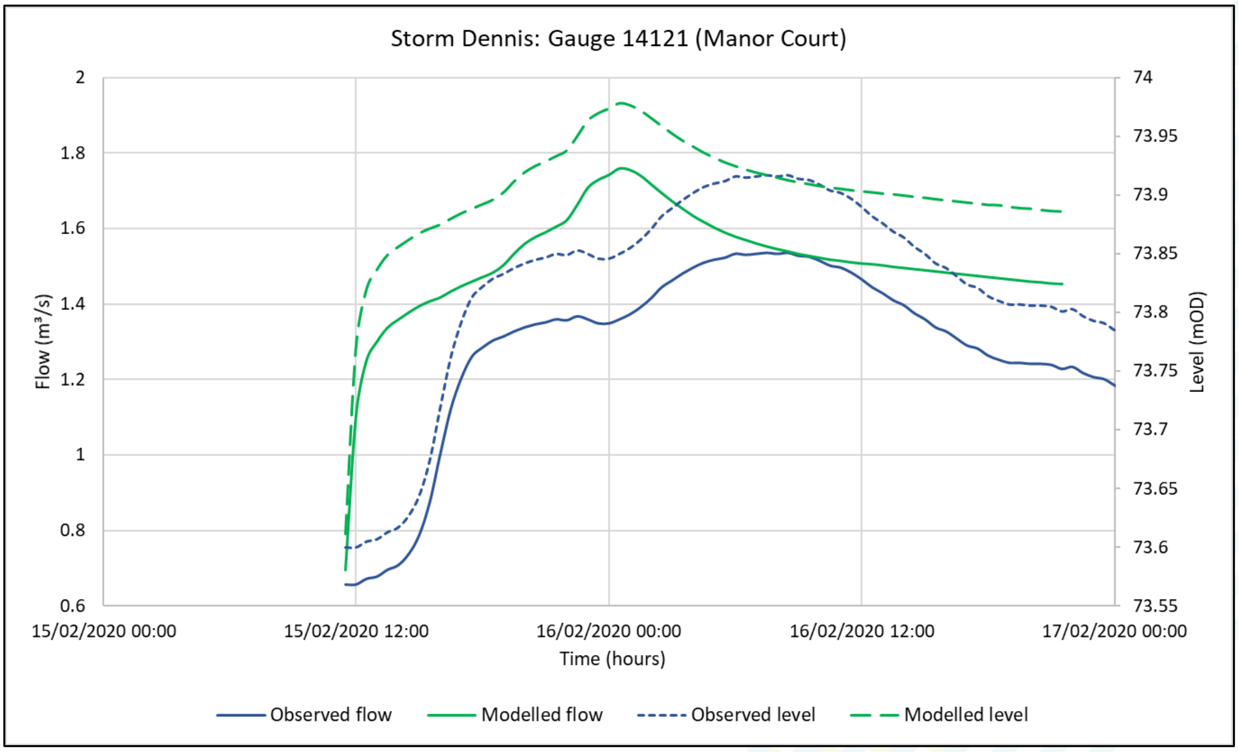


Figure 6-9: Storm Dennis gauge 14121 (Manor Court)

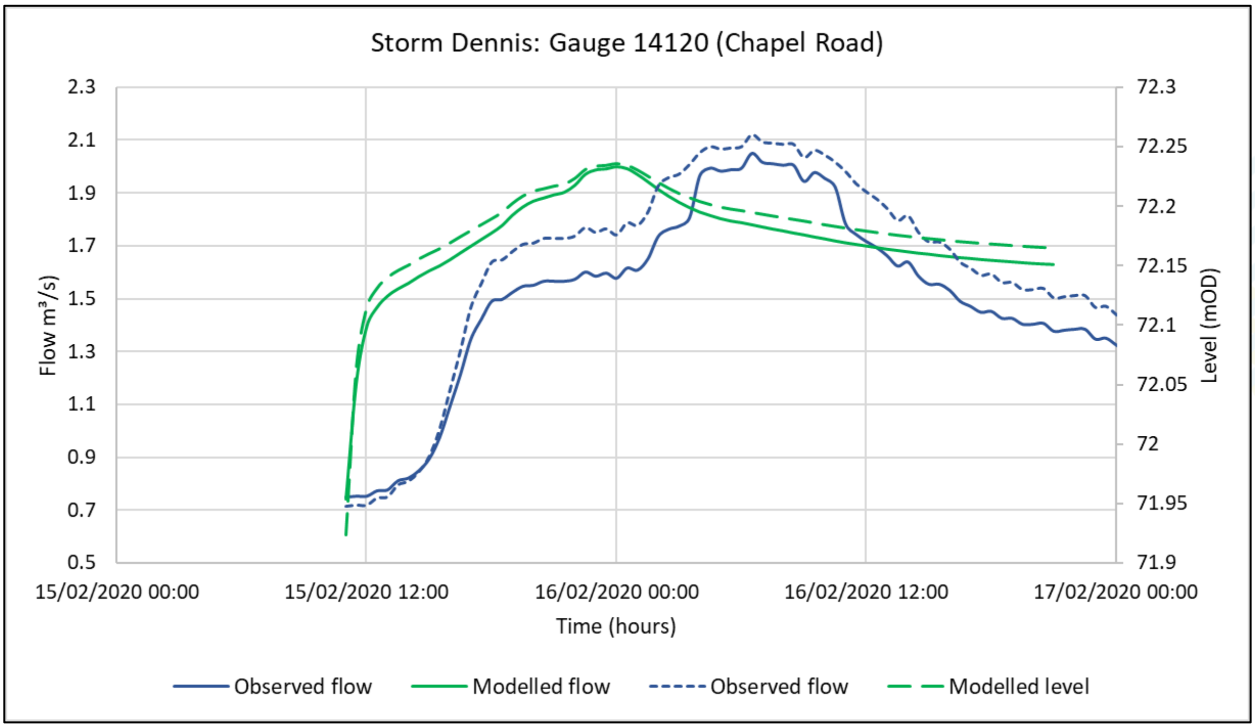


Figure 6-10: Storm Dennis: Gauge 14120 (Chapel Road)

6.3.4 Storm Ciara 2020

Storm Ciara occurred in February 2020 during a wet winter. Heavy rainfall resulted in increased water levels. Two houses upstream of Mountmellick were evacuated as a precaution, but no inhabited properties were reported as having flooded. A number of road closures were also recorded. Table 6-3 shows the event input values used in the FSSR16 method. As previously discussed in Section 6.3.1 a best fit calibration was achieved for this event by applying two hyetograph shapes highlighting the variability across the area.

Table 6-3: Hydrological input data: Storm Ciara

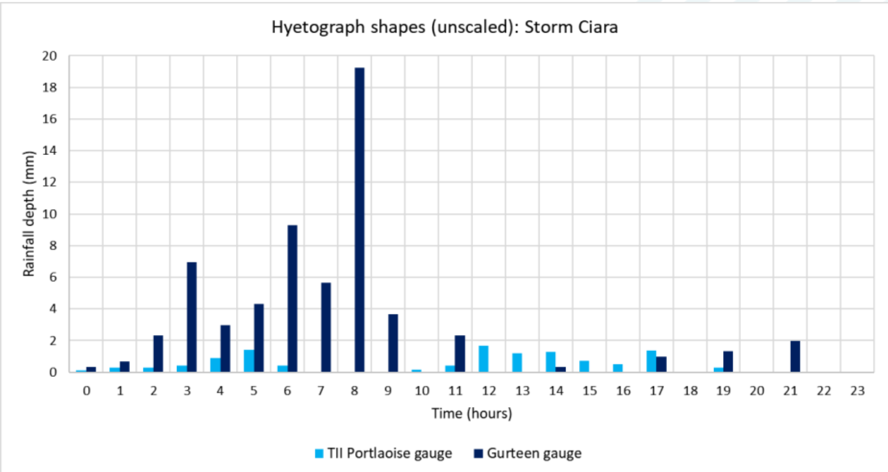
Parameter	
Storm duration	24 hours
Catchment wetness index	Upland catchments: 135.00 Lowland catchments: 132.60
Soil Moisture Deficit (from Gurteen gauge)	Well drained: 0 Moderately drained: -7.6 Poorly drained: -10
Percentage runoff	Based on SOIL class (as per normal FSSR16 procedure). Range 30-50%
Total rainfall recorded at Clonaslee gauge for event	62.40mm
Total rainfall values applied scaled by SAAR	Low SAAR catchment: 44.32mm Medium SAAR catchment: 59.94mm High SAAR catchment: 75.58mm
Hyetograph shapes	
Base flow	Dynamic base flow was applied to the Owenass and Pound watercourses based on the observed gauge hydrographs.

Figure 6-11, Figure 6-12, and Figure 6-13 show the modelled and observed responses on the Owenass and Pound gauges. Of the events Storm Ciara proved the most complex and difficult to calibrate conclusively. Understanding the crossflow interaction between the Owenass and Pound watercourses via the connected flood plain involved extensive hydraulic and hydrologic testing to establish the correct flow balance and levels observed during the event.

The total rainfall depth recorded at the Portlaoise TII gauge for the event was 7.40mm which is significantly less than that recorded at Clonaslee showing how highly variable the rainfall recorded is for various events across the catchment. The Portlaoise rainfall is such that if it were applied to the hydrological model it would not produce sufficient flows to replicate the event at the gauges or the flood extents observed.

On the Owenass the difference in peak flows is 0.83m^3/s and modelled peak water level is within ±0.05m of observed peak level. Along the Pound peak flows and levels again match well, there is only 0.14m^3/s difference in peak observed and modelled flow at the upstream gauge 14121 and modelled peak levels are within ±0.04m of observed. Downstream at gauge 14120 at Chapel Road there is a difference of 1.78m^3/s between modelled and observed flow and peak levels are within ±0.15m. Despite a good calibration between peak levels and flows for this event, again the wider variability in and lack of available rainfall data means that there is an offset in the timing of the modelled results compared to the observed which cannot be fully resolved. The overall calibration for this event is considered reasonable given the limitations.

The calibration of this event highlights the importance of, and sensitivity to, flood plain cross flow within the system and the interplay between hydraulics and hydrology. The peak reported level and flow on the Pound is a result of the cross flow from the Owenass entering the system. To achieve the calibration a balance of the flow exchange between the two watercourses had to be found by adjusting the hydrology to generate the observed hydraulic response. Refer to the hydraulics report for further discussion of this hydraulic mechanism.

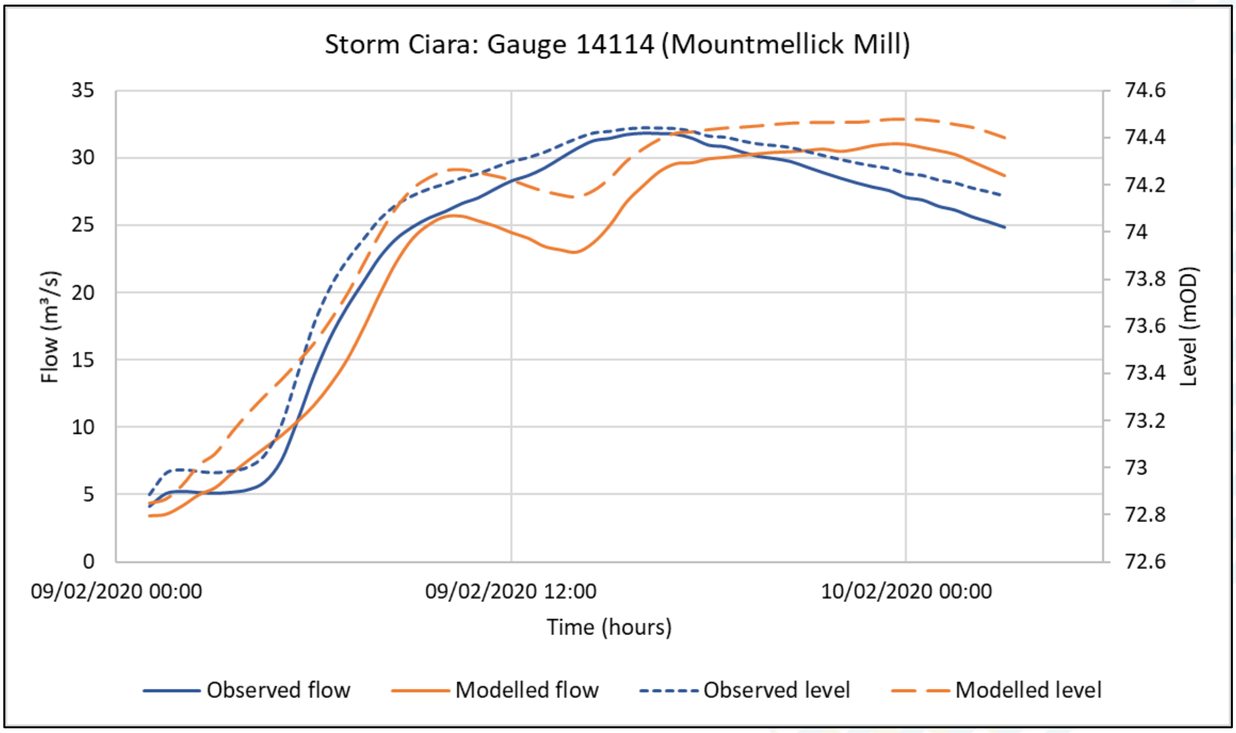


Figure 6-11: Storm Ciara: Gauge 14114 (Mountmellick Mill)

