Shannon Catchment-based Flood Risk Assessment and Management (CFRAM) Study

Inception Report – Unit of Management 23

Final Report

Appendix B: Preliminary Hydrological Assessment and Method Statement

25 July 2012

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Glossary

AEP	Annual Exceedance Probability (expressed as a percentage)
APMR	Areas of Potential Moderate Risk
APSR	Areas of Potential Significant Risk
CFRAM	Catchment Flood Risk Assessment and Management
DAD	Defence Asset Database
DAS	Defence Asset Survey
DoEHLG	Department of Environment, Heritage and Local Government
DEM	Digital Elevation Model (Includes surfaces of structures, vegetation, etc.)
DTM	Digital Terrain Model (often referred to as 'Bare Earth Model')
EPA	Environmental Protection Agency
FRMP	Flood Risk Management Plan
HEFS	High-End Future Scenario
HPW	High Priority Watercourses
IRR	Individual Risk Receptors
MPW	Medium Priority Watercourses
MRFS	Mid-Range Future Scenario
NTCG	National Technical Coordination Group
PFRA	Preliminary Flood Risk Assessment
RBD	River Basin District
UoM	Unit of Management
WFD	Water Framework Directive

1 Background

1.1 Background

The Shannon Catchment-based Flood Risk Assessment and Management (CFRAM) Study forms part of the National Flood Risk Assessment and Management Programme.

As part of the Shannon CFRAM Study, there is the requirement to complete a series of Inception Reports, one covering each unit of management within the Shannon River Basin District (RBD).

A major requirement of the Inception Report is to report on the hydrological aspects of the study. The work undertaken for the hydrological analysis to date will form the basis of a significant part of the Hydrological Report, scheduled for delivery in 2012. The hydrological aspects of the Inception Report are reported in this **Preliminary Hydrological Assessment and Method Statement.**

1.2 Preliminary Hydrological Assessment and Method Statement

This report fulfils the requirements of the preliminary hydrological assessment and method statement within the Inception Report, as set out under Section 2.4.2, Item (4) in the Stage I Project Brief:

a) A preliminary hydrological assessment, including a review of historical floods, catchment boundaries and hydrometric and meteorological data as defined in Sections 6.2, 6.3 and 6.4 (but not including Section 6.4.3).

b) Discussion of historical flood events, including the dates they occurred, their duration, mechanisms, depths, impacts (e.g., number of properties flooded, infrastructure affected, etc.), severity (e.g., flows, levels, estimated annual exceedance probability), etc.

c) A preliminary assessment of past floods and flooding mechanisms.

d) A detailed method statement, setting out the datasets to be used and the approaches to be followed for the hydrometric review as defined in Section 6.4.3, and statistical analysis of data for the estimation of design flows (Section 6.5) for all hydrometric stations (Final reporting of all aspects of the hydrological analysis shall be reported upon in the Hydrology and Hydraulics Report).

The requirements set out in sections 6.2, 6.3 and 6.4 (excluding 6.4.3) as referred to in a) above, are outlined below:

6.2. REVIEW AND ANALYSIS OF HISTORIC FLOODS
The Consultant shall analyse all available previous studies and reports and the historic flood data collected (see Sections 3 and 4) in terms of peak levels, flood extents, damage caused, flows, etc. Such data shall be utilised in the analysis described below. The Consultant shall also rank the historic flood events in the APSRs and, for fluvial flood events, within each catchment within the Study Area, in terms of magnitude, including those for which only outline information is available, and estimate annual exceedance probabilities for all such events using

appropriate statistical methodologies. The Consultant shall use the peak levels and flood extents, including anecdotal information from informed individuals, recorded or observed during historical flood events, as references for comparison with design flood levels (developed as per Section 6.5, 7.2 and 7.2) and flood extents (developed as per Section 7.5) to ensure consistency between observed events and design events, particularly with reference to the estimated annual exceedance probabilities of those events.

6.3. CATCHMENT BOUNDARIES

The Consultant shall, following necessary hydrological analysis, establish the catchment boundaries and sub-catchment boundaries for each of the Hydrological Estimation Points (see Section 6.5.3), and provide details of same to the OPW in compliance with GIS and hard copy format requirements for this project. The catchment boundaries defined for the purposes of the implementation of the Water Framework Directive will be provided to the Consultant to facilitate, and form the basis of this process, but the Consultant shall review and confirm these boundaries and, with the assistance of the OPW and, where relevant, through cooperation with consultants undertaking other CFRAM Studies, resolve any discrepancies arising.

6.4. ANALYSIS OF HYDROMETRIC AND METEOROLOGICAL DATA

6.4.1. Rainfall Data

The Consultant shall, promptly upon receipt, analyse historic and recorded rainfall data throughout the catchment in terms of severe rainfall event depths, intensities, durations, etc., and shall estimate probabilities for significant and / or recent events, with reference and comparison made to the Flood Studies Update data and other relevant research.

The OPW shall provide the Consultant upon appointment with the rainfall depth-duration frequency data as generated by Met. Éireann for the Flood Studies Update. This data, available in GIS format, provide national coverage of depth-duration-frequency data for 2km grid squares.

6.4.2. Hydrometric Data Review

The Consultant shall promptly upon receipt analyse the historic and recorded water levels, including tidal and surge levels and estimated flows (with due reference given to the rating reviews – Section 6.4.3), in terms of peak flood levels and flows, hydrograph shape, flood volumes, etc. and shall estimate probabilities for major or recent events, with reference and comparison made to the Flood Studies Report and / or other relevant research.

The hydrological work for the Inception report has focused on the Communities at Risk (CARs) and Individual Risk Receptors (IRRs) identified in Technical Note 007 (17^{th} March). The CARs and IRRs form the basic Areas of Potential Significant Risk (APSR) to which will be added the additional areas identified in the Flood Risk Review to form the final list of APSRs. The Flood Risk Review has been undertaken in parallel with this hydrological work.

2 Study Area

2.1 Introduction

The boundary of the Shannon CFRAM study area is delineated by the Shannon River Basin District (RBD) as defined for the Water Framework Directive. The Shannon RBD is designated an international RBD as a consequence of a small portion of the Shannon headwaters lying within County Fermanagh, Northern Ireland. This study will focus on the Shannon RBD within the Republic of Ireland.

2.2 Shannon River Basin District

The Shannon River Basin District is the largest River Basin District (RBD) in Ireland, covering approximately 17,800 km^2 and more then 20% of the island of Ireland. The Shannon RBD is an International RBD. The RBD includes the entire catchment of the River Shannon and its estuary as well as some catchments in North Kerry and West Clare that discharge to the Atlantic (ref. Figure 1).

The Shannon River rises in the Cuilcagh Mountains, at a location known as the Shannon Pot in the counties of Cavan and Fermanagh (in Northern Ireland). The river flows in a southerly direction before turning west and discharging through the Shannon Estuary to the Atlantic Ocean between counties Clare and Limerick. While the River Shannon is 260km long from its source to the Shannon Estuary in Limerick City, over its course the river falls less then 200m. Significant tributaries of the Shannon include the Inny, Suck and Brosna. There are several lakes in the RBD, including Lough Ree, Lough Derg and Lough Allen. Several of these lakes are on the River Shannon.

The RBD includes parts of 17 counties: Limerick, Clare, Tipperary, Offaly, Westmeath, Longford, Roscommon, Kerry, Galway, Leitrim, Cavan, Sligo, Mayo, Cork, Laois, Meath and Fermanagh. The population of the RBD is approximately 670,000 (based on CSO census data 2006). While much of the settlement in the RBD is rural there are five significant urban centres within the RBD: Limerick City (90,800), Ennis (24,300), Tralee (22,700), Mullingar (18,400), Athlone (17,500) and Tullamore (12,900). Agriculture is the primary land use in the district, using 70% of the land, and this is reflected in the district's settlement patterns.

2.3 Units of Management

Units of management, as developed by the OPW, constitute major catchments / river basins (typically greater than 1000km^2) or conglomerations of smaller river basins and their associated coastal areas.

There are five units of management within the Shannon River Basin District (Figure 1):

- Unit of Management 23 Tralee Bay – Feale
- Unit of Management 24 Shannon Estuary South
- Unit of Management 25/26 Shannon Upper and Lower
- Unit of Management 27 Shannon Estuary North
- Unit of Management 28 Mal Bay

This report appraises the Tralee Bay – Feale Unit of Management only. Analysis and discussion for the remaining units of management will be presented in separate reports.

2.4 Tralee Bay - Feale (UoM 23)

The Tralee Bay - Feale Unit of Management (or UoM 23) is shown in its wider context within the Shannon RBD in Figure 1, and in more detail in Figure 2. It encompasses areas of three counties; Kerry, Limerick and Cork (Figure 1). It is bounded on the northwest by the mouth of the Shannon Estuary and on the east and southeast by the Mulllaghareirk Mountains, forming the catchment divide between UoM 23 and 24 (Figure 2). Along the southern boundary from east to west are the Glanaruddery Mountains and the Slieve Mish Mountains which extend into the Dingle Peninsula. The total area of UoM 23 is approximately 1800 km^2.

