ATHEA FLOOD RELIEF SCHEME

HYDROLOGY REPORT

JULY 2022

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Abbreviations

AA	Appropriate Assessment
AEP	Annual Exceedance Probability
AFA	Area of Further Assessment
CAR	Community at Risk
CBA	Cost Benefit Analysis
CEMP	Construction Environmental Management Plan
CFRAM	Catchment Flood Risk Assessment Management
DDF	Depth Duration Frequency
EIA	Environmental Impact Assessment
EIAR	Environmental Impact Assessment Report
FRMP	Flood Risk Management Plan
FRS	Flood Relief Scheme
FSR	Flood Studies Report
FSSR	Flood Studies Supplementary Report
FSU	Flood Studies Update
HEP	Hydrological Estimation Point
HGF	Highest Gauged Flow
ING	Irish National Grid
LA	Local Authority
LCCC	Limerick City & County Council
MCA	Multi-Criteria-Assessment
mOD	Meters Over Datum (Malin)
NIS	Natura Impact Statement
OPW	Office of Public Works
PCDs	Physical Catchment Descriptors
PFRA	Preliminary Flood Risk Assessment
RBD	River Basin District
SUDs	Sustainable Drainage Systems
Tp	Time to peak
UoM	Unit of Management
WRAP	Winter Rainfall Acceptance Potential
WWTP	Wastewater Treatment Plant

1 Introduction

1.1 Background

Ryan Hanley Ltd. were appointed by Limerick City and County Council (LCCC) in September 2019 to undertake a Flood Relief Scheme (FRS) for Athea, Co. Limerick. Extensive flooding took place at Athea village in April 2005, July/ August 2008, September 2009 and again in September 2015. The July 31st/ August 1st 2008 resulted in the production of the *Athea Flood Severity and Impact Report* by JBA Consulting Engineers. In 2012, the National Preliminary Flood Risk Assessment (PFRA) project report and maps were produced, which provided the initial estimation of flood extents for Athea. This highlighted Athea as an Area of Further Assessment (AFA) and Community at Risk (CAR) area for the Catchment Flood Risk Assessment Management (CFRAM) study. Athea AFA was included in Unit of Management (UoM) 23 Tralee Bay-Feale in the Shannon CFRAM study. Jacobs Engineering Group completed the works on the Athea CFRAM study. The CFRAM study conducted hydrological assessments at catchment level for hydraulic analysis of predicted future design events and from that the initial designs of potential Flood Risk Management Plans (FRMPs), which were finalised in 2016.

The Hydrology Workshop for the project was undertaken on 31st March 2021 with the OPW, LCCC and Ryan Hanley. Responses to comments and queries raised at the workshop and in previous draft report reviews by the OPW and LCCC have been incorporated into this final report.

1.2 Objectives of Study

The objectives of this Hydrology Report are as follows:

1. Review all available documents and information pertaining to the hydrological assessment undertaken as part of the Tralee Bay - Feale River Basin (UoM 23) CFRAM study and the resulting flow data, including:
    - Hydrometric data, including that recorded since the CFRAM analysis;
    - Historic flood data, including that recorded since the CFRAM analysis;
    - Rating Curve equation data;
    - Meteorological data;
    - Flood Studies Update (FSU) Physical Catchment Descriptors (PCDs);
    - Catchment boundaries;
    - River network.
2. Undertake, in line with the Hydrological Method Statement (Chapter 4 of this report), a hydrological analysis comprising:
    - Establish Hydrological Estimation Points (HEPs) at representative river networks sites;
    - Statistical analysis of past flood events and past peak flows assessment;
    - Assessment of design flows at each HEP for numerous design event probabilities;
    - Undertake a joint probability analysis;
    - Analyse impacts on design flows for future environmental and land-use changes.

1.3 Structure of Report

The report structure comprises:

Chapter 2	Hydrology of Study Area
Chapter 3	Hydrological Data
Chapter 4	Method Statement
Chapter 5	Extreme Rainfall Analysis
Chapter 6	Past flood event hydrological analysis
Chapter 7	Gauge Rating Review
Chapter 8	Revised AMAX Series and Growth Factor Analysis
Chapter 9	Pluvial Flood Risk
Chapter 10	Design Flows
Chapter 11	Design Hydrographs
Chapter 12	Future Climate and Catchment Changes
Chapter 13	Joint Probability Analysis
Chapter 14	Conclusion and Summary

1.4 Athea Village

Athea Village is located in west County Limerick, 15.5km west of Newcastle West and 3km from the Limerick-Kerry border, as shown in Figure 1-1. The village is situated on the R523 Listowel to Ardagh regional road and the R524 Glin to Abbeyfeale regional road. The Galey River, which is within the Shannon River Basin District, rises in Rooskagh West (on the western slopes of Knockanimpuha Hill), to the east of Athea and flows in a westerly direction through Athea before joining the River Feale further downstream. The upstream catchment is located in a steep-sided valley with multiple small tributaries flowing down the valley, joining the Galey River.

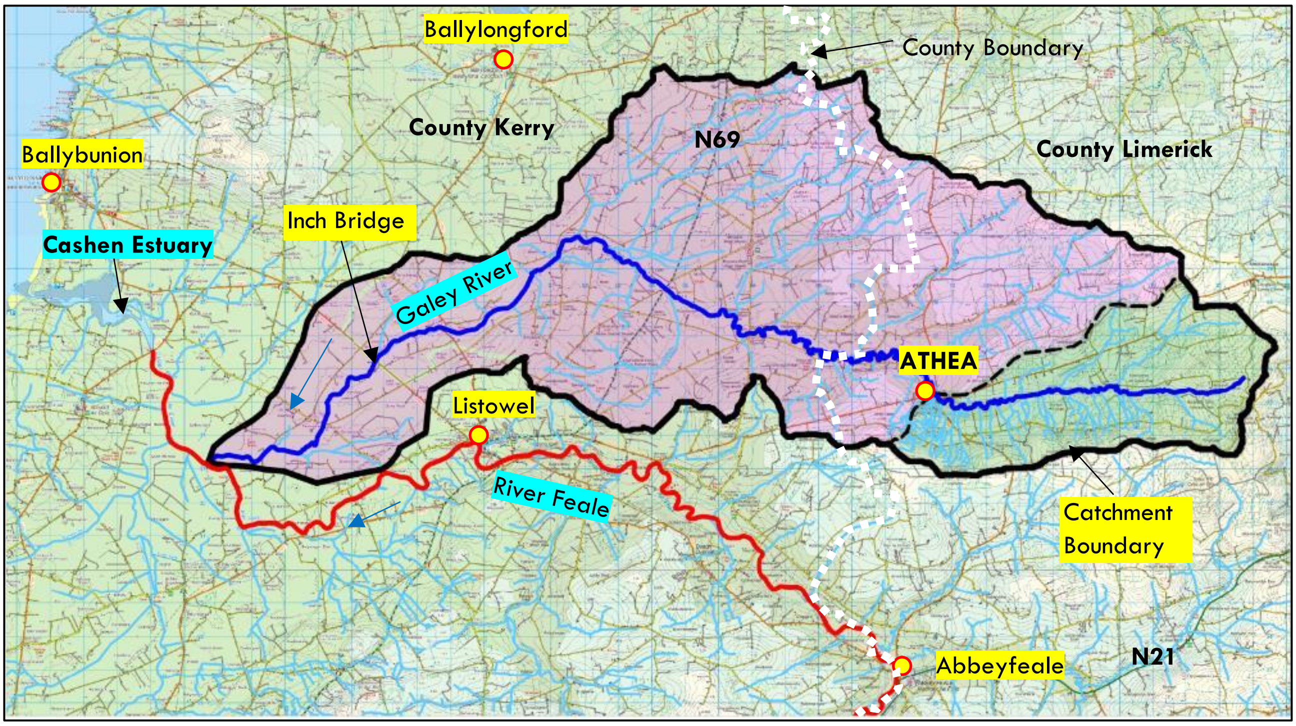


Figure 1-1: Galey River Catchment Overview Map

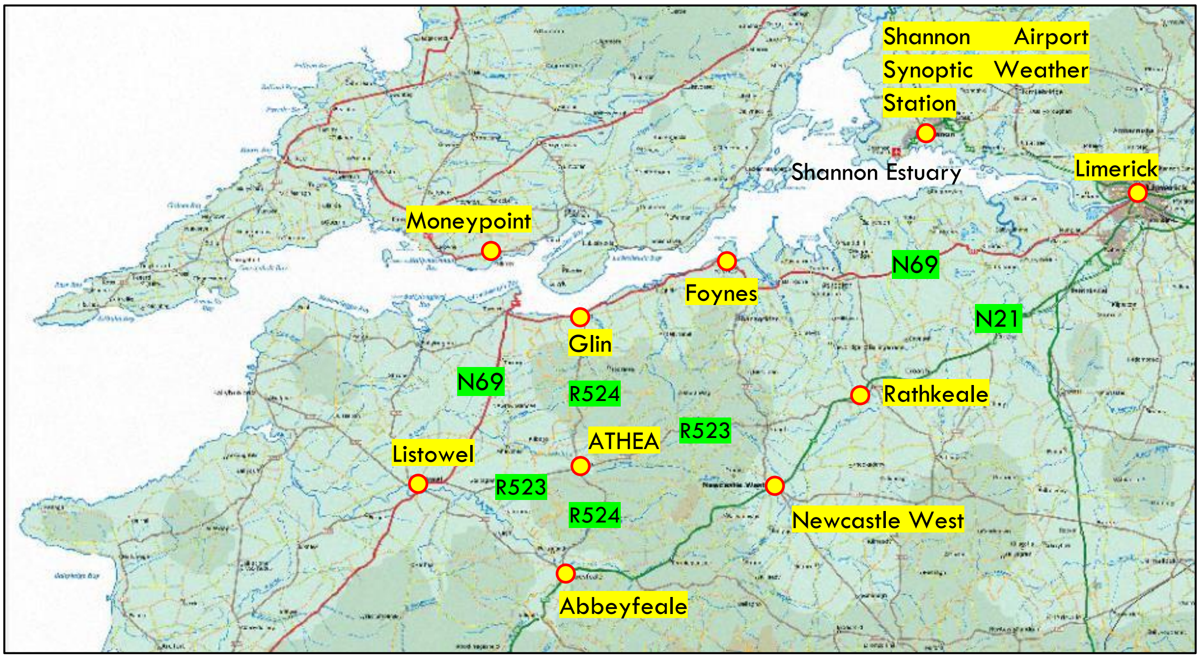


Figure 1-2: Regional Overview Map

2 Hydrology of Study Area

This section of the report includes:

- the Galey River's physical catchment descriptors (PCDs) at Athea Bridge and Inch Bridge,
- a review of the Galey River's catchment area and its sub-catchment area at Athea Bridge,
- an introduction to the catchment's average annual rainfall totals,
- the Athea Bridge's catchment land cover classifications derived from the CORINE database,
- the Athea Bridge's catchment geology and hydrogeology, and sediment transport classifications,
- a summary of the River Feale Arterial Drainage Scheme works in the Galey River catchment, and
- a description of the Galey River channel, its structures and its tributaries at Athea.

2.1 Catchment

2.1.1 Physical Catchment Descriptors

The Physical Catchment Descriptions (PCD)s used by OPW Flood Study Update (FSU) methodologies for estimating median annual maximum flood flow for catchments are built on those used within the Flood Studies Report (FSR). The FSU research derived values of catchment descriptors at intervals along flow paths for all catchments draining an area of at least 1km^2 throughout Ireland.

The main FSU PCD variables taken into consideration are:

- **Contributing Catchment Area** - This is the catchment area contributing to the river reach passing the gauge or focus point.
- **BFISOIL** - BFI is the Base Flow Index and expresses the subsoil nature within the catchment area. A value of 0.67 is indicative of a high base flow regime within the catchment. The range of measured BFI values in Ireland are between 0.26 and 0.91, while those in Northern Ireland are reported between 0.28 and 0.67.
- **SAAR** – This is the annual average rainfall within the contributing catchment. Where the FSR provided maps of generic results for various regions, the FSU is more focused on catchment specific values which are more accurate in their nature. The FSU values are based on an average value taken over the period of 1961-1990. A more up to date dataset for the period 1981-2010 is available.
- **FARL** - This is the flooding attenuation as a result of reservoirs and lakes, which has a large impact on the flow regime within a catchment. A high value of FARL could be indicative of a high percentage of lakes within the subject catchment or that of a river which regularly overtops its banks.
- **DRAIND** - This is the drainage density of the catchment measured in km per km^2.
- **S1085** - This represents the slope of the main channel, calculated between 10% and 85% of the channel length. This value must also be considered with caution when choosing a pivotal site, given that varying slopes result in varying flow dynamics. A long river with a small slope is generally considered a slow sluggish river, with possible overtopping with floodplain attenuation utilised during high flooding scenarios. While a shorter watercourse with a high slope could be considered a quick response catchment that may be liable to flooding on a regular basis.
- **ARTDRAIN2** - This characteristic is representative of additional drainage works carried out within the catchment, with a particular emphasis on arterial drainage works. Arterial drainage can be inclusive of anything between land drainage improvements to channel maintenance such as removal of vegetation, channel widening or dredging. Arterial drainage has a large impact on the flow dynamics within a channel and in most scenarios, the works result in an increase of surface water runoff and thus velocity within the channel. As such, it is an important influential characteristic that should be reviewed carefully in the comparison of sites for pivotal/donor site choice.
- **URBEXT** - Urban extent is used parallel to the 7 main variables for the quantification/estimation of QMED. The previous 7 descriptors allow the web portal to estimate the median flow rate experienced within the channel without the inclusion of increased surface runoff due to impermeable areas. URBEXT is then used to update the estimation based on the urbanised percentage of catchment, with higher values of urbanisation an indication of increased runoff and velocity resulting on increased flow in most cases.

The FSU PCDs from Inch Bridge gauge (Station No. 23001 & HEP 23_2929_1), as well as an ungauged point downstream of Athea village (HEP 23_2579_2) taken from the OPW FSU website are presented in Table 2-1 (and Figure 2-2 and

Figure 3-7 for locations). These PCDs have been reviewed for this study and a preliminary assessment on their appropriateness given in Table 2-1. A further review of the PCDs is presented in Section 9.

Table 2-1: FSU Physical Catchment Descriptors

Catchment Descriptor	Inch Bridge Gauge (23_2929_1)	Athea HEP (DS) (23_2579_2)	Comment
Area (km^2)	191.7	36.7	Area at Athea Bridge = 35.9km^2 and at 23-2579-2 (290m downstream of the bridge) = 36.7km^2. Ratio of catchment area at Athea Bridge to Inch Bridge = 19%
BFI Soil	0.322	0.33	See Note 1
SAAR (mm)	1084.0	1134.6	See Note 2
FARL	1	1	No lakes or reservoirs in either catchment but likely to be attenuation in the floodplains between Athea and Inch Bridge. No attenuation appreciable likely upstream of Athea.
DRAIND (km/km^2)	1.393	1.778	See Note 3. Higher Upstream catchment density
S1085 (m/km)	3.3	12.0	See Note 4. Significantly steeper upper catchment
ARTDRAIN2 (%)	0.19	0	No drainage works in Upper catchment. Note 5.
URBEXT (%)	0.3%	0.55%	Negligible

Note 1: The OPW used gauged information from around Ireland supplied by the EPA and OPW, soils and geological data from EPA and GSI and Teagasc soils hydrological classifications in their BFISoil assessment. A region of influence method was used by the OPW to estimate the BFI for ungauged locations. Given the catchment differences intuitively it would be expected that the BFI at Athea bridge would be higher than at Inch Bridge. The Flood Studies Report Winter Rainfall Acceptance Potential (WRAP) Method for the Inch and Athea Bridge catchments has been calculated the respective catchment soil factors at 0.45 and 0.47 (very high to extremely high runoff). The Inch gauge appears to have been used in this case as part of the BFI assessment and therefore the factor is taken as correct. There is no active EPA gauge data available to allow a comparison between actual base flow and total flows at Athea Bridge. The parameters for the two sites appear similar based on the BFISoil assessment review. In the Flood Studies Update programme Report (Work Package 5.5 Base Flood Index derived from Soils (August 2009), the BFIgauged and BFIsoil at Inch Bridge were reported at 0.3219 and 0.3281.

Note 2: A review of the Met-Eireann SAAR database (1981-2010) has confirmed average SAAR values for the catchments of 1,229.9mm/annum and 1390.4mm/annum respectively. These SAAR totals are used for this study (See Section 2.1.4 below). The FSU SAAR is based on period 1961-1990.

Note 3: A review of these parameters suggest that the FSU DrainD could be underestimated but is open to interpretation on what is an applicable drainage channel. This study assesses Athea Bridge DrainD > 2.1 and Inch Bridge DrainD =c1.4. The Athea Bridge Qmed etc. will be checked using DrainD of 2.1.

Note 4: The MSL and gradients were checked and the S1085 calculated at 3.35 and 12.4 respectively. Athea Bridge Qmed etc. will be checked using S1085 of 12.4m/km

Note 5: While no arterial drainage works were undertaken to the river channel upstream of Athea Bridge,

2.1.2 Catchment Area

The Galey River catchment is a sub-catchment of the River Feale (Cashen Estuary) catchment. The River Feale at Ferry bridge near Ballybunion has a catchment area of approximately 1,100km^2. The Galey River catchment area at Inch Bridge and at its confluence with the River Feale are 191.7km^2 and 213km^2 respectively.

The upstream Galey River catchment area from Rooskagh West to Athea is 36.6km^2 and comprises a relatively steep-sided valley with multiple small hillside tributaries (see Figure 2-1). The topography of the upper catchment upstream of Athea Bridge Figure 2-1) is relatively steep, ranging from 345mOD (Malin) (in Rooskagh West, 9.4km east of Athea) to circa 70mOD at Athea Bridge. The topography continues to drop toward the west with an elevation of approximately 10mOD at Inch Bridge – 26.6km downstream of Athea and approximately 7.2km upstream of the confluence with the River Feale/ Cashen River

The Galey River is a designated Special Area of Conservation (SAC) (Lower River Shannon SAC).

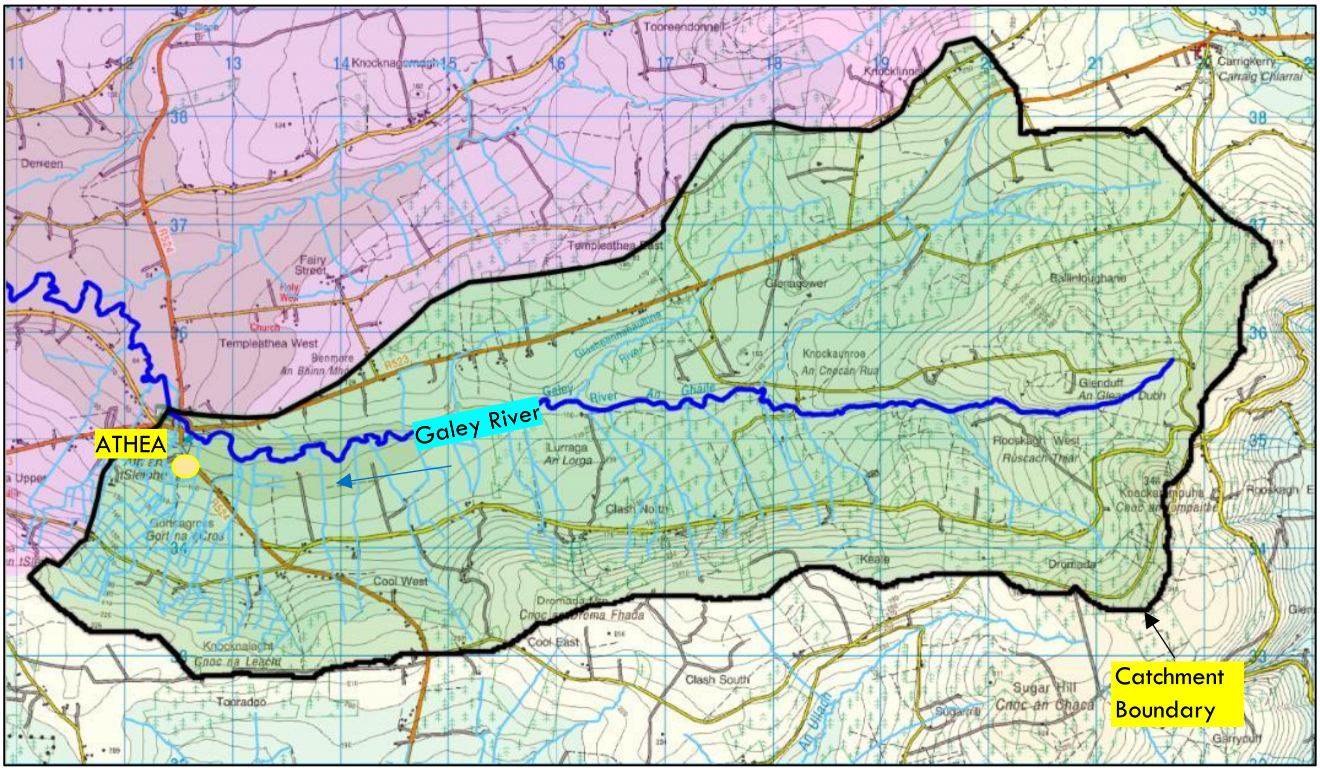


Figure 2-1: Galey River Catchment Extents at Athea, Co. Limerick

2.1.3 Mean Annual Rainfall

The Met Éireann 1981-2010 Annual Average Rainfall Grid shows that the Standard Annual Average Rainfall (SAAR) across the upper catchment of the Galey River ranges from 1250 to 1500mm. Using the SAAR 8110 dataset the catchment average rainfall in the Athea Bridge and Inch Bridge catchments has been calculated at 1392.4mm, and 1230.7mm respectively. The FSU portal SAAR for these two sites, by comparison is reported at 1134.6mm and 1084.0mm respectively and is based on the 1961 to 1990 period. The study's rainfall records are assessed in Section 3.1 and Section 5.0.

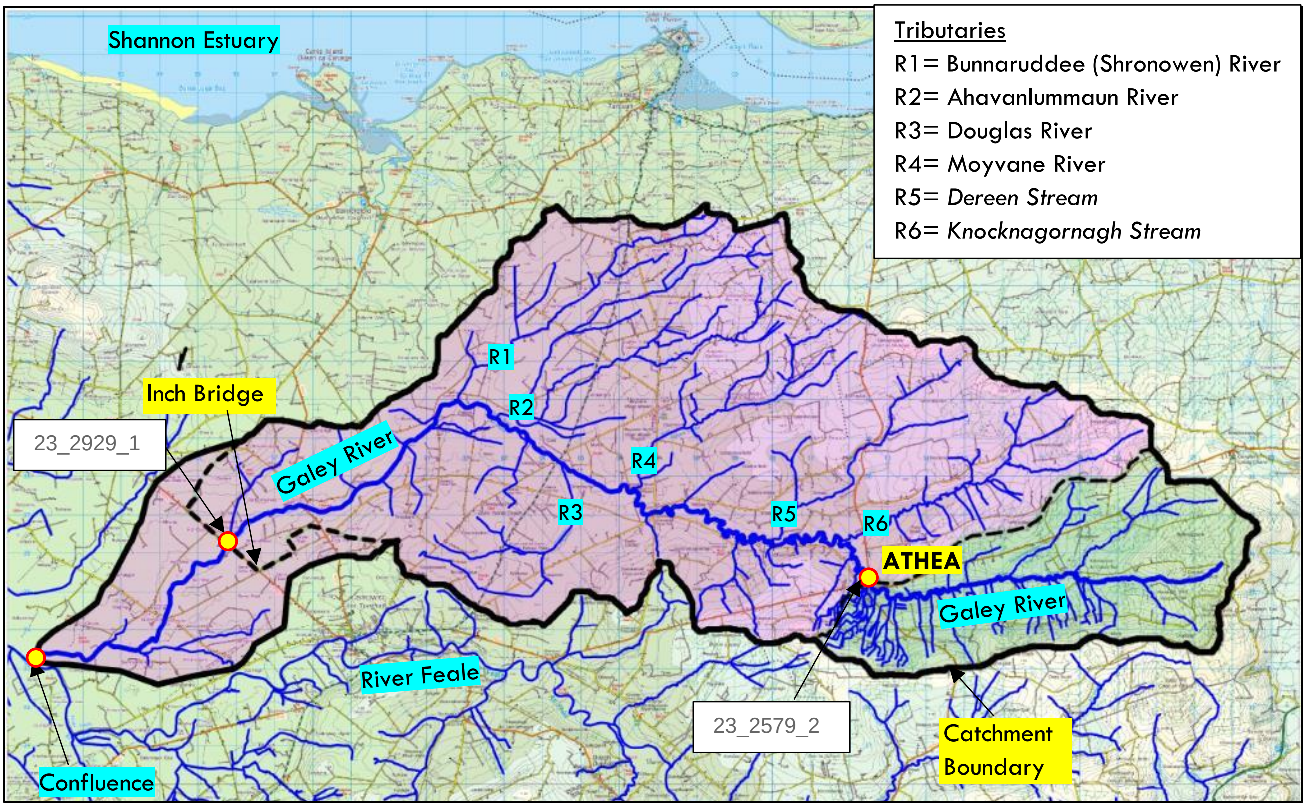


Figure 2-2: Galey River Catchment Extents at confluence with River Feale

2.1.4 Catchment Landcover

The CORINE (Co-ORdinated INformation on the Environment) data-series was established by the European Community (EC) as a means of compiling geo-spatial environmental information in a standardised and comparable manner across the European continent. The first iteration of the data-series covered the reference year of 1990 with subsequent releases covering the years 2000, 2006, 2012 and most recently 2018. The first dataset in 1990 provided a 'snapshot' baseline of the geographical distribution of natural and built environments across Europe.

The Galey River catchment upstream of Athea Bridge comprises a significant area of forestry lands which are being continually being developed with planting of coniferous forest, felling and harvesting of timber and re-planting of forest. As part of this commercial forestry development in the hilly catchment large areas of blanket peat lands have been reclaimed and planted. Using the CORINE database (sourced from the EPA) the progression of the land-use in the catchment over the past 30 years (1990 to 2018) has been assessed. Figure 2-3 and Figure 2-4 present the land-cover extents and Figure 2-5 summarises the accumulative land-cover areas of the 6 No. land-cover classifications over the study period in the Athea Bridge catchment. Table 2-2 and Table 2-3 summarises the land-covers areas and relative % cover of each classification to the overall catchment area.

Based on the CORINE database the blanket peat area in the catchment reduced from 36% to 14% of the overall catchment area between 1990 and 2000. The combined area of Transitional Woodland Scrub (including newly planted and recently felled forests areas) and Coniferous forest (referred to here as forestry) increased from 21% to 46% of the overall catchment over the same period. The "principally agriculture with areas of natural vegetation" landcover reduced from 13% to 10% of the overall catchment over the same period while the pasture and urban areas remained relatively unchanged. By 2018 the peat lands % landcover had reduced to 12% while the forestry landcover increased to 50%.

Within the forestry landcover category the relative area of coniferous forest reduced from 25% to 19% in the period 2012 to 2018 (period of harvesting) whilst the transitional woodland area increased from 22% to 31% (a combination of recently felled and newly planted forestry.

The impact of the change in landcover over the period 1990 to 2018 is further assessed in the Section 12 Future Climate, Environmental and Catchment Changes.

Table 2-2: Athea Bridge Catchment Landcover Type Areas

Year	1990	2000	2006	2012	2018
Landcover Type	**ha**	**ha**	**ha**	**ha**	**ha**
Pastures	1118.8	1069.8	1062.0	1062.0	1046.3
Land principally occupied by agriculture with areas of natural vegetation	460.3	366.6	366.6	366.6	338.7
Transitional woodland scrub	316.7	704.8	788.2	825.5	1137.6
Coniferous forest	446.6	989.7	956.8	927.5	681.4
Discontinuous urban fabric	20.0	20.0	20.0	20.0	20.0
Peat bogs	1309.6	521.0	478.3	470.3	447.8
Total	3671.9	3671.9	3671.9	3671.9	3671.9

Table 2-3: Athea Bridge Catchment Landcover Type % area of the overall catchment area

Land Cover Type	1990	2000	2006	2012	2018
Pastures	30%	29%	29%	29%	28%
Principally agriculture with areas of natural vegetation	13%	10%	10%	10%	9%
Transitional woodland scrub	9%	19%	21%	22%	31%
Coniferous forest	12%	27%	26%	25%	19%
Discontinuous urban fabric	1%	1%	1%	1%	1%
Peat bogs	36%	14%	13%	13%	12%
Total	100%	100%	100%	100%	100%

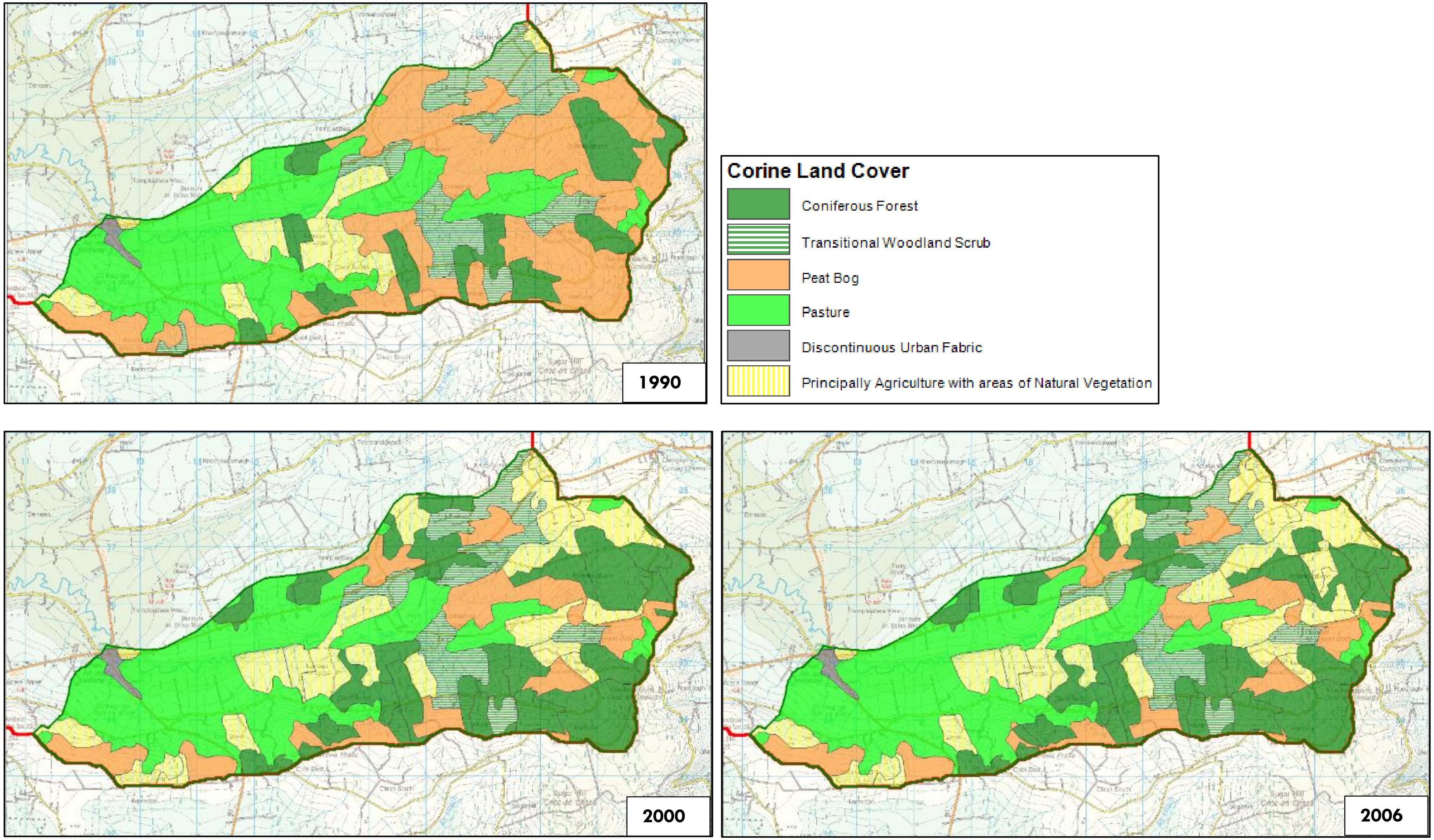


Figure 2-3: Landcover in the Galey River – Athea Bridge upstream catchment for reference years 1990, 2000 and 2006

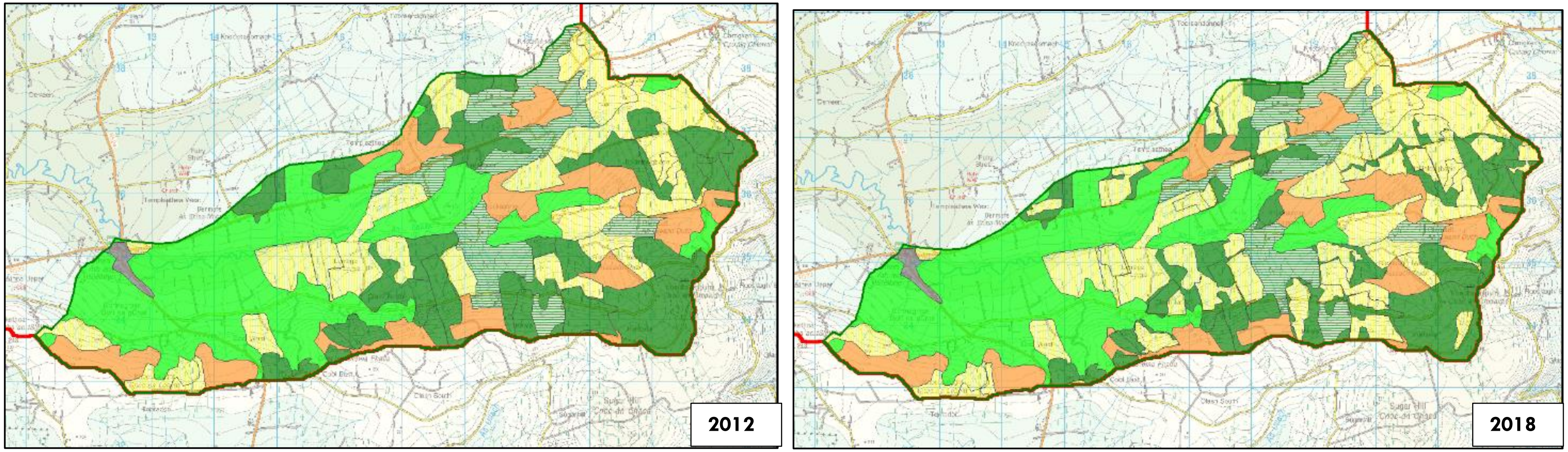


Figure 2-4: Landcover in the Galey River – Athea Bridge upstream catchment for reference years 2012 and 2018

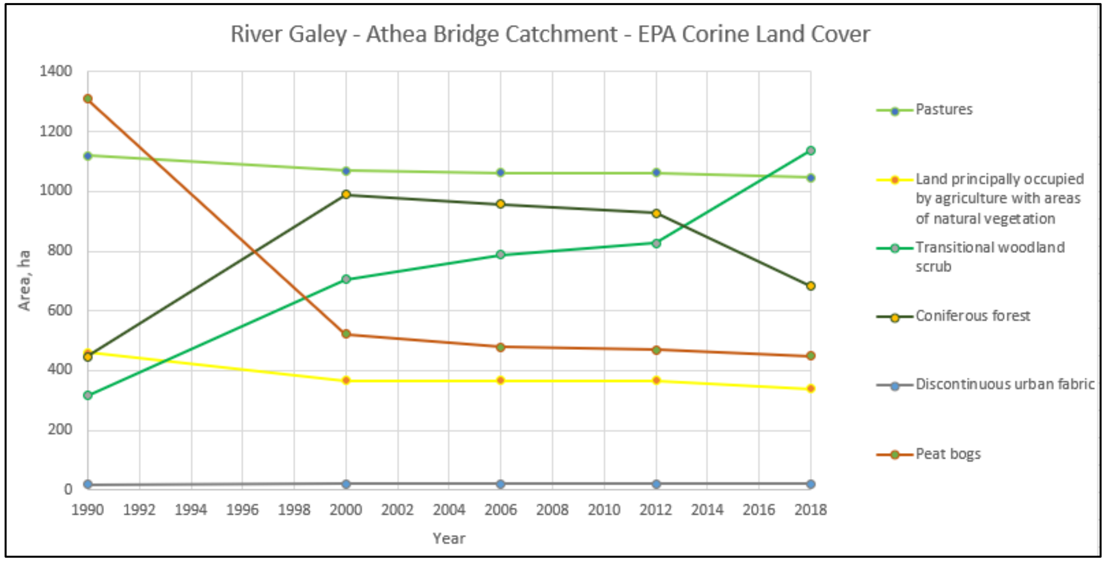


Figure 2-5: Landcover Change for the period 1990 to 2018

2.1.5 Geology & Hydrogeology

2.1.5.1 Bedrock

The underlying geology of the Galey River catchment is predominantly Carboniferous and Namurian Shales, Sandstones, Siltstones and Mudstones as part of the extended Clare Basin in the form of two formations, the Central Clare Group and the Shannon Group. The western extent of the catchment at Inch Bridge comprises Carboniferous Dinantian Visean Limestone (undifferentiated). An overview of the Galey River's geology shown in Figure 2-6.

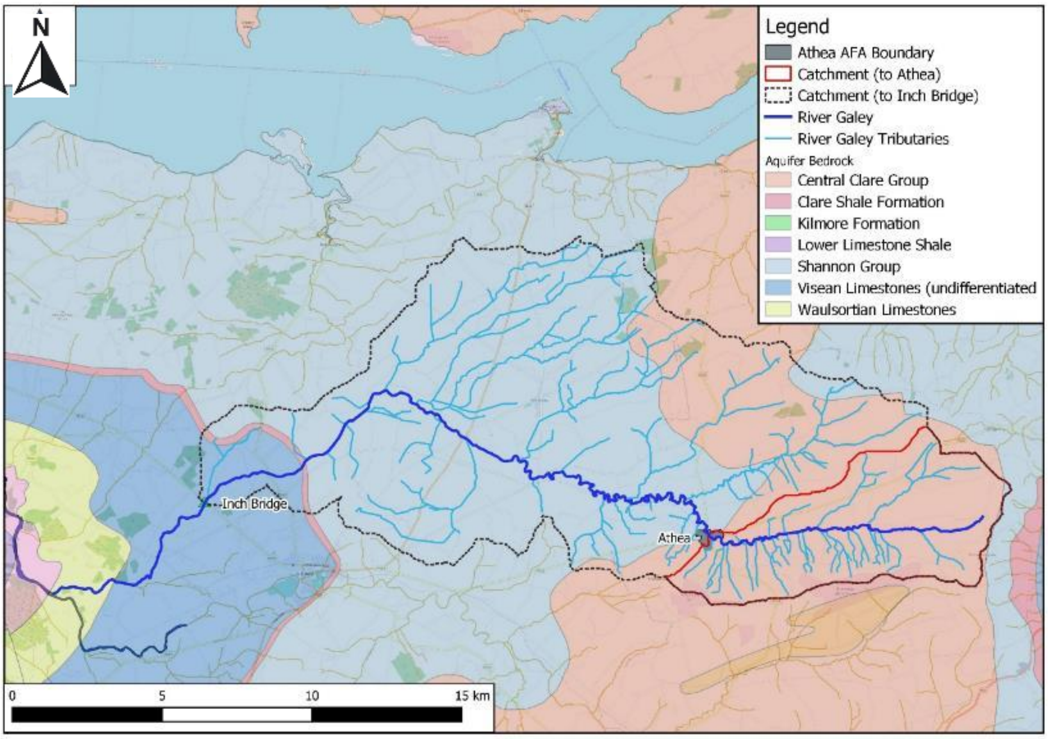


Figure 2-6: Geology of study area

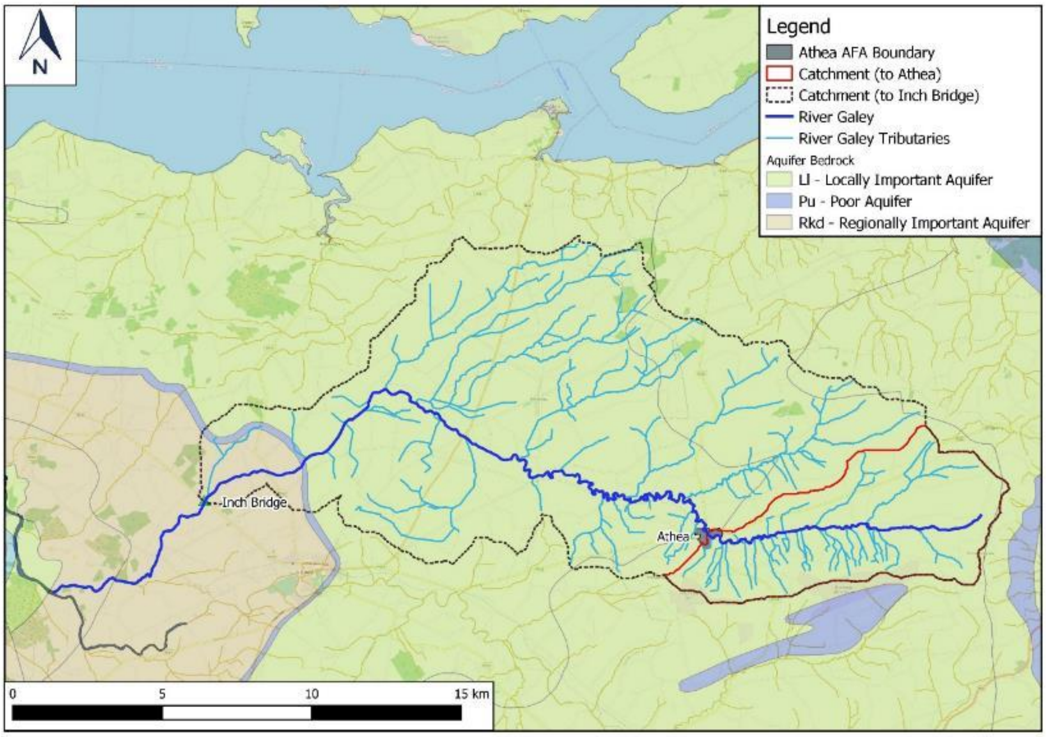


Figure 2-7: Groundwater resource overview

2.1.5.2 Subsoils

The subsoils within the Athea Bridge catchment include alluvium within the Galey River floodplain, tills derived from Namurian Sandstones and Shales, Blanket Peat, and bedrock outcrops in the upper regions (e.g. Rooskagh West) as shown in Figure 2-8.

Figure 2-9, which presents the Teagasc wet/ dry subsoils database upstream of Athea, shows the entirety of the upper catchment comprises Peat or Poorly Draining soil with small pockets of Well-Draining soils. Due to the geology and subsoils, catchment gradient, no appreciable floodplain attenuation and drainage improvement works within forestry lands, the Athea Bridge catchment would be expected to have very high run-off rates.

2.1.5.3 Groundwater Aquifers

The Athea Bridge catchment is predominantly located within Abbeyfeale Groundwater Body, which is reported to be a Locally Important Aquifer comprising a generally poorly productive bedrock with only localised productive zones. The western extent of the catchment at Inch Bridge is underlain by a Regionally Important Aquifer in a karstified region. Figure 2-7 provides an overview of groundwater resource within the catchment area. The GSI groundwater body database reported that in this aquifer, in general:

- Diffuse recharge will occur via rainfall percolating through the subsoil.
- The proportion of the effective rainfall that recharges the aquifer is largely determined by the thickness and permeability of the soil and subsoil, and by the slope.
- Due to the generally low permeability of the aquifers within this GWB, a high proportion of the recharge will then discharge rapidly to surface watercourses via the upper layers of the aquifer, effectively reducing further the available groundwater resource in the aquifer.

The Athea Public Water Scheme was historically supplied from a spring well on the hillside at Gortnagross, 1km south of Athea (130m contour) and had a reported yield of 90 to 183m^3/day. Athea is now supplied from the Abbeyfeale Public Water Supply (abstraction from the River Feale).

2.1.5.4 Groundwater Features and vulnerability

There are no recorded karst features within the study area on the GSI groundwater website database. Small springs are noted on OSI historical mapping on the hillside slopes to the south of Athea and these are shown to drain to the stream networks. The groundwater vulnerability at and to the south of Athea is, in general, reported as 'moderate' (GSI) which implies the depth to the bedrock aquifer would be expected to be in the range of 5 to 10m. The groundwater vulnerability is noted as high to extreme to the northeast of Athea Bridge where bedrock would be expected to be close or at the surface.

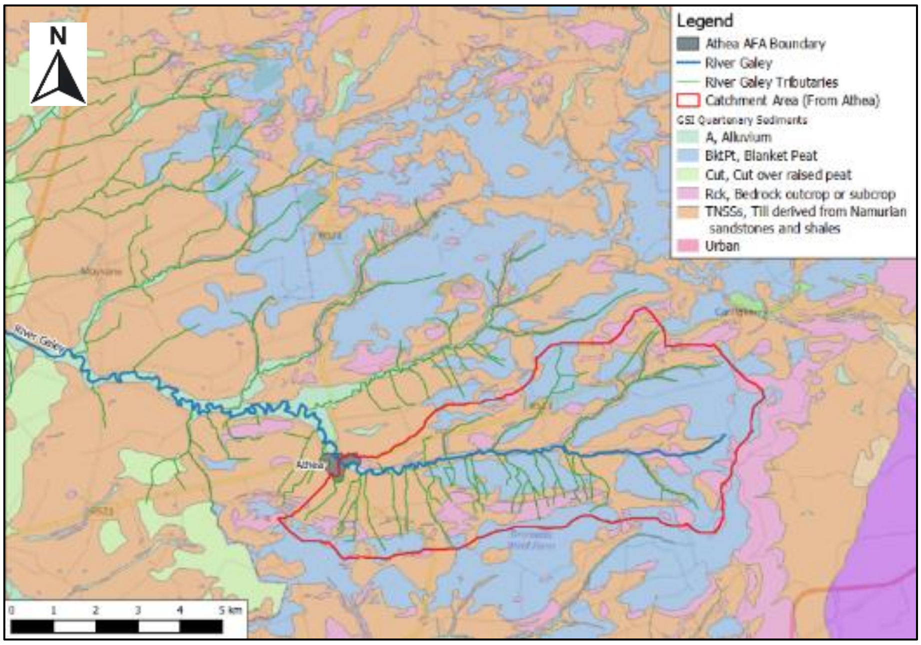


Figure 2-8: GSI quaternary sediments overview

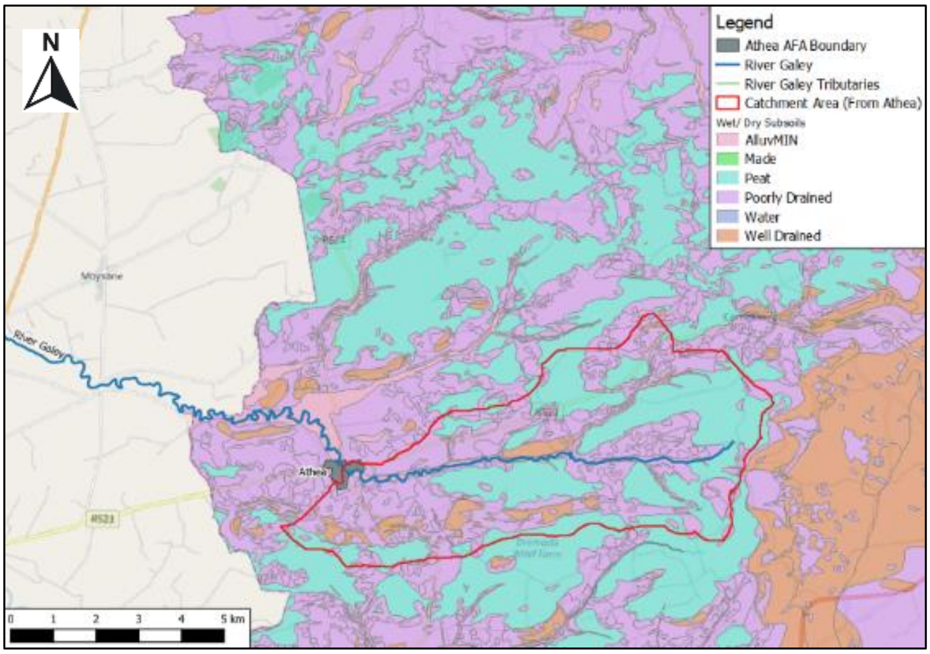


Figure 2-9: Wet/ dry subsoils overview

2.1.6 River Feale Arterial Drainage Scheme

The lower reaches of the Galey River catchment were included in the River Feale Arterial Drainage Scheme (see Figure 2-10) which was undertaken between 1951 and 1959. The Galey River channel and banks were historically maintained by riparian landowners until 1995, as stated in the Athea *Flood Severity and Impact Report* by JBA Consulting Engineers. It was noted that as part of the maintenance works, gravel clearing from the bed was undertaken by the riparian landowners in areas of high deposition, however, this was stopped following designation of the Lower River Shannon SAC.
Following a flood event at Athea in 2008, the Office of Public Works (OPW), at the request of LCCC, carried out emergency channel and bank maintenance along a section of the Galey River through Athea.

Lower reaches of the Galey River, from Moyvane westwards, are maintained by the OPW under the River Feale Arterial Drainage Scheme. The works involve channel and embankment maintenance.

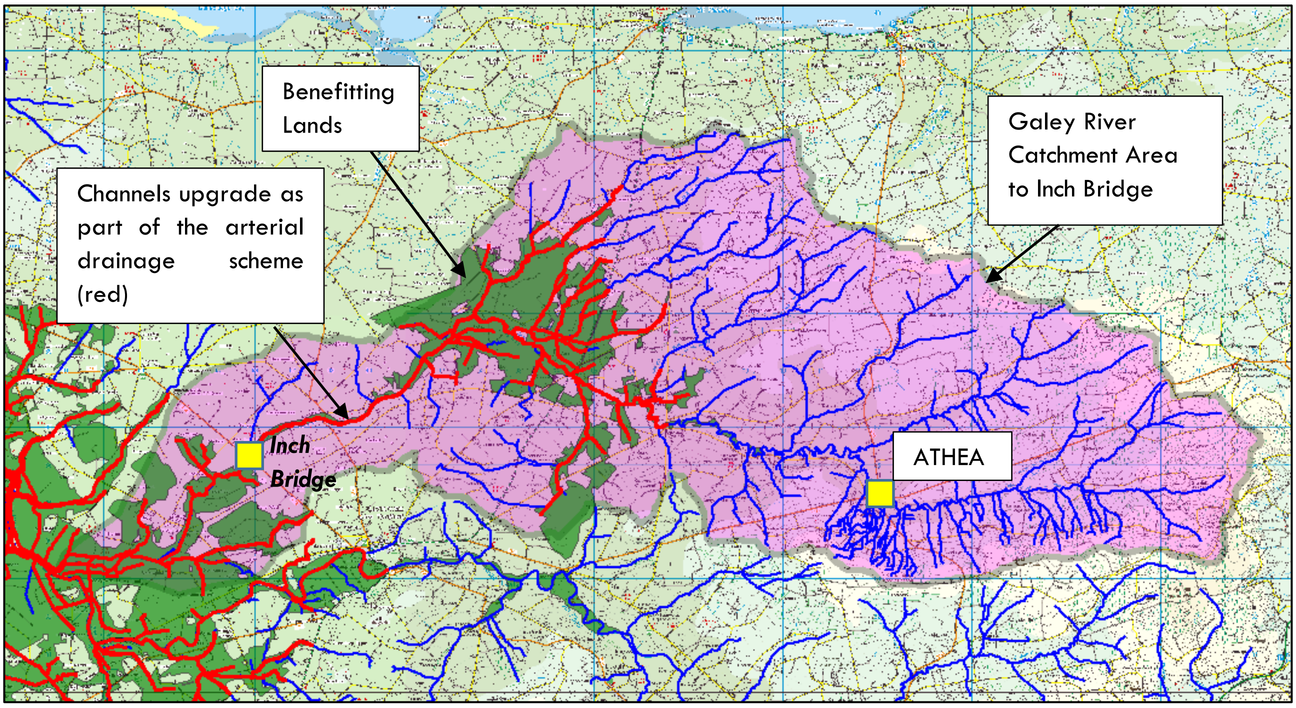


Figure 2-10: River Feale Arterial Drainage Works Extents with the Galey River Catchment

2.1.7 Description of River System at Athea

2.1.7.1 Galey River

The Galey River through the Athea study area, in general, flows in a north-westerly direction. In the reach 1km upstream of Athea Bridge, the river channels follows a series of two relatively long meander bends before a sharp meander bend approximately 200m upstream of the bridge. Immediately upstream of the bridge the channel turns to flow northwards, passes under the bridge and continues relatively straight for approximately 70m. Then the channel turns to flow north-westwards once more before passing through a sharp meander bend eastwards (270m downstream of Athea Bridge), and again northwards parallel to the R524. The channel then turns and flows, in general, north-westwards and passes through 9 No. further meanders before the road bridge at Athea Lower (c 4.8km downstream of Athea). The Athea WWTP is located close to the Galey River's right bank approximately 550m downstream of Athea Bridge.

A number of tributaries (in general minor), discharge to the Galey River within 1km upstream and 4.8km downstream of Athea Bridge. The largest of these is the Knocknagornagh Stream which is located 2.4km downstream of Athea Bridge. The tributaries also include the Athea East and West streams which flow through the immediate village study area. Further details on these tributaries are given in Section 2.1.7.3. The Galey River has a significant tributary contribution, as shown in Figure 2-1 and Figure 2-2, with the upper catchment having a relative denser concentration of tributaries.

The Galey River and its tributaries were surveyed as part of the CFRAM stage in 2012 and further channel surveying has subsequently been undertaken in 2020 for this study. This survey data, which is summarised in the Hydraulic Modelling Report for this study, has been used in this report to determine principal parameters.