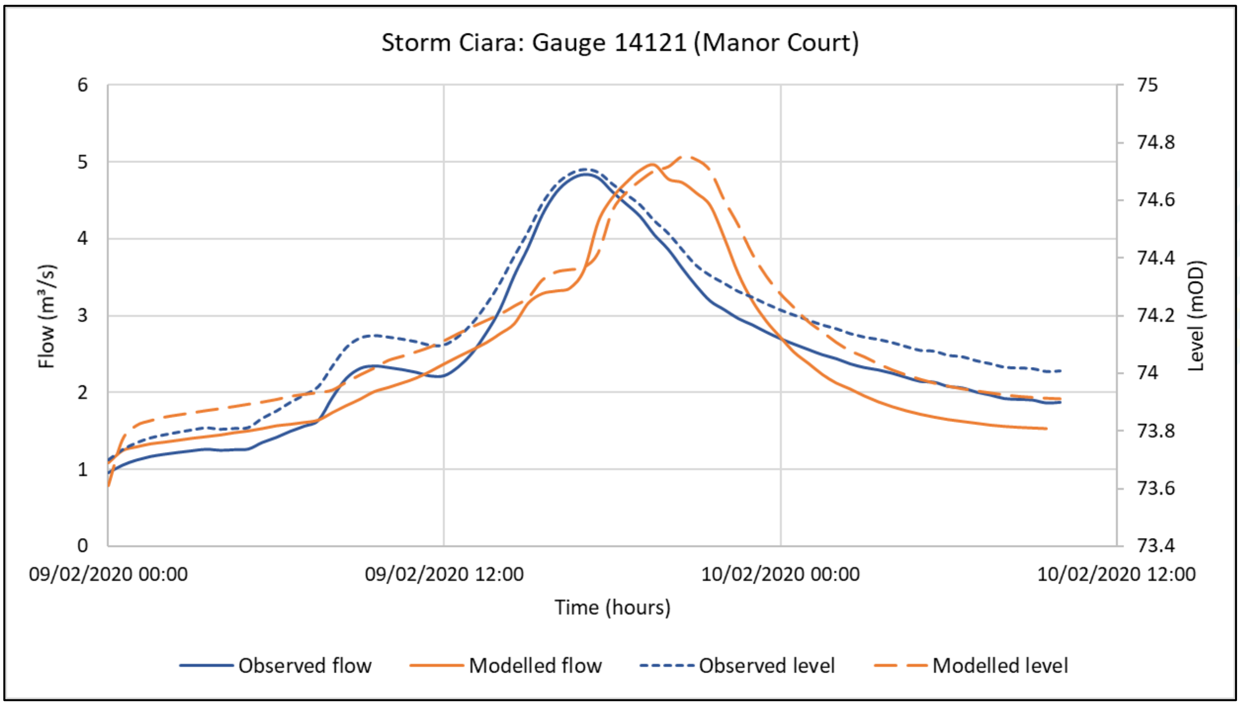


Figure 6-12: Storm Ciara: Gauge 14121 (Manor Court)

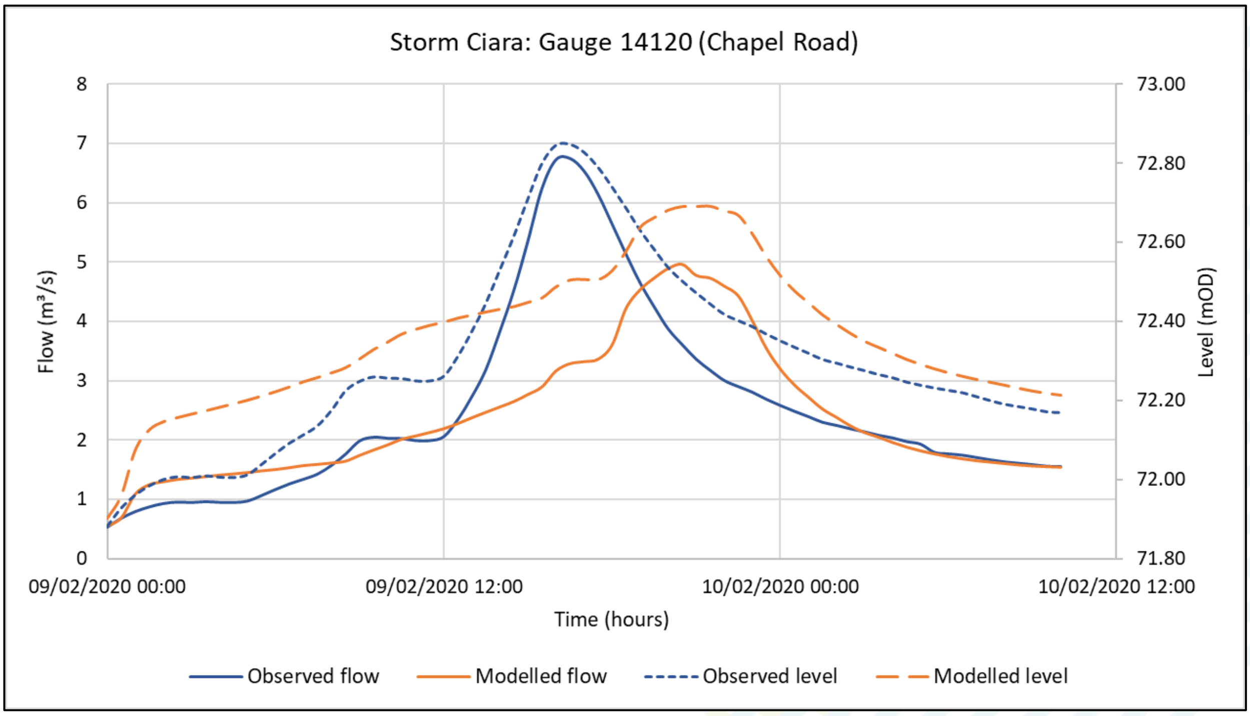


Figure 6-13: Storm Ciara: Gauge 14120 (Chapel Road)

6.3.5 November 2017

November 2017 is the most recent large flood event to affect the area. Conditions within the catchment were wet and it is noted that the channels were not as well maintained at this time resulting in increased debris within the watercourses. A bridge was also noted as having been blocked during the event (Convent bridge, refer to Figure 6-14). These event specific catchment conditions are represented in the hydraulic component of model calibration. Table 6-4 shows the event input values used in the FSSR16 method. The percentage runoff (PR) values applied for this event higher than those used in the Storm Ciara and Dennis. The higher 2017 PR values were sourced from the initial hydrological model calibration work discussed in Section 6.2 and better replicates the observed flood extents compared to when the PR values based on SOIL type are used. This is a known deficiency in the dynamic component of PR that is applied in FSSR16 from CWI and event rainfall depths.

Figure 6-14: Blockage at Convent bridge

Table 6-4: Hydrological input: November 2017

Parameter	
Storm duration	11 hours
Catchment wetness index	Upland catchments: 137.17 Lowland catchments: 127.97
Soil Moisture Deficit (from Gurteen gauge)	Well drained: 0 Moderately drained: -0.4 Poorly drained: -9.6
Percentage runoff	Based on initial hydrological calibration to Reary Bridge gauge: 60-70%
Total rainfall recorded at Clonaslee gauge for event	50.20mm
Total rainfall values applied scaled by SAAR	Low SAAR catchment: 35.66mm Medium SAAR catchment: 48.29mm High SAAR catchment: 60.80mm

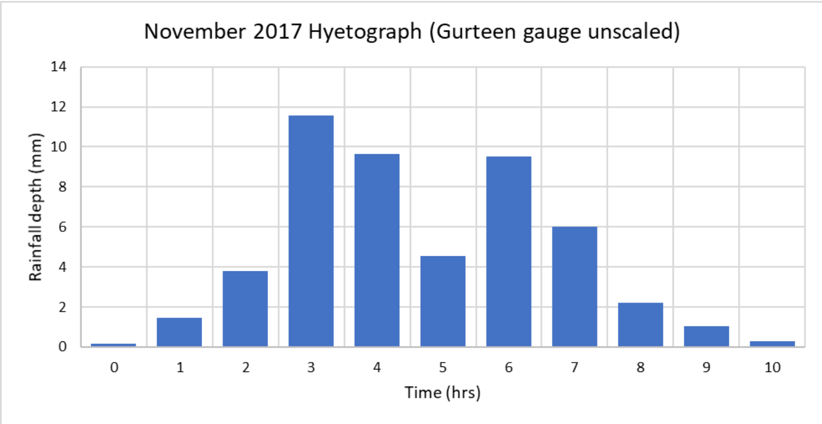
Hyetograph shape	
Base flow	Dynamic base flow was applied to the Owenass watercourse based on the observed gauge hydrograph.

Figure 6-15 compares the modelled and observed flows and levels at gauge 14114, the only gauge active in Mountmellick town during the event. There is a difference of 12.20m^3/s between the observed and modelled peak flow and modelled peak levels are within ±0.15m of the observed. In both the modelled and observed hydrographs there is a noted change at approximately 8am in the 22/11/2017 where level and flow plateau before rising again at the peak of the event.

From examining the modelled outputs these noted changes have been attributed to the activation of the flood plain upstream of the gauge resulting in a change in flow and level in the channel as additional flow volume preferentially moves into the flood plain. This flood plain activation and movement of flow is replicated in the modelled event and like Storm Ciara further highlights the importance of understanding the flood plain interaction and cross flow between catchments in relation to flood risk to Mountmellick town. Refer to the hydraulics report for more detail on the impact of flood plain interaction and crossflow. Overall, the calibration for this event is considered reasonable given the hydrological and hydraulic limitations and complexity of the system.

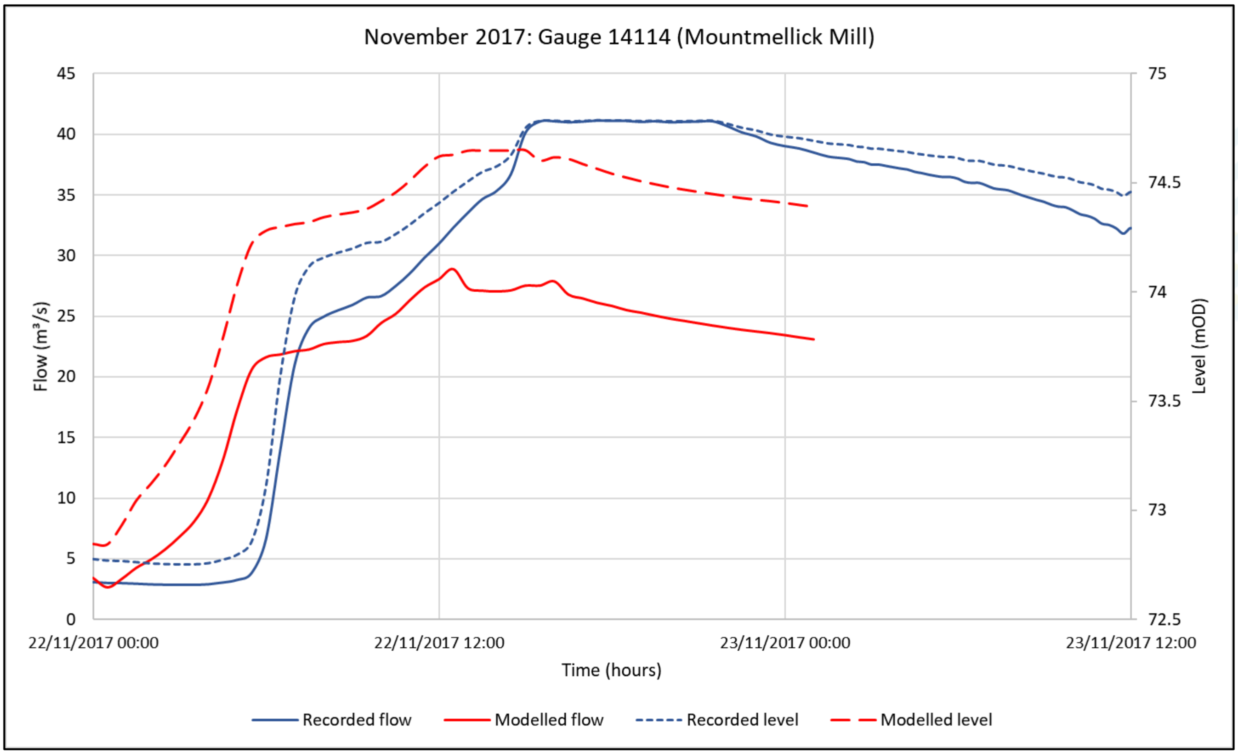


Figure 6-15: November 2017: Gauge 14114 (Mountmellick Mill)

6.3.6 Summary of hydrological calibration

The following points are noted in relation to hydrological calibration:

- Rainfall, its variability and limited data sets is the main limitation to successful calibration for this study. The use of different hyetograph shapes and rainfall depths from gauges for the different events shows this. While every effort has been made to account for the variability with the available data a timing offset is still present within the modelled outputs for all events as a result of it. With no additional data there is currently no way to improve this and it is a limitation of the method. Despite this all peak levels are within the calibration tolerances for the study and a reasonable calibration has been achieved for all three events.
- The adjustment of the Tp value for the Pound watercourse improved timing and modelled outputs compared to observed gauge records for both the 2020 events. The flow gauges were not operational in 2017, so the same comparison could not be made for this event. The Tp adjustment factor has therefore been applied in the estimation of design runs however it is noted that the improvement in TP adjustment on results is diminished in comparison to the wider variability in the system impacting the timing of flows.
- Changes in PR values impact the extent of flooding recorded, indicating antecedent conditions are an important factor in relation to flood risk to the town as shown by the increased flows and extents in the November 2017 event.
- Floodplain and cross flow interaction between watercourses results in complex flow patterns which limit the ability of the hydrometric gauges to accurately record the response of individual watercourses or peak event flows in larger events as with increasing event magnitude the cross flow between the watercourses increases and impacts the records at the various gauges. This

relationship highlights the importance of calibrating and understanding the hydraulics and hydrology of the system in tandem.

6.4 Design flow estimation

6.4.1 Design flow estimation and the Triogue system

Following the calibration of the Mountmellick hydrological model, a review of the flow estimation for the Triogue system was carried out. The Triogue and its tributaries and the system passing through Mountmellick town are hydraulically and hydrologically separate. The Triogue is represented in a separate hydraulic model (refer to the Hydraulic Report) with inflows independent of the Owenass – Pound cross flow system. Initially the FSSR16 method was used to estimate flows for the watercourse, however the flows estimated were considered uncharacteristically high for the watercourse with onset of flooding modelled at a lower than expected return period. Review of the catchment characteristics showed the catchment to be large and relatively flat compared to the catchments associated with the Slieve Bloom mountains (e.g. the Owenass). Based on the catchment characteristics, the FSRR16 method was determined to be unsuitable for flow estimation as it produced unrealistic flows for the Triogue. As the Triogue is a contained system, not subject to issues with cross flow the FSU HEP method has been used to estimate the inflows for the Triogue system. The final peak flow estimates for the Triogue and its lateral inflow can be found in Appendix C and further details of the FSU method in Appendix D of this report.

6.4.2 Design flow estimation – FSSR16 input requirements

Table 6-5 details the inputs required in each FM FSSR16 unit to allow estimation of flows. These inputs are in addition to the basic catchment descriptors (e.g. area), which were detailed earlier in this report. The table also details how they have been derived for the design run inflows. In each case, a 75% winter storm hydrograph profile has been used to generate the inflow because volume is a key factor to flood risk in the area.