The unit of management is dominated by the Feale catchment in the central and eastern area. The River Feale drains into Cashen Bay in its lower reaches where it becomes tidally influenced. This catchment, with a total area to the mouth of the Cashen of 1155 km^2 makes up around 65% of the total area of UoM 23.

Major tributaries to the Feale catchment include the Shannow, Brick, Galey, Smearlagh, Allaghaun, and Oolagh rivers. These typically drain the upland areas to the east and south of the area, with the exception of the Brick which predominantly drains a lowland area towards the west.

The southern and southwestern area is dominated by mountainous and upland areas with many steep and flashy watercourses, notably around the Dingle Peninsula and Tralee. The Slieve Mish mountains are to the south and southwest of Tralee, with Stack's Mountains to the east and northeast of Tralee. The main rivers in this area are the River Lee and Big River, both flowing into Tralee.

The western area along the Atlantic coast (Ballyheige Bay) is a mainly low lying area with small catchments draining to the west coast. This area is protected by an extensive coastal dune system. There are important drainage schemes in this area behind the dune system, notably the Akeragh Drainage System which discharges to the Atlantic approximately 3km south of Ballyheige.

The northwest coast, with the exception of the Cashen which also discharges here, is characterised by small rivers and streams discharging to the Atlantic Ocean.

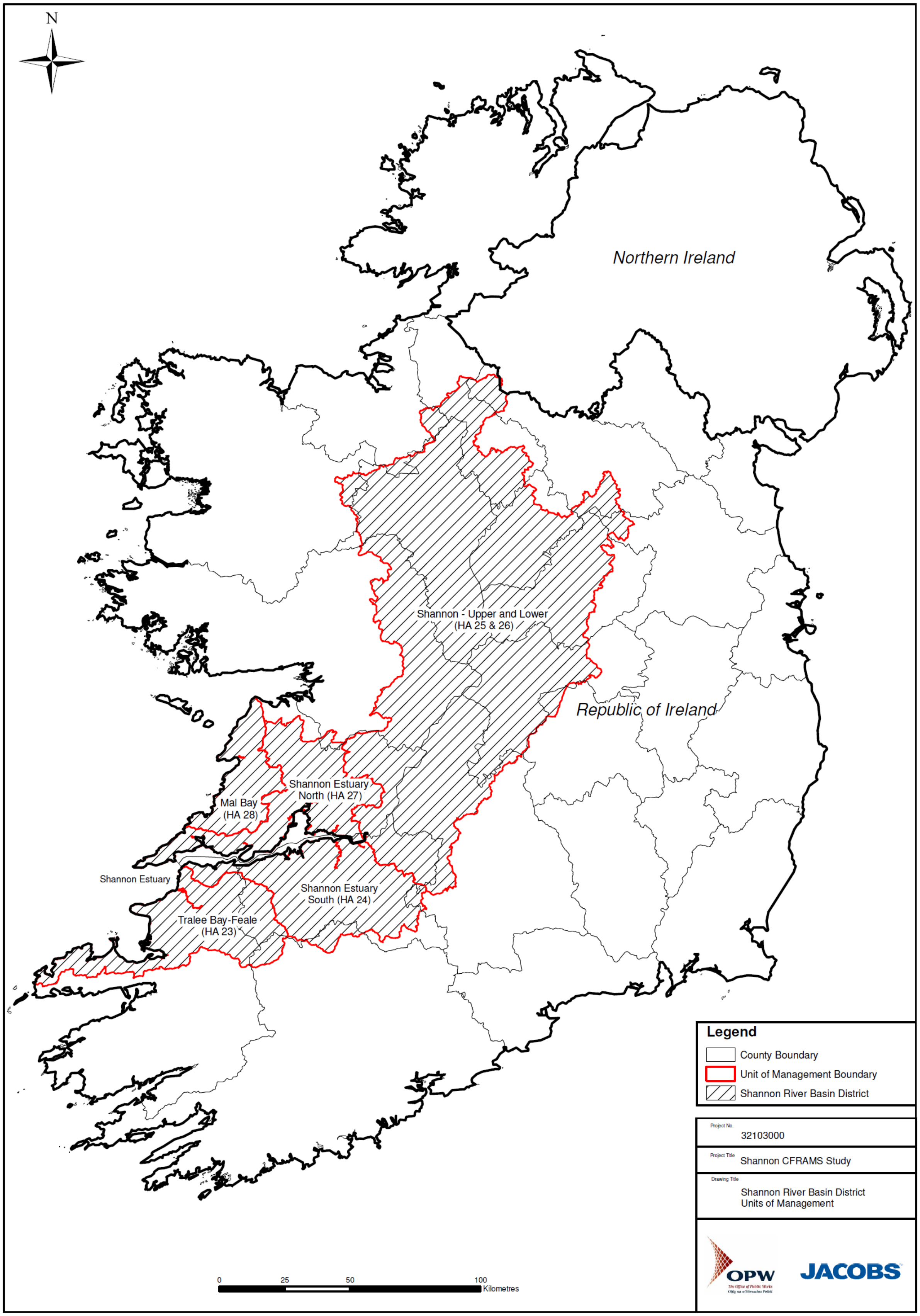

Figure 1 Shannon River Basin District and the five Units of Management

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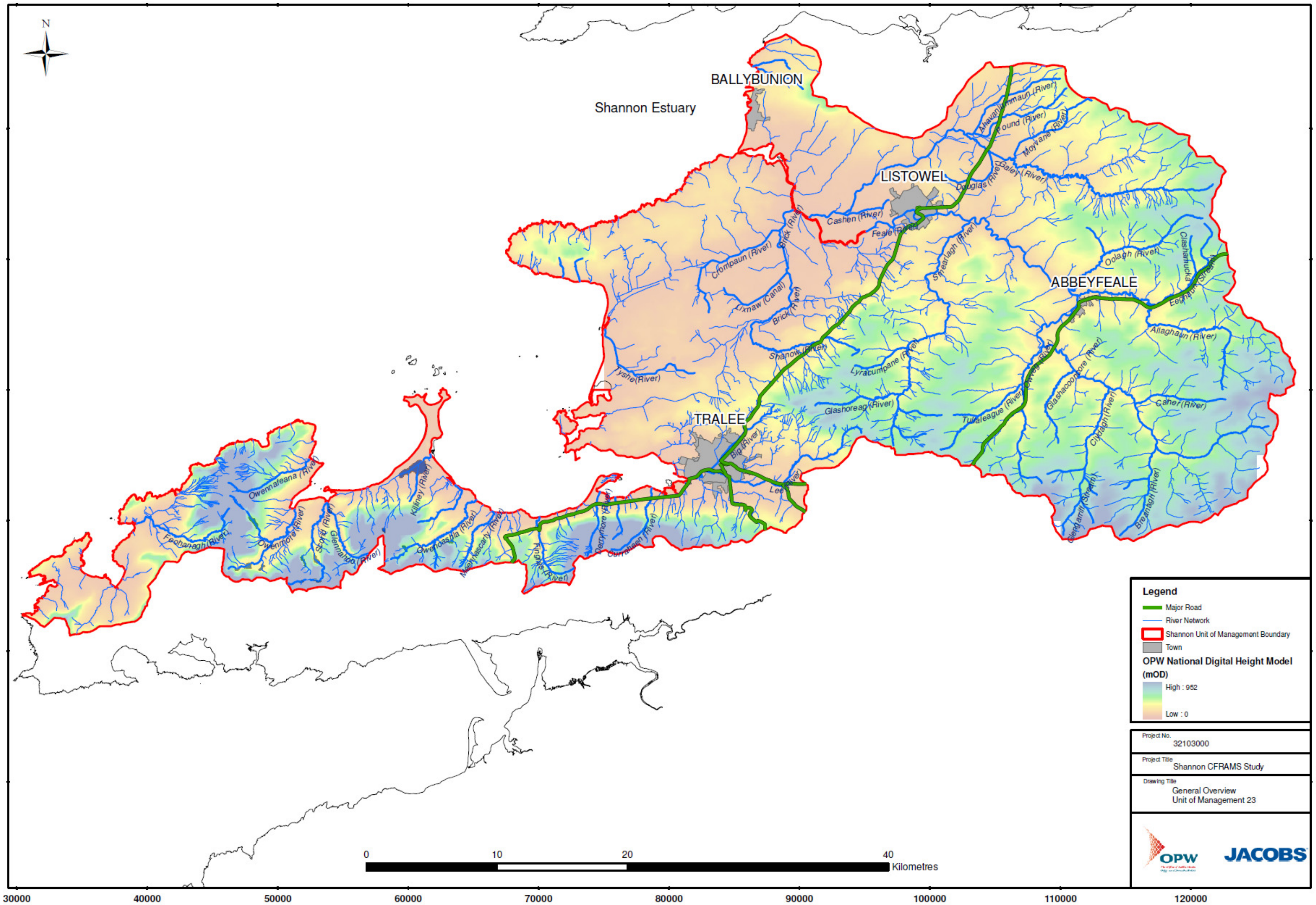


Figure 2 Tralee Bay – Feale Unit of Management

2.4.1 Communities at Risk

Communities within UoM 23 are at risk from tidal and/or fluvial flooding.
Table 2-A outlines the communities identified by OPW as at risk of fluvial or tidal flooding. The locations of the Communities at Risk (CARs) are shown in Figure 3.

