Kilkee Flood Relief Scheme – Hydrology Report

Final Report

July 2024

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Contract

This report describes work commissioned by Office of Public Works (OPW), on behalf of Clare County Council (CCC). Tom Sampson and Caoimhe Downing of JBA Consulting carried out this work.

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Purpose

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Abbreviations

AEP	Annual Exceedance Probability
AFA	Area of Further Assessment
AMAX	Annual Maximum
ARTDRAIN2	Arterial Drainage Index
BFIsoil	Baseflow Index
CCC	Clare County Council
CFRAM	Catchment Flood Risk Assessment and Management
DDF	Depth Duration Frequency
DRAIND	Drain Density
EPA	Environmental Protection Agency
FARL	Flood Attenuation from Rivers and Lakes
FRS	Flood Relief Scheme
FSU	Flood Studies Update
FSSR	Flood Studies Supplementary Report
GIS	Geographical Information System
HEFS	High End Future Scenario
HEP	Hydrological Estimation Point
mOD	Metres above Ordnance Datum
MRFS	Mid-Range Future Scenario
MSL	Main Stream Length
OPW	Office of Public Works
PFRA	Preliminary Flood Risk Assessment
SAAR	Standard Annual Average Rainfall
SFRA	Strategic Flood Risk Assessment
Tc	Time of Concentration
Tcp	Time of concentration of pipelines

1 Introduction

1.1 Overview

Kilkee is a popular seaside resort town located adjacent to Moore Bay on the west coast of County Clare. The Atlantic Stream and the Victoria Stream (referred to respectively as the Kilkee Upper and Kilkee Lower in the CRAM reports) are the major watercourses that flow through the town, with the Atlantic Stream to the north and the Victoria Stream to the south. Both watercourses are tidal. Kilkee is susceptible to both coastal and fluvial flood risk.

There have been a number of instances of flooding in Kilkee. The Victoria Stream is noted to overflow its banks over a length of 200-300m on an annual basis, causing flooding of Church Street, Well Road and a number of properties. Many more properties are at risk.

1.2 Purpose of the Project

The objective of this project is the identification, design and submission (for planning consent) of a Flood Relief Scheme, that is technically, socially, environmentally and economically acceptable, to alleviate the risk of flooding to the Community of Kilkee to a determined Standard of Protection, and to procure, manage and oversee the construction of that Scheme

A core part of the assessment will involve reviewing and, where necessary, updating the CFRAM Study outputs, including the hydrological and hydraulic analysis and options assessment.

As part of this, testing of proposed defences will be done using a hydraulic model of the watercourses and area. This hydrology method statement describes the proposed approach to reviewing the CFRAM Study and the steps needed to develop design flows for the hydraulic model to be used in assessment.

1.3 Hydrology Report aims and outlines

This hydrology report aims to:

- Review all the available data used in hydrological assessment including the available CFRAM documentation;
- Assess other key considerations such as joint probability and climate change.
- Provide detail on the development of design event flows.
- Provide inflows for a range of design events.

1.4 Previous Studies

1.4.1 Shannon Catchment Flood Risk Assessment and Management Study (CFRAM)

The Shannon CFRAM study carried out by Jacobs is the most up to date and detailed flood risk mapping study to be carried out in the area. Model S19 of Unit of Management 27 of the Shannon CFRAM includes the Kilkee AFA. The Victoria Stream and the Atlantic Stream and some tributaries are modelled as part of this study.

The final reports and flood maps for the Model 19 area were released in 2016, Figure 1-1 shows an example of the flood maps produced.

Refer to section 4 of this method statement for a full detailed review of the CFRAM hydrology methodology for Model S19.

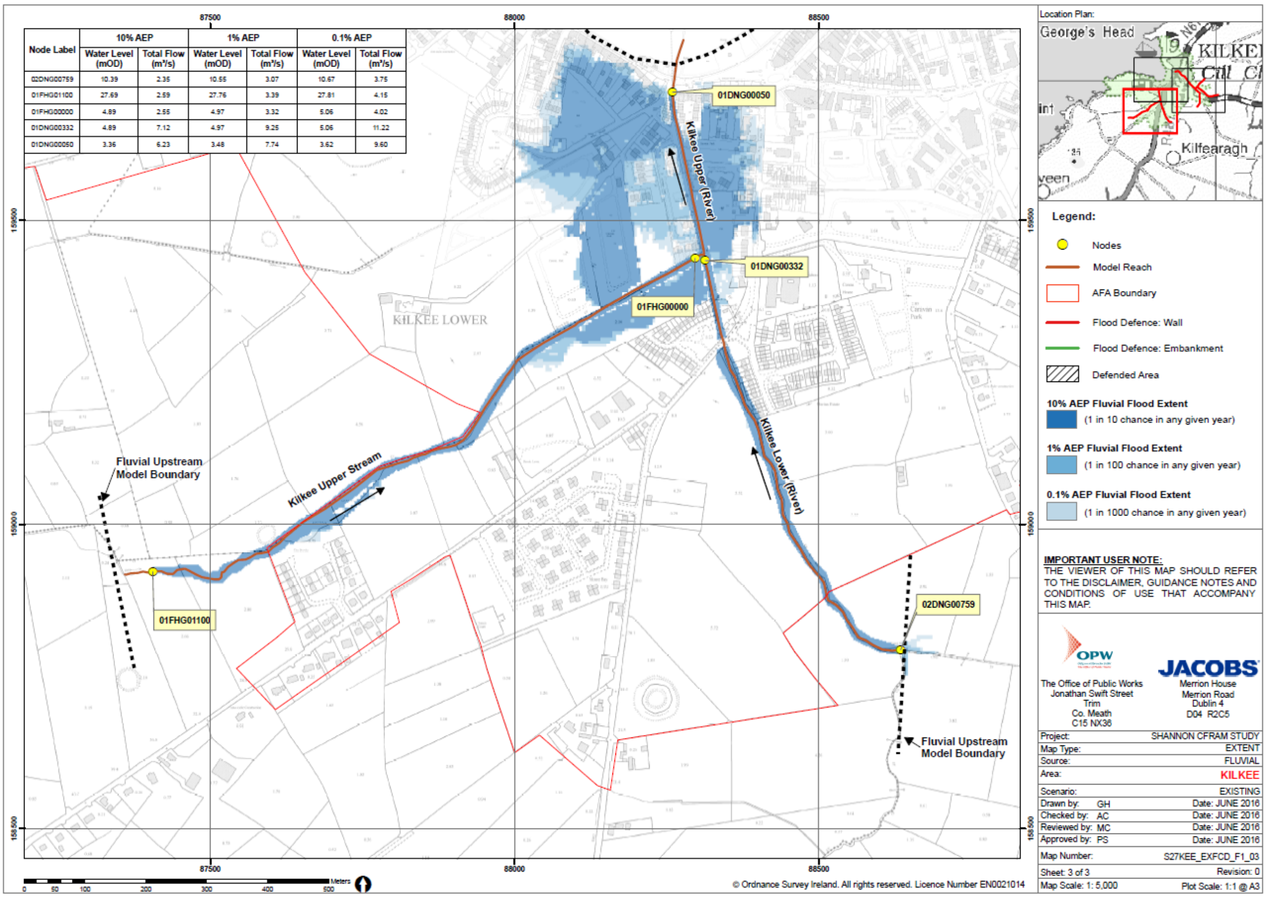


Figure 1-1: Example of CFRAM Flood Map in Kilkee

1.4.2 Clare County Council Strategic Flood Risk Assessment

As part of the Clare County Council Development Plan 2017-2023 a Strategic Flood Risk Assessment (SFRA) was carried out in order to inform development in Clare in relation to flood risk. Within the SFRA it is stated that the extents of Flood Zone A/B in Kilkee were determined using the Shannon CFRAM flood extents. The SFRA uses the CFRAM outputs to determine the implications for development within Kilkee. Figure 1-2 shows the flood zone mapping developed for the CCC SFRA (Section 11.3.2 West Municipal District Settlement Review).

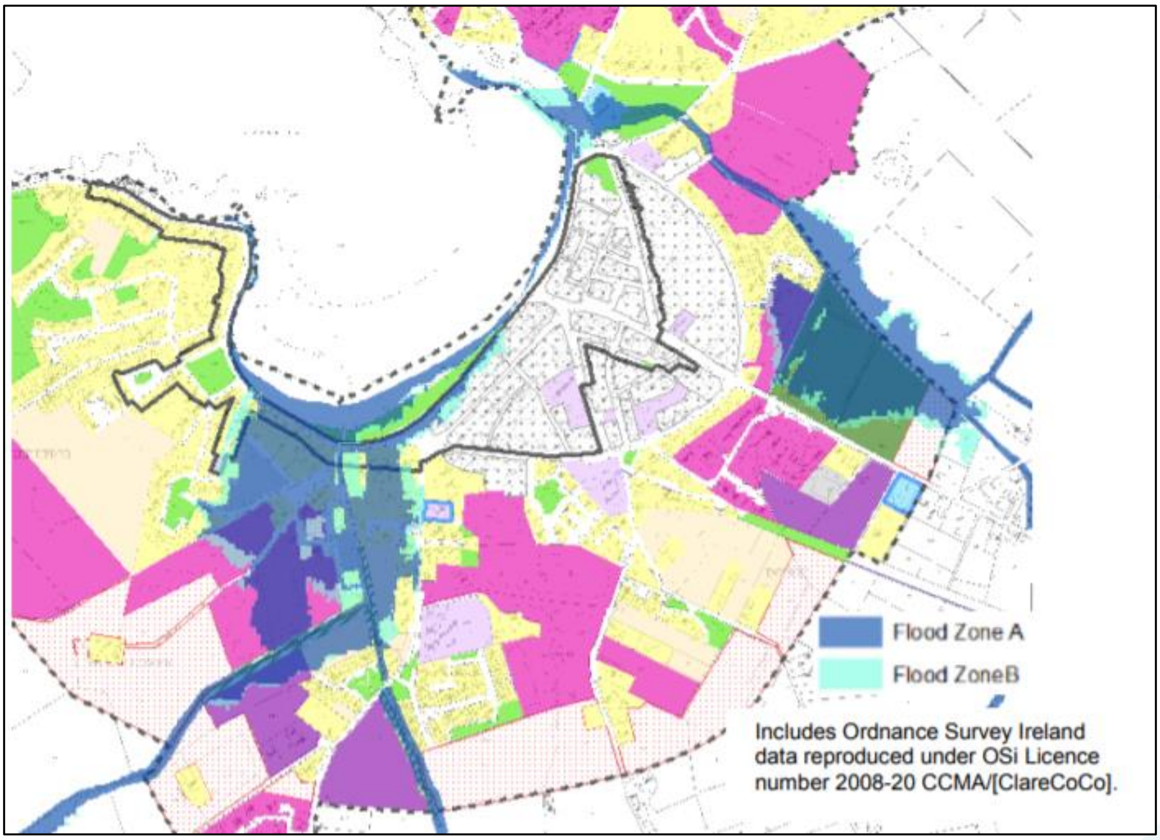


Figure 1-2: Clare County Council SFRA Flood Mapping

1.5 Historic Flood Data

A review of historic flood events was conducted using the Shannon CFRAM and floodmaps.ie. Flooding in Kilkee appears to be predominately during winter months. The following events in Kilkee were recorded:

- February 2020: Heavy rainfall as a result of Storm Ciara caused flooding along the Atlantic Stream. Possible blockage at the trash screens outfall was considered to contribute to the flooding
- October 2019: Flooding along Well Road and Victoria Park as a result of heavy rainfall causing the Victoria Stream to overflow its banks. 3 no. houses were flooded internally and over 20 houses were at risk.
- April 2015: Flood event caused by heavy rainfall which resulted in the Atlantic Stream bursting its banks.
- January 2014: Significant coastal flood along the Shannon Estuary. The coastal storm caused damage along the sea wall, resulting in the collapse of two sections. Much of the beachside infrastructure was also destroyed.
- February 1990: County Clare experienced serious tidal flooding with approximately 200 houses and many roads affected. Kilkee AFA was one of the most seriously affected areas.
- January 1965: Flood event caused by high tide and strong winds resulted in portions of the promenade wall being severely damaged and also affecting a house.
- October 1961: Flood event caused by torrential rainfall, damaging buildings along the seafront.

- December 1954: Event resulted in flooding to large areas of land and low-lying roads in Kilkee.
- October 1954: Flood Event was due to heavy rainfall and resulted in flooding to low lying roads and land in Kilkee.
- Recurring Events: Recurring flooding affects Church Street, Carrigaholt Road and Well Road car park when the Victoria Stream just north of the R487 road overflows its banks. This can affect a number of houses and is reported to happen approximately once a year. The flooding situation is said to be exacerbated by tides and winds.

2 Catchment overview

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

2.1 Watercourse

The AFA boundary defined by the CFRAM has an approximate area of 3.6km². The Victoria Stream and the Atlantic Stream are the two main watercourses that flow through the town of Kilkee. These are the two main watercourses considered in the Flood Relief Scheme. Both streams flow from south east to north west, with the Victoria Stream located to the south of the town and the Atlantic Stream located to the north of the town. The two streams have a number of tributaries and drainage channels which contribute to the flow through the area.

There are a number of key features along both streams. On the Victoria Stream these features include bridges, culverts, walls bounding the stream and stop logs at the outfall which has operating rules described in 2.1.1. On the Atlantic Stream key features include bridges, culverts and screens.

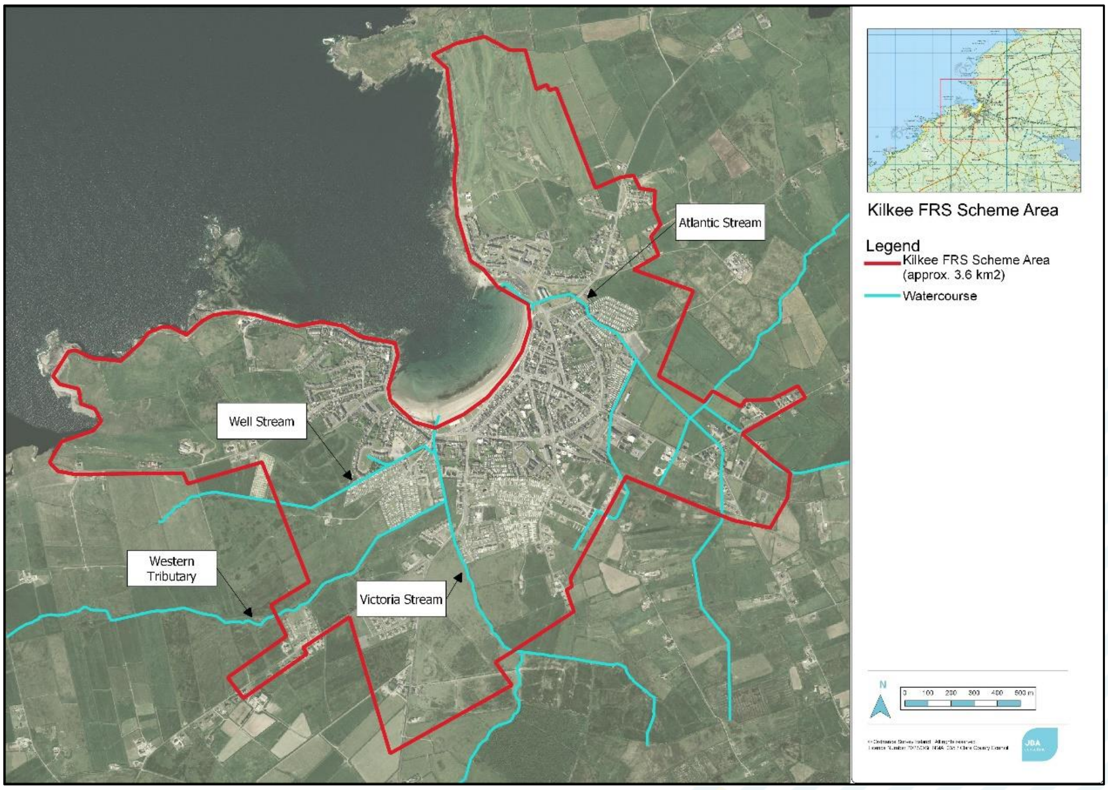


Figure 2-1: Kilkee AFA boundary and local watercourses

2.1.1 Operation Rules

Stop logs are placed at the outfall of the Victoria Stream during the summer months, end of May to end of August, each year. This is done to prevent the outfall of water onto the Blue Flag beach. During this time water from the Victoria Stream is directed through the foul water pumping station. The stop logs in place are removed during flood events however there is no formal trigger for removal.