The average channel slope (S1085) of the Galey River upstream of Athea Bridge is calculated at 12.4m/km, which is relatively steep. From Athea Bridge to Inch Bridge the channel gradient reduces with a resultant estimated S1085 of 3.3m/km. The channel gradients 1km upstream and 1km downstream of Athea Bridge have been calculated at:

- 1km upstream of Athea Bridge: 6.3m/km,
- 1km downstream of Athea Bridge: 5.4m/km, and;
- Reach extending from 1km upstream to 1km downstream: 5.9m/km.

Athea bridge is a triple-arch masonry structure comprising one central main arch and two side arches. The bridge piers are protected by cut waters and the approach to the bridge abutments are protected by masonry river walls. A pedestrian bridge spans the channel immediately upstream of the bridge (See Figure 2-19 and 2-20 below). A detailed description of the bridge and associated infrastructure is presented in the Athea FRS Hydraulic Modelling Report.

Figure 2-11 presents cross section locations and Table 2-4 summarises the channel width, depth and condition and locations for the section for the immediate reach through the village study area (circa 250m upstream and downstream of the bridge) based on CFRAM survey and site inspection. Further detail on the existing channel is provided in the Athea FRS Hydraulic Modelling Report. Figure 2-12 to Figure 2-15 present photographs of reaches of the Galey River channel at Athea.

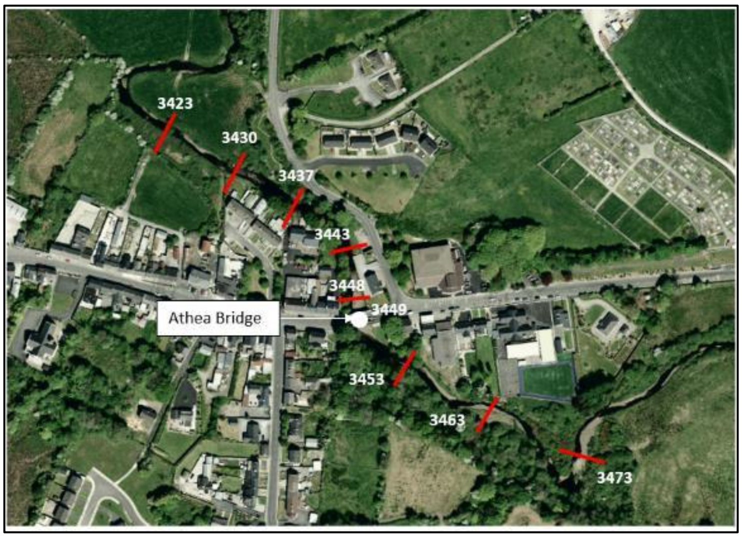


Figure 2-11: Galey River Channel Cross-Sections Locations upstream and downstream of Athea Bridge

Table 2-4: Galey River Channel Description at Athea

XS Ref	Typical Invert, mOD	Typical Width, m	Typical Channel Depth, m	Distance to Athea Bridge	Channel Description
3473	68.4	12m	1m	237m u/s	Shallow eroded channel, sloped banks, deposition and erosion, on meander.
3463	67.5	8- 14m	1.1m	143m u/s	Wide channel, steep **eroding right bank**, sloped left bank with deposition, cobbles, school on left bank, on meander.
3453	66.7	14m	1.2m	48m u/s	Wide Channel, steep right bank developed and bank protection, sloped left bank overgrown, downstream of bend,
3449	67.0	19m	3m	At the Bridge	Wide Channel, Sloped banks, parkland on banks, straight, gravel deposition
3448	66.5	19m	1.5m	17m d/s	Wide Channel, Sheer banks, development directly on banks, straight, gravel deposition. The left bank downstream of the bridge has recently been cleared of vegetation (April 2021) and the bank reformed by a third party
3443	66.3	9m	1.7m	55m d/s	Narrow, steep banks, cobble bedded, urban area, development directly on banks, sharp bend in channel
3437	66.0	10m	2.4m	120m d/s	Narrow, steep banks, cobble bedded, urban area, development directly on banks, after bend in channel
3430	66.0	9m	1m	180m d/s	Narrow, sloped banks, cobble bedded, agricultural/ urban area, Athea West outfall
3423	65.5	8m	1.5m	239m d/s	Narrow, steep banked, cobble bedded, in floodplain

Figure 2-12: Galey River looking upstream towards XS 3453 (March 2021)

Figure 2-13: Galey River looking upstream towards XS 3443 and XS3448 (March 2021 - left bank recently cleared)

Figure 2-14: Galey River looking downstream from Athea Bridge (before bank clearance works - August 2020)

Figure 2-15: Galey River looking downstream towards XS 3437 (November 2020)

Figure 2-16: River Galey behind Markievicz Park – XS 3423 (March 2021)

Figure 2-17: River Galey following channel clearance (upstream of Athea Bridge) (JBA, October 2008)

Figure 2-18: Gravel deposits upstream of Athea, 1km upstream of XS- 3473 (JBA, October 2008)

2.1.7.2 Sediment Transport

The CFRAM *Geomorphology Assessment Report (UoM 23)* assessed the potential risks posed within the catchment from erosion and sedimentation. CFRAM identified, using a 'bottom up" using catchment level information including stream power, soil type; sinuosity, land use, slope and historical channel change, that the Galey River deposition and erosion risk using as being:

- a Type 2 in the lower catchment and therefore at medium risk of deposition and erosion and;
- a Type 4 (upper catchment) river and therefore at high risk of deposition and erosion.

To further assess these CFRAM study conclusions relative to the Athea reach (upper catchment), a desk study assessment has been undertaken using the results from the pan European Sedimentation Analysis (Panagos et al 2015)[1] and WaTEM/SEDEM model[2] sedimentation/deposition to estimate the potential sediment yields, erosion and deposition within the Galey River catchment upstream of Athea.

The European Sedimentation Analysis used a modified version of the RULSE model (2015) to estimate the annual average soil loss. Figure 2-7 presents the potential sediment yield estimates in the Athea catchment from the Rulse Model which in this case range from 0 up to 7 tonnes/ha/year. Based on a catchment area of 3670 ha and sediment yield rates of between 0 and 3.5 t/ha/yr and an approximated average of 1.362 t/ha/yr, an indicative annual sediment yield rate is estimated at 5,000 tonnes per annum for the catchment.

[1] Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L., Alewell, .C. 2015. The new assessment of soil loss by water erosion in Europe. Environmental Science & Policy. 54: 438-447. DOI: 10.1016/j.envsci.2015.08.012

The WaTEM/SEDEM model[2] comprises two modelling steps for assessing the sediment deposition and the sediment transport. The first step refers to the application of the Revised Universal Soil Equation (RULSE) for estimating the sediment loss/deposition based on the rainfall erosivity and a number of catchment geomorphological characteristics. The second step corresponds to the gross erosion/transport through the route downslope across each pixel from hillslope to the riverine systems. Figure 2-7 presents the estimated deposition and the sediment transport derived from the model and shows that medium to high transport rates (0.4-2 t/ha/yr), along Athea catchment watercourses.

Sediment/ deposition surveys, monitoring and modelling would be required to improve on the indicative rates estimated above.

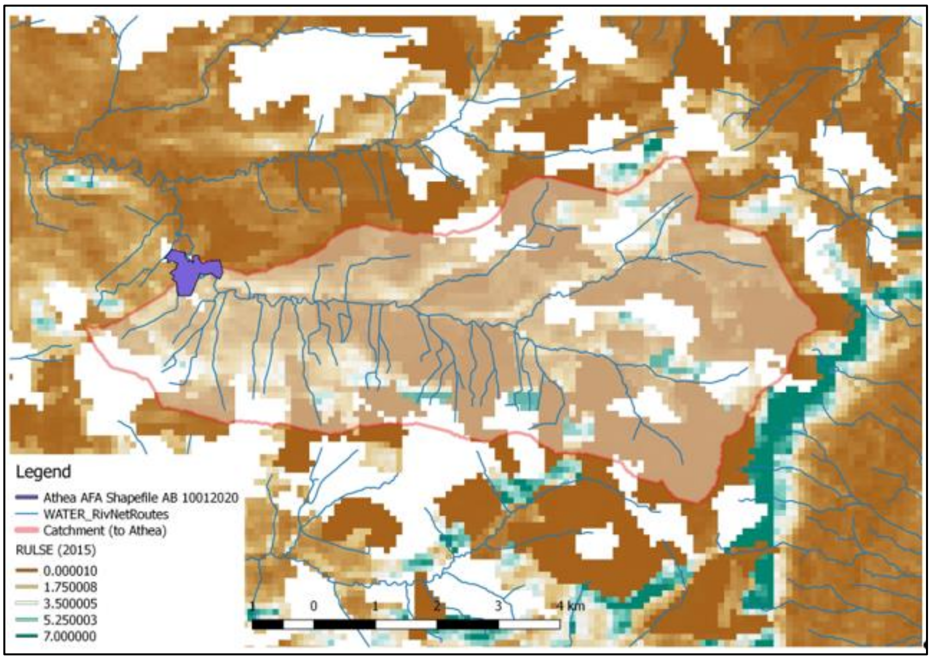


Figure 2-19: Rulse Model results for the Athea Catchment

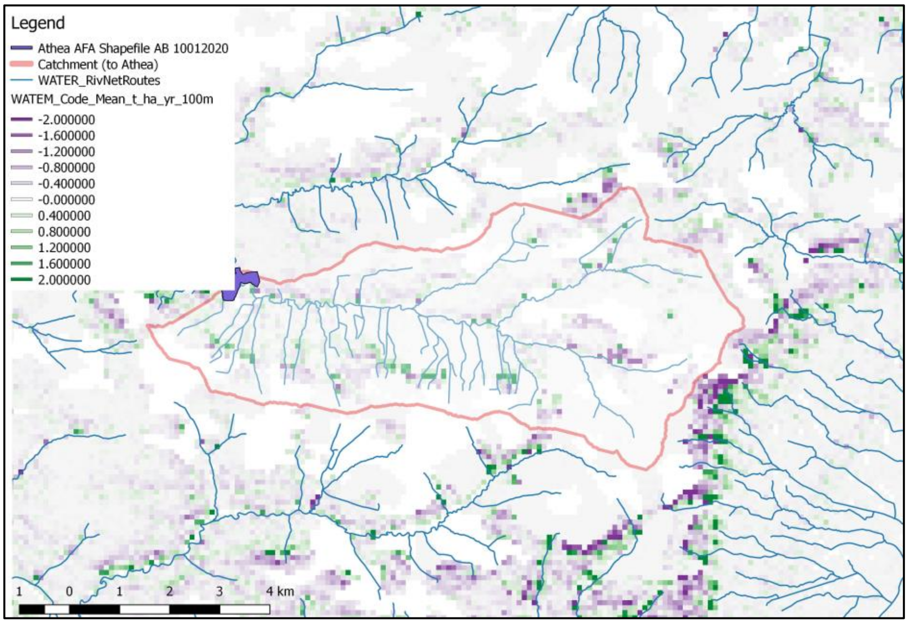


Figure 2-20: WaTEM/DEM results (negative values-transport, positive values deposit)

[2] Borrelli, P., Van Oost, K., Meusburger, K., Alewell, C., Lugato, E., Panagos, P. 2018. A step towards a holistic assessment of soil degradation in Europe: Coupling on-site erosion with sediment transfer and carbon fluxes. Environmental Research, 161: 291-29

2.1.7.3 Erosion and Deposition at Athea

In Section 2.1.7.2 the upper Galey River channel at Athea has been identified as being at high risk of erosion and deposition. Site walkovers and inspection of photographic evidence and aerial photography confirms significant deposition, erosion and sediment transport occur in Galey River reach at Athea. Significant aggradation comprising sediments, gravels and cobbles at Athea Bridge and a vegetated gravel island downstream of the bridge were evident during site walkovers in November 2020 and March 2021 This deposition potential impacts on the conveyance capacity and may therefore be increasing flood risk locally at Athea Bridge. It is understood that historically these deposits were routinely removed by local landowners, however, this practice was reported by locals to have ceased since the river was designated as part of the Lower River Shannon SAC (JBA, October 2008).

The reasons for the significant deposition and erosion in the Galey River reach at Athea village include:

- The upper catchment soils and subsoils are susceptibility to erosion, i.e. glacial till deposits and alluvium, blanket peat;
- Steep channel gradient in the upper catchment, high run-off rates and high stream density in the upper catchment.
- Drainage channel improvement associated with forestry developments.
- Natural change of channel alignment in the reach immediately upstream of the bridge with associated bank erosion and gravels deposition.
- An apparent change in channel gradient to slacker grades in the river reach through Athea where the river channel changes from a steep eroding upland river to a floodplain, depositing and meandering river reach downstream of Athea.
- Scouring at the bridge piers during flood events.
- Erosion of the alluvium deposit in the floodplain upstream of Athea Bridge by flash floods in the catchment.

Following the two flood events in 2008 (see Section 3.5.2) between 31St July and 6th August, Limerick Co. Co. requested the OPW to remove the gravel aggradation and flood debris from Athea Bridge as emergency works. The OPW removed 120 dumper loads of gravel from under the bridge after the 6th August 2008 event. However, the OPW reported that only within a few days, following a moderate flood, the gravel deposits under the bridge had re-established to levels similar to those previous to their emergency maintenance works. The OPW reportedly have undertaken similar works on four other occasions since following consultation with the IFI and NPWS up to 2011. The OPW do not have the authority under the 1945 Arterial Drainage Act to undertake channel maintenance works at Athea without appropriate assessments and consultation, and planning permission.

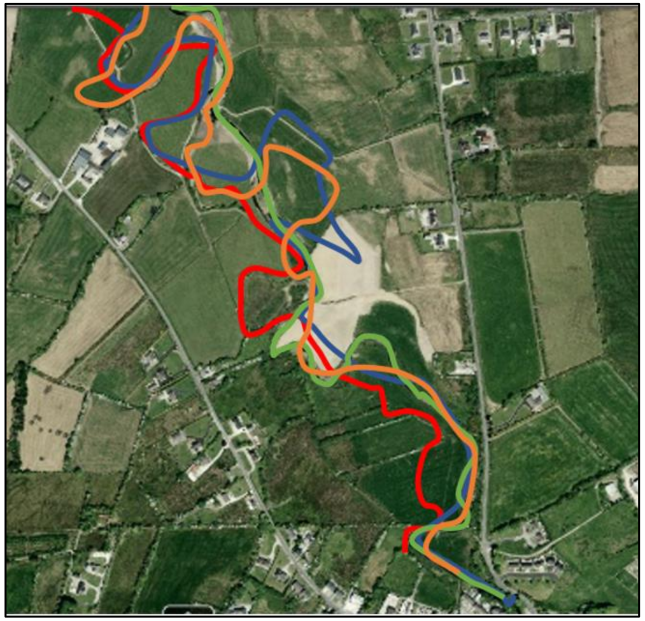
2.1.7.4 Channel Alignment Changes

A review of historical mapping for the Galey River confirms significant channel horizontal alignment changes at Athea in the past 100 years (see Figure 2-21 to 2-22).

A review of Aerial Photograph for the Galey River available from 1995 to present has identified appreciable horizontal alignment changes upstream and minor modifications downstream of Athea in the past 26 years (see Figure 2-23 to 2-29). Of note in these figures is the presence and subsequent apparent disappearance of a 'pinch point'/ deposition behind Markievicz Park between 2005 and 2012 and the tightening of the hairpin meander at XS 3473.

The most evident areas of alignment changes upstream and downstream of Athea Bridge in 1995 to 2021 period are highlighted in Figure 2-23 to 2-29 namely the reach behind Markievicz park (yellow border), Athea Bridge Reach (green border), School to dance hall reach (blue border) and significant meander (red border).

Figure 2-21: River Galey Horizontal Alignment at Athea (upstream reach) (1800 – Present)



Red: Townland Boundary. Townland boundaries often follow the routes of natural features, such as streams, ridges, etc. In this case, the townland boundaries are indicative of historic route of the River Galey.

Blue: First Edition OS Maps. These were prepared c1830s/40s and show the channel route at that point in time.

Amber: Second Edition OS Maps. These were prepared c1900 and show the channel route at that point in time.

Green: Current Aerial Imagery. This reflects the current path of the channel

See also Figures 2-28 and 2-29 below.

Figure 2-22: River Galey Horizontal Alignment at Athea (downstream reach) (1800 – Present)

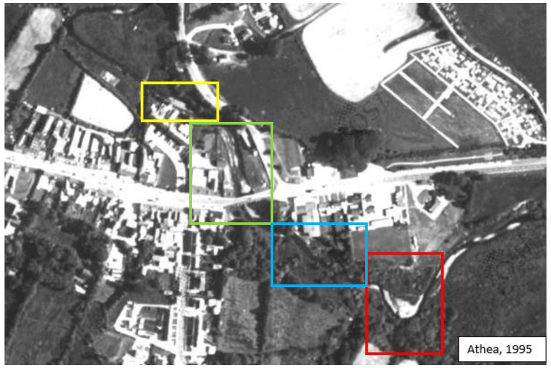


Figure 2-23: Athea 1995 (OSI)

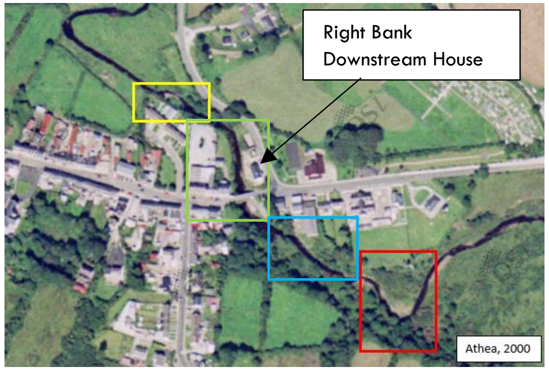


Figure 2-24: Athea 2000 (OSI)

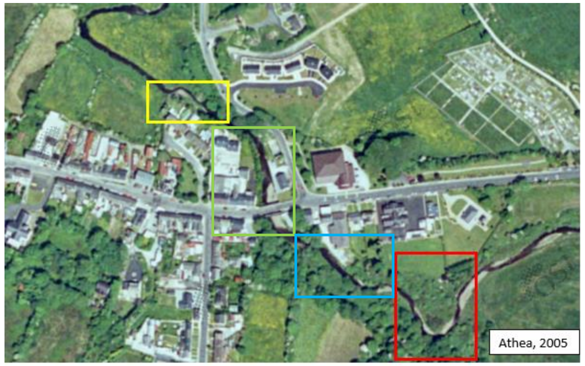


Figure 2-25: Athea 2005 (OSI)

Figure 2-26: Athea 2012 (OSI)

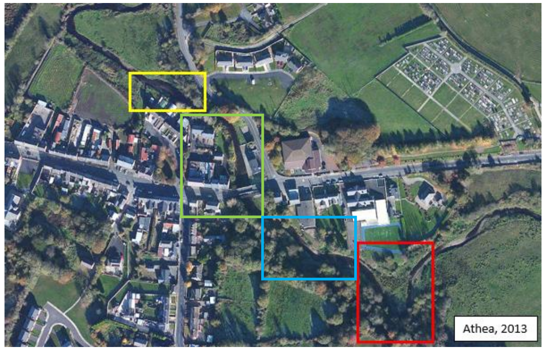


Figure 2-27: Athea 2013 (OSI)

Figure 2-28: Athea 2018 (OSI)

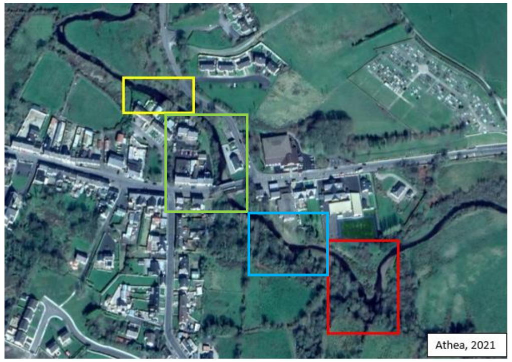


Figure 2-29: Athea 2021 (Bing)

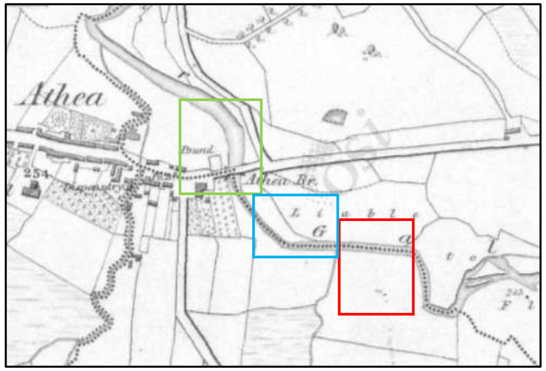


Figure 2-30: Athea 1st Edition 6" (1830/40)

Figure 2-31: Athea 25" (1900s)

Table 2-5 and Figure 2-32 summarises the progression of the deposition and erosion along the Athea reach. The most evident issues are:

- The school meander (220m upstream of Athea Bridge) has sharpened to a hairpin bend and may eventually break through and form a cut-off. The current meander downstream channel appears to be leading to increased erosion of the right bank adjacent to the school yard. The meander inner deposition area is low and is overtopped in flood conditions. If a full breakthrough occurs at the meander the channel may continue to straighten out and further migrate northward towards the school grounds. If the breakthrough occurs during a flood evident it could release large volumes of sediments/ gravels and vegetation/ scrub directly towards the bridge and cause a blockage. Comparison of historical mapping clearly shows the progression of the channel northwards. In 2015 concerns regarding bank erosion at school grounds were raised by the school and adjacent landowners and the vulnerability of the school sports ground was highlighted.
- The bend in the channel reach between the school and the dance hall is migrating westward and the approach channel is migrating northwards. The downstream bend is eroding the left bank upstream of Athea bridge approach channel.
- Significant deposition occurs at Athea Bridge. This is discussed in further detail in Section 2.1.7.5.
- The channel reach behind Markievicz Park is prone to deposition and could develop in a flow impediment during flood events. This area may have contributed to flooding during the August 2008 flood events. The channel is currently clear.
- The meander downstream of Markievicz Park appears to be sharpening and migrating westward slowly. [Note: Water levels behind the estate need to exceed 67.5mOD before an appreciable overflow to the downstream flood plain establishes.]

It is recommended that the assessment of options and the design of flood risk management measures also include for:

- the design of erosion and scour counter measures,
- the control and management of gravel deposition through the Athea Galey River reach,
- a channel monitoring and maintenance regime including flood debris mitigations.

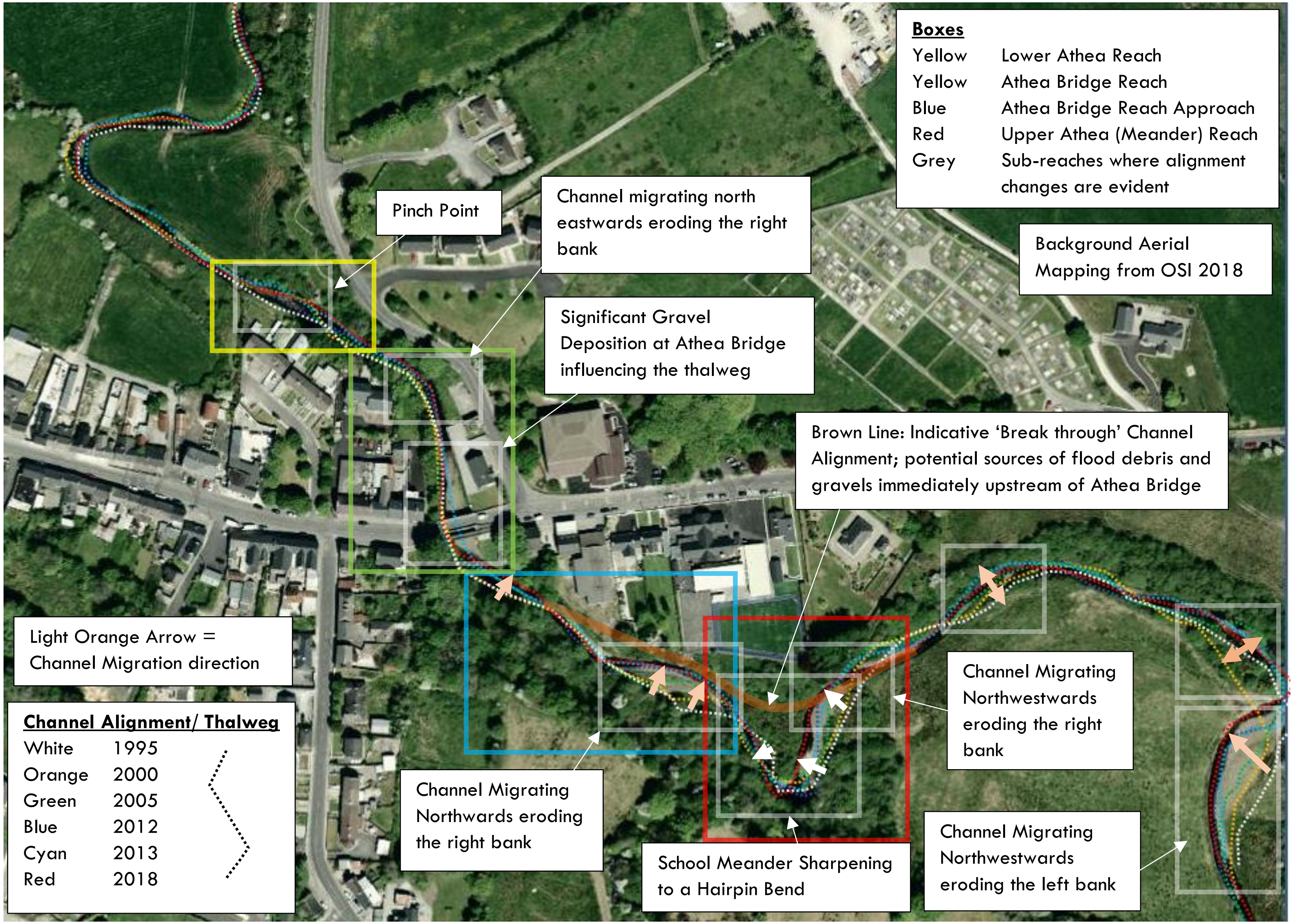


Figure 2-32: Apparent Channel Alignment Changes at Athea (1995 -2018)

Table 2-5: Galey River Alignment Changes at Athea 1995 to 2021

Year	Yellow Box	Green Box	Blue Box	Red Box
1995	In stream Deposition Evident	No Cois na Gaíle and RB DS house. Deposition at Bridge evident	Channel relatively straight	Wide meander large clear deposition area
2000	In stream Deposition and Trees Evident	No Cois na Gaíle RB DS house built. Deposition at Bridge less evident	Channel relatively straight	Wide meander vegetation on deposition area
2005	Elongation of the deposition and narrowing of the channel	Cois na Gaíle RB DS house built. Large Deposition at Bridge evident.	Bend in channel becomes evident moving westward and approach moving northward	Wide meander increased vegetation on deposition area
2012	Deposition and trees not evident. Wider Channel.	Less Deposition at Bridge evident	Bend sharpens and channel moves north ward. School Yard Extended	Approach channel to meander sharpening bend. Vegetation removed.
2013	Like above	Less Deposition at Bridge evident	Like above	Development of a hairpin meander
2018	Increase in Deposition	Large Deposition at Bridge evident	Bend in channel moving westward and approach moving northwards towards school yard	Further progression of hairpin leading to large deposition area on left bank and erosion of right bank deposition.
2021	Significant Deposition not Evident	Trees on left bank removed. Less Deposition at Bridge evident	Further progression westward on the bend.	Hairpin meander tightened significantly.

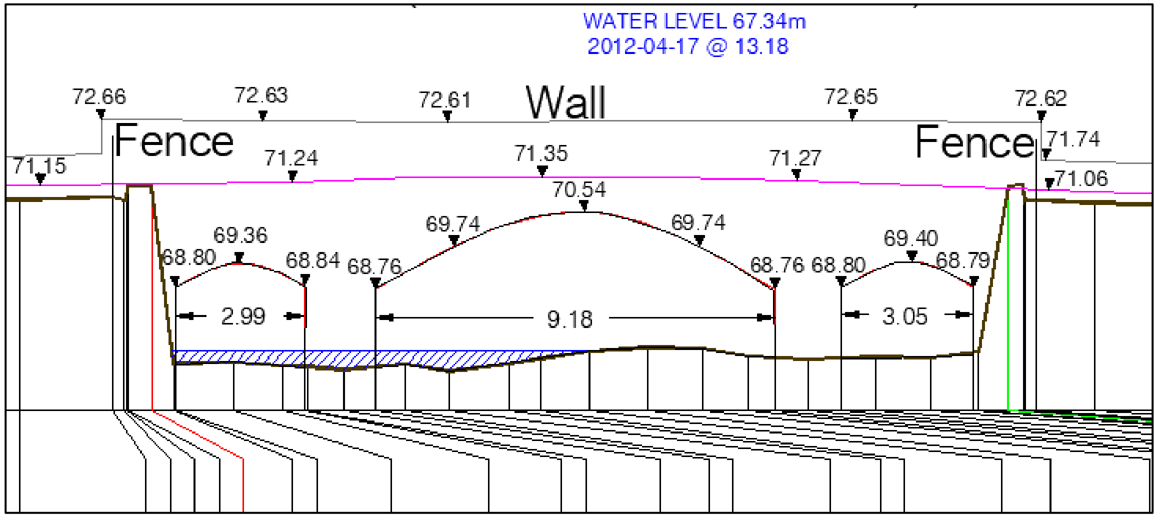


Figure 2-33: Upstream face of Athea Bridge – Survey April 2012.

2.1.7.5 Athea Bridge Aggradation

A comparison of photographic evidence from site walkovers in December 2008, 2019 and again in June and November 2020 by Ryan Hanley demonstrates how the deposition extents at Athea Bridge can change appreciably over short time scales. Table 2-6 presents a comparison of the bridge's effective open area survey in April 2012 and August 2020.

Table 2-6: Athea Bridge Arches Open Areas April 2012 and August 2020

Parameter	LB Arch	Central Arch	RB Arch
Span Width	2.99m	9.18m	3.05
Springing Level	68.8mOD	68.76mOD	68.8mOD
Soffit Level	69.36mOD	70.54mOD	69.4mOD
Invert (2012) and Ope area	67.1mOD, 6.3m^2	66.7 to 67.43mOD, 24.6m^2	67.2mOD, 6.0m^2
Invert (2020) and Ope area	67.1mOD, 6.2m^2	67.1 to 67.7mOD, 21.8m^2	67.25mOD, 5.8m^2
Invert (no gravels etc.)	66.7mOD, 7.4m^2	66.7mOD, 29.1m^2	66.7mOD, 7.5m^2
Pier Widths	1.6m		1.55m
Length	6.75m	6.75m	6.75m
Road Level at bridge	71.15mOD to 71.35mOD to 71.05mOD		
Top of Wall Level	72.66mOD to 72.61mOD (both parapets)		

The total open area has reduced between the April 2012 and August 2020 surveys from 36.9m^2 to 33.8m^2. The estimated clear open area at bridge, based on a channel invert at the bridge of 66.7mOD (i.e. equivalent to the lowest level surveyed in April 2012 and coincidently 1m lower than the highest current gravel level) is estimated at 44.0m^2. Therefore, the area of the bridge openings blocked by gravels in April 2012 and August 2020 was 7.1m^2 (16%) and 10.2m^2 (23%) respectively. The unblocked and partial blocked area at the bridge below 69.4mOD (soffit of small arches, approximate effective flow area during a flood event) is 38.75m^2 and 28.75m^2 respectively (i.e. 26% blockage). Based on a bridge length of 6.75m the volume of gravel currently under the arches is calculated at approximately 70m^3 (i.e. 2020 ope area – No gravel ope area) x 6.75m). 120 dumper loads of gravels were reported by the OPW to have been removed from under the bridge following the 2008 flood events, however, it was reported that within a short period the gravels had re-established to similar levels again.

Figure 2-34: Deposition at impacting on conveyance capacity at Athea Bridge (u/s) - August 2008

Figure 2-35: Central arch during site visit (u/s)- December 2019

Figure 2-36: Upstream face of Athea Bridge (left photo) showing signs of deposition and scouring and, Downstream of Athea Bridge (right photo) – gravel deposition with vegetation – November 2020.

Figure 2-37: Upstream face of Athea Bridge showing signs of deposition– June 2020.

Figure 2-38: Upstream face of Athea March 2021.

Figure 2-39: Gravel Aggradation downstream of Athea Bridge March 2021.

2.1.7.6 Athea Streams

At least six stream tributaries drain from the northern slopes of Knockathea and Knocknalaght hills (located to the south of Athea) to the Galey River along the river reach extending 800m upstream to 1,100m downstream of Athea Bridge. Three of these streams, as shown in Figure 2-40 were identified further to inspection of aerial mapping and site visits, as potential being a source of potential flood risk to Athea Village. These streams were surveyed as part of the CFRAM study in 2012 and referenced as Gal-B, Gal-F & G and Gal-I. For this study, these streams are referred to as Athea East Stream, Athea West Stream (& tributary) and Listowel Road Stream. Only Athea West stream was assessed by CFRAM. The extents of these streams' networks have been mapped based on inspection of the CFRAM survey, a site walkover in November 2020 and review of LIDAR topographical data, and current and historic OSI Mapping and aerial photography. A note describing the streams visited in November 2020 is presented in Appendix B and includes information on culvert sizes and channel conditions.

Figure 2-40 and Figure 2-42 and Table 2-7 presents the estimated Athea Village streams' catchment extents and descriptors. The overall Athea West catchment is shown to include some drainage from urban areas to the west of the Abbeyfeale Road and the drainage along the western extents of Con Colbert Street. A further review of the catchment area immediately upstream of Athea is included in Section 9 Pluvial Flood Risk.

Table 2-7: Athea Streams Catchment Characteristics

Ref	Stream	Area, km^2	MSL, km	Gradient (S1085), m/km	Soil Type
A	Athea West	0.55	1.56	56.4	poorly drained, high run-off rate (WRAP Soil Type 4 or 5). FSU BSISoil approx. 0.33
B		0.40	1.3	58.5	
C	Athea East	1.10	2.28	67.3	
D		0.85	2.04	68.0	
E	Listowel Rd.	0.39	1.69	54.4	

Drainage channels appear to have been excavated historically on the hillside above Athea to divert flows from the natural gradient towards these stream channels, including:

- **Point 1** at the bend in the Athea East stream system it appears that the natural channel was diverted eastwards away from draining directly down into Athea Village via the Athea West Stream. An overgrown earthen bund divides the catchment at this location. The original 'dry' channel bed (now a minor tributary of the Athea West Stream) is clearly evident downstream of the bund.
- **Point 2** during extreme rainfall events there is potential for flows in the open channels in the Athea East Stream catchment, aligned across the hillside gradient, to flood out and discharge overland via the natural gradient and be intercept by the Athea West Stream channels. These additional overland flows could potentially increase flood risk in Athea Village.
- **Point 3** It is also feasible that the Athea West Stream partially drains to the Listowel Road Stream catchment during flood events.

Immediately downstream of Point 1, a 0.9m diameter pipe culvert crosses under a farm access track. If this culvert was to block during a flood event, there is a potential for the stream flows to back-up and flow overland downhill towards existing house developments (Hillside Drive) or to breach over the earthen bund at Point 1 and discharge to the Athea West stream. The Abbeyfeale Road Bridge at Point 4 comprises a single arch structure 2.38m wide and 2.17m high and 8.1m long (See description in Appendix B). Figure 2-41 and Figure 2-43 present photographs at Point 1 and 3.

Table 2-7 summarises the landcover type areas in the two stream catchments:

Table 2-7: Athea Streams Landcover Areas

Catchment	Total, km^2	Pasture, km^2	Peat Bog, km^2	Forestry, km^2	Discontinuous Urban, km^2
Athea West (A)	0.55	0.47 (85%)	0	0	0.08 (15%)
Athea East (C)	1.10	0.65 (59%)	0.19 (17%)	0.26 (24%)	0

The Athea East Stream catchment includes 3 No. wind turbines and associated access road and drainage in its upper area. The stream channel shows significant signs of erosion in particular upstream of Point 1 where bank undermining and erosion is evident, and upstream of Point 4 where the channel is over 5m deep.

The Athea West Stream, which flows northwards through Athea village and crosses under the R523, has been culverted for much of its downstream length as shown in Figure 2-45. The culvert has historically been prone to blockage. A CCTV contract was procured as part of this project to confirm the condition of the culvert and the urban drainage system at Athea. A summary of the CCTV survey is included with the Hydraulic Modelling Report and is discussed in Section 9 Pluvial Flood Risk.

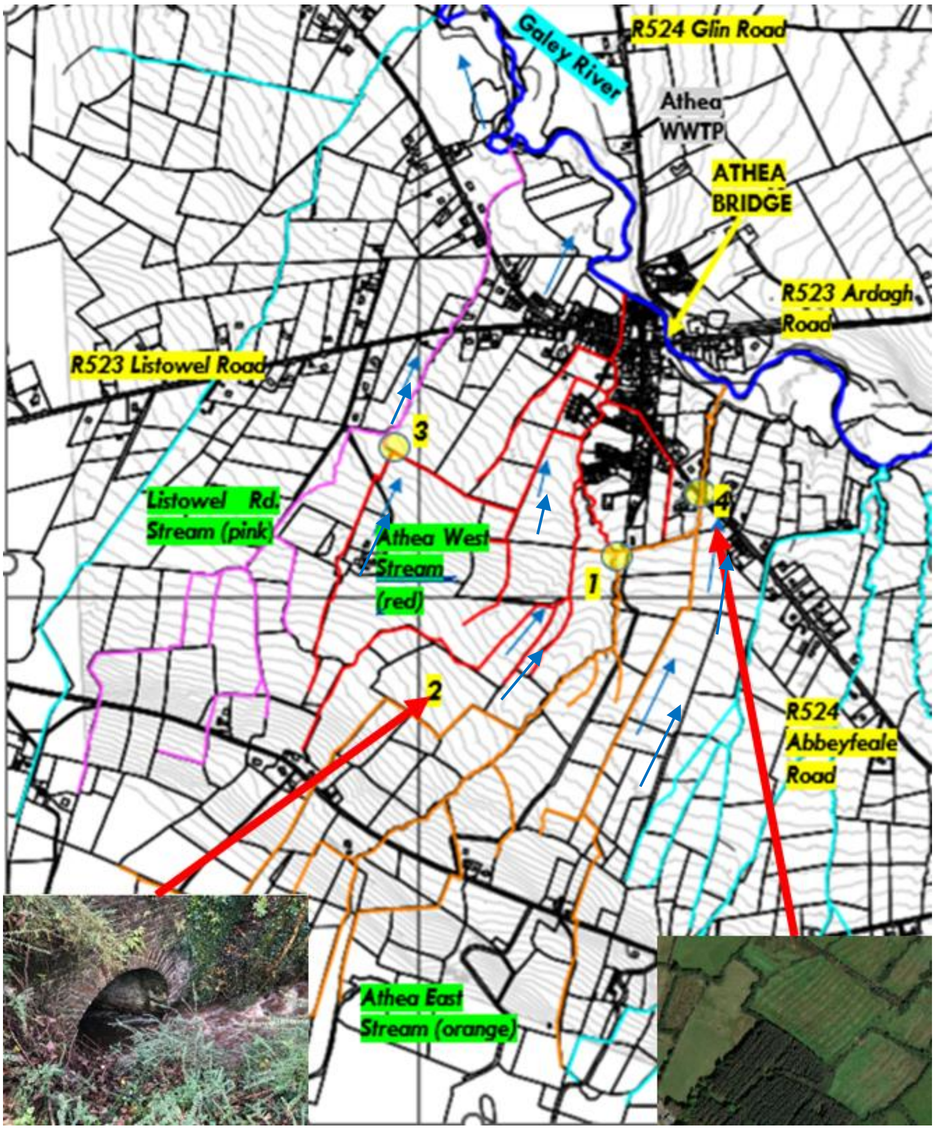


Figure 2-40: Athea Village streams

Figure 2-41: Point 1 Athea East Stream Raised Berm in background (overgrown) and downstream pipe culvert (0.9m diameter)Point D) (November 2020).

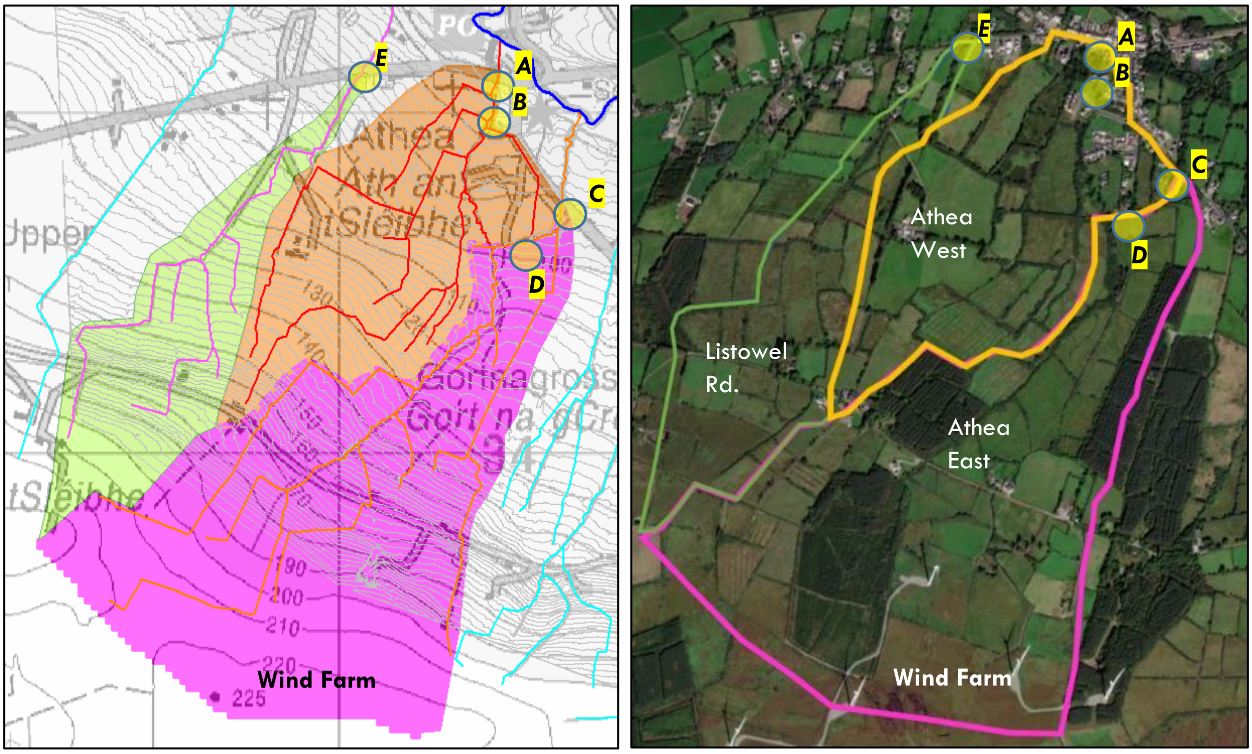


Figure 2-42: Athea Streams Catchment Area

Figure 2-43: Point 3: CFRAM photos 23GALG00083 DN and 23GALH00004 DN

Figure 2-44: (Left and Centre) Athea West Stream Channel at its confluence with Galey River downstream of Point A. (Right) Listowel Road Culvert.

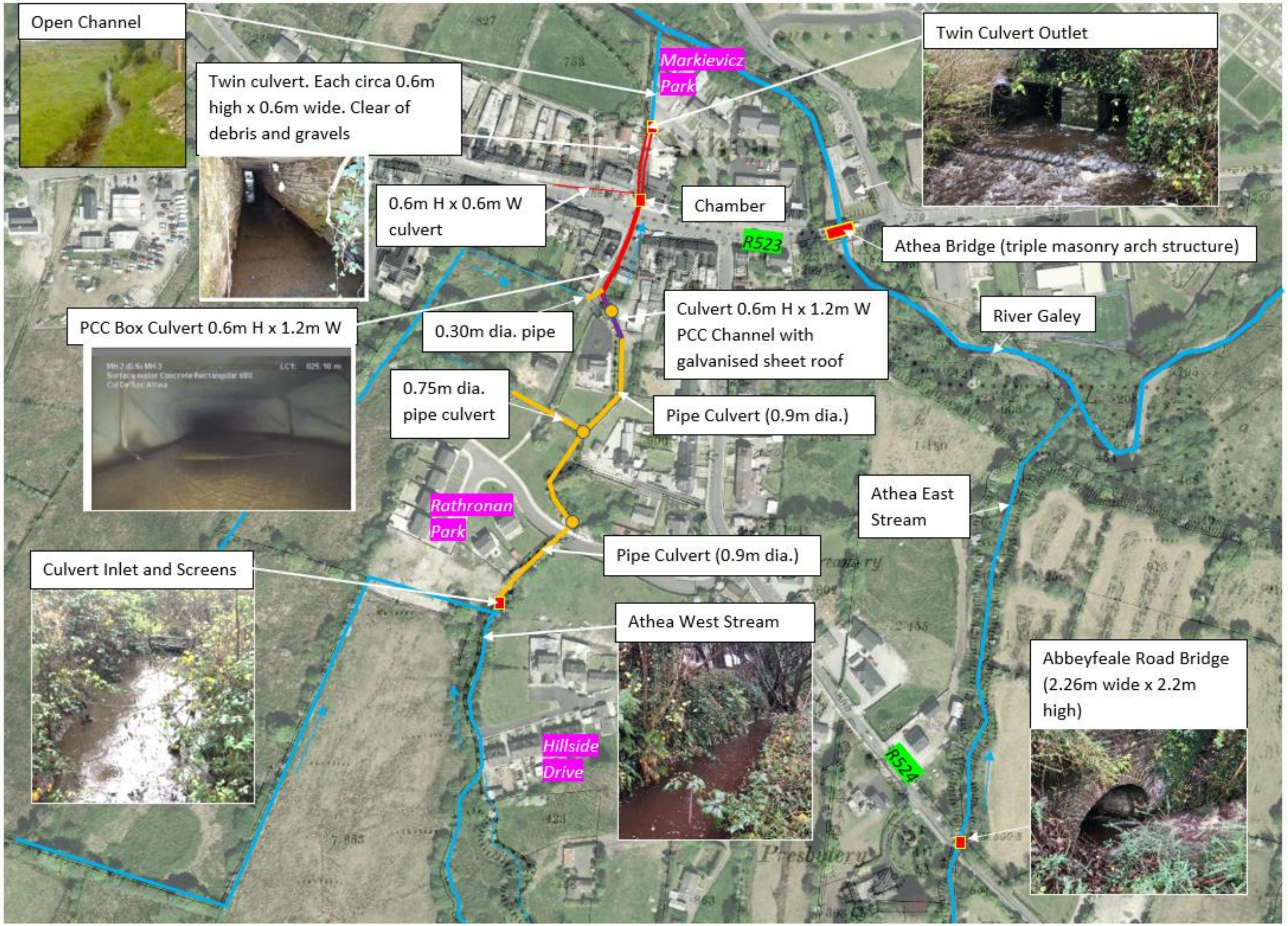


Figure 2-45: Athea West Stream Culvert

3 Hydrological Data

This section of the report sets out:

- Meteorological Data available for the Galey River Inch Bridge and Athea Bridge catchments.
- River Gauge Data available for the Galey River.
- Pluvial and Groundwater Flood Risk Data available for Athea.
- Historical Flood reports for Athea.
- CFRAM Hydrology Summary.

3.1 Meteorological Data

3.1.1 Existing Met Éireann Rain Gauges

There are 5 No. active Met Éireann rain gauges located within or near the Inch Bridge and Athea Bridge catchments boundary, namely:

- Athea (Templeathea);
- Ballyhahill_Glenbawn.
- Newcastle west (Castle Demesne);
- Listowel (Bunaghara).
- Moneypoint (Clare)

The locations of the rain gauges immediately adjacent Athea are shown in Figure 3-1 with a summary of the gauges in Table 3-1.

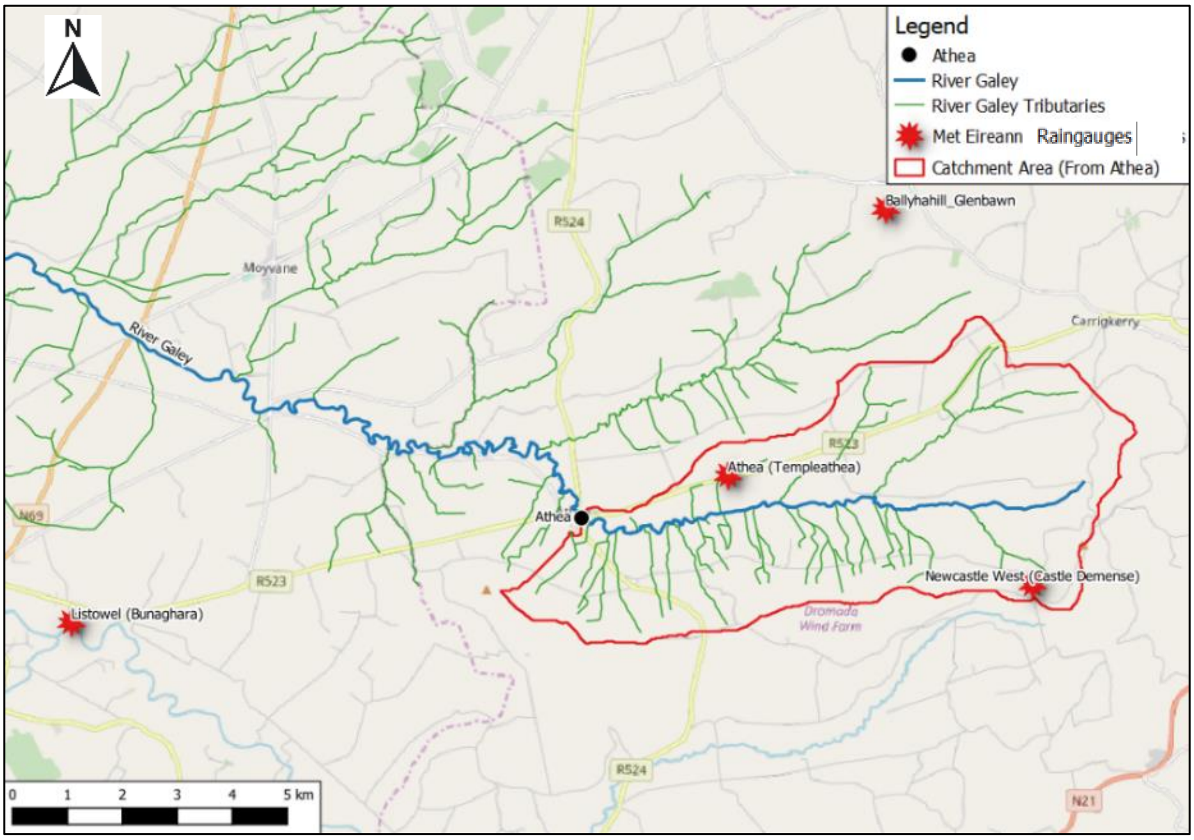


Figure 3-1: Meteorological rain gauges in proximity to catchment

While these rain gauges were not utilised in the Shannon CFRAM study for Athea, the Athea (Templeathea) gauge data was reviewed. The CFRAM review of this rain gauge highlighted that a large portion of data was missing – e.g. 27.3% of days missing between 1st July 1985 and 30th September 2019.

In addition to the above rain gauges, the meteorological data from the Shannon Station has been reviewed as part of this study for Athea to provide indicative rainfall patterns to augment data from the local rain gauges and is discussed further in Section 5.

The Moneypoint rain gauge and Shannon Synoptic Weather Station are located on the Shannon Estuary approximately 19km northwest and 35km north east of Athea (See Figure 1-2).

Table 3-1: Summary of meteorological gauges

Station No.	Name	Station Type	Status	Recordings	Easting	Northing	Start of Record	End of Record
2610	Athea (Templeathea)	Rainfall	Active	Daily	115235	135860	1985	-
5711	Newcastle West (Castle Demesne)	Rainfall	Active	Daily	120775	133870	1992	-
3410	Listowel (Bunaghara)	Rainfall, Air Temp, Grass Temp, 10cm Soil Temp	Active	Daily	103285	133185	2013	-
6311	Ballyhahill_ Glenbawn	Rainfall	Active	Daily	118100	140705	2000	-
5311	Moneypoint	Rainfall	Active	Daily	102800	152000	1986	
518	Shannon Airport	Synoptic Gauge	Active	Hourly	137900	160300	1937	-

The extreme rainfall return period tables for the Athea Bridge and Inch Bridge catchments have been developed using the OPW FSU Depth Duration Frequency (DDF) portal and are included in Section 5.

An analysis of the rainfall data available for the study area is also included in Section 5.

3.1.2 NASA Meteorological Data

To supplement the Met Éireann rainfall dataset, remote sensing rainfall records sourced from NASA (product GPM IMERG final precipitation) at a 30-minute time steps was collected and assessed. This assessment is presented in Section 6 for three past flood events.

The Integrated Multi-satellitE Retrievals for GPM (IMERG) algorithm combines information from the GPM satellite constellation to estimate precipitation over the majority of the Earth's surface. This remote dataset is particularly valuable for the areas of the Earth's surface that lacks precipitation-measuring instruments on the ground.

Due to absence of reliable rainfall gauge data in the study area, it is proposed to use the NASA sub-hourly rainfall data presented above, together with the Met Éireann rainfall data, to develop hyetographs for historical extreme flood events at Athea which in turn will be used to estimate peak pluvial and fluvial flows.

3.2 Available River Gauge Data

3.2.1 River Gauges

There are 3 No. active recorder river gauges on the Galey River, as shown in Figure 3-2, at Inch Bridge (23001), Athea U/S (23052) and Athea D/S (23051). There are two inactive staff gauges in the catchment at Station No. 23004 (Galey Bridge) and Station No. 23014 (Athea). Table 3-2 summarises the gauges within the catchment area.