For design runs the SPR values for each catchment are derived from WRAP SOIL type. However, review of the SPR values applied to WRAP class 2 soils catchments showed a lower SPR than was expected of the catchment, particularly given eye-witness descriptions of more saturated catchments. As a result, the SPR SOIL class 2 catchments were changed to SOIL class 3 (SPR increase from 0.30 to 0.40).

It is worth noting that as the hydrological model is distributed it accounts for rainfall variation across the area via the input of rainfall depth values based on the Met Eireann DDF values (M52D and M525D) and SAAR. However, the variation in the design storms cannot be as pronounced as the variation observed across the different rain gauges in the calibration events due to the limitations of data, lack of rainfall gauges to refine variation of database values and the inability to predict rainfall patterns of storms.

Figure 6-16 shows the design inflow hydrographs for the 1%AEP event for a number of the watercourses. Peak flows estimated for each AEP event are reported for each inflow in Appendix C of this report.

Table 6-5: FSSR16 input parameters

Input parameter	Design run value
SAAR	Standard Average Annual Rainfall over catchment area in mm. For design runs the latest SAAR data for the period 1980 – 2010 has been used
M52D	Depth of rain estimated to fall for a 20%AEP (5 year) event with a duration of 2 days. This value is sourced from the MET Eireann DDF database for each catchment.

Input parameter	Design run value
M525D	Depth of rain estimated to fall for a 20%AEP (5 year) event with a duration of 25 days. This value is sourced from the MET Eireann DDF database for each catchment.
SPR	Standard Percentage runoff – proportion of rainfall falling on the catchment that enters the river system instead of being intercepted. For design runs the SPR values for each catchment are derived from WRAP SOIL type and a dynamic PR component based on CWI and rainfall depth. SPR has been replaced by a calculated version based on BFI host value. Due to the cross connections between watercourses it is impossible to estimate runoff for a given event at Mountmellick Mill GS.
CWI	Catchment wetness index estimated using the FSSR method.
Tp	Default time to peak estimated from the FSSR16 unit has been used for all watercourses apart from the Pound where Tp is adjusted by 1.13 following Tp analysis carried out using gauge 14121 (refer to Section 6.3.2).
Flow return period	Altered to match the desired AEP event.
Storm duration	An 11-hour design storm duration has been used following sensitivity analysis carried out using the hydraulic model (refer to the hydraulic user report). This is also the duration of the 2017 event.

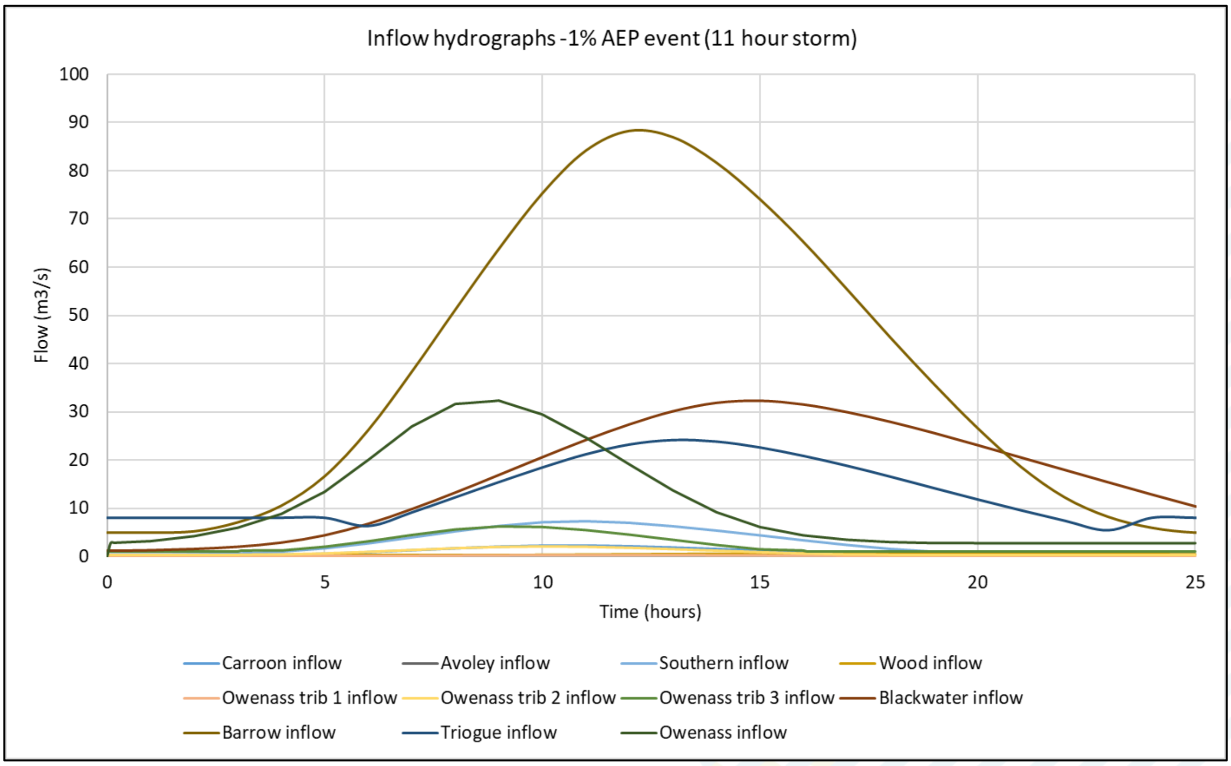


Figure 6-16: Inflow hydrographs – 1%AEP event (11 hour storm)

6.5 Design flow comparisons

Table 6-6 compares the estimated 1% AEP design inflows for a number of upstream locations (refer to Figure 6-17 for locations). Flow comparisons have been limited to upstream of where cross flow between the Pound and Owenass occurs to ensure a like for like comparison to be made. The flow estimates in the upper sub-catchments of the watercourses is determined by the method applied. In most cases the FSSR flow estimates are the highest for each watercourse. The FSSR estimate on the Owenass is lower but is within the range of the SECFRAM and FSU estimates. Overall, the higher FSSR flow estimates provide a more conservative approach in relation to peak flows applied compared to the other methods.

Table 6-6: Peak 1% AEP flow estimate comparisons

FSSR16 inflow Node	FSSR16	SECFRAM	FSU
503_hep_00027	1.56m³/s	1.00 m³/s	No FSU node
503_hep_00021	N/A	25.47 m³/s	24.14 m³/s
503_hep_00011d (combined upstream Owenass inflows at this point)	57.26 m³/s	58.90 m³/s	50.73 m³/s
503_hep_00004a (flow at SECFRAM inflow point)	2.45 m³/s	0.61 m³/s	No FSU node

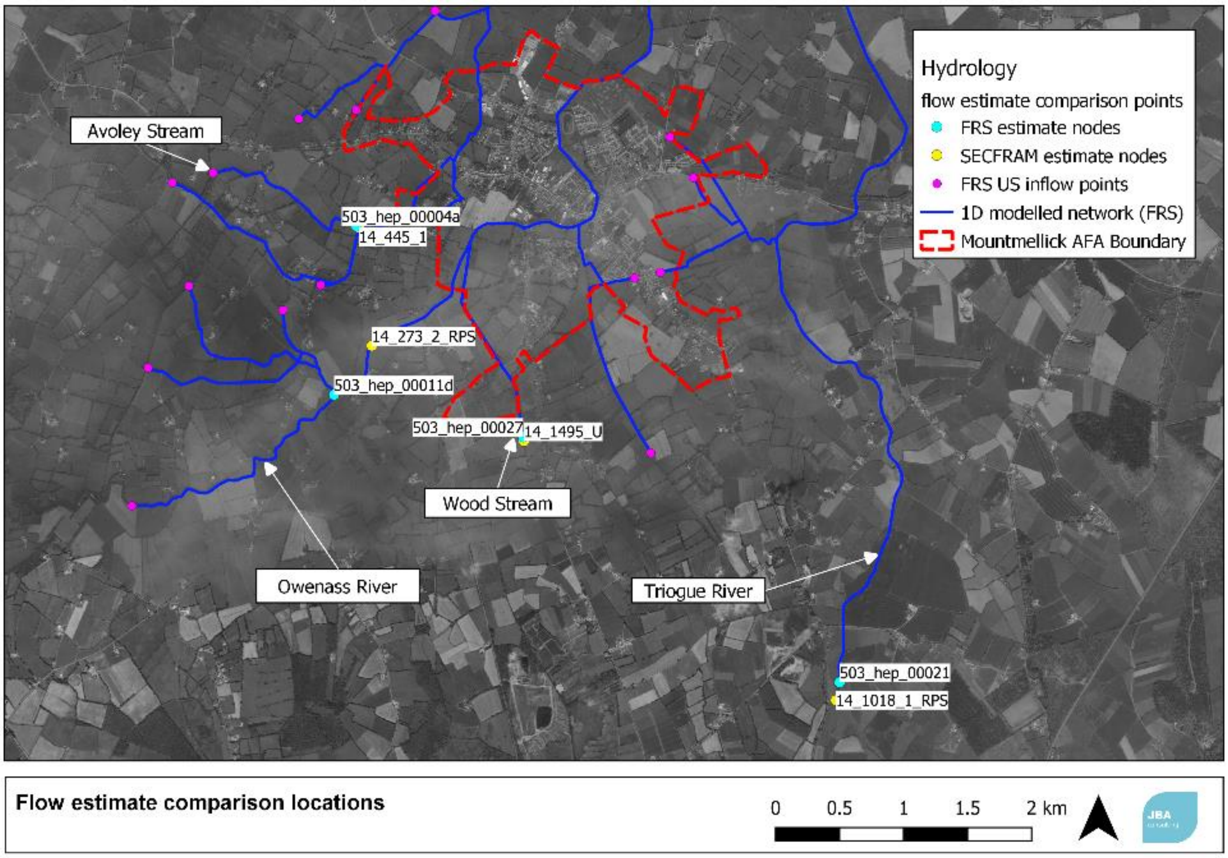


Figure 6-17: Flow estimate comparison locations

6.6 Flood frequency curve analysis

The flood frequency curve generated within the FSSR16 method has been used for higher exceedance events. The FSSR method is known to generate steep growth curves which may not always be appropriate to use. To ensure that the generated growth curve is appropriate for the Mountmellick catchments, a comparison of flood frequency curves (FFCs) was carried out.

Figure 6-18 shows the FFCs estimated at the Mountmellick Mill gauge (14114) using single site analysis and the FSU pooling group method, and also shows peak flows extracted from the model for a range of return periods. The Log-normal 2 parameter distribution has been used for the single site analysis as it was found to best match the recorded data values.

The modelled flows at the gauge location do not match the FFCs generated through statistical approaches. The modelled flows show a very flat FFC, due to large amounts of out of bank flooding occurring upstream of the gauge and overflow to the Pound River resulting in a decreased flow passing through the gauge for a given event. It highlights that estimating flows at the gauge using a single site, or HEP, approach results in overestimation of flow at the gauge for a given event as it does not account for the impact of floodplain interaction which is a critical element in this system. For example, the 2017 event at the gauge was modelled and observed to have a return period of approximately the 1% AEP event, whereas using the FSU growth curve results in a return period of just over 10% AEP and even less for the single site analysis growth curve. This underrepresentation of the potential return period based on growth curve is further compounded when the upstream modelled Owenass flow for 2017 is considered which shows the 2017 return period upstream was closer to a 0.5 %AEP return period flow.

When the FFCs are compared to modelled flows upstream of the gauge along the Owenass watercourse there is a better match for a given AEP event. Looking at the upstream modelled flow values shows the steepness of the FSSR16 FFC compared to the other curves. Again, when the flows at the gauge are considered the effect of the curve steepness is dampened as large flows are needed at the upstream to generate any values of significance at the gauge due to the loss of flow into the floodplain.

Based on these observations it was decided that although the FSSR16 FFC is steep it is still appropriate to use for generating higher design run flows as the impact of the flood plain on flows is more significant and higher flows at the upstream extent are necessary to generate realistic flooding downstream within the town.

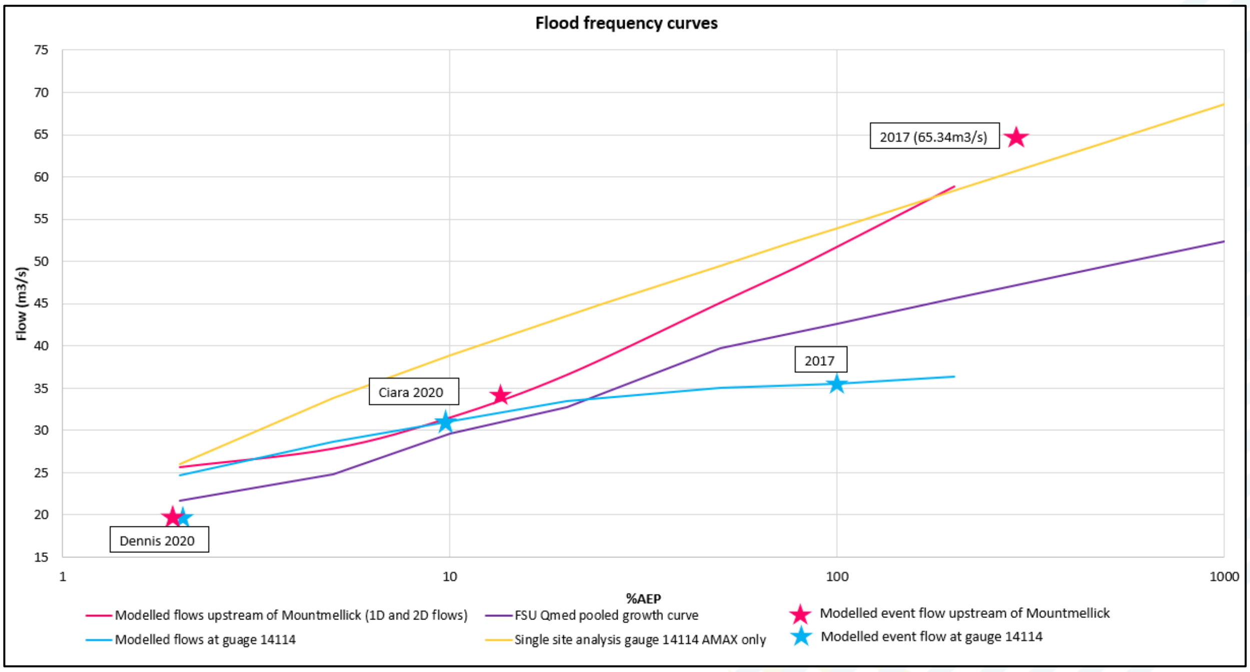


Figure 6-18: Flood frequency curves

6.7 Surface water contributions

Due to the complications in understanding the Mountmellick urban storm water systems (refer to Section 3.7) assessment of potential surface water contributions has been carried out using a rain on grid model of the Mountmellick town area (refer to the hydraulic model report for more detail). This was done to establish where potential point inflows could be placed and estimate surface water inflows into the fluvial model. Results from this analysis found that there were no key points where surface water would enter the watercourses via an overland route based on topography, it also highlighted that the urban contributions of flow were minimal. Given these outcomes and no clear inflow points of flows of significance found, it is appropriate to account for the contribution of the urban runoff within the lateral inflow units along the Owenass and Pound via the URBEXT value used in the FSSR16 units and select point inflows where only storm water would contribute to the watercourse. For the inflows, flows were extracted from the rain on grid model and applied to the fluvial hydraulic model. Refer to Figure 6-19 for surface water application locations, with peak inflows detailed in Appendix C.