2.2 Topography

Refer to Figure 2-2 for the study area topography. The catchment is generally flat and low lying at the centre of the bay but rises steeply to the east and the west. Elevations in the catchment ranges from 2mOD at the bay to 65mOD to the south west, at the upper reaches of the Victoria Stream tributary.

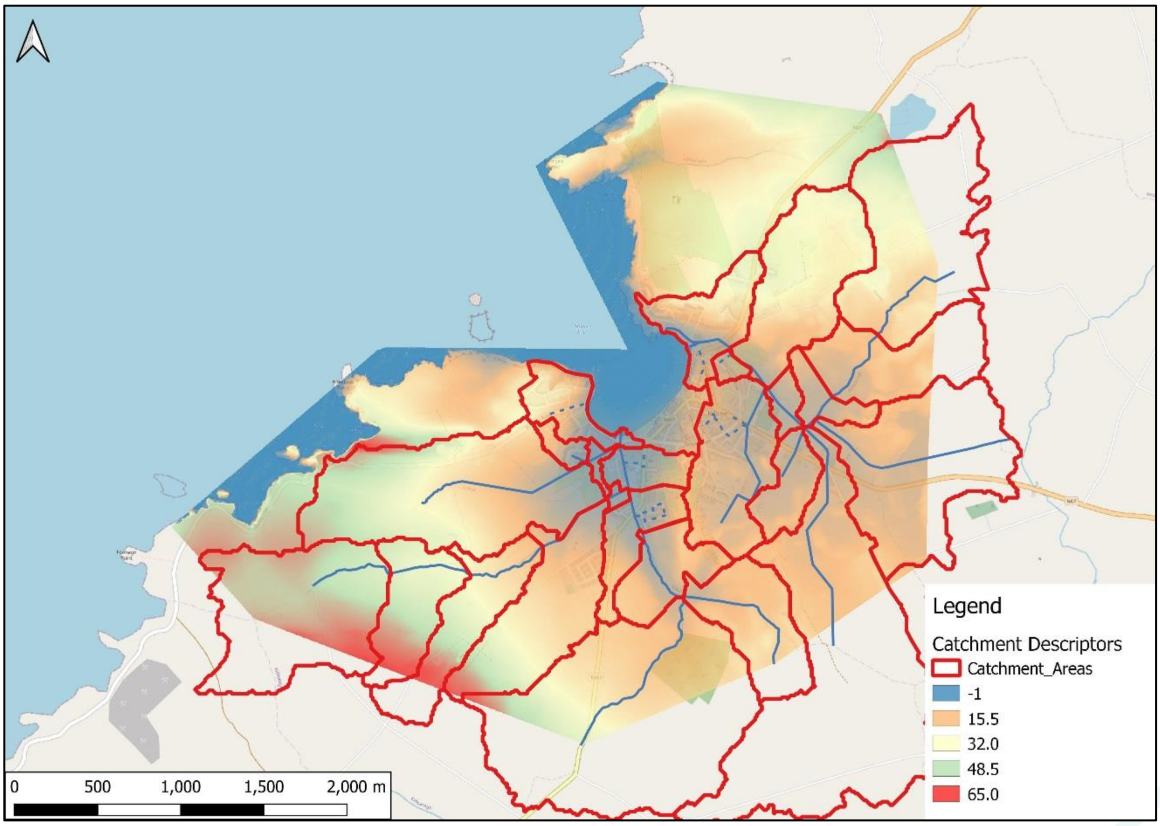


Figure 2-2: Topography of Kilkee AFA

2.3 Land Use

Land use is varied with a mixture of urban, arable, and grasslands present within the catchment, Figure 2-3. Kilkee town is the only urban area. The main land use in the upland catchment areas of both the Victoria and Atlantic Stream is pastures with some agricultural land with natural vegetation at the most upstream points. The upstream catchments mainly comprise of peaty poorly drained mineral and blanket peat.

Kilkee is a significant tourist centre in West Clare and there are a significant number of caravan parks in the town.

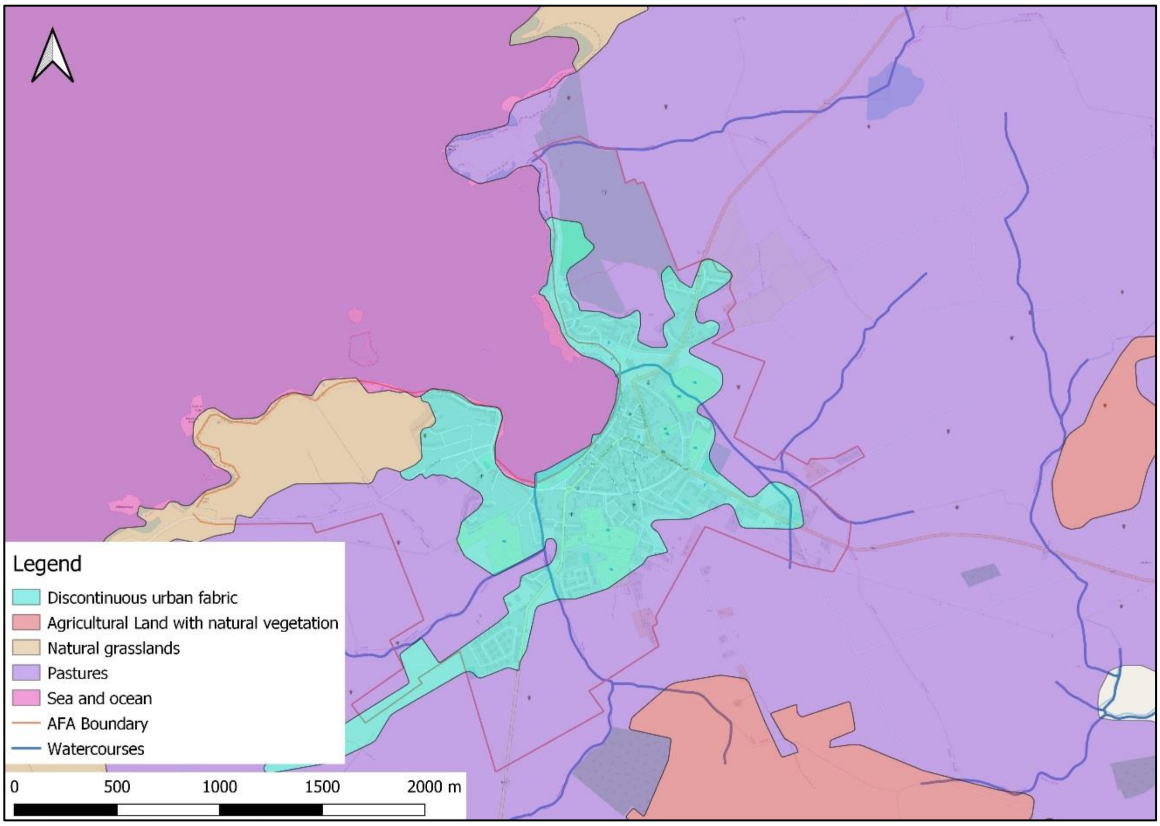


Figure 2-3: Land use map (CORINE land use data set 2018)

2.4 Bedrock Geology and Quaternary Sediments

The bedrock of the study area consists mainly of Central Clare Group Formation, which is described as sandstone, siltstone and mudstone. Quaternary deposits of till derived from Namurian sandstones and shales, and blanket peat are found throughout the catchment. Figure 2-4 highlights the variety of quaternary sediments.

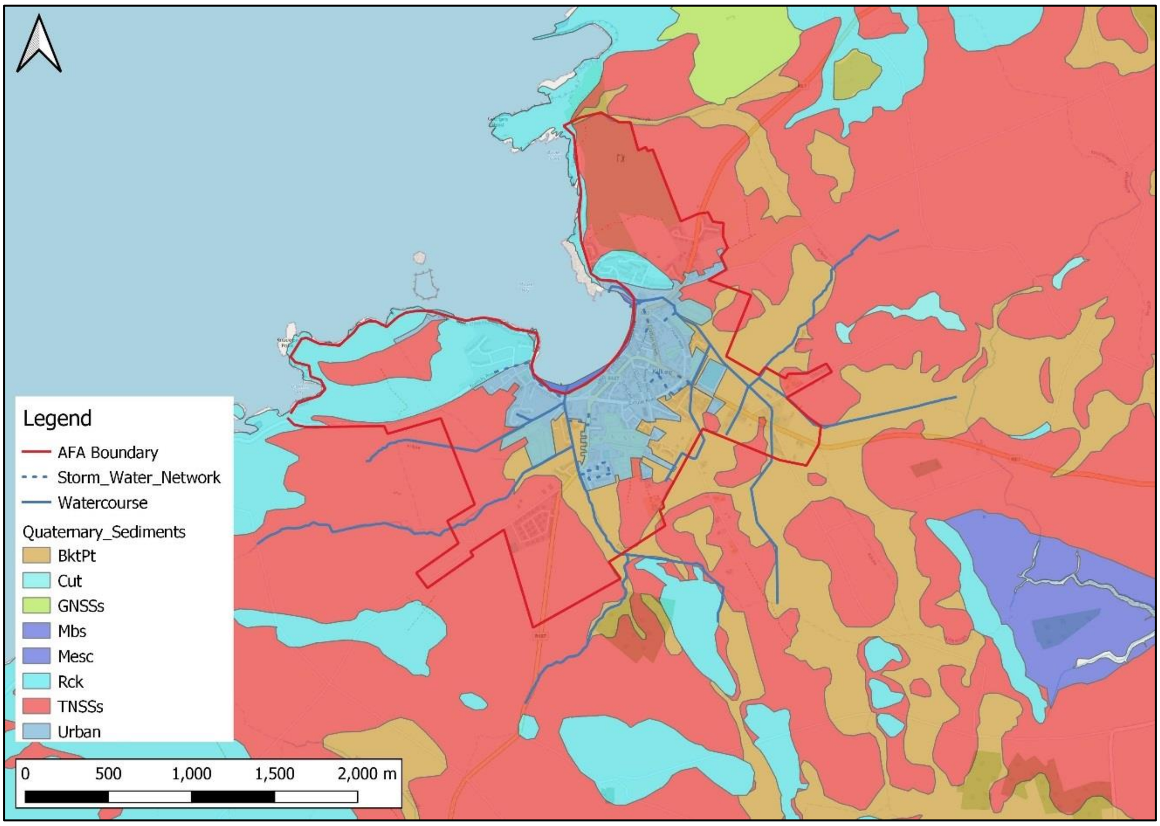


Figure 2-4: Quaternary Sediments

3 Data Review

This section reviews the available data for the project which has been obtained from a variety of sources.

Table 3-1: Summary of available data

Type of data	Data relevant to this study?	Data available?	Source of data	Details
Topographic data and mapping	Yes	Yes	OPW	2m, 5m and 10m resolution LIDAR data was also provided
Watercourse extents	Yes	Yes	OPW/EPA	Blue line network available from EPA. Surveyed watercourse lines available from CFRAM survey
Catchment characteristics	Yes	Yes	OPW/FSU	Catchment database from CFRAM study and FSU catchment database and underlying datasets
Historic flood data	Yes	Yes	CFRAM documentation	Flood history assessment
			CCC	Flood data records, photographs, videos and reports
			News articles	Various events and sources
			Public consultation	Eyewitness accounts and anecdotal information
Rainfall data for events	Yes	Yes	MET Eireann	Rain gauges located within the wider area but not within the study area.
River gauge data	Yes (if available)	No	OPW/EPA	There are no active or inactive river gauges on either Atlantic or Victoria Streams
Tidal Gauge Network	Yes	No	Marine Institute	Closest Tidal gauge at Kilrush Lough and closest wave buoy located off Doughmore Bay. There is a tidal prediction point located at Seafields Point, Quilty.
CFRAM study method & outputs	Yes	Yes	CFRAM	CFRAM Documentation (inception, hydrology, hydraulics reports), existing model, survey data, GIS data (extents)
Rain Gauges	Yes	Yes	OPW	Two OPW rain gauges are located within the Victoria Stream catchment since 2021
Water Level Monitoring data	Yes	Yes	Capital Water Systems	Two water level monitors, one on the Victoria and one on the Atlantic Stream, were in place from January 2021 to April 2022.
Other data or information	Yes	Yes	CCC	Location of storm water network in Kilkee

Type of data	Data relevant to this study?	Data available?	Source of data	Details
				Pumping logs and data will be useful for hydraulic model validation and options appraisal.
			Irish Water	Foul sewer network maps of Kilkee town

3.1 Catchment Characteristic Data

3.1.1 Watercourses

A review of the CFRAM watercourse GIS line was completed using the available data (2m LIDAR, storm water network maps, historic maps (sourced from geohive.ie) and a site visit by JBA/CCC staff on the 5th of February 2020.

Following the identification of errors and missing channels the watercourse network line was manually updated.

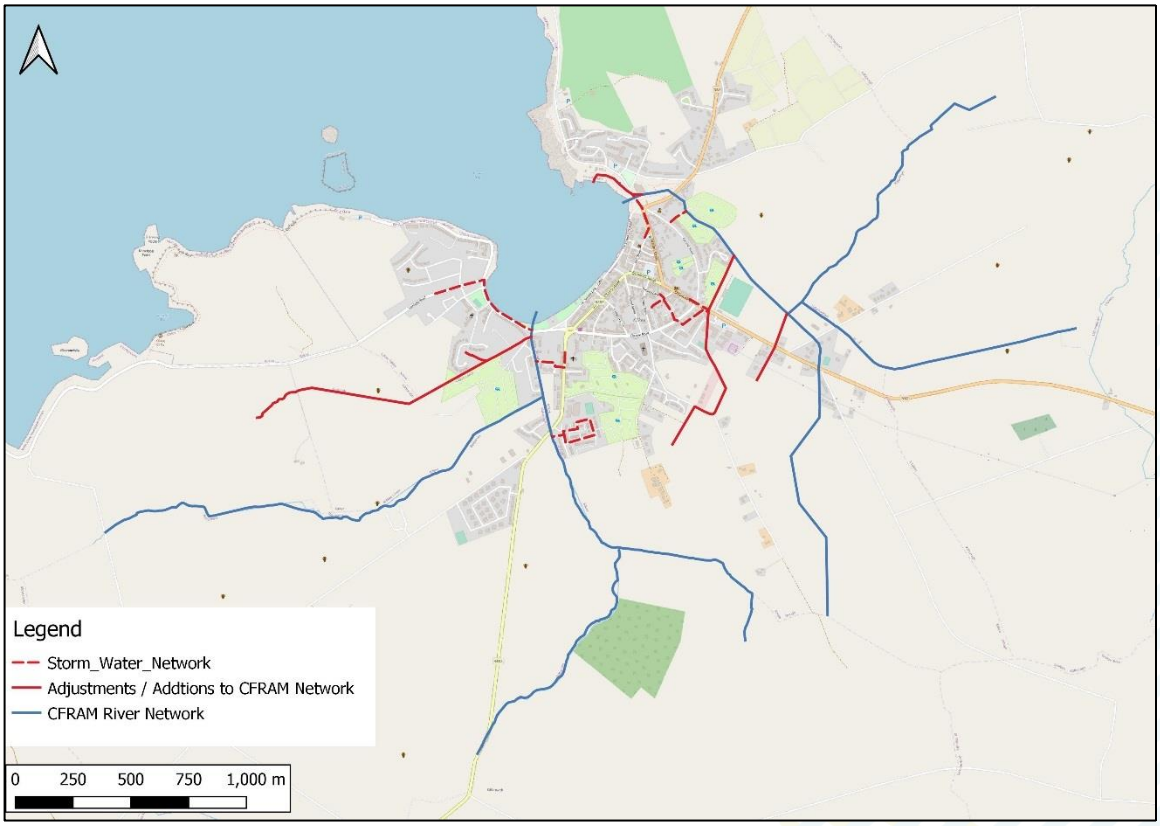


Figure 3-1: Updates to the watercourse network line

3.1.2 Catchment descriptors review

Figure 3-2 shows the Hydrological Estimation Points (HEPs) and catchments used in the CFRAM study. 21 HEPs were used in the CFRAM study. The CFRAM HEP catchments area were kept the same as the FSU catchment areas. The CFRAM HEP catchment descriptors were examined to identify if updates or changes had occurred. Refer to Table 3-2 for the findings of the review.