Table 3-2: Summary River Gauges

Station No.	Name	Station Type	Catchment Area (km²)	Status	Co-ordinates	Record	Gaugings
23001	Inch Bridge	Water level. Realtime Data available. Recorder	191.7	Active	E95729, N136181	1949 to 1959 Pre-Arterial Drainage Scheme and 1960 to present post- arterial drainage scheme. Flow gaugings available since 1972	134 No., 1972 - 2017
23004	Galey Bridge	Water level. Staff gauge	124.1	Inactive	E104397, N138385	1944-1969	None
23014	Athea	Water level. Staff gauge	36.0	Inactive	E112498, N135418	1978-2011	111 No. 1977 - 2011
23051	Athea D/S	Water level. Realtime Data available. Recorder	36.0	Active	E112613, N135129	April 2021 onwards	None
23052	Athea U/S	Water level. Realtime Data available. Recorder	36.0	Active	E112627, N135051	April 2021 onwards	None

3.2.1.1 Galey Bridge (23004)

From the review of hydrometric data provided for Galey Bridge gauge, only stage gaugings were recorded between 1944 and 1968 and no flow measurements were available. This information cannot be practically used to augment this hydrological assessment.

3.2.1.2 Athea Bridge (23014)

A similar review has been completed for Athea Bridge gauge. The gauge was maintained by the EPA and the data collected comprised spot flow measurements only. No continuous water level or flow records are available. A total of 111 No. readings were recorded between September 1977 and July 2011. The peak flow recorded was 8.7m³/s (9th September 1993). There was insufficient data collected to allow a meaningful extreme flow statistical analysis to be undertaken.

3.2.1.3 Athea D/S and U/S (23051 and 23052)

The Athea U/S and Athea D/S gauges, which are located immediately upstream and downstream of Athea Bridge, were installed and became operational in April 2021. These gauges have been installed to allow the flood stage hydrograph at Athea Bridge to be recorded and to determine the flood afflux due to Athea Bridge and the dynamic gravel deposition at the bridge. There is no flow gauge record available for the site. The gauge datum has been surveyed at these gauges by the OPW hydrometrics team.

The links to the gauges real-time water level data are available at https://waterlevel.ie/0000023051/0001/ and https://www.epa.ie/hydronet/#23052.

There is insufficient gauge data available to date (July 2022) available which would directly inform this hydrological study.

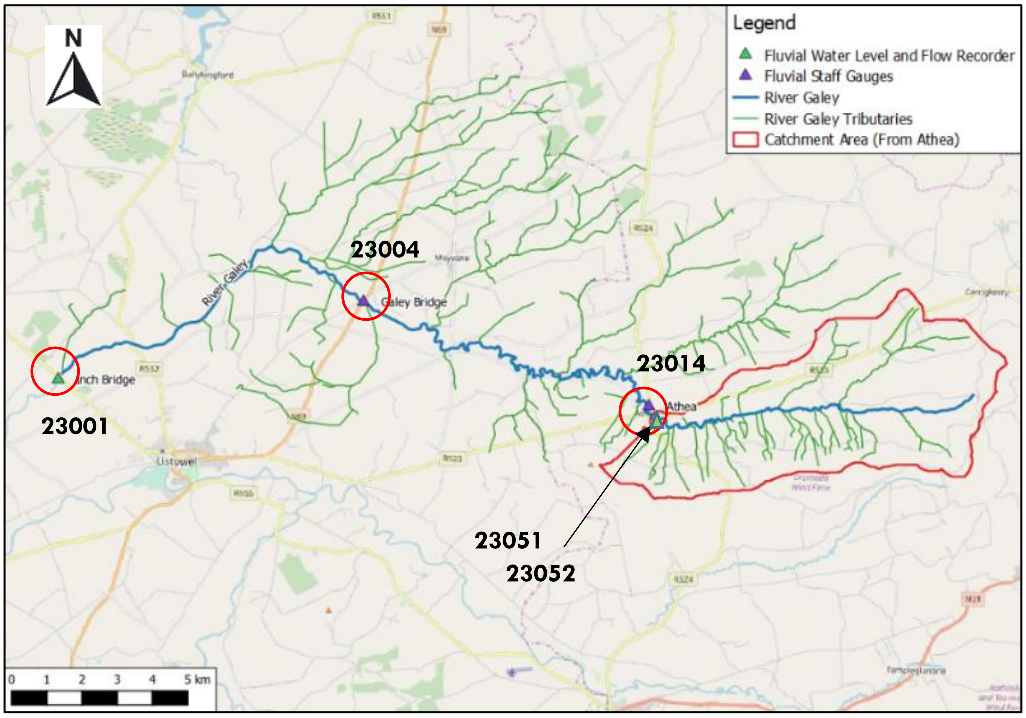


Figure 3-2: Fluvial gauge locations

3.2.1.4 Inch Bridge (23001)

The only active, continuous recording gauge on the Galey River is located on the left bank upstream on Inch Bridge of the R553 Listowel to Ballybunion regional road. Figure 3-3 and Figure 3-4 shows photographs of the Inch Bridge gauge.

There has been a continuous record at this gauge since 1949. The River Feale Arterial Drainage Scheme was completed in 1959. Water level (stage) data is available at this gauge since 1960 (60 years). Flow gaugings data (134 No. gaugings), gauge zero data, and rating curve data is available since 1972. There are no flow gaugings available prior to 1960. Annual Maxima data is available for the gauge from 1960 onwards. No rating review was conducted for this gauge by the CFRAM study other than a check of the November 1997, January 1998 and March 1998 gaugings. It was noted in the CFRAM as being the only appropriate station for flood estimation within the Galey River study area. Station 23001 Inch Bridge has a reported quality rating of A2.

A full rating review has been undertaken for Inch Bridge gauge is Section 6 of this report.

Figure 3-3: View of Inch Bridge gauge

Figure 3-4: Staff gauge at Inch Bridge

3.3 Available Pluvial Flood Risk Data

The current OPW Preliminary Flood Risk Assessment (PFRA) mapping did not identify a pluvial flood risk at Athea.

There is known pluvial flood risk associated with the blockage and the capacity of the existing 'Athea West Stream' culvert which crosses the R523 and the potential pluvial flood risk to low-lying buildings in the village arising from road and hillside run-off. There has been one recorded significant pluvial event in recent years which is discussed Section 3.5. A pluvial flood risk assessment based on a site walkover and assessment of historical extreme rainfall events is included in Section 9 below which is used to inform the project's hydraulic analysis.

3.4 Available Groundwater Flood Risk Data

A review of the GSI groundwater flood risk mapping confirms that there is no groundwater flood risk at Athea. No groundwater features of note have been identified in the study area. (See Section 2.1.5.4).

3.5 Historical Flood Reports

Five significant flood events have been reported at Athea in recent years, as follows:

- April 2005;
- 31st July – 1st August 2008;
- 6th August 2008;
- 2nd September 2009; and
- 11th September 2015.

The 6 No. highest floods on record on the Galey River, based on a review of the Inch Bridge gauge AMAX stage series, occurred in:

- December 1973
- December 1962
- February 1995
- 3 No. January 2005, December 1968 and November 2009 (almost the same peak level for the three events)

There is no information available regarding the flood impact at Athea Village during the above 6 No. flood events. There were no floods of note recorded at Athea Bridge through the remainder of the 1970s and through the entire 1980s. A significant flood event was recorded on the River Feale at Listowel on the 11th August 1986 but there is no reports of flooding at Athea Village associated with this event.

The estimated return periods of these flood events are discussed, relative to rainfall, in Section 5 and in Section 7, following the Inch Bridge gauge rating curve review which is presented in Section 6. The magnitudes of the above flood event, based on the Inch bridge gauge, is discussed in brief below and again in Section 7.

3.5.1 2005 Flood events

3.5.1.1 January 2005

A significant flood, 4th highest on record, was recorded on the 8th January 2005 at Inch Bridge when a water level of 2.935m (10.06mOD Malin) was recorded at the gauge. There are no flood reports for this event at Athea. The total daily rainfall depths on the 6th to 8th January 2005 at Athea rain gauge were recorded at 39.5mm, 25.1mm and 4.2mm respectively.

3.5.1.2 April 2005

There is little information available on the reported April 2005 flood event. Floodinfo.ie presents a map from Limerick County Fire Service, which highlights areas affected by flooding and the type of flooding that occurred throughout Co. Limerick. Heavy rainfall was the reported reason for the flood event at Athea. The FRMP for UoM 23 states that the area adjacent to Athea Bridge and one residential property flooded (no further information available). The peak water level on the staff gauge at Inch bridge in April 2005 was recorded at 1.2m (8.34mOD Malin) on the 2nd April. The highest recorded daily rainfall total recorded at Athea in April 2005 was on the 5th and 6th April when 18.9mm and 12.3mm total rainfall were recorded. It is likely the April 2005 report refers to the January 2005 event.

3.5.2 2008 Flood Events

3.5.2.1 31st July/ 1st August 2008

Between 31st of July and 1st of August 2008, a severe localised rainfall event took occurred in the upper Galey River catchment at Athea when 63.3mm and 8.6mm (daily totals) were recorded at Athea rain gauge on the 31st July and 1st August. The upstream catchment was likely saturated and river flows already elevated before this event due to heavy rainfall on the on the 27th and 28th July (17.2mm and 22.9mm total daily rainfall depth respectively). Based on a review of the *Athea Flood Severity and Impact Report* by JBA Consulting Engineers and topographical surveying carried out for this study it is concluded that during the flood event that:

- Flood levels peaked at Athea Bridge around midnight.
- The peak flood level at Athea Bridge was approximately 0.3m below the soffit of the central arch (Note: this equates to a peak level of **70.24mOD).**
- The peak flood level at Bridge House (downstream of the bridge on the left bank) was approximately 1.1m above the basement floor level which equates to approximately **69.78mOD**. (Note: the peak flood at the property on the 6th August reached 69.28mOD).
- The peak flood level at the houses at Cois na Gaíle exceeded **69.1mOD**.
- There was localised flooding of the R523 to the east of Athea Bridge and it was temporarily impassable. (Note: The road becomes flooded when upstream flood levels exceed 70.1mOD.)
- The flood levels are reported to have risen rapidly for a period of 25 minutes from about 11:20pm onwards on the 31st July and to have receded appreciable by the next morning (1st August).
- 21 No. properties (JBA, Oct 2008) were reported to have flooded or impacted by flooding including:
  - the two houses immediately downstream of Athea Bridge, the Gables pub, 4 No. houses at Cois na Gaíle and 8 No. houses at Markievicz Park.
  - Right bank upstream of Athea Bridge including 5 No. houses, 1 No. office (note: approximate flood level <70.27mOD) and dancehall (note: reported approximate flood waters level of c**70.3mOD**).
- Athea National School yard flooded (flood level of >70.4mOD). The Limerick Leader newspaper reported that *"The school and schoolyard were flooded in the summer of 2008, when Newcastle West and Athea were among the worst areas affected by flooding in West Limerick. The house, next door to the school was also badly affected by that flood, with water coming up the long garden and covering the ground floor to the height of two to three steps of the stairs. The family had to evacuate the house for three months."*
- The Athea Wastewater Treatment Plant (WWTP) was impacted during the flood event. (note: the JBA reported that the WWTP site flooded, which would imply a flood level of circa 68mOD at the plant).
- Flow conveyance in the river channel was reported to have been reduced due to flood debris and gravel accumulations at Athea Bridge, and due to flood debris, overgrowth and vegetation along the channel downstream of the bridge into addition to large accumulation of gravel behind Markievicz Park.
- The associated extreme rainfall event had an estimated return period > 250years.

Figure 3- shows the properties impacted by the flood event between the 31st of July and 1st of August 2008. The water level at Inch Bridge gauge peaked at 2.72m (9.85mOD Malin) on the 01/08/2008, the 9th highest on record.

Based on the information provided, a preliminary estimate of the peak flood flow during the event, for indicative purposes only, has been carried out here.

- The flow area under the bridge at the peak of the flood event has been estimated at approximately 35m^2 (based on a flood level of 70.15mOD under the bridge.
- The flood level difference across the bridge was of the order of 0.30m to 0.4m (70.2mOD to 69.8-69.9mOD).
- Based on a flow of velocity of say 1.8 - 2.1m/s, the discharge rate under the bridge would have been of the order of 63.0 to 73.5m^3/s.
- The overflow depth across the R523 did not likely exceed 0.2m and the flow width was of the order of 12m (road width), giving an approximate flow area of 1.8m^2. If the road overflow velocity was, say, 0.5 to 1.0m/s, the peak flow across the R523 was of the order of <1.5m^3/s.
- Therefore, as a preliminary estimate, the peak flow, on the 1st August 2008 event at Athea Bridge was of the order of 64.5 to 75m^3/s.

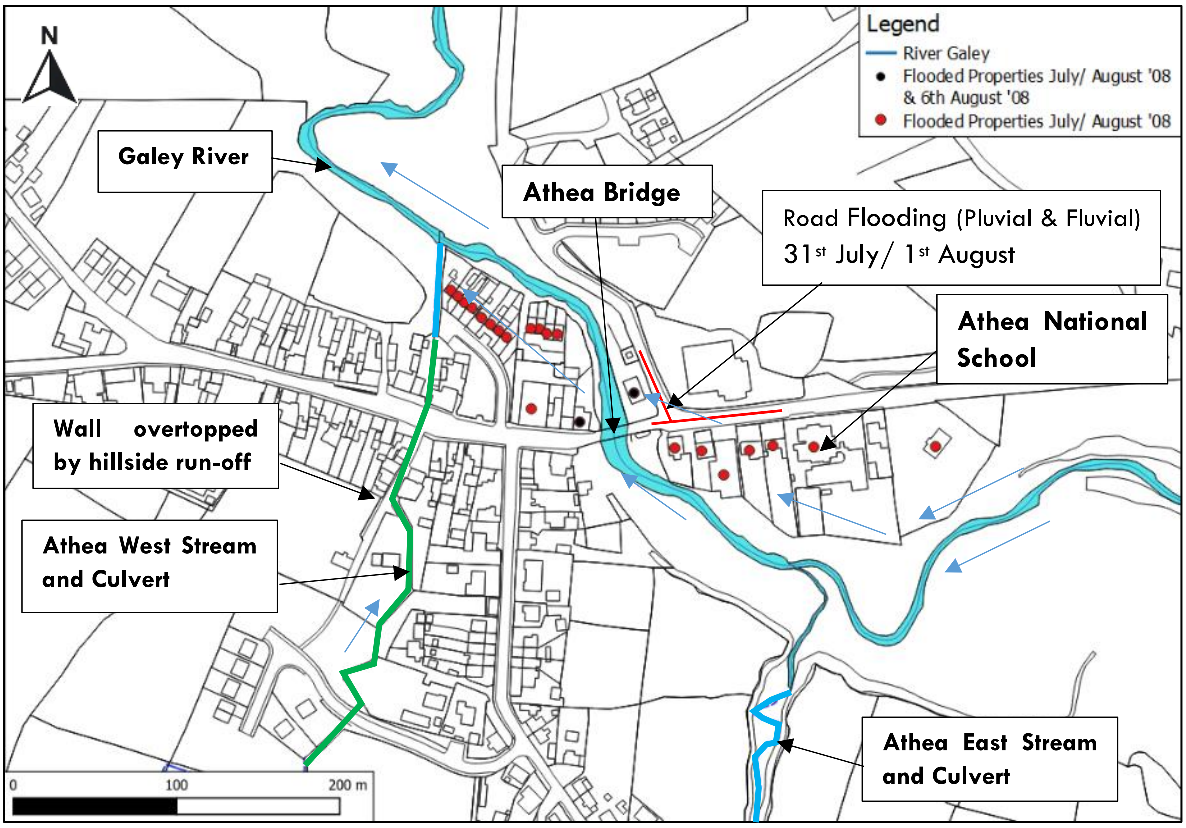


Figure 3-5: Impacted properties during the 31st July / 1st August and 6th August 2008 flood events

Figure 3-5A: Flooding on the Ardagh Road near the school the 31st July / 1st August 2008

3.5.2.2 6th August 2008

On the 6th of August 2008, a second localised flood event occurred in Athea due to intense rainfall (53mm rainfall recorded at Athea). In the *CFRAM Inception Report (UoM 23)*, it was noted that the rainfall was less intense than that of the 31st of July/1st of August 2008. However, due to deposition and debris, the capacity at Athea bridge was greatly reduced and the river overtopped its banks and flooded 2 No. properties, as shown in Figure 3-5 above. On the 6th August 2008 Shannon rain gauge reported a record hourly rainfall total of 38mm between 5pm and 6pm. If a similar rainfall event occurred in the Athea catchment, it would likely have resulted in a significant spate flood event. The water level at Inch Bridge staff gauge peaked at 2.10m (9.22mOD Malin) at around 2am on the 7th August 2008 which further suggests that the rainfall event and flood event was localised to the Athea Bridge catchment.

3.5.3 2009 Flood Events

3.5.3.1 2nd September 2009

On the 2nd of September 2009, a heavy rainfall event (daily total 26mm to 32mm rainfall) was recorded at the catchment rain gauges. Locals reported that the days preceding the event had been 'very wet' and that the rainfall on the 2nd September 2009 was intense. The Shannon rain-gauge reported rainfall intensities of up to 7.7mm/hr on the morning of the event. A major blockage to the 'Athea West Stream' culvert located between Rathronan housing estate and Markievicz Park housing estate, was reported to have occurred within the culvert at the inlet to the twin culverts downstream of Con Colbert Street. This major blockage caused surcharging of the culvert and overland flows downhill towards Con Colbert Street (R523). 6 No. properties were flooded, and roads and other property damaged. Local Authority (LA) staff resolved the issue by removing the blockage. This culvert has since been upgraded (see Figure 2-27 above and the CCTV survey report included with the Athea FRS Hydraulics Report). The inlet screens to the culvert were visited during November 2020 (refer also to Appendix B) were noted as being substantially blinded with debris and vegetation and to be overgrown.

Figure 3-6 shows the flooding and road damage as a result of the 2nd September 2009 rainfall event and blocked culvert at Athea and Figure 3-6shows a map of the 6 No. affected properties. In summary, the localised flood event appears to have been due to blockage in the culvert coinciding with a moderately intense rainfall event.

The water level on the Inch Bridge staff gauge peaked at 2.26m (9.39mOD Malin) at 8:15pm on the 2nd September 2009.

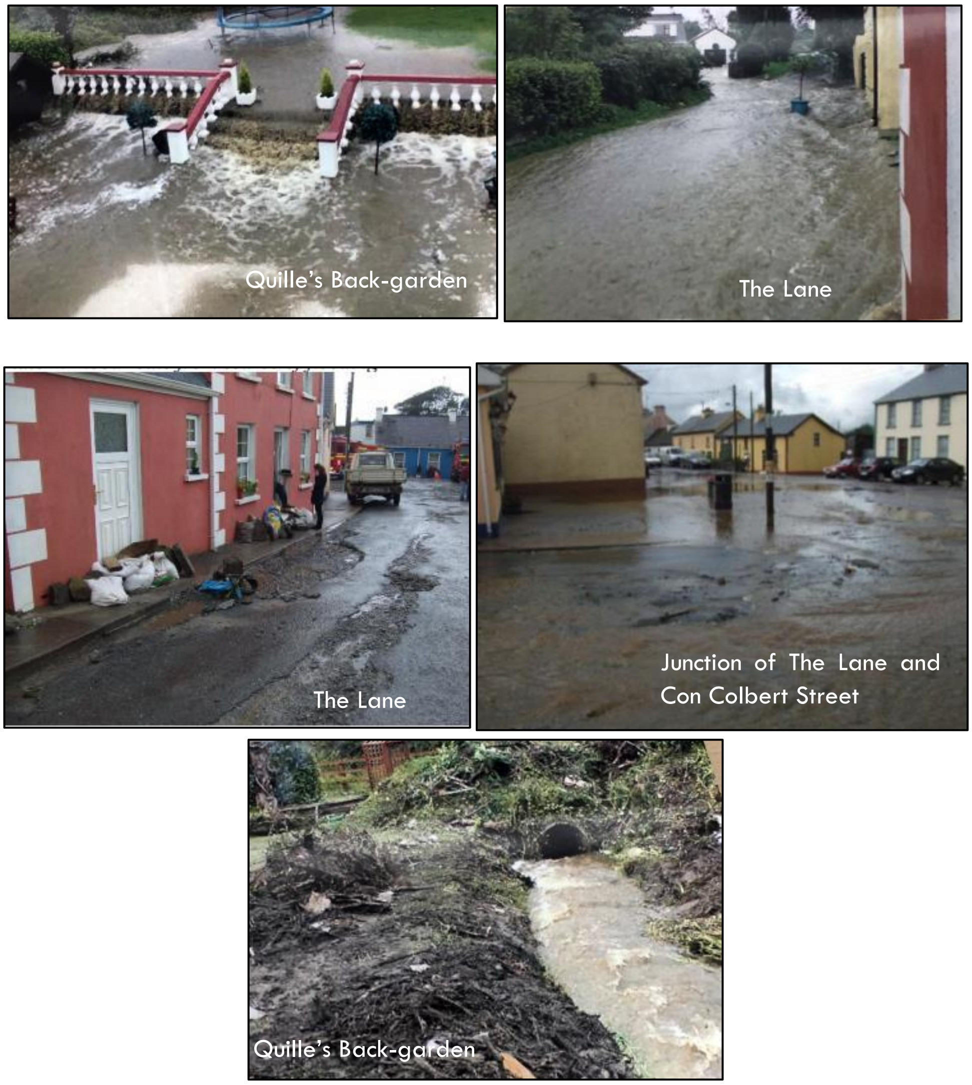


Figure 3-6: Flooding and flood damage at Quille's, The Lane and Con Colbert Street, Athea, 2nd September 2009

Figure 3-7: Wall at The Lane which is reported to be overtopped followings periods of heavy rainfall.

3.5.3.2 November 2009

There are no reports of flood damage associated with an extremely wet period recorded at Athea between 29th October and 26th November 2009 [Total rainfall depth for the 27days = 310-350mm]. On the 18th November 2009 alone over 47mm rainfall was recorded at the Athea rain gauge while only 16.7mm was recorded at Shannon. The water level at Inch Bridge staff gauge peaked at 2.92m (10.05mOD Malin) on the 19th November 2009.

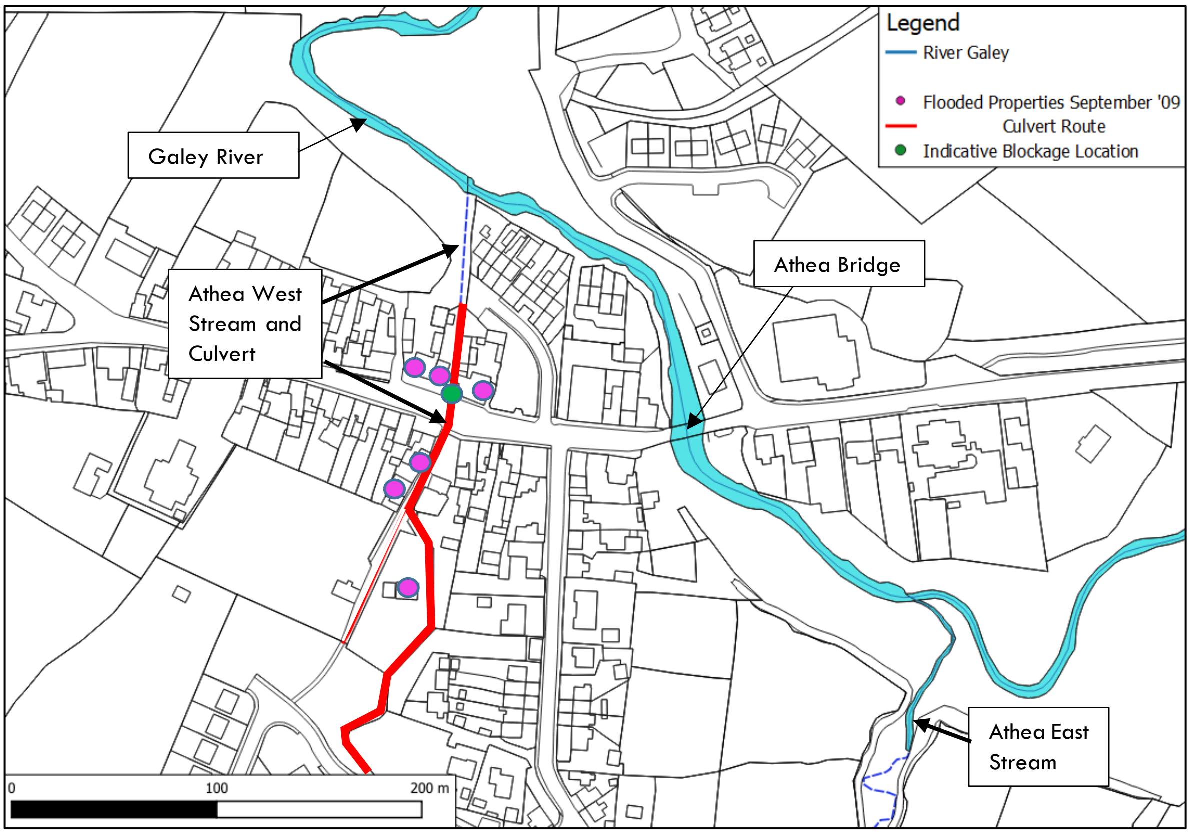


Figure 3-8: Properties flooded during the 2nd September 2009 flood event

3.5.4 2015 Flood Event

3.5.4.1 September 2015

On the 11th of September 2015, a flood event occurred in Athea due to intense rainfall event in the upper Galey catchment (47.6mm the 6th highest on record at Athea (Templeathea) rain gauge). At the peak of the flood, the river was reported (in the Limerick Leader newspaper) to have been 0.1m below the soffit of the right bank arch (note: flood level of circa **69.3mOD** or circa 1m lower than the Jul/Aug 2008 peak flood level) at Athea Bridge, while at least 2 No. properties are likely to have flooded (properties on the left and bank downstream of the bridge to a depth of <0.6m). The estimated flow area under the bridge at the peak of the event is estimated at 29.5 - 30m^2. Based on a flood flow velocity of 1.5m/s, the peak flood flow would have been of the order of 44.3 to 45m^3/s.

Figure 3-9 and Figure 3-10 present photographs taken from the September 2015 event. Two days after a further heavy rainfall event was recorded (34.6mm on the 13th September). There is no record of flooding associated with this second rainfall event.

Figure 3-9: Flood waters directly upstream of Athea Bridge September 2015

Figure 3-10: Flood waters downstream of Athea Bridge (looking upstream at Athea Bridge) September 2015

The highest water level at the Inch Bridge staff gauge was recorded at 2am on the 12th September at 2.67m (9.8mOD Malin), the 11th highest on record.

3.5.5 Summary

The following table presents a preliminary summary of historic flood levels, daily rainfall totals and properties flooded described above. A more detailed summary will be included in the Hydraulic Modelling Report.

Table 3-3: Recent Past Flood Events data

Flood Event	Cause	Maximum Flood Level, mOD	Daily Rainfall Depth Totals, mm	Number of Properties Impacted
6th January 2005 (reported in April 05)	Heavy Rainfall	No info.	39.5mm, 25.1mm on 6th and 7th January	1
31st July/ 1st August 2008	Extreme Rainfall over a short duration, channel and bridge blockages	70.24mOD and 69.78mOD u/s and d/s of Athea Bridge, flood level difference across the bridge of circa 0.4m.	63.3mm on 31st July	21
6th August 2008	Extreme Rainfall over a short duration, channel blockage	69.28mOD d/s of Athea Bridge	53mm	2
2nd September 2009	Blockage of Athea West Culvert and moderate rainfall event	Overland flow	c30mm	6
19th November 2009	Extreme Rainfall Event	No info.	47mm	None reported
11th September 2015	Extreme Rainfall Event	69.3mOD u/s of bridge	47.6mm	2

3.6 Design Hydrology

The OPW's consultant for the Shannon CFRAM study, Jacobs, focussed on the use of gauged flow data supplemented by FSU techniques, where no flow data was available. The design hydrology approach (Jacobs- CFRAM) is summarised as follows:

1. Gauging station reviews undertaken (noted as being critical in providing reliable information to be used as pivotal sites for hydrological adjustments of ungauged sites flood estimates);
2. Updating of the AMAX series gauging stations;
3. Estimation of the median of annual maxima flows (Qmed) for gauging stations and then comparison of it to the associated Qmed calculated using the FSU regression equation to obtain an appropriate Qmed adjustment factor;
4. Estimation of Qmed at all ungauged HEPs using the FSU regression equation and the adjustment factor;
5. Production of flood frequency estimates for the gauged data to calculate a range of annual exceedance probability (AEP) peak flows and in turn determine the growth factors by pooling group and single site analysis;
6. Estimation of the hydrograph shape;
7. Estimation of the design flood hydrographs at each HEP;
8. Calibration of the design hydrology through hydraulic modelling.

The following sections detail the hydrological methods that had been undertaken in the CFRAM study only for the Athea AFA.

3.6.1 CFRAM Qmed Estimation

At a gauged site, Qmed can be determined from the annual maximum (AMAX) flow series. At ungauged sites, Qmed can be estimated using the OPW FSU regression equation which is based on 7-catchment descriptors. Where there is no gauged data, confidence intervals can be applied to the calculation. Qmed estimates can be improved by adopting a pivotal station, whether in the same or neighbouring catchment or in a hydrologically similar catchment.

The CFRAM study determined the Qmed estimate and Qmed adjustment factors at the available flow gauging stations in each catchment in UoM 23. Table 3-4 presents the CFRAM Qmed estimate and adjustment factor from the Inch Bridge gauge on the Galey River. The table specifies, for the gauging station, the Qmed estimate based on AMAX data and a synthetic estimate based on the FSU regression equation including an urban adjustment (refer to FSU Work Package 2.3). The Qmed adjustment factor is calculated by dividing the observed Qmed divided by the synthetic Qmed. The AMAX series from 1961 to 2009 were used by CFRAM to estimate the observed Qmed for Inch Bridge gauge.

Table 3-4: CFRAM Qmed & Qmed adjustment factors

Reach	Gauging Station No.	Qmed Observed (m^3/s)	Qmed (urban) Synthetic (m^3/s)	Adjustment Factor (-)	Justification
Galey	23001	103.5	66.5	1.56	Station 23001 is the only gauge within the reach suitable for flood estimation. The station has an A2 FSU classification, with check gaugings up to 1.1* QMED. The adjustment factor was applied at all HEPs within the Athea model.

3.6.2 CFRAM Flood Growth Curves

In the CFRAM study, the Inch Bridge gauge was identified as being suitable for flood frequency analysis and flood growth curves were determined, analysed and plotted against each other (see Figure 3-11). The AMAX series was plotted against an EV1 based distribution-based frequency curve adopted to the AMAX data and three frequency curves, based on pooling group results, plotted against the reduced variate and an Annual Exceedance Probability (AEP) scale.

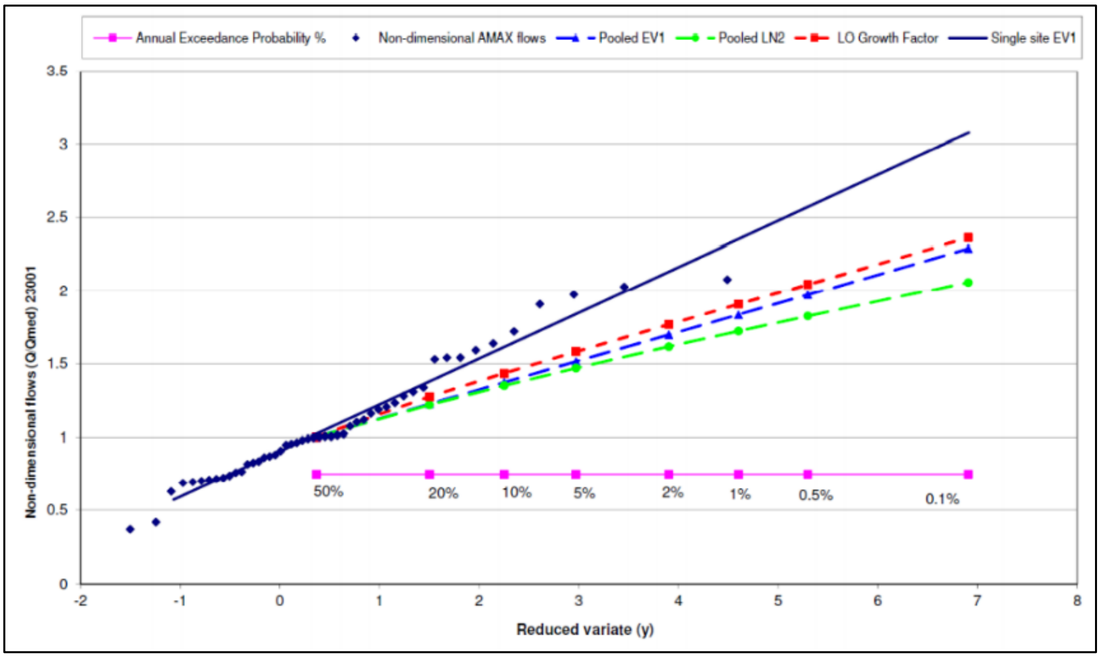


Figure 3-11: CFRAM Flood Frequency Curves for Inch Bridge gauge

A review of pooled versus single site growth curves was undertaken by CFRAM for Inch Bridge gauge and it was determined that a single site EV1 distribution was most suitable. The CFRAM Growth factors (relative to Qmed) for this gauge are shown in Table 3-5.

Table 3-5: CFRAM Growth factors applied to Galey River from Inch Bridge gauge

Annual Exceedance Probability (AEP) %	Growth Factors for Galey reach
50%	1.00
20%	1.38
10%	1.61
5%	1.84
2%	2.13
1%	2.35
0.5%	2.57
0.1%	3.08

A review of the growth factors to be used for this study is included in Section 7.

3.6.3 CFRAM Hydrograph Shapes

For gauged river reaches, gauged data of past events was used to determine hydrographs shapes. In reaches where no gauged data was available, an appropriate hydrograph shape was selected from a gauged pivotal site.

The CFRAM study determined one hydrograph shape for the entire Galey River reach and this was derived from observed events at Inch Bridge gauge in the lower reaches of the catchment. Figure 3-5 presents the peak flood non-dimensional hydrograph shapes at Inch Bridge used by CFRAM study in development of the hydrograph for the Galey River. The CFRAM study derived a synthetic hydrograph shape, as shown in Figure 3-6, for the Athea West stream.

The hydrographs shapes were applied with peak flows at the required HEPs throughout the Athea hydraulic model by the CFRAM study.

An assessment of the design hydrographs for this study is included in Section 10.

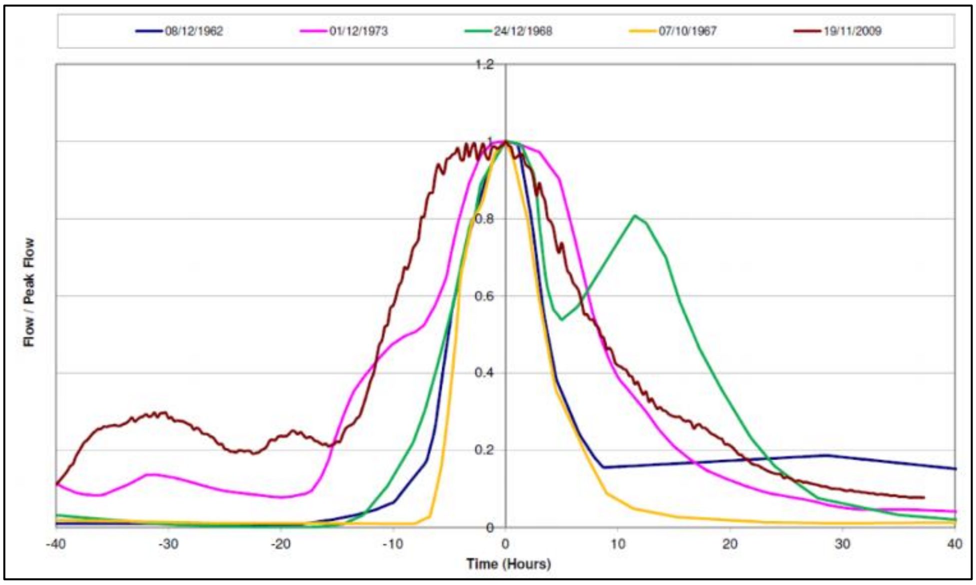


Figure 3-5: CFRAM Non-dimensional hydrograph shape for the Galey River (Inch Bridge gauge)

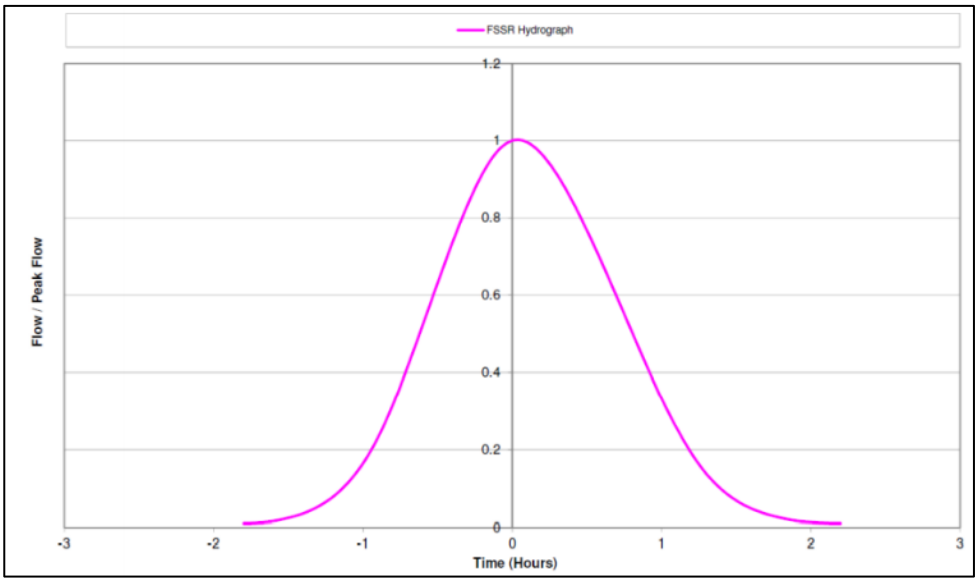


Figure 3-6: CFRAM Non-dimensional (unit hydrograph) FSSR hydrograph shape for the Athea West Stream

3.6.4 CFRAM Hydrological Estimation Points

HEPs are points at intervals along a watercourse at which flow estimates are derived, based on PCDs. These flow estimates are used to calibrate hydraulic models to ensure that flow is represented along the watercourse.

HEPs and target design flows estimates (FSU derived) for return periods up to 0.1% AEP were determined as part of the *CFRAM Hydrology Report (UoM 23)* for the Galey River and Athea West Stream" in Athea. The CFRAM HEP locations are presented in Figure 3-7 and in Appendix D.

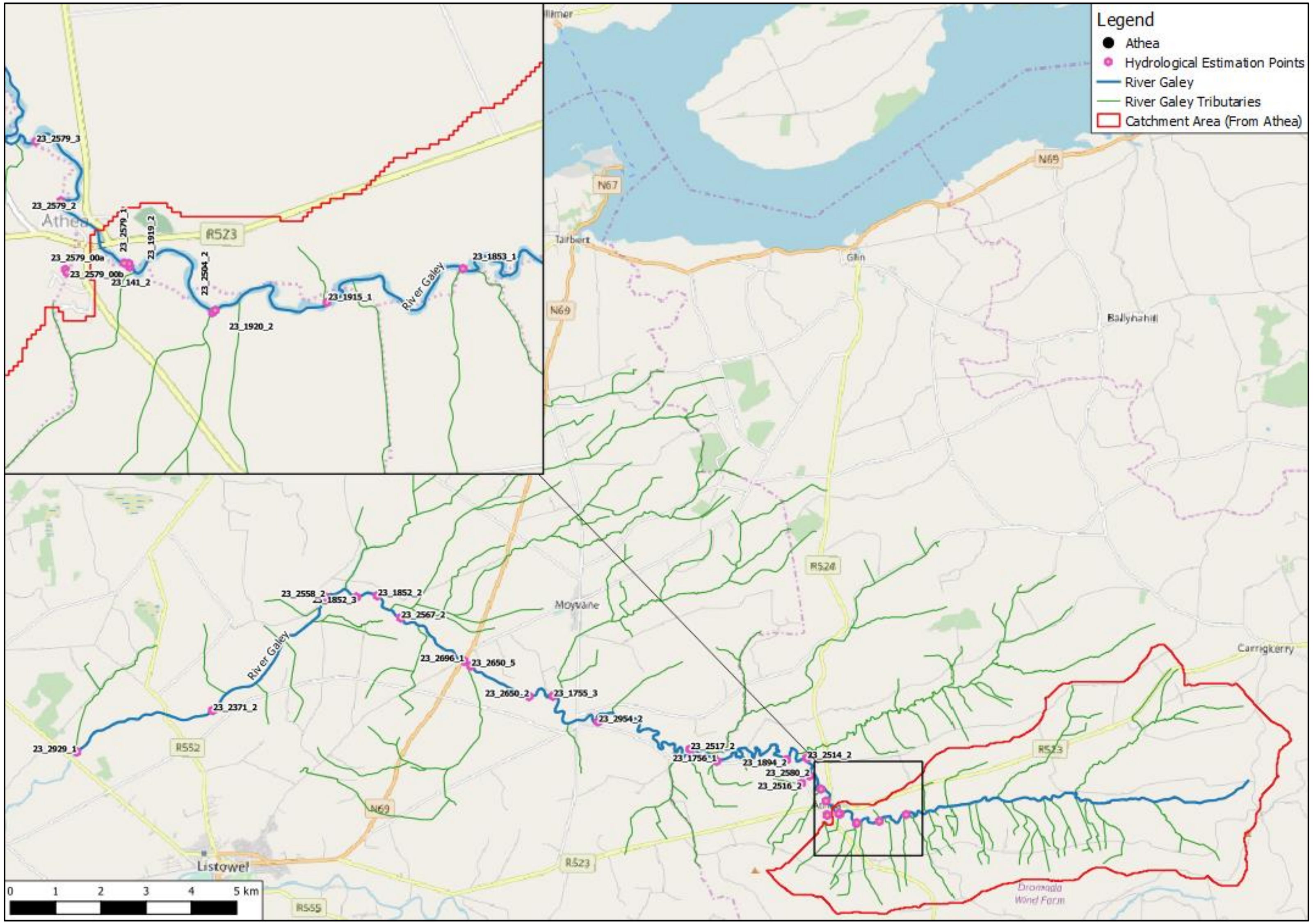


Figure 3-7: CFRAM HEPs

4 Method Statement

This section of the report sets out the approach/ method followed by this study for Athea FRS to assess the hydrology of the study area and is predominantly based on assessments of the catchment characteristics, the available river and rainfall gauges' data, surveys, site-walkovers and past CFRAM studies and the needs of the study, as set out below.

4.1 Needs of the Study

The project brief called for:

- the review of all available documents and information pertaining to the hydrological assessment undertaken as part of the *Tralee Bay - Feale River Basin (UOM23) CFRAM study* and the resulting flow data. This was completed in Chapters 2 and 3 of this report.
- estimation of design flood parameters for 8 No. AEPs, ranging from 50% to 0.1%; derive best estimate design fluvial flood parameters including peak flows, hydrographs, flood volumes and other design flood parameters as necessary. The design flows are required at a number of HEPs within the Athea study area. An update of design flows for the Galey River and its tributaries is needed for the Athea catchment area, as far downstream as Inch Bridge. This includes amending the flows and/ or locations of HEPs, establishing new HEPs (if required) and justifying the locations of HEPs.
- an assessment of potential for groundwater and pluvial flooding within the study area.
- a review and update of the rating equation is required at Inch Bridge gauge.
- the identification of any additional watercourses or tributaries that require more detailed hydrological analysis and thus, hydraulic analysis, which is discussed in Section 4.2.

4.2 Hydrological Analysis Objectives and Methods

The objectives and methods chosen to complete hydrological analysis for this study are detailed in the following sections.

4.2.1 Hydrological Estimation Points

4.2.1.1 Existing HEPs

The location of the CFRAM HEPs for the Galey River and its tributaries as far as Inch Bridge was set out in Section 3.6.4 above.

In accordance with the guidance given in the project brief, the HEPs in the Athea study area will include the following:

- upstream boundaries of all modelled watercourses,
- points on receiving channels upstream and downstream of the confluence of any tributary,
- point on tributaries upstream of the confluence with the receiving channel,
- at each hydrometric gauging station
- locations as necessary to accurately represent the inflows, additional to tributaries, along the modelled watercourses,
- other points at suitable locations as necessary to ensure that there is at least one Hydrological Estimation Point every 500 metres along all modelled watercourses.

The extents of river model for the scheme includes:

- The Galey River from upstream of the Athea East confluence to the Inch Bridge Gauge, 27.3km. The channel length between Inch Bridge and Athea Bridge is approximately 26.8km.
- The Athea West Stream at Athea, 500m, including the culvert through Athea
- The Athea East Stream at Athea, 600m

An overview of Galey River inverts along the proposed model reach, based on the CFRAM 2012 survey, is presented in Table 4-1 and Figure 4-1. Within the first (upper extents) 2.9km of the model the channel invert drops from 69.4mOD to 54.5mOD (difference 14.9m). It is unlikely that flood levels downstream of this channel extents would have any noticeable impact on floods at Athea Village and its environs. The tributaries within the proposed model reach, upstream of the Knocknagornagh Stream confluence, have relatively small and steep catchments and would be expected to peak in advance of the Galey River at Athea Bridge and have a small impact on flood risk at Athea Bridge.

Table 4-1: Channel Inverts

Location	CFRAM Section	Approximate Channel Invert	Comment
500m upstream of Athea Bridge	23Gale03493	69.4mOD	Proposed Model upstream extents.
Athea Bridge	23GALE03449D	67.2mOD	Main river structure at Athea
325m downstream of Athea Bridge	23GALE03423	65.6mOD	Upstream of Athea WWTP. Channel Invert is 1.6m lower than at Athea Bridge
860m downstream of Athea Bridge	23GALE03363	62.2mOD	Downstream of Athea WWTP. Channel Invert is 5m lower than at Athea Bridge
Knocknagornagh Stream Confluence	23GALE03199	54.5mOD	2.4km downstream of Athea Bridge. Channel Invert is >12.5m lower than at Athea Bridge
Athea Lower Bridge	23GALE02944D	49.2mOD	Channel Invert is 18m lower than at Athea Bridge. 4.8km downstream of Athea Bridge
Ahavoher Bridge	23GALE02236D	32.7mOD	11.8km downstream of Athea Bridge
Galey Bridge	23GALE01868D	22.6mOD	15.5km downstream of Athea Bridge
Shrone Bridge	23GALE00982D	13.5mOD	24.2km downstream of Athea Bridge
Inch Bridge	23GALE00734D	7.0mOD	26.8km downstream of Athea Bridge

4.2.1.2 Proposed HEPs

Further to review of the Galey River system, site walkovers and a review of the CFRAM HEPs, 20 No. HEPs have been proposed for this study as summarised in Table 4-2 and Figure 4-2 and 4-3. Table 4-2 includes a justification for the selection of the HEPs in the study area. HEPs have been included on the Athea East and Athea West streams as there are confirmed flood risks (based on past flood event information and site inspections) associated with both watercourses which may require a flood risk management measure involving both streams. HEPs have also been included for the tributaries immediately downstream of Athea as far as the Knocknagornagh Stream confluence for completeness in accordance the brief's requirements. Downstream of that confluence, HEPs on the tributaries have not been included as they would not be expected (due to elevation) to have any impact on the flooding regime at Athea.