No.	Location	Easting	Northing	At risk of fluvial flooding?	At risk of tidal flooding?
CAR 1	Abbeydorney	84750	123250	Yes	No
CAR 5	Athea	112412	134873	Yes	No
CAR 10	Banna	75750	123000	Yes	Yes
CAR 39	Listowel	98500	133000	Yes	No
CAR 56	Tralee	82750	114000	Yes	Yes

Table 2-A Communities at Risk in* Tralee Bay – Feale *(UoM 23)

2.4.2 Individual Risk Receptors

A number of assets within the Shannon RBD have been identified as Individual Risk Receptors (IRRs). These assets located outside of an Area of Potential Significant Risk and if flooded, would give rise to significant detrimental impact or damage.

There are no individual risk receptors located in UoM 23.

3 Hydro-Meteorological Data and Availability

3.1 Introduction

Within the Shannon River Basin District the hydro-meteorological network is owned and operated by various government and private organisations. These include:

- the Office of Public Works (OPW);
- Environmental Protection Agency (EPA);
- Waterways Ireland;
- Electricity Supply Board (ESB);
- Met Éireann;
- Local Councils;
- Bord Na Mona;

Hydro-meteorological data is collated, quality assured and distributed primarily by the following organisations:

- flow and lake levels and flows by the OPW, the EPA (on behalf of Local Councils), Waterways Ireland and ESB;
- rainfall data by Met Éireann;
- tidal data by the OPW.

Historically, organisations have collected data in accordance with their own requirements. This historical requirement is important to bear in mind when considering the appropriateness of flow data, for example if low flows were the target of monitoring, the location may be inappropriate for high flow assessment.

Since the introduction of the Arterial Drainage Act 1945, the OPW has collected flow and level data, with an emphasis on high flows, to monitor the impact of drainage schemes.

A national programme of hydrological data collection is coordinated by the EPA in accordance with the Environmental Protection Act 1992. However, there is not currently any single organisation responsible for collecting flow or level data, although in a recent strategic review the recommendation was made that this responsibility should be given to the OPW (JBA, 2008). The following organisations each have a role with regards to collection of flow or level data:

- Office of Public Works
- Environmental Protection Agency
- Waterways Ireland
- Electricity Supply Board

Organisations listed above were all approached for data during the data collection phase of the Shannon CFRAM study.

3.2 Data Requirements

The following hydro-meteorological data sets were identified as essential for the Shannon CFRAM hydrological assessment:

- Instantaneous (15 minute or digitised chart logger) river and lake level, flow and tidal data;
- Daily mean river and lake level, flow and tidal data;
- Rating equations and reviews for hydrometric sites;
- Spot flow gaugings;
- Annual Maximum (AMAX) flow and level series;
- Daily and sub-daily rainfall;
- Soil Moisture Deficit;
- All Flood Studies Update (FSU) reports and worksheets.

The EPA hydrometric register (dated January 2011) lists 44 river and lake level, flow and tidal level gauging stations within UoM 23 (Appendix A), of which only 16 locations are currently active.

Within this preliminary data collection phase, all efforts were made to obtain a full record of all available hydrometric data within UoM 23. Various hydrometric data sets were provided by the OPW at the start of the Shannon CFRAM Study. When incomplete data sets were identified and it was not possible to obtain all records, 'key' hydrometric stations were identified to ensure that sufficient data was obtained to fulfil our requirements for the study. Key stations were identified based on the following criteria:

- Proximity to Communities at Risk or Individual Risk Receptors;
- Whether a rating review was required (ref. Table 3-G);
- Whether a hydrometric station improved the spatial distribution of data throughout the UoM and sub-catchments.

Where appropriate, short records, inactive stations, staff gauge or flow measurement only sites were included in the list on the basis that even minimal data may provide some information on peak flows or flow characteristics in the absence of any other information.

At this stage all gauges within the UoM have been considered, and the key stations of Table 3-A were selected on the basis that they are likely to be of greatest value based on the criteria listed above. However, it is conceivable that in subsequent stages of the study, data from other gauging stations may prove to be useful. Exclusion of a gauge at this stage does not imply that it would not be considered further.

Station No.	Station Name	Water course	Status	Station type	Proximity to CAR/IRR?	Rating Review required ?	Improve Spatial Coverage?
23001	Inch Br.	Galey	Active	Data Logger	Athea		
23002	Listowel	Feale	Active	Data Logger	Listowel		
23011	Ballycarty	Lee (Kerry)	Inactive	Autographic Recorder	Tralee		
23012	Ballymullen	Lee (Kerry)	Inactive	Autographic Recorder	Tralee	Yes	
23014	Athea	Galey	Active	Staff Gauge Only	Athea	Yes	
23021	Shannow Br	Shannow	Active	Staff Gauge Only	Abbeydorney	Yes	
23022	Tralee Clonalour	Big (Kerry)	Active	Data Logger	Tralee		
23030	Sleveen Main Channel	Brick	Active	Data Logger	Abbeydorney		

Table 3-A Key hydrometric stations identified for Tralee Bay - Feale (grey boxes indicate no data)

3.3 Hydrometric Network in Relation to CARs and IRRs

As fluvial flooding is the most common cause of flooding at APSRs, with the exception of those noted in Table 2-A (if any), it has been assumed that irrespective of the precise causes of historic flooding, observations from the nearest river gauge would be a useful indicator of flood risk (ref. Figure 3).

Of the five Communities at Risk (CAR), Listowel and Tralee both have hydrometric gauging stations located within the immediate locality which are recording instantaneous flows. On the Galey at Athea a staff gauge has been installed, providing occasional water level information. No gauge is located within the vicinity of Abbeydorney, however a recorder gauge is located further downstream on the River Brick and upstream on the River Shannow. No gauges are located within proximity of Banna. Consideration should be given to improving the gauging network in Abbeydorney and Banna for the benefit of future flood studies.

There are no IRRs in UoM 23.