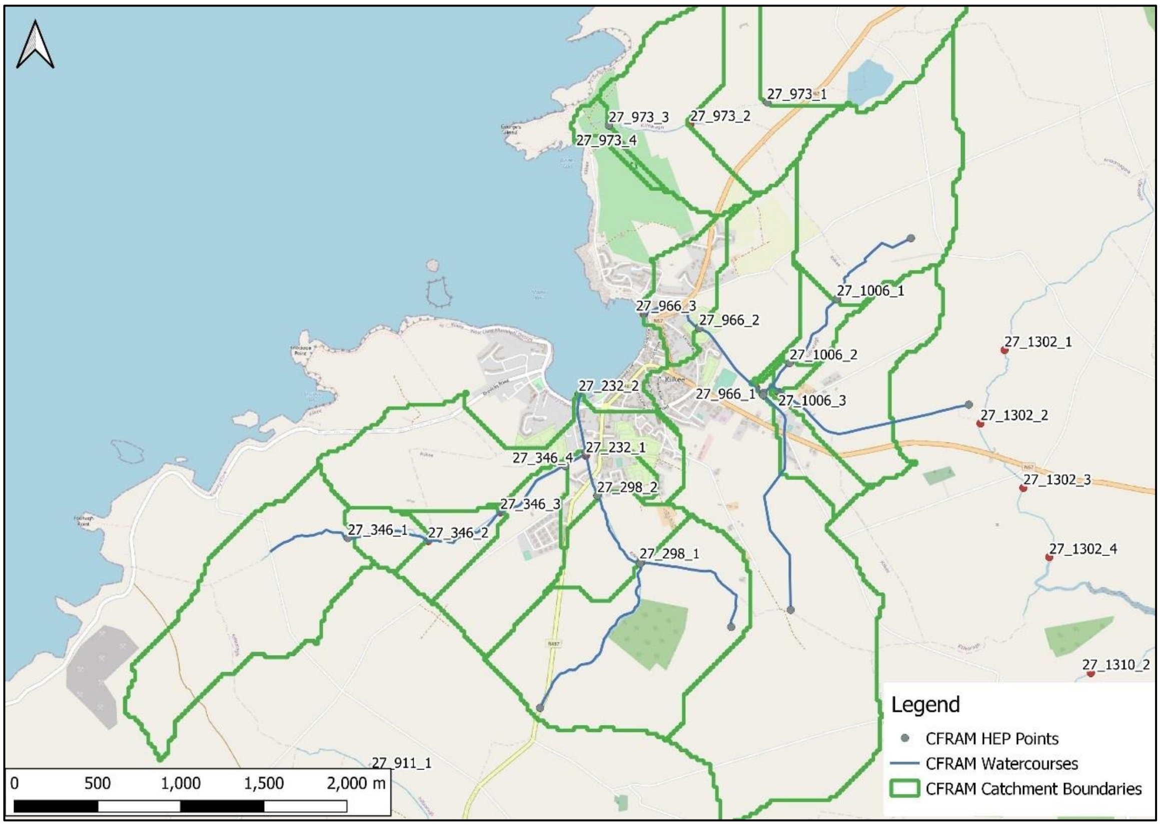


Figure 3-2: CFRAM HEP Catchments

Table 3-2: CFRAM Catchment descriptor review

Descriptor	Data used in original FSU	Updated data set	Need for adjustment?
Area	Catchment areas delineated using a hydrologically adjusted DTM	2m resolution LiDAR	Inspection of the catchment boundaries carried out using GRASS GIS software. Catchments adjusted based on findings from GRASS GIS analysis. Additional catchments included to account for additional reaches, and storm water network.
SAAR	Gridded annual rainfall data for the period 1961 – 1990 from MET Eireann used to generate catchment SAAR values	Gridded annual rainfall data for the period 1981 – 2010 from MET Eireann now available	Comparison between the two datasets showed a difference reported in SAAR values with higher values being reported in the more recent dataset.
FARL	Waterbodies defined using EPA waterbodies shapefile and the % of catchment area with lakes or reservoirs calculated	No major alterations or adjustments to the initial dataset	There are no reservoirs or lakes within the study area therefore no updates to this descriptor is needed. The body of water to the north of the catchment is a drinking water reservoir.
BFI Soil	Catchment wide value of baseflow index estimated using watercourse data	No change to dataset used	No changed to BFI Soil within the Study Area, however values of BFI soil for each changed catchment (see above) revised.
URBEXT	Corine land cover 2000 dataset used to get % of urban land use within the catchments	Corine land cover 2018 dataset released	Minimal changes to URBEXT values for lowland catchments within the Kilkee townland area.
MSL	Stream length measured from GIS shapefile of watercourses	No update	MSL for each individual catchment measured based on updated catchment boundaries
S1085	Slope determined using OSi DEM data	Updated topographic datasets (e.g., 2m LiDAR)	S1085 for each individual catchment calculated based on updated catchment boundaries
Drain D	Calculated by dividing channel length by catchment area	Updated topographic data available for catchment area review	Following review of catchment areas there was no need to adjust Drain D values.
ArtDrain2	Measured using a GIS line shapefile from the OPW	Updated map layers	No changes in channels affected by arterial drainage, no need for adjustment

3.2 Meteorological data

3.2.1 Gauge Data

There are no long-term rain gauges present within the Kilkee FRS study area, Figure 3-3 shows the closest active gauges and Table 3-3 summarises the data available. Kilkee, Moneypoint, Quilty, Kilmihil and Mullagh are voluntary rainfall stations and rainfall is measured using rain gauges. These gauges are not synoptic. Shannon Airport is a manned weather station and rainfall is measured using tipping bucket gauge. There are two OPW rain gauge in place within the Victoria Stream catchment area. The gauges have been in place since January 2021.

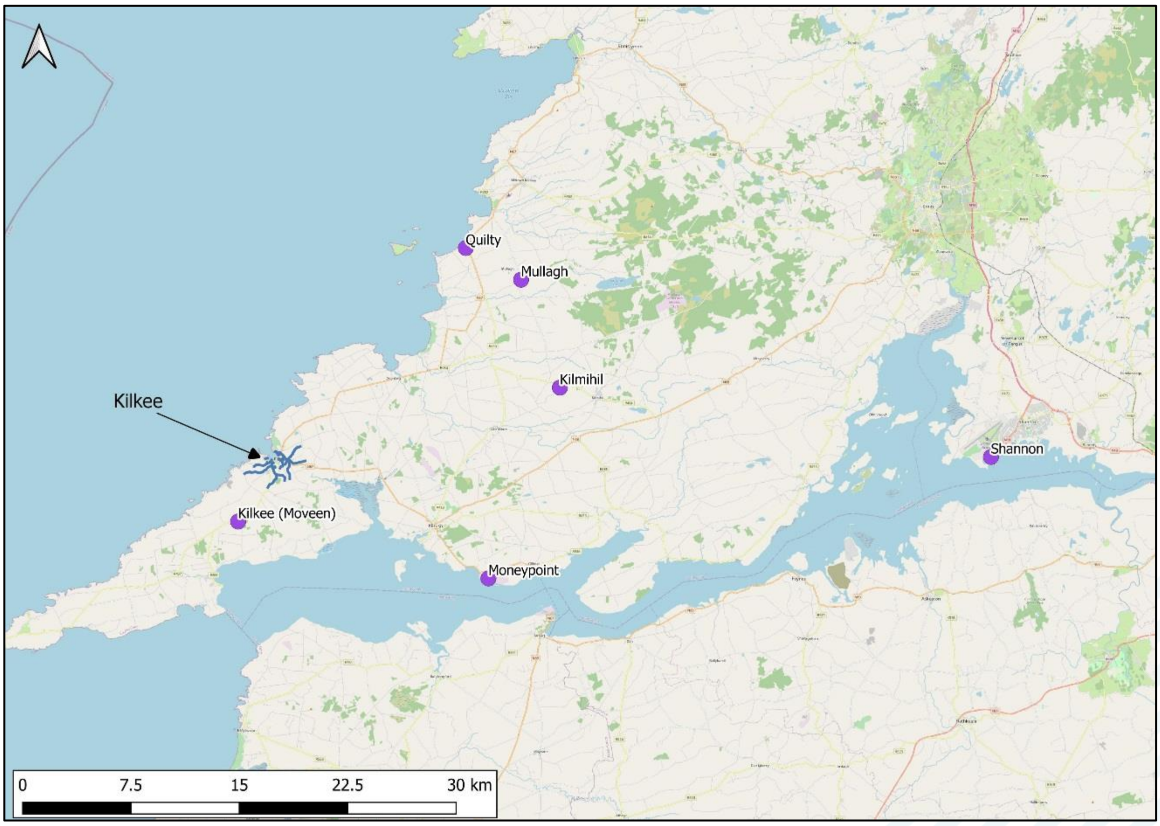


Figure 3-3: Long Term Rain Gauges near Kilkee Study Area

Table 3-3: Active Meteorological Gauges

Gauge Name	Gauge Number	Approximate distance from study area(km)	Data Resolution	Data Record
Kilkee (Moveen)	2117	4.69km	Daily	2013 - present
Moneypoint E.S.B	5311	16.42km	Daily	1986 - present
Quilty	2017	19.66km	Daily	1999 - present
Kilmihil (Shyan)	1317	20.08km	Daily	1984 - present
Mullagh (Carrowlagan)	1417	21.25km	Daily	1984 - present
Shannon Airport	518	49.26km	Hourly	1937 - present
Kilkee Lower	82701	0km	15 mins	2021 - present
Kilkee Lower Back Up	82701	0km	15 mins	2021 - present

3.2.2 Met Eireann Depth Duration Frequency Data

Rainfall depths for the various return periods and storm durations can be sourced from the MET Eireann Depth Duration Frequency (DDF) dataset. See Table 3-4 for data for grid point 6555, which is located within the AFA boundary. Grid points 6556 and 6435 are located upstream of the AFA boundary. Depths for return periods or durations not provided by MET Eireann will be interpolated from available data.

Table 3-4: Rainfall depths (mm) for various durations and return periods sourced from the MET Eireann DDF database for grid point 6555

	Annual Exceedance Probability (AEP) %					
Duration (mins)	50%	20%	10%	5%	2%	1%
30	9.2	10.8	11.9	12.9	14.8	15.7
60	11.9	14	15.4	16.8	18.7	20.3
120	15.4	18.1	19.9	21.8	24.3	26.4
240	18	21.1	23.2	25.3	28.3	30.7
360	23.3	27.4	30.3	33.1	36.7	39.8
540	27.1	31.9	35.1	38.2	42.7	46.6
720	30.2	35.5	39.0	42.6	47.6	51.6

A review of this DDF point data was completed to identify if there were any significant differences between this point and points further inland. A review of the DDF points for 30km inland was completed and the M5-2day, M5-60mins and r values were compared as shown below in Table 3-5. No significant differences were noted between DDF points.

Table 3-5: Review of DDF Points inland from Kilkee

DDF Node	Distance East from Kilkee (km)	M5-2day	M5-60mins	r
6555	0	55.9	14	0.250
6556	2	55.9	14.3	0.256
6557	4	55.6	14.7	0.264
6558	6	58.9	14.9	0.253
6559	8	56.4	15.1	0.268
6560	10	55.1	14.6	0.265
6561	12	55.2	14.5	0.263
6562	14	55.6	14.4	0.259
6563	16	56.4	15.1	0.268
6564	18	57	15.4	0.270
6565	20	58.1	15.5	0.267
6566	22	58.1	15.7	0.270
6567	24	59.6	15.7	0.263
6568	26	59.6	15.7	0.263
6569	28	58.8	15.8	0.269
6570	30	59.9	15.9	0.265

The M100-60mins data was also reviewed for the DDF points surrounding Kilkee. Figure 3-4 shows that there is large variance in the M100-60min surrounding Kilkee, with an increase in rainfall depth of 25% within 6km to the east, and 49% within 6km south of Kilkee. If this data set is to be used, then careful consideration shall be made for these variances.

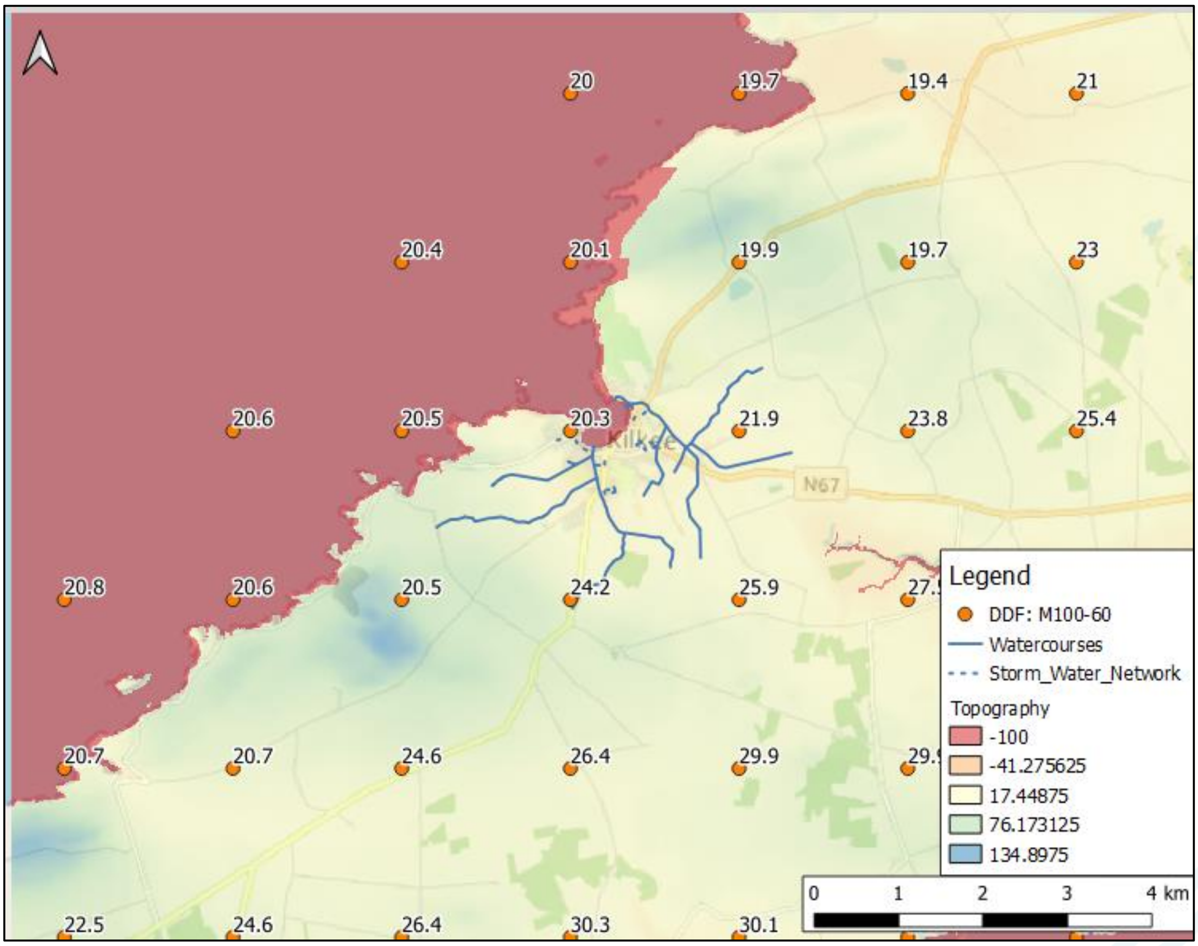


Figure 3-4: M100-60min data for DDF points surrounding Kilkee

3.2.3 Meteorological Data Review for Flood Events

3.2.3.1 14th October 2019

Using the Moneypoint gauge daily data and the Shannon Airport gauge hourly data, the rainfall distribution over the 14th of October was estimated. The Kilkee Moveen gauge was not used for this analysis as there was no rainfall data available after September 2019. Moneypoint gauge was then chosen as it was the closest of the remaining gauges to the study area. The hourly Shannon data has been adjusted by the ratio of the total daily Moneypoint to total daily Shannon recorded rainfall. Figure 3-5 shows the estimated rainfall profile. Peak rainfall depth of 5mm was estimated to have occurred at 6am. A total of 23.8mm fell in 12 hours on the 14th of October. This corresponds to a pluvial return period of less than 2 years.