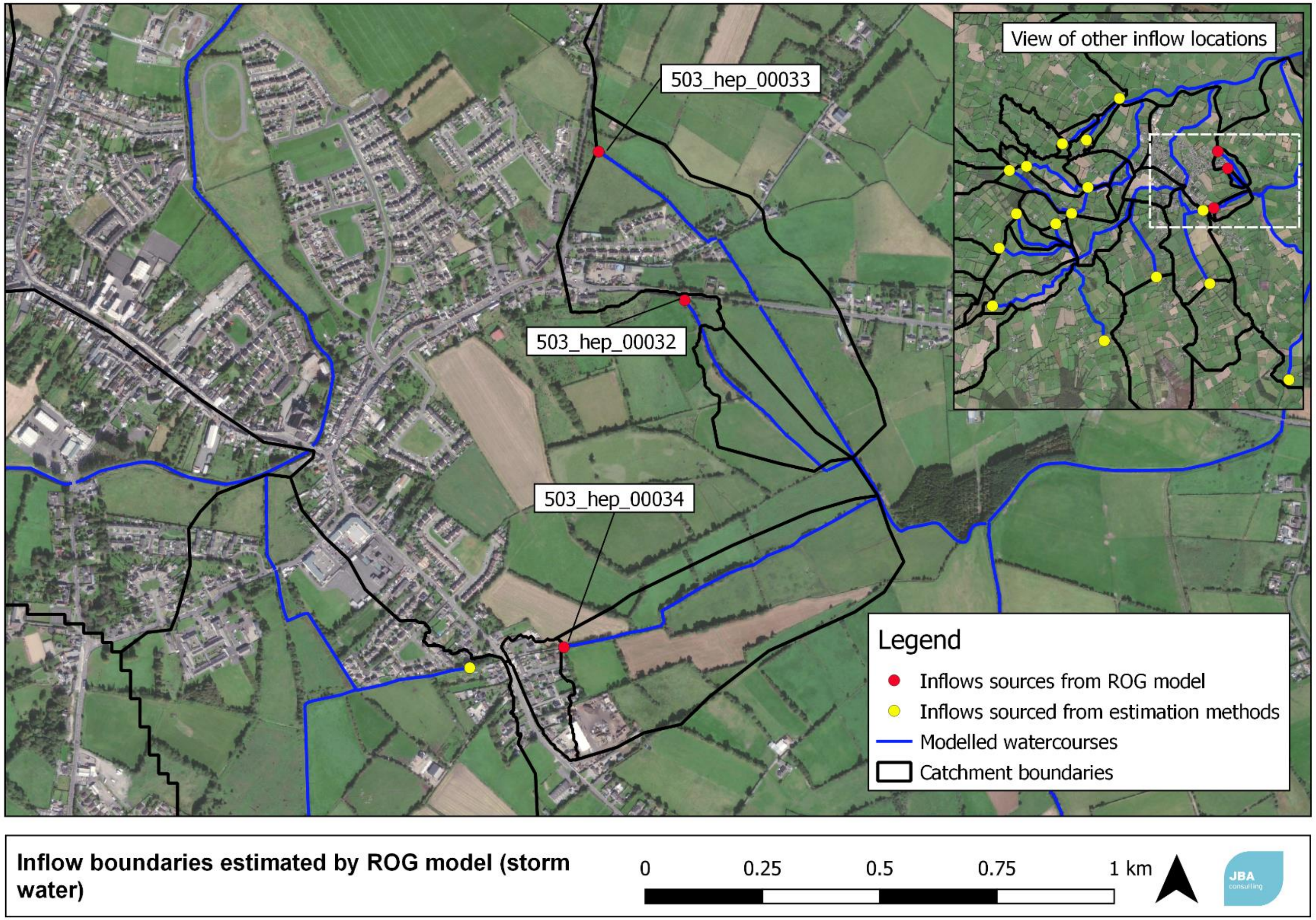


Figure 6-19: Inflow boundaries estimated by ROG model (storm water)

6.8 Future environmental and catchment changes

Specific advice on the expected impacts of climate change and the allowances to be provided for future flood risk management in Ireland is given in the OPW draft guidance[5], which calls for estimation of design flood parameters for two future scenarios, each intended to be a possible representation of flood conditions in 100 years time, i.e. around the year 2120:

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

The scenarios encompass changes in extreme rainfall depths, flood flows, sea level, land movement, urbanisation and forestry. The allowances for each of these aspects, apart from urbanisation, are set out in the brief. The sections below set out how design flood parameters for the future scenarios have been defined.

6.8.1 Impact of climate change on river flows

The guidance states that flood flows and /or rainfall shall be increased by 20% and 30% respectively for the MRFS and HEFS. This change has been implemented in the Pound and Owenass catchments by increasing rainfall depths, and in the Triogue model by scaling up the peak flow values.

6.8.2 Impact of urbanisation

For urbanisation the approach adopted is to calculate future urban growth patterns based on the core strategy for Mountmellick. The Corine land use map for 2018 gives an urban area of 215 Ha for Mountmellick. Although the plan does not extend to the 100 year horizon, it gives an indication of where development is to be targeted for the plan period, which can be interpreted to be the likely focus of growth for the future. No distinction is made between the mid-range and high-end scenarios as regards urbanisation.

The Core Strategy for Mountmellick gives a project population increase of 6.3% between 2016 and 2027, with a resulting increase in required housing units of 181, of which 121 will be delivered on greenfield land, requiring 4 Ha of land, which is less than a 2% increase on the current developed area.

When reviewing the above analysis, the following should be borne in mind:

Whilst it is possible to draw conclusions about the patterns of growth over the next 100 years, the scale of this growth is not known.

The development plan includes the requirement for SUDS to be included in new builds, so run off and flood generating potential should be reduced into the future.

The aim of the guideline document, The Planning System and Flood Risk Management is to ensure flood risk does not become unmanageable within a catchment; over future development plan periods, SFRAs will be undertaken which will assess and reassess flood risks presented by planned development, and ensure those risks remain manageable.

5 OPW Assessment of Potential Future Scenarios, Flood Risk Management Draft Guidance, 2009

Future design flows have been tested using a future URBEXT value which is based on a percentage increase of the current URBEXT value.

For the majority of catchments the increase in flows is extremely minor, or non-existent as the existing urban proportion is extremely small, or even zero, with little increase in QMED seen regardless of the scale of future urbanisation. It has therefore been decided to test a 5% growth to URBEXT for all catchments for the MRFS and a 10% increase for the HEFS, reflecting the possible future growth in Mountmellick, but recognising the capping factors on increases in flood risk discussed above. As can be seen from Table 6-7, the increase in URBEXT is marginal in the downstream locations, and as there is no measurable urbanisation in the upper catchments, URBEXT has no impact at all on flows entering Mountmellick.

Table 6-7: Comparison of URBEXT values

Flow location relative to Mountmellick town	Current URBEXT value	MRFS URBEXT (+5%)	HEFS URBEXT (+10%)
Owenass US	0.000	0.000	0.000
Owenass DS	0.009	0.010	0.010
Pound US	0.000	0.000	0.000
Pound DS	0.027	0.029	0.030
Triogue DS	0.090	0.094	0.098
Triogue US	0.076	0.080	0.084

It should be noted that most hydrological methods that allow for the effect of urbanisation on design flows, including both the adjustment for QMED in the FSU and the allowances for time to peak and percentage runoff in the FSR rainfall-runoff method, are based on analysis of flood data from existing urbanised catchments. Most of these catchments include a wide range of development types, ranging from old town centres with no runoff mitigation measures to recent developments with SUDS or other measures aimed at restricting the runoff from the developed area. The downstream flooding impacts of future development should be minimised and so it is to be hoped that the allowances for the impact of urbanisation on future design flows represent a conservative worst case scenario.

6.8.3 Impact of changes to forestry

Deforestation and afforestation can potentially influence flood risk by affecting surface runoff. Although the theory of increasing tree cover resulting in a reduction in peak flows is popular, scientific studies have shown that the influence of forests on flooding and runoff is more complex[6], with differences between modelled and observed relationships noted. The CEH Study (2017) found the "majority of statements from observed case studies report that the peak flows of large flood events are not influenced by the presence or absence of trees in the catchment."

Perhaps because of the complications of the crop cycle and management practices (such as drainage), there is little evidence from regional flood studies that the area covered by forest is a significant independent variable in the regression equations used for flood

6 CEH Wallingford (2017), Do trees in UK relevant river catchments influence fluvial flow peaks? A systematic Review.

estimation[7]. However, this does not mean that forests have no effect on a local scale. Forests and forest soils (with their deep litter layer) are capable of storing and transpiring more water than grassland or arable crops. Therefore, in the absence of complicating factors such as drainage, one can expect a reduction in downstream flood volumes and an increase in time to peak. Changing the time to peak can be a particular concern in areas where flood risk is exacerbated when two tributaries peak at the same time. Conversely, in some areas, changing the time to peak, for example through creation of attenuation areas of one tributary, can stop the peaks coinciding, and therefore reduce flood risk.

There are a number of ways that land use within the upper catchments of the Owenass and Pound rivers systems could change in the future, depending on the full impact of climate change, government policies and local industry drivers. A conversation has been opened with Coillte, who are responsible for the forestry activities in the uplands of the catchments.

Under the MRFS, the OPW climate change guidance recommends that the impacts of afforestation are investigated through a decrease in time to peak of a sixth; this allows for potential accelerated runoff that may arise as a result of drainage of afforested land. This means the volume of water in the river is unchanged, but the rate at which it runs of the land into the watercourse is increased.

Applying a generic change at all HEPs across the study area to represent the impact of increased afforestation could be carried out, but changing the time to peak to take account of change in land management is extremely generic. Although it may be perceived that an activity only has one impact, the run-off generation mechanisms vary considerably through the lifetime of the plantation, and depending on the specific management practices (relating to drainage and felling cycles) which are operated). A generic decrease in Tp does not take into account the spatial distribution of such changes. It also fails to account for the impact of different kinds of planting; increased runoff is more likely to occur as a result of commercial conifer plantations than the creation of broadleafed woodlands (which have been shown to reduce runoff through generation of an active litter layer).

It is currently not possible to relate the generic increase in Tp to a specific quantity of afforestation. Generic change factors also fail to account for the conflicting impacts of different land management practices; for example the creation of insensitive ever-green forests in one part of the catchment may be balanced by afforestation, or other management practice, in another.

To better understand the risks presented by changing land use patterns in the study area, a review of the distribution of the catchment characteristic ‘FOREST’ has been carried out. Although the area is largely rural, forestry practice is limited and is generally located in the upper parts of the river catchments, and largely focused in the Slieve Blooms.

Rather than apply a uniform adjustment factor to account for the impact of forestry, and analysis of each catchment has been carried out immediately upstream of the AFA. This reflects the fact that small scale changes in the upper catchments would not have an impact at the AFA downstream and often on a larger and less responsive river. Adopting a non-uniform approach also ensures that catchments which are largely urban are not also subject to forestry related changes in flow.

The HEPs upstream of the AFA were divided into three bands: those with a FOREST value of less than 0.25, 0.25-0.5 and over 0.5. Where FOREST is under 0.25 it was determined unlikely that any changes in forestry management would generate significant changes in flood risk, and certainly it would not be possible to say that any changes that were to occur would be linked to forestry; it is more likely that changes in arable farming practice or urbanisation would take place; these watercourses included the Clontygar and the Triogue.

7 Institute of Hydrology (1991). Plynlimon research: The first two decades. Report No. 109, Institute of Hydrology.

A FOREST value of 0.25-0.5 shows a greater current forest cover. Although changes to forest management practice in these catchments will occur, it is unlikely that sweeping changes would arise; instead the phased nature of forestry means that while some areas are cleared, others in the catchment are growing, thus balancing the impacts of drainage and felling. These catchments included the Owenass and Pound. Whilst the changes in forestry management practices occurring in catchments with a FORSET value of greater than 0.5 are unlikely to have a combined significant impact, it was considered that there was enough of a potential impact to warrant further investigation. However, although the Pound and Owenass catchments had greater FOREST values in the Slieve Blooms, by the time the rivers reach Mountmellick the FOREST value has dropped to below 0.5.

Therefore, as the likely impact of changes in forestry management practices are so uncertain, and relate to such a relatively small area in the upper catchments, the impacts have been excluded from the development of future scenarios.

6.8.4 Results: future flow estimation parameters

Design flows for the two future scenarios have been obtained by adjusting the present-day design flows, applying in combination the factors representing increases due to climate change and urbanisation but discounting forestry impacts, using the parameters provided in Table 6-8.

Table 6-8: Future scenario parameters

Parameter	MRFS increase	HEFS increase
Extreme rainfall depths	+20%	+30%
Flood flows	+20%	+30%
Urbanisation	Increase URBEXT by 5%	Increase URBEXT by 10%
Forestation	Not considered significant	Not considered significant

6.9 Joint Probability

A single storm event of a given magnitude was applied to all watercourses in the catchment, reflecting the large frontal storm systems that pass over the study area. From the work undertaken on hydrological and hydraulic calibration, it appears that the pattern of rainfall distribution in 2017, Storm Ciara and Storm Dennis was important, but there is insufficient observations of hourly rainfalls to understand the pattern over the study area. For the purposes of flood mapping the interconnected nature of the watercourses has led to adopting a single design storm profile and duration. For design it is likely that the two watercourses will be treated separately, and individual events will be applied to both the Pound and the Owenass. This does depend on the option selected. A joint probability analysis is an over complication of an already complex system and will be review depending on the preferred option selected.