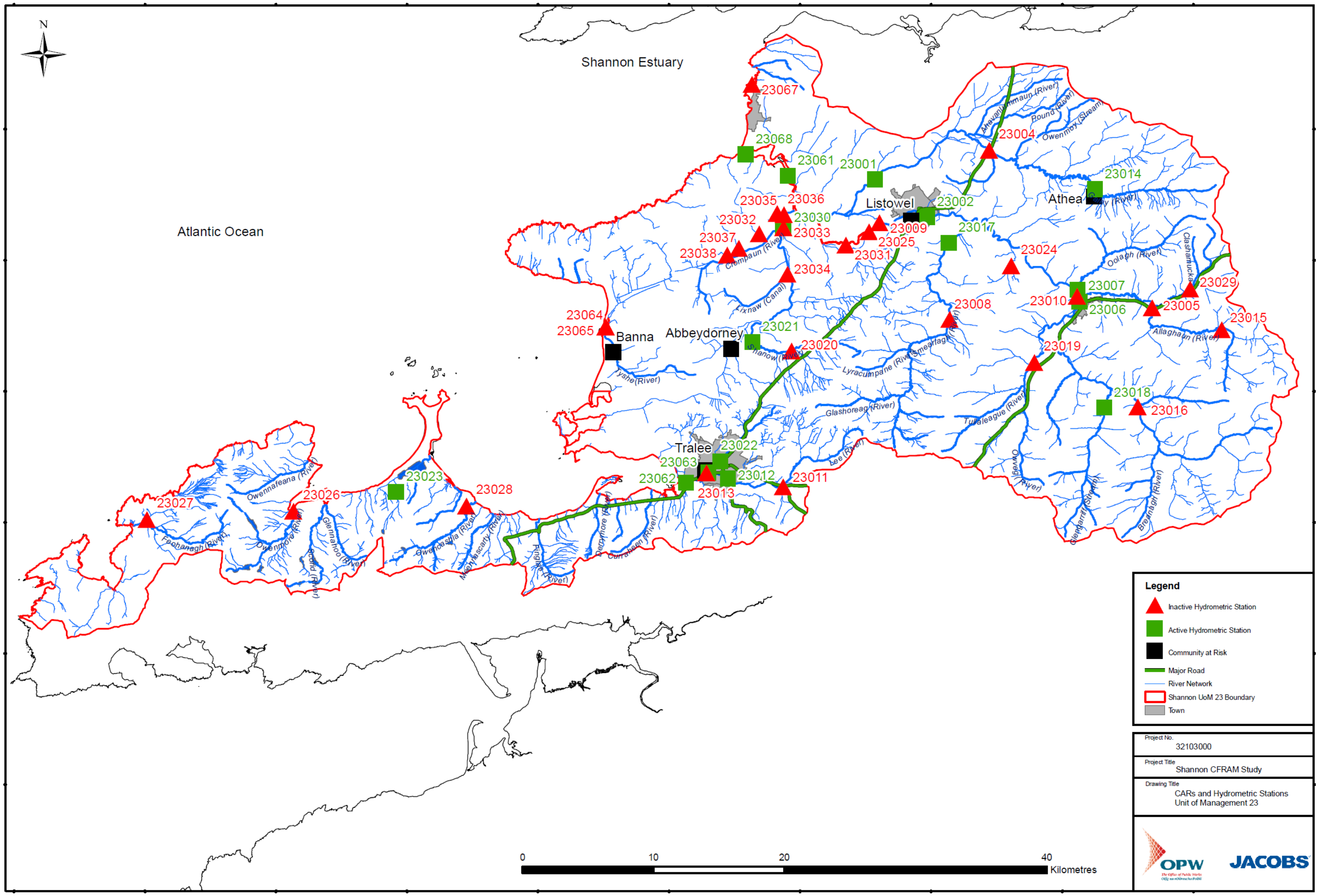


Figure 3 Location of hydrometric gauging stations in relation to Communities at Risk within Tralee Bay – Feale Unit of Management

3.4 Rainfall Data

3.4.1 Background

Rainfall measurement in Ireland is coordinated by Met Éireann with data collected from their own raingauges and those operated by individual volunteers and organisations. Rainfall data is collected hourly, daily or monthly.

The majority of the approximately 750 raingauges located throughout Ireland are daily read the remainder being monthly read gauges located in remote areas. Monthly readings are of little value to this study and will not be considered any further. Across Ireland, Met Éireann run 15 sub-daily gauges, where rainfall is measured on an hourly basis, these provide valuable information on rainfall intensity. No details on the Met Éireann quality assurance procedures applied to rainfall data were available.

Met Éireann also operate two radars for rainfall detection, one at Dublin Airport and the other at Shannon Airport. These provide almost complete coverage of Ireland. Data from the radars are processed to produce a number of different products including intensity and periodic totals. This data will be used as part of this study where appropriate, but is unlikely to be sufficiently accurate to be used in calibration of models. However, it may be feasible to use the data in some form if suitable ground truthing is possible near to the location of interest. The radar data can provide useful information on the extent of rainfall for particular events, when there are issues about how widespread the event may have been.

The National Roads Authority (NRA) may be another potential source of sub-daily rainfall information. The NRA has recently established a network of sensors along major roads to measure and record the type and intensity of precipitation at 10 minute intervals. This information is used to help warn the NRA of extreme weather and warn drivers of road conditions. One NRA rainfall sensor is located within the Tralee Bay - Feale Unit of Management, adjacent to the N21 at Abbeyfeale. Insufficient data was available at the time of writing of this report to determine the precision of the NRA rainfall sensors or to correlate the rainfall depths estimated from the sensors with Met Éireann daily rain gauges. The accuracy of the data compared to traditional measuring devices therefore remains untested. With such uncertainty it was not deemed appropriate for use in this study.

3.4.2 Daily Rainfall Data

Daily rainfall data is recorded at 15 locations within the Tralee Bay – Feale Unit of Management. Storage raingauges are used to collect rainfall and are read and emptied daily at 09:00 hours. This daily threshold can result in a storm event being recorded over two consecutive days, potentially leading to an underestimation of daily rainfall depth versus a 24 hour rainfall depth obtained over no fixed time period.

Table 3-B summarises the raingauges located within Tralee Bay – Feale Unit of Management and the availability of data. Figure 4 shows the distribution of the raingauge network.

Raingauge no.	Raingauge name	Data available?
509	Cloghane	Yes
1209	Tralee U.D.C	Yes
1509	Tralee (Lisaboula)	Yes
1510	Lyreacrumpane (Reenagown)	Yes
1610	Brosna (Mt. Eagle)	Yes
1809	Castlegregory Rough Point	Yes
1909	Dingle (Baile Na Ngall)	Yes
2009	Ardfert Ballymacquinn	Yes
2010	Listowel (Inch)	Yes
2310	Listowel (Grogeen)	Yes
2410	Rockchapel (Cappaphaudeen)	Yes
2610	Athea (Templeathea)	Yes
2710	Knocknagoshel (Meinleitrim)	Yes
2810	North Kerry Landfill	Yes
3010	Listowel (Gurtocloghane)	Yes

Table 3-B Daily rainfall data available within Tralee Bay – Feale

3.4.3 Sub-Daily Rainfall Data

Sub-daily or hourly rainfall is recorded at Airports and TUCSON (The Unified Climate and Synoptic Observations Network) stations. At these locations rainfall is automatically measured by tipping bucket raingauges with 0.1 or 0.2 mm buckets.

There are no Met Éireann hourly rainfall stations located within the Tralee Bay – Feale area.

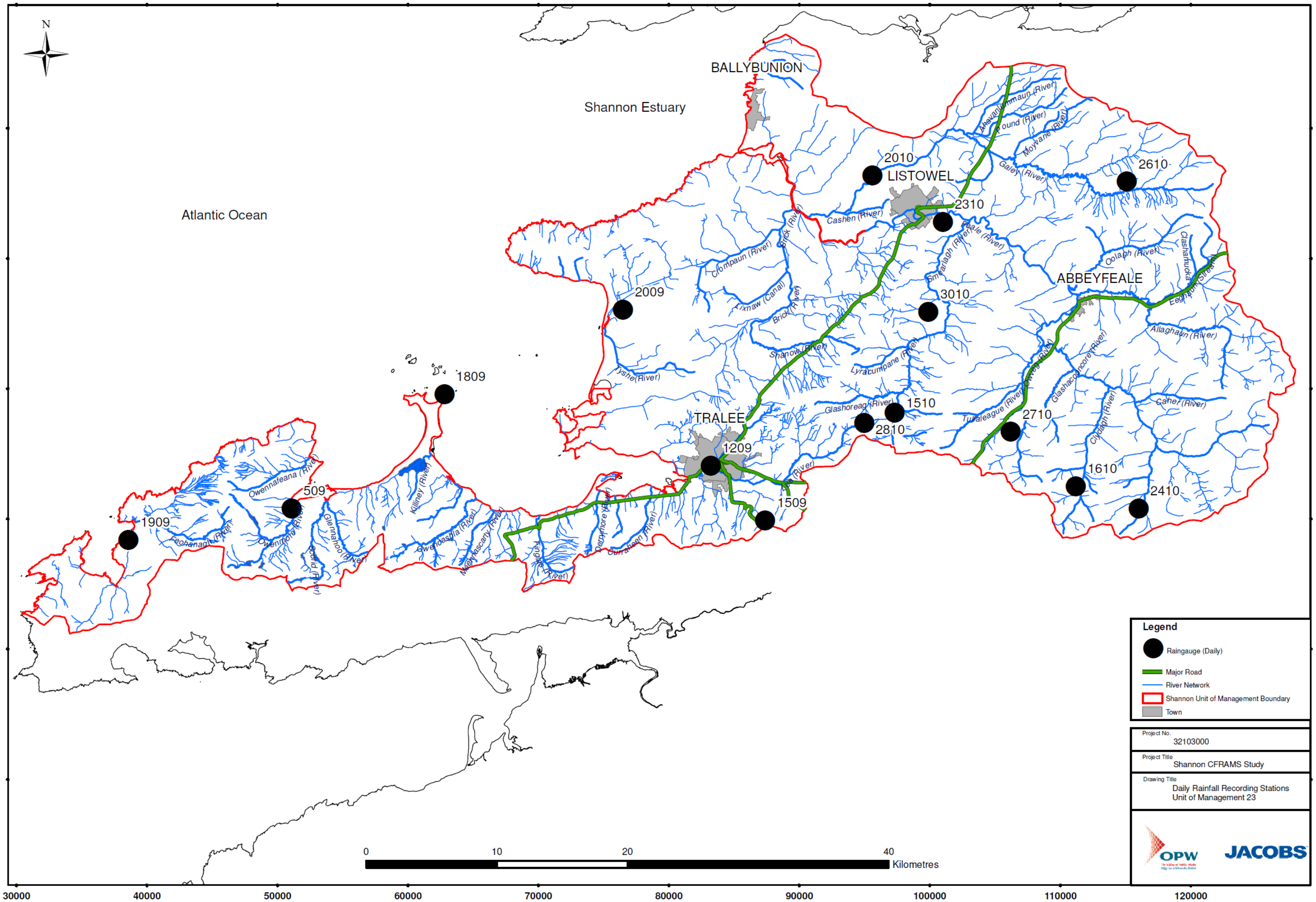


Figure 4 Location of daily raingauges within Tralee Bay – Feale Unit of Management

3.5 Hydrometric Data

3.5.1 Background

The location of hydrometric stations in the Tralee Bay – Feale Unit of Management is shown in Figure 3. The majority of active flow and level gauging stations within UoM 23 are located on the River Feale and River Brick and their tributaries. A small cluster of flow measurement sites are located on the River Galey and in the vicinity of Tralee on the River Lee and Big River. There are isolated gauges located on watercourses on the Dingle Peninsula, although the majority of these are now classified as inactive.