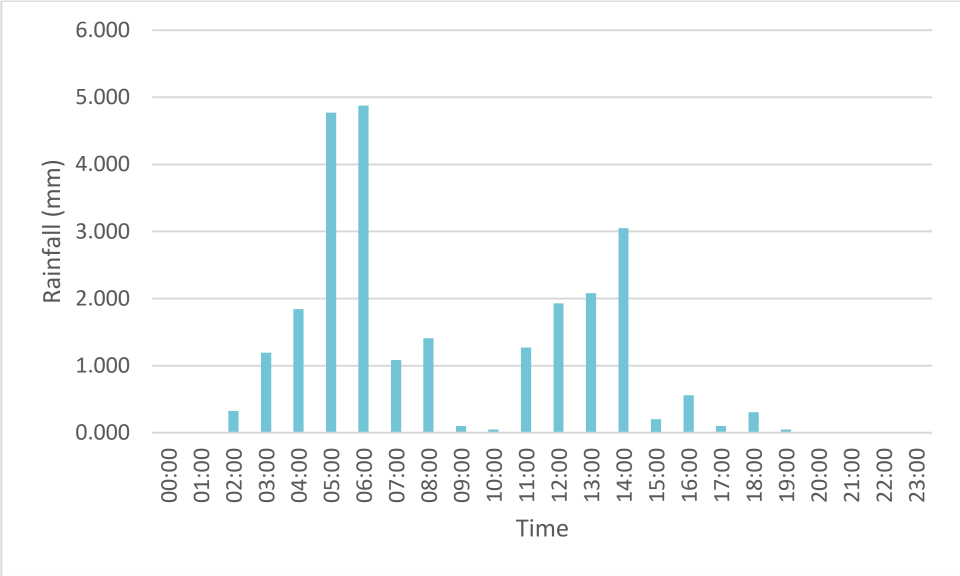


Figure 3-5: Estimated Rainfall distribution on the 14th of October 2019

High tide on the 14th of October was recorded in Kilrush Lough at approximately 6am and 6pm with a recorded water level of 5.3m at 6am and 5.49m at 6pm. Peak rainfall coincides with the peak tide both occurring at 6am.

Highest wind speed of 10 knots occurred at 7am with north easterly winds at this time, recorded at Shannon Airport. Sea level pressure on the 14th reduced from 1004.6hPa at 1am to 1001hPa at 6am, the time of peak rainfall. The sea level pressure reduced even further to 1000hPa at 8am before gradually rising again.

3.2.3.2 26th February 2016

Using the Kilkee (Moveen) gauge daily data and the Shannon Airport gauge hourly data, the rainfall distribution over the 26th of February 2016 was estimated, Figure 3-6. Peak rainfall of 1.04mm was estimated to occur at 8pm on the 26th of February. A total of 2.07mm of rainfall fell between 7pm and 11pm on the 26th of February (i.e., 4hrs). This corresponds to a rainfall return period of less than 2 years.

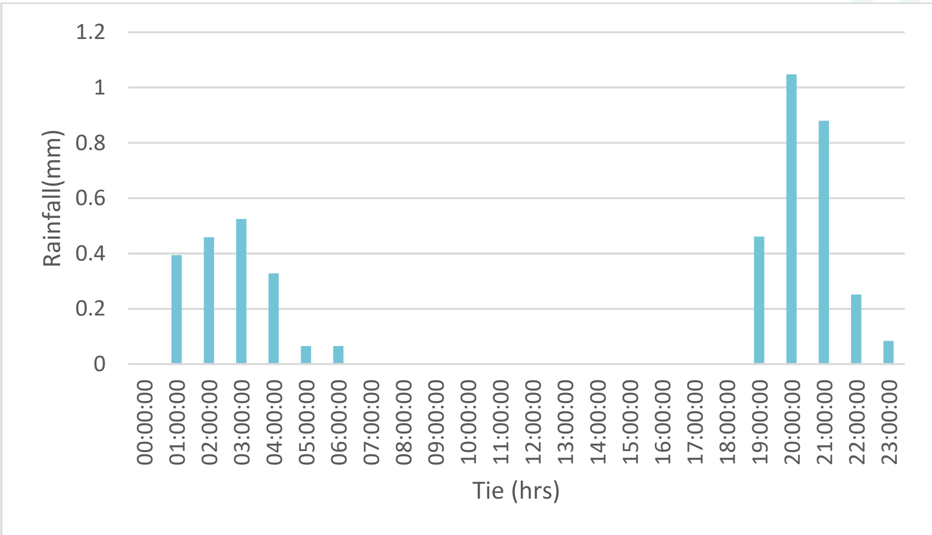


Figure 3-6: Estimated Rainfall Distribution on the 26th of February 2016

High tide on the 26th of February was recorded in Galway Port at approximately 7:40am and 7:50pm with a recorded water level of 5.5m at 7:40am and 5.2m at 7:50pm. High tide does correspond with the time peak rainfall occurred.

Highest wind speed of 11 knots occurred at 2am with north westerly winds at this time, recorded at Shannon Airport. The mean sea level pressure, measured at Shannon Airport gauge was at its lowest of 1002.9hPa at 4pm, which does not correspond with the peak rainfall.

3.2.3.3 8th February 2016

The Flood event on the 8th of February 2016 coincided with Storm Imogen. Using the Kilkee (Moveen) gauge daily data and the Shannon Airport gauge hourly data, the rainfall distribution over the 7th and 8th of February 2016 was estimated, Figure 3-7 and Figure 3-8, respectively. Peak rainfall depth of 5.3mm was estimated to occur at 6am on the 8th of February. A total of 17.6mm of rainfall fell between 7pm on the 7th of February and 6am on the 8th of February (i.e., 12hrs). This corresponds to a pluvial return period of less than 2 years.

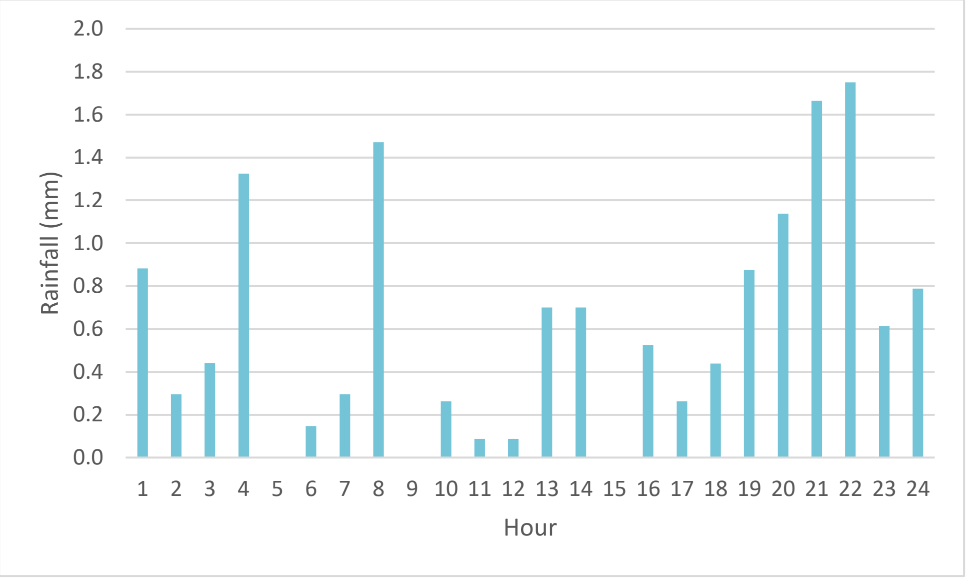


Figure 3-7: Estimated Rainfall distribution on the 7th February 2016

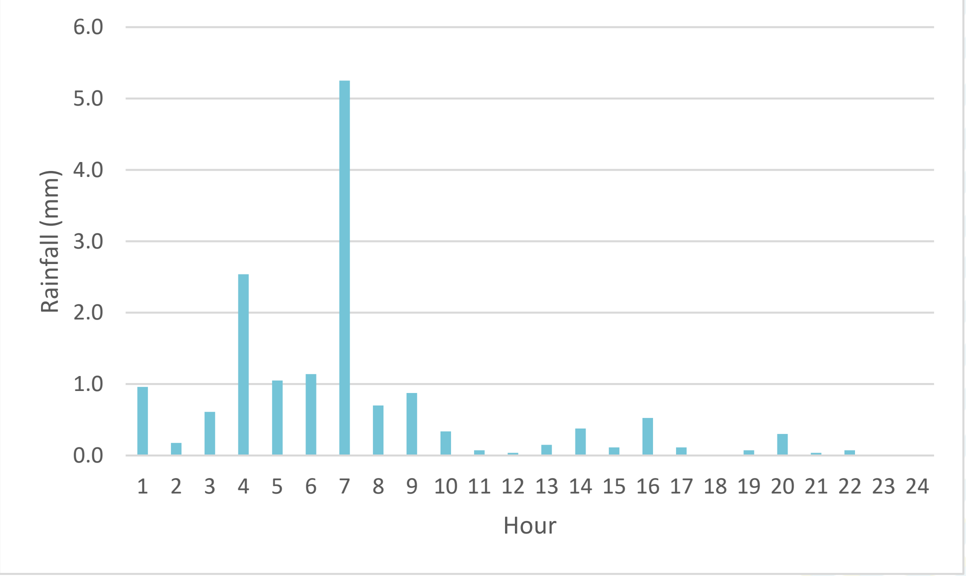


Figure 3-8: Estimated Rainfall distribution on the 8th February 2016

High tide on the 8th of February was recorded in Galway Port at approximately 4:30am and 5pm with a recorded water level of 6.28m at 4:30am and 5.6m at 5pm. High tide does not correspond with the time peak rainfall occurred.

Highest wind speed of 34 knots occurred at 5am with south westerly winds at this time, recorded at Shannon Airport. The mean sea level pressure, measured at Shannon Airport gauge was at its lowest of 970.5hPa at 4am, although this is not the time of peak rainfall it corresponds to the period of heavy rainfall.

3.2.3.4 12th April 2015

Using the Kilkee (Moveen) gauge daily data and the Shannon Airport gauge hourly data, the rainfall distribution over the 11th of April 2015 was estimated, Figure 3-9. Peak rainfall depth of 8mm was estimated to have occurred at 7am. Between 1am and 9am (9 hours) there was a total of 33.5mm of rainfall. This corresponds to a pluvial return period between 5 and 10 years.

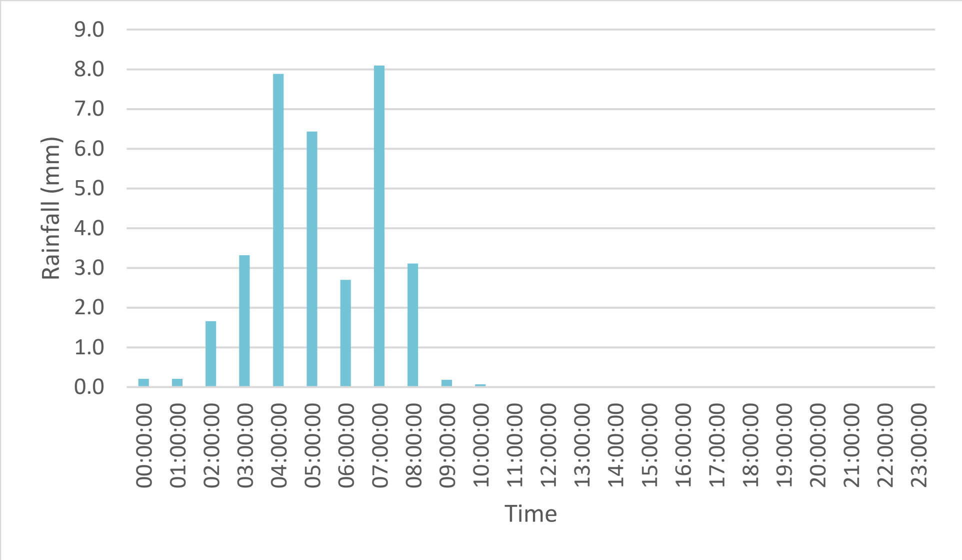


Figure 3-9: Estimated Rainfall distribution on the 12th April 2015

High tide on the 12th of April was recorded at Galway Port at approximately 10:30am and 10:50pm, with a water level of 4.45m at 10:30am and 4.44m at 10:50pm. High tide does not correspond with the time peak rainfall occurred.

Highest wind speed of 20 knots was recorded at Shannon Airport at 6pm from a southerly direction. The mean sea level pressure, measured at Shannon Airport gauge was at its lowest of 1010.6hPa at 5am, although this is not the time of peak rainfall it corresponds to the period of heavy rainfall.

3.2.3.5 1st January 2014

Using the Kilkee (Moveen) gauge daily data and the Shannon Airport gauge hourly data, the rainfall distribution over the 1st of January 2014 was estimated, Figure 3-10. Peak rainfall of 0.8mm was estimated to have occurred at 8am on the 1st of January 2014.

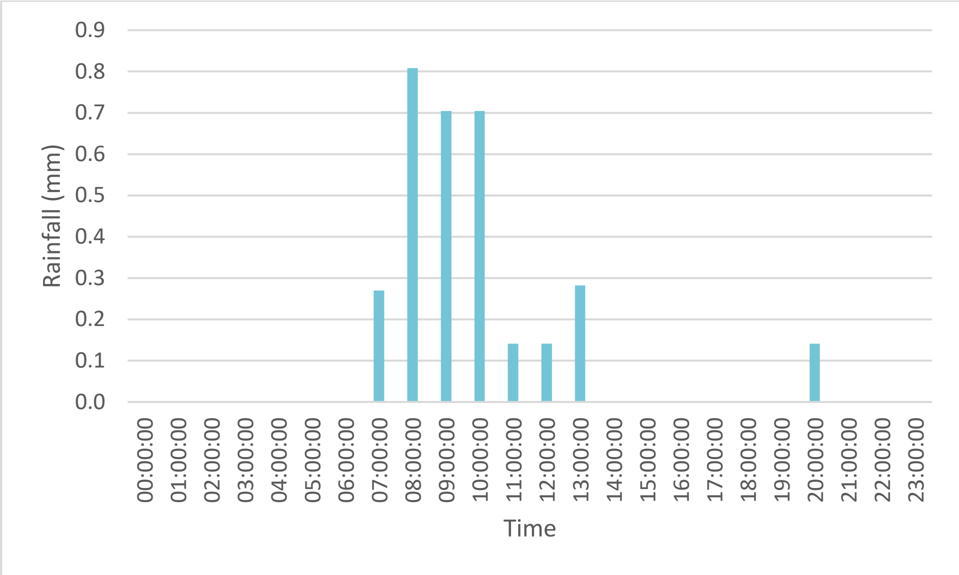


Figure 3-10: Estimated Rainfall distribution on the 1st January 2014

High tide was recorded at Galway port at approximately 4:30am and 5pm, with a water level of 5.93m at 4:30am and 5.99m at 5pm. High tides do not coincide with peak rainfall times.

Highest wind speed of 13 knots was recorded at Shannon Airport at 8am from an easterly direction, however wind direction was predominantly westerly for the latter half of the day. Mean sea level pressure was lowest at 11am, reducing from 989hPa at 1am to 971.3hPa at 11am. This dip in pressure corresponds to the period of rainfall between 7am and 1pm.

3.3 Hydrometric Data

There are no active or inactive long term gauging stations on either of the watercourses of interest. Calibration of the hydrology model against historic events is therefore not possible. Validation of the hydraulic model with event rainfall will therefore be critical.

Two water level monitors were installed on 6th of January 2021, one on the Victoria Stream and the other on the Atlantic Stream. The monitors were removed on the 7th of April 2022. In the time that the monitors were in place no flood events were recorded, they therefore cannot be used to validate / calibrate the model.

3.4 Groundwater Data

There are no recorded groundwater flooding events within the study area. Bedrock is classified as locally important aquifer, which is moderately productive in local zones, with a number of local wells located to the east and south west of the town. Groundwater subsoil permeability is classified as low for much the study area. Groundwater vulnerability ranges from low, to the east, to rock at or near surface, along the coastline. Potential for saturation of the subsoils following heavy rain and increased overland flow. Antecedent conditions in the catchment will affect this.

3.5 Met Eireann Data Update July 2023

In July 2023 Met Eireann released the results of new rainfall estimate research. The goal of this research was to calculate return values for various return periods (2, 5, 10, 20, 50, 100 and 120 years) for specific rainfall thresholds ranging from 15 minutes to 24 hours (15 and 30 minutes and 1, 2, 3, 4, 6, 12 and 24h) and from 1 to 25 days (1, 2, 3, 4, 6, 8, 10, 12, 16, 20 and 25 days), based on a denser network of stations with up-to-date data and according to the depth-duration frequency model described by Fitzgerald (2007). The new estimations of rainfall intensities will be used in building design in support of Action 203 of Ireland's Climate Action Plan 2021 – Develop specific climate maps and data for use in building design to enhance resilience in support of climate change adaptation and to support the National Adaptation Framework.

Whilst this data arrived at the latter stages of this project, an assessment was undertaken as to the potential difference between this new data set and previous Met Eireann data for the site. The following table provides a summary of the results of this assessment for the Victoria Catchment.

Table 3-6 Met Eireann Data Update

Element	Units	Previous Met Eireann Data	July 2023 Data
Unit Hydrograph time to peak	Hours	2.952	2.952
Instantaneous UH time to peak	Hours	2.452	2.452
Critical Storm Duration	Hours	6.403	6.403
Design Storm Depth	mm	65.668	67.5
Standard Percentage Runoff	%	75	75
Percentage Runoff	%	79.205	79.421
Unit Hydrograph Peak	m3/s/mm	0.113	0.113
Baseflow	m3/s	0.053	0.053
Baseflow adj	m3/s	0.180	0.180
Hydrograph Peak	m3/s	3.444	3.548

For the largest of the Victoria sub-catchments for the 100yr event rainfall total is ~ 1.8mm more. This translates into a 3% increase in peak flow, which is minimal. Therefore, it is proposed to proceed with the use of the original Met Eireann Data.