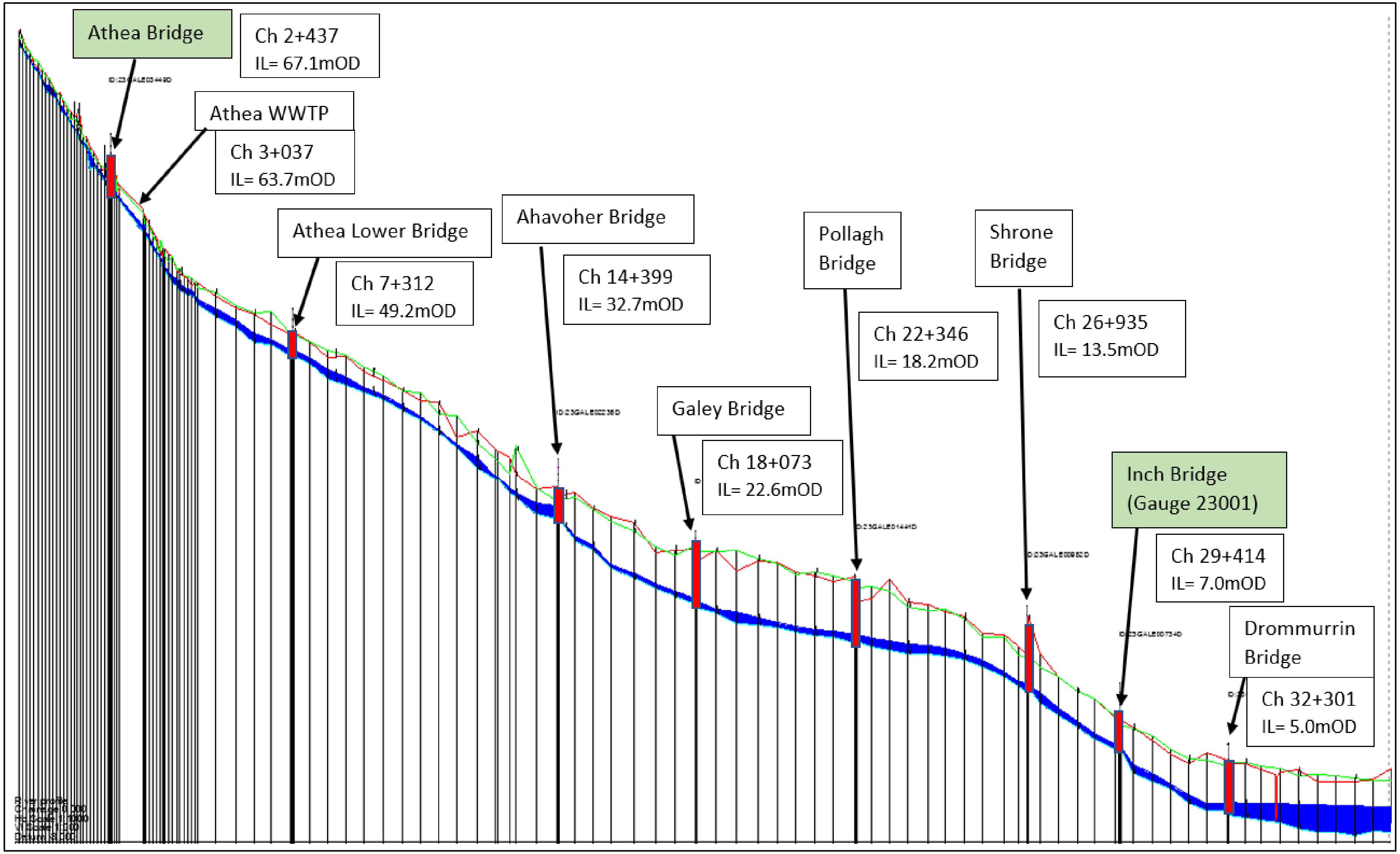


Figure 4-1: Galey River Longitudinal Section from upstream of Athea Bridge to its confluence with the River Feale

Table 4-2: Proposed Athea FRS HEP

Ref	HEP-Ref	Watercourse	Location	Reason
1	23_Galey01	Galey River	Inch Bridge	Hydrometric Gauge site. Model's downstream boundary condition.
2	23_Galey02	Galey River	upstream of Pollagh bridge	Significant hydraulic Structure, Point on modelled channel downstream of significant tributary confluence
3	23_Galey03	Galey River	Galey Bridge	Potential hydrometric gauging station. Significant hydraulic Structure, Point on modelled channel downstream of significant tributary confluence
4	23_Galey04	Galey River	Upstream of Ahavoher Bridge	Potential hydrometric gauging station. Significant hydraulic Structure
5	23_Galey05	Galey River	Confluence with the Dereen Stream	Point on modelled channel downstream of significant tributary confluence
6	23_Galey06	Galey River	d/s of confluence with the Knocknagornagh Stream	Downstream of significant confluence
7	*23_Knock_01*	*Knocknagornagh S.*	*Upstream of Confluence with the Galey River*	*Upstream of significant confluence*
8	23_Galey07	Galey River	Upstream of Confluence with tributary	Upstream of significant confluence. Downstream of a minor confluence
9	*23-AthUp-01*	*Athea Upper Stream*	*Upstream of Confluence with the Galey River*	*Upstream of confluence*
10	23_Galey08	Galey River	Upstream of Confluence with tributary	Upstream of minor confluence. Downstream of a minor confluence
11	*23_LstRd-01*	*Listowel Road Stream*	*Upstream of Confluence with the Galey River*	*Upstream of confluence*
12	23_Galey09	Galey River	Upstream of Confluence with tributary	Upstream of minor confluence. Distance between nodes.
13	23_Galey10	Galey River	Downstream of Confluence with Athea West Stream	Downstream of a minor confluence
14	23_AtheaWest01	Athea West Str.	At the inlet to Athea Village culvert	Upstream of significant hydraulic structure
15	23_AtheaWest02	Athea West Str.	Upstream of extents of modelled reach	Upstream boundary of modelled watercourse
16	23_ConCol01	Urban Drainage Contributing Area	Hillside and Urban Run-off discharging onto Con Colbert Street	Potential Hillside catchment not intercepted by watercourses discharging into an urban area.
17	23_ArdRd01	Urban Drainage Contributing Area	Hillside and Urban Run-off discharging onto Ardagh Road	Potential Hillside catchment not intercepted by watercourses discharging into an urban area.
18	23_Galey11	Galey River	Athea Bridge	Potential hydrometric gauging station. Significant Hydraulic Structure, Point on modelled channels downstream of a confluence
19	23_AtheaEast01	Athea East Str.	At the Abbeyfeale Road Culvert	Upstream of significant hydraulic structure
20	23_AtheaEast02	Athea East Str.	Upstream of extents of modelled reach	Upstream boundaries of modelled watercourse
21	23_Galey12	Galey River	Upstream of Confluence with Athea East Stream	Upstream of Confluence with Athea East Stream
22	23_Galey13	Galey River	Upstream of extents of modelled Galey River reach	Upstream boundary of modelled watercourse

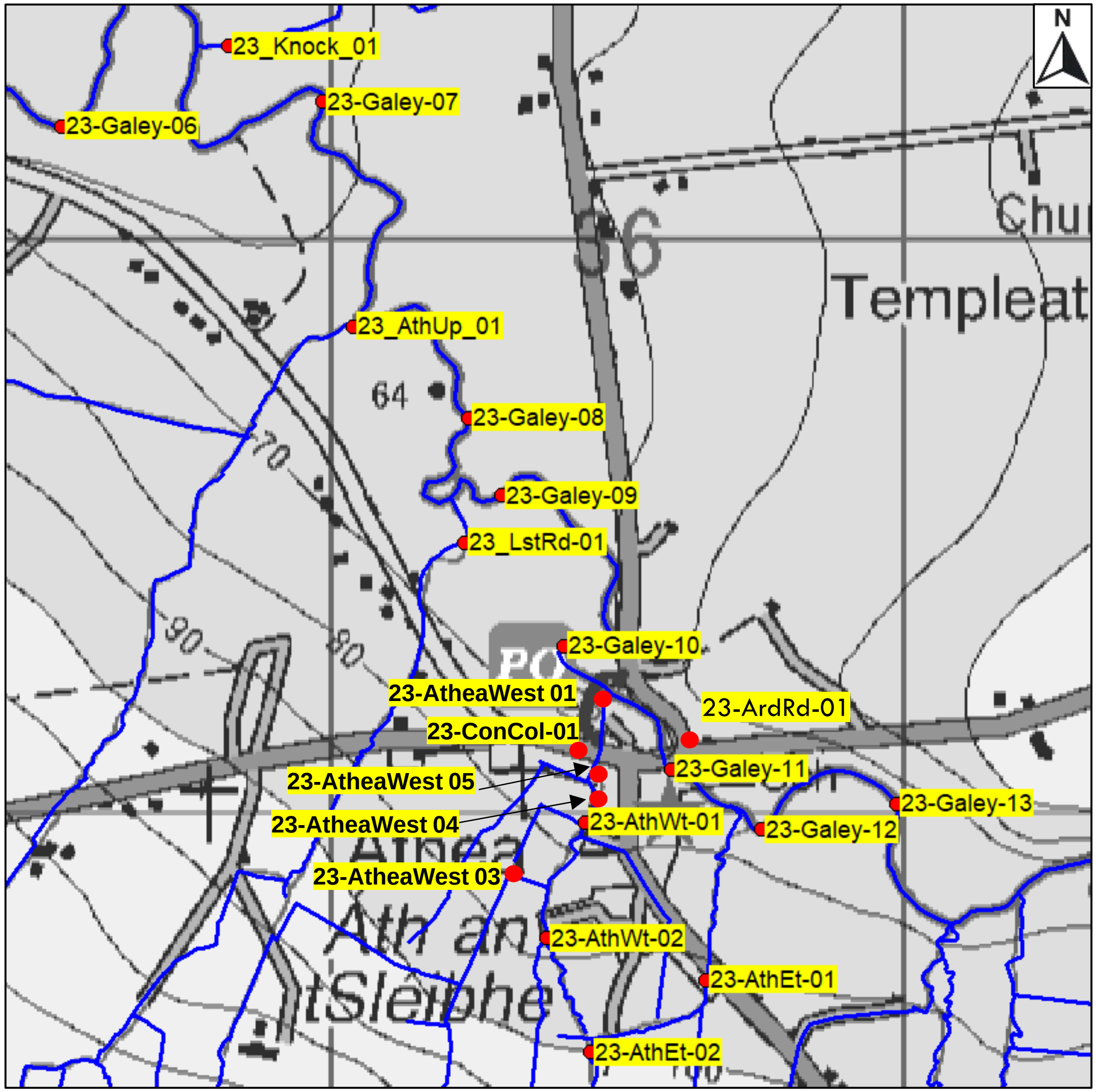


Figure 4-2: Proposed Athea FRS HEPs (Athea)

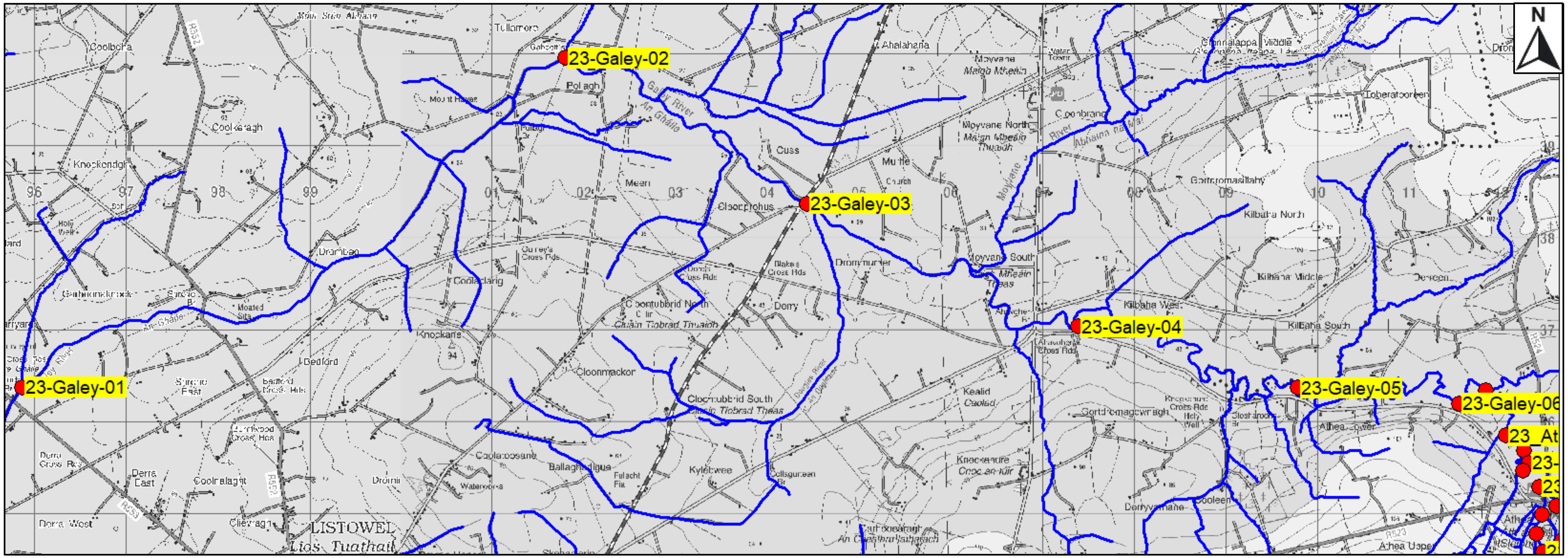


Figure 4-3: Proposed Athea FRS HEPs (Galey)

4.2.2 Design Flood Parameters

The project's brief requested that an estimate of the design flood parameters should be carried out that for HEPs including analysis for the full range of design event probabilities (current scenario) using suitable methodologies based on catchment characteristics and data availability. The following sections detail the analysis to be carried out as part of the hydrological study.

4.2.3 Design Event Probabilities

Design flood estimate will be derived at each HEP as set out above for 8 No. AEPs, namely 50%, 20%, 10%, 5%, 2%, 1%, 0.5%, 0.1%.

4.2.4 Estimation of Design Flood Parameters

As set out in the brief, a number of design flood flows will be assessed, which include the following:

- <u>Fluvial:</u> For all HEPs for the full range of design event probabilities, best estimate design flows will be derived including peak flows, hydrograph shape and critical storm duration.
- <u>Pluvial:</u> An analysis of rainfall depths and intensities for a range of design rainfall event AEPs will be carried out for sub-catchments within the Athea village study area.

4.2.5 Design Event Flow Estimation Methods

Design fluvial flood flows for this study have been estimated using a range of methodologies (as applicable), which include:

1. Statistical analysis of historic gauged levels and flows for estimating appropriate flood growth factors/curves;
2. Ungauged catchment characteristics estimation methodologies to calculate index design flood flows and growth curves;
3. Rainfall-runoff or catchment modelling if the scheme requires event-based simulation; and
4. Assessment and justification of the proposed critical storm durations and joint probabilities.

Other than the long establish hydrometric gauge at Inch Bridge, 26.8km downstream of Athea Bridge, there are no appropriate gauge data available for the study area watercourses and thus the estimation of design flows for the study will need to primarily rely on ungauged catchment characteristics methodologies (note: the recently installed (April 2021) Athea Bridge gauges have currently an insufficient data set to inform design flow estimation). As many of the catchments of relevance in the study area are small, direct application of the OPW FSU 7-variable equation method, which is recommended for catchments with an area greater than 25 km^2, may not be appropriate and therefore guidance given in the OPW's *FSU Report - Work Package 4.2 Flood Estimation in Small and Urbanised Catchments* has been considered for these smaller catchments.

Table 4-3 presents the ungauged catchment estimation equations of relevance set out in the report and comments on their appropriateness and associated standard factorial errors. The FSR 6-variable equation developed for Ireland is also included here for comparison.

Table 4-3: Ungauged Catchment Methods

Method	Equation	Comment	Comment
FSSR6 (3-Variable Equation)	$Qbar = 0.00066\ Area^{0.92}\ SAAR^{1.22}\ Soil^{2.0}$	FSE=1.931	Recommends comparison of these methods (OPW).
IH124 #	$Qbar_{Rural} = 0.00108\ Area^{0.89}\ SAAR^{1.17}\ Soil^{2.17}$	FSE=1.952 (over-estimates)	
FSU 3v #	$QMED = 0.000302\ AREA^{0.829}\ SAAR^{0.898}\ BFI^{-1.539}$	*FSE>2 (not tested for small catchments (OPW))*	*Qmed to Qbar conversion factor of 0.96 (OPW)*
FSU-7v	$Q_{MEDrural} = 1.237x10^{-5}\ AREA^{0.937}\ BFIsoils^{-0.922}\ SAAR^{1.306}\ FARL^{2.217}\ DRAIND^{0.341}\ S1085^{0.185}\ (1+ARTDRAIN2)^{0.408}$	FSE= 1.86	For catchments >25km^2 (FSE =1.37). When used for catchments <25km^2, FSE increases.
FSU4.2a	$Qmed = (2.0951x10^{-5})\ (AREA^{0.9245})\ (SAAR^{1.2695})\ (BFI^{-0.9030})\ (FARL^{2.3163})\ (S1085^{0.2513})$	FSE=1.686	Performs much better than FEH and FSU (3v) and is an improvement on the FSU (7v) for small catchments
FSR Six Variable Equation	$Qbar = 0.00042\ Area^{0.95}\ Fs^{0.22}\ Soil^{1.18}\ SAAR^{1.05}\ S_{1085}^{0.16}\ (1+Lake)^{-0.93}$	SFE = 1.47	Proven estimation method used prior to FSU. Included for comparison

The appropriate ungauged methodologies to be used for this study's calculation/ comparison of the design flow are the deemed to be the IH124, FSU-7v, FSU4.2a and FSR 6v.

Due to the relatively large area of the Athea Bridge catchment covered by forestry, a sensitivity analysis on some of the PCDs which could be influence by forestry will be carried out for this study.

In the CFRAM study, it was determined that a single site EV1 distribution was appropriate to determine the flood growth curve. An updated analysis of flood growth curves has been undertaken for this study.

4.2.6 Hydrograph Shapes

An analysis of hydrographs shapes and the related times to peak for each watercourse within the study area has been undertaken (See Section 11).

4.2.6.1 Galey River

As part of the CFRAM study, a hydrograph shape was derived for the entire Galey River reach and applied throughout the hydraulic model at relevant HEPs. The adopted hydrograph was derived from observed events at Inch Bridge gauge in the lower part of the river reach. This has been reassessed for this study to determine if this is the most suitable hydrograph shape for the Athea reach.

The recently installed gauges at Athea Bridge, while only having to date recorded a number of small flood events (likely less than 1 in 1year events), do suggest, a time to peak of <6 hours) and an initial step recession (similar duration) followed by a period of gradual recession over the following day.

The hydrograph recorded at Inch Bridge gauge coinciding with July 31st/ August 1st flood event had an approximate time to peak of 6 hours and a recession duration of >20 hours. Peak flow was recorded during this event at 6:30am on 1st August, or approximately 6.5 hours after the peak at Athea Bridge. This event's hydrograph at Inch Bridge has been examined to inform the hydrograph shape for the Athea Bridge reach. A synthetic hydrograph shape has also been developed for comparison purposes.

4.2.6.2 Tributaries

For the CFRAM, a synthetic hydrograph shape was applied to the Athea West stream tributary, as this is ungauged and much smaller than the Galey River. The time to peak for this was determined as 1.5 hours. Synthetic hydrographs have been derived for the relevant tributaries in this study (Section 11.)

4.2.7 Joint Probability

Joint probability analysis will be carried out in order to quantify the dependency between flows from the Galey River and the smaller tributaries and the Athea village storm drainage/ pluvial regime. It is expected that the main Galey River hydrograph will be appreciably different to that of the small tributary and pluvial catchments. A combined analysis to link the fluvial flows of the main river with the peak flows of the relevant smaller tributary catchment has been undertaken in Section 13 below.

4.2.8 Additional Hydrometric

An assessment of potential additional gauging sites along the Galey has been undertaken by Ryan Hanley for this study which is summarised in Appendix C. In summary, installation of two gauges in the Athea Bridge reach was recommended and these were installed in April 2021. Information from these gauges, in time, will significantly improve the understanding of the upper catchment's flood regime and stage hydrograph shape and assist with calibration of the associated hydraulic model. Due to the spate nature of the river system, prompt establishment on site would be required to gauge peak flood velocities etc. and therefore collection of appropriate flow data to develop a suitable stage-flow rating curve for a gauge at Athea Bridge would be difficult. No sites were identified upstream of the Athea Bridge reach were identified as suitable (i.e. due overbank flow and channel stability, access) for installation of hydrometric gauges.

Installation of gauges at the Ahavoher and Galey Bridges would likely not significantly improve the hydrometrics understanding and model calibration at the Athea Bridge reach compared to the Inch Bridge for similar reasons (i.e. significant difference in physical catchment descriptions and multiple tributaries between them and Athea Bridge). A gauge at Ahavoher Bridge could potentially be a suitable site for gauging flood flows for the combined upper reaches of the Galey River catchment and should be considered for installation and could potentially in time, after an appropriate record of flows and levels has been collected, be used as the downstream boundary for updating Athea Bridge model. The invert level difference between Athea Bridge and Ahavoher Bridge is >34m (See Figure 4-1 above).

4.2.9 Model Calibration

The downstream boundary condition used for the existing CFRAM model, was at Inch Bridge gauge, which is a reliable and good quality gauge with 71 years of gauged flow and water level data. The Galey River at Inch Bridge gauge has a catchment area of 191.7km^2 which is significantly larger than that at Athea Bridge (36.6km^2) and their associated catchment slopes and mainstream lengths are 3.3m/km and 38.5km, compared to 12.4m/km and 11.7km respectively. Due to the significant differences in catchment characteristics between the two sites, and multiple tributaries and drainage channels discharging to the Galey between Athea and Inch Bridge, direct use of the Inch Bridge gauge to calibrate flood events in the Athea Bridge reach would be difficult.

The flood event for which peak flood level information at Athea is available and whose Inch Bridge hydrograph appears to be somewhat representative of a flood event at Athea Bridge, due to the apparent localised nature of the flood event in the Athea Bridge catchment, is the 31st July / 1st August 2008 flood event (JA08). The Galey River channel and bridge at Athea during the JA08 event was reported to be partially blocked by flood debris, vegetation and gravel deposition and subsequently channel maintenance works were carried out by the OPW. As noted in Section 2, gravel deposition at Athea Bridge and its downstream reach is dynamic and the effective capacity of the channel is constantly changing. Furthermore, works were undertaken by a landowner in early 2021 to clear the overgrowth and reprofile the river's left bank downstream of Athea Bridge. Based on the above multiple changes to the channel's condition and capacity it would be difficult to calibrate a hydraulic model at the Athea Bridge reach to JA08 event.

It is proposed, therefore, that the Galey River hydraulic model at Athea Bridge for the current scenario will be developed based on the current channel conditions and a precautionary approach comprising a sensitivity analysis of the channel's Manning's roughness coefficients, blockage scenarios in the channel through Athea and a range of conservative downstream boundary conditions in the channel reach within 1 km downstream of Athea Bridge (note: the channel bed gradient in the first 1km of the channel reach downstream of Athea Bridge is approximately 0.6% (1 in 176 m/m).

4.2.10 Climate & Catchment Change Assessment

The OPW guidance note, entitled '*Assessment of Potential Future Scenarios for Flood Risk Management*' *(OPW, 2009)* sets out the recommended specific policies for the allowances to be used when estimating future scenarios catchment design flows based on climate change, urbanisation and afforestation.

Two climate change scenarios are referenced as described below:

- 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 change in rainfall storm intensities, 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.

Table 4-4 presents the OPW guidance on the future design flow scenario allowance as specified by the Project Brief.

Table 4-4: Allowance for Future Scenarios

	MRFS	HEFS
Extreme Rainfall Depths	+20%	+30%
Flood Flows	+20%	+30%
Urbanisation	To be agreed with the client	
Afforestation	-1/6Tp[3]	-1/3Tp+10%SPR[4]

[3] Reduce the time of peak by one sixth allow for potential accelerated runoff that may arise as a result of drainage of afforested land.
[4] Reduce the time to peak (Tp) by one third and add 10% to the Standard Percentage Runoff (SPR) to allow for increased runoff rates that may arise following felling of forestry.

The principal impact of climate change on flood risk will be the projected increase in intensity and frequency of rainstorm events. Table 4-4 presents the standard allowances which are used in this study to calculate the MRFS and HEFS design flows.

4.2.10.1 Urbanisation

The estimated urban area draining to the Athea West Stream and Galey River are summarised in Section 8-3.

While urbanisation is not significant in the overall Athea Bridge catchment, high urban runoff rates do occur at Athea Village due to the steep catchments and significant hillside runoff contribution. It is not expected that urbanisation will be a significant future scenario in the Athea Bridge catchment and therefore no associated allowance is recommended. It is recommended that run-off from all new developments which drain to the Athea West and Athea East streams and the Galey River incorporate sustainable drainage systems (SUDs) to attenuate flows to greenfield run-off rates and improve urban run-off quality.

4.2.10.2 Afforestation

Afforestation has the potential to affect the runoff response from the Athea catchment. This was considered in the CFRAM study (UoM 23), which took the assumption that forestry would double in catchments in the future. From the Ryan Hanley review, we have estimated that forestry currently covers 45% of the catchment. To account for the potential effect of forestry cycles, new or unmaintained drainage systems and increased afforestation, the approach from the CFRAM was to increase peak flow by 10% for the forestry coverage in the MRFS (i.e. 4.5%) and 20% in the HEFS (i.e. 9%) for the Athea Bridge catchment.

During the development of these forestry plantations, peat lands would have been reclaimed, access roads would have been constructed and channels would have been excavated to improve drainage. The combination of these will have resulted in changes to catchment run-off rates. As the forests mature the effective run-off (catchment annual water yield) will have, indeed, temporarily decreased. However, harvesting, thinning and clear felling, as part of the commercial forestry development, can led to increased catchment run-off rates and consequentially, if unmitigated, can lead to an increase in hillside channel erosion and ultimately increased peak flows in the Galey River.

As identified in Section 2, a significant portion of the catchment area upstream of Athea has been developed for forestry and equally a significant area of mountain peat blanket bog areas has been reclaimed and drained as part of the forestry development. Currently approximately 50% of the Galey River catchment at Athea Bridge and 24% of the Athea East Stream catchment can be classed as transitional woodland scrub and coniferous forest. Trinity College Dublin and GSI prepared a report (entitled Land use changes, flood alleviation options and the associated impacts on the Gort Lowland Karst Catchment in Co. Galway October 2020) which investigated the potential effects of forestry development in the Slieve Aughty on peak flood levels in lowlands floodplains. The Slieve Aughty study area shared similar characteristics to that of the Athea catchment including the original soil cover comprising blanket peat, an overlying impermeable bedrock, steep catchment with a high stream density, a SAAR of circa 1,300mm/annum and approximate 50% coverage by actively managed commercial forestry. The report identified that afforestation in upland areas impacts the annual water yield, baseflow and the peak flow in different ways through the forestry life cycle, i.e. land reclamation and drainage, planting, growing, harvesting/ felling/ thinning and re-planting. A review by TCD of previous forestry hydrological impact studies concluded that:

- Drainage of the lands before planting increases peak flows in the early years of the plantation with the effects persisting for 10 years or longer. Initial increase in runoff following afforestation can range between 10 – 18%
- Peak flows from a mature forest can be similar to unforested land or can be reduced in some circumstances. Rapid reductions in the initial increases in runoff develop once the canopy cover becomes established and drains begin to infill (10-15 years). At maturity forestry can decrease the annual water-yield by up to 32%.
- Clear felling and thinning of forestry results in local short-term (<3 years) increases in both peak flows and baseflows.
- Forestry drainage tends to increase baseflows in the early years of the forestry cycle and was shown to not only cause an increase in peak storm discharge from the catchment (peak hydrographs increased by up to 30%) but also a reduction in the time to peak and an impact the shape of the hydrograph recession.

The TCD report included a table (Table 4-5) on one approach they used summarising the proportional change in cumulative runoff relative to the pre-forestation scenario of various forestry land use description and the proportion of forested lands assumed for each scenario.

Table 4-5 Summary of forestry coverage types used in the assessment (TCD, October 2020)

Forestry land use Description	Proportional Change in Cumulative runoff	Portion of forested lands assumed
Thinning	+18%	20%
Clear-felling	+18%	10%
Trees not yet matured <5years	+10%	15%
Tree not yet matured 5-15years	+7.5%	25%
Matured Trees > 15years	-10%	30%

The more conservative approached TCD used for their Slieve Aughty assessment comprised a lumped increase of 18% and 36% in annual water yield for the entire forestry area. Using these three approaches TCD calculated proportional changes in runoff volumes at 2.9%, 8.9% and 17.9% respectively for the Slieve Aughty study area. The review of the TCD report has identified the potential for significant increases in run-off rates due to forestry and it is concluded that similar effects have likely occurred in the Athea Bridge catchment and are prevailing in the current scenario. Such increases are not directly included in the FSU Qmed PCD estimation methodology and therefore, following a suitably precautionary approach, the increase in run-off rate of +8.9% (median of the TCD results) is taken as the forestry factor (FF) in the current scenario has been adopted for the portion of the catchment currently under forestry (i.e. both transitional wood and scrub and coniferous forest). The MRFS and HEFS allowances set out in Table 4-4 are used to project potential future further increases in run-off rates and changes to the hydrograph shape.

4.2.10.3 Athea Physical Catchment Descriptors

A review has been undertaken for this study of the FSU Physical Catchment Descriptors (PCD) to be used in estimation of the current scenario design Qmed flows for the Athea Bridge catchment and a number PCD parameters amendments have been recommended to those reported in the FSU database as follows:

Table 4-6: FSU Physical Catchment Descriptors - Athea HEP (DS) (23_2579_2)

Catchment Descriptor	Following Review	Comment
Area (km^2)	36.7	Unchanged. Athea Stream catchments defined.
BFI Soil	0.322	BFISoil reported at Inch bridge.
SAAR (mm)	1390.4	Met-Éireann SAAR database (1981-2010) rainfall depth
FARL	1	Unchanged
DRAIND (km/km^2)	2.1	A higher drainage channel density calculated
S1085 (m/km)	12.4	A steeper S1085 calculated
ARTDRAIN2 (%)	0	Any increase due to forestry drainage is being accounted for in the forestry allowance factor
URBEXT (%)	0.55%	Unchanged

4.3 Conclusion

The aim of the Hydrological Method Statement is to confirm the degree to which Tralee-Bay Feale River Basin design flows remain valid or have significant changes from the CFRAM study and to set out the proposed methods for completing the objectives of the hydrological analysis.

Following a thorough review of the CFRAM hydrology study and project's brief requirement it has been concluded that:

- The CFRAM HEPs for this study require augmentation to include for minor tributaries at Athea and updates due to recent flood events.
- A thorough analysis with regards to Qmed and the flood growth curve is required to determine the optimal design flows.
- Alternative hydrological methods are required for the small stream catchments at Athea and a comparison made with FSU method design flow estimate.
- The hydrograph shape of the main Galey River applied in the CFRAM study will be checked and updated with the most recent flow gauge data at Inch Bridge gauge.
- The synthetic hydrograph shape for small tributaries will be analysed and updated, if required.
- A preliminary pluvial flood risk assessment, which was not part of the CFRAM, will be carried out along with a preliminary joint probability analysis.

5 Extreme Rainfall Analysis

5.1 Introduction

An analysis of the study area's rainfall is presented in this section, including extreme rainfall depths for different storm durations and return periods derived by OPW Depth Duration Frequency (DDF) portal and review of Met Éireann rain gauge data (See Figure 3-1) and other datasets.. Data from the Shannon Airport rain gauge (see Figure 1-2), which provides rainfall records at 1-hour time step and past flooding events analysis, has also been reviewed. Section 6 reviews rainfall data sourced from NASA and the associated hydrological rainfall-runoff modelling for past flood events in the Athea catchment.

5.2 Annual Average Rainfall

The flow estimates presented in the OPW FSU website are understood to have been calculated using the 1961-1990 Standard-period average annual rainfall (SAAR) database for Ireland. In the interim Met Éireann have issued the 1981-2010 SAAR for Ireland. With respect to the Galey River catchment the reported SAAR (averaged across the respective catchments) for the periods have increased noticeably as follows:

- At Inch Bridge the 1961-1990 and the 1981-2010 SAAR are calculated at 1084mm/annum and 1230.7mm/annum respectively (a 13.5% increase)
- At Athea Bridge the 1961-1990 and the 1981-2010 SAAR are calculated at 1134.6mm/annum and 1390.4mm/annum (a 22.7% increase)

Given the significance of these difference it is proposed that the more recent SAAR dataset is used in this study.

5.3 Extreme Rainfall Depths

The rainfall depths for specific storm durations and return periods, derived using the OPW FSU DDF web portal application, for the Galey River catchments at Athea Bridge (23_2579_2) and at Inch Bridge (23_2929_2) are summarised in Table 5-1 and Table 5-2. The rainfall depths presented in the table relate to event probabilities, ranging from 2 year to 1000year return periods (50% to 0.1%AEP) and rainfall durations ranging from 1 hour to 96 hours.

Table 5-1: Athea Bridge Catchment Rainfall Depths – Duration/ Return Period data

Return period (years)	Duration (hour) and total rainfall depth (mm)											
	1 hour	2 hour	4 hour	6 hour	7 hour	9 hour	12 hour	15 hour	24 hour	36 hour	48 hour	96 hour
1000	53.3	66.7	82.9	93.8	98.3	106	115.4	123.3	143.3	151.9	160.2	189.1
500	45.4	57.3	71.7	81.5	85.5	92.4	101	108.1	126.3	135	143.2	171.6
250	38.7	53.7	62	70.6	74.4	83.3	90.6	96.7	112.7	119.3	128.0	155.6
100	31.3	40.2	51.1	58.7	61.8	67.2	74	79.6	94	102.5	110.3	136.7
50	26.7	34.5	44.2	50.9	53.7	58.6	64.6	69.7	82.7	91.0	98.5	123.9
10	18.1	23.8	31	36.1	38.2	41.9	46.6	50.6	60.7	68.2	74.9	97.6
5	15	19.9	26.2	30.6	32.5	35.8	39.9	43.4	52.3	59.4	65.7	87.2
2	10.9	14.7	19.6	23.1	24.6	27.2	30.6	33.4	40.7	46.9	52.5	71.7

Table 5-2: Inch Bridge Catchment Rainfall Depths – Duration/ Return Period data

Return period (years)	Duration (hour) and total rainfall depth (mm)									
	1 hour	2 hour	4 hour	6 hour	9 hour	12 hour	15 hour	24 hour	36 hour	48 hour	96 hour
1000	42.2	53.9	67.4	76.4	86.3	93.9	100.1	114.5	122.4	129.9	155.5
500	36.1	46.5	58.7	66.9	75.9	82.8	88.6	101.9	109.8	117.1	142.1
250	30.9	40.1	51.1	58.5	66.7	73.1	78.4	90.6	98.4	105.5	129.8
100	25.1	33	42.5	49	56.2	61.9	66.6	77.6	85.2	92	115.1
50	21.4	28.4	36.9	42.8	49.4	54.5	58.9	69	76.3	82.8	105
10	14.7	19.8	26.3	30.9	36.1	40.2	43.7	51.9	58.5	64.3	84.2
2	9	12.5	17	20.2	24	27.1	29.7	35.9	41.5	46.4	63.3

5.4 Thiessen Polygons

A comparison of the nearby open rain gauges relative to the Inch Bridge and Athea Bridge catchments using Thiessen polygon analysis has been undertaken and Table 5-3 and Figure 5-1 present the % area of the catchments closest to the various gauges:

Table 5-3: Rain gauge Data distribution (Thiessen Polygons)

Rain-gauge Station	Inch Bridge, km²	% of catchment	Athea Bridge, km²	% of catchment
Moneypoint (5311)	10.9	5.7%	0	0%
Listowel (3410)	75.6	39.4%	0	0%
Athea (2610)	77.1	40.2%	27.3	74.6%
Newcastle West (5711)	1.55	0.8%	1.6	4.4%
Ballyhahill (6311)	26.6	13.9%	7.7	21.0%
Total	**191.7**		**36.6**	

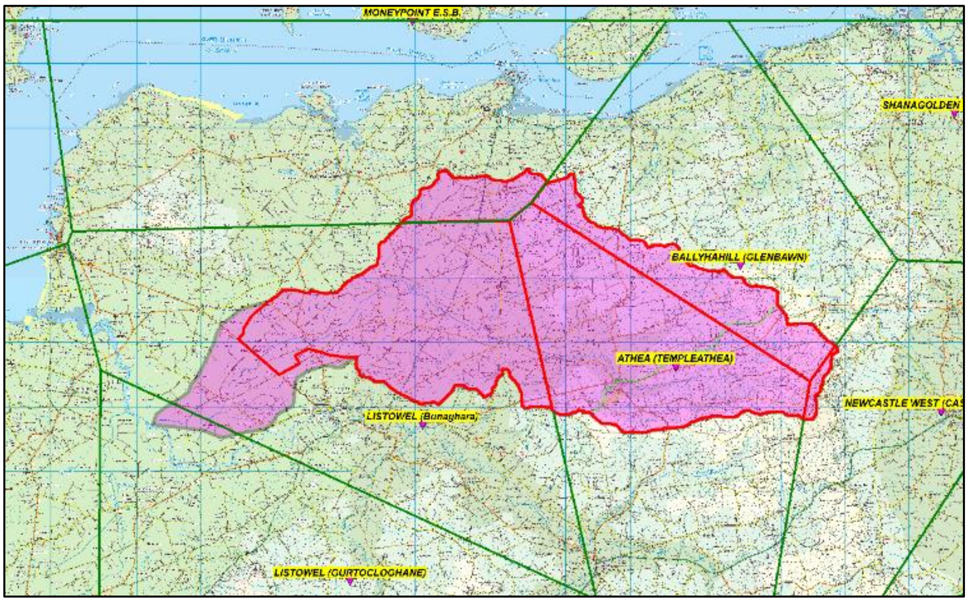


Figure 5-1: Thiessen Polygons – Rain-gauges / Galey Catchment

5.5 Rainfall Analysis

Rainfall datasets, one each for the Inch Bridge and Athea Bridge, have been calculated for the study area based on the available rain-gauge data and their catchment proportional influence (Table 5-2) for the period February 2001 to August 2020. There is insufficient data to expand the rainfall dataset outside this period. Figure 5-2 and Figure 5-3 present the dataset's daily rainfall depths and annual maximum for both catchments.

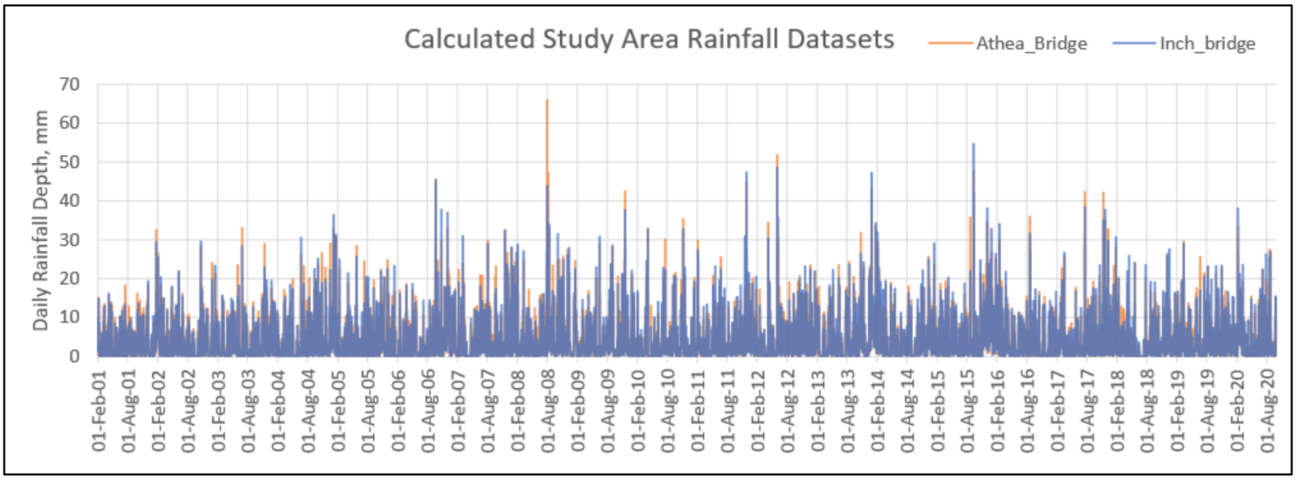


Figure 5-2: Inch bridge and Athea Bridge Daily Rainfall totals (Feb 2001 to Aug 2020)

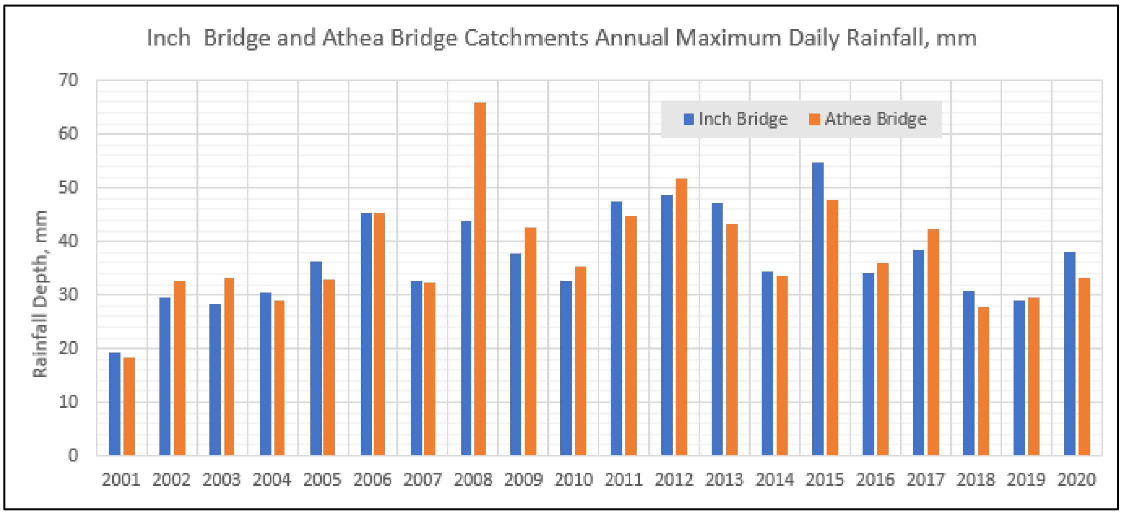


Figure 5-3: Catchment's Annual Maximum Rainfall Depths (Feb 2001 to Aug 2020)

The 2-day and 4-day average total rainfall depths for the dataset are presented in Figure 5-4 and 5-5

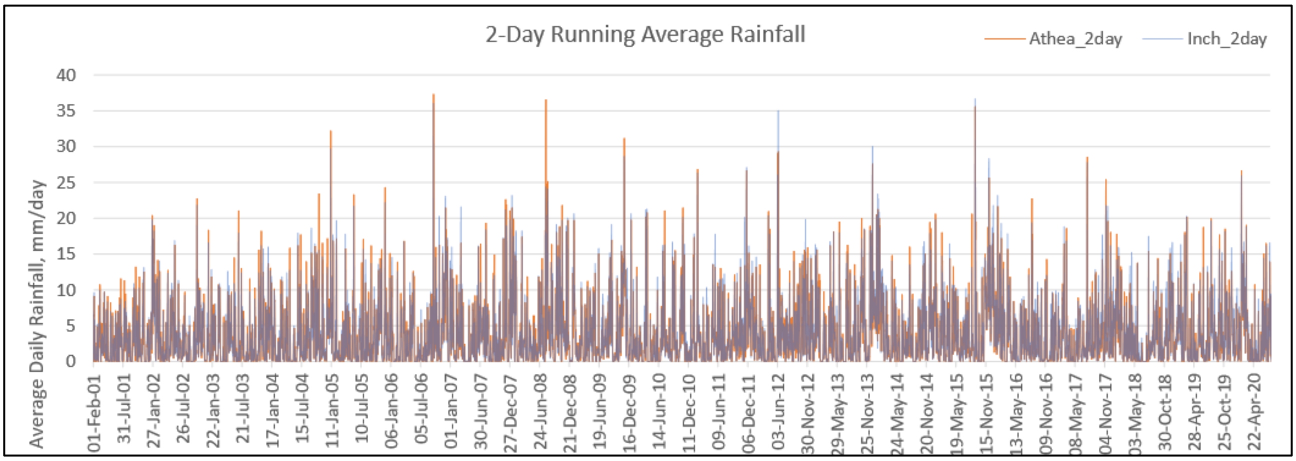


Figure 5-4: 2-day running average rainfall

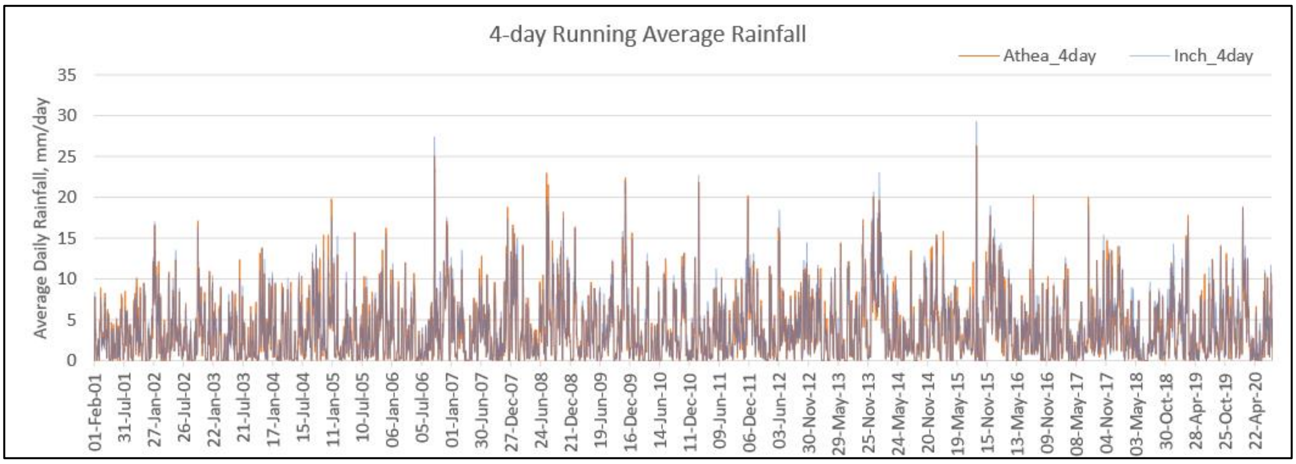


Figure 5-5: 2-day running average rainfall

Table 5-4: 2001 to 2020 period Peak Rainfall Events Return Periods

Parameter	Rank	Inch Bridge Catchment	Return Period	Date	Athea Bridge Catchment	Return Period	Date
Daily Rainfall	1	54.7mm	16y	11/09/2015	65.9mm	16y	31/07/2008
	2	48.6mm	8y	02/06/2012	51.8mm	5y	02/06/2012
	3	47.4mm	7y	28/11/2011	47.8mm	4y	11/09/2015
Maximum 2-day	1	36.7mm	29y	11/09/2015	37.3mm	10y	22/09/2006
	2	36.1mm	26y	21/09/2006	36.6mm	9y	02/08/2008
	3	35.1mm	21y	07/06/2012	35.6mm	8y	12/09/2015
Maximum 4-day	1	29.3mm	162y	13/09/2015	26.32mm	18y	13/09/2015
	2	27.4mm	95y	21/09/2006	25.0mm	13y	21/09/2006
	3	23.1mm	25y	2/02/2014	23.0mm	7y	31/07/2008

There is a continuous rainfall record for the Athea rain-gauge from 1985 onwards. A gamma statistical distribution was fitted to the annual maximum daily rainfall depth for the Athea rain gauge as shown in Figure 5-6.

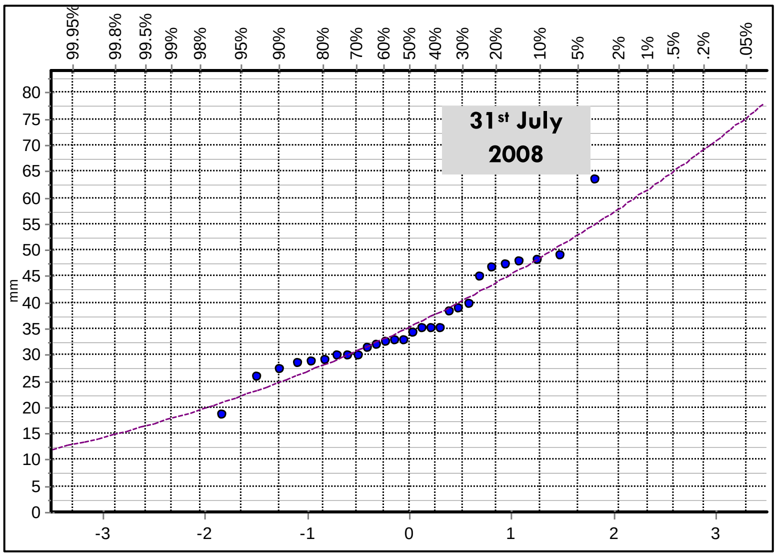


Figure 5-6: Gamma statistical distribution plot annual maximum rainfall depths (Athea rain-gauge)

5.6 Recent Past Flood Events Rainfall

Table 5-5 presents a summary of the total rainfall depth associated with the flood events reported in Section 3 and the estimated relevant rainfall period for the event.

Table 5-5: Recent Past Flood Event Rainfall Return Periods (based on Met Éireann daily data)

Flood Event	Location	1-day	2-day average	4-day average	Return period Estimate (Note#1, #6)	Comment
7-8th January 2005	Inch B.	36.4mm	29.7mm	17.7mm	c2y Inch B.	
	Athea B.	31.5mm	32.2mm	19.8mm	<10y Athea B.	
April 2005	Inch B.	21.4mm	17.8mm	10.9mm	<2y Inch B.	
	Athea B.	18.9mm	15.8mm	9.6mm	<2y Athea B.	
July/August 2008	Inch B.	43.9mm	24.4mm	20.1mm	c2y Inch B.	Note#2
	Athea B.	65.9mm	36.6mm	23.0mm	10y-50y Athea B.	
6th August 2008	Inch B.	33.7mm	17.9mm	10.0mm	*<2y Inch B.*	**Note#3. See Section 5.7**
	Athea B.	47.2mm	24.8mm	13.4mm	*2y-10y Athea B.*	
2nd Sept 2009	Inch B.	28.6mm	19.2mm	12.4mm	<2y Inch B.	Note#4
	Athea B.	28.0mm	17.0mm	12.1mm	<2y Athea B.	
19th November 2009	Inch B.	37.7mm	28.7mm	22mm	2y-10y Inch B.	
	Athea B.	42.5mm	31.1mm	22.4mm	10y Athea B.	
11th September 2015	Inch B.	54.7mm	36.7mm	29.3mm	2y-10y Inch B.	Note#5
	Athea B.	47.8mm	35.6mm	26.3mm	10y-50y Athea B.	

Note #1: Estimated return period based on the 1day, 2-day and 4-day rainfall events. There have been more intense rainfall events of shorter duration than the 1-day, in particular relative to the Athea Bridge catchment, which could result in a higher flooding return period than suggested here.

Note #2: Based on the storm duration of the 1st August 2008 extreme event as being 6 hours based on Shannon Airport gauge records (Appendix A) and JBA report, it is estimated that the event was of the order of 0.4% to 0.2% AEP rainfall event.

Note #3: Met Éireann prepared a dedicated section for this event and catchment in their Climatological Note No. 11 entitled "2008 Summer Rainfall in Ireland". Section 5.7 below summarises the Met Éireann note.

Note#4: Based on the storm duration of the 2nd September 2009 extreme event as being 6 to 9 hours based on Shannon Airport gauge records (Appendix A) it is estimated that the event was less than a 10%AEP rainfall event. The flood damage associated with this storm event was likely primarily due to blockage in the Athea Village Culvert.

Note#5: Met Éireann issued an Orange rainfall warning for the event with a warning of 60mm to 70mm possible on high ground. A review of the Valentia (67.5mm 24hrs) and Shannon (37.8mm 24hrs) synoptic gauges concluded a regional rainfall return period for any duration during the 24 hour period at less than 1 in 5 years. There is no information available on the storm duration in the Athea Bridge catchment. However, if the storm event at Athea rain gauge (say 90% of the total daily rainfall, 43mm) was concentrated over 6 hours the return period would have been of the order of 1 in 25years. The flood event on the 11th September 2015 appears to have resulted from a very localised intense rainfall event in the upper Galey catchment. See Section 3.6.5.

Note#6: Does not infer directly as being the effective rainfall, as this would differ depending on the antecedent conditions (saturated conditions etc.) and the time of year (e.g. evapotranspiration)). A higher run-off rate would be expected in Winter than summer due to likely saturated ground conditions and minimal evapotranspiration.

In general, for the recent past flood events, the Athea Bridge catchment had a higher estimated rainfall return period than Inch Bridge. Based on the 1-day, 2-day and 4-day rainfall durations the peak 2015 and 2008 (see Note#3) events had return periods of between 10 and 50 years, the November 2009 event has a return period of 10 years and the remaining events had rainfall return periods of less than 10years. (See also Note #1)

A comparison of Table 5-4 to Table 5-5 identified that a significant flood event also occurred in recent years in the Galey catchment around the 21st September 2006 which would had an estimated return period of 10 and 25 years and would likely have been more apparent at Inch Bridge.

5.7 July 31st /August 1st 2008

Met Éireann prepared a case-study on the July 31st 2008 rainfall event for the Athea – Newcastle West area of Co. Limerick (https://www.met.ie/cms/assets/uploads/2017/08/Summer2008rainfall.pdf) following the flood event in the River Arra (Newcastle West)catchment. The report is summarised as follows:

- The catchments' soils were close to saturation following a period of heavy rainfall during the period 27th to 29th July
- On the 31st July a depression (low pressure) moved northwards over Ireland and become slow-moving over the Midwest, bringing exceptional heavy falls of rain to the west Limerick area.
- The 7-hour and 14-hour rainfall totals at Athea rain gauge were estimated at 59.5mm and 63.3mm respectively.
- The 7-hour and 14-hour rainfall totals at Ballyhahill rain gauge were estimated at 66.8mm and 71mm respectively.
- The 7-hour and 14-hour rainfall totals at Newcastle West rain gauge were estimated at 79.8mm and 84.9mm respectively.
- Met Éireann prepared a 24 hour grided rainfall accumulation map for the Athea – Newcastle West area as presented in Figure 5-7, which suggests heavier rainfall than recorded at the three above gauges likely fell in the Galey River catchment
- The Met Éireann analysis has shown that rainfall totals, in the order of 60-100mmm, occurred over an area of approximately 450km^2 in west County Limerick and northwest County Cork, with approximately 95% of the rain falling in a 7-hour period.

Using the Thiessen polygons developed for the catchment area, the 7 hour and 14-hour rainfall total in the Athea Bridge catchment have been estimated at 61.9mm and 65.9mm respectively with associated rainfall return periods estimated at 100 years and 40 years respectively based on the OPW FSU DDF portal database. The rainfall totals for the 31st July 2008 are further assessed in Section 6.

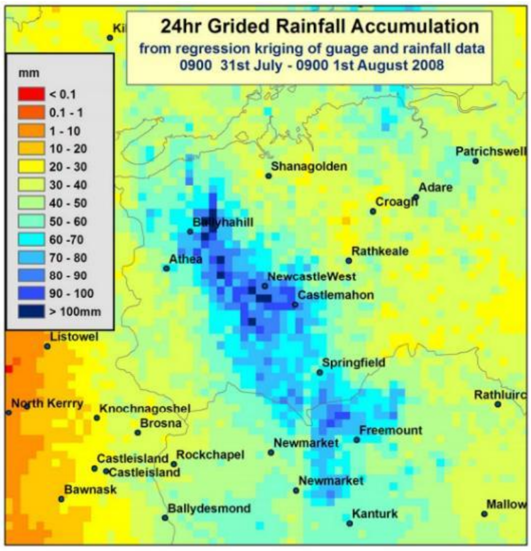


Figure 5-7: Rainfall totals derived from radar data 31st July 2008 (Met Éireann)

5.8 December 1973 Flood Rainfall

A review of the Inch Bridge gauge historic data has identified that the most extreme flood in Galey River catchment on record occurred on 1st December 1973. In the Met Éireann report entitled" Exceptional Weather Events – Rainfall – November – December 1973" it was stated that for the period of 27th November to the 1st December "the rainfall was remarkable prolonged and heavy. Serious flooding was reported in many areas of the south and west, particularly in Counties Kerry, Cork and Limerick." https://www.met.ie/cms/assets/uploads/2017/08/Nov1973_Rain.pdf.

The return period of the 4-day rainfall event regionally was estimated in the report at 1 in 50years and periods of intense rain (waves) were reported through the 4-day period. There are no hourly rainfall records readily available for Shannon Airport for this period.

On the 30th November approximately 65.0mm of rain was recorded at each of Abbeyfeale, Athea and Listowel rain gauges. The 4-day rainfall total at these gauges was of the order of 128.2 to 136mm. The peak 1-day and 4-day total rainfall depths for the event from the Met Éireann report are presented in Figure 5-5.

Referring to OPW FSU DDF database, the estimated rainfall return periods of the 1973 Galey River flood's 4-day and peak 1-day events have been calculated at between 1 in 250 and 1 in 360years, and 1 in 35 years respectively.

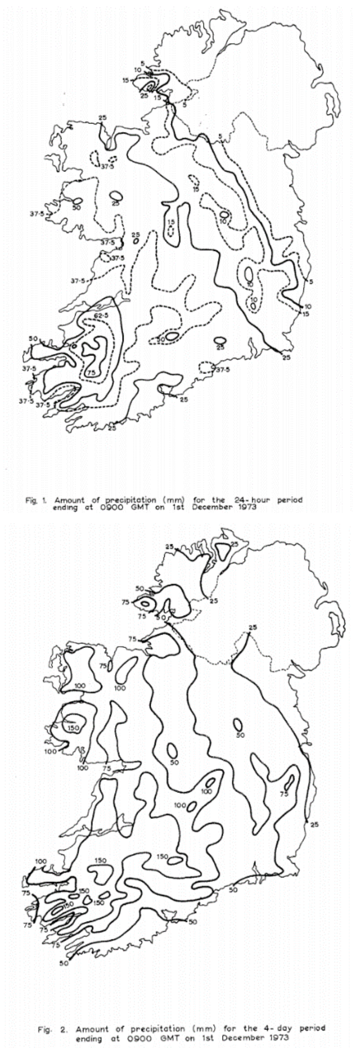


Figure 5-8: Peak1-day and 4-day Rainfall depths for the November- December 1973 Event

6 Past flood event hydrological analysis

6.1 Introduction

In order to compensate for the lack of appropriate historical gauge flow data on the Galey, a rainfall-runoff analysis has been carried out to estimate the peak of flows of three recent extreme flood events at Athea Bridge namely the July 31st /August 1st 2008, 2nd September 2009 and 11th September 2015 flood events. These estimated peak flows in combination with anecdotal peak flood level data, in turn, have been used to inform the calibration of Galey hydraulic model at Athea.

As set out in Section 5 the existing Met Éireann rain-gauges in the study area only provide daily rainfall totals which are insufficient for estimation of peak flood flows in the flashy river catchment at Athea. To supplement the Met Éireann rainfall dataset, remote sensing rainfall records sourced from NASA (product GPM IMERG final precipitation) at a 30-minute time steps was collected and assessed.

A CN-unit hydrograph hydrological rainfall-runoff model was then developed, using the NASA rainfall dataset. The model is based on the unit hydrograph approach and was applied using the worldwide-known HEC-HMS software. The model uses as inputs extreme rainfall records gathered by NASA and the runoff coefficient also known as CN along with the time of concentration estimated in catchment base. For the rainfall transformation in real runoff the runoff coefficient must be applied and can be determined by converting the real rainfall to runoff using appropriate coefficient runoff factors through can be assessed the losses, the effective rainfall etc.