Gauging stations within the Shannon RBD are generally located within natural sections and therefore generally do not have any purpose-built control structures to ensure critical flow e.g. a flume or weir. However, the majority of gauging station sites are located downstream of man-made structures, such as bridges. These structures will provide some stability to the rated section but without critical flow there is unlikely to be a consistent relationship between flow and level. In addition, any geomorphological changes to the channel cross-section will result in further changes to the flow-level relationship.

Water levels are recorded at the majority of stations. However, ratings have only been developed at selected locations. Both flows and levels will be useful in this study.

Depending on the station configuration, flow and level measurements can either be discrete or continuous measurements in time. The EPA hydrometric register specifies three broad station types within the Shannon RBD, viz. staff gauge, flow measurement site and recorder:

Staff gauge – this is a fixed plate with levels marked on, which is used to read off the water level during visits. This will provide a record of discrete water levels with limited use for flood estimation purposes. However, where no other flow or level data is available, staff gauge readings may be used to obtain some indication as to the behaviour of water levels at a given location. Staff gauge stations for which check gaugings (spot flow gaugings) are available are also referred to as **flow measurement sites**. Flow measurement sites are also of limited use for flood risk purposes, except where check gaugings have been taken at high flows.

Recorder – Indicates a station fitted with a staff gauge and an automatic water level recorder. The automatic level recorder can either be an autographic recorder or a digital datalogger. An autographic recorder is a simple float-operated device that records the water level by activating a pen marking the water level on a chart. These charts are then digitised to convert the data to a digital format. A datalogger is a device that records water levels in digital format in 15-minute intervals. Both types of recorder can be considered instantaneous for fluvial and tidal flooding purposes.

Autographic recorders are gradually being replaced by digital data loggers within the Shannon RBD. This removes the requirement to digitise the records and also allows the transmission of the water level data via telemetry.

Check gaugings may also be available at recorder sites and are used to develop or confirm the rating relationship between the level and flow.

3.5.2 Instantaneous Flow and Level Data

Level data measured either via autographic recorder or at 15 minute intervals by a data logger will be collectively treated as instantaneous data. Water levels recorded by an autographic recorder are digitised at inflection (or change) points and should therefore reliably capture any significant changes to the water levels at a site.

Instantaneous data for varying periods of record is available at 19 stations within UoM 23 (Table 3-C). These stations are located on Figure 5 along with their current status (active or inactive). Jacobs have been advised that not all data from autographic recorders has been digitised and uploaded onto the archives and will therefore not be readily available for this study. However, for specific events, such data may be of benefit (which will require digitising by OPW) and will be requested as the need for such data arises. Data listed in Table 3-C outlines all the digital data available and provided to Jacobs.

Instantaneous flow and level data are useful for event analysis as it provides a greater temporal resolution than the daily mean flow and level series. This is especially important for analysing events in fast-responding flashy catchments.

3.5.3 Daily Mean Flow or Level Data

Daily mean flow and level data is derived from a 15 minute flow or level series. Daily mean flow data is useful when seeking a long-term view of the flow or level record to help identify any trends or sudden shifts in the dataset and to obtain an understanding of the behaviour of flows at a given location.

Initially, all daily mean flow and level data was obtained via the OPW hydro-data website (http://www.opw.ie/hydro/). The OPW later provided daily mean flows for some OPW stations listed as requiring a rating review (ref. Table 3-D). In some instances the two data series for a given station were not consistent; where this was the case the data provided directly by the OPW was used. Daily mean flows have been provided for three stations within the Tralee Bay-Feale Unit of Management.

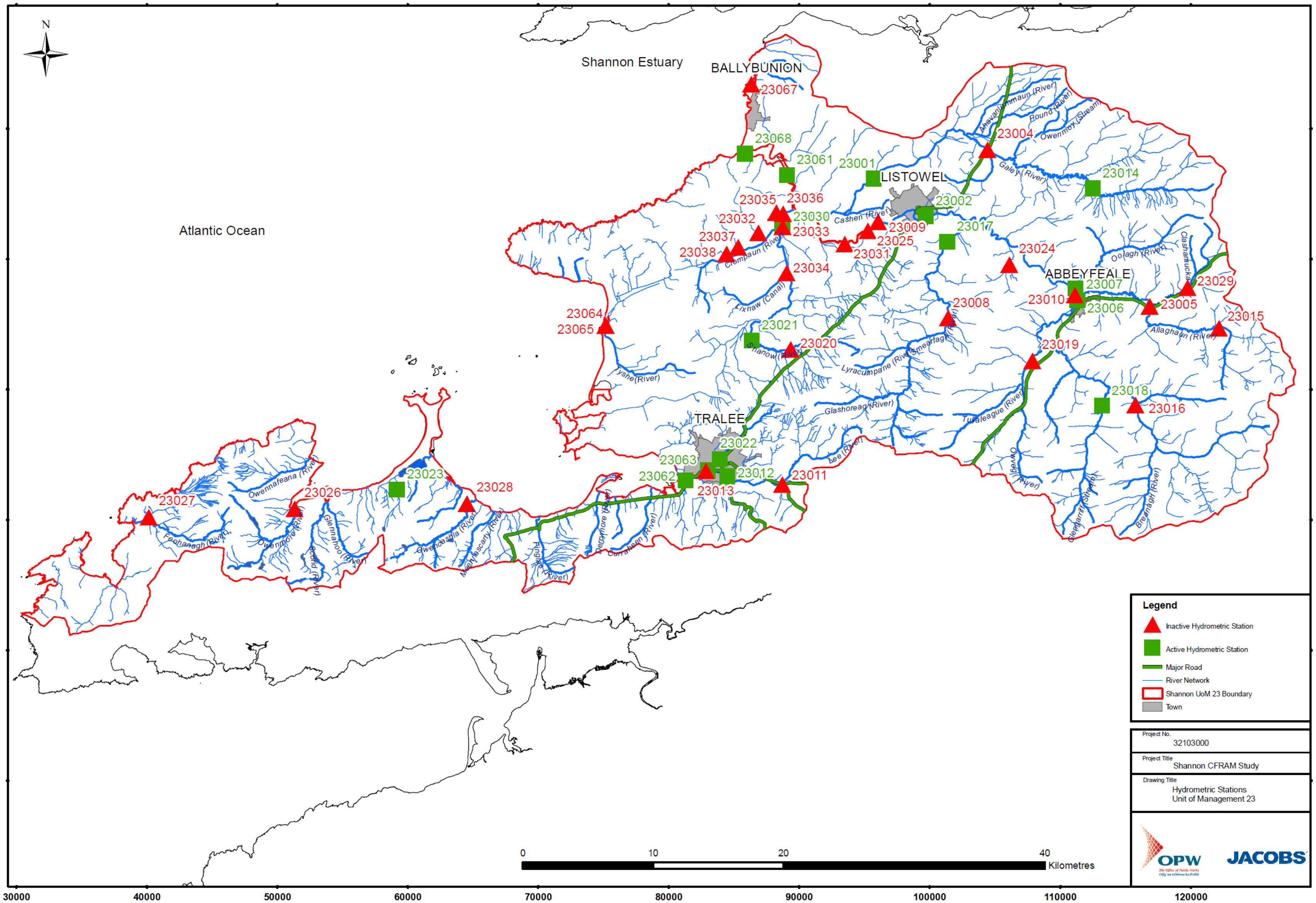


Figure 5 Location of hydrometric gauging stations within the Tralee Bay – Feale Unit of Management

Station number	Station name	Watercourse	UoM 23 sub-catchment	Station status	15 min flow start	15 min flow end	15 min level start	15 min level end
23001	Inch Br.	Galey	Feale	Active	01/01/1960	10/09/2010	01/01/1960	10/09/2010
23002	Listowel	Feale	Feale	Active	18/10/1946	10/09/2010	18/10/1946	10/09/2010
23005*	Goulburn	Allaghaun	Feale	Inactive			08/03/1976	10/08/2006
23006*	Neodata	Feale	Feale	Active			23/03/1976	04/01/2011
23007	Oolagh Rly. Br.	Oolagh	Feale	Active			26/02/1976	14/08/2000
23008	Knockaunbrack	Smearlagh	Feale	Inactive			12/07/1977	17/07/2008
23011	Ballycarty	Lee (Kerry)	Lee (Kerry)	Inactive			01/01/1972	01/01/1983
23012	Ballymullen	Lee (Kerry)	Lee (Kerry)	Active	04/04/1974	15/12/1994	04/04/1974	15/12/1994
23017	Trienearagh	Smearlagh	Feale	Active	10/06/1981	21/05/2011		
23022*	Tralee Clonalour	Big (Kerry)	Big (Kerry)	Active	15/11/1985	22/03/2011	15/11/1985	23/03/2011
23030	Sleveen Main Channel	Brick	Feale	Active			01/01/2000	10/09/2010
23031	Poulnahaha	Feale	Feale	Inactive			01/01/2000	31/08/2009
23032	Lisnagoneeny	Stream	Feale	Inactive			01/01/2000	07/03/2005
23033	Sleveen Back Channel	Brick	Feale	Inactive			01/01/2000	07/03/2005
23034	Lixnaw	Brick	Feale	Inactive			01/01/2000	07/03/2005
23035	Ratoo Road	Stream	Feale	Inactive			04/09/2002	08/03/2005
23036	Ratoobank	Stream	Feale	Inactive			19/09/2002	08/03/2005
23037	Drumroe	Stream	Feale	Inactive			01/01/2000	11/07/2002
23038	Cloneen	Stream	Feale	Inactive			01/01/2000	11/07/2002