4 Review of CFRAM Hydrology

4.1 Overview

The final Shannon CFRAM Hydrology report and flood maps were released in 2016. This section reviews the CFRAM hydrology and highlights new information available or changes in the catchment that have occurred since its completion.

In compliance with the Kilkee Flood Relief Scheme tender specification, Coastal boundaries will be documented in the hydraulic reporting.

4.2 Flow Estimation Methods – Qmed Estimation

Flow estimation was carried out for 21 Hydrological Estimation Points (HEPs) in the Shannon CFRAM Model S19 area.

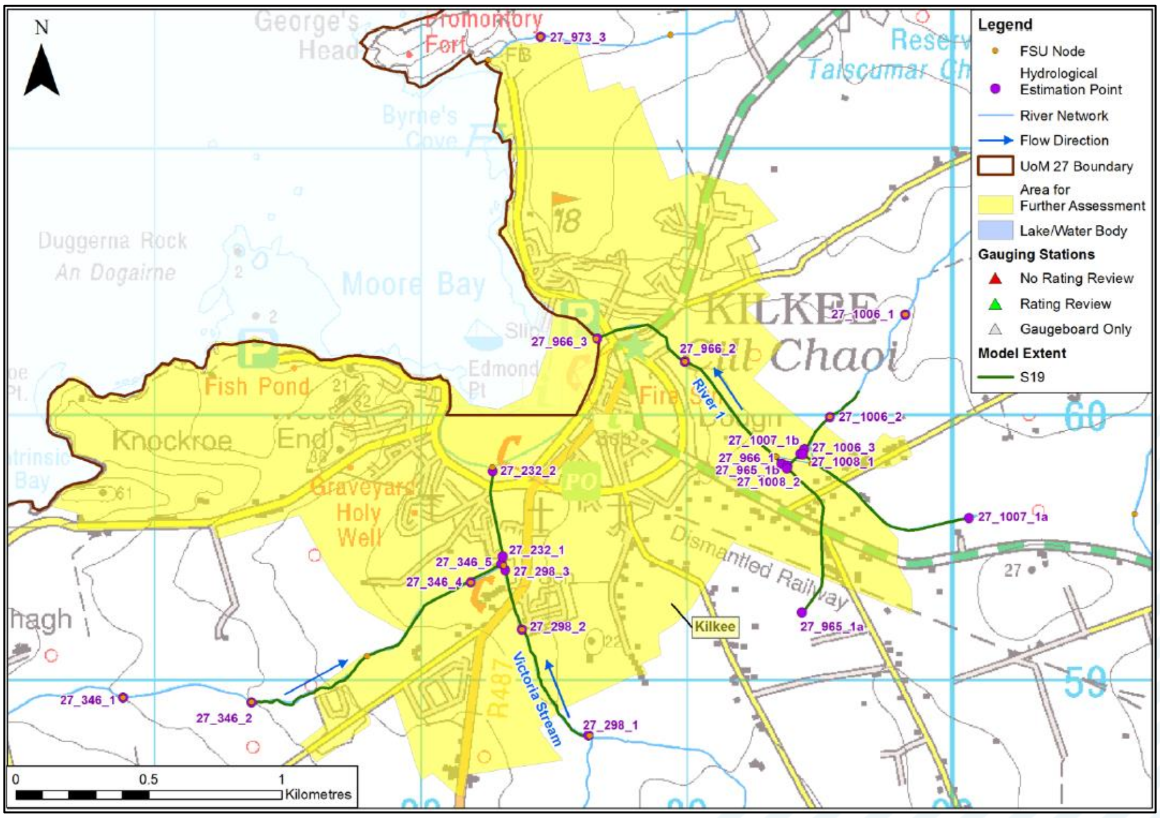


Figure 4-1: Model S19 HEPs and model extent (Source: Shannon CFRAM Unit of Management 27, Hydrology Report, July 2016)

Of the 20 HEPs 4 were created for the CFRAM study all others were sourced from the FSU ungauged location node database which was the source of the catchment descriptor data.

The Qmed at all HEPS was determined using the Flood Studies Update catchment descriptor-based equation (FSU PCD). The FSU PCD method was the recommended approach for Qmed estimation in all ungauged catchments for the CFRAM studies (refer to Guidance Note 21 - CFRAM guidance note on flood estimation for ungauged catchments).

According to the CFRAM documentation an adjustment factor was applied to the Qmed values. As there are no gauges in Kilkee the Qmed adjustment factor was estimated using multiple pivotal sites. The adjustment factors were estimated using a weighted geometric mean of the five hydrologically most similar gauged sites in the country. The use of a single pivotal site was considered but no suitable station was found that was hydrologically similar and sufficiently near to the subject site.

4.3 Growth Curve Generation

The growth curves (GCs) for the SECFRAM study were developed in accordance with the FSU guidance. As the catchment is ungauged there was no gauging stations suitable for flood frequency analysis. A pooling group was therefore developed based on the catchment descriptors at HEP node 27_1006_2 on the Atlantic Stream Tributary. A LN2 distribution was chosen as it was a best fit for the pooling group stations and applied to the entire catchment. A total of 21 hydrometric gauges were used in the pooling group.

4.4 Joint Probability

A joint probability analysis was carried out for the Kilkee AFA to determine the appropriate combinations of flows and sea levels to be used for the design probability events. The CFRAM Joint Probability Scenarios were adopted from the Lee Catchment Study. The scenarios were minorly adjusted as no fluvial data for magnitudes less than the 50% were available. Two scenarios were developed for each joint probability AEP, a fluvial dominant and a tidally dominant scenario.

Table 4-1: Event combinations used in joint probability analysis carried out for Kilkee AFA CFRAM Study

	Joint Probability Design Event	AEP Adopted for Fluvial Flows and Tidal Levels	
Scenario	Overall AEP	Fluvial	Tidal
1	50%	50%	500%
2	50%	50%	50%
3	20%	20%	500%
4	20%	50%	20%
5	10%	10%	200%
6	10%	50%	10%
7	5%	2%	100%
8	5%	50%	5%
9	2%	2%	50%
10	2%	50%	2%
11	1%	1%	50%
12	1%	20%	1%
13	0.5%	0.5%	10%
14	0.5%	10%	0.5%
15	0.1%	0.1%	2%
16	0.1%	2%	0.1%

5 Updated Catchment Data

JBA have reviewed and updated the blueline river network, catchment boundaries and catchment descriptors. These are supplied as accompanying GIS datasets. Appendix B contains a table of catchment descriptors.

The catchment descriptors for downstream catchments which will be added as lateral inflows to the hydraulic model have been derived to describe the lateral catchment contribution and not the total upstream descriptor. For example, BFI soil is the average soil type of the lateral sub-catchment, and MSL and S1085 represent the length and slope of typical channels within the lateral sub-catchment not the total upstream descriptor. This distinction is to suit the rainfall runoff approach and not a subtraction of FSU ungauged node descriptors.

Total downstream catchment descriptors have also been derived as a reality check for the hydrological and hydraulic modelling. These take the form of FSU style HEPs which are the description of the total upstream catchment (not the sum of the individual inflows catchments).

Figure 5-1 presents an example of how the sub-catchments and total catchment descriptors differ.

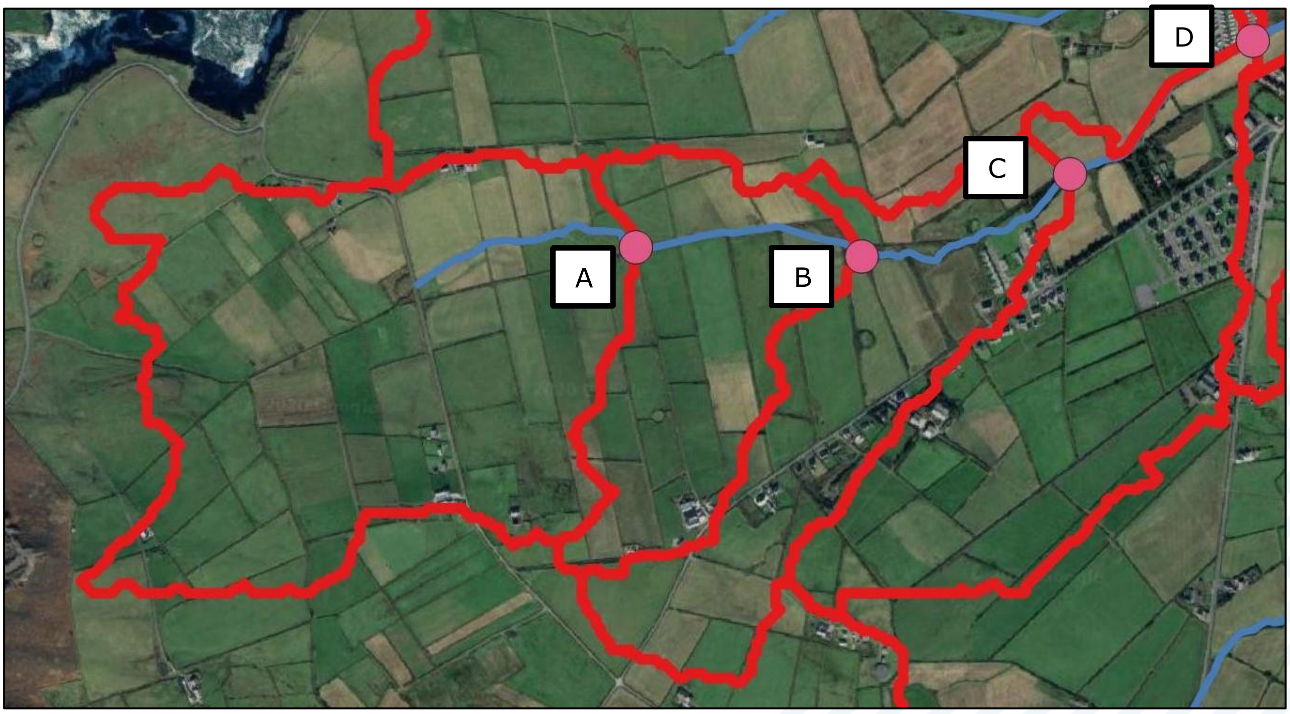


Figure 5-1. Annotated example of inflow catchments and overall catchments.

Catchment A is the upstream sub-catchment with catchment descriptors derived in the standard FSU manner. Catchments B, C and D are lateral contributing sub-catchments with descriptors derived for the additional lateral catchment only. Catchment D outlet is also the point for the whole catchment calculation with FSU type descriptors for the whole contributing catchment to this point, as used for checks.

5.1 Catchment Splitting

In two of the sub-catchments in the Atlantic model, the lateral contributing sub-catchments were further divided based on the weighted application by area. Without dividing these lateral sub-catchments, an overestimation of flows was applied upstream of critical structures causing them to surcharge in key events, inundating properties. Figure 5-2 shows the locations of the sub-catchment splitting for each of the two catchment boundaries.

It is noted that this further division of the lateral contributing sub-catchments is applied within the model build rather than in the catchment boundaries and HEPs defined in Appendix A.

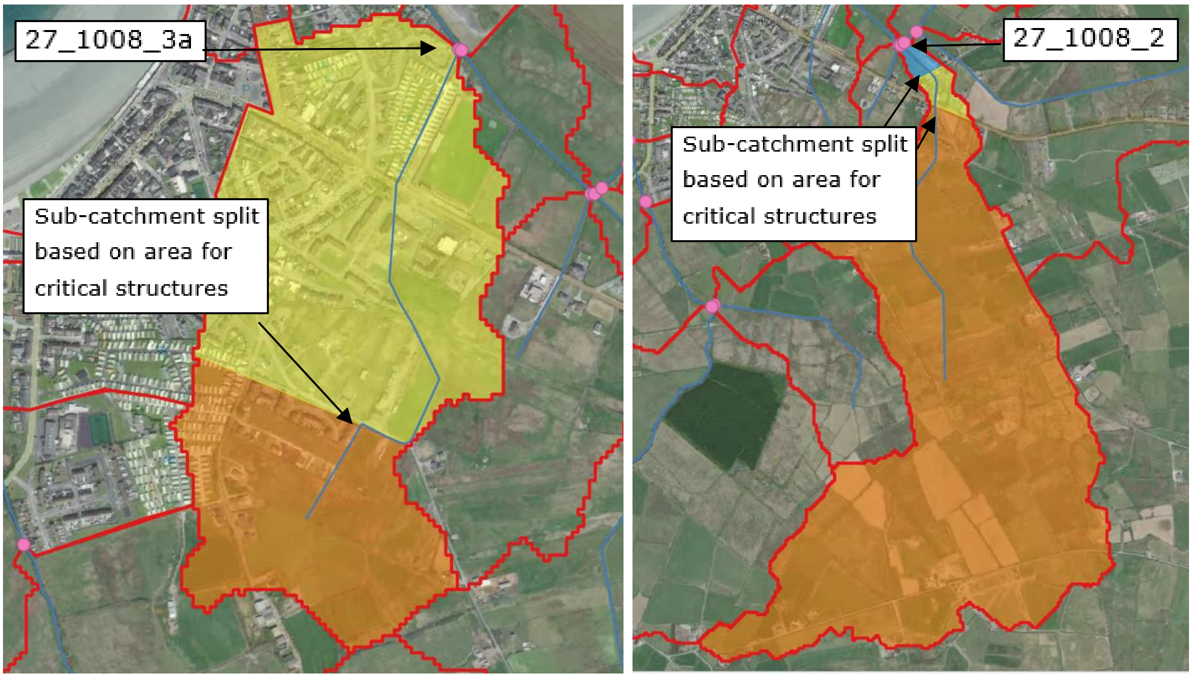


Figure 5-2: Sub-catchment Split in Atlantic Model

6 Design Flow Estimation

6.1 FSSR 16 Rainfall Runoff

As the catchment areas in Kilkee are relatively small there is too much uncertainty in the ability of FSU methods to derive representative inflows in the traditional HEP estimation approach. Therefore, the FSSR16 rainfall-runoff method has been used to estimate inflow hydrographs for the hydraulic model.

A rainfall-runoff model of the Kilkee catchment area was developed within Flood Modeller and separate FSSR16 units for each sub catchment have been constructed. This hydrological model will be linked into the main hydraulic model, at which point flows will be finalised.

Table 6-1 details the specialist inputs required in each FM FSSR16 unit to allow estimation of flows. These specialist inputs are in addition to the basic catchment descriptors (e.g., area), which were detailed earlier in this report. The table also details how they have been derived for the design run inflows.

As flooding in Kilkee has occurred in both winter and summer months the 75% winter storm hydrograph profiles and the 50% summer storm hydrograph profiles were both compared. Figure 6-1 shows a comparison of winter and summer hydrograph profiles for sub catchment 27_1008_3. The summer profile has a higher peak flow; however, the winter profile has a larger volume of flow. In each case, a 75% winter storm hydrograph profile has been used to generate the inflow. Volume is considered a key factor to flood risk in the area so the selection is not likely to be critical but a sensitivity test using summer storm profiles will be carried out in the hydraulic modelling.

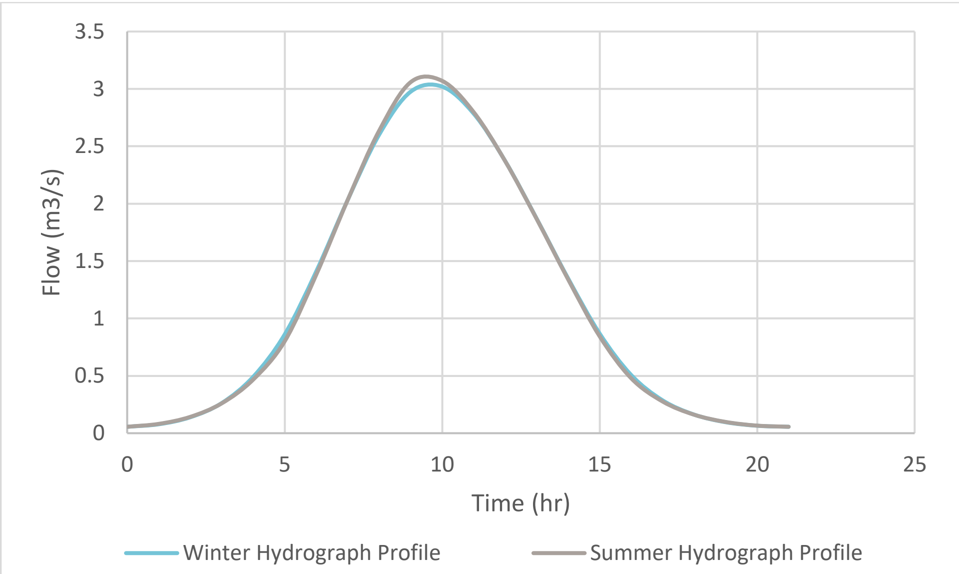


Figure 6-1: Comparison of summer and winter hydrograph profiles for sub catchment 27_1008_2

Interim peak flows estimated for each AEP event are reported for each inflow in Appendix C.1 of this report. An example of the 1% AEP FSSR 16 hydrographs developed for the sub catchments along the Atlantic Stream are shown in Figure 6-2. Refer to Appendix A for location of the catchments mentioned below.