The Barrow has a significantly different response to rainfall, and the flood history shows it is impacted by rain events which do not affect the Pound and Owenass, and vice versa. A scoping study into joint probability will be carried out in relation to the Barrow and its impact on the Owenass and Pound. This will be reported on in the hydraulic report but will look at a high flow on the Barrow and low flow on the Pound and Owenass, and also a low flow on the Barrow and high flow on the Pound and Owenass.

7 Establishment of a hydrological reporting network

Hydrological Estimation Points (HEPs) are points along a watercourse where flows are estimated, checked against modelled flows, and reported on, with differences explained or flows rescaled to match. To make this approach valid, the HEPs have to be in locations where there is no out of bank flow or cross flow between watercourses. The HEP approach uses a set of descriptors specific to a catchment to estimate flows to a specific point. However, the HEP approach is not suitable for a large proportion of watercourse length in this study due to the cross flow between the Owenass and Pound systems. When cross flow occurs, the overall catchment considered is changed as the other watercourse from which water is entering/leaving now must also be taken into account. The flows estimated at HEPs are no longer representative of the system and therefore the reported and estimated flows at a given HEP would differ as the estimates would not account for the additional cross flows. The reporting of in channel flow within the key cross flow areas would also misrepresent the total flow as any additional flow in the floodplain would not be accounted for.

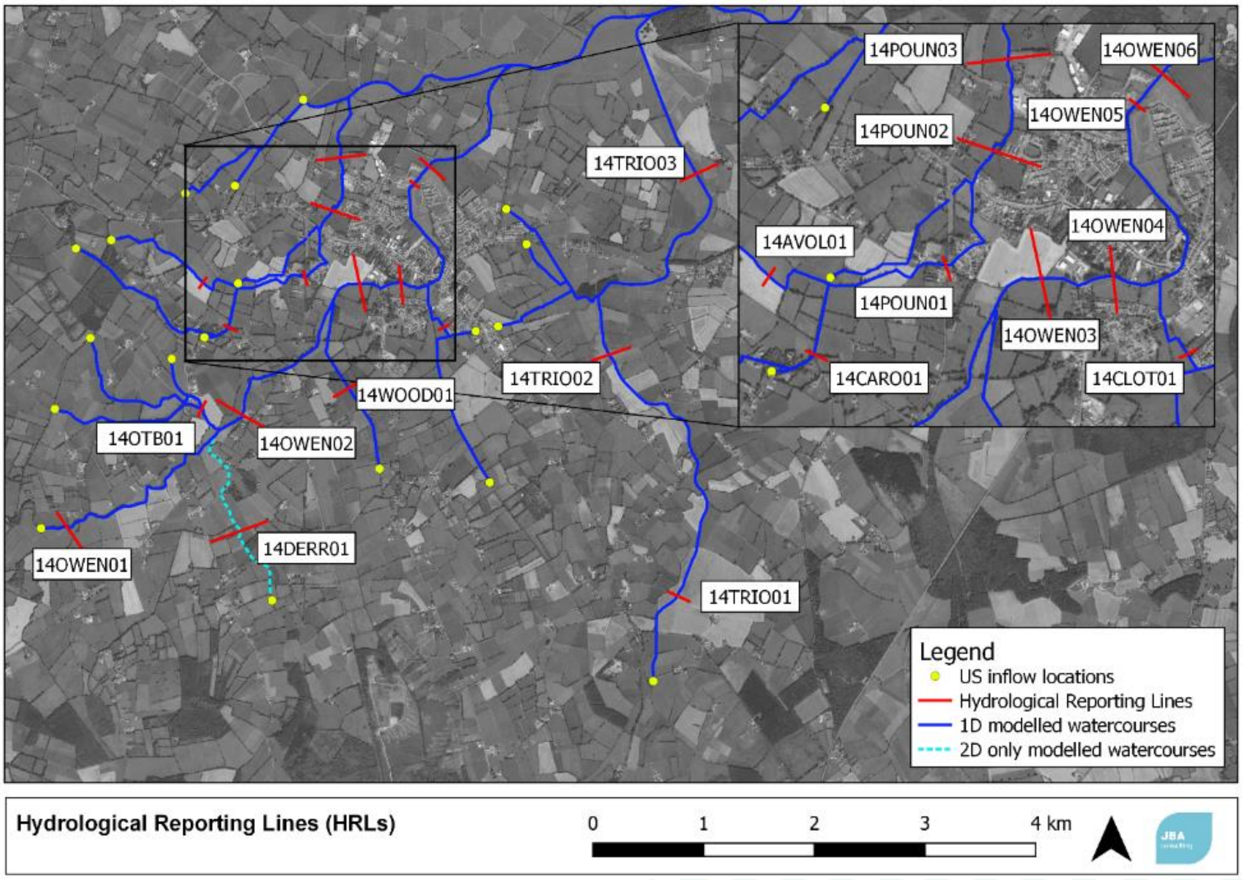


Figure 7-1: Hydrological Reporting Lines (HRLs)

To address this, Hydrological Reporting Lines (HRLs) are used instead of HEPs. HRLs have been devised so that the combined flood plain and in channel flow is reported as the peak flow. HRLs are in areas where flood plain flow needs to be taken into account to accurately report peak flow; in these locations cross flows mean flow comparisons with estimates cannot be confidently carried out. Comparisons with flow estimations can be carried out at HRLs upstream where flow is in channel and only comes from a single watercourse. Figure 7-1 shows the locations of these HRLs within the context of the hydraulic model and study area. Flow at these reporting locations are provided in the Hydraulics Report (Appendix B).

8 Summary

This report provides detail of the estimation of design inflow hydrographs for use in a hydraulic model for the Mountmellick FRS project.

The available hydrological data has been reviewed and an understanding of the catchment and its response established. The wide range of data available for the area included flood history, meteorological data, and hydrometric gauge records. However, their resolution across the catchment is poor, and this leads to significant uncertainty in the hydrological calibration. The routing element of the hydrological model performed by the hydraulic model does provide confidence in the overall understanding of the hydrological processes and how these can be defined for design flows.

The methods and flows from the previous hydrological assessment (SECFRAM) have also been examined and their suitability evaluated in relation to the requirements of the FRS.

Using a 1D-2D linked hydraulic model rating reviews have also been carried out for three of the hydrometric gauges. Updated rating curves were established for the two gauges on the Owenass River (14114 and discontinued gauge 14033) while it was found that no reliable flow stage relationship could be established for the Borness gauge on the River Barrow due to flood plain interaction and the hydraulic influence of the Borness bridge. A model-based rating has also been prepared for the two new gauges on the Pound but is subject to uncertainty as there is no way to validate the Q-h relationship at time of writing.

Due to the presence of cross flow and floodplain interaction within the system it was determined that the use of traditional HEP approaches to derive nodal flow values resulted in unrealistic flows as they failed to account for floodplain flow and storage upstream. To address this, design flows have been developed using a the FSR rainfall runoff method. A distributed rainfall-runoff model of the wider catchment area was developed within Flood Modeller including routing units and FSSR16 FM inflow units for upstream and lateral inflows into the hydraulic model. The hydrological and hydraulic models were calibrated using three recorded storm events. Surface water flow contributions were also examined. The combined hydrologic and hydraulic calibration further highlighted the interconnectedness of the system within Mountmellick and its importance in flow transfers and flood risk within Mountmellick town. Analysis of the flood frequency curve for Mountmellick Mill gauge also showed that the November 2017 event at the gauge was approximately a 1%AEP event and Storm Ciara was approximately a 10%AEP event

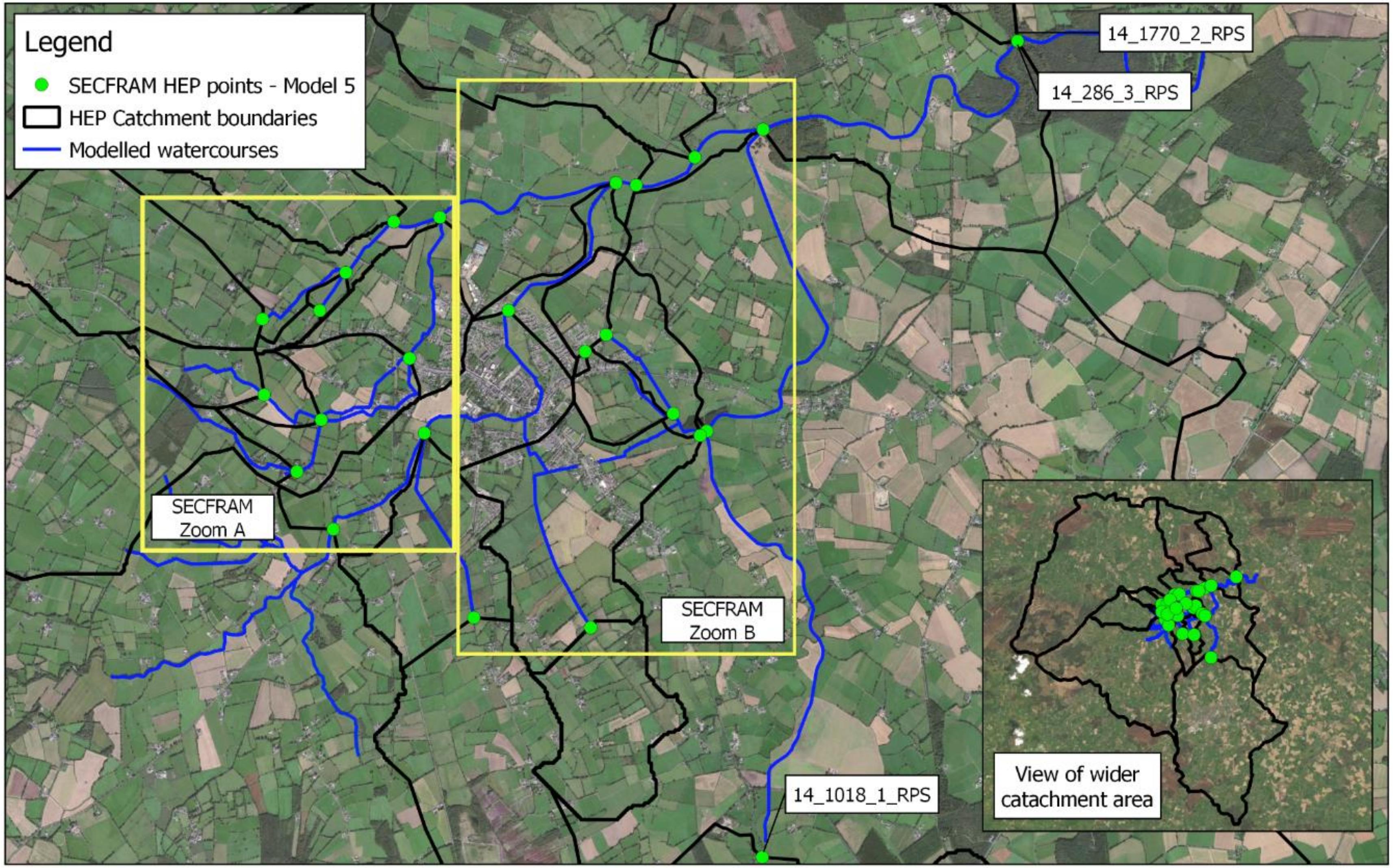
The following recommendations are made based on this study:

- Two sub-daily rain gauge is recommended to be installed within the study area.
- An additional hydrometric gauge located further upstream in the catchment along the Owenass watercourse is recommended to help gain better understanding of the cross flow and flood plain interactions.

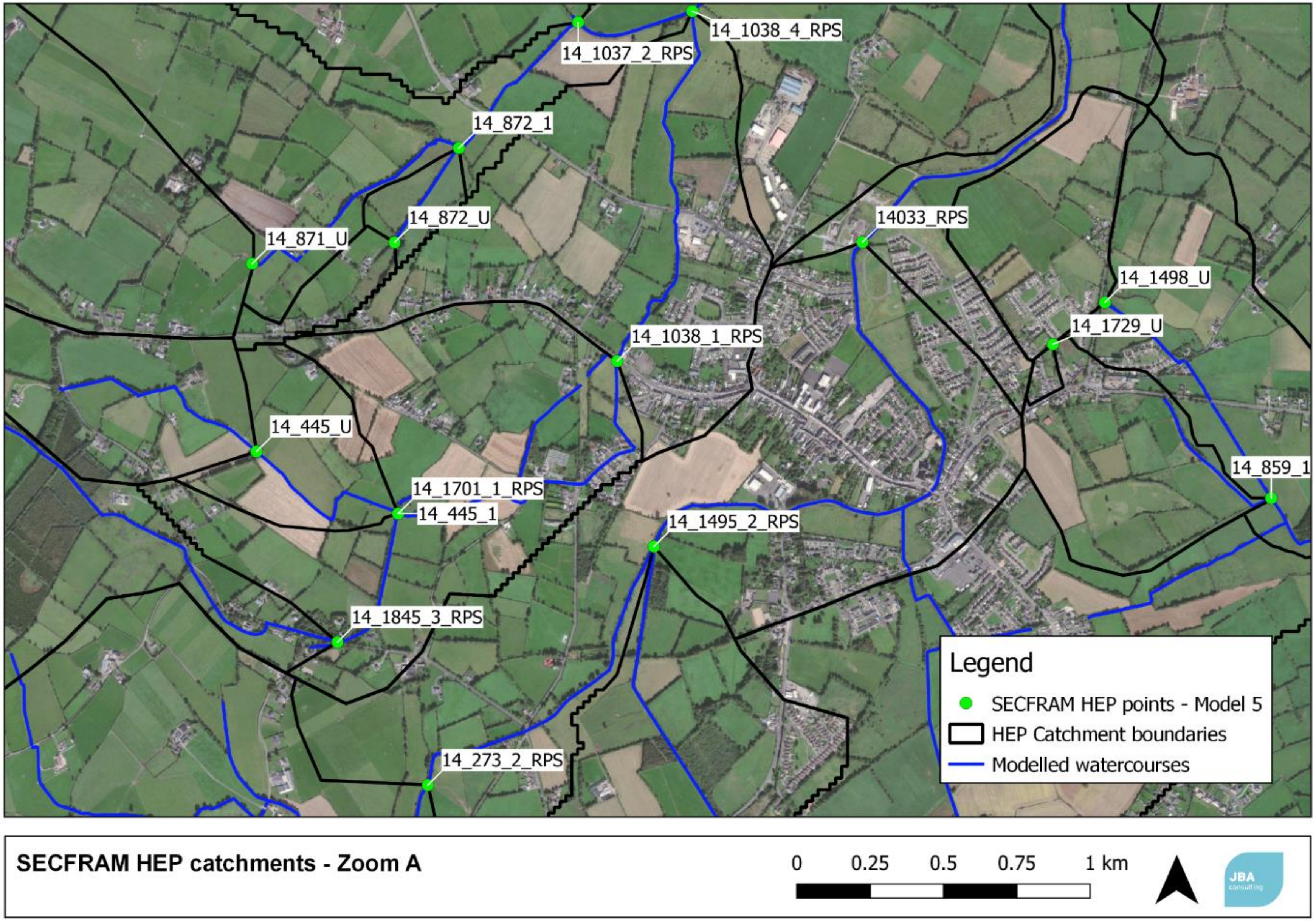
The peak flows for the range of AEP events estimated using the FSSR 16 method are provided in Appendix C.