** Instantaneous data from the EPA is a combination of regular 15 minute data (from data loggers) and irregular data based on digitised chart data (from autographic recorders).*

Table 3-C Instantaneous flow and level data available within UoM 23 and their period of record (Grey boxes indicate no data available)

Station no.	Station name	River	UoM 23 sub-catchment	Daily mean flow data		Daily mean level data	
				Record start	Record end	Record start	Record end
23001	Inch Br.	Galey	Feale	01/01/1960	18/12/2005	01/01/1960	18/12/2005
23002	Listowel	Feale	Feale	18/10/1946	10/09/2010	01/11/1946	02/07/2008
23012	Ballymullen	Lee (Kerry)	Lee (Kerry)			08/07/2004	10/09/2010

Table 3-D Daily mean flow and level data available within UoM 23 and their period of record (Grey boxes indicate no data available)

3.5.4 OPW Quality Codes

To assist users of daily mean and instantaneous flow and level data, the OPW have assigned quality codes to each flow or level value. The quality codes indicate whether the data has been checked and if so, what confidence the OPW have in the data. Quality codes assigned by the OPW have been grouped into broader classifications for this study as outlined in Table 3-E. Where quality codes did not match an OPW code, they were classed as ‘unknown’. These quality codes will be referred to as necessary when considering how the data is to be used.

OPW Code	OPW Description	Jacobs classification
WATER LEVEL DATA		
1	Unchecked digitised water level data – Data is provisional only and must be used with caution	Unchecked
31	Inspected water level data – Data may contain some error, but has been approved for general use	Good
32	As per Code 31, but where the digitised water level data has been corrected	Good
99	Unchecked imported water level data – Data is provisional only and must be used with caution	Unchecked
145	Data is below prescribed data range and must only be used with caution	Beyond Limits
146	Data is above prescribed data range and must only be used with caution	Beyond Limits
150	Partial statistic – Data has been derived from records that are incomplete and do not necessarily represent the true value	Caution
101	Unreliable water level data – Data is suspected of being erroneous or is artificially affected (e.g., during drainage works) and must only be used with caution	Caution
>150	Data is not available as it is missing, erroneous or of unacceptable quality	Missing
ESTIMATED FLOW DATA		
31	Flow data estimated using a rating curve that it is considered to be of **good** quality and inspected water level data – Data may contain some error, but is considered to be of acceptable quality for general use	Good
32	As per Code 31, but using water level data of Code 32	Good
36	Flow data estimated using a rating curve that it is considered to be of **fair** quality and inspected or corrected water level data – Data may contain a fair degree of error and should therefore be treated with some caution	Fair
46	Flow data estimated using a rating curve that it is considered to be of **poor** quality and inspected or corrected water level data – Data may contain a significant degree of error and should therefore be used for indicative purposes only	Poor
56	Flow data estimated using an extrapolated rating curve (see Section 3.2) and inspected or corrected water level data – Reliability of data is unknown and it should therefore be treated with caution	Caution
99	Flow data that has been estimated using unchecked water level data – Data is provisional only and must be used with caution	Caution
101	Flow data that has been estimated using unreliable water level data – Data is suspected of being erroneous and must only be used with caution	Caution
145	Data is below prescribed data range and must only be used with caution	Beyond Limits

OPW Code	OPW Description	Jacobs classification
146	Data is above prescribed data range and must only be used with caution	Beyond Limits
150	Partial statistic – Data has been derived from records that are incomplete and do not necessarily represent the true value	Caution
>150	Data is not available as it is missing, erroneous or of unacceptable quality	Missing

Table 3-E OPW quality codes and corresponding Jacobs classification

3.5.5 Annual Maximum Flow and Level Data

The annual maximum flow or level is usually derived from the highest recorded value in a continuously measured data series for the hydrometric year (1 October to 30 September).

Annual maxima data was provided from two sources, the OPW and the FSU (via the OPW). Where both sets of data were available for a given location, the OPW advised that the former series be used in preference, due to the additional work undertaken to extract the peak flows. The FSU series was developed for the Flood Studies Update in 2005/6 and accordingly the series ends in 2004. AMAX data was available at eight hydrometric stations, including four tidal gauges located within UoM 23 (Table 3-F).

Station number	Station name	Waterbody	AMAX (Flows) (from OPW)	AMAX (Levels) (from OPW)
23001	Inch Bridge	Galey	1960 - 2009	1960 - 2009
23002	Listowel	Feale	1946 - 2009	1946 - 2009
23012	Ballymullen	Lee (Kerry)	1974 - 1991	1974 - 2009
23031	Poulnahaha	Feale		1999 - 2008
23061*	Ferry Br.	Feale Esty		1946 - 2009
23062*	Blennerville	Lee Esty		1979 - 2009
23063*	Ballyard	Lee Esty		1974 - 2009
23068*	Moneycashen	Feale Esty		1980 - 2009

** Tidal stations*

Table 3-F Annual maximum flow and level data for hydrometric gauges located within UoM 23

3.5.6 Hydrometric Station Rating Reviews

A rating curve defines the relationship between water levels and flows for a given location. The rating curve is usually established as the line of 'best fit' to check gaugings measured at the gauged location throughout a range of flows and levels.The rating is often described using one or more rating equations, so that flows can be estimated for any water level (within the range). Abrupt changes in the cross section width (e.g. where the cross section changes from in-bank to out-of-bank) will result in transitions (in the form of 'kinks') in the rating curve. Multiple rating equations may be required to adequately describe the segments of the rating curve between these transition points. There may not be a consistent relationship between flows and levels. This can be a result of an unstable cross-section, where the rating changes over time, making the rating equations invalid until new equations are established. Actual flows may vary for a given water level hysteresis, blockage, instability of the cross-section or hydraulic backwater effects.

Table 3-G and Figure 6 illustrate the gauging stations for which rating reviews are required. Table 3-G also outlines which equations and check gaugings have been provided. No rating equations have been provided for stations managed by the EPA, stations 23014 and 23021.

Station number	Station name	River	Rating review required by the OPW?	Rating equations received?	Check gaugings received?
23001	Inch Bridge	Galey	No	**Yes**	**Yes**
23002	Listowel	Feale	No	**Yes**	**Yes**
23011	Ballycarty	Lee (Kerry)	No	**Yes**	**Yes**
23012	Ballymullen	Lee (Kerry)	**Yes**	**Yes**	**Yes**
23014	Athea	Galey	**Yes**	No	No
23021	Shannow Br	Shannow	**Yes**	No	No

Table 3-G Summary of gauging station rating reviews required and rating equations and check gaugings provided for UoM 23.