The critical storm duration determined from the FSSR 16 method is shown in Appendix 0. Various storm durations will be tested in the hydraulic model to determine the critical storm duration for the catchment.

It is noted that due to limitation of the Flood Modeller software the lowest return period flood event that could be input was the 2.5-year return period. Therefore, in order to determine the 2-year return period or the 50% AEP flows a factor was applied to the 2.5-year flows. The factor applied was 0.91 and is based on the FSSR 16 growth curve.

Table 6-1: FSSR16 input parameters

Input parameter	Design run value
SAAR	Standard Average Annual Rainfall over catchment area in mm. For design runs the latest SAAR data for the period 1980 – 2010 has been used.
M52D	Depth of rain estimated to fall for a 20%AEP (5 year) event with a duration of 2 days. This value is sourced from the MET Eireann DDF database for each catchment.
M525D	Depth of rain estimated to fall for a 20%AEP (5 year) event with a duration of 25 days. This value is sourced from the MET Eireann DDF database for each catchment.
SPR	Standard Percentage runoff – proportion of rainfall falling on the catchment that enters the river system instead of being intercepted. For design runs the SPR values for each catchment are derived from WRAP SOIL type.
CWI	Catchment wetness index estimated using the FSSR method.
Flow return period	Altered to match the desired AEP event.
Storm duration	An 11-hour design storm duration was initially used, recommended Storm Durations are shown in Appendix 0

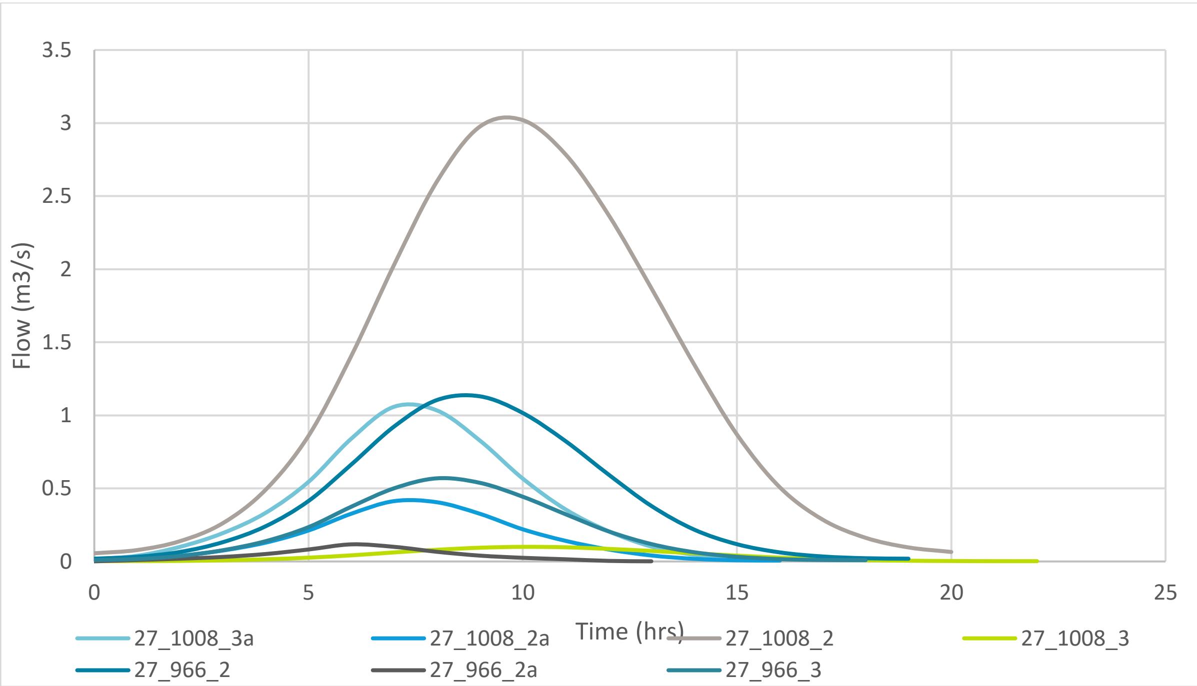


Figure 6-2: 1% AEP Hydrographs for sub catchments along the Atlantic Stream

6.2 FSU Method

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

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

$$Q_{med}RURAL = (1.237 \times 10^{.5})(AREA^{0.937})(BFISoil^{-0.922})(SAAR^{1.306})(FARL^{2.217})(DRAIND^{0.341})(S1085^{0.185})((1 + ARTDRAIN2)^{0.408})$$

The Urban Adjustment Factor (UAF) is applied to the above equation to give the final Qmed value. The UAF is calculated as follows

$$UAF = (1 + URBANEXT)^{1.482}$$

The FSU small catchments Qmed was determined using the following equation

$$Q_{med_{SC}} = (2.0951 \times 10^{-5})(AREA^{0.945})(SAAR^{1.2695})(BFISoil^{-0.903})(FARL^{2.3163})(S1085^{-0.2513})$$

The CFRAM study used the FSU method. This method is highly uncertain for small catchments and therefore is not recommended for the catchments in Kilkee. It must also be noted that any FSU pooling group will not be based upon sufficient number of small catchment AMAX records. However, the Qmed values were calculated to provide a comparison for the FSSR 16 flows calculated as described above. Comparing both methods show that the FSU method gives a lower Qmed that the FSSR 16 method suggesting that the FSU method is not an accurate representation of the catchments. FSU Qmed flows are shown in Appendix 0.

6.3 IH 124 Method

The IH 124 Report examined the response of small catchments, less than 25km^2, to rainfall and derived an improved flood estimation equation (Marshall & Bayliss, 1994). A total of 87 sites were used to develop the method. Equations to estimate Qbar were developed for both rural and urban catchments. Th rural equation was used for catchments with an URBANEXT less than 0.025km^2.

The IH124 method of flow estimation uses a soil value which is based on the percentage of the catchment within each WRAP soil class. The soil value associated with each WRAP class is shown in the table below.

Table 6-2: Soil values for IH124 flow estimation

WRAP Class	Soil Value
1	0.15
2	0.3
3	0.4
4	0.45
5	0.5

The Qbar calculated from the IH124 method was adjusted to give the peak flow for the various AEP events using the regional growth curve. Peak flows for a number of return periods for the sub catchments for the Victoria and Atlantic Streams are shown in Appendix 0. The hydrograph shape determined from the FSSR 16 method above is applied to the rational methods flows determined, an example of the rational method hydrographs for sub catchment 27_1009_1 are shown in Figure 6-3.

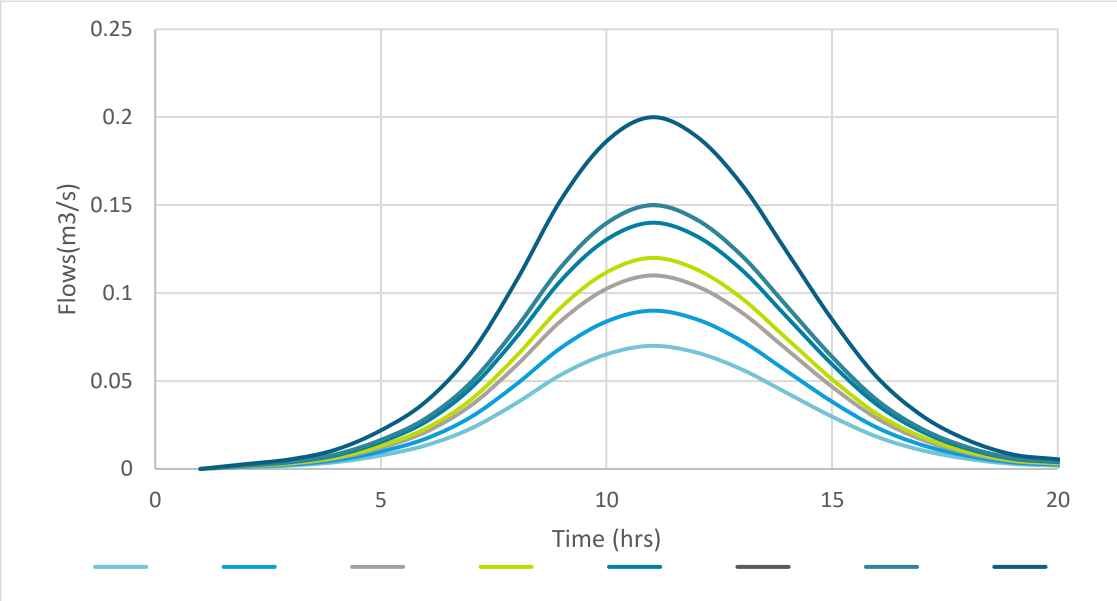


Figure 6-3: IH 124 hydrographs for Sub catchment 27_1009_1 for various return periods

6.4 Rational Method

The rational method determines the peak discharge. It relates peak flow to catchment area, rainfall intensity and runoff coefficient. The formula is as follows:

$$Q = CiA$$

The runoff coefficient for the for the catchments was based on catchment use, slope and soil types. The runoff coefficients used for the sub catchments in Kilkee, and the corresponding catchment description is shown in Table 6-3.

Table 6-3: Runoff Coefficients used for Rational Method Flow Estimation

Runoff Coefficient	Catchment Description
0.16	Rural area with majority pasture with rolling slopes
0.325	Urban Area with majority residential usage
0.8	Urban area with majority urban business

The time of concentration of the catchment was used for the estimation of the flow for the Natural Method. The Bransby – Williams Equation for natural catchments was used for the purpose of this study.

$$t_c = \frac{(F_c.L)}{(AREA^{\frac{1}{10}}.S^{\frac{1}{5}})}$$

Where tc is the time of concentration in minutes, F is a conversion Factor (58.5), L is the length of the flow path from catchment divide to outlet (km), AREA is the area in km², and S is the slope of the catchment in m/km. For urban catchments 5 minutes was added to the above calculated time of concentration to account for time taken to flow off roofs. A check was completed on the urban catchments which have storm water sewers to determine the time of concentration of the stormwater sewers pipes (tcp). The critical storm duration will be determined using sensitivity testing of the hydraulic model. The time of concentration will be tested as a storm duration in the hydraulic model.

Rainfall intensity was determined using the Met Eireann DDF rainfall depth values for each return period.

The rational method was used to determine the peak flows for the urbanised sewer sub catchments in the vicinity of the town Appendix 0 show the peak flows for a number of return periods. The hydrograph shape determined from the FSSR 16 method above is applied to the rational methods flows determined, an example of the rational method hydrographs for sub catchment 27_1009_1 are shown in Figure 6-4.

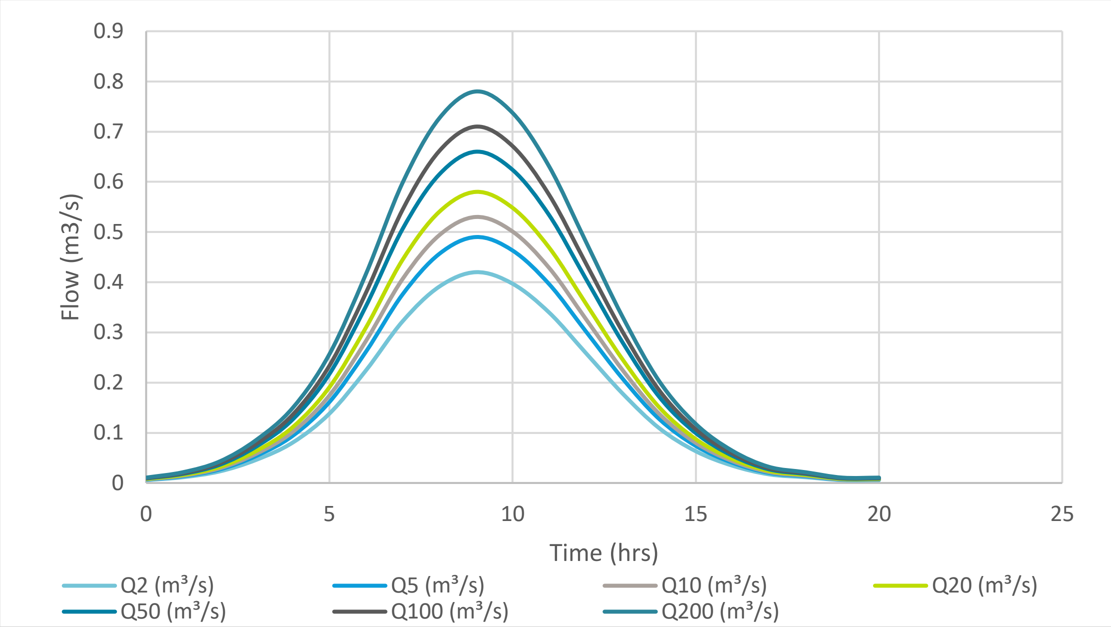


Figure 6-4: Hydrographs for Sub catchment 27_1009_1 for various return periods

6.5 Flow Comparison

The FSU method is highly uncertain for small catchments and therefore will not be used for the catchments in Kilkee.

The IH 124 method is appropriate for small catchments, like those present in Kilkee. However, the method is more suited to generally flat catchments. As the catchments in Kilkee are relatively steep the IH 124 method was deemed to not be representative of the catchments.

The FSSR RR method is appropriate for small catchments and upper reaches (fast and steep) which much flashier floods and steep growth curves. As the upland catchments in Kilkee are relatively steep, the FSSR 16 method has been chosen to represent these catchments.

For the downstream, sewer urbanised catchments the rational methods and the FSSR 16 method are both considered and compared below for the Q100 peak flow. The FSSR 16 produces the worst case flows for the majority of the catchments, so will be used as the flow estimation method.

Table 6-4: Comparison of Q100 peak flows for FSSR and rational methods

Catchment	Catchment Area (km^2)	FSSR 16 (m^3/s)	Rational Method (m^3/s)
27_1009_1	0.025	0.073	0.071
27_346_5	0.014	0.078	0.15
27_232_2	0.174	0.479	0.04
27_232_1a	0.118	0.257	0.34
27_232_1	0.187	0.471	0.08
27_1008_3a	0.448	1.059	0.70
27_966_2a	0.028	0.117	0.02
27_966_3	0.263	0.569	0.64

6.6 Tidal Curves

Tidal curves have been developed for each AEP event, as shown in Figure 6-5. The peak tidal levels for each tidal AEP are shown in Table 6-5. The peak of the tidal curves are based on the IBE1781_CWWS_Kilkee_Rp01_D01 report issued in August 2021. The levels provided in this work include for wave set up. Wave set up can occur on wide relatively flat beaches where large storm waves break and reform resulting in a lowering of the mean sea level under the first line of breaking waves and a subsequent increase in the mean sea levels closer to the beach. This increase or set-up of the mean water levels close to the beach means that reformed waves approaching a coastal structure at the back of the beach may be slightly larger due to the locally increased water depth at the toe of the structure. The height of the waves that can approach Kilkee is strongly influenced by the water depth in the area, therefore wave set-up could potentially have a significant impact on the inshore wave climate in Kilkee. The CFRAM peak tidal levels (Hydraulics Report UoM27) are compared to the tidal levels developed for this study in Table 6-5. Both the CFRAM and the tidal levels presented in this table are nearshore levels. There is a significant difference in the levels, largely attributed to the inclusion of wave set up.

Refer to the associated Hydraulic Report Appendix B (19109-JBAI-XX-XX-RP-C-00368-Hydraulic_Model_User_Report_P02) for details on how the tidal curves were developed.