The model uses the following inputs:

- extreme rainfall records gathered by NASA
- runoff coefficient (CN)
- estimated time of concentration on a catchment basis

To convert rainfall to real runoff, appropriate runoff coefficient (CN) factors, based on catchment characteristics, initial soil moisture condition and effective rainfall, have been applied. Three CN soil moisture ranges scenarios have been used for the assessment and are outlined below:

1. Dry initial soil moisture condition scenario: Corresponds to cumulative 5-days rainfall depth less than 13mm
2. Average initial soil moisture condition scenario: Corresponds to cumulative 5-days rainfall depth ranges between 13mm and 38mm.
3. Wet initial soil moisture condition scenario: Corresponds to cumulative 5-days rainfall depth ranges above 38mm

The remote rainfall records were calibrated using the daily rainfall gauges in the Athea study area.

Figure 6-1, **Figure 6-2** and **Figure 6-3** show the generated hourly hyetographs for the 2008, 2015 and 2009 events for which a maximum record of 20.8/hr mm , 9.6mm/hr and 7.9mm/hr has been assessed respectively and compared to the estimated rainfall return periods (based on FSU database) presented in Table 5-1..

Table 6-1: Recent Past Flood Event Rainfall Return Periods (following NASA data review)

Event	Peak Rainfall, mm/hr	Storm Duration, hr	Total Storm Rainfall, mm	Estimated Rainfall Return Period
July 31st/ August 1st 2008	20.8 (8pm)	7 hours (6pm to 11pm)	64.4mm	125years
11th September 2015	9.6 (9am)	17 hours (4am to 8pm, spanning two events)	71.6mm	47 years
2nd September 2009	7.9 (10am)	4 hours (10am to 1pm)	21.0mm	2 year

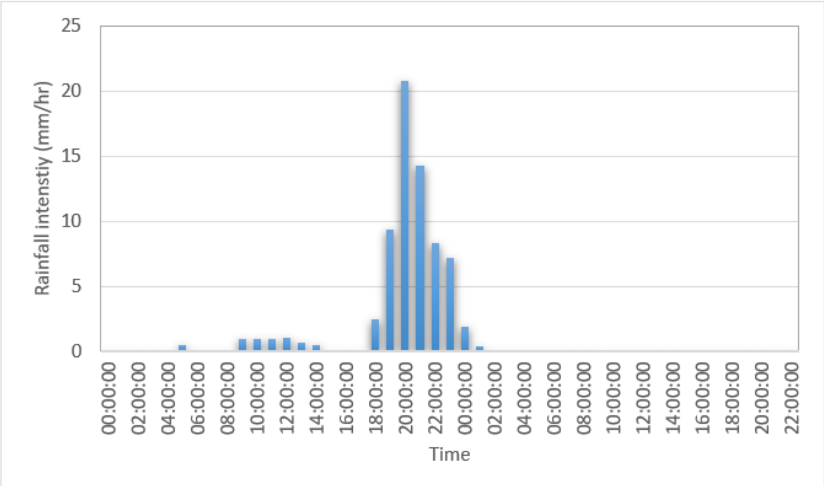


Figure 6-1: Generated Hyetograph 31st July/ 01st August 2008

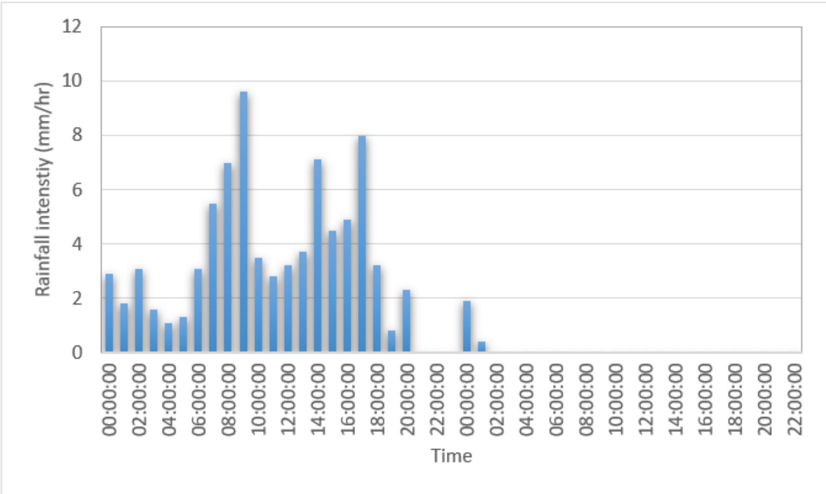


Figure 6-2: Generated Hyetograph 11th September 2015

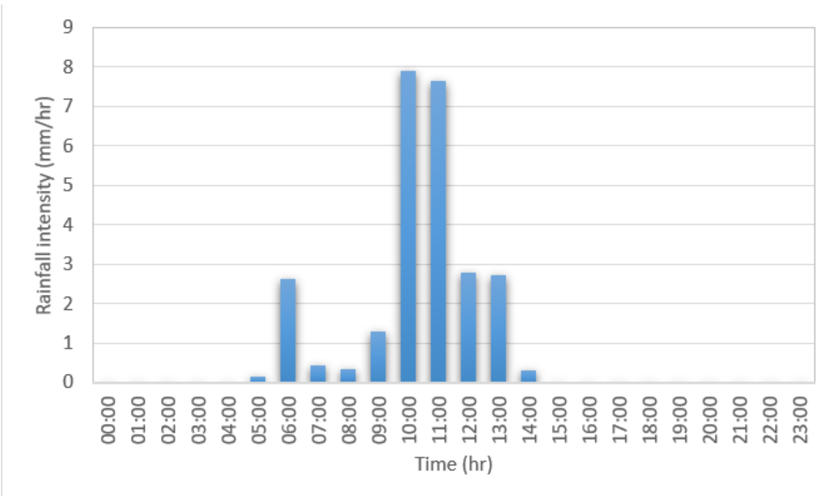


Figure 6-3: Generated Hyetograph 02nd September 2009

Wet conditions were selected to simulate catchment's CN runoff coefficient for events due to high sum of recorded values for the 5-days before the event.

Error! Reference source not found., Error! Reference source not found. **and** Error! Reference source not found. present the hydrographs generated using the CN Rainfall-Runoff Model for the above three events on Galey River at Athea Bridge, with corresponding peak flood flows of 77.3 m^3/sec (31 July to 01 August 2008), 44.2 m^3/sec (11 September 2015) and 20.3 m^3/sec (02 September 2009) respectively

The peak flow for the 2008 event which was estimated above at between 64.5m^3/s and 75m^3/s, agrees closely with the calculated peak using the CN rainfall-runoff method. It is recommended that 77.3m^3/s is used as the calibration peak flow for the 2008 event.

The peak flow for the 2015 event which was estimated above at 45m^3/s, agrees closely with the calculated peak using the CN rainfall-runoff method. It is recommended that 44.2m^3/s is used as the calibration peak flow for the 2015 event.

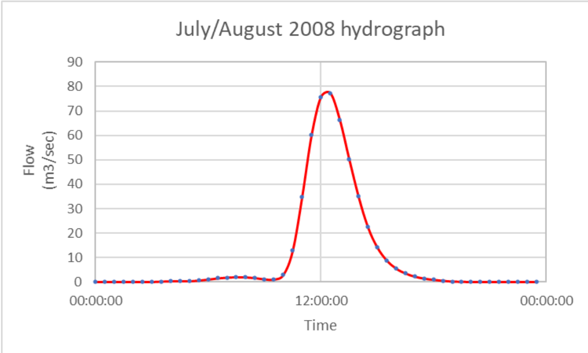


Figure 6-4: Generated Hydrograph 31st July/01st August 2008

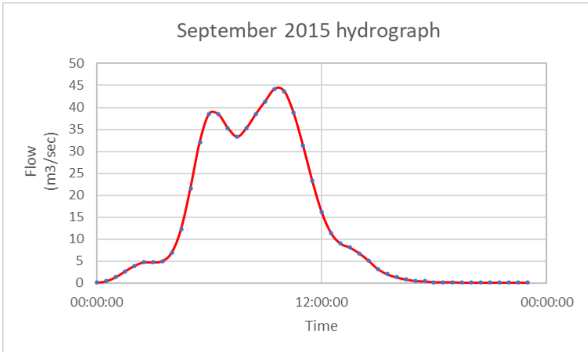


Figure 6-5: Generated Hydrograph 11th September 2015

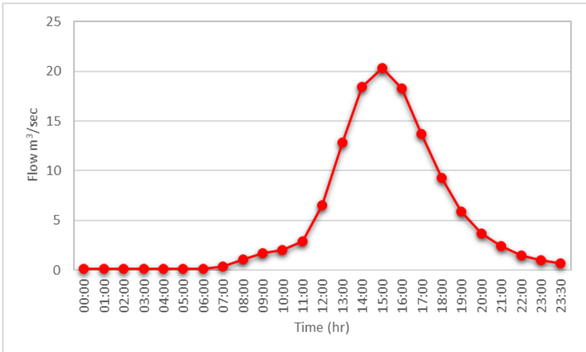


Figure 6-6: Generated Hydrograph 02nd September 2009

6.2 July/August 2008 flood event

Athea and Newcastle West in County Limerick experienced the most severe flooding in recent decades on the night of July 31st / August 1st 2008.

The flood event was not as significant further down the catchment at Inch Bridge where the only operational and calibrated river gauge in the entire catchment exists. Therefore, there was no operational gauges at Athea during this flood event from which peak flows and flood hydrograph shapes data could be collected and analysed. The catchment area at Athea Bridge is 33.5km^2 and at Inch Bridge is 191.7km^2.

Flood event report was prepared for Limerick Co. Co. by JBA and Met Eireann prepared a case study on the event. This is detailed in section 5.7 of the hydrology report. The flood event was associated with a 7-hour duration intense rainfall event and, within the Galey catchment, was very much localised to the Athea Bridge catchment. There are no sub-hourly recording gauges within the Galey catchment. There are three rain gauges in the study area which collect daily rainfall totals. Met Eireann approximated rainfall intensities in the catchment for the event based on a donor sub-hourly rain gauge to the south. The rainfall event was estimated to have had a return period of the order of 100year.

Direct use of the Inch Bridge gauge for estimation of peak flood flow rates was examined and deemed not appropriate due to the differing catchment attributes and the localised nature of the rainfall event but the gauge did provide an indicating of the upper threshold of the peak flood flow. Due to the absence of gauged data for the Galey at Athea Bridge it was necessary for Ryan Hanley to pursue various approaches to allow an appropriate estimation of the peak flood flow and hydrograph shape for the 2008 event to be completed with a good degree of confidence:

Approach No. 1

- Anecdotal peak flood level information was collected from the public and local authority upstream and downstream of Athea Bridge. As the flood event occurred around midnight, no photographic evidence of the levels at the bridge were available (Section 3.5.2.1of the hydrology report)
- Anecdotal information on the condition of the channel and bridge following the flood event was gathered.
- The peak flood flow area at the bridge was estimated from the CFRAM cross-section drawings and post-flood photographs, together with the anecdotal peak flood level data. (See Section 2.1.7.5 of the hydrology report).
- A typical range of flood flow velocities through the bridge in combination with the approximate peak flood flow area at the bridge were used then to approximate the peak flood flow rate.
- The peak flood flow rate range was approximated at between 63.0 and 73.5m^3/s. This approach was deemed to be only appropriate to provide an indicative range and therefore other approaches were required.

Approach No. 2

- The peak flood flow was then estimated at estimate 77.3m^3/s using the FSR Unit Hydrograph methodology based on detailed review of the catchment characteristics, on the SAAR 8110 dataset and a 7-hour storm duration (which is approximately the critical time to peak for the catchment) and the reported approximated rainfall totals provided by Met Eireann for the event.
- This estimate was higher than the indicative range which suggested (a) high flow velocities at the bridge, (b) larger flood flow area and (c) overland flow bypassing the bridge
- While FSR method was a significant improvement on the calculated indicative range, the confidence regarding the rainfall totals and storm duration had not been confirmed and Ryan Hanley therefore deemed it necessary to undertake further additional approaches to improve the confidence in the peak flood flow estimation.

Approach No. 3

- To improve the confidence in the rainfall a detailed assessment of NASA GPM-IMERG 30-minute time step remote sensing records of rainfall intensities was undertaken for the Athea Bridge catchment. The confirmed statistical error for rainfall data is reported at +/- 10% based on previous case studies[5]. The rainstorm associated with the event at Athea was confirmed as a 7-hour rainstorm with a median total rainfall depth of 64.4mm, which equates to rainfall event return period of the order of 125 years. This rainfall depth agrees closely with the Met Eireann approximations.
- A CN-unit hydrograph hydrological rainfall runoff analysis was undertaken for the catchment using this rainfall data and the peak design flood flow estimated at 77.5 m^3/sec using median rainfall intensities as set out above.
- This peak flood flow calculation agreed closely with the FSR unit hydrograph method and used the best available recorded rainfall dataset for the catchment and therefore no further analysis was deemed necessary.

[5] Feng, K., Hong, Y., Tian, J., Luo, X., Tang, G., & Kan, G. (2021). Evaluating applicability of multi-source precipitation datasets for runoff simulation of small watersheds: a case study in the United States. European Journal of Remote Sensing, 54(sup2), 372-382

7 Gauge Rating Review

This section includes:

- A review of the available gauge data for the study area.
- A rating curve review for the Inch Bridge gauge.
- A revised rating curve, in the power law format, i.e. $Q = C(h-e)^{\beta}$, for the Inch Bridge gauge, and;
- The revision of instantaneous flows, annual maxima and Qmed, Qbar values for Inch Bridge gauge based on the revised rating curve.

As set out in Section 3.2 (Available River Gauge Data), river gauge data has been collected historically at three locations in the Galey River catchment at Inch Bridge (23001), Galey Bridge (23004) and Athea Bridge (23014), however only the Inch Bridge gauge has an adequate gaugings dataset available to allow a rating review to be completed.

7.1 Inch Bridge (23001)

7.1.1 Current Rating Curve and Gauge Zero

A summary of the CFRAM review of the Inch Bridge gauge rating equation is given in Section 3.2.1.4 above. Table 7-1 and Table 7-2 present the gauge zero history provided by the OPW for Inch Bridge and the Inch Bridge gauge current rating curve equations. Two variations of ratings were historically developed for the gauge by the OPW, the first from August 1954, and the second (current) one is understood to be valid since 5th of June 1972. The existing rating curve for Inch Bridge gauge is shown in Figure 7-1.

Table 7-1: Inch Bridge gauge zero history

Value [mOD]	Datum	Valid From	Valid to
7.054	Malin	01/08/1954	05/06/1972
7.130	Malin	06/06/1972	08/09/1980
7.143	Malin	09/09/1980	10/09/1996
7.137	Malin	11/09/1996	Present

Table 7-2: Current Inch Bridge rating curve equations

Limb No.	C	e	β	Min stage (m)	Max stage (m)
1	25	-0.05	1.997	0	0.119
2	21	0	1.586	0.120	1.152
3	20	0	1.931	1.153	3.5

Note: The parameters for the existing rating where $Q = C\ (H - e)^{\beta}$ are given as (Q = flow, H= stage)

7.1.2 Gauged Data Review

There have been 172 No. flow gaugings undertaken at Inch Bridge between 1945 and 2011. As the River Feale Arterial Drainage Scheme was completed in 1959, the gaugings before 1959 (23 no.) are taken as not appropriate to represent the existing system. The flow gaugings up to 1959 did not exceed 57.91m^3/s. The remaining 149 No. are included in this gauge rating curve assessment. Since the start of 2015, 10 No. gaugings have been undertaken with the largest recorded flow of 59.5m^3/s (04/01/2016). The gaugings since the CFRAM hydrology report for the study area was issued in July 2016 have not exceed 15m^3/s. Table 7-3 summarises the number and range of gaugings at Inch Bridge.

Table 7-3: Inch Bridge Gaugings Ranges

Gauge Flow Range, m^3/s	Stage Range, m (corrected to current)	No.	% of Total	Comment
0 to 1	-.004 to 0.36	70	47%	Low flows. Potential susceptible to debris, deposition, scouring etc.
1 to 5	0.13 to 0.44	41	27.5%	
5 to 10	0.41 to 0.69	14	9.4%	
10 to 40	0.62 to 1.39	19	12.8%	
40 to 60	1.59 to 1.80	3	2%	Low number of gaugings for this range
60 to 100		0	0%	No readings in this range
100 to 120	2.57, 2.48	2	1.3%	106, 116.5m^3/s. Low number of gaugings for this range. The higher gauged flow had a surveyed lower stage.

The majority of the gaugings (74.5% of the total gaugings) coincide with low to very low flows, ($5m^3/s$ or less). These lower range of gauged flows are likely susceptible to error due to variations in the channel bed from debris, deposition and erosion etc. In total there are only 38 No. gaugings over $5m^3/s$ at the bridge and only 5 No. of these are over $40m^3/s$.

Figure 7-1 presents the full dataset of gaugings relative to the current rating curve. Figure 7-2 presents the dataset up to $5m^3/s$, Figure 7-3 presents the dataset between $5m^3/s$ and $40m^3/s$ and Figure 7-4 presents the dataset between $5m^3/s$ and $120m^3/s$ relative to the existing gauge rating curve. The full gaugings dataset is included in Appendix E. While flows of up to $210m^3/s$ have been estimated at the bridge using the current rating curve, the gauge is only currently rated up to $116m^3/s$ (i.e. maximum flow gauging on record).

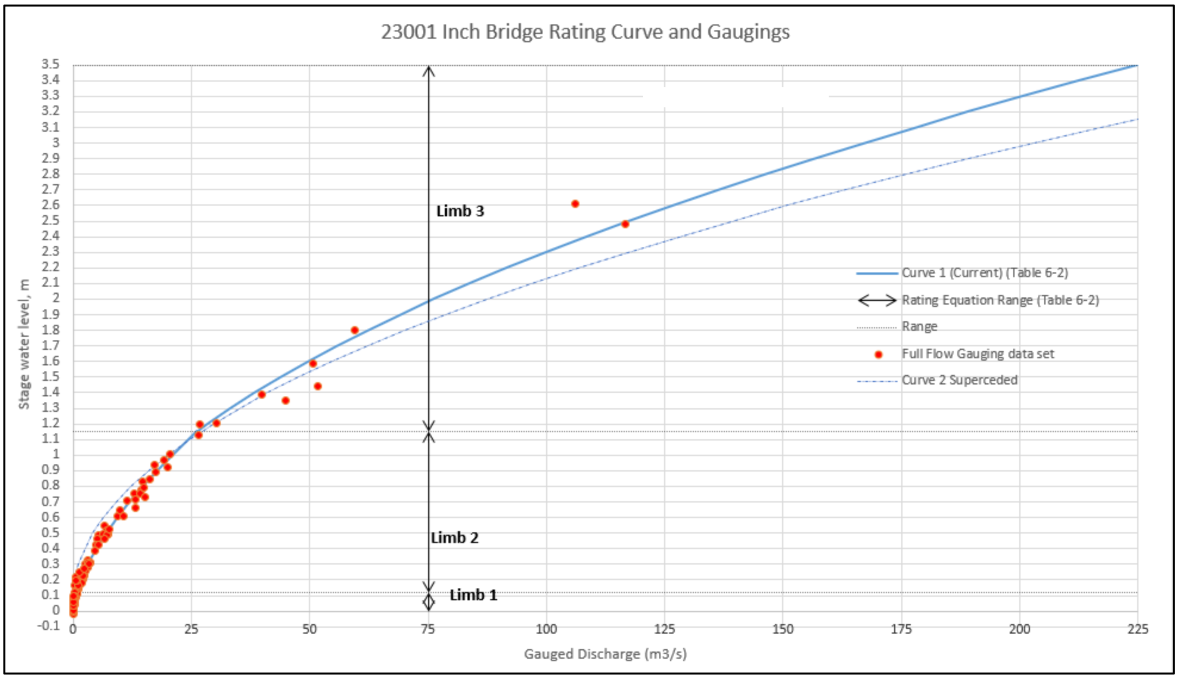


Figure 7-1: 23001 Inch Bridge Current rating curve and Full gauging dataset

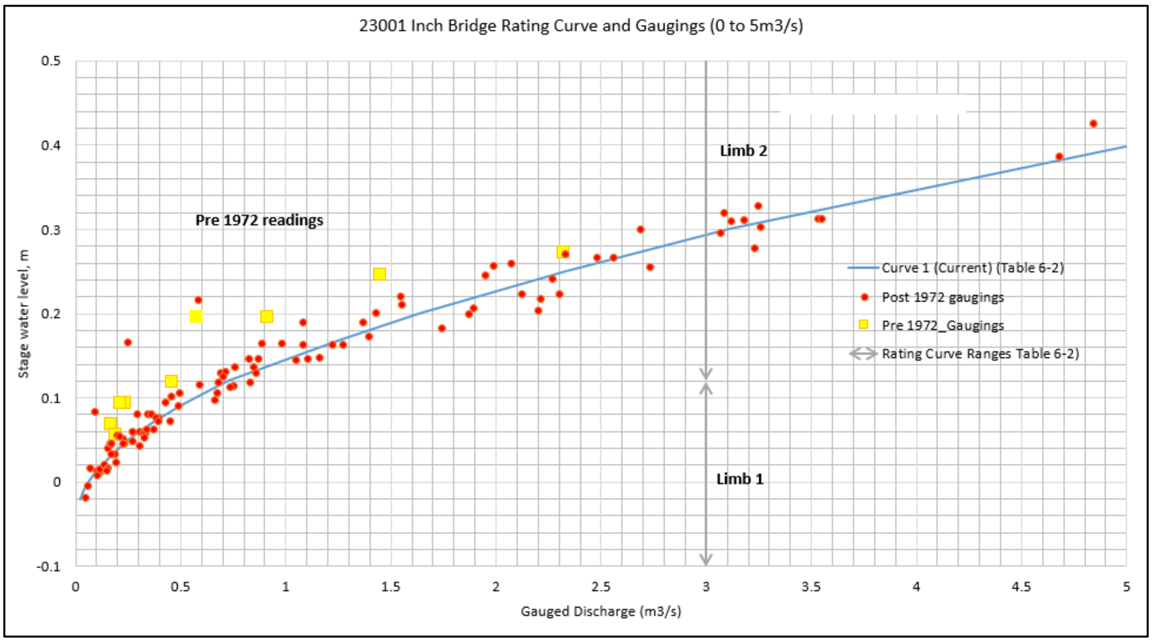


Figure 7-2: 23001 Inch Bridge Current rating curve and Low Flow gauging dataset

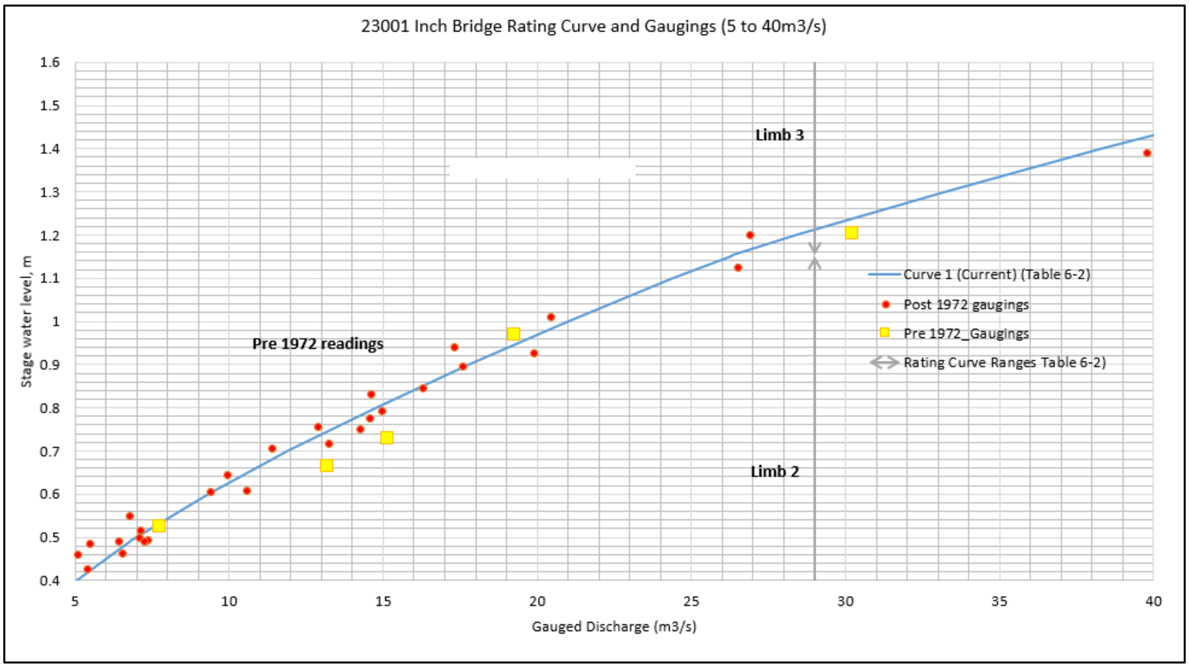


Figure 7-3: 23001 Inch Bridge Current rating curve and Moderate Flow gauging dataset

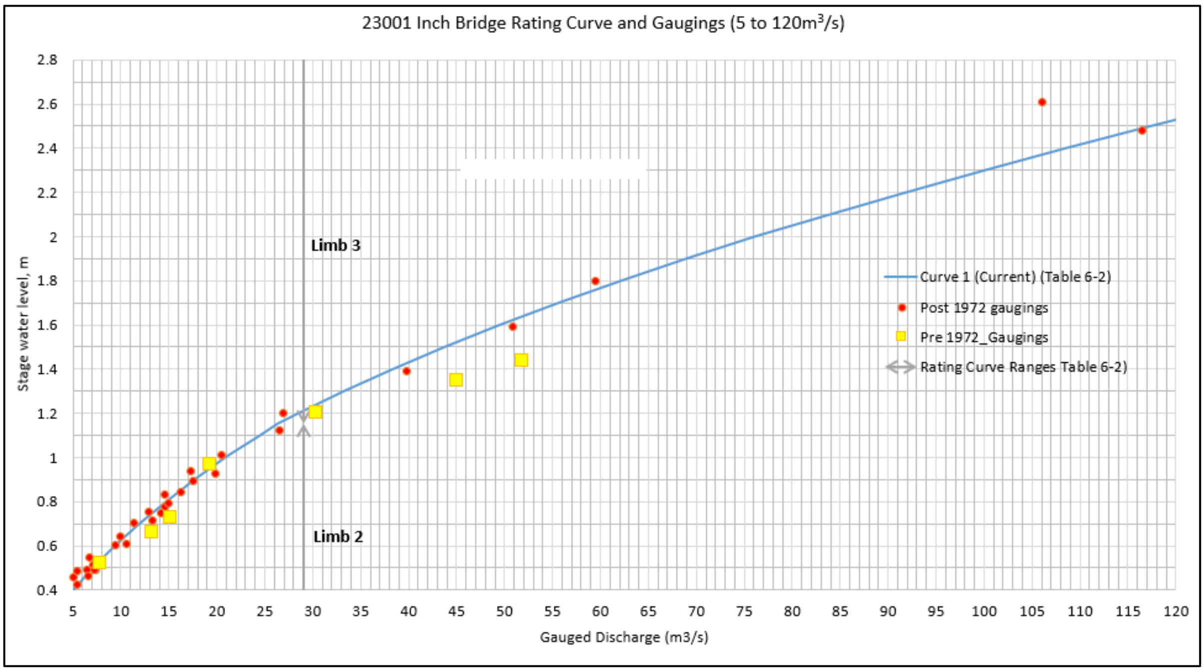


Figure 7-4: 23001 Inch Bridge Current rating curve and Higher Flow gauging dataset

By visual inspection it appears that:

- the pre 1972 low flow (0 to 3m^3/s) (9 No.) gaugings recorded, in general, had lower flows for higher stages. It is proposed, therefore, that the pre-1972 low flow readings range are omitted from the rating review. The existing low flow rating curve appears optimum but will be checked here.
- The pre 1972 moderate flows (3 to 30m^3/s) (4 No.) gaugings appear follow the same trend as the post 1972 gaugings, albeit with in general higher flows gauged for lower stages. It is proposed that the pre-1972 moderate flow readings range are included in the rating review. The existing moderate flow rating curve is optimum but will be checked here.
- The pre 1972 higher flows (>30m^3/s) gaugings (2 No.) recorded higher flows for lower stages than the post 1972 gaugings. It is proposed that the sensitivity of including the pre-1972 low flow readings range is assessed for the rating review.

- The higher gaugings i.e. 106m^3/s (29/11/2011, stage 2.61m) and 116m^3/s (06/03/1998, stage 2.48m) stages differ appreciably. The available gaugings notes do not clarify the potential reasons for the discrepancy. More gaugings will be required at this higher range of flows to confirm the appropriate rating curve for flood events. The high velocities associated with these flow rates could impact on the accuracy of the gaugings.

7.1.3 Gaugings Flow Velocities

To further understand the magnitude of gaugings during high flow conditions at Inch Bridge, an overview has been undertaken of the average flow velocities at the bridge and the upstream channel section (based on CFRAM channel and bridge survey data and the estimated flow area) when the gaugings were recorded. Inch Bridge comprises a twin spin bridge (arches with slab extensions upstream and downstream. Each span is 7.9m wide, the channel invert is typically 7.0mOD, the soffit of the bridge is approximately 11.5mOD and the arch springs are at 10.15mOD. The bridge is 10.82m long. Its central pier is approximately 1m wide and includes cut-waters and scour protection. There is no information on the dimensions of the scour protection works but they are approximately 0.3m wide and 1.4m from photographic evidence and the staff gauge reading (1m = 8.14mOD, circa 20 - 25m^3/s on 24/11/2020, 15:35). The maximum water level recorded was 10.5mOD (13.21mOD Poolbeg) with an estimated flood flow peak of 210m^3/s (01/12/1973). Figure 7-5 and Figure 7-6 present a photo of Inch bridge and the estimated effective flow area at Inch bridge and its immediate upstream channel cross-section relative to stage depth. Table 7-4 presents the estimated average channel velocity at the gauge for the maximum recorded level and top 4 No. gauged flows and the bridge and channel flow areas compared to stage.

Figure 7-5: Upstream face of Inch Bridge (24th November 2020)

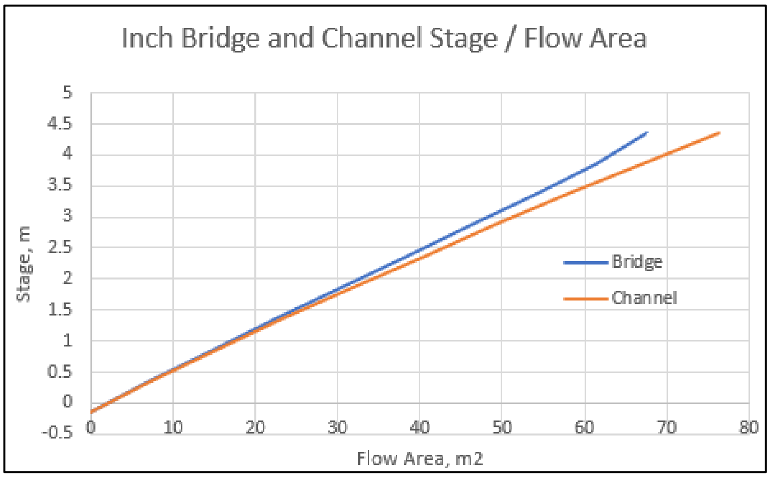


Figure 7-6: Inch Bridge and immediate upstream channel cross section flow areas compared to stage.

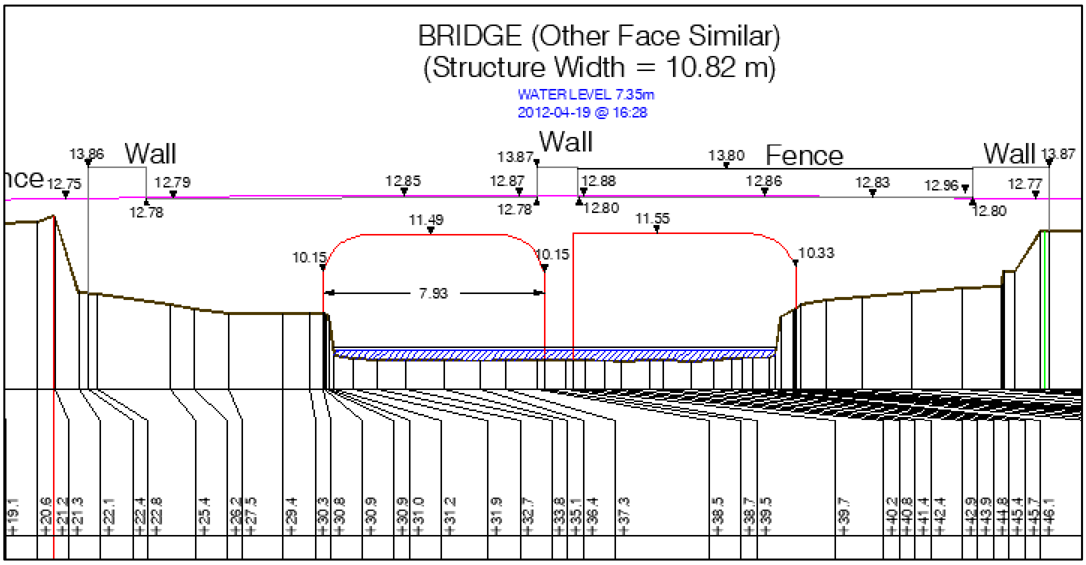


Figure 7-7: Inch Bridge CFRAM Survey

Table 7-4: Estimated Average Velocities for varying Flow Rates

Flow Rate, m^3/s	Gauged Water Level, mOD	Bridge, m/s	Channel, m/s
210.0 R	10.5#, ##	3.9	3.6
116.5 G	9.59	2.90	2.7
106.0 G	9.70	2.6	2.4
59.5 G	8.94	2.0	1.9
50.8 G	8.72	1.9	1.9
39.8 G	8.53	1.7	1.7
26.9 G	8.34	1.4	1.3

Note: R= recorded (extrapolated), G =flow gauging, # Bridge springing at 10.15mOD, ## = almost 1m higher than maximum recorded gauging stage

Given that the typical flow measurement error is 10% to 15%, gauging during flood conditions at Inch Bridge could have higher errors and be problematic due to the high flow velocities. The accuracy of extrapolation beyond the previous maximum gauging at Inch Bridge could be further impacted by:

- the reduced open area due to the prominence of the bridge arches downstream of the gauge at higher stage levels,
- the likely turbulent conditions associated with the high flow velocities,
- contraction and afflux at the bridge
- flood debris getting caught at the central pier and between the deck and high flood levels.

7.1.4 Supplementary Modelled Data

To supplement the available gaugings dataset beyond the current maximum gauging flow of $116m^3/s$, a hydraulic model has been developed for the Inch Bridge reach and high flow rates between 170 and 220 m^3/s have been simulated to estimate the resultant gauge stage level. This model output (supplementary modelled data) is summarised in Table 7-5 and has been included in the dataset for the analysis of the revised rating curve. Further details of the hydraulic model at Inch Bridge are include in the Athea FRS Hydraulic Modelling Report.

Table 7-5: Supplementary Modelled Data

Flow Rate, m^3/s	Modelled Stage, m
169.2	3.13
181.0	3.30
191.0	3.44
202.0	3.66
220.0	3.80

7.1.5 Revised Rating Curve

Revised Rating Curves at Inch Bridge gauge for the various stage ranges have been developed in the power law format for the gaugings dataset (including the supplementary modelled data). Figure 7-8 to Figure 7-10 present the revised curves generated for each range. Figure 7-9 also includes a rating with the lower stage gaugings pre 1972 for completeness and demonstrates that their inclusion would slightly over-estimate flows for the lower stages and under-estimate flows for the higher stages compared to their exclusion and consequently it is proposed to omit these lower stage gaugings pre 1972 from the revised rating curve dataset. Table 7-6 summarises the revised rating curve power law parameters and ranges.

Table 7-6: Proposed Revised Inch Bridge rating curve equations

Equation No.	C	e	β	Min stage (m)	Max stage (m)
A	1.771	-0.824	15.097	0	0.119
B	21.191	0	1.602	0.120	1.149
C	22.819	0	1.708	1.150	3.800

Note: The parameters for the existing rating where Q = C (H - e)$^{\beta}$ are given as (Q = flow, H= stage)

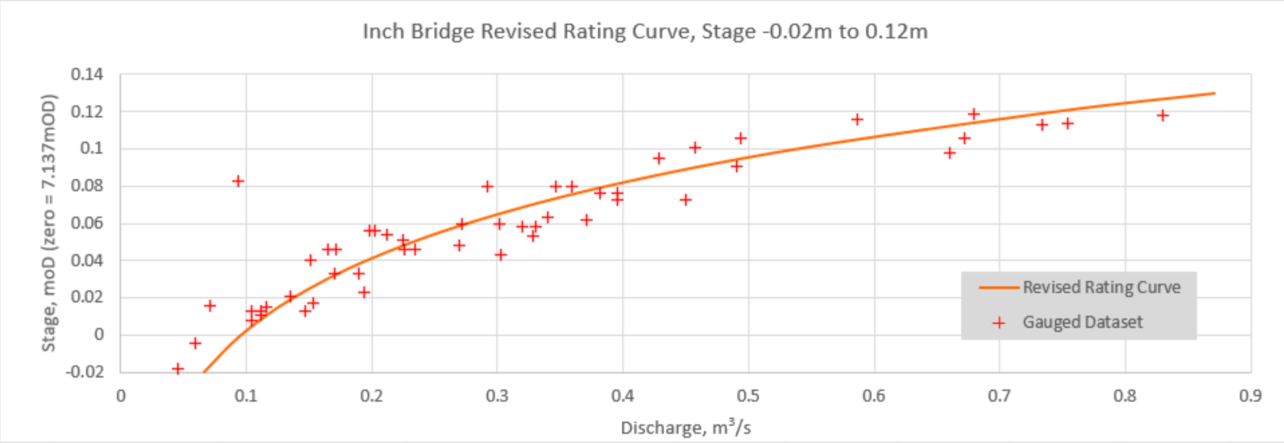


Figure 7-8: Revised Rating Curve (Equation A)

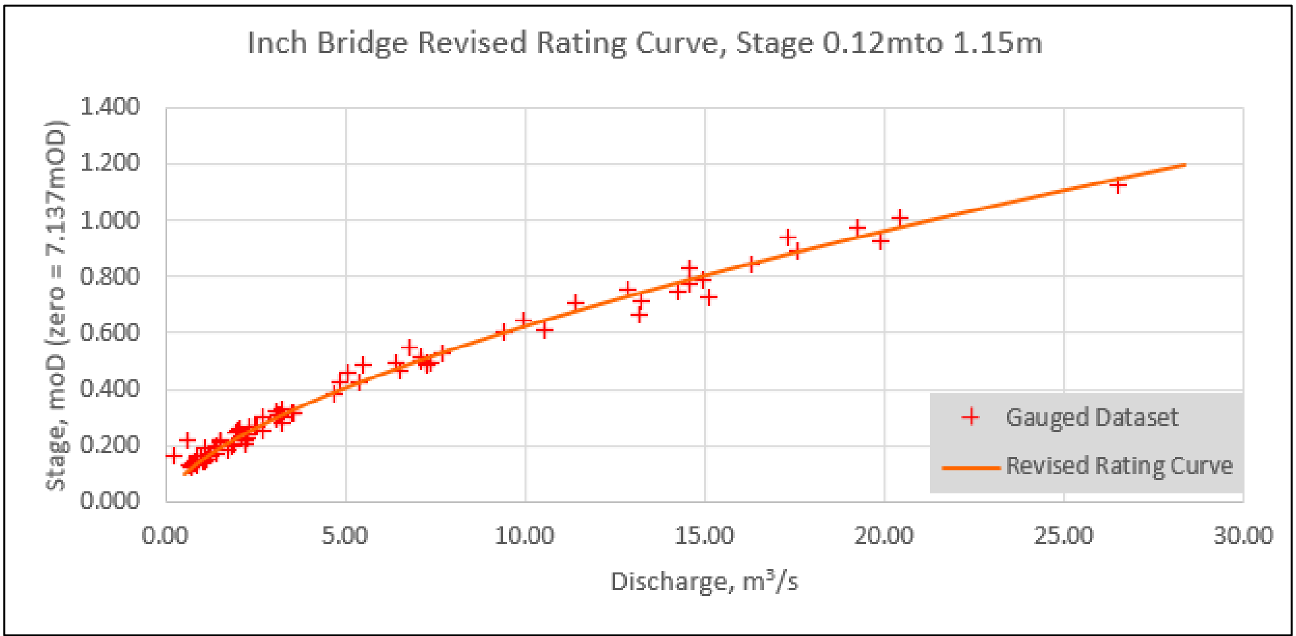


Figure 7-9: Revised Rating Curve (Equation B)

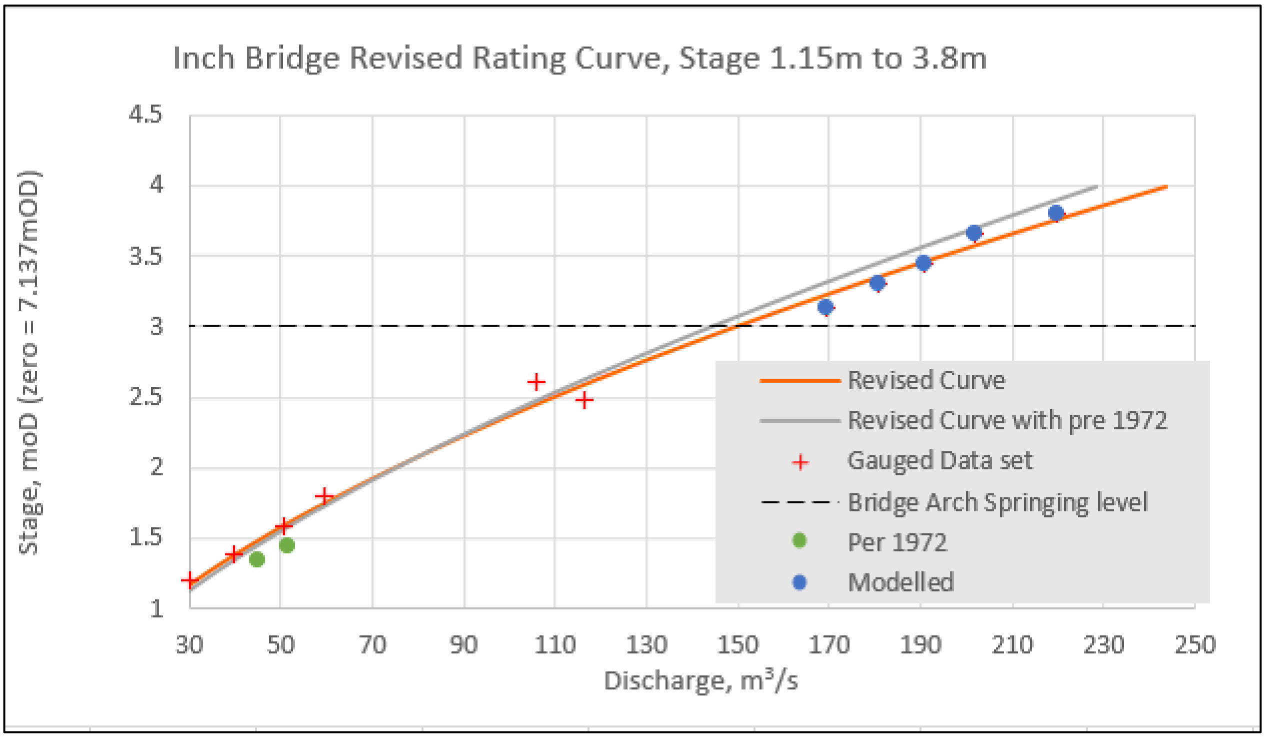


Figure 7-10: Revised Rating Curve (Equation C)

7.1.6 Current and Revised Rating Curve Comparison

Figure 7-11 presents a comparison of the Current Rating Curve (Table 7-2) and Revised Rating Curve (Table 7-5) for the Inch Bridge gauge. The revised rating curves have been extrapolated to a stage level of 3.8m by hydraulic modelling.

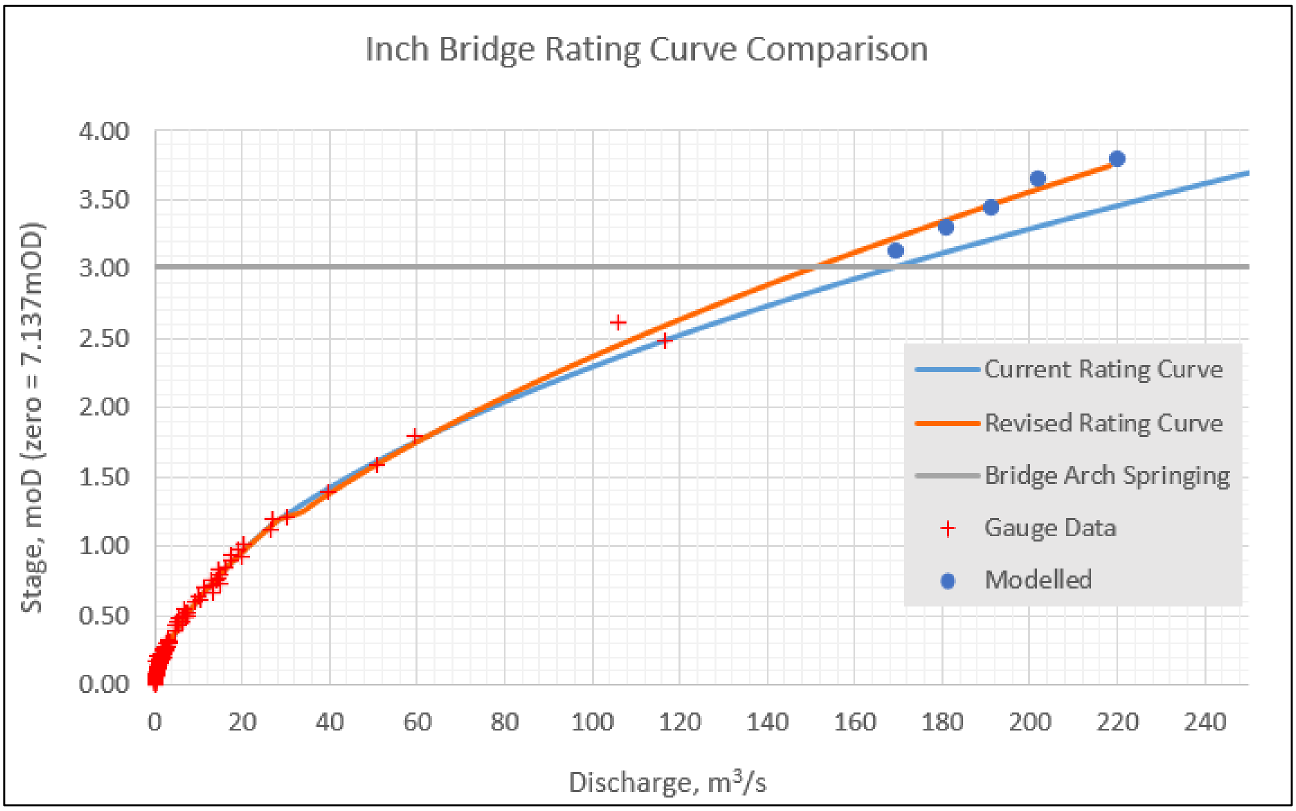


Figure 7-11: Rating Curves Comparison

The revised rating curves provides a better fit for the lower gaugings range. Changes in the riverbed (i.e. erosion, deposition etc.), debris accumulation etc. could have an impact on the stage / discharge relationship at these shallow flow depths. There are insignificant differences between the rating curves for the 0.15m to 1.2m stage range. The revised curve estimates slightly higher discharges relative to stage for 1.2m to 1.5m stage range and then in 1.5m and 2.1m stage range there are insignificant differences. Beyond the 2.1m stage, the curves deviate noticeable with the revised curve predicting lower flows for higher stages. This is not unexpected as the current curve appears to ignore the 106m^3/s gauging while the revised considers both the 106 and 116m^3/s gaugings and model outputs. It is recommended that additional gaugings at the higher flow range are surveyed to further improve the rating curve.

It is proposed that the revised rating curve is used for calculation of the Amax series, Qmed, Qbar etc. for this study.

7.2 Conclusion

It is concluded that:

- The revised rating curve appears to represent the post 1972 gaugings dataset better than the current rating curve.
- The revised rating curve has been extrapolated using hydraulic modelling.
- The revised rating curve is suitable to be used for calculation of the Amax series, Qmed, Qbar etc. for this study.

8 Revised AMAX Series and Growth Factor Analysis

8.1 Introduction

This section includes:

- The revision of the Inch Bridge gauge AMAX series based on the revised rating curve developed in Section 6.
- A single site growth factor analysis for the Inch Bridge AMAX series.
- Review of the historic flood events' return period and magnitude at Inch Bridge.
- Assessment of the correlation between daily rainfall total and peak flows at Inch Bridge.
- Single site growth factors analysis for adjacent catchments.
- FSU pooling growth factors analysis for the Athea Bridge catchment

The analysis in this section allows the appropriate growth factors for the Athea Bridge catchment to be recommended and provides a sensitivity on the growth factors which allows more confidence in the selected study area growth factors to be illustrated.

8.2 Revised Inch Bridge (23001) Gauge AMAX Flow Data

As set out in Section 6, a proposed revised rating curve has been calculated for the Inch Bridge Gauge (23001) and consequently a revision of the AMAX series is required. There is a long annual maxima data record for Inch Bridge comprising 12 No. years AMAX stage data only (1960-1972) and 48 No. years of stage and flow AMAX (1972-2020) for hydrometric years 1960 to 2019. As the arterial drainage scheme in the Galey catchment was completed in the 1959 any AMAX data before 1960 has been disregarded.

A revised AMAX series for Inch Bridge, extending back to 1960 has been calculated using the proposed revised rating curve. Figure 8-1 presents a comparison between the proposed revised and 'current' rating curve dataset.

The CFRAM study reported three high Amax flows at Inch Bridge gauge during the 1960s including 215 m^3/s (1962), 197 m^3/s (1967) and 204 m^3/s (1968). These reported flows have been reviewed based on the proposed revised rating curve and the Amax recorded stage data (corrected for the period's appropriate gauge zero). This review recommends that the 1962, 1967 and 1968 AMAX flows be revised downwards to 148.4m^3/s, 137.9m^3/s and 142.0m^3/s respectively. These revisions are important and are significant with respect to the design flow estimation for the scheme. A fourth high AMAX flow from this period was recorded in the 1964 at 126.3m^3/s.

The revised rating curve AMAX flow series are less than those of the current rating curve, with increasing difference as stage increases (See Figure 7-10 above).

- The revised average annual maxima flow (Qbar) at the gauge is calculated at **98.08m^3/s** compared to the existing rating's 103.69m^3/s.
- The revised and current median of the annual maxima flows (Qmed) for the dataset are calculated at **95.71m^3/s** compared to 96.91m^3/s respectively.

The highest gauged flow (HGF) is 116.55m^3/s. The ratio of HGF to Qmed is calculated at 1.22 suggesting the gauge has an A2 rating. However, as set out in Section 6, the variance of the gaugings at the higher extents has led to some uncertainty in the rating beyond 60m^3/s. While hydraulic modelling has improved the rating curve extrapolation, flow gaugings above 125m^3/s would be required, and the rating curve revised accordingly, to allow the Inch Bridge gauge be given an A1 rating.

https://opw.hydronet.com/data/files/Work%20Package%202_1%20-%20Final%20Report.pdf

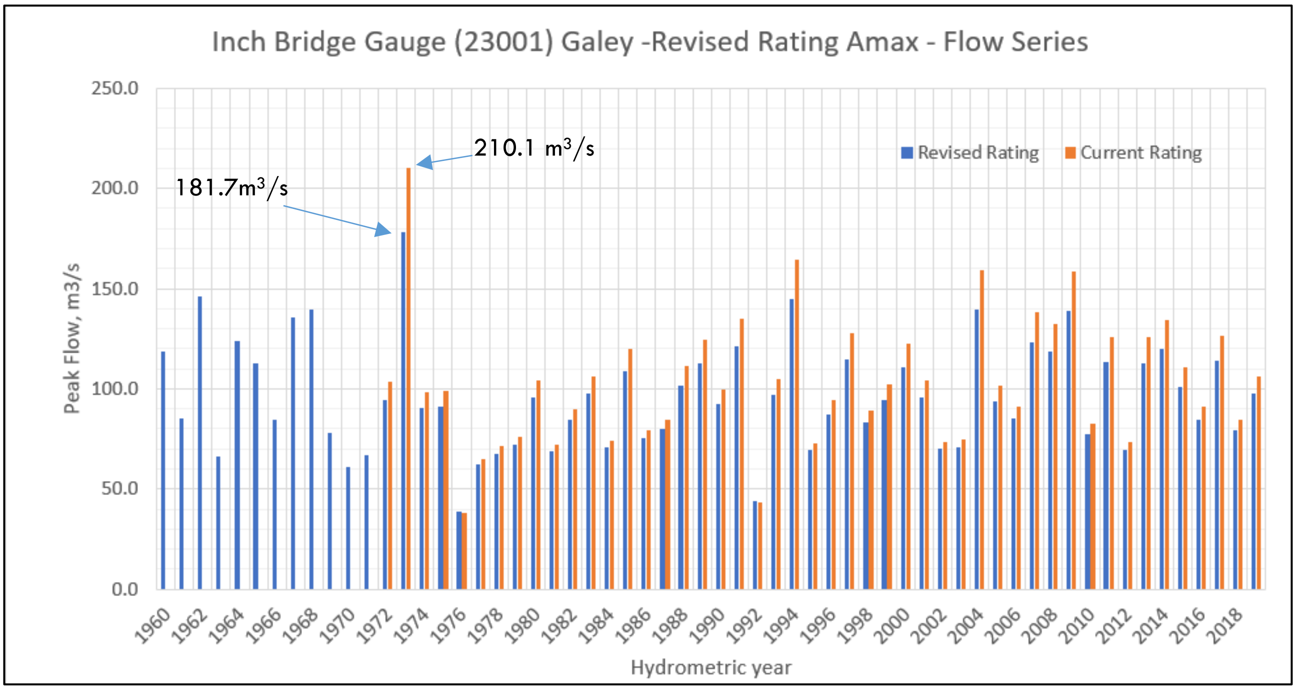


Figure 8-1: Rating Curves Comparison

8.3 Inch Bridge Growth Factors Analysis

An EV1 (Gumbel) statistical frequency analysis (OPW FSU WP2.2 recommended approach) has been undertaken for this study using the full 60 years of revised Inch Bridge AMAX flow data set to calculate the single site analysis growth factors for the site and to allow the return periods of historic flood events in the catchment to be estimated. Table 8-1 and Figure 8-2 present the analysis results of the EV1, EV1-68% Upper Confidence Interval (UCI) and EV1-95% UCI and their calculated growth factors relative to the revised Amax Qbar and Qmed.