Appendices

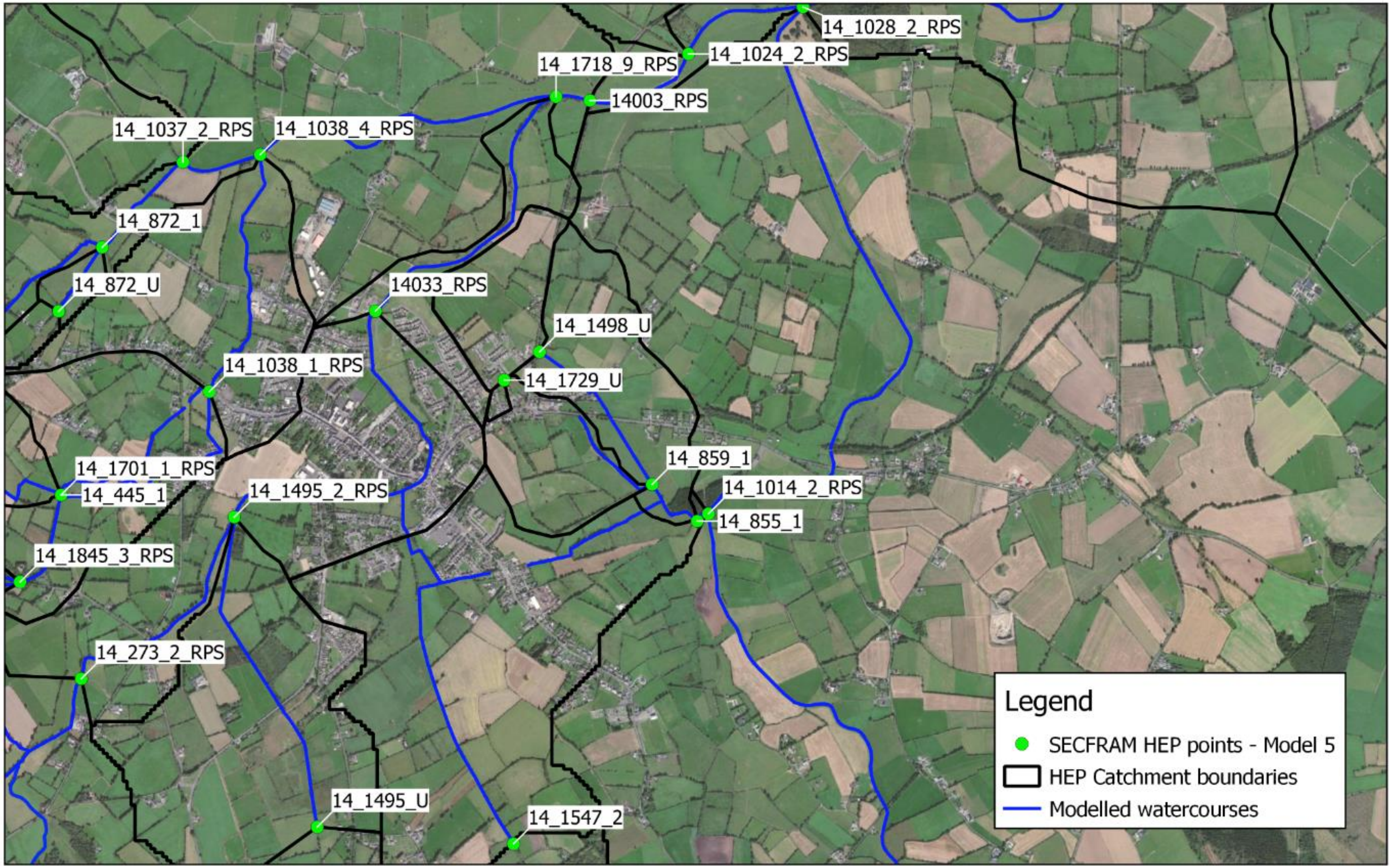
A SECFRAM HEP catchments and descriptors



SECFRAM HEP catchments



SECFRAM HEP catchments - Zoom A



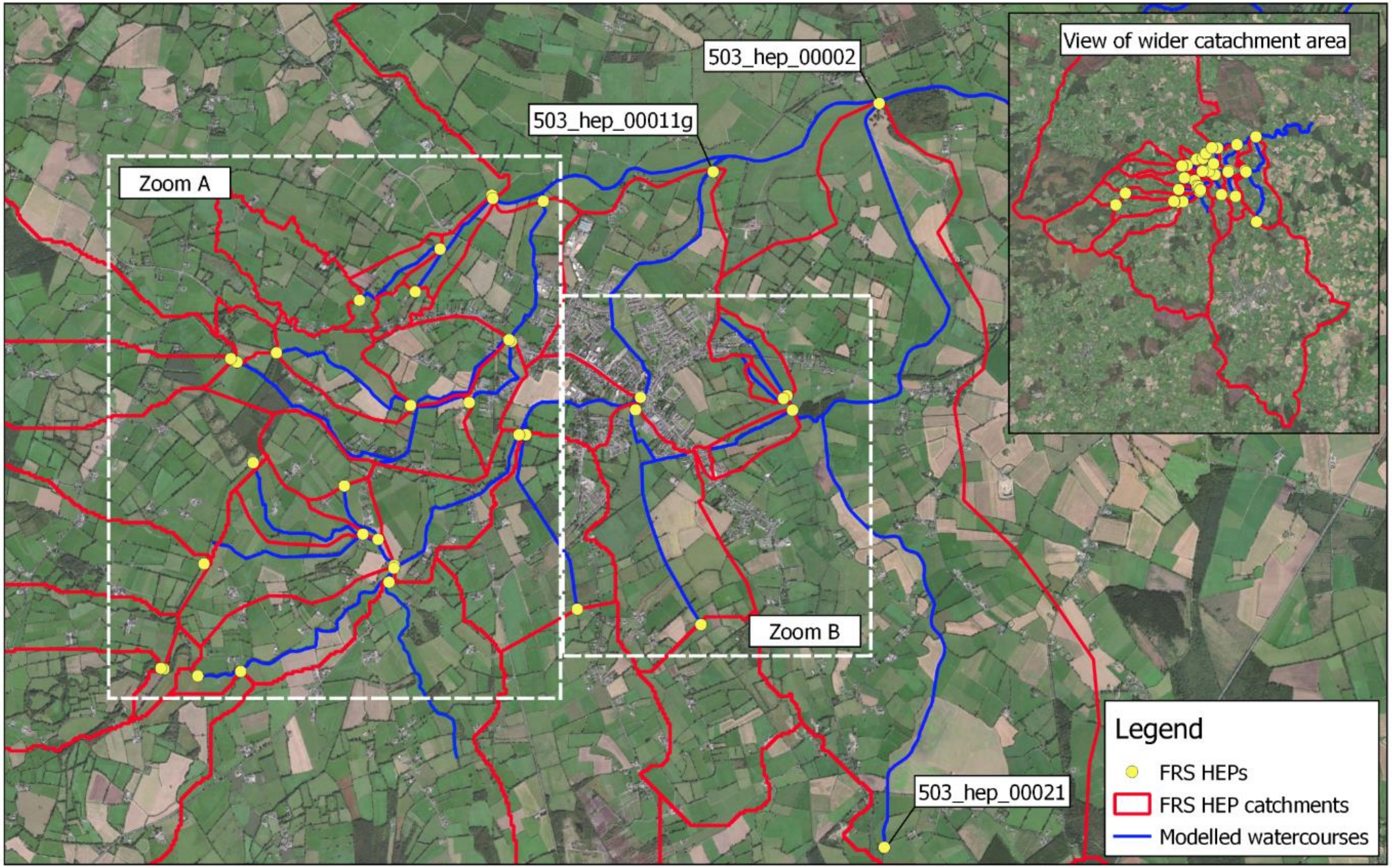
SECFRAM HEP catchments - Zoom B

0 0.25 0.5 0.75 1 km

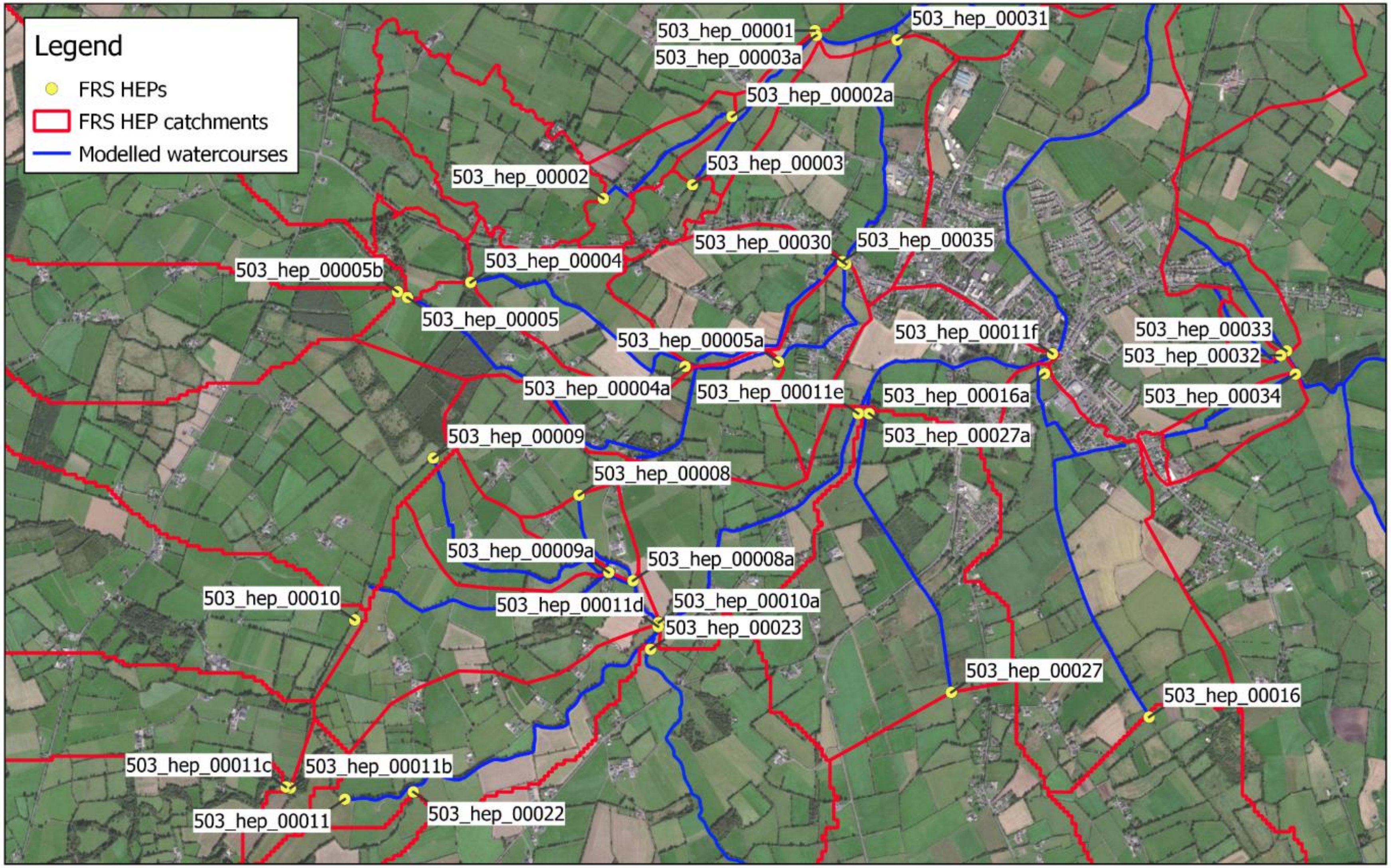
Catchment ID	Descriptors												
	Centroid X	Centroid Y	Area	SAAR	FARL	BFI Soil	URBEXT	MSL	S1085	Stream Frequency	Drain D	ArtDrain2	Soil (WRAP)
14_871_U	241682	208732	2.79	1191.01	1.00	0.57	0.00	NA	NA	1.00	NA	0.00	2.00
14_872_U	243442	208053	0.09	1191.01	1.00	0.57	0.00	NA	NA	1.00	NA	0.00	2.00
14_872_1	243895	208548	0.16	1191.01	1.00	0.57	0.00	NA	NA	1.00	NA	0.00	2.00
14_1037_2_RPS	244302	208977	104.28	1190.86	1.00	0.58	0.00	29.34	10.23	125.00	0.99	1.93	2.00
14_1845_3_RPS	240106	207404	11.17	1172.52	1.00	0.50	0.00	7.37	9.93	9.00	1.42	0.00	2.00
14_445_U	242665	207728	0.46	1185.61	1.00	0.53	0.00	NA	NA	5.00	NA	0.00	2.00
14_445_1	240363	207409	0.72	1185.61	1.00	0.53	0.00	NA	NA	NA	NA	0.00	2.00
14_1701_1_RPS	240363	207409	12.22	1157.74	1.00	0.52	0.00	7.90	8.44	11.00	1.47	0.00	2.00
14_1038_1_RPS	240564	207419	12.94	1145.71	1.00	0.52	0.20	9.12	6.67	15.00	1.59	0.00	2.00
14_1038_4_RPS	240849	207481	13.97	1129.58	1.00	0.52	2.71	10.46	5.85	15.00	1.55	0.00	2.00
14_273_2_RPS	239918	202578	72.71	1163.12	1.00	0.48	0.00	14.34	14.87	75.00	1.12	0.00	2.00
14_1495_U	245139	204035	3.46	941.41	1.00	0.55	0.00	0.00	0.10	NA	NA	0.00	2.00
14_1495_2_RPS	244986	204661	4.95	941.41	1.00	0.55	1.48	1.64	0.10	11.00	0.57	0.00	2.00
14_1547_2	246102	204753	1.38	927.07	1.00	0.55	0.00	0.89	0.10	1.00	0.65	0.00	2.00
14_880_Trib			3.18		1.00	NA	NA	NA	NA	NA	NA	0.00	4.00
14033_RPS	239200	202590	78.89	1145.22	1.00	0.45	0.85	17.61	11.37	87.00	1.12	0.00	4.00
14_1718_9_RPS	240372	202842	79.89	1143.18	1.00	0.45	0.90	19.19	10.17	87.00	1.11	0.00	4.00
14003_RPS	238998	207655	206.3	1179.99	1.00	0.57	0.00	29.82	10.06	145.00	1.03	0.01	4.00