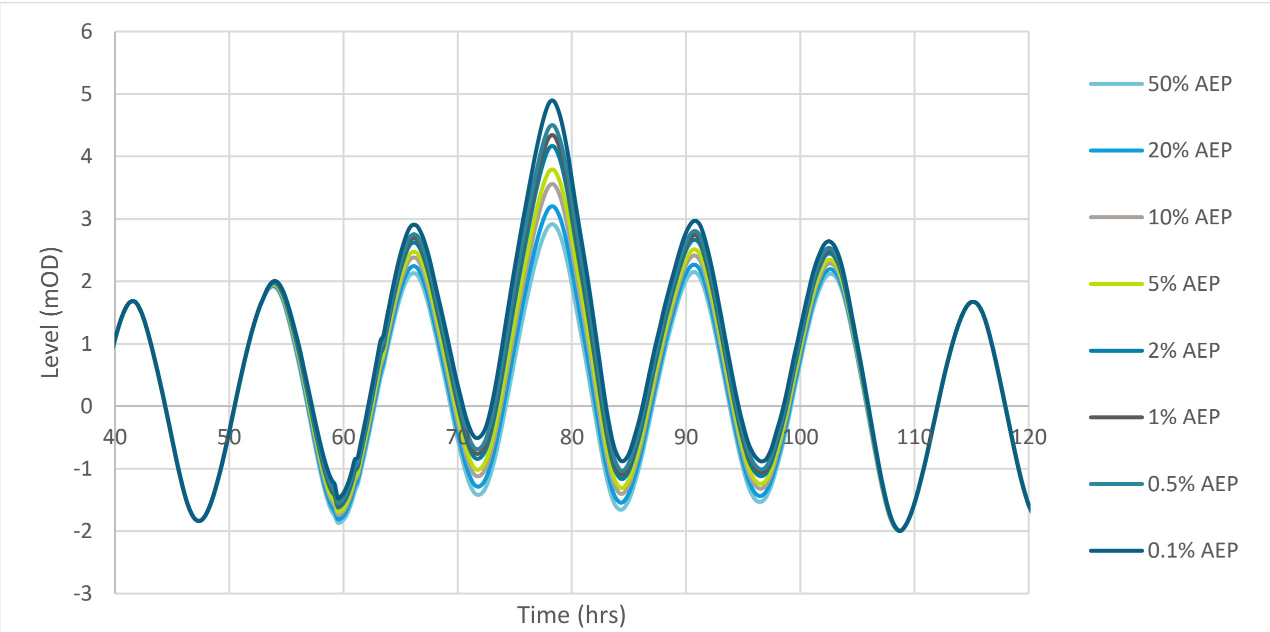


Figure 6-5: Tidal Curves

Table 6-5: Peak Tidal Levels (mOD OSGM02) developed from this study compared to peak tidal levels used in the CFRAM study

AEP (%)	Peak Tidal Level (mOD OSGM02)	CFRAM Tidal Levels (mOD OSGM02)
50	2.91	2.61
20	3.20	2.73
10	3.56	2.82
5	3.79	2.90
2	4.17	3.02
1	4.34	3.10
0.5	4.50	3.19
0.1	4.90	3.37

6.7 Climate Change

To account for the effects of climate change the rainfall depths will be adjusted for fluvial events. Forestation is not likely to occur in the Kilkee catchment and will not be considered in the climate change analysis. Mean Sea Level Rise will be considered as part of the coastal boundary. The future scenarios do not account for any potential changes to the meteorological systems which may affect the offshore wave climate or wind speeds and therefore affect the sea level. Table 6-6 provides the climate change parameters applied to the 1% AEP design run.

Table 6-6: Climate change parameters

	MRFS	HEFS
Extreme Rainfall Depths	+ 20%	+ 30%
Mean Sea Level Rise	+500mm	+1000mm

6.8 Joint Probability

Joint Probability analysis predicts the probability of occurrence of events in which two or more partially dependent variables are simultaneously of high or extreme values. Joint probability between coastal and fluvial events, is considered to be a significant issue on the Victoria Stream.

An initial assessment of joint probability was completed using the Defra method 'desk study approach'. The simplified method for joint probability analysis based on dependence and marginal extremes was originally developed by CIRIA (1996). This method was developed further into the 'desk study approach' which is recommended as best practice by Defra. The 'desk study approach' has been developed into a software tool by JBA. Inputs required are:

- marginal extremes of variables in this case fluvial flow and tidal levels.
- dependence (χ) value.
- number of records per year;
- joint exceedance return periods required.

Dependence between river flow and tidal level is represented by χ. The Defra/EA study found that χ >0.1 has high dependence, and χ <0.1 has a lower dependence. For Kilkee a moderate dependence of χ = 0.1 between fluvial flow and tidal water level was assumed as the catchment is short and flashy, and the tidal levels have been known to affect flooding along the Victoria. A table of appropriate combinations of fluvial flow and tidal level was developed for each joint return period. Table 6-7 below shows the extreme ends of the combinations developed, i.e., high fluvial flow return period and low tidal water level return period, and a low fluvial flow return period and high tidal water level return period.

Table 6-7: Joint exceedance return periods

Joint Return Period (yrs)	Fluvial (yrs)	Tidal (yrs)
2	0.2	0.2
	2	0.02
5	0.2	1
	5	0.05
10	0.1	10
	10	0.1
20	0.2	20
	20	0.2
50	0.5	50
	50	0.5
100	1	100
	100	1
200	2	200
	200	2
1000	10	1000
	1000	10

Return period years which were between the standard return period years were also rounded to the nearest return period, for example 1.25-year tidal level above was round to the 1-year return period. Combinations of tidal levels and fluvial flows for each probability are shown below in Figure 6-6.

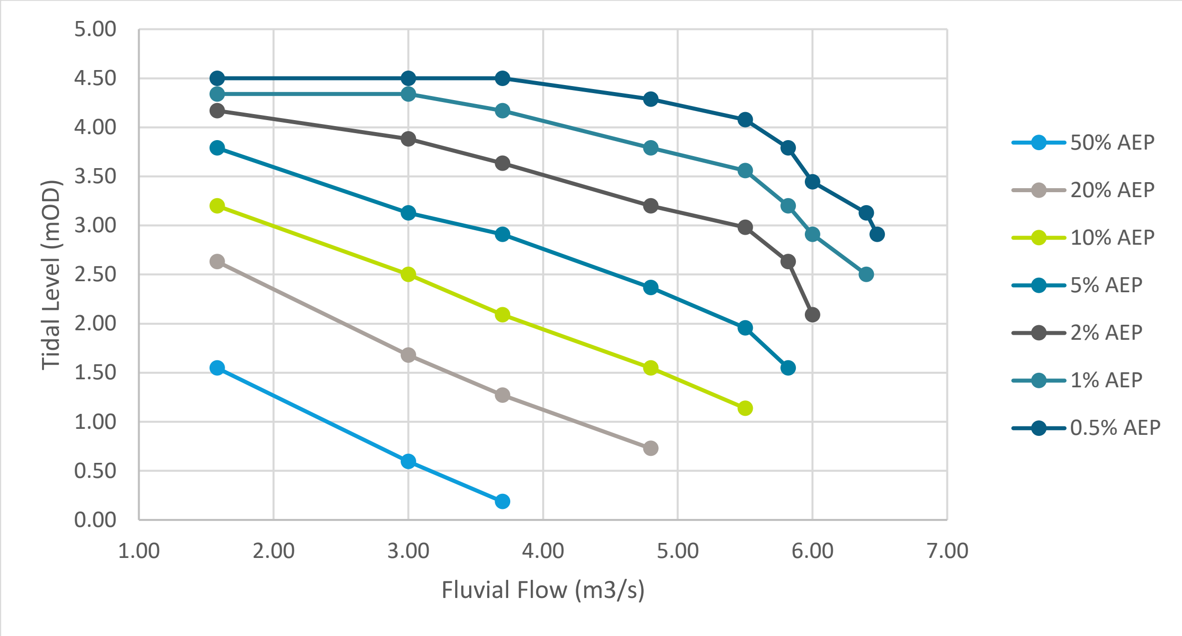


Figure 6-6: Joint exceedance curves at the Victoria Stream Boundary Walls

The extreme scenarios were tested in the hydraulic model i.e., the 0.5% Tidal AEP combined with 50% Fluvial AEP and the 0.5% Fluvial AEP combined with the 50% Tidal AEP. This determined that the tidal and fluvial zones pivot around the restriction in the channel at the ESB sub station on the Victoria and that there is no section of river reach where the tidal and fluvial are equally dominant. A detailed analysis of the joint probability combinations shown above is therefore not required. The fluvial element dominates the water level upstream of the boundary walls on the Victoria Stream and the tidal levels dominate downstream of this point. Therefore, when assessing the flood risk the extreme ends of the combinations developed i.e., the combinations shown in Table 6-7, are to be used. This will potentially change when new measures are tested and with climate change. This will be explored in the Options Report.

There is no tidal influence on the Atlantic Stream as the area of flood risk is above the tidal levels, even in climate change scenarios.

Refer to 19109-JBAI-XX-XX-RP-H-00368_Hydraulic_Model_User_Report_P03 for details of this analysis.

6.9 Model Calibration and Validation

As there are no hydrometric gauges located within the catchment area, calibration of the model will not be undertaken. Instead, model validation will be undertaken using event rainfall hyetographs in the hydraulic model and known flood levels and extents from recorded events. Rainfall hyetographs have been calculated for a number of events as shown in Section 3.2. The rainfall hyetographs have been developed by applying the rainfall profile recorded at Shannon Airport to the recorded daily rainfall depth recorded at a rain gauge at a closer proximity to the Kilkee catchment, Kilkee (Moveen) or Moneypoint gauges. As the Shannon Airport gauge is within 50km of the Kilkee catchment it is consider that the rainfall profile will be representative of the rainfall profile at Kilkee. The rainfall depths are taken from rain gauges which are at a closer proximity to the catchment, Kilkee (Moveen) and Moneypoint gauges being 4.69km and 16 43km respectively.

Validating the catchment wetness index will be completed using the soil moisture deficit for the nearest gauge (Shannon Airport). An iterative process will be used to validate the catchment wetness index used for the Kilkee catchment in the hydraulic model.

A detailed validation of the flow estimation cannot be undertaken as no storm has been recorded since the installation of the water level gauges in the Victoria and Atlantic Streams. However, a comparison can be completed with the estimated recorded extents from previous events. Figure 6-7 compares the 50% AEP and 10% AEP modelled flood extents. The historic flooding extents in the figure below have been developed from photographs and local knowledge of previous flood events. The extents match reasonably well with the approximate recorded historic flooding, which validates the hydrology. The modelled extents are more extensive that what has been reported in the past particularly along the upstream of the Atlantic Stream.

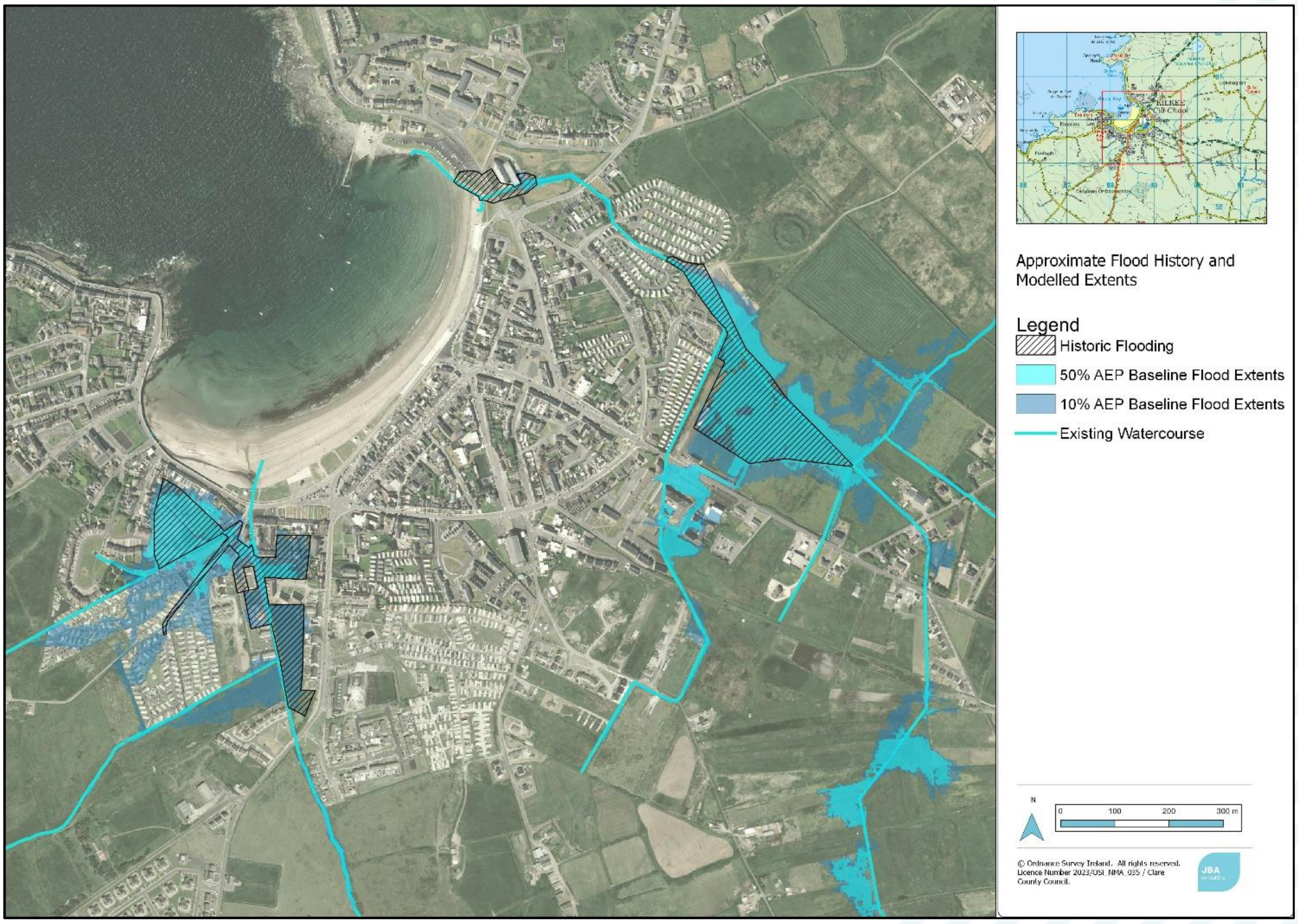


Figure 6-7: Approximate Flood History compared to 50% and 10% AEP extents

7 Summary

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

The available hydrological data available has been reviewed and an understanding of the catchment and its response established. The wide range of data available for the area included flood history, meteorological data, and hydrometric gauge records.

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

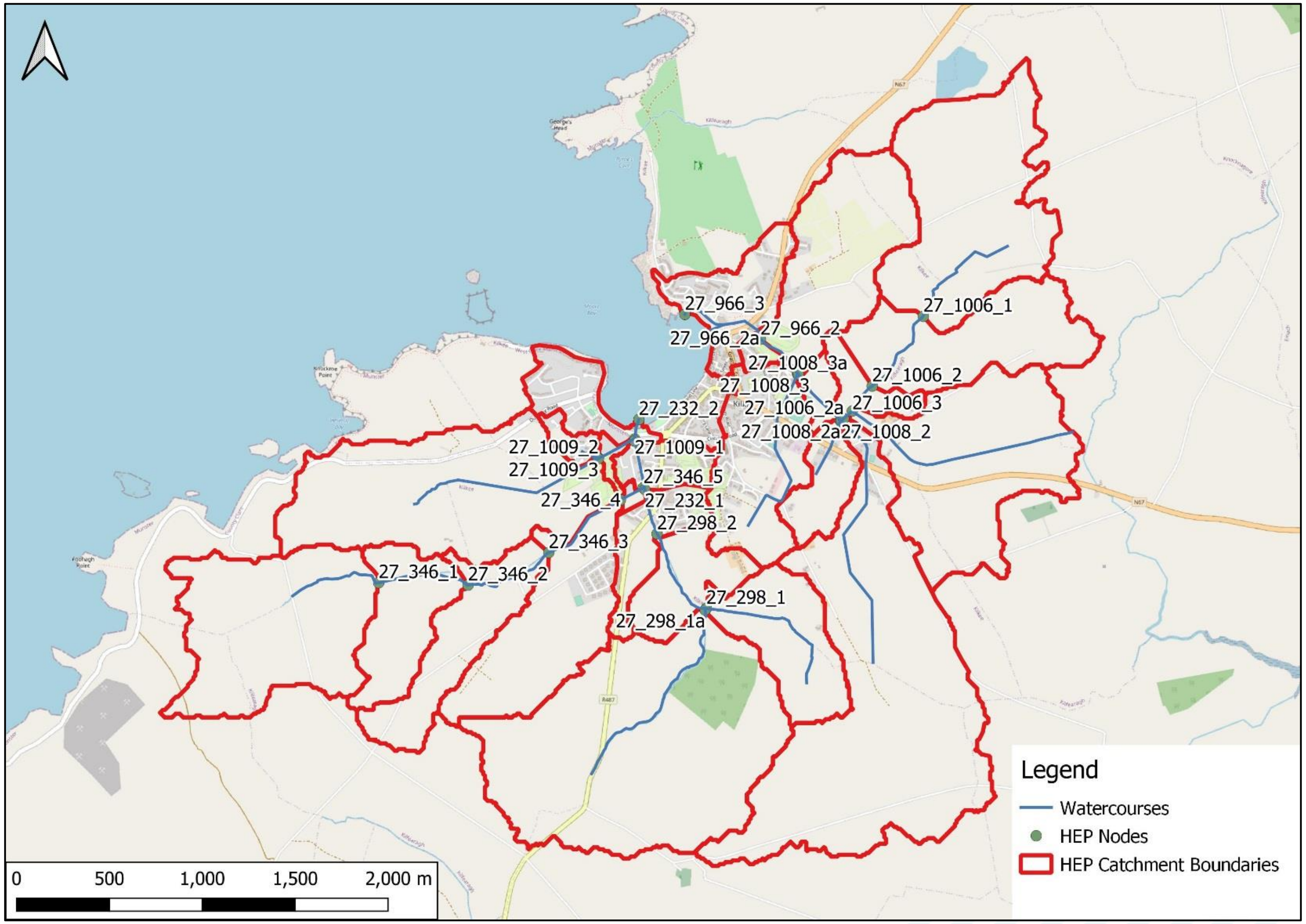
Design flows have been developed using a the FSSR rainfall runoff method. A distributed rainfall-runoff model of the catchment area was developed within Flood Modeller FSSR16 FM inflow units for each sub catchment. This hydrological model will be linked with the hydraulic model. The FSSR 16 method is recommended for the catchments.