Table 8-1: Calculated Flood Return Period flows and calculated Growth Factors for AMAX flows (1960- 2020)

Flood Return Period (Years)	AEP %	Flow (m^3/s)	Growth Factor EV1 Flow		Flow (m^3/s)	Growth Factor EV1 Flow (68% UCI)		Flow (m^3/s)	Growth Factor EV1 Flow (95% UCI)	
		EV1	Qbar	Qmed	EV1- 68% Upper CI	Qbar	Qmed	EV1- 95% Upper CI	Qbar	Qmed
1 in 2	50%	93.71	0.96	*0.98*	96.95	0.99	*1.01*	100.19	1.02	*1.05*
1 in 5	20%	118.15	1.20	*1.23*	123.61	1.26	*1.29*	129.07	1.32	*1.35*
1 in 10	10%	134.34	1.37	*1.40*	141.71	1.44	*1.48*	149.09	1.52	*1.56*
1 in 20	5%	149.86	1.53	*1.57*	159.18	1.62	*1.66*	168.50	1.72	*1.76*
1 in 50	2%	169.95	1.73	*1.78*	181.85	1.85	*1.90*	193.75	1.98	2.02
1 in 100	1%	**185.01**	1.89	*1.93*	198.87	2.03	2.08	212.74	2.17	2.22
1 in 200	0.50%	200.01	2.04	*2.09*	215.85	2.20	2.26	231.68	2.36	2.42
1 in 1000	0.10%	234.77	2.39	*2.45*	255.19	2.60	2.67	275.62	2.81	2.88

While Figure 8-2 shows the flow dataset as, in general, lying within the 68% confidence intervals and therefore appropriate for the dataset, there is a case for using the 95% UCI for the larger flows due to:

- a small number of gaugings at the upper range which, in themselves, are at variance,
- the increased potential for gauging errors due to high flow velocities at the gauge site, and,
- change in downstream conditions (arches etc.) at Inch Bridge at the higher flood levels.

Hydraulic modelling of the Inch Bridge reach has been undertaken to assist with extrapolation of the rating curve to cover high flow rates beyond the available gauging dataset and has demonstrated that using the 95% UCI is not warranted.

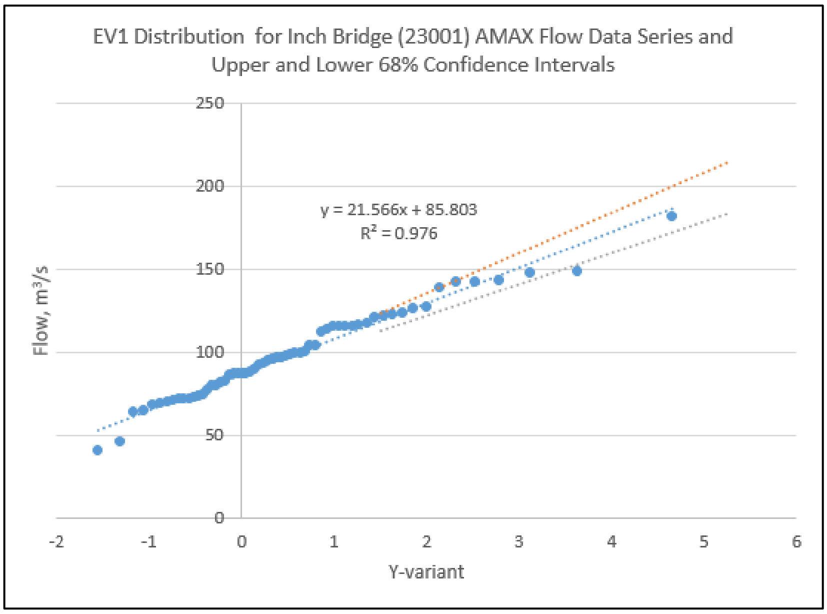


Figure 8-2: EV1 (Gumbel)- Analysis Inch Bridge (Galey River) (1960 to 2020)

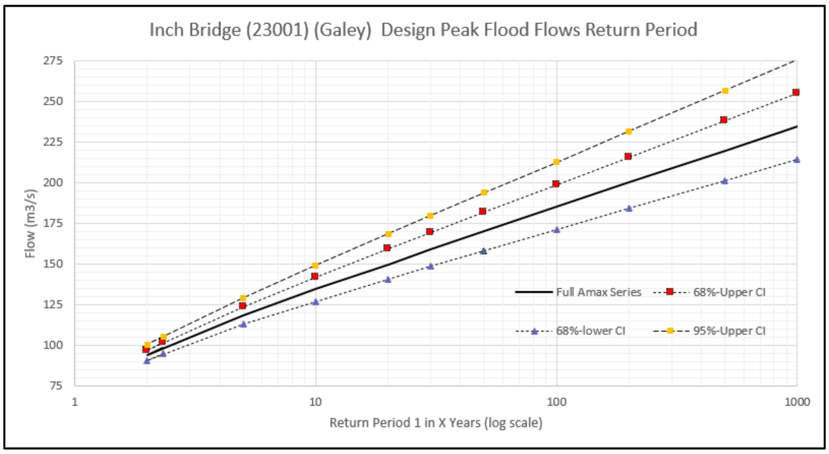


Figure 8-3: EV1 (Gumbel) Estimated Flood Flow Return Periods and Upper and Lower confidence intervals.

8.4 Historic Extreme Flood Events Return Period

Table 8-2 presents the 11 No. highest recorded Amax flows at Inch Bridge for the revised flow dataset and includes:

- a ratio of the flow to Qbar and Qmed for the dataset,
- the estimated return period of the event,
- the peak average catchment run-off rate, and
- the date of the peak flow.

The 1973 flood event at 181.1m^3/s was clearly the largest recorded with an estimated return period of 1 in 50years (2%AEP) (68% UCI) and an outlier compared to the remainder of the dataset. A review of the Met Éireann report on the 1973 rainfall event (See section 5.8) and the FSU DDF database suggests a 4-day and peak 1 -day rainfall return period of between 250 and 360years, and 35years respectively. The difference between the peak water levels and flows of the 2nd and 6th ranked events is less than 10cm and 6.3m^3/s, with return periods ranging from 1in 19 to 1 in 14. 4 No. of the 8 No. highest flows occurred in the 1960s. The peak flow magnitude of the 1995 (ranked 3rd) flood event was equivalent to the 1962 (ranked 2nd) event.

Table 8-2: Review of AMAX flow data from 1960 to 2019 (Top 11 largest Amax flows)

Rank	Flow, m³/s	Gauge Stage, m current gauge zero	Calculated Growth Factor relative to ..		EV1 68% UCI-Estimated Return Period	Catchment Run-off Flow/km²	Date
			Qbar	Qmed	1 in X years		
1	181.1	3.363	1.85	1.89	c 50	0.94	01/12/1973
2	*148.4*	2.993	1.51	1.55	<20	0.77	08/12/1962
3	147.0	2.976	1.50	1.54	<20	0.77	22/02/1995
4	142.3	2.920	1.45	1.49	c10	0.74	08/01/2005
5	*142.0*	2.917	1.45	1.48	c 10	0.74	24/12/1968
6	141.5	2.910	1.44	1.48	10	0.74	19/11/2009
7	*137.9*	2.867	1.41	1.44	< 10	0.72	07/10/1967
8	*126.3*	2.723	1.29	1.32	< 10	0.66	12/12/1964
9	125.4	2.712	1.28	1.31	< 10	0.65	01/08/2008
10	123.4	2.686	1.26	1.29	c 5	0.64	12/09/1992
11	122.4	2.673	1.25	1.28	< 5	0.64	12/09/2015

8.5 Rainfall Correlation

An indicative comparison has been made the Inch Bridge rainfall datasets (see Section 5) and the Inch Bridge flow dataset to determine if an apparent correlation exists and is presented in Figure 8-4. A time-lag between the daily rainfall totals and the flow has been included based on iteration. The comparison period is the 2018 and 2019 hydrometric years.

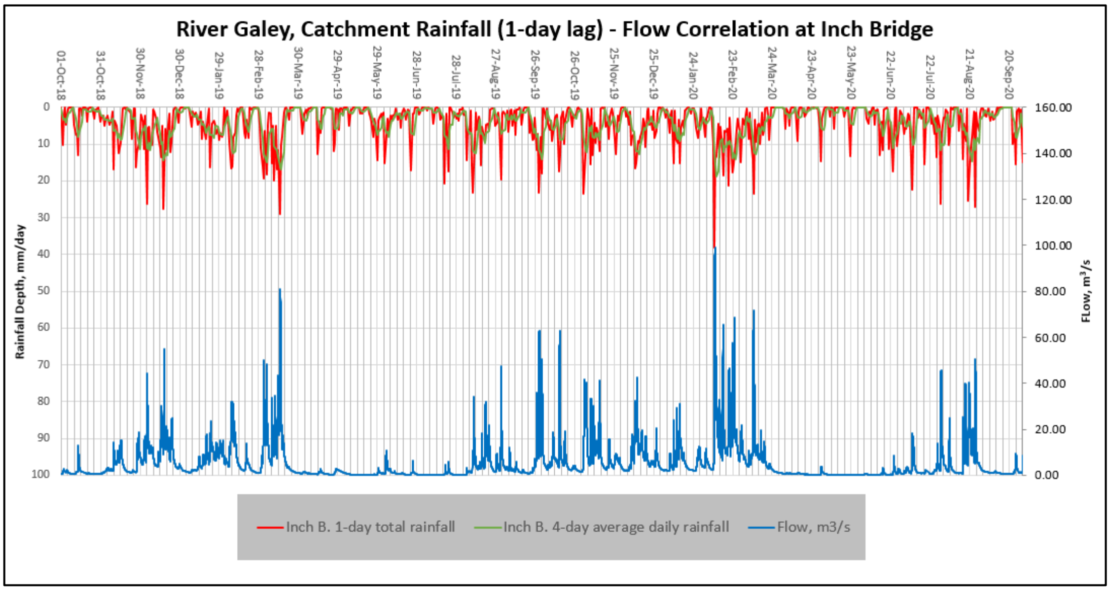


Figure 8-4: Comparison of Rainfall Intensity and Flow at Inch Bridge - Sample 2-year duration

The comparison demonstrates that:

- a lag of approximately 1-day appears to exist between the peak rainfall in the catchment and peak flows at Inch Bridge,
- the catchment responds rapidly to short duration rainfall events (<2day)
- a daily rainfall total of 29.0mm on 15th March 2019 corresponded with a peak flow of 81.2m³/s (16/03/2019 at 1:30pm)
- a daily rainfall total of 38.1mm on 8th February 2020 corresponded with a peak flow of 99.3m³/s (09/02/2020 at 1:15pm) (rising from a low flow of 4.6m³/s 24hours before)
- a daily rainfall total of 26.3mm on the 4th December (2018) and 29th July (2020) corresponded with flow peaks of 44.2m³/s (5/12/18 at 7am) and 45.8m³/s (30/07/20 at 9am) respectively. The peak 4-day average rainfall intensity leading up to both events was approximately 11mm/day.

- a daily rainfall total of c23.4mm on the 28th September (2019) and 1st November (2019) corresponded with flow peaks of 62.7m³/s (29/09/19 at 4:15am) and 41.6m³/s (02/11/19 at 6pm) respectively. The September and November 4-day average rainfall intensities peaked at 14.2mm/day and 12.2mm/day.

It is concluded that:

- While a correlation does exist between short duration heavy rain (with a lag of 1 -day) and peak flows, there is no immediate identified correlation between the magnitude of the daily rainfall and the resultant peak flow.
- While antecedent conditions influence peak flows, the seasonality of the rainfall event (i.e. evapotranspiration) does not appear always to be a significant factor.
- Peak flow magnitude is likely influenced by shorter (6 – 12 hour) rainfall events more so than long duration events (>1 day).

Figure 8-5 and Figure 8-6 present graphs to investigate the correlation magnitude of the association between daily mean and peaks flows respectively and total daily rainfall with a lag of 1 day and rainfall above 6mm/day (arbitrary) for the Athea Bridge and Inch Bridge (gauge) catchments.

The graph confirms a moderate to relatively strong correlation between the two variables for the sample hydrometric years 2018-2019 for both the mean and peak flow.

A similar exercise comparing daily peak flows >10m³/s at Inch bridge to both catchments' total rainfall (lag 1-day) demonstrated a strong correlation (Pearson's r =0.71).

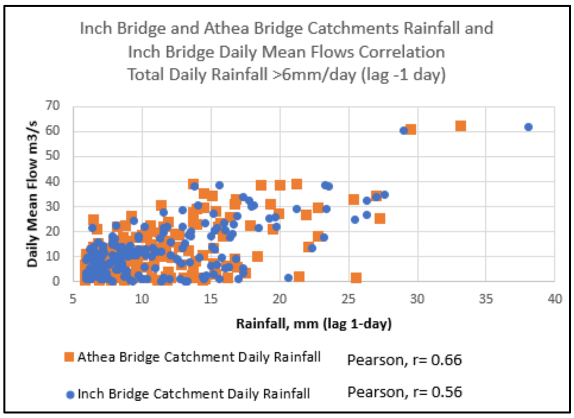


Figure 8-5: Correlation of Daily Mean Flow compared Total Daily Rainfall

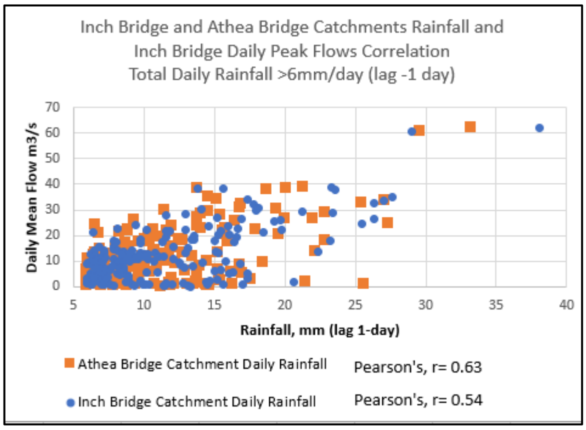


Figure 8-6: Correlation of Daily Mean Flow compared Total Daily Rainfall

8.6 Adjacent Catchments Growth Factors Analysis

A review of the OPW FSU Portal identified 7 No. gauged sites which could be considered "adjacent" to the Athea Bridge catchment. Of these 7 No., 1 No. is on the Galey River, 1 No. is on the River Feale, 3 no. are on the River Deel, 1 No. on the River Lee (Tralee) and 1 No. on the River Maine (Farranfore). Table 8-3 presents the FSU single site (EV1 distribution) analysis for 5 No. of these gauges (note: only one of the three River Deel gauges was analysed) and the respective catchment area at each gauge site. While the FSU tool performs a combined analysis for the single site analysis, for this assessment the growth curves, in general, were derived from the gauge data only (i.e. weight factor =1) as appropriate.

Table 8-3- Single site analysis AEP Growth Factors for adjacent gauged catchments

AEP %	Galey (Inch Bridge) (23001) (Table 7-1)	Galey (Inch Bridge) (23001) 68% UCI (Table 7-1)	Feale (Listowel) (23002)	Deel (Grange Br.) (24012)	Lee (Tralee) (23012)	Maine (Farranfore) (22003)
	191.7 km²		646.8 km²	366.3 km²	61.6 km²	271.3 km²
50%	0.98	*1.01*	1	1	1	1
20%	1.23	*1.29*	1.29	1.13	1.25	1.22
10%	1.40	*1.48*	1.48	1.21	1.42	1.36
5%	1.57	*1.66*	1.66	1.29	1.57	1.5
2%	1.78	*1.90*	1.89	1.39	1.78	1.68
1%	1.93	*2.08*	2.07	1.47	1.93	1.81
0.5%	2.09	*2.26*	2.24	1.55	2.09	1.94
0.1%	2.45	*2.67*	2.65	1.72	2.44	2.25

8.7 FSU Pooling Growth Factors Analysis

Using the OPW FSU portal pooling analysis tool the growth factors for Athea Bridge catchment have been estimated. Both Euclidean (hydrological similarity is defined in terms of Euclidean distance based on size-wetness-permeability) and Geographical (geographically closest) pooling methods and the EV1 and GEV distributions were used for the analysis, and the results summarised in Table 8-4 and 8-5 below.

Table 8-4: Growth Factors derived from FSU Pooling Analysis at Athea Bridge (Euclidean Method)

AEP %	Growth Factor (EV1)	Growth Factor (GEV)	Table 7-1 (EV1)
50%	1	1	*0.98*
20%	1.25	1.25	*1.23*
10%	1.42	1.4	*1.40*
5%	1.58	1.54	*1.57*
2%	1.78	1.71	*1.78*
1%	1.94	1.83	*1.93*
0.5%	2.09	1.94	*2.09*
0.1%	2.45	2.18	*2.45*

Table 8-5: Growth Factors derived from FSU Pooling Analysis at Athea Bridge (Geographical Method)

AEP %	Growth Factor (EV1)	Growth Factor (GEV)	Table 1 (EV1)
50%	1	1	*0.98*
20%	1.21	1.2	*1.23*
10%	1.35	1.33	*1.40*
5%	1.48	1.44	*1.57*
2%	1.65	1.58	*1.78*
1%	1.78	1.68	*1.93*
0.5%	1.90	1.77	*2.09*
0.1%	2.20	1.97	*2.45*

8.8 Growth Factor Analysis Conclusion

Based on the above analysis:

- A comparison of the Table 8-1 (Inch Bridge EV1) growth factors to those derived using the FSU pooled analysis EV1 distribution (Euclidean method) at Athea Bridge (Table 8-4) demonstrates a very close agreement. This would suggest that the Inch Bridge growth factors would be suitable for the Athea Bridge site.
- A comparison of the Table 8-1 (Inch Bridge EV1) growth factors to those derived using the FSU pooled analysis EV1 distribution (Geographical method) at Athea Bridge (Table 8-5) demonstrates that the Table 8-1 growth factors are higher. This suggest that using the Inch Bridge growth factors would be suitably conservative for the Athea Bridge site.
- A comparison of the adjacent gauged catchment EV1 distribution growth factors (Table 8-3) has shown that the Table 8-1 growth factors are:
    - less than those on the River Feale at gauge 23001 but very similar to the 68% UCI growth factors presented in Table 7-1. This would suggest that the Inch Bridge 68% UCI growth factors would be suitable for the Athea Bridge site,
    - higher than the Deel and the Maine growth factors, and
    - similar to the River Lee (Tralee) growth factors.

It is concluded from the growth factor analysis that, following a precautionary but not overly conservative approach, the 68% upper confidence interval growth factors (Table 8-6) derived from the revised Inch Bridge AMAX series are appropriate to be used for the design flows at Athea Bridge catchment.

Table 8-6: Athea Bridge Growth Factors

Flood Return Period (Years)	AEP %	Growth Factor EV1 Flow (68% UCI)	
		Qbar	Qmed
1 in 2	50%	0.99	*1.01*
1 in 5	20%	1.26	*1.29*
1 in 10	10%	1.44	*1.48*
1 in 20	5%	1.62	*1.66*
1 in 50	2%	1.85	*1.90*
1 in 100	1%	2.03	*2.08*
1 in 200	0.50%	2.20	*2.26*
1 in 1000	0.10%	2.60	*2.67*

9 Groundwater and Pluvial Flood Risk

9.1 Introduction

Based on a review of the hydrogeology and the GSI groundwater flood risk mapping for Athea, it is concluded that groundwater flood risk at Athea is low and no further associated assessments are required.

Two sources of potential pluvial flood risk have been identified at Athea namely:

- Catchment (hillside) Run-off
- Urban Run-off

The following subsections include an overview of the potential pluvial flood risk mechanism at Athea and their associated hydrology and presents an estimate of the pluvial flood flow rates observed at Athea during past extreme rain-storm events.

9.2 Catchment Runoff

As set out in Section 2.1.7.3 there is a network of channels and minor watercourses to the south of Athea village which drain small steep hillside catchments through Athea to the Galey River. The minor watercourse reported as being of potential flood risk to Athea are the Athea West and Athea East Streams. These channels, which in places are overgrown, ill-defined and unmaintained, appear to have been significantly modified historically. There is potential during an intense rain-storm for these channel flows to flood out of bank either due to capacity or blockages (i.e. both at channels and culverts) which could lead to concentrated overland flows down the hillside towards Athea. These overland flows in turn may:

- be intercepted by downstream channels within its own associated catchment and conveyed to the Galey River with no further flood risk,
- be diverted to downstream channels of adjacent catchments (perhaps following historic flow routes) leading to increase flows and flood risk, or,
- not be intercepted by channels and drain directly overland into Athea village leading to additional pluvial risk.

While not confirmed, it is feasible that during the September 2009 flood event (Section 3.5.3.1) excess flows from the Athea East Channel spilled over into the Athea West catchment leading to an overwhelmed system which, combined with culvert blockages in Athea West culvert, resulted in a significant overland flow which flooded houses and damaged roads. Full or partial blockage of the Athea West culvert (including the screens) on the Athea West stream system could lead to an overland flow through Athea via The Lane (as observed in the September 2009). Similarly, a blockage of the land access culvert on the Athea East stream system could result in flows backing up and diversion to the Athea West Stream with could overwhelm the Athea West culvert capacity. These various flood mechanisms have been further examined in the Athea FRS Hydraulic Modelling Report to identify the potential associated catchment runoff flood risk to Athea. Design flows for additional HEP within the stream catchments will be calculated as necessary to inform the pluvial flood risk assessment.

There are no reports or indication of flood risk associated with the Listowel Road Stream culvert to Athea and therefore it has been screened out for further pluvial flood risk assessment.

9.3 Urban Drainage

9.3.1 Contributing Areas

Athea Village streets and roads are drained by a system of storm and combined sewers (kerbs and gullies), culverts and roadside open drains. A walkover of the village during November 2020 identified a relatively low number of road gullies, many of the gullies were completely blocked with silt. Much of the storm drainage system in the village centre is understood to drain to the Athea West culvert which ultimately drains to the Galey at Markievicz Park.

A CCTV survey of the village's storm drainage system (by AQS-2021) and a review of available storm drainage maps (JBB/WYG 2007) has been completed for Athea for this study and is summarised in Figure 9-1. The village's roads drain via road gullies to a network of storm sewers, combined sewers and the Athea West Stream culvert. The sewer networks do not exceed 300mm diameter. The main combined sewer branch which drains all the village to the west (LB) of the Galey River, crosses under the Galey River (225mm diameter pipe) approximately 30m downstream of Athea Bridge (channel invert 66.7mOD) and drains to a sewerage pumping station located on the river's right bank. The pumping station forwards wastewater to the Athea WWTP which is located approximately 0.5km north of the village on the Glin Road. A combined sewer overflow (CSO) chamber (cover level = 68.7mOD and invert= 66.22mOD) is located on the pipe line to the pumping station to the rear of the Gables close to the river's left bank downstream of Athea Bridge, which discharges excess flows to the Galey River. There is a flap valve chamber located on the CSO outfall pipe which is reported to be seized in an open position but since 18 October 2021, the flap valve has been taken apart, checked and re-assembled to a correct working state. The LCCC crew maintain the CSO weekly and have reported that there is no history of manholes or gullies surcharging or overflowing in the village. There is no overflow at the pumping station. The river crossing pipe cover is likely less than 0.5m.

Storm drainage from the Rathronan Estate and Hillside Drive Estates, and the Lane and a part of Con Colbert Street drain to Athea West Stream culvert. Road gullies concentrated at the junction of Abbeyfeale and Listowel Roads and the Ardagh and Glin Roads are understood to drain to the combined sewer network.

The capacity of the storm drainage system is further considered in the Athea FRS Hydraulic Modelling Report.

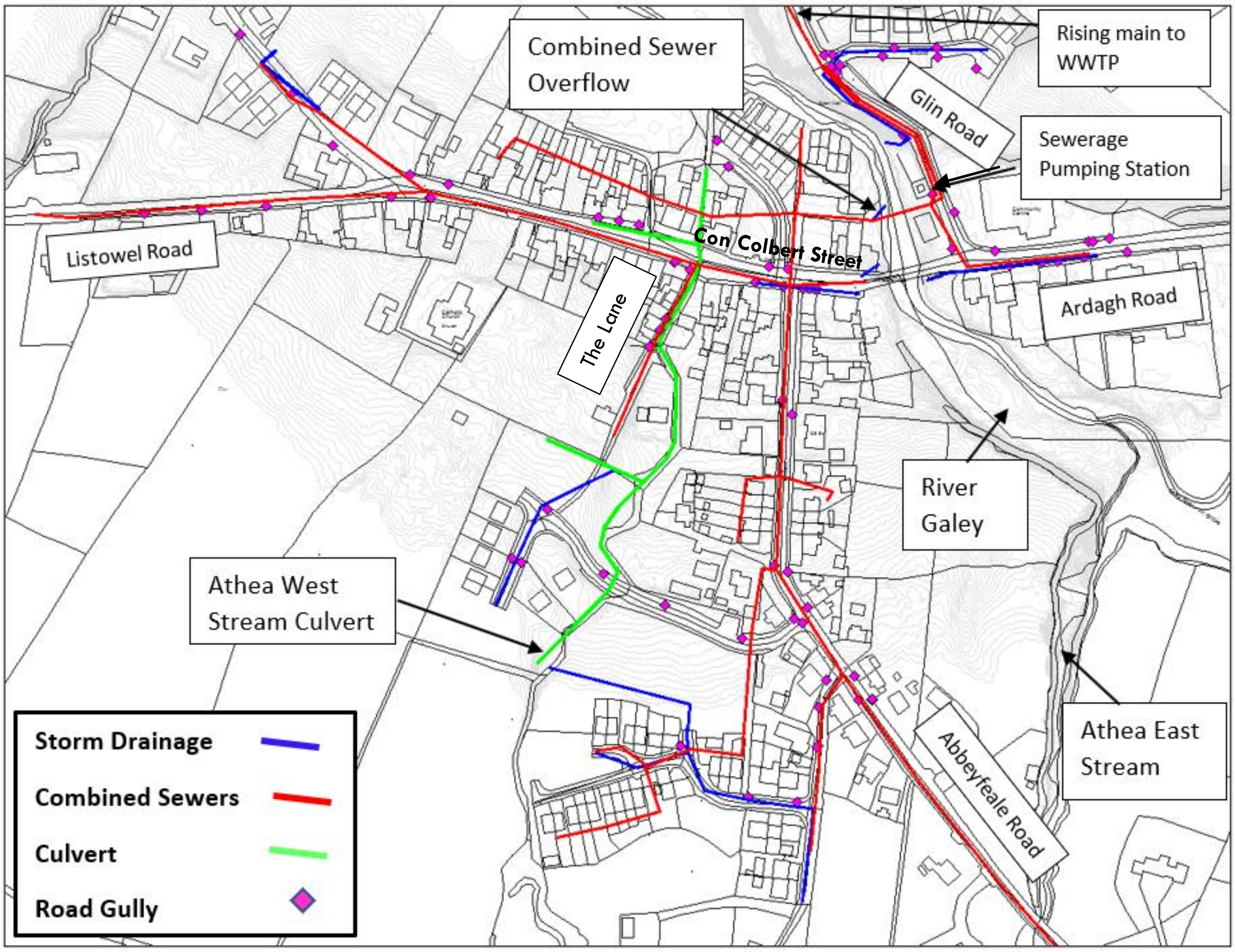


Figure 9-1: Urban Drainage at Athea.

Five steep roads drain to the centre of Athea and ultimately the Galey River as summarised in Table 8-1:

Table 9-1: ***Maximum Road lengths draining to Athea Village centre***

Road	Name	Approximate Length, m (note 1)	
A	Ardagh Road	2000	*Note1: approximate maximum continuous length of road (i.e. where there is no stream*
B	Glin Road	110	
C	Abbeyfeale Road	450	
D	Listowel Road	450	

E	The Lane	120	*crossing which can be used to drain the roads).*

There are likely additional drainage outlets from the roads, other than road gullies, that drain to adjacent lands but in general, road gullies were the most evident principal road drainage mechanism. During an intense short duration rainfall event (e.g. a summer thunder storm) it is likely that significant road run-off (pluvial) flow rates occur at Athea which would be expected to promptly overwhelm the existing road gully capacity, resulting in significant kerb side pluvial/ urban run-off flows. The time of concentration of these pluvial flows would be expected to be short due to the steep road gradients and associated high flow velocities.

There are number of terraced houses in Athea, in particular along the north side of Con Colbert Street, which have finished floor levels and path levels at or below the adjacent road level. There are no reports of these houses historically being flooded from road-runoff. Urban run-off flows during rainstorms, not intercepted by the road gullies, are likely to drain towards the Gables public house and Collins' shop, down the laneways adjacent to and 25m west of Collin's shop and into the Markievicz Park and Cois na Gaíle estates.

Figure 9-2: Example Low lying Finished floor and path levels on Con Colbert Street relative to road levels.

Figure 9-3: Steep approach roads (Abbeyfeale Road) with few gullies. Driveways etc. also drain to the road.

Figure 9-4 presents the estimated urban and hillside runoff contribution areas to the existing sewerage and Athea West Culvert system and the apparent flow directions based on the CCTV survey, as-built drawings, site walkovers and contour mapping generated from LIDAR data. The contributing areas are subdivided into their apparent drainage system, namely the village's storm drainage system, combined sewer system and the direct connections to the Athea West Stream culvert (i.e. not the catchment discharging via the inlet screens to the culvert). Table 9-2 presents a summary of the urban drainage contributing areas.

Contributing areas A01, A02, A05, A07, A11 and A12 have appreciable hillside areas which would be expected to discharge significant run-off to the road and street at network during rainstorm events. Local residents have reported that run-off from A05, which normally drains to the Athea West stream culvert for example, overtops a wall at the Lane following heavy rainfall and flows down to Con Colbert Street. Similar run-off flowpaths would be expected from A01 and A03 discharging to Con Colbert Street via lane ways between houses and other properties on the south side of the street.

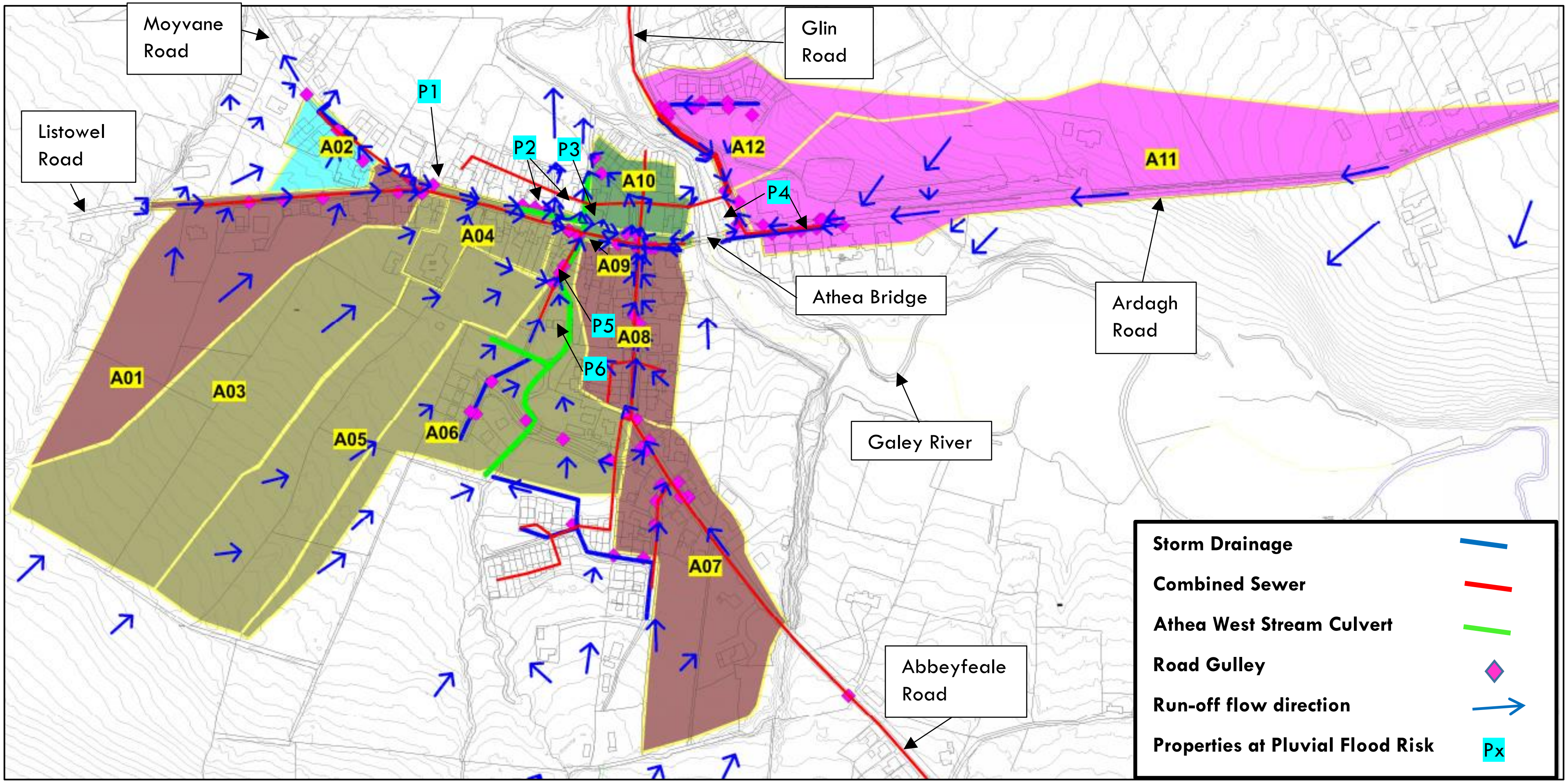


Figure 9-4: Catchments discharging to the Urban Drainage System at Athea.

Table 9-2: *Urban Drainage Contributing Areas at Athea Village*

Name	Total Area, ha	% Urban	Drainage System	Drainage Type
A01	3.2	10%	Combined Sewer	Listowel Road and upper Con Colbert Street gullies
A02	0.5	18%	Storm Drainage	Moyvane Road gullies
A03	4.4	0%	Athea West Culvert	Culvert gullies on Con Colbert Street
A04	0.8	40%	Athea West Culvert	Culvert gullies on Con Colbert Street
A05	3.3	0%	Athea West Culvert	Open drain which discharges to the culvert at the Lane
A06	3.1	22%	Athea West Culvert	Rathronan Estate gullies, open drain and associated the 750mm pipe connection and gullies along the Lane.
A07	2.8	20%	Combined Sewer	Upper Abbeyfeale Road gullies (downhill of Athea East stream)
A08	0.7	60%	Combined Sewer	Lower Abbeyfeale Road gullies (downhill of Athea East stream)
A09	0.9	100%	Storm Drainage, Combined Sewers	Lower Con Colbert Street gullies. Outfall upstream of Athea Bridge on the left bank to Galey River.
A10	0.6	75%	Storm Drainage, Combined Sewers	Markievicz Park and Cois na Gaíle gullies. Outfalls to Galey River and Athea West Stream.
A11	6.1	20%	Storm Drainage.	Ardagh Road gullies. Road verge outlets. Storm drainage Outfall upstream of Athea Bridge on the right bank to Galey River.
A12	1.6	28%	Storm Drainage	Glin Road and Gaelside Road Gullies. Outfall downstream of Athea Bridge on the right bank to Galey River.

During a rainstorm it is likely, due to capacity, steep road gradients and existing gullies condition, that:

- Much of A01 runoff would flow down Con Colbert Street to drain to A04 and A09.
- Much of A07 and A08 runoff would flow down Abbeyfeale Road to drain to A09.
- Excess run-off along the northside of Con Colbert Street in A04 discharges northward down the laneway to fields,
- Excess run-off on the southside of Con Colbert Street in the A04 and the Lane in A06 would pond in front of the butchers shop before crossing the road and discharging northwards down the laneway and towards Collins' Shop.
- Excess runoff in A09 would overflow into A10 towards Markievicz park and Cois na Gaíle.
- Flows not intercepted by the road gullies in A11 along the lower Ardagh Road overflow
  - from the road to the river channel upstream of the bridge and through low lying properties to the south of the Ardagh Road, and;
  - towards Lower Glin Road and low-lying property downstream of Athea Bridge.
- Flows not intercepted by the road gullies in A12 drain to the low-lying property downstream of Athea Bridge.

The total potential maximum additional contributing area to the Athea West Stream Culvert downstream of its inlet chamber located upstream Rathronan estate includes A01, A03, A04, A05 and A06 and is calculated at 14.8ha (1.3ha of which is urban); however, the actual contributing area is less due to gully capacity in A01 and the overflow routes at the laneways along the northside of Con Colbert Street in A04 and possible gully connections to the combined sewer system in A09.

9.3.2 Urban flows of August 2008 event

In order to identify the potential pluvial flood risk at Athea, an assessment of the extreme rainfall event on the night of the 31st July 2008 (which was equivalent to a 100year rainfall event) comprising development of an urban rainfall runoff CN-unit hydrographs model to estimate the pluvial peak flow rates from the catchments described in Table 9-2 above.

The remote sensing rainfall timeseries, described in Section 6, have been used as input and wet catchment runoff coefficients were selected. Four catchment groups were modelled namely:

- A01 referring to hillside and urban runoff upstream of the junction of Listowel and Moyvane road,
- the cumulative hillside and urban catchments runoff of the A03, A04, A05 and A06,
- the cumulative mostly urban catchments of A07 and A08 runoff discharging west of Athea bridge, and;
- the hillside and urban catchment of A11 runoff discharging east of Athea bridge.

Figures 9-5 to 9-8 and Table 9-3 presents the calculated hydrographs and peak run-off rates at each catchment group on the 31st July 2008

Table 9-3: *Peak Pluvial Flow Estimates 31/07/2008*

Catchment Group	Peak Flow Rate, m^3/sec
A01	0.14
A03, A04, A05 and A06	0.5
A07, A08	0.16
A11	0.25

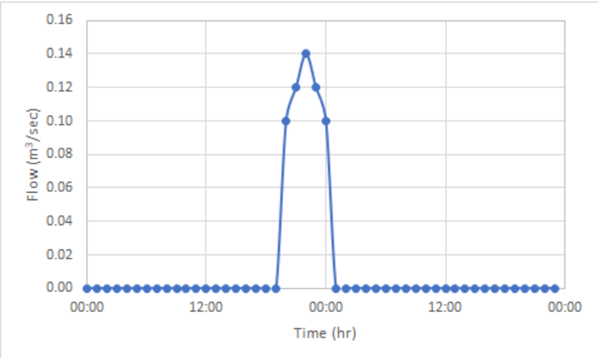


Figure 9-5: Pluvial Run-off hydrograph of A01

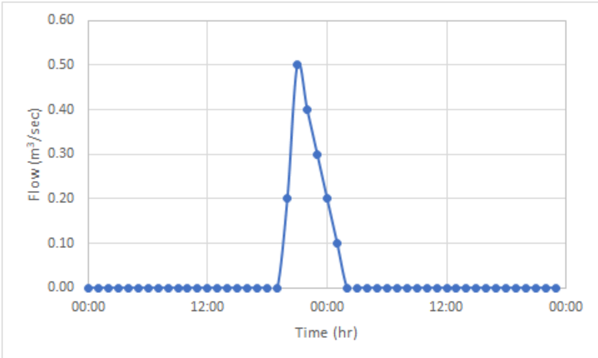


Figure 9-6: Pluvial Run-off hydrograph of A03, A04, A05 and A06

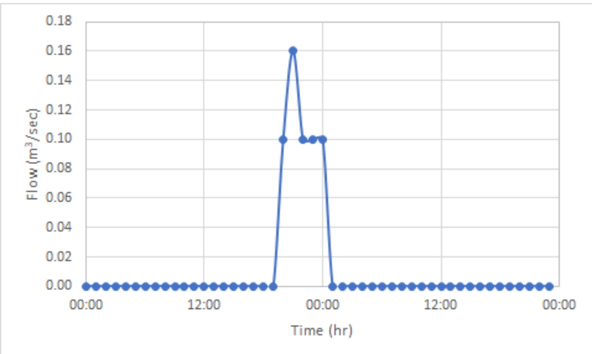


Figure 9-7: Pluvial Run-off hydrograph of A07 and A08

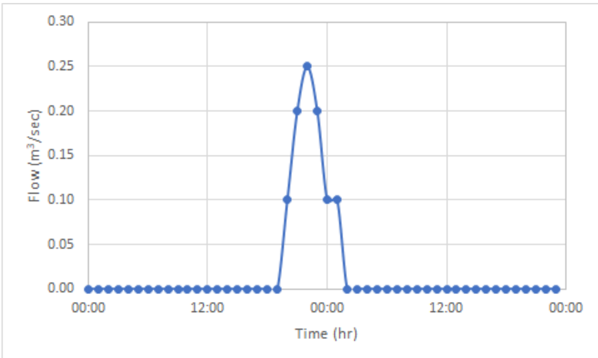


Figure 9-8: Pluvial Run-off hydrograph of A11

Not all of these arising pluvial flows would have been expected to have discharged directly to the low-lying areas and properties at Athea due to the presence of road gullies (albeit only a small number), roadside ditch and lands and property access openings discharging to downslope lands which ultimately would drain to the Galey. The condition of the road gully and storm drainage infrastructure, ditch openings etc. when the 2008 flood event occurred is not known. Therefore, a precautionary approach is proposed. It is estimated that:

Peak flows discharging to lower Athea urban area (including Cois na Gaíle and Markievicz Park and lower Con Colbert Road) west of the bridge (excluding a fluvial overflow from the Athea West stream), considering approximately 0.30m^3/s would have been intercepted and diverted to the Galey via road drainage and openings and laneways between building, would be of the order of 0.30m^3/s.

Peak flows discharging to lower Athea urban area east of the bridge, considering approximately 0.05m^3/s would have been intercepted and diverted to the Galey via road drainage and roadside ditch openings, would be of the order of 0.20m^3/s.

The in-combination effect of the fluvial and pluvial flooding during the 2008 flood event would have been:

- road drainage capacity would have been overwhelmed and drainage outlets would have been fully surcharged by the river greatly restricting
- peak pluvial flows occurred ahead of the peak fluvial flows
- low-lying areas e.g. Ardagh Road downhill from the school and Markievicz Park/ Cois na Gáile would have been inundated from pluvial run-off prior to inundation from the river.
- The pluvial flows while likely "masked" by the fluvial overland flows, would have been significant.

It would have been difficult for the public to discern the flood sources during the event as it peaked around midnight. Anecdotal information regarding the Newcastlewest flooding on the same night described the main N21 as "flowing like river". Similar pluvial flowpaths and conditions likely occurred at Athea.

9.3.3 Potential Urban Drainage Flood Risk

Following a review of the 31st July 2008 rainfall event and the apparent pluvial flow paths in the village, four potential sources of pluvial flood risk associated with the urban drainage system at Athea Village have been identified, as follows:

- Due to the steep and relatively large hillside contributing areas discharging directly to Athea Village in particular at Con Colbert Street and the junction of the Glin and Ardagh Road, there is the potential for pluvial flooding of low-lying properties adjacent to the streets during intense rain-storms.
- High flood levels in the Galey River could potentially backwater / surcharge the storm drainage and CSO outfalls. During extreme flood conditions, such as was experienced during the July 31st/ 1st August 2008 flood event, it is likely that the high flood levels upstream of Athea Bridge would surcharge the storm drainage at Lower Con Colbert Street and on Ardagh Road sufficiently to cause them to flood out onto the roads and establish flowpaths towards low-lying properties.
- The CSO behind the Gables would also flood during such an event, resulting in flooding of the Athea WWTP pumping station, backing up of the sewerage system and potentially the discharge of untreated wastewater onto the roads and into properties.
- Similarly, high flood flows in the Athea West Stream and high flood levels in the downstream floodplain could result in culvert surcharging and the culvert flooding onto the streets and roads via gully connections, in particular along the Lane (near P5) and at Con Colbert Street (near P2).

Properties at 6 No. locations (P1 to P6 on Figure 9-4) have been identified as potentially being at risk of being impacted by pluvial run-off.

Figure 9-5 presents the potential pluvial flood risk areas at Athea in the absence of fluvial flooding based on topographical mapping inspection, anecdotal historical evidence supplied by residents at Athea, and site walkovers.

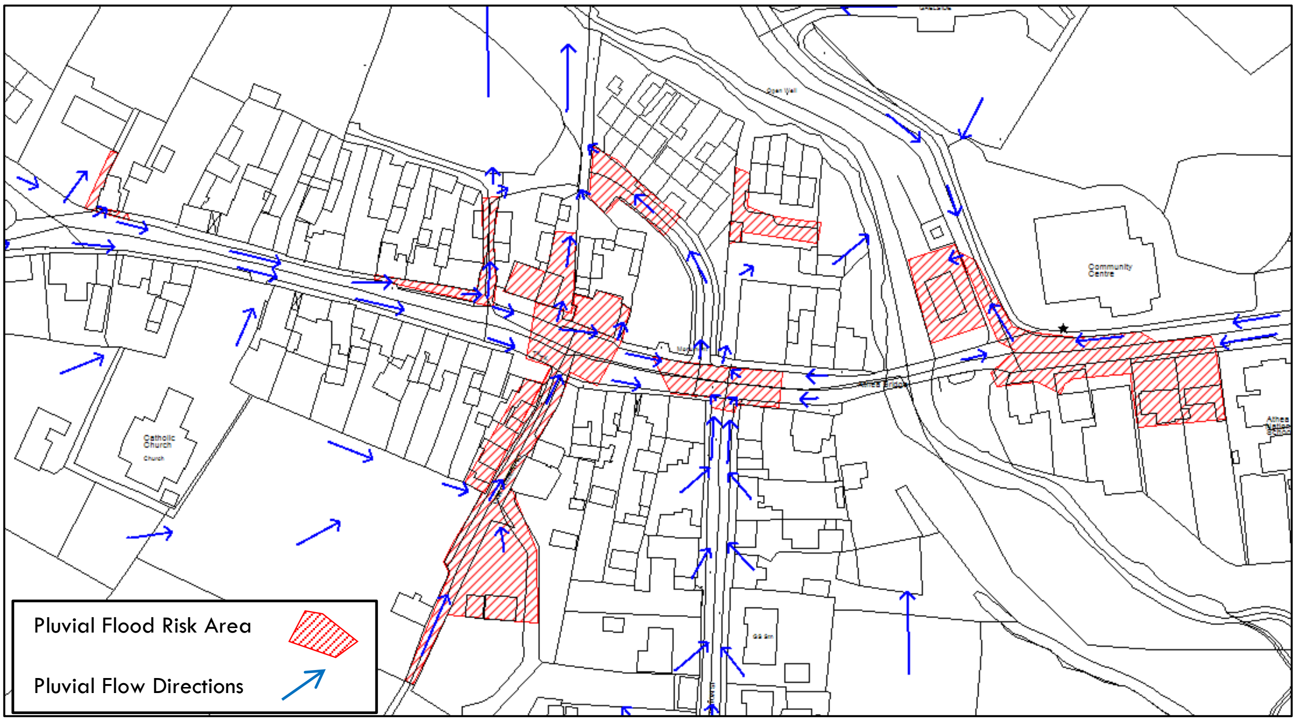


Figure 9-10: Athea Pluvial Flood Risk Areas.

9.3.4 Recommendations

The following works are recommended to mitigate potential pluvial flood risk associated with the urban drainage system:

- All gullies are cleaned out and storm sewers jetted to maximise the existing sewer capacity.
- An urban drainage hydraulic assessment is undertaken for Athea as part of the detailed design stage.
- Open channel and culverts works are undertaken to intercept and divert hillside run-off from A01, A03 and A05 directly to the Listowel Road Stream or the Athea West Stream.
- Install a new storm drainage system along Listowel Road, Con Colbert Street and lower Abbeyfeale Road (Dalton Street) which discharge flows to the Galey River downstream of Markievicz Park with a new culvert and not via the Athea West Stream Culvert.
- Install large storm gullies along the new storm drainage system.
- Divert exist road gully connections from the combined sewer system to the new storm drainage system to prevent hydraulically overloading the WWTP during rainstorms.
- The new storm drainage outfall is designed to facilitate either on land storage or include over-pumping facilities behind the proposed flood defences during extreme flood events.
- Install raised kerbs at footpaths along the upper (northern side) of Con Colbert Street to prevent road runoff discharging onto the foot path.
- Existing and new storm drainage outfalls which drain low-lying areas are fitted with non-return valves and outfall headwalls.
- The CSO outfall to the rear of the Gables is fitted with a suitable non-return valve and the CSO chamber and other combined sewer manholes within the design fluvial flood risk area are protected from inundation.
- The cover to the sewer pipe crossing under the Galey River is confirmed and considered if any channel dredging works are progressed.
- The Athea West Stream Culvert is extended to discharge directly into the Galey River downstream of Markievicz Park and a non-return valve fitted on the outlet.
- The storm drainage from Markievicz Park and Cois na Gaíle are diverted towards the new storm drainage system.
- SUDs are implemented at all new development at Athea to attenuate flows to greenfield run-off rates and improve urban run-off quality.

10 Design Flows

10.1 Introduction

This study's hydrological analysis has been undertaken based on the best practice guidance for Irish catchments contained within the FSU guideline documents and other industry standard methodologies, as applicable, for minor tributaries at Athea as discussed in Section 4.2.

This section includes:

- Review of proposed HEPs.
- Design Flood Flows for each HEP for the current scenario.

10.2 Hydrological Estimation Points

Section 4.2.1 and Figures 4-2 and 4-3 present a summary of and justification for the proposed 22 No. HEPs to be used in this assessment including:

- 13 No. HEP on the Galey River from Inch Bridge to 500m upstream of Athea Bridge
- 3 No. HEP on tributaries immediately downstream of Athea, one HEP each on the Knocknagornagh, Athea Upper and Listowel Rd. streams
- 2 No. HEP on the Athea West stream
- 2 No. HEP on the Athea East stream
- 2 No. Urban Drainage HEP at Con Colbert Street and Ardagh Road.

10.3 Design Flow Estimates

10.3.1 Estimation Methodology

The design event flow for the proposed HEPs on Galey River and its tributaries at Athea, in line with the project brief, is the 1% AEP event. Section 4.2.5 above sets out the design flow methodologies proposed to be undertaken for this study, including as applicable the FSU-7u, FSU-4.2a, IH124, FSR-6v ungauged catchment methods (including small catchments) all using the Inch Bridge gauge derived growth factors and the Unit Hydrograph (FSR) methodology using Met Éireann rainfall return period data for the catchment.

The design flow calculations for the proposed HEPs (see Figure 4-2 and 4-3 are presented in Tables 9-1 to 9-6.

10.3.2 Main Galey River channel

The Qmed at Inch Bridge has been estimated using two methods:

- Analysis of the Amax series flow data (revised rating curve) at Inch Bridge gauge (23001)
- Using PCDs (collated from the OPW FSU portal) and the OPW FSU 7-variable (7v) equation with the updated SAAR (81-10) dataset.

The Qmed calculated using the revised Amax series analysis and FSU PCD 7v equation were respectively calculated at 95.7m^3/s and 79.0m^3/s which equates to a catchment adjustment factor (CAF) for the catchment's FSU estimations of 1.21.

The Qmed and %AEP design flows for all the proposed HEPs along the main Galey River channel as far as Athea (23-Galey-07) have been calculated using the FSU PCDs, the FSU 7v method, catchment adjustment factor (CAF) and the growth factors presented in Table 7-6 above.

10.3.3 Galey River at Athea

Table 4-6 above, following a review of the PCDs, presents the proposed parameters for the Qmed calculation at Athea.

The Qmed and %AEP design flows for all the HEPs in Galey River channel at Athea (23-Galey-07 to 23-Galey-13) have been calculated using the FSU PCDs (see Table 4-6 above), the FSU 7v method, catchment adjustment factor (CAF), forestry factor (FF) of +8.9% relative to the portion of the catchment covered by forestry (see Section 4.2.10.2) and the growth factors presented in Table 7-6 above. Extensive felling of forestry in the catchment over a short period of time without an appropriate replanting or similar mitigations could lead to higher temporary effective run-off rates increases of up to +18%. The Qmed at Athea Bridge for the two forestry scenarios has been calculated at 33.5m^3/s and 35m^3/s.

10.3.4 Tributaries

The Qmed and %AEP design flows for the study area tributaries, which in general are small steep catchments with very high run-off rates (Soil > 0.45), and negligible urban extents, have been calculated using the PCDs, the FSU 4.2a ungauged catchment method (OPW recommended for small catchments) and the Amax analysis Qmed AEP% growth factors and are presented in Tables 10-6 overleaf. For completeness and comparison, Qmed estimates for these smaller catchments have also been calculated using the FSU 7v and are included in Tables 10-3 and 10-4.

These estimates, in turn, have been cross checked by comparison to Qbar estimates derived using the FSSR6 and IH-124 and to Qmed estimates derived using the FSU-3v (note: in general, it would be expected that there would be little difference between Qbar and Qmed for small rural catchments). It is noted that these cross-check estimation methods do not include catchment slope parameters which would be considered significant for these smaller catchments at Athea and consequently it is likely that these cross-check methods will underestimate the peak flows.