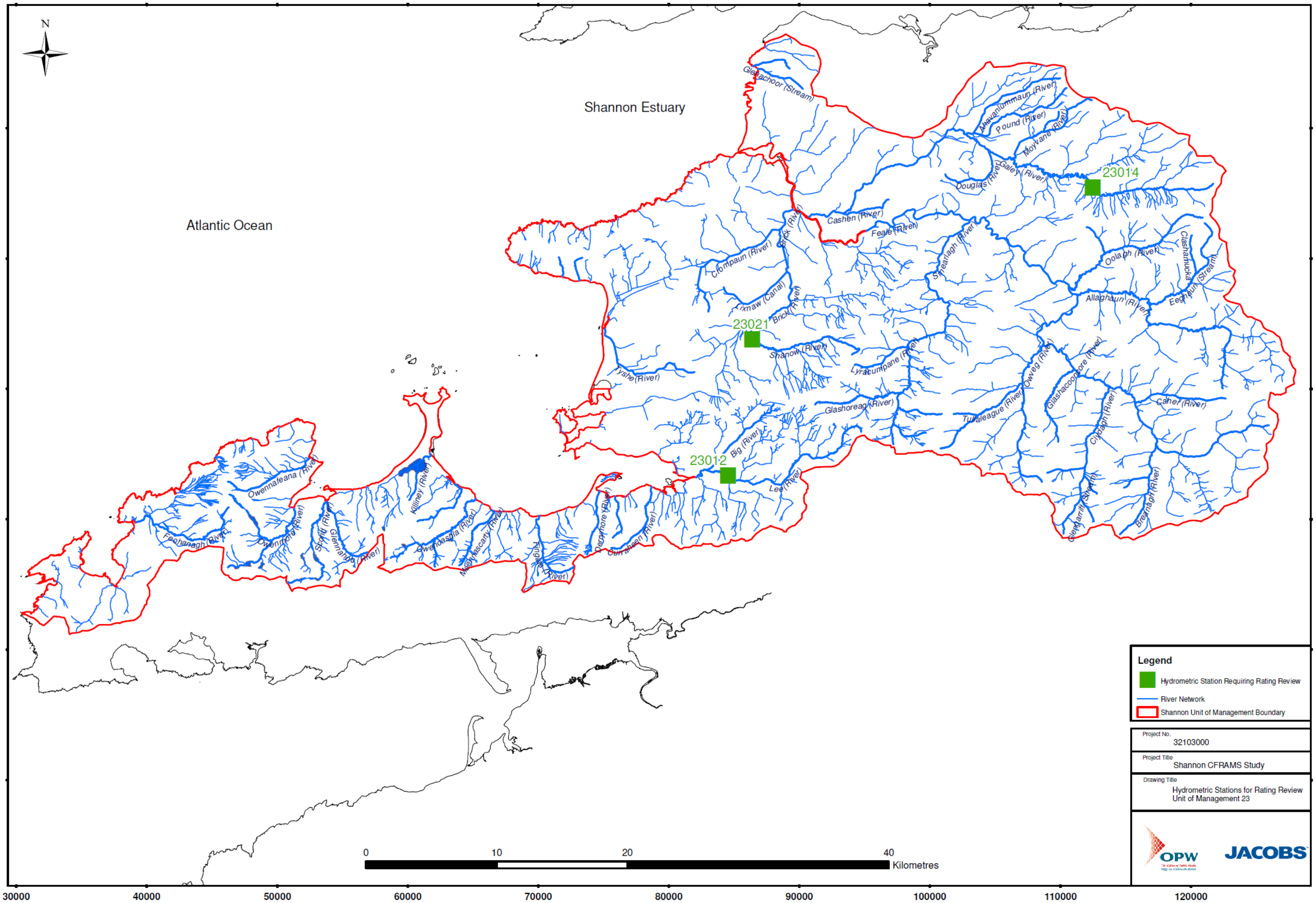


Figure 6 Hydrometric gauging stations within Tralee Bay – Feale requiring a rating review

3.5.7 Check Gaugings

Frequent check gaugings (spot flows) are required across a range of flows to establish and maintain a rating relationship. For this study, where flood flows are of particular significance, frequent check gaugings at high flows are essential to ensure confidence in flood flow estimates.

Check gaugings will be reviewed in association with the rating equations as part of the rating reviews and high flow suitability assessments to be undertaken later in the project.

A summary of stations for which check gaugings have been provided is given in Table 3-G.

3.5.8 Gauging Station Visits

Hydrometric gauging stations requiring a rating review as stated in the OPW brief (Table 3-G) were visited by Jacobs staff and observations recorded.

3.6 Coastal Data

OPW have provided the results from the Irish Coastal Protection Strategy Study (ICPSS). This gives extreme tidal peak levels for the following annual probabilities: 50%, 20%, 10%, 5%, 2%, 1%, 0.5%, 0.1% for the south western coast and the Shannon Estuary.

OPW has also provided results from the ICWWS (Irish Coastal Wave & Water Level Modelling Study) screening analysis which highlight coastal locations potentially vulnerable to wave overtopping for the south western coast and the Shannon estuary.

For these locations, detailed wave and still water level model outputs are available in the form of shoreline prediction points and their associated predicted water level and wave climate (wave height H_{mo}, period T_p and mean direction) combinations for a range of annual probabilities (50%, 20%,10%, 5%, 2%, 1%, 0.5% and 0.1%). These outputs include both the current condition and two future scenarios (Mid Range Future Scenario [MRFS] and High End Future Scenario [HEFS]).

3.7 Flood Studies Update

Following its publication in 1975 (NERC) the Flood Studies Report was adopted as the standard approach for flood estimation in Ireland. In 2004, the Flood Policy Review Group recognised that, with advances in flood estimation along with an additional 30 years of flow data, the development of new or recalibrated flood estimation methods could significantly improve flood estimation in Ireland. Since 2005, the OPW implemented the Flood Studies Update (FSU) programme. Revised methodologies arising from the study have not yet been publicly distributed, but the package of works is complete and will be tested within this study.

A summary of the main work packages relevant to this study is outlined below:

3.7.1 Work Package 1.2 – Estimation of Point Rainfall Frequencies

A rainfall depth duration frequency model was developed for Ireland that allows point rainfall estimates to be made for durations from 15 minutes to 25 days and for return periods up to 0.2% (1 in 500) Annual Exceedance Probability (AEP) (0.4% [1 in 250] AEP for durations less than 24 hours). The model uses median rainfall as the index rainfall and log-logistic growth curves to determine rainfall with other frequencies. The associated software will allow annual exceedance probability of rainfall to be mapped at a 2 km grid and rarity estimates to be made for point measurements (on a sliding scale). These estimates are used within this study to assess extreme rainfall events and to inform the assessment of flood events. At a sample of sites the Depth Duration Frequency (DDF) estimates have been compared to measured rainfall frequency (see Section 6.7).

3.7.2 Work Package 2.1 – Flood Flow Rating Review

Within this package of works, flow data from the OPW, EPA and ESB was collated and reviewed by Hydro-Logic between July 2005 and March 2006, with the aim of identifying sites which had a useable AMAX series and stage-discharge relationships from which accurate high and flood flows could be obtained. To assist with the review, a gauging station classification was developed, which grouped stations of interest as A1, A2, B or C (ref. Table 3-H).

<table>
<tr><th colspan="2">FSU Classification</th><th>Definition</th></tr>
<tr><td rowspan="3">A</td><td>Both</td><td>Suitable for flood frequency analysis. These were sites where the highest gauged flow (HGF) was significantly higher than the mean annual flood (Q_{med}) [HGF > 1.3 x Q_{med}] and it was felt by the OPW that the ratings provided a reasonable representation of extreme flood events</td></tr>
<tr><td>A1</td><td>Confirmed ratings for flood flows well above Q_{med} with the HGF > than 1.3 x Q_{med} and/or with a good confidence of extrapolation up to 2 x Q_{med}, bankfull or, using suitable survey data, including flows across the flood plain.</td></tr>
<tr><td>A2</td><td>Rating confirmed to measure Q_{med} and up to around 1.3 x Q_{med}. At least one gauging for confirmation and good confidence in the extrapolation.</td></tr>
<tr><td colspan="2">B</td><td>Flows can be estimated up to Q_{med} with confidence. Some high flow gaugings must be around the Q_{med} value.</td></tr>
<tr><td colspan="2">C</td><td>Sites within the classification have the potential to be upgraded to B sites but require more extensive gauging and/or survey information to make it possible to rate the flows to at least Q_{med}.</td></tr>
</table>

Table 3-H FSU gauging station classification (from Hydrologic, 2006)

No indication is given in the report as to the total number of gauging stations reviewed, only the number of sites selected as A1, A2 and B and therefore considered suitable for flood analysis, as summarised in Table 3-I. Please note some stations have their records split over different periods of time in which case each period is classified separately as a record.

FSU Classification	Total number of records	Number of records in Shannon RBD	Number of records in UoM 23
A1	75	18	2
A2	119	22	2
Total A records	*194*	*40*	*4*
B	103	11	0

Table 3-I Number of stations suitable for flood flow analysis classified A1, A2 or B

This FSU classification has been borne in mind when reviewing flood flows and will form the basis of high flow quality assessments undertaken later in the project. Table 3-J summaries the four FSU rating reviews and classifications for the separate periods of record within UoM 23.

Station Number	Station Name (period of record)	River Name	Final FSU Classification[1]	Rating Remarks (limit of reliable extrapolation, stability, concerns over particular gaugings, assumptions made etc)
23001	Inch Bridge (Post 05/06/72)	Galey	A2	Use HL rating from datum shift on 05/06/72 to date up to bankfull at 3.38m. Flow at bankfull allows site to be classed as A1 [1].
23002	Listowel (Post 01/01/74)	Feale	A1	'Use RC5 for the period from 01/01/74 to date. Site was moved upstream at this time. Extrapolate to bankfull to give flows of 870 cumecs making site an A1. This top end needs further high flow gaugings to confirm. Insufficient gauging data between 14/03/72 and 01/01/74 for use in the FSU.
23002	Listowel (Pre 14/03/72)	Feale	A1	Use RC3 for the period from SOR to 14/03/72. Extrapolation up to bankfull will give flows of 760 cumecs. Site to be classed as A1
23012	Ballymullen (01/12/1984 to 06/01/92)	Lee (Kerry)	A2	Use RC1 for the period from 01/12/84 to 01/12/92. Upper limit of extrapolation is to HGF as tidal influences are hard to predict, more high flow gaugings needed to assess whether extrapolation can be undertaken. No flows are calculated after 1992 as drainage work took place. Since 1996, when the recorder was reinstated, there has been insufficient gaugings to create a reliable flood flow rating.