Catchment ID	Descriptors												
			2										
14_1024_2_RPS	244965	213700	19.20	903.86	1.00	0.55	0.00	9.46	3.18	19.00	1.26	0.00	4.00
14_1018_1_RPS	248159	197282	83.79	879.46	1.00	0.66	8.97	17.98	4.30	55.00	0.82	0.00	2.00
14_1498_U	245910	208293	0.35	1144.58	1.00	0.45	0.17	NA	NA	1.00	NA	0.00	4.00
14_1729_U	245890	207768	0.02	1145.87	1.00	0.45	0.45	NA	NA	1.00	NA	0.00	4.00
14_859_1	246151	207471	0.40	930.90	1.00	0.55	0.07	0.71	5.06	1.00	NA	0.00	2.00
14_855_1	246245	207875	1.40	930.90	1.00	0.55	0.07	3.77	0.30	13.00	1.85	0.00	2.00
14_1014_2_RPS	246010	206359	5.01	930.85	1.00	0.55	7.19	3.85	1.05	13.00	1.87	0.00	4.00
14_1028_2_RPS	248218	199691	115.96	879.41	1.00	0.66	7.39	25.64	2.28	93.00	0.93	0.00	4.00
14_286_3_RPS	249578	210506	347.02	1048.87	1.00	0.53	2.64	36.29	7.86	387.00	1.01	0.00	4.00

B FRS HEP catchments and descriptors

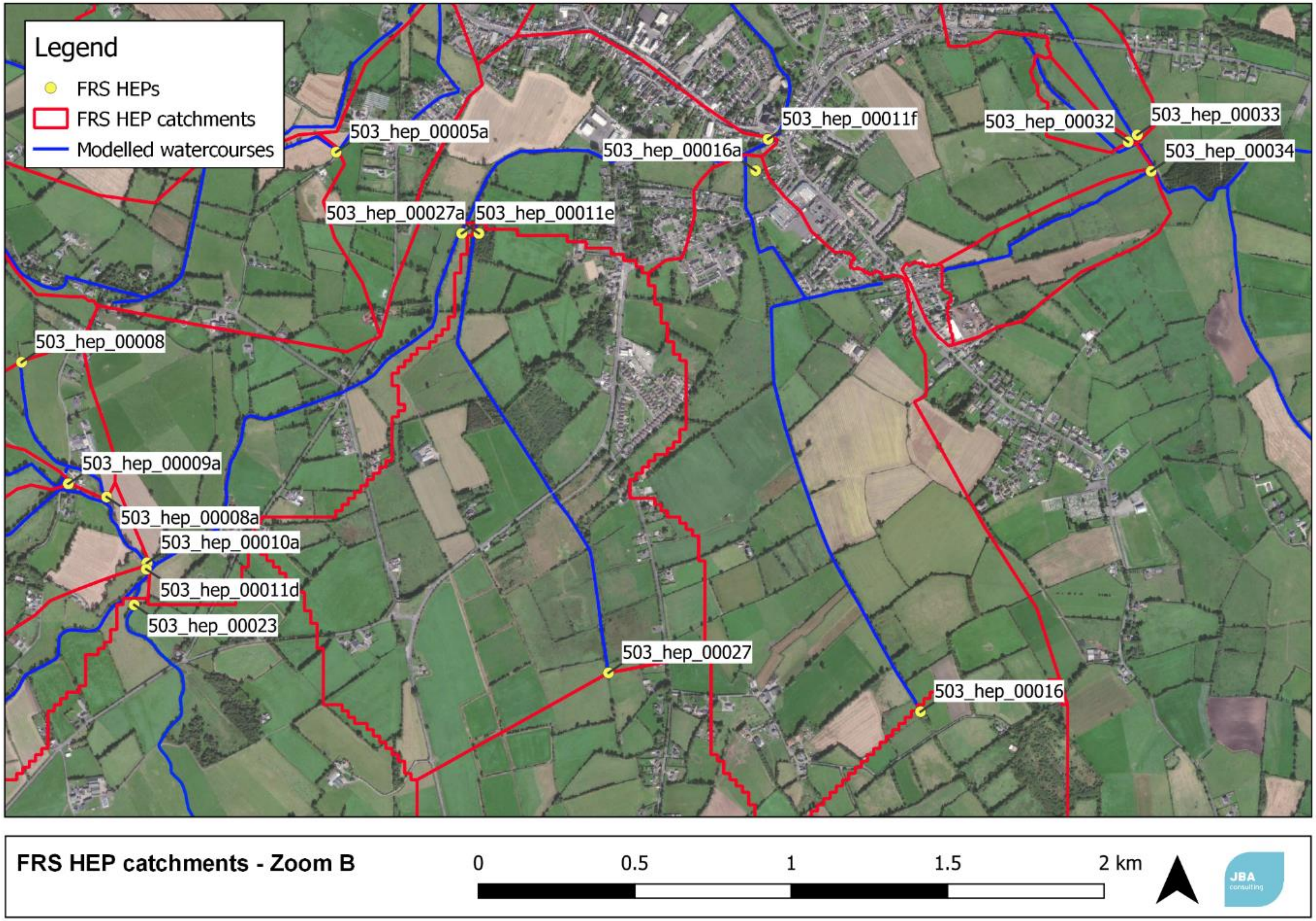


FRS HEP catchments



FRS HEP catchments - Zoom A

0 0.5 1 1.5 2 km


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

Catchment ID	Descriptors												
	Water course	Centroid X	Centroid Y	Area	SAAR	FARL	BFI Soil	URBEXT	MSL	S1085	Stream Frequency	Drain D	ArtDrain2
503_hep_00001	BARO	210670	237570	108.60	1186.67	1.00	0.57	0.00	29.34	10.23	129.00	0.96	0.01
503_hep_00002	FARM	242619	208041	0.67	946.00	1.00	0.57	0.00	1.42	2.23	1.00	2.12	0.00
503_hep_00002a	FARM	243447	208367	0.21	919.00	1.00	0.53	0.00	0.10	6.00	1.00	3.93	0.00
503_hep_0003	GRAG	243546	208083	0.12	930.00	1.00	0.53	0.00	0.58	2.23	1.00	4.83	0.00
503_hep_0003a	GRAG	244005	208621	0.16	897.00	1.00	0.52	0.00	6.60	0.15	1.00	41.25	0.00
503_hep_00004	AVOL	242301	207882	0.16	1164.55	1.00	0.56	0.00	0.72	6.85	1.00	0.20	0.00
503_hep_00004a	AVOL	243053	207598	0.53	946.00	1.00	0.56	0.00	0.33	4.54	1.00	2.55	0.00
503_hep_00005	CARO	240180	208510	2.84	1047.00	1.00	0.56	0.00	2.40	8.33	1.00	0.84	0.00
503_hep_00005a	CARO	243163	207128	0.85	1241.00	1.00	0.50	0.00	0.65	0.31	1.00	0.76	0.00
503_hep_00005b	CARO	239930	208150	3.04	1002.00	1.00	0.53	0.00	4.79	14.35	5.00	1.30	0.00
503_hep_00008	OTB1	248050	206914	0.42	1092.50	1.00	0.50	0.00	0.82	1.85	1.00	1.95	0.00
503_hep_00008a	OTB1	243185	206437	0.14	974.00	1.00	0.50	0.00	0.30	10.20	1.00	3.57	0.00
503_hep_00009	OTB2	239740	206800	2.08	1092.50	1.00	0.46	0.00	5.94	13.83	3.00	2.23	0.00
503_hep_00009a	OTB2	242644	206387	0.33	974.00	1.00	0.46	0.00	0.30	6.66	1.00	3.30	0.00
503_hep_00010	OTB3	239510	206800	5.00	1241.40	1.00	0.42	0.00	4.94	16.45	3.00	2.29	0.00

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BARRY & PARTNERS consulting engineers

JBA consulting

Catchment ID		Descriptors												
503_hep_00010a	OTB3	242694	205951	0.82	1002.00	1.00	0.42	0.00	0.77	3.89	1.00	0.94	0.00
503_hep_00011	OWEN	237210	204080	0.15	1204.00	1.00	0.32	0.00	0.10	6.00	1.00	0.60	0.00
503_hep_00011b	OWEN	238720	205750	1.89	1204.00	1.00	0.46	0.00	3.36	18.77	9.00	2.17	0.00
503_hep_00011c	OWEN	237060	203570	4.41	1204.00	1.00	0.31	0.00	4.37	18.77	9.00	1.05	0.00
503_hep_00011d	OWEN	242666	205465	0.81	1075.00	1.00	0.37	0.00	0.47	6.38	2.00	2.68	0.00
503_hep_00011e	OWEN	244027	206526	0.71	926.00	1.00	0.46	0.00	0.60	2.50	1.00	0.85	0.00
503_hep_00011f	OWEN	244893	207335	0.47	890.00	1.00	0.45	0.21	0.42	3.57	1.00	0.90	0.00
503_hep_00011g	OWEN	245472	208049	2.18	870.00	1.00	0.45	0.36	0.50	2.00	1.00	1.10	0.00
503_hep_00016	CLOTA	246120	204780	1.38	891.00	1.00	0.55	0.00	0.89	0.10	1.00	0.65	0.00
503_hep_00016a	CLOTA	245607	206246	1.56	890.00	1.00	0.55	0.01	0.36	30.55	1.00	1.28	0.00
503_hep_00021	TRIO	248990	203602	85.08	897.46	1.00	0.66	0.09	17.98	4.30	55.00	0.82	0.00
503_hep_00021a	TRIO	247514	206311	11.30	879.38	1.00	0.66	0.07	7.50	6.60	15.00	0.66	0.00
503_hep_00022	OWENS	239080	203260	8.00	1271.00	1.00	0.42	0.00	8.44	1.63	7.00	15.11	0.00
503_hep_00023	BLAC	240990	201490	39.19	1042	1.00	0.50	0.00	11.54	2.31	31.00	0.94	0.00
503_hep_00025	OWEN	236930	205750	2.39	1361.00	1.00	0.52	0.00	1.70	45.67	3.00	1.16	0.00
503_hep_00026	OWEN	235010	203570	11.42	1504.00	1.00	0.31	0.00	5.98	21.49	13.00	0.83	0.00
503_hep_00027	WOOD	244963	205721	3.20	925.30	1.00	0.55	0.00	3.10	1.55	1.00	0.94	0.00

Catchment ID		Descriptors											
503_hep_00027a	WOOD	244665	206270	1.51	939.00	1.00	0.55	0.00	0.90	5.50	1.00	0.59	0.00
503_hep_00030	GARR/POUN	244311	207424	0.26	920.00	1.00	0.53	0.20	0.90	0.43	1.00	0.28	0.00
503_hep_00031	POUN	244430	208386	0.92	1130.17	0.99	0.52	0.00	0.50	2.00	1.00	1.25	0.00
503_hep_00032	ROFF	246485	207438	0.04	396.65	1.00	0.56	0.00	0.11	5.90	1.00	12.50	0.00
503_hep_00033	BCBG	246427	207731	0.21	930.90	1.00	0.55	0.00	0.30	10.30	1.00	2.62	0.00
503_hep_00034	CLOTB	246375	207027	0.19	635.65	1.00	0.56	0.00	0.20	5.60	1.00	2.95	0.00
503_hep_00035	GARR	243851	207681	0.53	920.00	1.00	0.53	0.00	0.99	2.16	1.00	0.53	0.00

C Design flows

HEP	Watercourse	Area	50%AEP	20%AEP	10%AEP	5%AEP	2%AEP	1%AEP	0.5%AEP	0.1%AEP	1%AEP MRFS	1%AEP HEFS
503_hep_00001	Barrow	107.40	36.26	47.74	56.62	65.99	78.69	88.28	99.49	134.20	105.94	114.76
503_hep_00002	Farm	0.67	0.40	0.40	0.40	0.40	0.50	0.56	0.63	0.86	0.67	0.73
503_hep_00002a	Farm	0.21	0.11	0.15	0.17	0.20	0.25	0.28	0.31	0.43	0.34	0.36
503_hep_00003	Graigue	0.12	0.05	0.06	0.07	0.08	0.10	0.11	0.13	0.18	0.13	0.14
503_hep_00003a	Graigue	0.16	0.02	0.03	0.03	0.04	0.05	0.05	0.06	0.08	0.06	0.07
503_hep_00004	Avoley	0.16	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.27	0.24	0.26
503_hep_00004a	Avoley	0.53	0.24	0.24	0.38	0.45	0.54	0.61	0.69	0.94	0.73	0.79
503_hep_00005	Carroon	2.84	1.13	1.50	1.80	2.11	2.74	2.84	3.21	4.36	3.41	3.69
503_hep_00005a	Carroon	0.85	0.32	0.42	0.50	0.59	0.71	0.80	0.90	1.23	0.96	1.04
503_hep_00005b	Carroon	3.04	1.23	1.63	1.95	2.28	2.52	3.08	3.48	4.73	3.70	4.00
503_hep_00008	Owenass trib1	0.42	0.15	0.20	0.24	0.28	0.33	0.38	0.43	0.58	0.46	0.49
503_hep_00008a	Owenass trib1	0.14	0.07	0.10	0.12	0.14	0.17	0.19	0.21	0.29	0.23	0.25
503_hep_00009	Owenass trib2	2.08	0.86	1.14	1.36	1.60	1.92	2.16	2.45	3.33	2.59	2.81
503_hep_00009a	Owenass trib2	0.33	0.15	0.21	0.25	0.29	0.35	0.39	0.45	0.61	0.47	0.51
503_hep_000010	Owenass trib3	5.00	2.52	3.35	3.99	4.67	5.59	6.28	7.09	9.60	7.54	8.16
503_hep_00010a	Owenass trib3	0.82	0.34	0.45	0.54	0.63	0.76	0.86	0.97	1.33	1.03	1.12
503_hep_00011	Owenass	0.15	0.09	0.12	0.15	0.17	0.20	0.23	0.26	0.35	0.28	0.30
503_hep_00011b	Owenass	1.89	2.00	2.00	2.00	2.00	2.00	2.00	2.29	3.13	2.40	2.60
503_hep_00011c	Owenass	4.41	2.26	3.04	3.61	4.21	5.04	5.66	6.39	8.65	6.79	7.36
503_hep_00011d	Owenass	0.81	0.37	0.52	0.62	0.73	0.87	0.98	1.11	1.51	1.18	1.27
503_hep_00011e	Owenass	0.71	0.26	0.35	0.42	0.49	0.59	0.67	0.76	1.03	0.80	0.87
503_hep_00011f	Owenass	0.47	0.19	0.26	0.30	0.36	0.43	0.49	0.55	0.75	0.59	0.64