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

Recommendation for future monitoring:

- At least 2 rain gauges are recommended within the catchment in locations representative (and easy to maintain and calibrate) of the upland and town itself.
- At least 1 level gauge on each of the Atlantic and Victoria catchments as a means of developing a rainfall to level relationship to start to build an early warning system based on rainfall forecast. The level gauge can also validate the hydraulic models, confirm the tidal influence and even be used as an alert for possible blockage of a structure.
- Monitoring of local tidal levels, sea level and storm surge.

A Catchment Boundaries and HEP labels



B Catchment Descriptors

B.1 Inflow sub-catchment descriptors

Catchment	Area (km²)	URBEXT	SAAR (mm)	MSL (km)	S1085 (m/km)	DRAIND (km/km²)	FARL	BFISoil	ARTDRAIN2
27_1009_1	0.025	0.629	1156	0.228	0.117	1.305	1	0.33	0
27_1009_2	0.048	0.1368	1156	0.099	23.316	1.305	1	0.33	0
27_1009_3	0.975	0.0376	1173	1.684	23.900	1.305	1	0.33	0
27_346_1	0.793	0	1175	0.938	17.955	0.885	1	0.33	0
27_346_2	0.314	0.0151	1173	0.529	17.972	1.408	1	0.33	0
27_346_3	0.369	0.1154	1173	0.518	31.369	1.408	1	0.32	0
27_346_4	0.535	0.1392	1164	0.499	16.204	1.329	1	0.32	0
27_346_5	0.014	0.2001	1164	0.139	11.340	1.385	1	0.32	0
27_298_1a	1.516	0	1169	1.201	19.261	0.724	1	0.33	0
27_232_2	0.174	0.5821	1156	0.097	41.461	1.305	1	0.33	0
27_232_2a	0.118	0.6129	1164	0.266	5.412	1.305	1	0.33	0
27_232_1	0.187	0.4112	1164	0.251	5.949	1.305	1	0.33	0
27_298_2	0.236	0	1164	0.516	8.147	0.724	1	0.33	0
27_298_1	0.364	0	1156	0.851	14.359	0.678	1	0.33	0
27_1006_1	0.868	0	1147	0.651	11.370	0.521	1	0.33	0
27_1006_2	0.516	0	1148	0.514	10.370	0.887	1	0.33	0
27_1006_3	0.815	0	1148	1.251	4.052	1.088	1	0.33	0
27_1006_2a	0.110	0	1164	0.241	5.198	1.088	1	0.33	0
27_1008_3a	0.448	0.3495	1150	1.022	3.902	0.678	1	0.33	0
27_1008_2a	0.164	0.1449	1161	0.314	10.389	0.678	1	0.33	0
27_1008_2	1.610	0.0099	1161	1.437	5.886	0.678	1	0.33	0
27_1008_3	0.059	0.0097	1150	0.348	1.611	0.678	1	0.33	0
27_966_2	0.567	0.0644	1150	0.289	3.266	0.678	1	0.33	0
27_966_2a	0.028	0.629	1150	0.085	14.118	0.724	1	0.33	0
27_966_3	0.263	0.2817	1150	0.509	2.409	0.724	1	0.33	0

Uniform FSSR Rainfall Runoff DDF parameters for all sub-catchments are applied:

M5-2D: 55.9

M5-60min: 14.0

r: 0.25

B.2 HEP style catchment descriptors (at downstream of each catchment)

Catchment	Area(km²)	URBEXT	SAAR (mm)	MSL (km)	S1085 (m/km)	DRAIND (km/km²)	FARL	BFISoil	ARTDRAIN2
Well Stream	1.05	0.02	1162	1.91	23.23	1.31	1.00	0.33	0.00
Victoria Stream	5.67	0.04	1161	1.98	10.91	0.68	1.00	0.33	0.00
Atlantic Stream	5.45	0.06	1152	2.59	4.94	0.72	1.00	0.33	0.00

B.3 Rational Method Tc, slope and length parameters

Area(KM2)	C	PIPE LENGTH (km)	Slope of Pipe (Assuming slope of ground) (km/km)	tcp (mins)	DISTANCE FROM CATCHMENT DIVIDE (km)	Slope of Stream Flow path (m/km)	tc (mins) *5mins added if catchment urban
0.0249	0.325	N/A	N/A	N/A	0.225	7.128	6.619
0.0480	0.325	N/A	N/A	N/A	0.378	56.05	6.686
0.9753	0.16	N/A	N/A	N/A	1.77	24.11	6.915
0.7931	0.16	N/A	N/A	N/A	1.079	16.01	4.670
0.3137	0.16	N/A	N/A	N/A	0.798	12.45	3.985
0.3688	0.16	N/A	N/A	N/A	1.034	47.79	3.883
0.5354	0.16	N/A	N/A	N/A	0.978	46.96	3.550
0.0143	0.16	N/A	N/A	N/A	0.138	13.47	0.924
1.5161	0.16	N/A	N/A	N/A	1.581	26.58	5.795
0.1735	0.325	0.547	0.027	547	0.707	16.76	8.530
0.1183	0.8	0.206	0.008	206	0.489	21.16	7.421
0.1873	0.325	0.44	0.014	440	0.815	21.06	8.858
0.2361	0.16	N/A	N/A	N/A	0.485	8.742	2.675
0.3635	0.16	N/A	N/A	N/A	0.937	13.99	4.505

Area(KM2)	C	PIPE LENGTH (km)	Slope of Pipe (Assuming slope of ground) (km/km)	tcp (mins)	DISTANCE FROM CATCHEMENT DIVIDE (km)	Slope of Stream Flow path (m/km)	tc (mins) *5mins added if catchment urban
0.8676	0.16	N/A	N/A	N/A	1.485	26.54	5.778
0.5156	0.16	N/A	N/A	N/A	1.0039	16.77	4.597
0.8154	0.16	N/A	N/A	N/A	1.11	4.513	6.172
0.1103	0.16	N/A	N/A	N/A	0.214	7.103	1.327
0.4483	0.8	0.334	0.0026	334	0.988	6.853	10.365
0.1642	0.16	N/A	N/A	N/A	0.773	10.713	4.244
1.6096	0.16	N/A	N/A	N/A	2.809	9.1812	12.661
0.0591	0.16	N/A	N/A	N/A	0.338	2.3964	2.773
0.5665	0.16	N/A	N/A	N/A	1.238	25.444	5.052
0.0283	0.325	0.081	0.0166	81	0.198	16.919	6.183
0.2631	0.8	0.209	0.0291	209	0.747	48.420	7.894

C Flow Estimation

C.1 FSSR 16 Rainfall Runoff Peak Flows

Catchment	50% AEP (m³/s)	20% AEP (m³/s)	10% AEP (m³/s)	5% AEP (m³/s)	2%AEP (m³/s)	1% AEP (m³/s)	0.5% AEP (m³/s)	0.1% AEP (m³/s)
27_1009_1	0.027	0.038	0.047	0.055	0.065	0.073	0.082	0.110
27_1009_2	0.045	0.066	0.078	0.091	0.108	0.122	0.137	0.184
27_1009_3	0.780	1.153	1.356	1.582	1.887	2.115	2.382	3.198
27_346_1	0.856	0.932	1.097	1.279	1.516	1.711	1.926	2.587
27_346_2	0.284	0.383	0.451	0.526	0.627	0.703	0.792	1.063
27_346_3	0.320	0.473	0.557	0.651	0.777	0.872	0.982	1.321
27_346_4	0.442	0.654	0.770	0.899	1.073	1.204	1.356	1.823
27_346_5	0.033	0.049	0.058	0.068	0.081	0.090	0.102	0.137
27_298_1a	1.228	1.882	2.212	2.579	3.073	3.444	3.875	5.196
27_232_2	0.184	0.273	0.321	0.374	0.445	0.499	0.561	0.750
27_232_1a	0.100	0.140	0.165	0.192	0.229	0.257	0.290	0.389
27_232_1	0.174	0.258	0.303	0.353	0.420	0.471	0.529	0.709
27_298_2	0.177	0.261	0.307	0.358	0.427	0.479	0.539	0.724
27_298_1	0.285	0.421	0.495	0.578	0.689	0.773	0.870	1.169
27_1006_1	0.848	1.255	1.477	1.723	2.054	2.302	2.591	3.476
27_1006_2	0.433	0.640	0.753	0.878	1.046	1.173	1.320	1.770
27_1006_3	0.540	0.797	0.936	1.091	1.299	1.454	1.636	2.192
27_1006_2a	0.089	0.133	0.156	0.182	0.217	0.243	0.274	0.367
27_1008_3a	0.392	0.579	0.681	0.794	0.945	1.059	1.191	1.596
27_1008_2a	0.152	0.226	0.260	0.309	0.369	0.413	0.465	0.622
27_1008_2	1.122	1.655	1.944	2.264	2.696	3.020	3.397	4.551
27_1008_3	0.050	0.055	0.064	0.075	0.086	0.100	0.113	0.151
27_966_2	0.417	0.617	0.725	0.846	1.008	1.130	1.272	1.707
27_966_2a	0.060	0.064	0.075	0.088	0.104	0.117	0.132	0.176
27_966_3	0.210	0.311	0.366	0.426	0.508	0.569	0.640	0.857

C.2 FSSR 16 Rainfall Runoff Storm Durations

Catchment	Storm Duration (hrs)
27_1009_1	7.762
27_1009_2	3.198
27_1009_3	6.028
27_346_1	6.230
27_346_2	5.447
27_346_3	4.023
27_346_4	4.537
27_346_5	3.661
27_298_1a	6.403
27_232_2	1.922
27_232_1a	6.100
27_232_1	3.645
27_298_2	6.897
27_298_1	6.491
27_1006_1	4.310
27_1006_2	6.441
27_1006_3	10.054
27_1006_2a	6.745
27_1008_3a	4.584
27_1008_2a	4.643
27_1008_2	9.117
27_1008_3	9.963
27_966_2	7.081
27_966_2a	2.170
27_966_3	6.094

C.3 FSU Method

Catchment	QMEDrural (m^3/s)	UAF	QMEDurban (m^3/s)	QMED (small catchments) (m^3/s)
27_1009_1	0.008	2.061	0.016	0.025
27_1009_2	0.039	1.209	0.047	0.012
27_1009_3	0.676	1.056	0.714	0.198
27_346_1	0.465	1.000	0.465	0.177
27_346_2	0.228	1.023	0.233	0.075
27_346_3	0.302	1.176	0.355	0.078
27_346_4	0.368	1.213	0.446	0.128
27_346_5	0.012	1.310	0.015	0.005
27_298_1a	0.794	1.000	0.794	0.311
27_232_2	0.146	1.974	0.287	0.034
27_232_2a	0.070	2.031	0.143	0.041
27_232_1	0.110	1.666	0.183	0.060
27_298_2	0.118	1.000	0.118	0.069
27_298_1	0.190	1.000	0.190	0.088
27_1006_1	0.358	1.000	0.358	0.199
27_1006_2	0.217	1.000	0.217	0.106
27_1006_3	0.371	1.000	0.371	0.252
27_1006_2a	0.061	1.000	0.061	0.038
27_1008_3a	0.181	1.559	0.283	0.148
27_1008_2a	0.085	1.222	0.104	0.046
27_1008_2	0.650	1.015	0.660	0.437
27_1008_3	0.023	1.014	0.023	0.028
27_966_2	0.218	1.097	0.240	0.192
27_966_2a	0.018	2.061	0.037	0.008
27_966_3	0.103	1.445	0.149	0.102

C.4 IH 124 Method Peak Flows

Catchment	50% AEP (m³/s)	20% AEP (m³/s)	10% AEP (m³/s)	5% AEP (m³/s)	2%AEP (m³/s)	1% AEP (m³/s)	0.5% AEP (m³/s)	0.1% AEP (m³/s)
27_1009_1	0.07	0.09	0.11	0.12	0.14	0.15	0.16	0.2
27_1009_2	0.06	0.08	0.09	0.1	0.12	0.13	0.14	0.17
27_1009_3	0.75	0.95	1.08	1.26	1.4	1.55	1.7	2.06
27_346_1	0.58	0.73	0.83	0.97	1.08	1.19	1.3	1.58
27_346_2	0.25	0.32	0.36	0.42	0.47	0.52	0.57	0.69
27_346_3	0.37	0.47	0.54	0.62	0.69	0.76	0.84	1.02
27_346_4	0.54	0.68	0.77	0.9	1	1.1	1.21	1.47
27_346_5	0.02	0.03	0.03	0.04	0.04	0.05	0.05	0.07
27_298_1a	1.02	1.29	1.47	1.72	1.91	2.1	2.3	2.8
27_232_2	0.39	0.49	0.56	0.63	0.72	0.8	0.87	1.06
27_232_1a	0.29	0.36	0.42	0.47	0.54	0.59	0.65	0.79
27_232_1	0.33	0.42	0.48	0.54	0.62	0.68	0.75	0.91
27_298_2	0.19	0.24	0.28	0.33	0.36	0.4	0.44	0.53
27_298_1	0.28	0.36	0.41	0.48	0.53	0.58	0.64	0.77
27_1006_1	0.61	0.77	0.88	1.02	1.13	1.25	1.37	1.66
27_1006_2	0.38	0.48	0.55	0.64	0.71	0.79	0.86	1.05
27_1006_3	0.57	0.72	0.83	0.97	1.07	1.18	1.3	1.58
27_1006_2a	0.1	0.12	0.14	0.17	0.18	0.2	0.22	0.27
27_1008_3a	0.65	0.82	0.93	1.05	1.21	1.33	1.46	1.77
27_1008_2a	0.95	1.2	1.37	1.6	1.77	1.96	0.43	0.52
27_1008_2	1.07	1.35	1.54	1.8	1.99	2.2	2.41	2.92
27_1008_3	0.06	0.07	0.08	0.09	0.1	0.11	0.13	0.15
27_966_2	0.48	0.6	0.69	0.81	0.9	0.99	1.08	1.31
27_966_2a	0.08	0.1	0.12	0.13	0.15	0.17	0.18	0.22
27_966_3	0.36	0.46	0.52	0.59	0.68	0.74	0.82	0.99

C.5 Rational Method Flows

Catchment	50% AEP (m^3/s)	20% AEP (m^3/s)	10% AEP (m^3/s)	5% AEP (m^3/s)	2%AEP (m^3/s)	1% AEP (m^3/s)	0.5% AEP (m^3/s)
27_1009_1	0.42	0.49	0.53	0.58	0.66	0.71	0.78
27_346_5	0.09	0.1	0.11	0.12	0.14	0.15	0.16
27_232_2	0.03	0.03	0.03	0.04	0.04	0.04	0.05
27_232_1a	0.18	0.21	0.22	0.24	0.28	0.34	0.38
27_232_1	0.04	0.05	0.06	0.06	0.07	0.08	0.08
27_1008_3a	0.39	0.46	0.56	0.54	0.61	0.70	0.70
27_966_2a	0.01	0.02	0.02	0.02	0.02	0.02	0.03
27_966_3	0.37	0.44	0.46	0.51	0.59	0.64	0.70

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