The cross-checks confirmed that the FSU4.2a Qmed estimates for the HEP were higher than the other methodologies by a ratio ranging 1.3 to 1.5 (average 1.4) and by a ratio ranging 1.3 to 1.4 (average 1.36) when compared to the FSU-7v.

There is a significant variance between the other methodologies including the FSU-7v and FSU4.2a estimates for HEP 23_Knock_01. It is proposed that the FSU-7v estimates be adopted for this HEP.

Table 9-2 above summarise the Urban Drainage Contributing Areas at Athea Village. The pluvial flows associated with these areas are assessed in the Athea FRS Hydraulic Modelling Report. The Urban Drainage assessment identified the potential for:

- significant hillside run-off to discharge to Con Colbert Street following rainstorms. The associated contributing areas are A01, A03, A04, A05 and the associated HEP is 23-ConCol01.
- significant hillside run-off to discharge to the Ardagh Road following rainstorms. The associated contributing areas are A11 and the associated HEP is 23-ArdRd01.

The peak Qmed and AEP flows associated with these two HEP have been calculated, for indicative purposes, using the FSU4.2a equation and presented in Table 10-7. These will be further assessed in the Athea FRS Hydraulic Modelling Report.

The design Qmed at Athea Bridge (23_Galey11) is calculated at 33.5m^3/s based on a BFIsoil of 0.322. As set out in Section 2.1.1 the range of measured BFI values in Ireland range from 0.26 to 0.91. To demonstrate the sensitivity of the design flow estimation at Athea Bridge to BFISoil, the Qmed has been calculated for a range of BFISoil from 0.29 to 0.33 and presented below in Figure 10-1, which confirms that small changes in BFISoil result in a significant variation in the estimated Qmed.

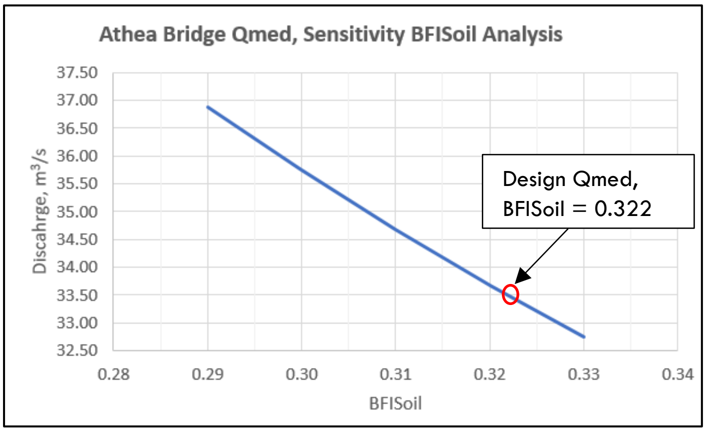


Figure 10-1: Athea Bridge Qmed Estimation Sensitivity Analysis to BFISoil

Table 10-1: HEP PCDs and Qmed estimation using FSU 7v method (main channel to Athea)

Ref	HEP	CFRAM HEP	Area,	BFISoil	SAAR 61-90	SAAR1981-2010	FARL	DRAIND	S1085	ARTDRAIN	Qmed (PCD)	Urb Factor	Qmed (PCD,Urb)	Qmed (PCD, Urb, CAF)
			km²			mm/annum			m/km		m³/s		m³/s	m³/s
1	23_Galey01	23_2929_1	191.7	0.322	1083.97	1229.9	1	1.373	3.3837	0.1804	78.45	1.007	78.99	95.71
2	23_Galey02	n/a	169.5	0.3256	1088.9	1239.75	1	1.423	4.453	0.1433	73.50	1.005	73.87	89.51
3	23_Galey03	23-2696-1	124.12	0.326	1093.18	1269.49	1	1.4	5.6231	0.052	56.76	1.004	57.00	69.06
4	23_Galey04	23_2954	89.94	0.3278	1103.17	1309.69	1	1.498	6.0417	0	44.18	1.004	44.38	53.77
5	23_Galey05	n/a	78.98	0.328	1104.34	1332.25	1	1.521	8.3596	0	42.67	1.005	42.89	51.97
6	23_Galey06	23-1894-2	59.06	0.3108	1119.94	1366.74	1	1.684	10.3975	0	38.06	1.007	38.32	46.43

Table 10-2: HEP PCDs and Qmed estimation using FSU 7v method (main channel at Athea)

Ref	HEP	CFRAM HEP	Area,	BFISoil	SAAR 61-90	SAAR 1981-2010	FARL	DRAIND	S1085	ARTDRAIN	Qmed (PCD)	Urb Factor	FF	Qmed (PCD, Urb, FAF)	Qmed (PCD, Urb, FAF, CAF)
			km²			mm/annum			m/km		m³/s			m³/s	m³/s
7	23_Galey07	23_2514-2	40.928	0.322	1130.7	1370.0	1	2.1	10.66	0	28.39	1.010	1.040	29.80	36.11
8	23_Galey08	23_2580_1	37.677	0.322	1133.5	1386.1	1	2.1	11.67	0	27.13	1.011	1.043	28.59	34.65
9	23_Galey09	23-2579-3	36.876	0.322	1134.3	1390.4	1	2.1	12.00	0	26.83	1.009	1.044	28.26	34.24
10	23_Galey10	23_2579_2	36.607	0.322	1134.6	1390.4	1	2.1	12.40	0	26.81	1.009	1.044	28.25	34.23
11	23_Galey11	n/a	35.96	0.322	1135.2	1390.4	1	2.1	12.40	0	26.37	1.003	1.045	27.64	33.49
12	23_Galey12	23-2579_1	34.79	0.322	1135.2	1390.4	1	2.1	12.40	0	25.56	1.003	1.047	26.83	32.51
13	23_Galey13	23-1920_2	33.651	0.322	1135.1	1390.4	1	2.1	12.67	0	24.88	1.000	1.048	26.07	31.59

Table 10-3: HEP PCDs and Qmed estimation using FSU 7v method (tributaries at Athea)

Ref	HEP	CFRAM HEP	Area,	BFISoil	SAAR 61-90	SAAR 1981-2010	FARL	DRAIND	S1085	ARTDRAIN	Qmed (PCD)	Urb Factor	FF	Qmed (PCD, Urb, FAF)	Qmed (PCD, Urb, FAF, CAF)
			km²			mm/annum			m/km		m³/s			m³/s	m³/s
14	23_Knock_01	n/a	17.818	0.31	1095.65	1367.7	1	1.493	14.75	0	12.72	1.000	1.043	13.28	16.09
15	23-AthUp-01	23_2514	1.28	0.3325	1095.72	1264	1	1.952	52.34	0	1.26	1.000	1.005	1.27	1.54
16	23_LstRd-01	n/a	0.39	0.322	1133.49	1264	1	2.1	54.40	0	0.44	1.000	1.000	0.44	0.53
17	23_AtheaWest01	n/a	0.543	0.322	1135.16	1264	1	2.1	58.50	0	0.61	1.000	1.000	0.61	0.74
18	23_AtheaWest02	n/a	0.164	0.322	1135.16	1264	1	2.1	58.50	0	0.20	1.000	1.000	0.20	0.24
19	23_AtheaEast01	n/a	1.1	0.322	1135.16	1264	1	2.1	67.30	0	1.21	1.000	1.019	1.24	1.50
20	23_AtheaEast02	n/a	0.85	0.322	1135.16	1264	1	2.1	68.00	0	0.95	1.000	1.025	0.98	1.19

Note: FF = Forestry Factor, CAF = Catchment Adjustment Factor, Urb = Calculated Urban Factor

Table 10-4: %AEP design flows (FSU 7v method)

Ref	HEP	Qmed	%AEP	50%	20%	10%	5%	2%	1%	0.50%	0.10%
			Qmed – GF (68% UCI)	1.01	1.29	1.48	1.67	1.91	2.04	2.26	2.68
Main Channel (up to Athea)		m3/s		m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s
1	23_Galey01	95.71		97.0	123.6	141.7	159.2	181.9	**198.9**	215.8	255.2
2	23_Galey02	89.51		90.7	115.6	132.5	148.9	170.1	**186.0**	201.9	238.7
3	23_Galey03	69.06		70.0	89.2	102.3	114.9	131.2	**143.5**	155.8	184.1
4	23_Galey04	53.77		54.5	69.4	79.6	89.4	102.2	**111.7**	121.3	143.4
5	23_Galey05	51.97		52.6	67.1	76.9	86.4	98.7	**108.0**	117.2	138.6
6	23_Galey06	46.43		47.0	60.0	68.7	77.2	88.2	**96.5**	104.7	123.8
Main Channel (at Athea)											
7	23_Galey07	36.11		36.6	46.6	53.5	60.1	68.6	75.0	81.4	96.3
8	23_Galey08	34.65		35.1	44.7	51.3	57.6	65.8	72.0	78.1	92.4
9	23_Galey09	34.24		34.7	44.2	50.7	57.0	65.1	71.2	77.2	91.3
10	23_Galey10	34.23		34.7	44.2	50.7	56.9	65.0	71.1	77.2	91.3
11	23_Galey11	33.49		33.9	43.3	49.6	55.7	63.6	69.6	75.5	89.3
12	23_Galey12	32.51		32.9	42.0	48.1	54.1	61.8	67.6	73.3	86.7
13	23_Galey13	31.59		32.0	40.8	46.8	52.5	60.0	65.6	71.2	84.2
Tributaries at Athea											
14	23_Knock_01	16.09		16.3	20.8	23.8	26.8	30.6	33.4	36.3	42.9
15	23-AthUp-01	1.54		1.6	2.0	2.3	2.6	2.9	3.2	3.5	4.1
16	23_LstRd-01	0.53		0.5	0.7	0.8	0.9	1.0	1.1	1.2	1.4
17	23_AtheaWest01	0.74		0.7	1.0	1.1	1.2	1.4	1.5	1.7	2.0
18	23_AtheaWest02	0.24		0.2	0.3	0.4	0.4	0.5	0.5	0.5	0.6
19	23_AtheaEast01	1.50		1.5	1.9	2.2	2.5	2.8	3.1	3.4	4.0
20	23_AtheaEast02	1.19		1.2	1.5	1.8	2.0	2.3	2.5	2.7	3.2

Table 10-5: Qmed and Qbar estimations for small catchments (including Forestry Factor)

Ref	Method	FSSR6	IH-124	FSR-6v	FSU-3v	*FSU7*	FSU4.2a
	Parameter	**Qbar**	**Qbar**	**Qbar**	**Qmed**	***Qmed***	**Qmed**
	HEP	m³/s	m³/s	m³/s	m³/s	m³/s	m³/s
14	*23_Knock_01*	13.09	11.95	9.54	13.63	13.28	16.99
15	23-AthUp-01	1.08	1.07	1.09	1.24	1.27	1.67
16	23_LstRd-01	0.37	0.38	0.53	0.47	0.44	0.58
17	23_AtheaWest01	0.48	0.49	0.71	0.62	0.61	0.80
18	23_AtheaWest02	0.18	0.19	0.26	0.23	0.20	0.26
19	23_AtheaEast01	1.09	1.11	1.36	1.13	1.24	1.62
20	23_AtheaEast02	0.87	0.89	1.06	0.92	0.98	1.29

Table 10-6: %AEP design flows – Small Catchments (FSU 4.2a method)

		FSU4.2a	%AEP	50%	20%	10%	5%	2%	1%	0.50%	0.10%
Ref	**HEP**	**Qmed**	**GF**	**0.98**	**1.24**	**1.41**	**1.57**	**1.78**	**1.94**	**2.10**	**2.46**
		m³/s		m³/s	m³/s	m³/s	m³/s	m³/s	m³/s	m³/s	m³/s
14	*23_Knock_01*	16.99		17.21	21.95	25.16	28.26	32.29	35.31	38.32	45.31
15	23-AthUp-01	1.67		1.70	2.16	2.48	2.78	3.18	3.48	3.78	4.46
16	23_LstRd-01	0.58		0.58	0.75	0.85	0.96	1.10	1.20	1.30	1.54
17	23_AtheaWest01	0.80		0.81	1.03	1.18	1.33	1.52	**1.66**	1.80	2.13
18	23_AtheaWest02	0.26		0.27	0.34	0.39	0.44	0.50	0.55	0.60	0.70
19	23_AtheaEast01	1.62		1.64	2.09	2.40	2.69	3.08	**3.36**	3.65	4.32
20	23_AtheaEast02	1.29		1.30	1.66	1.90	2.14	2.44	2.67	2.90	3.43

Table 10-7: %AEP design flows – Hillside and Urban Areas (FSU 4.2a method)

		Area	BFISoil	SAAR	FARL	S1085	Urb	FSU4.2a		%AEP	50%	20%	10%	5%	2%	1%	0.50%	0.10%
Ref	**HEP**	**km²**						**Qmed**	**Qmed.Urb**	**GF**	**0.98**	**1.24**	**1.41**	**1.57**	**1.78**	**1.94**	**2.10**	**2.46**
		km²						m³/s	m³/s		m³/s	m³/s	m³/s	m³/s	m³/s	m³/s	m³/s	m³/s
21	23_ConCol01	*0.117*	*0.322*	*1264*	*1*	*60.00*	1.082	0.19	0.21		0.21	0.27	0.31	0.35	0.40	0.44	0.47	0.56
22	23-ArdRd01	*0.061*	*0.322*	*1264*	*1*	*62.00*	1.310	0.11	0.14		0.14	0.18	0.21	0.23	0.27	0.29	0.32	0.37

11 Design Hydrographs

11.1 Introduction

The design hydrographs for the Galey River and its tributaries at Athea have been derived here based on the following:

- Review of the extreme flood hydrographs recorded at Inch Bridge.
- FSR unit hydrograph assessment
- FSU hydrograph assessment

11.2 Extreme Flood Events Hydrographs

A review of the extreme flood event hydrographs recorded at Inch Bridge has been undertaken to allow the anatomy of the Galey River flood events to be investigated i.e. duration and rates of the rising and recession limbs, time to peak, and hydrograph shape.

Table 8-2 presents the 11 No. highest ranked recorded flood events at Inch Bridge. Section 5 presents an analysis of the rainfall leading up to the recent flood events and other historical flood events where data is available. The recorded hydrographs for the highest flood events (1973) and the recent extreme flood events (1995, 2005, 2009, 2008 and 2015) have been developed using the revised rating curve and presented in Figure 10-1 for comparison. Figure 11-2 presents the non-dimensional hydrograph shape for these events (i.e. flow/ peak flow relative to time). The peak flow for each event has been set at T=0 hrs and the flood durations is extended 36 hours either side of T= 0 hrs.

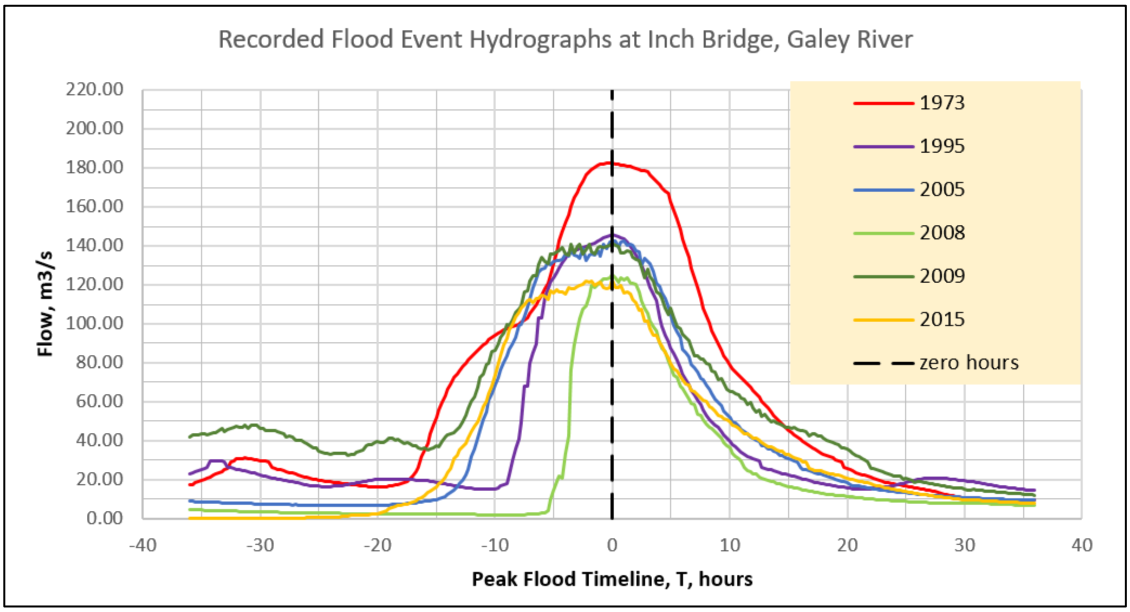


Figure 11-1: Recorded Flood Events Hydrographs

(note: flood event reference here relative to the calendar year not hydrometric year)

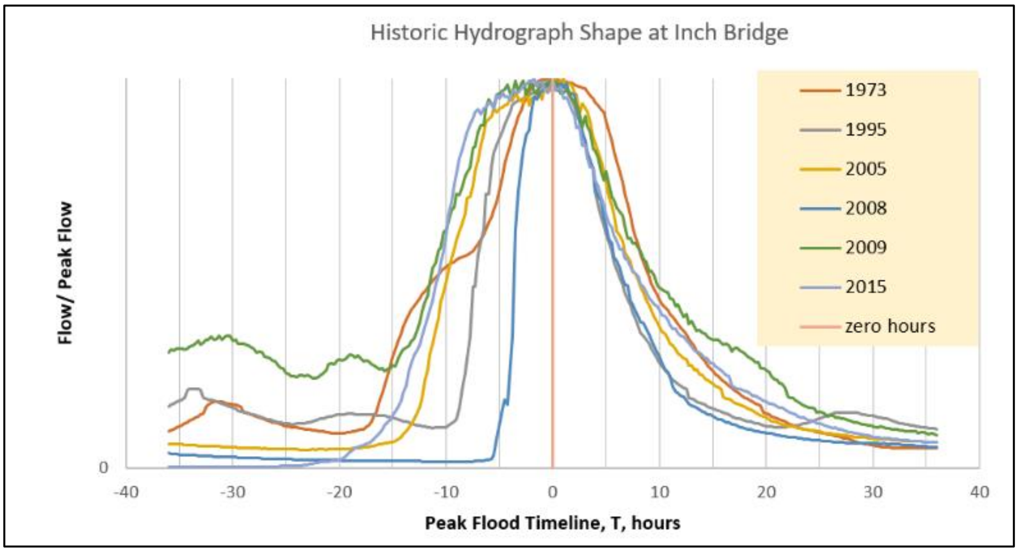


Figure 11-2: Non-dimensional Hydrograph Shapes at Inch Bridge

Table 11-1 presents the date, flow rates and approximate time to peak and flood duration for each of these events.

Table 11-1: Past hydrographs peak flows, time to peak, flood duration

Hydrometric Year	Flood Event	River Flow at start of rising limb, m^3/s	Peak flow recorded, m^3/s	Time to Peak, hours	Approximate Flood Duration (end of recession limb), hours
1973	1/12/1973	20	182.6	17.25	40
1994	22/02/1995	18	146	9.25	34
2004	08/01/2005	10	142.7	16	36
2007	01/08/2008	3	125.4	5.5	19.5
2009	19/11/2009	36	141.5	16	42
2014	12/09/2015	1	122.4	16	42

The shape of 2005, 2009 and 2015 flood events have similar rising limbs gradients (circa +14m^3/s/hour) and an 8-hour peak flow "plateau" duration. The historic 1-day rainfall associated with these events have an estimated return period of only 2 years. It is likely, therefore, that a shorter duration (<24hour) intense rainstorm gave rise to these flood events.

The 1995 and 2008 flood events have similar steep rising limbs (circa +30m^3/s/hour) and recession limbs (circa -12m^3/s/hour). The 1995 peak flow "plateau" was approximately 6 hours while the 2008 event peak was only 4 hours. The historic 1-day rainfall associated with the 2008 event has an estimated return period of 2 years, Met Éireann have reported that flood's rain storm was concentrated over 7 hours and the calculated rainfall depth for the event is c62mm. The return period of this rainfall event, which resulted in the 21 no. properties being impacted by flooding or flooded at Athea, has been estimated at 103years.

The 1973 event appears to have comprised two significant rainstorms (waves) occurring in quick succession. While the overall rate of rise for the event was c 10m^3/s/hour, the individual rate of rise of the two storms were 15- 18m^3/s/hour. The peak flow "plateau" was approximately 4 hours long for the event.

11.3 FSR Synthetic Hydrograph

A synthetic hydrograph peak flood flow assessment has been undertaken for strategic HEP in the Athea study area using the Unit Hydrograph method (FSR Volume I, Chapter 6 and the Ciria Book 14 - Design of Flood Storage Reservoirs, Section 3.3) and the FSU rainfall application. Hydrographs have been developed based on the FSU synthetic summer and winter design storm profiles.

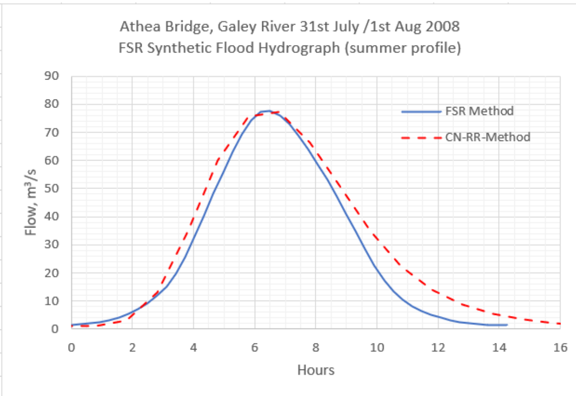
An iterative process has been followed for each HEP to determine the 100-year RP rainfall storm duration which results in the 1% AEP peak flow which matches the design 1% AEP flows calculated above. The calculated 'time to peak' of the flood events has been checked against gauged data (i.e. Inch Bridge Gauge analysis), flood event reports (e.g. Met Éireann Rainfall August 2008, Engineering reports), the hydrographs generated by the CN-rainfall-runoff model or anecdotal information where it exists. The 2008 flood event peak flow, as estimated through the rainfall-runoff analysis presented in section 6, was approximately 77.3 m^3/sec.

Hydrographs have been developed for HEP 23-Galey-11 (Athea Bridge), 23_AthWest-01(Athea culvert), 23_AthEast-01 (Abbeyfeale Road Bridge), 23-Galey-04 (Ahavoher Bridge), 23-Galey-03 (Galey Bridge) and 23-Galey-01 Inch Bridge. Additional hydrographs will be developed as required to inform the scheme's hydraulic assessment.

11.3.1 Athea Bridge

The catchment characteristics of the Galey River at Inch Bridge and Athea Bridge differ appreciably. The Athea Bridge catchment area is only 19% that of the Inch Bridge catchment, is a significantly steeper catchment, has a higher drainage channel density and approximately 50% of its catchment has been developed for commercial forestry. In addition, Inch Bridge is located over 26km downstream of Athea Bridge. As a result, in general, the Galey River at Athea Bridge would be expected to be flashier and have a shorter time to peak compared to that of the Inch Bridge. There is no long-term hydrometric gauge record available for the Galey River at Athea. The hydrometric gauges installed in April 2021 at Athea Bridge (23051 and 23052) have, to date, only recorded moderate flood events (return periods less than 1 in 1 years). Therefore, historic reports and anecdotal information have been used to guide the unit hydrograph iterative process.

The 31st July/ 1st August 2008 flood event is estimated to have had a time to peak of 6.0 hours (based on review of the Inch Bridge gauge hydrograph and anecdotal information for the event) and a peak 7-hour rainfall total of 64.4mm (See Section 6). As a cross check on the CN-rainfall runoff method described in Section 6, a synthetic hydrograph (summer profile) has been developed using the FSR method for the 2008 event for Athea Bridge (HEP 23-Galey-11) based on these parameters and is presented Figure 11-3.



Hour	Flow, m3/s	Hour	Flow, m3/s	Hour	Flow, m3/s
0.0	1.5	**5.0**	55.9	**9.9**	22.8
0.3	1.7	**5.3**	63.0	**10.2**	17.5
0.6	2.0	**5.6**	69.4	**10.5**	13.3
0.9	2.5	**5.9**	74.5	**10.9**	10.4
1.2	3.3	**6.2**	77.4	**11.2**	8.1
1.6	4.3	**6.5**	77.7	**11.5**	6.4
1.9	5.5	**6.8**	75.9	**11.8**	5.1
2.2	7.1	**7.1**	72.8	**12.1**	4.0
2.5	9.2	**7.4**	68.8	**12.4**	3.2
2.8	11.9	**7.8**	64.0	**12.7**	2.5
3.1	15.2	**8.1**	58.7	**13.0**	2.1
3.4	19.5	**8.4**	53.1	**13.3**	1.7
3.7	25.7	**8.7**	47.2	**13.6**	1.6
4.0	32.8	**9.0**	41.0	**14.0**	1.5
4.3	40.4	**9.3**	34.8	**14.3**	1.5
4.7	48.2	**9.6**	28.6		

Figure 11-3: Athea Bridge 2008 Flood Event FSR synthetic and CN rainfall-runoff (remote rainfall NASA) hydrographs

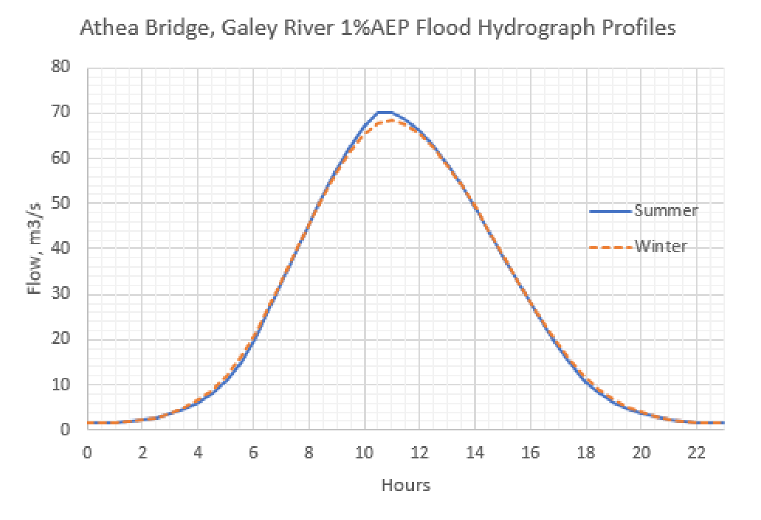
The assessment suggests:

- an overall design rainstorm duration of 7 hours (equivalent to a rainfall RP of 125years),
- the resultant peak flow was 77.7m^3/s and the flood time to peak was approximately 6.5 hours. This compares well with the CN-rainfall runoff method analysis included in Section 6 in method magnitude and hydrograph shape
- The peak flow estimate is greater than the preliminary estimated range of 63.0 and 73.5m^3/s (see section 3.5.2.1). The estimated average flow at the bridge at the peak of the event was of the order of 2.2m/s. The peak run-off rate from the Athea Bridge catchment during the event was equivalent to 2.3m^3/s/km^2.
- the July 31st / August 1st 2008 flow event was circa 11% higher than that calculated 1% AEP design flow calculated using the FSU 7v method (69.6m^3/s). The peak flow was equivalent to that of a 0.5% AEP flood event (see Table 10-4).
- the July 31st / August 1st 2008 event was equivalent to the design 1% AEP event for Athea Bridge.
- this estimated peak flow represents 62% of the peak flow recorded at Inch Bridge for the same event, which confirms the localised and intense nature of the event in the Athea Bridge catchment (See Section 5-7).

- The FSR hydrograph (summer profile) method and the CN-RR method together with the remote sensing (NASA) rainfall data are appropriate for the study reach.

It is recommended that consideration be given to using the 31st July /1st August 2008 peak flow as the design peak flow (c77.5m^3/s) event for the scheme.

Figure 11-4 presents the 1% AEP FSR synthetic summer and winter profile flood hydrographs generated for Athea Bridge



Hour	Flow, m3/s	Hour	Flow, m3/s	Hour	Flow, m3/s
0.0	1.5	**8.0**	45.1	**16.0**	28.3
0.5	1.5	**8.5**	51.5	**16.5**	23.3
1.0	1.6	**9.0**	57.4	**17.0**	18.6
1.5	1.8	**9.5**	62.8	**17.5**	14.3
2.0	2.2	**10.0**	67.1	**18.0**	10.5
2.5	2.8	**10.5**	70.0	**18.5**	8.0
3.0	3.6	**11.0**	70.1	**19.0**	6.2
3.5	4.7	**11.5**	68.6	**19.5**	4.8
4.0	6.2	**12.0**	66.0	**20.0**	3.8
4.5	8.2	**12.5**	62.5	**20.5**	3.0
5.0	10.9	**13.0**	58.4	**21.0**	2.4
5.5	14.5	**13.5**	53.9	**21.5**	2.0
6.0	19.7	**14.0**	49.0	**22.0**	1.7
6.5	25.7	**14.5**	44.0	**22.5**	1.6
7.0	32.0	**15.0**	38.8	**23.0**	1.5
7.5	38.6	**15.5**	33.5		

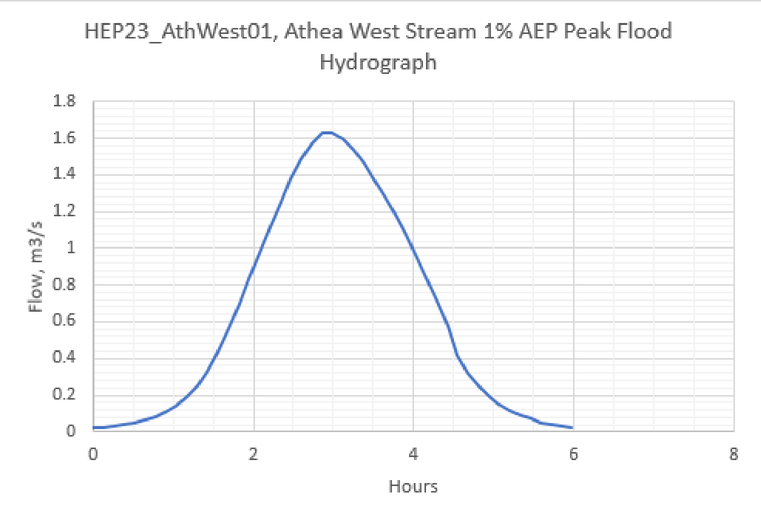
Figure 11-4: Athea Bridge 1% AEP Design Hydrograph

11.3.2 Athea West and East Streams

Given the small and steep catchments associated with the Athea West (23-AthWest-01) and Athea East streams it is expected that their associated time to peak is short (<3 hours).

<u>Athea West</u>

A synthetic hydrograph has been developed for the 1% AEP Athea West stream design flow (See Figure 11-5). The design rainstorm has an estimated time to peak and storm duration of 1.5 hours and 3.5 hours respectively, and a 100year RP rainfall depth of 49.8mm. The resultant peak flow and flood time to peak is estimated at 1.63 m^3/s and approximately 3.0 hours respectively. This design flow agrees closely with that calculated by the FSU4.2a method.

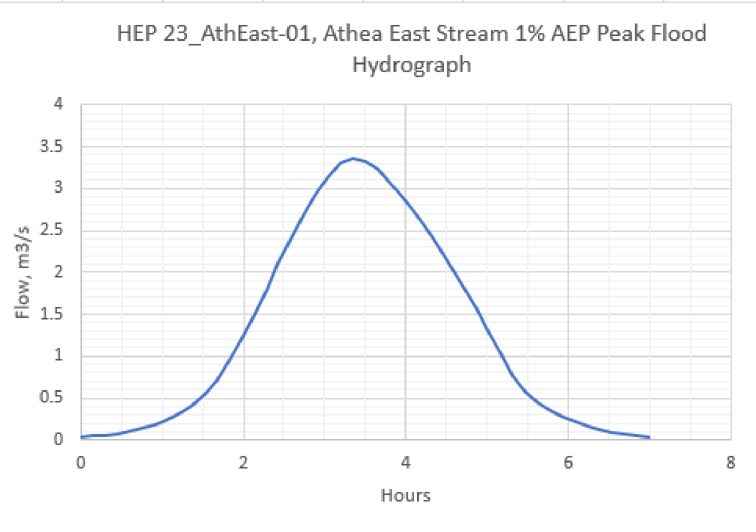


Hour	Flow, m3/s	Hour	Flow, m3/s	Hour	Flow, m3/s
0.0	0.0	**2.1**	0.98	**4.2**	0.8
0.1	0.0	**2.2**	1.11	**4.3**	0.7
0.3	0.0	**2.3**	1.25	**4.4**	0.6
0.4	0.0	**2.5**	1.37	**4.6**	0.4
0.5	0.0	**2.6**	1.48	**4.7**	0.3
0.7	0.1	**2.7**	1.57	**4.8**	0.2
0.8	0.1	**2.9**	1.63	**4.9**	0.2
0.9	0.1	**3.0**	1.63	**5.1**	0.1
1.0	0.1	**3.1**	1.59	**5.2**	0.1
1.2	0.2	**3.3**	1.54	**5.3**	0.1
1.3	0.2	**3.4**	1.46	**5.5**	0.1
1.4	0.3	**3.5**	1.38	**5.6**	0.1
1.6	0.4	**3.6**	1.28	**5.7**	0.0
1.7	0.6	**3.8**	1.18	**5.9**	0.0
1.8	0.7	**3.9**	1.08	**6.0**	0.0
2.0	0.8	**4.0**	0.96		

Figure 11-5: Athea West Stream (23-AthWest-01) 1% AEP Design Hydrograph

<u>Athea East</u>

A synthetic hydrograph has been developed for the 1% AEP Athea East stream design flow (See Figure 11-6). The design rainstorm has an estimated time to peak and storm duration of 1.5 hours, and 3.5 hours respectively, and a 100year RP rainfall depth of 49.9mm. The resultant peak flow and flood time to peak is estimated at 3.1 m^3/s and approximately 3.3 hours respectively. This design flow is less with that calculated by the FSU4.2a method (3.36m^3/s). The hydrograph has, therefore, been proportionally increased to match the FSU4.2a estimate.



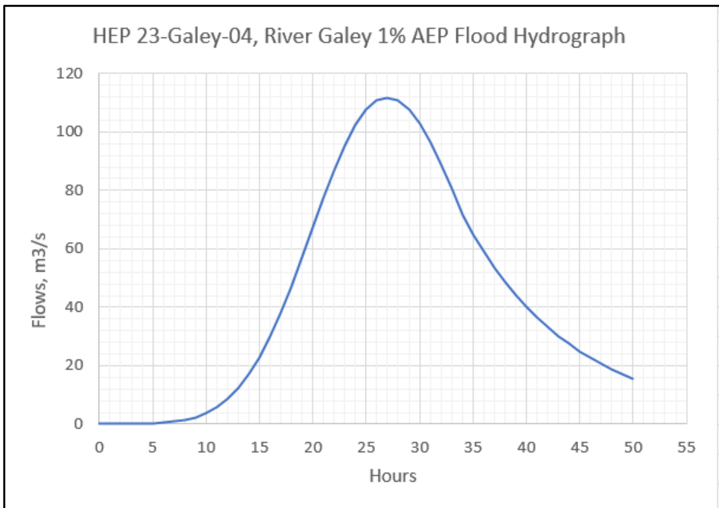
Hour	Flow, m3/s	Hour	Flow, m3/s	Hour	Flow, m3/s
0.0	0.0	**2.4**	2.10	**4.9**	1.6
0.2	0.0	**2.6**	2.39	**5.0**	1.3
0.3	0.1	**2.7**	2.67	**5.2**	1.0
0.5	0.1	**2.9**	2.93	**5.3**	0.8
0.6	0.1	**3.0**	3.14	**5.5**	0.6
0.8	0.1	**3.2**	3.30	**5.6**	0.5
0.9	0.2	**3.3**	3.36	**5.8**	0.3
1.1	0.2	**3.5**	3.32	**5.9**	0.3
1.2	0.3	**3.6**	3.22	**6.1**	0.2
1.4	0.4	**3.8**	3.08	**6.2**	0.2
1.5	0.5	**4.0**	2.91	**6.4**	0.1
1.7	0.7	**4.1**	2.72	**6.5**	0.1
1.8	0.9	**4.3**	2.51	**6.7**	0.1
2.0	1.2	**4.4**	2.29	**6.8**	0.1
2.1	1.5	**4.6**	2.06	**7.0**	0.0
2.3	1.8	**4.7**	1.81		

Figure 11-6: Athea East Stream (23-AthEast01) 1% AEP Design Hydrograph

11.4 FSU Hydrograph Method

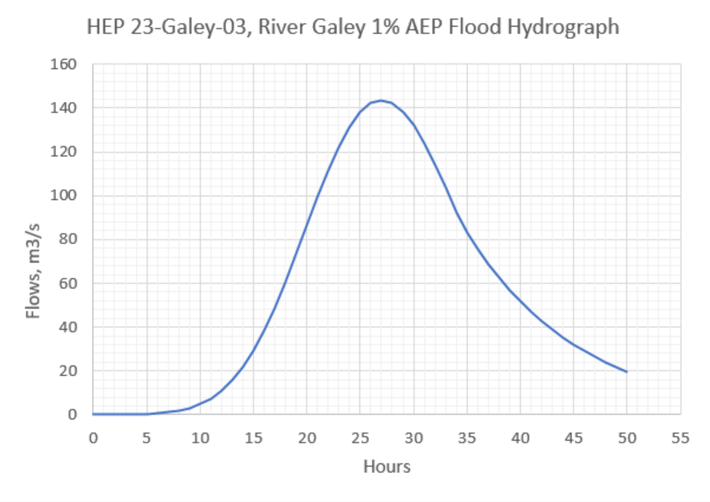
The flood hydrographs developed for Athea bridge and the Athea streams using synthetic unit hydrograph method are deemed appropriate to represent the design flood events at Athea. The flood hydrographs for the HEP at Ahavoher, Galey and Inch bridges have been derived using the FSU web portal hydrograph module. Inch bridge gauge has been used a pivotal site for the three sites; however, it is noted that the associated rating curve has been revised and also that the SAARs used in the FSU (1961-1990) are approximately 20% less than the 1981-2010 Met Éireann dataset. For the purposes of generating these hydrographs, an adjustment factor has been applied to the flows to ensure the peak flows match the design flows derived in Section 9. The 1973, 2005 and 2008 peak flood events have been used to develop the design hydrograph shape. Figures 11-7 to 11-9 present the adjusted FSU generated hydrographs for the main channel HEPs.

Figure 11-10 presents a comparison between the FSU generated hydrographs and the recorded hydrographs at Inch Bridge which shows that the adjusted FSU generated hydrograph at Inch Bridge is a good representation of the recorded flood hydrographs and confirms that the hydrographs presented in Figure 11-7 to Figure11-9 are appropriate for the hydraulic assessment.



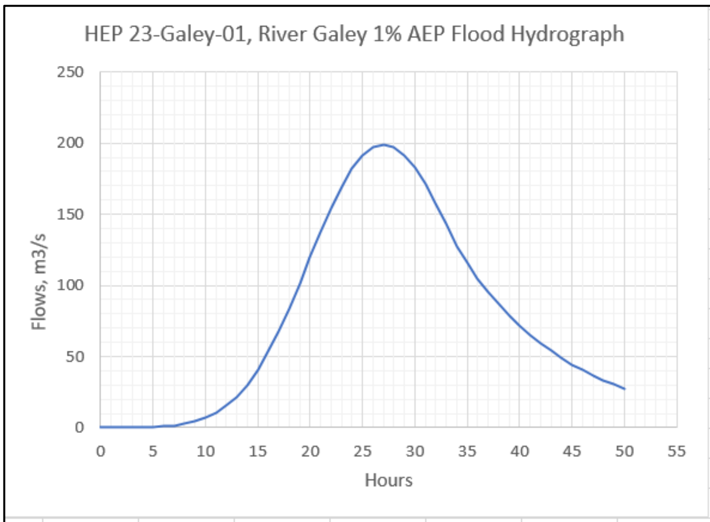
Hour	Flow, m3/s	Hour	Flow, m3/s	Hour	Flow, m3/s
1.0	0.0	**17.0**	38.1	**33.0**	80.5
2.0	0.0	**18.0**	47.2	**34.0**	71.8
3.0	0.1	**19.0**	57.0	**35.0**	64.9
4.0	0.1	**20.0**	67.1	**36.0**	59.0
5.0	0.3	**21.0**	77.2	**37.0**	53.6
6.0	0.5	**22.0**	86.6	**38.0**	48.7
7.0	0.9	**23.0**	95.1	**39.0**	44.3
8.0	1.5	**24.0**	102.1	**40.0**	40.3
9.0	2.4	**25.0**	107.4	**41.0**	36.6
10.0	3.8	**26.0**	110.7	**42.0**	33.3
11.0	5.8	**27.0**	111.7	**43.0**	30.2
12.0	8.6	**28.0**	110.7	**44.0**	27.5
13.0	12.2	**29.0**	107.6	**45.0**	25.0
14.0	17.0	**30.0**	102.7	**46.0**	22.7
15.0	22.9	**31.0**	96.3	**47.0**	20.6
16.0	29.9	**32.0**	88.8	**48.0**	18.8

Figure 11-7: Galey River (23-Galey-04) 1% AEP Design Hydrograph (FSU Hydrograph)



Hour	Flow, m3/s	Hour	Flow, m3/s	Hour	Flow, m3/s
1.0	0.0	**17.0**	48.9	**33.0**	103.4
2.0	0.0	**18.0**	60.7	**34.0**	92.2
3.0	0.1	**19.0**	73.2	**35.0**	83.4
4.0	0.2	**20.0**	86.2	**36.0**	75.8
5.0	0.3	**21.0**	99.1	**37.0**	68.9
6.0	0.6	**22.0**	111.3	**38.0**	62.6
7.0	1.1	**23.0**	122.2	**39.0**	56.9
8.0	1.9	**24.0**	131.2	**40.0**	51.7
9.0	3.1	**25.0**	138.0	**41.0**	47.0
10.0	4.9	**26.0**	142.1	**42.0**	42.7
11.0	7.4	**27.0**	143.5	**43.0**	38.8
12.0	11.0	**28.0**	142.1	**44.0**	35.3
13.0	15.7	**29.0**	138.2	**45.0**	32.1
14.0	21.8	**30.0**	131.9	**46.0**	29.2
15.0	29.4	**31.0**	123.7	**47.0**	26.5
16.0	38.5	**32.0**	114.0	**48.0**	24.1

Figure 11-8: Galey River (23-Galey-03) 1% AEP Design Hydrograph (FSU Hydrograph)



Hour	Flow, m3/s	Hour	Flow, m3/s	Hour	Flow, m3/s
1.0	0.0	**17.0**	67.8	**33.0**	143.3
2.0	0.1	**18.0**	84.0	**34.0**	127.8
3.0	0.1	**19.0**	101.5	**35.0**	115.5
4.0	0.2	**20.0**	119.5	**36.0**	105.0
5.0	0.5	**21.0**	137.3	**37.0**	95.5
6.0	0.9	**22.0**	154.2	**38.0**	86.8
7.0	1.5	**23.0**	169.3	**39.0**	78.9
8.0	2.6	**24.0**	181.8	**40.0**	71.7
9.0	4.3	**25.0**	191.2	**41.0**	65.2
10.0	6.7	**26.0**	196.9	**42.0**	59.2
11.0	10.3	**27.0**	198.9	**43.0**	53.8
12.0	15.2	**28.0**	197.0	**44.0**	48.9
13.0	21.8	**29.0**	191.5	**45.0**	44.5
14.0	30.2	**30.0**	182.8	**46.0**	40.4
15.0	40.7	**31.0**	171.4	**47.0**	36.7
16.0	53.3	**32.0**	158.0	**48.0**	33.4

Figure 11-9: Galey River (23-Galey-01) 1% AEP Design Hydrograph

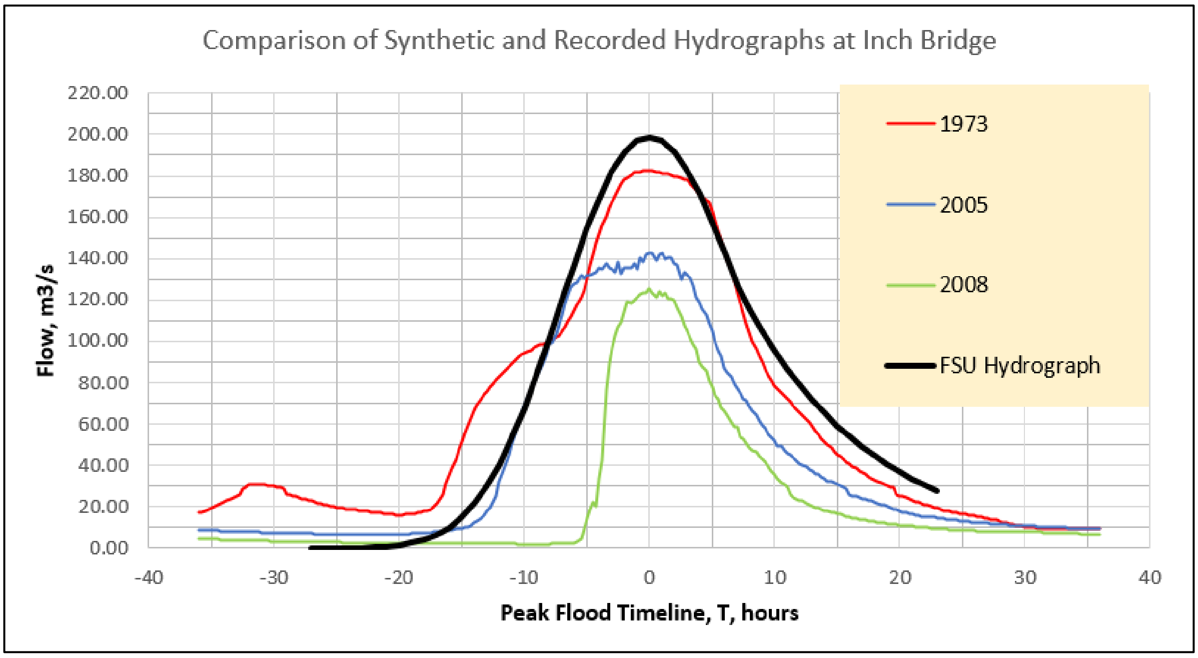


Figure 11-10: Comparison of Synthetic and Recorded Flood Hydrographs at Inch Bridge

12 Future Climate and Catchment Changes

12.1 Introduction

Section 4.2.10 and Table 4-4 (and Table 12-1) presents the allowances recommended by the OPW to estimate the impact of MRFS and HEFS climate and catchment changes on the design flows in the Athea study area.:

Table 12-1: Allowance for Future Scenarios

	MRFS	HEFS
Extreme Rainfall Depths	+20%	+30%
Flood Flows	+20%	+30%
Urbanisation	No urbanisation changes agreed with the Client	
Afforestation	-1/6Tp[6]	-1/3Tp+10%SPR[7]

It is unlikely that any significant urban development will occur in the Athea Bridge catchment area in the future and therefore no allowance for urbanisation has been assessed.

The effect of the increased extreme rainfall depths on the Athea study area design 1% AEP hydrographs have been assessed here with and without the future afforestation allowances. These, in turn, have been compared to the design 1%AEP flood flow rates including for the MRFS and HEFS allowances and the afforestation allowances on their own.

12.2 Future Scenarios Design Flows

The current and future 1% AEP design scenario flood flows at Athea Bridge are summarised in Table 12-2:

Table 12-2: Athea Bridge Peak flows for MRFS and HEFS scenario

Location	Current, 1%AEP, m^3/s	Future Scenario		Allowance	1% AEP, m^3/s	Increase over Current Scenario 1% AEP
Athea Bridge	69.6	Rainfall	MRFS	+20%	83.82	+20.4%
			HEFS	+30%	90.68	+30.3%
		Peak Flows	MRFS	+20%	83.52	+20%
			HEFS	+30%	90.48	+30%
		Afforestation	MRFS	-1/6Tp	77.62	+11.5%
			HEFS	-1/3Tp+10%SPR	89.25	+28.2%
		Rainfall and Afforestation	MRFS	Combination	95.03	+36.5%
			HEFS	Combination	115.6	+66%

The current and future 1% AEP design scenario flood flows in the Athea Streams are summarised in Table 12-3 and Table 12-4.

[6] Reduce the time of peak by one sixth allow for potential accelerated runoff that may arise as a result of drainage of afforested land.
[7] Reduce the time to peak (Tp) by one third and add 10% to the Standard Percentage Runoff (SPR) to allow for increased runoff rates that may arise following felling of forestry.

Table 12-3: Athea West Stream Peak flows for MRFS and HEFS scenario

Location	Current, 1%AEP, m³/s	Future Scenario		Allowance	1% AEP, m³/s	Increase over Current Scenario 1% AEP
Athea West	1.66	Rainfall	MRFS	+20%	1.95	+17.5%
			HEFS	+30%	2.12	+27.7%
		Peak Flows	MRFS	+20%	2.0	+20%
			HEFS	+30%	2.16	+30%

Table 12-4: Athea East Stream Peak flows for MRFS and HEFS scenario

Location	Current, 1%AEP, m³/s	Future Scenario		Allowance	1% AEP, m³/s	Increase over Current Scenario 1% AEP
Athea East	3.36	Rainfall	MRFS	+20%	4.02	+19.6%
			HEFS	+30%	4.35	+29.5%
		Peak Flows	MRFS	+20%	4.03	+20%
			HEFS	+30%	4.37	+30%
		Afforestation	MRFS	-1/6Tp	3.82	+13.7%
			HEFS	-1/3Tp+10%SPR	4.71	+40%
		Rainfall and Afforestation	MRFS	Combination	5.01	+49.1%
			HEFS	Combination	6.12	+82%

12.3 Erosion and Deposition

As demonstrated in the sections 2.1.7.1 to 2.1.7.5 and section 3.5.2, and as highlighted in project's Hydraulic Report, sediment (gravels) deposition has been a proven significant contributor to flood risk during past flood event at Athea village associated with channel and bridge open area blockage. A preliminary analysis associated with future rainfall projections and the catchment erosion and deposition regime has been undertaken in order to estimate the future catchment erosivity. Using future rainfall projections[8] for 2050 derived from General Circulation Models based on the calibration and downscaling from historical rainfall baseline gauges (1950-2000) to provide a high spatial resolution of 1 km^2, the future erosivity in the catchment has been indicatively estimated as ranging between from 750 to 800 MJmm/(ha.h.yr). This estimation suggests that sediment transport in the Athea catchment will increase in line with increases in rainfall intensity associated with climate change which in turn has the potential to contribute further to flood risk at Athea. This conclusion further emphasises the recommendation that erosion and sediment countermeasures are incorporated into the scheme.

12.4 Conclusion

The above future scenarios design flows demonstrate the vulnerability of Athea Village to the impact of potential increases in rainfall and the impact of unmanaged afforestation. The most extreme HEFS scenario estimates a 66% increase in the 1% AEP design flow in the Galey River. Such an extreme flood flow rate would likely have a devasting impact on Athea. Equally the capacity of the Athea West and Athea East culverts would likely be exceeded during such scenarios leading overland flows through the village.

In addition, the future flood flow rates would be expected to increase erosion and deposition along the river and stream channel and the exacerbate the timber and sediment blockage risks during flood events.

It is clear from the above that unmanaged felling of forestry and upstream drainage improvements has the potential to significantly impact Athea village. Consultation and collaboration with the upstream landowners will be essential as part of the Athea FRS in order to develop a catchment management plan to mitigate the identified potential future increases in flood risk at Athea. Such mitigations could comprise 'Slow the Flow' methods including strict regulation of forestry development and operations in the catchment, replanting clear-felled plantations with permanent deciduous forestry,

[8] Panagos, P., Ballabio, C., Meusburger, K., Spinoni, J., Alewell, C., Borrelli, P. 2017. Towards estimates of future rainfall erosivity in Europe based on REDES and WorldClim datasets. Journal of Hydrology, 548: 251-262

damming forestry drainage channels, reinstating streams and construction of attenuation ponds. Indeed, increased planting of deciduous forestry in the upper catchment could also mitigate the future effect of increased rainfall intensity and channel erosion in the catchment.

It is recommended that:

- The flood risk assessment for Athea FRS consider the above future design flows to confirm the vulnerability of the village to climate and catchment changes and inform the decision of the appropriate design standard for Athea.
- The design of flood protection works, and culvert and channel upgrades at Athea either include or allow (be readily adaptable) for the future scenario design flows (i.e. larger freeboards and increased culvert capacity).
- A Catchment Management Plan is progressed now for the Galey River catchment upstream of Athea Bridge to identify measures that will assist in the mitigation of potential significant increases in flood risk at Athea associated with climate change.

13 Joint Probability Analysis

A joint probability analysis has been carried out for Athea relating its three potential flood sources, i.e. the Galey River, the Athea West and East streams, and the village storm drainage system.

The assessment of the July 31st 2008 flood event (Section 6 and 9) using remote sensing rainfall data (NASA) and a CN-rainfall runoff model estimated that the pluvial (hillside and urban) peak flows likely occurred approximately 2 to 3 hours before the Galey peaked. However, due to the overall lack of hourly rainfall data and river gauges at Athea this assessment for the 2008 event can only be taken as indicative. It is not feasible to undertake a joint probability analysis of historic flood events at the village and therefore this analysis is based on the synthetic hydrographs developed for the study area and a precautionary approach.

As identified in Section 10 the time to flood peak of the stream's design flood event have been estimated at <3 hours while that of the Galey River at Athea bridge is of the order of 6 hours. The relative magnitude of the streams' peak flows compared to the river's peak flow is small. It is probable that the rainstorm that would cause an extreme flood flow in the Galey River at Athea Bridge would also result in high flood flows in the Athea streams' catchments. Given the catchment characteristics and prevailing wind direction (south west) it is probable that:

- the 'flood' rainstorm would pass over Athea village before reaching the catchment's upland area.
- the streams' peak flood would have passed a number of hours before the river flood would peak, and;
- the joint probability of the streams' and river's flood peaks occurring at the same time at Athea is medium to low.