HEP	Watercourse	Area	50%AEP	20%AEP	10%AEP	5%AEP	2%AEP	1%AEP	0.5%AEP	0.1%AEP	1%AEP MRFS	1%AEP HEFS
503_hep_00011g	Owenass	2.18	0.82	1.09	1.29	1.51	1.82	2.05	2.24	3.17	2.46	2.67
503_hep_00016	Clontygar A	1.38	0.19	0.25	0.29	0.34	0.40	0.45	0.51	0.70	0.54	0.59
503_hep_00016a	Clontygar A	1.56	0.81	1.09	1.29	1.52	1.84	2.07	2.35	3.22	2.48	2.69
503_hep_00021	Triogue	85.08	11.66	15.04	17.26	19.36	22.15	24.14	26.24	31.02	28.97	31.38
503_hep_00021a	Triogue	11.30	1.81	2.33	2.68	3.00	3.44	3.75	4.07	4.81	4.49	4.86
503_hep_00022	Owenass south	8.00	3.45	4.60	5.44	6.35	7.57	8.50	9.58	12.93	10.20	11.05
503_hep_00023	Blackwater	39.19	10.29	13.52	15.91	18.57	22.18	24.90	28.09	37.97	29.88	32.37
503_hep_00025	Owenass	2.39	1.88	2.55	3.00	3.49	4.16	4.66	5.24	7.03	5.59	6.06
503_hep_00026	Owenass	11.42	8.44	11.49	13.44	15.55	18.42	20.57	23.07	30.72	24.68	26.74
503_hep_00027	Wood	3.20	0.30	0.40	0.51	0.54	0.65	0.73	0.82	1.11	0.88	0.95
503_hep_00027a	Wood	1.51	0.33	0.43	0.47	0.60	0.72	0.81	0.91	1.23	0.97	1.05
503_hep_00030	Garroon/Pound	0.23	0.09	0.12	0.14	0.16	0.19	0.22	0.26	0.33	0.26	0.29
503_hep_00031	Pound	0.92	0.40	0.53	0.63	0.74	0.87	0.99	1.12	1.53	1.19	1.29
503_hep_00032	Run off drain	0.04	0.017	0.023	0.025	0.025	0.030	0.032	0.033	0.034	0.04	0.04
503_hep_00033	Ballyculbeg	0.21	0.48	0.50	0.61	0.68	0.77	1.22	1.30	3.92	1.46	1.59
503_hep_00034	Clontygar B	0.19	0.43	0.45	0.55	0.62	0.70	1.10	1.18	3.54	1.32	1.43
503_hep_00035	Garroon	0.59	0.20	0.25	0.29	0.34	0.41	0.46	0.52	0.72	0.55	0.60

Key		
Point inflow	Lateral inflow	Storm water point inflow

D FSU Method – Triogue system

D.1 The FSU method

The Flood Studies Update (FSU) method to estimate Qmed as described in research reports produced from FSU work packages 2.2 and 2.3, has been used. Qmed can be estimated using a regression equation based on seven different physical catchment descriptors, in conjunction with an urban adjustment, developed in FSU work package 2.3.

The multivariate regression equation was developed on the basis of data from 199 gauged catchments, linking Qmed to a set of catchment descriptors.

$$QMED = 1.237 \times 10^{-5} AREA^{0.937} BFI_{soil}^{-0.922} SAAR^{1.306} FARL^{2.217} DRAIND^{0.341} S1085^{0.185} (1 + ARTDRAIN2)^{0.408}$$

Where:

- AREA is the catchment area (km2).
- BFIsoils is the base flow index derived from soils data
- SAAR is long-term mean annual rainfall amount in mm
- FARL is the flood attenuation by reservoir and lake
- DRAIND is the drainage density
- S1085 is the slope of the main channel between 10% and 85% of its length measured from the catchment outlet (m/km).
- ARTDRAIN2 is the percentage of the catchment river network included in the Drainage

The urban extent can be taken into account using the following equation:

$$Q_{MEDfinal} = Qmed\,(1 + URBEXT)^{1.482}$$

Where URBEXT is the percentage of the catchment covered by urban land use.

Following the calculation of QMED the calculated adjustment factor and a growth curve are applied to generate the peak flows for AEP events. In this case the growth curve produced by the FSU pooling group for the ungauged catchment has been applied.

The catchment descriptors can be used to determine Qmed. The Qmed value for the Triogue HEP 14_1810_1 was found to be 11.66 m^3/s. In order to improve on this initial estimate of QMED, the data transfer process can be used. In the terminology of the FSU research reports, the gauging station where the adjustment factor is calculated is referred to as a donor site. An adjustment factor for QMED is calculated as the ratio of the gauged to the ungauged estimate of QMED at the gauging station. This factor is then used to adjust the initial estimate of QMED at the hydrological estimation point. Following review of potential gauges it was determined that no pivotal adjustment factor be applied (refer to Section D.2).

The growth factors for this site are also calculated from the FSU using pooling groups.

For pooled analysis within the FSU, gauges are chosen on the basis of their similarity with the subject catchment according to three catchment descriptors, i.e. AREA, SAAR and BFIsoil. The report on FSU WP 2.2 presents two alternative equations for calculating the similarity of catchments according to these three descriptors. For this study, equal weight was given to each of these variables, applying the similarity distance formula given as Equation 10.2 in the report on FSU WP 2.2.

Not all gauges in Ireland were considered for use in pooling, because the analysis required to fit a flood growth curve makes use of the magnitude of each annual maximum flow, and thus it is necessary that even the highest flows are reliably measured. This excludes gauges where there is significant uncertainty in the high flow rating.

Although there is some evidence from research on UK data that flood growth curves are affected by additional catchment descriptors such as FARL, the FSU research found that FARL was not a useful variable for selection of pooling groups (uncertainty was greater when FARL was included than when it was excluded) and therefore no attempt was made to allow for the presence of lakes in the composition of pooling groups. Similarly, no allowance was made for arterial drainage in selecting pooling groups.

For pooled growth curves, WP 2.2 recommends considering 3-parameter distributions, because the extra data provided by the pooling group ensures that the standard error is lower than it would be for single-site analysis. The report states that either the generalised extreme value (GEV) or generalised logistic (GL) distributions are worth considering. For this study, GEV has been fitted for the pooled analysis.

D.2 Pivotal gauge review

Three gauges were considered for use as the Triogue pivotal gauge. The assessment of pivotal gauges was carried out in comparison to HEP 14_1810_1 which is the upstream node used in the study but for ease the same adjustment will be applied to the other HEP along the watercourse (lateral inflow HEP). The details of these gauges are summarised in Table D-1.

Table D-1 Pivotal gauge summary

Number	**14005**	**14006**	**1014**
Name	Portarlington	Pass Bridge	Portlaoise
FSU gauge quality ranking	A2	A1	Not ranked in FSU
Years of suitable data			9
Catchment area (km2)	405.48	1063.59	47.70
Qmed gauged m^3/s	38.27	80.26	4.12 (post 2010)
Qmed(rural) m^3/s	75.92	110.77	6.45
Pivotal adjustment factor	0.50	0.72	0.64
On same watercourse as subject site (Y/N)	No – located on Barrow	No - located on Barrow	Yes, located upstream of estimation point
In same catchment as subject site (Y/N)	No	No	Yes
URBEXT	0.024	0.017	0.099
Any other catchment features (e.g. Arterial Drainage)			Gauge moved 300m upstream in 2010 – increased water level noted as a result of this

Number	14005	14006	1014
Operator	OPW	OPW	EPA
Status	Active	Active	Active
Reasons for choosing or dismissing	Used in weighting as downstream of site and provides inclusion of extended AMAX records.	Catchment too different to ungauged site	Used in weighting due to location along watercourse

Review of the available data for the gauges shows that they are of varying quality and similarity to the ungauged site 14_1810_1 (refer to Appendix B for catchment details). Of the three gauges considered 14006 Pass Bridge is discounted as it is considered too dissimilar to the ungauged location as it is significantly larger and along another watercourse. Of the remaining gauges to consider neither are truly suitable for use as a pivotal gauge. Gauge 14014 is located along the same watercourse however it has a reduced AMAX record due to gauge changes, has a catchment area half that of 14_1810_1 and a higher URBEXT value. Gauge 14005 is downstream of the site, has a longer AMAX record and has a similar URBEXT to the ungauged location but is not on the same watercourse and has differing catchment characteristics. In all cases these gauges generate pivotal adjustment factors less than 1 (0.50 – 0.72) which would decrease the FSU unadjusted Qmed values for the catchment (11.66). The reduced Qmed value is considered unrealistic given the size of the ungauged catchment therefore no adjustment is to be applied.

D.3 Pooling group details

The pooling group was derived based on the catchment characteristics of FSR node 14_1801_1. Table D-2 shows the site-specific pooling group derived for the Triogue catchment. Figure D1 gives a comparison of pooling group catchment characteristics and Table D-3 provides a summary of the pooling group statistics. The final growth curve is shown in Table D-4.

Table D-2: FSU pooling group

Gauge Number	Watercourse	Location	AMAX record years in FSU database	Cumulative AMAX years
25023	Little Brosna	Miltown	33	33
14009	Cushina	Little Brosna	25	58
14007	Stradbally	Derrybrock	24	82
14013	Burren	Ballinacarrig	49	131
07001	Trembelstown	Tremblestown	18	149
16001	Drish	Athlummon	33	182
06026	Lagan (Glyde)	Aclint	46	228
06025	Dee	Burley	30	258
26022	Fallan	Kilmore	33	291
25025	Ballyfinboy	Ballyhooney	31	322
16051	Rossestown	Clobanna	13	335
07003	Blackwater (Enfield)	Castlerickard	46	381
14011	Slate	Rathangan	25	406

Gauge Number	Watercourse	Location	AMAX record years in FSU database	Cumulative AMAX years
25022	Camcor	Syngefield	22	428
09010	Dodder	Waldron's bridge	19	447
25027	Ollatrim	Gourdeen	42	489

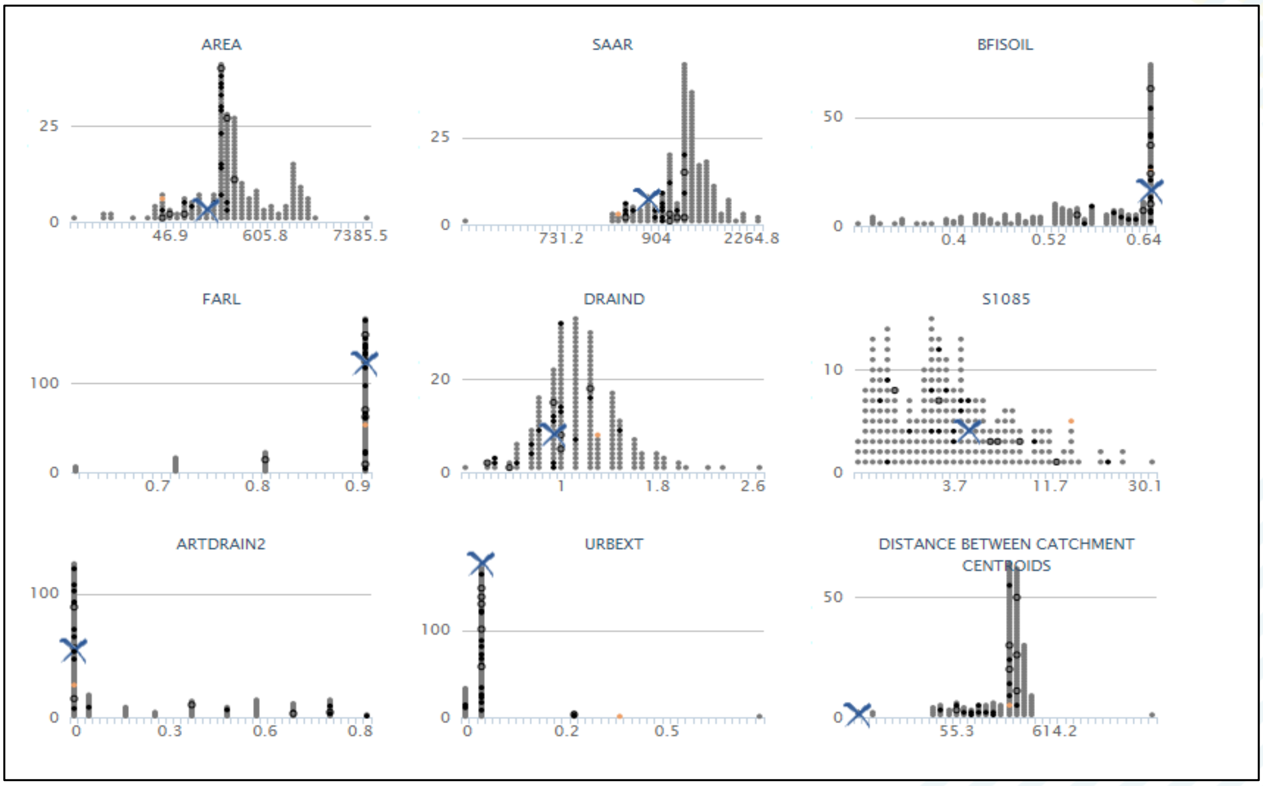

Figure D-1: Pooling group descriptor comparison

Table D-3: Pooling group statistics

Total number in group	**16**
Cumulative years	489
Skew	0.105
Kurtosis	0.117
Distribution	GEV

Table D-4: Triogue growth curve

AEP (%)	Growth factor
50	1.00
20	1.29
10	1.48
5	1.66
2	1.90
1	2.07
0.5	2.25

AEP (%)	Growth factor
0.1	2.66

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