It is recommended that the peak 1% AEP flood levels calculated in the Galey River at the stream outfall sections will be used as the downstream boundary condition for the independent flood risk hydraulic analysis for the streams. This precautionary approach for an otherwise low joint probability event will therefore negate any further detailed joint probability analysis for these systems.

As shown in Table 4-1 and Figure 4-1, the Galey River channel gradient at Athea is steep and the closest downstream tributary of significance, the Knocknagornagh Stream, is 2.4km downstream and 12.5m lower than the channel invert at Athea Bridge. With respect to flood risk at Athea village, the joint probability of the Knocknagornagh stream and the Galey River at Athea Bridge peaking at the same time is therefore inconsequential.

It is probable that the storm drainage system and urban area run-off discharging to the Athea West Stream culvert and village's combined sewer system could peak at approximately the same time as the stream catchments (associated with the same or potentially separate rain-storms). It is recommended, following a precautionary approach, that both peak flows are assessed as occurring coincidentally. This associated in-combination flood risk can be mitigated by diverting the storm drainage to an independent outfall pipe/ new storm drainage system.

Significant blockages of culverts and channels associated with gravel deposition and flood debris arising for bank erosion are highly probable to coincide with extreme flood events. The joint probability of the Athea West Stream and Athea East Stream culverts blocking during the flood events depends on multiple factors including the degree of channel maintenance being undertaken, channel erosion, flood debris etc. and is difficult to assess. As set out in Section 4.2.9, a sensitivity analysis of various blockage scenarios and flood return periods will be simulated to determine associated potential flood risk.

14 Conclusion and Summary

A hydrological analysis for Galey River and its tributaries at Athea, Co. Limerick has been undertaken as part of the Athea FRS study. The analysis presented supersedes the CFRAM study findings and is in line with the Ryan Hanley Hydrological Method Statement report. The main findings are as follows:

A. The SAAR used in the CFRAM study relates to the 1961- 1990 rainfall dataset. This study has used the current 1981-2010 SAAR dataset. The current dataset represents an increase of between 13% and 22% in SAAR within the study area.

B. The Galey River catchment area at Athea is 36.7km^2 and comprises a hilly, steep and high run-off lands. 50% of the catchment upstream of Athea is covered by forestry lands. An assessment of the catchment for the period 1990 to 2018 using the EPA CORINE database has identified significant forestry development in the 1990s and increased tree-felling/ harvesting in the 2012 to 2018 period.

C. The hillside drainage system to the south of Athea (Athea West and Athea East streams) has been defined as part of this study and the associated catchment areas determined. The Athea West stream catchment drains to a complex and long culvert system which has a history of blocking. A large hillside catchment area has been identified as discharging directly to Con Colbert Street.

D. Erosion and deposition are evident in the Athea Galey River reach and appreciable bank erosion is occurring adjacent to the school upstream of Athea Bridge. There is potential that a meander at the school could be become cut-off and lead to increase erosion along the school bank.

E. Significant deposition occurs at Athea Bridge and associated channel reach which is estimated to be currently blocking up to 26% of the effective flow area at the bridge and was probably a significant contributor to flood risk during the July 31st 2008 flood event.

F. Athea Bridge and associated channel reach are prone to blockage by flood debris during flood events.

G. While there is a robust network of rain gauges with long period datasets in the vicinity of the Athea Bridge catchment; these gauges only collect daily rainfall totals. The nearest synoptic weather station is located at Shannon. It is recommended that a new hourly recording rain gauge is installed at Athea to inform future management of the Athea Bridge catchment

H. Inch Bridge gauge (23001) is the only hydrometric station with adequate water level records and gaugings on the Galey River. Its contributing area is over 5 times that of Athea Bridge. It has 60years of water level data available.

I. The most significant Galey River flood event at Athea in recent years occurred around midnight on the July 31st/ August 1st 2008 which resulted in 21 No. properties at Athea and Athea WWTP being impacted by flooding or flooded. The return period of the associated rainfall event has been estimated at approximately 1 in 125years

J. The most significant flood event in recent years in the streams' catchments occurred on 2nd September 2009 and was associated with a culvert blockage coinciding with a moderate rain-storm which resulted in 6 No. properties flooding.

K. The largest flood on record in the Galey catchment (at Inch Bridge gauge) occurred on the 1st December 1973 when a flow of 182.6m^3/s was recorded. There is no record of significant flooding at Athea during this event.

L. 22 No. HEPs have been assessed for the study area including two each on the Athea West and East streams and two urban areas.

M. An assessment of the available hydrometric data has concluded that a combination of statistical analysis of gauge data and ungauged catchment flood estimation methods were required to calculate the study areas design flows.

N. A review of potential sites for additional hydrometric gauges to inform this study has been completed. The OPW subsequently installed two new gauges at Athea Bridge in April 2021. It is recommended that a series of flow gaugings are completed at the downstream gauge coinciding with flood events. Establishment on site for such a survey would be difficult given the spate nature of the river at Athea.

O. 5 No. rain gauges in the vicinity of the study area have been used, together with Thiessen polygons and the FSU DDF database to calculate and assess the study area's design and historical flood events rainfall return periods for the catchment. Due to the lack of Met Éireann hourly rainfall records within the study area, it was necessary to use NASA sourced sub-hourly rainfall dataset in combination with Met Éireann daily rainfall records to appropriately assess of the rainfall intensities relative to catchment's 'flashy' nature.

P. Based on an assessment the July 31st/ August 1st 2008 rainstorm flood event the return period of the 2008 flood event in Athea Bridge catchment has approximated at 1 in 200years. A CN rainfall-runoff analysis using 30-min remote sensing records (NASA) has been undertaken to compensate for the lack of river gauges at Athea and to augment the existing rain gauge (daily totals) dataset available in the study area. The rainfall associated with the event at Athea was an intense 7-hour rainstorm (64.4mm) with an estimated return period of 125 years. The peak flood flow during this event at Athea has been calculated at 77.5m^3/sec (approximately a 1 in 200year (0.5% AEP) event). In summary, in the absence of a well calibrated river gauge at Athea Bridge a thorough analysis of the best available catchment and rainfall data has been used to estimate the peak flood flow at Athea Bridge on the night of 31st July/ 1st August 2008. The statistical error associated with the main inputs to the estimation method, total rainfall depth and rainstorm duration, has been confirmed at +/- 10%. Based on this Ryan Hanley has concluded that estimated peak flood flow rate of 77.5m^3/s and the derived hydrograph shape are appropriate for the Athea Flood Relief Scheme hydraulic assessment with a good degree of confidence. A similar analysis was carried out for the events of September 2015 and September 2009 for which an estimated peak flow of 44.2 m^3/sec and 20.3 m^3/sec have been assessed respectively.

Q. The 4-day and peak 1-day events rainfall return periods of the 1973 flood event have been calculated at between 1 in 250 and 1 in 360years, and 1 in 35 years respectively.

R. A full rating curve review has been undertaken for the Inch Bridge gauge for this study and a revised rating curve developed.

- In order to compensate for the lack of gaugings at the higher flow extents of the curve and variance between two high flow gaugings, hydraulic modelling of the river reach at Inch Bridge has been undertaken to improve the extrapolation of the rating curve for extreme flood flows.
- It is recommended, going forwards, that gaugings are undertaken coinciding with high flows >100m^3/s.
- The adjustment factor between the Qmed (gauge) and Qmed (FSU 7v) has been calculated at 1.18. The peak flow during the 1973 flood event at Inch bridge is calculated at 182.6m^3/s revised down from 210.1m^3/s. The magnitude of the 1960 flood events have also been revised downwards.
- The associated Amax series has been revised. The growth curves associated with the 68% upper confidence interval analysis of the revised AMAX series have been used to calculate the main channel design flows.

S. Design flows for the 22 No. HEP in the study area have been calculated. The FSR 7v and the FSU 4.2a methods have been used to calculate the design flows in the Galey River and the Athea streams respectively.

- The 1% AEP design flow at Athea Bridge has been calculated at 69.6m^3/s.
- The 1% AEP design flow at Athea West Stream Culvert and the Athea East Stream culvert on the Abbeyfeale Road have been calculated at 1.66m^3/s and 3.36m^3/s.

T. Design Flood Hydrographs for the Athea West, Athea East, Galey River at Athea Bridge and the Galey River between Ahavoher and Inch Bridge have been developed using a combination of synthetic hydrograph FSU, FSR methods and past flood event hydrographs.

U. A preliminary pluvial flood risk assessment has been undertaken for Athea Village based on CCTV survey on the culvert and sewer system, topographical contour mapping and property threshold level survey.

- There is a significant pluvial flood risk at Athea associated with blockages at Athea West culvert. Recommendations have been given for immediate and ongoing maintenance of the inlet to the culvert.
- A large hillside area discharges directly to Con Colbert Street and the Ardagh Road. There is insufficient storm drainage infrastructure at Athea to convey the associated flood flows.
- Low lying buildings on Con Colbert Street, and on the Glin and Ardagh Roads between the school and the bridge together with roads at Markievicz Park and Cois na Gaíle are at pluvial flood risk.

V. Climate and catchment change analysis have been completed for the Galey River catchment at Athea and has identified that Athea is potentially extremely vulnerable to the effects of increased rainstorm intensities and afforestation in the catchment. It is recommended that:

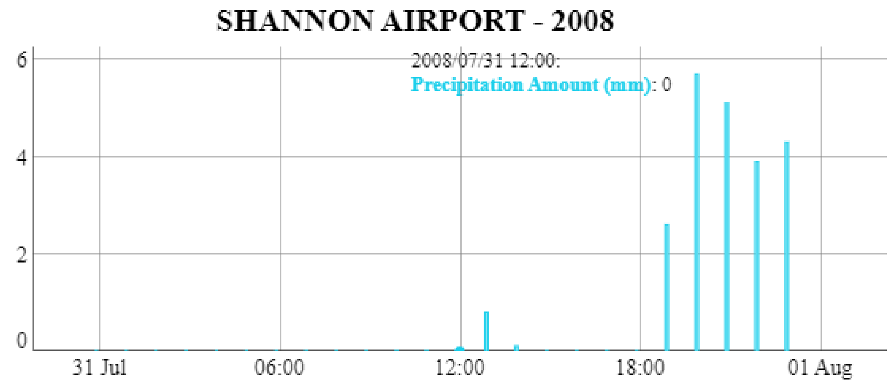
   - A catchment management plan is developed in consultation and collaboration with the upstream landowners to mitigate a potential significant future increases in flood risk at Athea.
   - A higher design standard than the 1% AEP be considered for the Athea FRS assessment to account for the identified vulnerability of the village to future climate, channel and catchment changes.

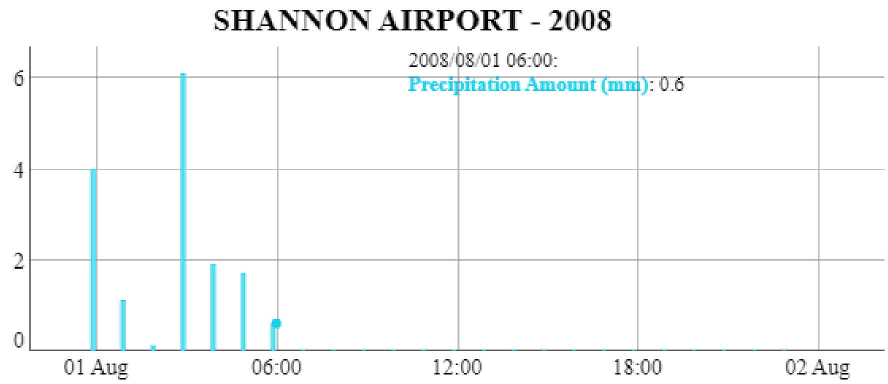
W. Due to the lack of hourly rainfall and river gauge data at Athea, the joint probability analysis for Athea Village for the various flood sources (i.e. fluvial (river), fluvial (streams) and pluvial) has been undertaken based on a precautionary approach.

X. Due to the significant differences in catchment characteristics between the Inch Bridge and Athea Bridge sites, and multiple tributaries and drainage channels discharging to the Galey between the two sites, direct use of the Inch Bridge gauge to calibrate historic flood events in the Athea Bridge reach would be difficult. The flood event for which peak flood level information at Athea is available and whose Inch Bridge hydrograph appears to be somewhat representative of a flood event at Athea Bridge, due to the apparent localised nature of the flood event in the Athea Bridge catchment, is the 31st July / 1st August 2008 flood event. The Galey River channel and bridge at Athea during this event was reported to be partially blocked by flood debris, vegetation and gravel deposition and subsequently channel maintenance works were carried out by the OPW. Works were undertaken by a landowner to clear the overgrowth and reprofile the river's left bank downstream of Athea Bridge in early 2021. Based on the above multiple changes to the channel's condition and capacity it would be difficult to calibrate a hydraulic model at the Athea Bridge reach to the agree with the 2008 extreme flood event. It is recommended, therefore, that the Athea reach hydraulic model for the current scenario is developed based on the current channel conditions and a precautionary approach comprising a sensitivity analysis of the channel's Manning's roughness coefficients, blockage scenarios in the channel through Athea and a range of conservative downstream boundary conditions in the channel reach within 1 km downstream of Athea Bridge.

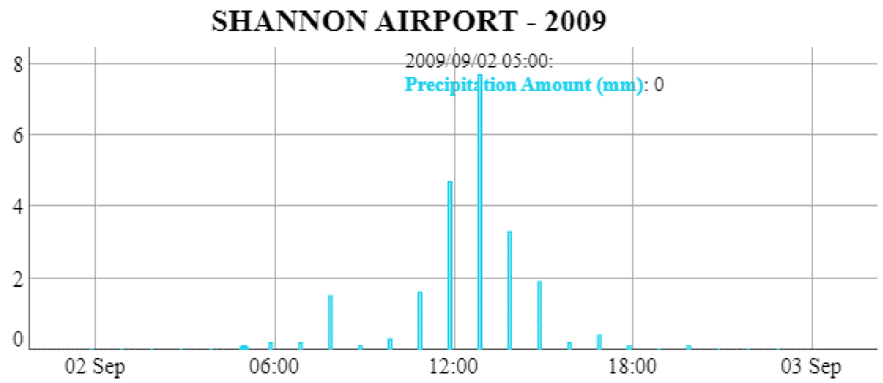
Appendix A: Rainfall Records

August 2008 Event - Records

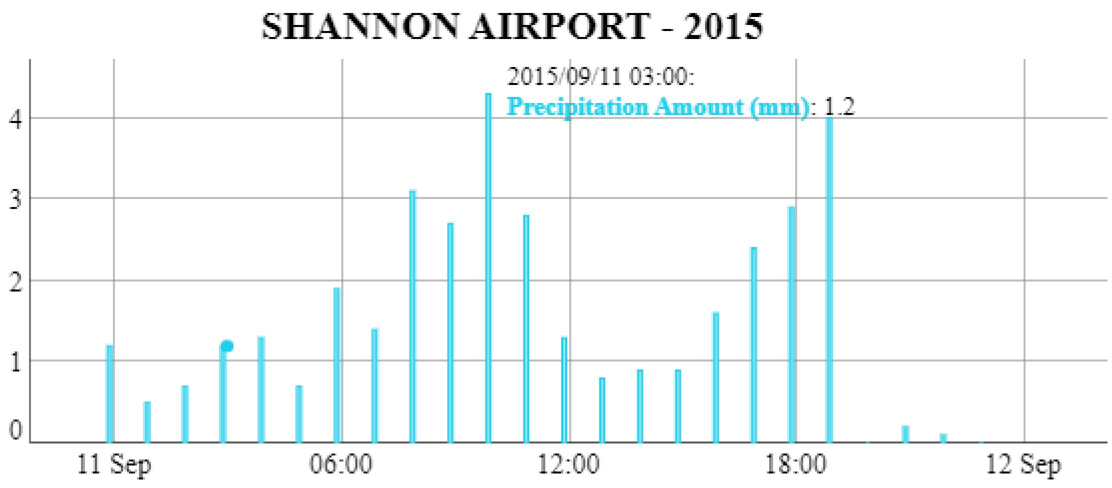




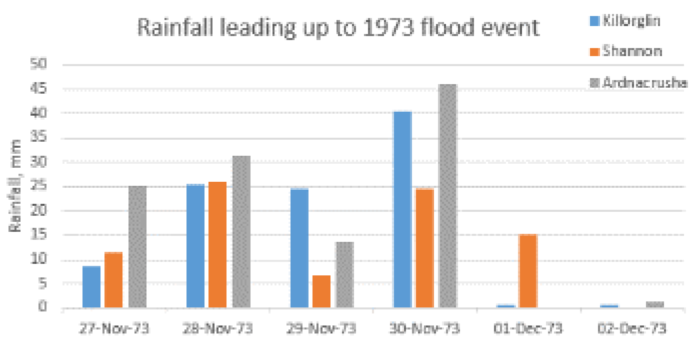
September 2009 Event - Records

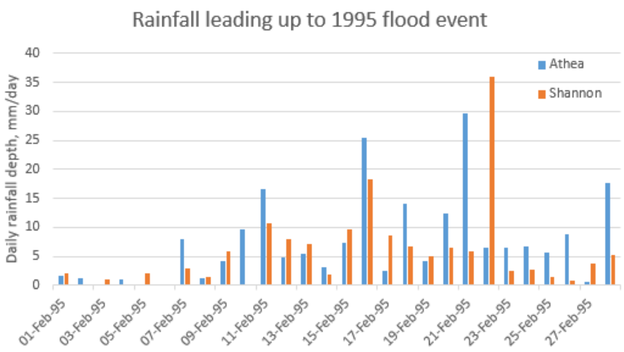


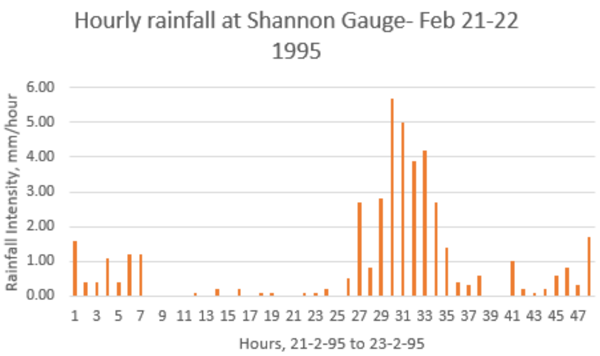
September 2015 Event - Records

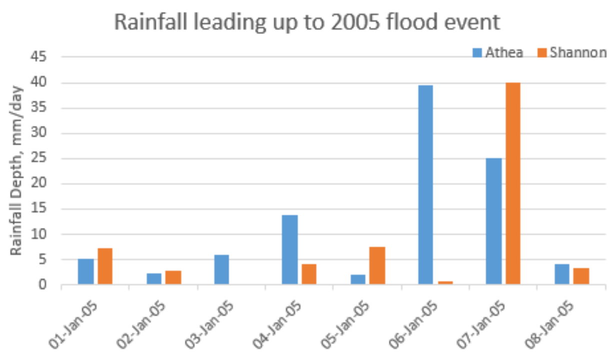


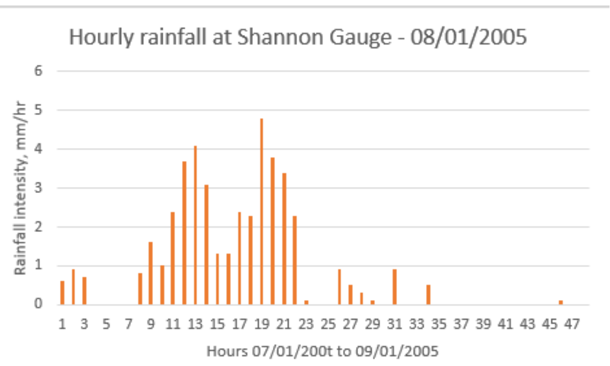
Rainfall records for previous past flood event (Shannon Airport rainfall gauge station, Athea rainfall gauge station)

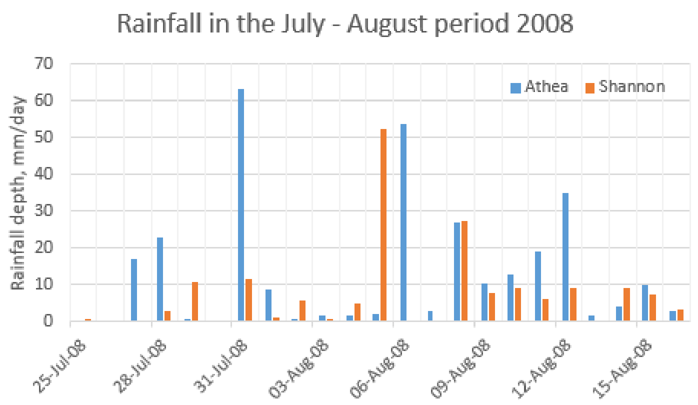


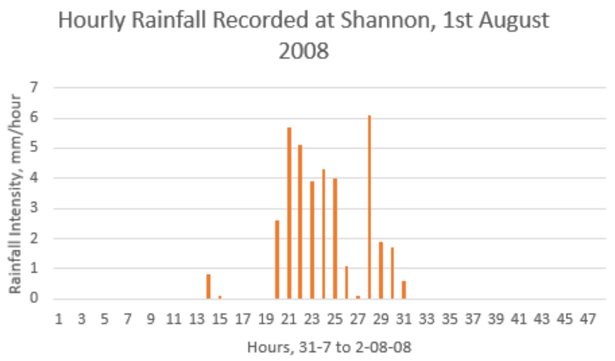


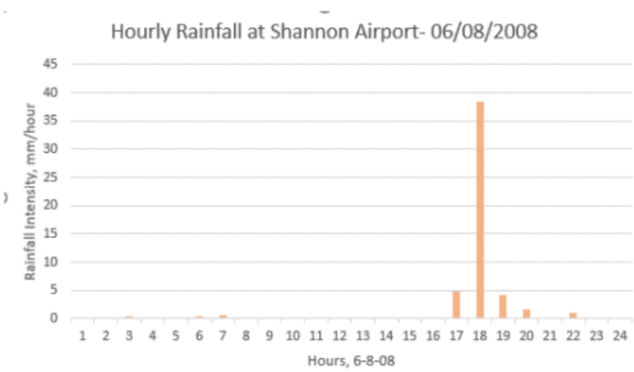


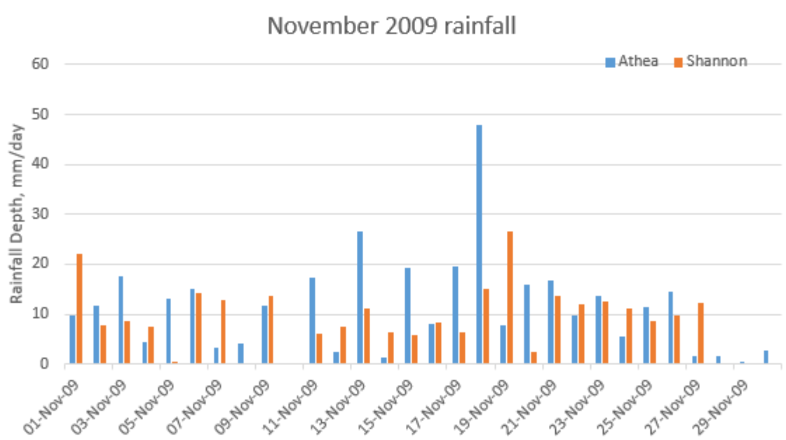

Rainfall leading up to 2005 flood event
Athea
Shannon
Rainfall Depth, mm/day

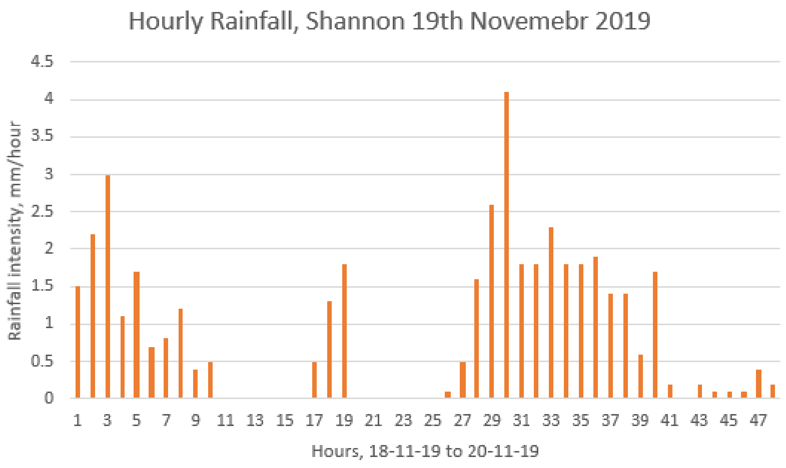

Hourly rainfall at Shannon Gauge - 08/01/2005
Rainfall intensity, mm/hr
Hours 07/01/200t to 09/01/2005


Rainfall in the July - August period 2008
Athea
Shannon
Rainfall depth, mm/day


Hourly Rainfall Recorded at Shannon, 1st August 2008
Rainfall Intensity, mm/hour
Hours, 31-7 to 2-08-08


Hourly Rainfall at Shannon Airport- 06/08/2008
Rainfall Intensity, mm/hour
Hours, 6-8-08


November 2009 rainfall
Athea
Shannon
Rainfall Depth, mm/day


Hourly Rainfall, Shannon 19th Novemebr 2019
Rainfall intensity, mm/hour
Hours, 18-11-19 to 20-11-19
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47

Appendix B: Athea Streams Site Visit 24/11/2020

Introduction

A site visit was undertaken by Ryan Hanley on 24th November 2020 to Athea, Co. Limerick to:

- inspect the stream channels and culvert system at Athea,
- collect additional anecdotal information on flooding,
- record the prevailing aggradation under Athea Bridge,
- assess the pluvial flood risk at Athea
- estimate the Athea West and East stream catchment areas
- inspect the bridges downstream of Athea as suitable sites for gauging
- make suggestion on urgent flood relief works
- make suggestions on potential flood risk management measures

The site visit corresponded with a moderately wet day (yellow rainfall warning) when the catchment was saturated.

Stream and River Channels and flooding at Athea.

The three stream channels and the river channel which flow through Athea, namely the Listowel Road stream, Athea West stream and Athea East Stream and the Galey River, were visited. Figure D-1 and Table 1 summarise the findings of the channel inspections.

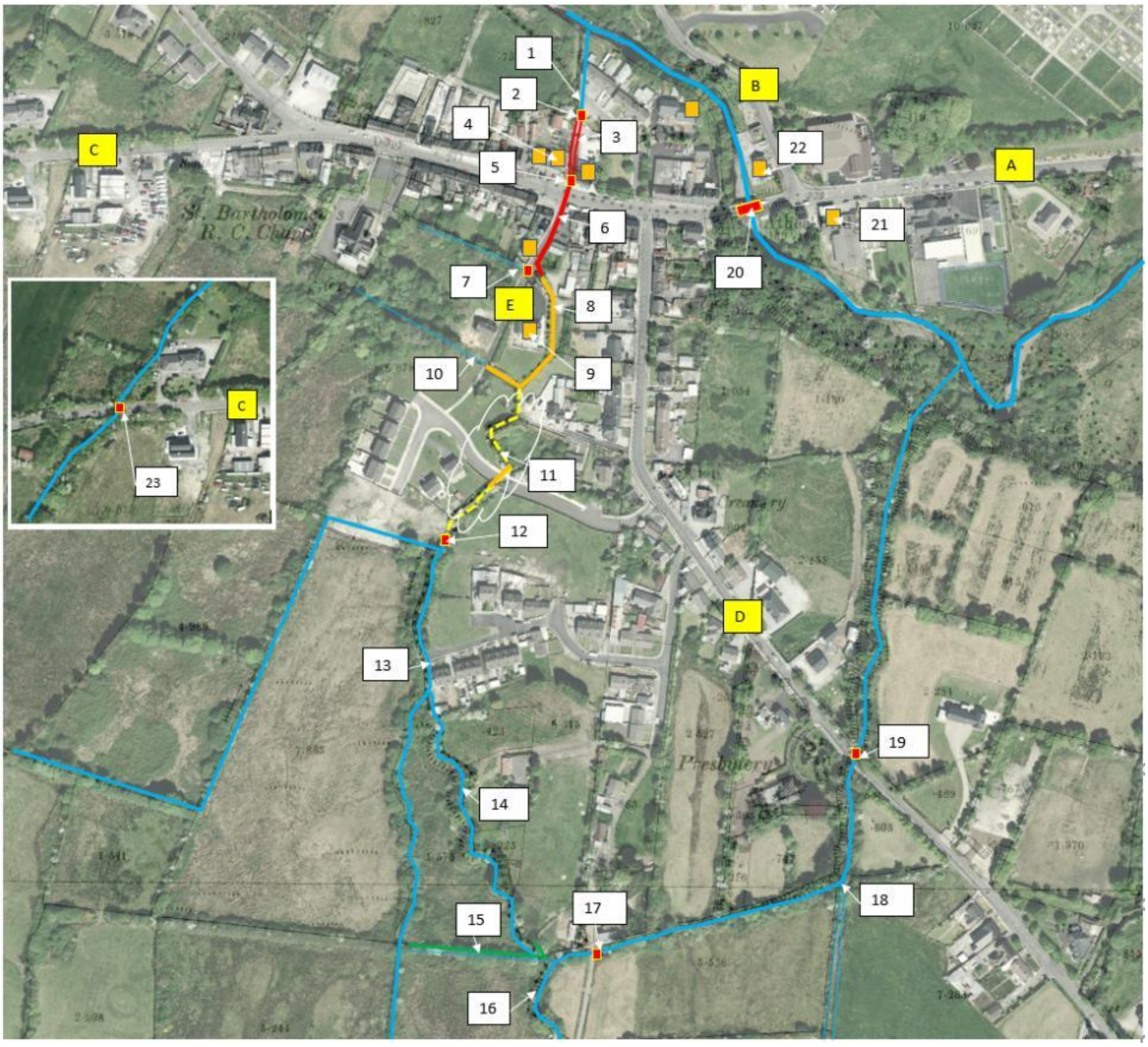


Figure D-1: Athea Site visit notes locations

Site Ref	Comment
1	Outlet channel from Athea West Stream. Overgrown. Channel blocked by field gate which was collected flood debris. Risk to Markievicz Park. Access from site ref 4
2	Outlet headwall. Twin stone box culverts (stone slabs and stone wall construction). Passes under rear and street boundary walls.
3	Twin stone box culvert, slabs removed and channel visible. Each circa 0.6m high x 0.6m wide. Currently clear of debris and gravels
4	Existing house (which flooded) is being renovated and partially demolished. A new extension (which has planning permission) is proposed towards Collin's Shop which may encroach over the culvert. The twin-stone culvert continues upstream to beyond the street boundary wall. Slabs have fallen in within the site in the past and have been reinstated.
5	Following the September 2009 flood event LCC upgraded the Athea West Stream culvert including the construction of a manhole at the upstream end of the twin culverts. A tree branch got stuck in the culvert at the inlet to the twin culverts during the September 2009 event and blocked the culvert. This resulted in flooding of several houses and Collins' shop and houses up the lane (Quille's Lane).
6	Houses along 'The Lane' were flooded in September 2009. Following the September 2009 flood event LCC upgraded the old culvert with a box culvert up the lane as far as Quille's house and the culvert extended as a 900mm pipe to the inlet chamber and screens upstream of Rathronan Estate. Site visits and the CCTV survey have confirmed multiple storm water connections to the Athea West Stream culvert between Site 12 and Site 5.
7	An open drain if reported overtops the roadside wall and flood onto the lane following heavy rain.
8	An existing pipe culvert and section of open drain through Quille's private lands/ gardens were replaced with a 0.9m dia. pipe culvert and 0.6m x 1.2m culvert following the September 2009 event. Culvert details presented in the CCTV report accompanying the Hydraulic Modelling Report for this study
9	Quille's have a large amount of photographs available and detailed information on the September 2009 flood. These people will need to be consulted with.
10	Small open drain which is now overgrown. Overflows down the lane.
11	Channel Alignment and culvert detail in this section confirmed by CCTV survey 0.9m diameter pipe culvert under the road at the Rathronan estate..
12	The existing inlet structure and screens to the Athea West culvert was overgrown and blocked by flood debris during the site visit in November 2020 and significant backing up of flows was noted. High risk of full blockage at the screens which could result in an overland flood discharging to 'The Lane' and Con Colbert Street. **It is recommended that maintenance works is undertaken at this inlet structure and frequent inspections carried out, in particular before forecasted rainfall warnings events.** A 900mm pipe culvert (ogee pipe, short length) cross the channel upstream of the inlet. An open drain flows into the Athea West channel immediately upstream of the 900mm pipe. Drainage pipes from Rathronan estate discharge to the stream. Oil pollution was evident. Flood Debris included plastic and branches (some which were removed during the site visit). It was evident that the inlet structure should be upgraded and an access track provided and it should be fenced off. Children appear to play around the area. Apparent that the Rathronan development could extend up hill in the future phases. Access for maintenance essential.
13	Athea West Stream is a small steep hill side channel likely to respond rapidly to rain storms. Stream channel is overgrown. Small amounts of trash evident. Potential for timber debris to be washed down. Channel not readily accessible for maintenance. Deep channel in places. Channel partially fenced off. The upper channel is completely overgrown.
14	Minor channel which appears historically to have conveyed a large flow. Now only drains local runoff. Wide channel accessible by livestock. No sign of overflow from Athea East Stream but may have been historically. Small flow rate evident
15	An open drain located upstream of an earthen bank/ field boundary. Drain is very overgrown. Not clear if it flows both to east and west. The open drain intercepts hillside runoff. The earthen bank is high at the bend with Athea East

	stream and not likely overtopped. If the bank was not in place Athea East stream would overflow into Athea West Stream during flood events. It is important that this bank is further investigated and upgraded to prevent an overflow into Athea.
16	Athea East Stream is a significant hillside stream channel. Very deep channel in place, significant signs of erosion. Steep and fast flowing. Flow on the 24/11/20 was circa 0.3m^3/s at Site 17. Channel bends at earthen bank before continuing east. Channel is overgrown and some signs of metal dumping. Apparent that large flows are conveyed in the channel. Average channel gradient between Points 17 and 19 is 1m in 25.8m (3.9%).
17	A 6.1m long 900mm pipe culvert across the Athea East Stream for a farm access track. No signs of blockage. Potentially could block from timber flood debris etc. Potentially surcharges and overtops the access road. Invert and parapet level are 94.7mOD and 96.5mOD. Left bank level <96.0mOD Flow depths of up to 0.4m upstream of Site 17 on the site visit day. Flow depth at outlet from culvert (jet) was 0.225m to 0.25m.
18	Two tributaries discharge to the Athea East channel. The main channel is several metres deep at this location. Significant erosion evident.
19	Abbeyfeale Road Bridge. Masonry Arch culvert. 2.38m wide by 2.17m high opening. Arch springing height at 1.07m. 8.11m long. Upstream and downstream Invert levels are 85.01mOD and 83.8mOD. Road Level 89.5mOD Very steep gradient. High potential for erosion. The channel bed is protected from scouring with stone paving at the culvert. Well maintained bridge. Needs to be regularly inspected to ensure it is not blocked with flood debris. Deep channel. No evidence that it has surcharged and flooded the main road. Culvert has appreciable capacity but likely only adequate for peak flood flow. The downstream channel is very steep. Could not readily access the bridge to take measurements.
20	Athea Bridge over the main Galey River channel. Three arches: two smaller side arches and one large central arch. The flow was concentrated in the two side arches and at the left pier side of the main arch on the 24th Nov 2020. A large volume of gravel and cobble deposition at the central arch was evident. A gravel aggradation island has formed and is vegetated downstream of the bridge; approximately 25m-30mlong and 3m to 5m wide. The channel under the bridge was dredged historically and was cleaned out by the OPW following a recent flood event but it quickly filled back up again following another flood. It would appear appropriate from a flood risk point of view that the excess deposition would be frequently removed from the bridge and the island downstream removed to maximise the capacity of the bridge and reduced upstream flood risk. Not clear that there is any potential to trap and remove gravels upstream. Extremely erosive channel. Significant sediment transportation. The bridge is reported to surcharge during extreme flood events out onto the school side bank (right bank) and impact houses and buildings (Site 21). The basement of the house downstream of Athea Bridge on the right bank (Site 22) floods during extreme events. Owned by a locally developer. The riverbank likely would have had to been infilled to construct this house. Downstream on the left bank, at the Cois na Gaíle housing development, houses flood here from the Galey. Some of these houses appear to have been constructed on the river's floodplain. Overall Athea Bridge is a very large structure and the flood flow to force it to surcharge onto the main road, compared to the minor flow evident on the site visit day, would be significant. The Galey River flood is reported to be very flashy and the peak passes quickly. Potential for flood debris is significant (large trees and branches) from eroded bank collapses during flood events.
23	Mountain stream bridge on the Listowel Road has recently been upgraded by Triur. 1.1m wide and 1.4m high stone arch bridge. Deep channel. No evidence of surcharging. Bridge should be inspected regularly to check for flood debris. Channel at bridge protected by stone paving. Very steep channel.

Table D-1: Site Walkover Notes

Gravel Deposition at Athea Bridge

Significant gravel deposition/ aggradation and island formation evident at Athea Bridge.

Photographs: Athea Bridge 24/11/20

Appendix C: Additional Gauge Sites Review

A review of potential additional river gauge sites be undertaken for the Galey River catchment upstream and downstream of Athea.

Table E-1 presents a summary of the bridge sites between Athea and the Inch Bridge with respect to the suitability for hydrometric gauging.

Bridge Name	Catchment Area, km²	Comment	Photo
Athea Bridge	36.6	Athea Bridge would not be the most suitable hydrometric gauging due to the dynamic nature of gravel deposition and channel scouring at the structure. A staff gauge (EPA-23014) was installed downstream of Athea Bridge for a duration (1978 – 2011) and only spot flow measurements (non-flood conditions) were collected. No arterial drainage works within its catchment.	
Athea Lower Bridge	60.4	Not suitable site due to significant potential for overbank flow bypassing the bridge on the left bank. Large tributary just upstream (17.8km²). Meandering reach. Single span bridge.	
Ahavoher Bridge	90.7	Potentially suitable for gauging high flows. Not suitable for low flows due to the steep downstream channel, fish-ladder and low flow channel. Three arch bridge. Overbank flow on right bank during flood events (irregular cross-section - not preferential for gauging). Straight channel immediately upstream of bridge. Realigned Channel. No gravel deposition evident (TBC). Afflux at the bridge (piers and flood debris) could distort gauged stage data. https://moyvane.com/location/rivers-and-bridges/	 
Galey Bridge	126.33	Previous gauge site. Now inactive. The Douglas River (14.5km²) tributary immediately upstream of bridge. Second large tributary (Moyvane – 14km²) between Ahavoher and Galey Bridge. Three Span Bridge. Potential suitable site but complex gaugings due to the tributary. Modified Channel. Gauging at Douglas Bridge and Moyvane Bridge may assist. Significant differences in PCD between this site and Athea Bridge.	 

Moyvane Bridge	13.2	Upgraded bridge on spate river channel. Likely difficult to measure flood flows for gaugings due to short time to peak. Downstream bridge at Moyvane South likely backwatered from the Galey during flood events.	
Douglas Bridge	13.5	Arterial Drainage Channel. Likely difficult to measure flood flows for gaugings due to short time to peak. Channel potentially backwatered during flood events from Galey	
Shrone Bridge	184.62	Wide single arch bridge with rapids downstream. Northern approach includes two smaller arches. Possible overbank flow during flood events. No advantage to installing gauge at this site as Inch bridge is only 2.4km downstream.	 
Inch Bridge	192.19	Active gauge with long record. Automatic recorder station. Twin span bridge. Relatively straight channel upstream and downstream with floods likely conveyed within bank (TBC). Meandering low land channel. Significant differences in PCD between this site and Athea Bridge.	 

Table E-1: Potential Gauge Sites review along the Galey River

Potential additional hydrometric gauge sites were identified on the Galey River between Inch bridge and Athea Bridge, namely at the Athea Bridge reach, at Ahavoher Bridge and at Galey Bridge as described below

<u>Athea Bridge Reach</u>
Installation of gauges along the Athea Bridge reach would significantly improve the understanding of the upper catchment's flood regime at Athea and calibration of the associated hydraulic model, albeit that the site is not the most suitable for gauging due to the channel characteristics and dynamic gravel deposition regime along the reach.

There are no sites upstream of the Athea Bridge reach on the Galey River identified as suitable (i.e. due overbank flow and channel stability, access) channel reaches where hydrometric gauging could be installed.

Due to the spate nature of the river system, it would not be feasible for a hydrometric team to establish on site to gauge peak flood velocities at Athea Bridge. The dynamic nature of the gravel deposition at the Athea Bridge reach would make development of an appropriately accurate stage-flow rating curve not feasible for the site

It is recommended that:

- a gauge is reinstated downstream of the bridge where water levels would be recorded and flow gaugings measured to allow a stage-discharge relationship curve to be derived.
- a gauge is installed at the upstream end of Athea Bridge (left bank) to record water levels for comparison to the downstream gauge and to improve the bridge calibration in the hydraulic model, coupled with recent river bed survey data at the bridge.

Ahavoher Bridge
The Ahavoher Bridge could be a relevant gauge site with respect to Athea Bridge due to catchment characteristics and relative catchment area. However, gaugings (on site flow measurements) may prove unreliable/ complicated due to overbank flow on the right bank, the presence of the fish ladder at the bridge and the steep downstream channel and cascades.

It is not recommended that a gauge is installed at Ahavoher Bridge specifically for calibration of the Athea Bridge reach but a gauge at this location would improve the overall understanding of the upper catchment's response to storm events.

Galey Bridge
The Galey Bridge has historic gauging data available. Two tributaries, namely the Douglas and the Moyvane Rivers, drain to the Galey River between the Ahavoher and Galey Bridges with the Douglas confluence located immediately upstream of Galey Bridge. Gauging the Douglas and Moyvane Rivers, in combination with Galey Bridge, would allow the main channel flows to be estimated. It would be difficult to gauge (on site flow velocity measurements) at these two minor rivers due to the short time to peak and channel characteristics. Afflux at Galey Bridge (piers and flood debris) could distort gauged stage data.

It is not recommended that a gauge is installed at Galey Bridge specifically for calibration of the Athea Bridge reach but a gauge at this location could further support the long-term gauge record at Inch Bridge and demonstrate the effect of arterial drainage works on the lower catchment compared to the upper catchment.

Inch Bridge
The Inch gauge is a suitable and well-established site for measuring flows for the entire catchment. The gauge, however, may not be directly representative of the Athea Bridge catchment due to its comparative area difference, arterial drainage works in the system, degree of catchment attenuation and multiple tributaries between the two sites.

Addendum to Gauge Assessment
The OPW with LCC installed two gauges on the Galey River upstream and downstream of Athea Bridge during April 2021 and the links to the real-time data is available at:
https://waterlevel.ie/0000023051/0001/
https://www.epa.ie/hydronet/#23052

It is recommended that the staff gauge zero is surveyed and the database updated accordingly.

Appendix D: CFRAM HEP Flows (ss)

River	Location	HEP Reference	Annual Exceedance Probability (AEP) %							
			50%	20%	10%	5%	2%	1%	0.50%	0.10%
Galey	U/S extent	23_1853_1	26.4	36.3	42.5	48.5	56.2	62	67.8	81.1
		23_1915_1	27.5	37.9	44.4	50.7	58.7	64.8	70.8	84.8
		23_1920_2	27.5	37.9	44.4	50.7	58.7	64.8	70.8	84.8
		23_1919_2	30	41.3	48.3	55.1	63.9	70.5	77	92.2
	U/S of Athea	23_2579_1	30	41.3	48.3	55.1	63.9	70.5	77	92.2
	D/S of Athea	23_2579_2	30	41.3	48.3	55.1	63.9	70.5	77	92.2
		23_2579_3	30	41.3	48.3	55.1	63.9	70.5	77	92.2
		23_2580_2	31.2	43	50.3	57.4	66.5	73.4	80.2	96
		23_2514_2	32.2	44.3	51.9	59.2	68.6	75.7	82.7	99
		23_1894_2	46	63.3	74.2	84.6	98	108	118	142
		23_1756_1	46.1	63.5	74.3	84.8	98.3	108	119	142
		23_2517_2	52.2	71.9	84.3	96.1	111	123	134	161
		23_2954_2	55.7	76.7	89.8	102	119	131	143	171
		23_1755_3	56.4	77.7	91.1	104	120	133	145	174
		23_2650_2	63.9	88	103	118	136	150	164	197
		23_2650_5	65.2	90	105	120	139	153	168	201
	Galey Bridge	23_2696_1	73	101	118	134	156	172	188	225
		23_2567_2	74.7	103	121	138	159	176	192	230
		23_1852_2	90	124	145	166	192	212	231	277
		23_1852_3	90	124	145	166	192	212	231	277
		23_2558_2	96.4	133	156	177	206	227	248	297
		23_2371_2	102	140	164	187	217	239	261	313
	Inch Bridge	23_2929_1	104	143	167	191	221	244	266	319

River	Location	HEP Reference	Annual Exceedance Probability (AEP) %							
			50%	20%	10%	5%	2%	1%	0.50%	0.10%
Tributary	U/S extent	23_2579_00a	0.18	0.25	0.29	0.33	0.39	0.43	0.47	0.56
	U/S extent	23_2579_00b	0.63	0.86	1.01	1.15	1.33	1.47	1.61	1.93

Appendix E: Galey River OPW Hydrometrics Flow Gaugings

Inch Bridge.

Date	Time	Stage, m	Flow, m^3/s	Remark
30/05/2017	14:40:00	0.08	0.292	
04/05/2017	13:24:00	0.06	0.272	Measured at gauge
01/02/2017	15:30:00	0.32	3.087	Measured at gauge
22/12/2016	14:04:00	0.755	12.879	Measured at gauge. A little debris caught on bridge column.
22/02/2016	14:04:00	0.5	7.09	Taken at Gauge. Some debris caught on u/s end of centre pier
04/01/2016	14:34:00	1.8	59.526	Taken at gauge.
02/12/2015	14:45:00	1.01	20.461	Measured at gauge.
20/04/2015	14:07:00	0.145	1.05	Measured at gauge.
27/02/2015	13:28:00	0.605	9.41	Measured at gauge. Moderate debris on centre pier of road bridge.
10/02/2015	15:12:00	0.19	1.37	Measured at gauge
17/12/2014	12:33:00	1.39	39.799	Measured at gauge.
25/11/2014	13:46:00	0.31	3.12	Measured at gauge.
28/10/2014	13:56:00	1.125	26.509	
10/09/2014	12:00:00	0.06	0.302	At U/S face of Road Bridge.
27/06/2014	12:00:00	0.13	0.856	
13/08/2013	14:49:00	0.13	0.688	Measured at gauge.
25/04/2013	14:44:00	0.895	17.58	
14/11/2012	15:34:00	0.94	17.3	
14/05/2012	14:52:00	0.165	0.98	Taken at gauge.
29/11/2011	13:10:00	2.61	106	Taken at gauge
18/11/2011	12:02:00	0.705	11.4	Taken at Gauge
23/06/2011	14:33:00	0.26	2.07	Measured at Gauge
10/01/2011	13:08:00	0.485	5.5	
10/11/2010	15:54:00	0.46	5.09	
26/07/2010	14:27:00	0.19	1.08	
28/06/2010	12:24:00	0.04	0.151	
11/05/2010	14:38:00	0.08	0.346	
28/01/2010	15:34:00	0.3	2.69	
02/07/2008	12:00:00	0.165	0.885	
29/06/2007	12:00:00	0.21	1.5503	
23/11/2006	12:00:00	0.845	16.3	
02/08/2006	12:00:00	0.056	0.202	
14/03/2006	12:00:00	0.425	4.84	
06/01/2005	12:00:00	0.55	6.77	
12/09/2000	12:00:00	0.22	1.5466	
22/06/1999	12:00:00	0.08	0.359	
13/01/1999	12:00:00	0.925	19.894	
08/09/1998	12:00:00	0.328	3.246	
06/03/1998	12:00:00	2.48	116.545	
04/03/1998	12:00:00	0.645	9.956	
08/01/1998	12:00:00	1.59	50.828	
31/12/1997	12:00:00	0.83	14.603	
20/11/1997	12:00:00	1.2	26.911	
09/10/1997	12:00:00	0.775	14.566	
08/04/1997	12:00:00	0.095	0.429	
02/07/1996	12:00:00	0.05	0.198	
30/08/1995	12:00:00	0.005	0.112	
29/08/1995	12:00:00	0.015	0.135	
24/05/1995	12:00:00	0.113	0.679	
04/05/1994	12:00:00	0.51	7.113	
13/04/1994	12:00:00	0.21	0.586	
27/10/1993	12:00:00	0.125	0.715	
24/03/1993	12:01:00	0.14	0.869	
24/03/1993	12:00:00	0.14	0.824	

12/08/1992	12:00:00	0.485	6.438	
16/07/1992	12:00:00	0.12	0.699	
27/05/1992	12:00:00	0.095	0.457	
25/11/1991	12:00:00	0.745	14.243	
11/09/1991	12:00:00	0.045	0.225	
13/08/1991	12:00:00	0.195	1.431	
19/06/1991	12:00:00	0.1	0.494	
03/08/1989	12:00:00	0.04	0.165	
27/07/1989	12:00:00	0.048	0.212	
29/05/1989	12:00:00	0.16	0.25	
02/12/1987	12:00:00	0.2	1.892	
30/09/1987	12:00:00	0.14	1.104	
05/08/1987	12:00:00	0.13	0.76	
06/05/1987	12:00:00	0.1	0.672	
30/04/1986	12:00:00	0.235	2.27	
08/01/1986	12:00:00	0.42	5.41	
28/11/1984	12:00:00	0.785	14.95	
23/07/1984	12:00:00	0.01	0.071	
14/09/1983	12:00:00	0.11	0.587	
26/07/1983	12:00:00	0.04	0.171	
04/05/1983	12:00:00	0.29	3.07	
24/02/1983	12:00:00	0.25	1.991	
03/11/1982	12:00:00	0.38	4.68	
21/09/1982	12:00:00	0.26	2.56	
29/07/1982	12:00:00	0.04	0.234	
04/11/1981	12:00:00	0.485	7.3	
11/08/1981	12:00:00	0.04	0.226	
30/07/1981	12:00:00	0.07	0.395	
02/07/1981	12:00:00	0.085	0.491	
04/06/1981	12:00:00	0.26	2.48	
30/04/1981	12:00:00	0.07	0.382	
09/04/1981	12:00:00	0.13	0.849	
28/01/1981	12:00:00	0.24	1.948	
19/08/1980	12:00:00	0.18	1.395	
10/07/1980	12:00:00	0.08	0.395	
13/05/1980	12:00:00	0.065	0.32	
07/05/1980	12:00:00	0.05	0.303	
24/04/1980	12:00:00	0.08	0.45	
21/02/1980	12:00:00	0.32	3.53	
23/01/1980	12:00:00	0.723	13.24	
10/10/1979	12:00:00	0.225	2.21	
02/04/1979	12:00:00	0.285	3.23	
28/03/1979	12:00:00	0.5	7.377	
23/01/1979	12:00:00	0.497	7.25	
07/11/1978	12:00:00	0.125	0.83	
02/08/1978	12:00:00	0.105	0.66	
10/07/1978	12:00:00	0.21	2.2	
22/05/1978	12:00:00	0.065	0.33	
08/05/1978	12:00:00	0.155	1.16	
10/04/1978	12:00:00	0.17	1.22	
07/03/1978	12:00:00	0.207	1.87	
14/02/1978	12:00:00	0.277	2.33	
13/09/1977	12:01:00	0.02	0.112	
13/09/1977	12:00:00	0.069	0.371	
07/07/1977	12:00:00	0.03	0.194	
31/05/1977	12:00:00	0.055	0.269	
24/05/1977	12:00:00	0.07	0.34	
27/04/1977	12:00:00	0.262	2.73	
26/04/1977	12:00:00	0.32	3.55	

21/04/1977	12:00:00	0.23	2.3	
19/04/1977	12:00:00	0.17	1.27	
09/03/1977	12:00:00	0.318	3.18	
28/02/1977	12:00:00	0.23	2.12	
08/02/1977	12:00:00	0.615	10.56	
04/11/1976	12:00:00	0.47	6.54	
07/10/1976	12:00:00	0.121	0.754	
02/09/1976	12:00:00	-0.011	0.045	
11/08/1976	12:00:00	0.003	0.059	
22/07/1976	12:00:00	0.02	0.104	
21/07/1976	12:00:00	0.024	0.153	
30/06/1976	12:00:00	0.022	0.116	
26/05/1976	12:00:00	0.12	0.734	
27/04/1976	12:00:00	0.06	0.328	
11/08/1975	12:00:00	0.09	0.093	
08/07/1975	12:00:00	0.02	0.147	
01/07/1975	12:00:00	0.015	0.104	
11/06/1975	12:00:00	0.04	0.189	
06/03/1975	12:00:00	0.19	1.741	
11/10/1973	12:00:00	0.31	3.26	
05/07/1973	12:00:00	0.17	1.082	
04/09/1972	12:00:00	0.04	0.17	
15/07/1971	12:00:00	0.152	0.164	
22/04/1971	12:00:00	0.203	0.456	
09/03/1971	12:00:00	0.33	1.444	
29/07/1970	12:00:00	0.356	2.32	
17/06/1970	12:00:00	0.14	0.187	
23/09/1969	12:00:00	0.279	0.906	
02/09/1969	12:00:00	0.178	0.232	
24/08/1968	12:00:00	0.178	0.212	
10/12/1964	12:00:00	0.61	7.7	
09/12/1964	12:01:00	1.289	30.21	
09/12/1964	12:00:00	1.054	19.23	
08/12/1964	12:00:00	0.813	15.12	
07/12/1964	12:00:00	1.524	51.79	
01/03/1962	12:00:00	0.279	0.572	