Table 3-J Summary of FSU Rating Classification for hydrometric stations within UoM 23.

Note:
[1] The classifications in column 4 are the final FSU classifications and are the ones to be used. OPW has confirmed that the comment in column 5 regarding the quality class for station 23001 (Galey at Inch Bridge) should be ignored.

3.7.3 Work Package 2.2 Flood Frequency Analysis

Work Package 2.2 covers the development of techniques with which to estimate the design flood for a range of exceedance probabilities for rivers in Ireland. The recommended methods are broadly analogous to those specified in the UK Flood Estimation Handbook but with Ireland specific equations to reflect the differing hydrological conditions. These differences are expressed in the AMAX data having a lower variability and skewness than commonly found elsewhere.

The procedures are based on the AMAX series from approximately 200 gauging station records with lengths ranging from 10 to 55 years. A subset of these, made up of 85 sites with the best records, was used for the most detailed analyses.

Guidance is provided on the estimation of design flows at gauged and ungauged locations and on the estimation of uncertainty. It recommends the use of Qmed as the index flood. Gauged site data is preferred over any estimate from catchment descriptors. However synthetic estimated from catchment characteristics can be significantly improved by using pivotal sites (analogue or donor catchments with gauged data). The use of growth curves or factors are applied to the index flood derived from regional pooling groups. The report concludes that whilst no single statistical distribution can be considered to be 'best' at all locations both the Extreme Value Type 1 (Gumbel) and the lognormal distributions provide a reasonable model for the majority of stations.

3.7.4 Work Package 3.2 Hydrograph Width Analysis

Methods are developed to produce the design flood hydrograph of given return period at gauged and ungauged sites in Ireland. For each site, the peak flow of the hydrograph so produced matches the corresponding design flow provided by Work-Package WP2.2: Flood Frequency Analysis for the same return period.

In the case of a gauged site, a non-parametric approach is applied to a set of observed flood hydrographs to estimate the characteristic flood hydrograph for the station. An alternative parametric form of 'derived' hydrograph is also developed whereby the non-parametric form is fitted by a 3-parameter curve.

For an ungauged site, regression-based expressions are used to estimate the values of relevant hydrograph descriptors which are then applied, following a parametric approach, to produce its characteristic flood hydrograph.

Characteristic flood hydrographs are, by rescaling, developed into the required design flood hydrograph.

3.8 Historic Flood Events

The flood history of the Communities at Risk and Individual Risk Receptors has been examined primarily using the www.floodmaps.ie website. Further details are presented in Section 8.

3.9 Outstanding Data and Recommendations

Rating review histories and check gaugings are outstanding for two gauging stations, 23014 and 23021, which have been identified by the OPW as requiring a rating review. If this data is available it would be useful for the subsequent phase of work. Clarification of the FSU classification of station 23001 is also sought.

4 Hydrological Estimation Points

4.1 Introduction

Section 6.5.3 of the Generic CFRAM Study Brief 'Hydrological Estimation Points' states that:
"*The consultant shall derive best estimate design fluvial flood parameters based on the methods referred to above at Hydrological Estimation Points. The Hydrological Estimation Points shall include all of the following:*

- *points on the HPW that are central within each APSR, and immediately upstream and downstream of the APSR,*
- *all hydrometric gauging stations (as specified in the tender documentation of the Specific Tender Stage [Stage II]).*
- *points upstream and downstream of the confluences of all tributaries that potentially contribute more than 10% of flow of the main channel immediately upstream of the confluence for a flood event of a particular AEP,*
- *upstream boundaries of hydraulic models, and,*
- *other points at suitable locations as necessary to ensure that there is at least one Hydrological Estimation Point every 5kms along reaches of all modelled river (i.e. either HPW or MPW).*"

Following Jacobs' Technical Note TD010, which detailed the proposed methodology and timing of defining the Hydrological Estimation Points (HEPs), a trial was carried out to identify potential issues related to the proposed methodology.

4.2 Methodology

For the reasons outlined in Section 4.0 of Jacobs' Technical Note TD010, to avoid reworking of the data, the derivation of HEPs within the study area and corresponding catchments boundaries will be completed after the Inception Report Phase, but within 2 months of Jacobs receiving a final list of APSRs and resolution to any catchment area discrepancies.

To aid the identification of any problems with the proposed methodology, the HEP definition process was trialled for the whole of Unit of Management 24.

In this trial HEPs were determined applying the criteria set out in Section 6.5.3 of the Generic Brief, using the preliminary APSR boundaries. It should be noted that HEPs are only required along watercourses for which a hydraulic model is proposed (confirmed by OPW on 24th June 2011). For ease of application of the FSU design flood methods, HEP locations were chosen to be coincident with the nodes used in FSU to define catchment descriptors where this was reasonable. Where the catchment area to a HEP (upstream, centre and downstream of APSRs, upstream and downstream of confluences, gauging station locations, upstream boundaries of hydraulic models) differed from that to the nearest FSU node by more than 10% of the catchment area, the HEP location was moved to the precise critical location.

The HEPs for UoM 24 were defined in a point shapefile, and given an attribute field specifying the reference number of the FSU ungauged subcatchment that the HEP was coincident with. This will allow for a fast process of attributing FSU catchment descriptors to HEPs. HEPs that are not coincident with FSU nodes did not get a

reference in the attribute field; however, this constitutes only a small number of HEPs. Catchment descriptors for these HEPs will have to be attributed manually.

The trial HEPs have been provided to OPW using the Sharepoint.file sharing system.

4.3 Lessons Learned

The HEP definition trial resulted in the following lessons learned:

1. Generally the HEPs at the critical locations (i.e. hydrometric stations, confluences, etc.) were chosen coincident with the nearest FSU node available. An exception applies where moving the HEP to the nearest FSU node would result in a change in catchment area of 10% or more, in which case the HEP was placed at the critical location.
2. At confluences, it was generally found that three FSU nodes are coincident, representing the two contributing catchments and the combined catchment. It was decided that the HEPs would be positioned at the next FSU node upstream and downstream along the watercourse with the largest upstream catchment (where the difference in catchment area from the upstream node to the confluence was not more than 10%), and in the confluence itself for the watercourse with the smallest upstream catchment. If moving a HEP from the confluence to the nearest upstream or downstream FSU node would have resulted in a change in catchment area of 10% or more, then the HEP was placed in the confluence. To make it clear which HEP belongs to which subcatchment (watercourse), any HEP placed “in” a confluence was actually positioned approximately 10m upstream or downstream of the confluence dependent of whether it represents one of the tributary catchment or the combined catchment respectively.
3. At a confluence of watercourses which were both part of the proposed model extent, a HEP was defined for each tributary, even if one of the tributaries contributes less than 10% in catchment areas. If such a confluence occurred within an APSR then a HEP was defined for the midpoint within the APSR for each tributary, where applicable.
4. When the rules for HEP definition would result in the definition of two HEPs for one FSU node, then only one HEP was defined.

4.4 Conclusions

Based on the HEP definition trial, it was concluded that:

1. The trial allowed Jacobs staff to obtain experience in defining Hydrological Estimation Points (HEPs) along the proposed model extents.
2. Based on the experience obtained during the trial, the proposed methodology provided a good basis for the HEP definition work, noting the lessons learned described in Section 4.3 above.

4.5 Recommendations and Way Forward

Once the APSRs are agreed, and the HEP catchment boundaries have been confirmed following a review of FSU catchment boundaries by Jacobs (see Chapter 5 below), it is recommended that the HEPs are defined following the agreed methodology, noting the lesson learned as described in Section 4.3 above.

5 Catchment Boundaries

5.1 Introduction

Following Jacobs' Technical Note TD010, which detailed the methodology to compare different catchment boundary datasets, this chapter details the findings of the comparison of the different catchment boundaries for catchment UoM 24, which was carried out using the methodology as set out in the Technical Note.

5.2 Data

The datasets in Table 5-A were compared.

Title	Description	Comments
WFD Areas	Water Framework Directive River Basin District boundaries. Used to define Units of Management.	Identical to Units of Management Boundaries. Derived from 20m H-DTM (the hydrologically corrected DTM) with some manual correction.
Automatic Gauged Catchment Boundaries	Automatically generated outlines for the gauged areas.	Automatically derived from 20m H-DTM (the hydrologically corrected DTM).
Manually Adjusted Gauged Catchment Boundaries	Manually adjusted applied to catchments where area derived from the automatic gauged boundaries varied by more than 5% from the hard copy OPW catchment area maps.	Provided by OPW (from Oliver Nicholson via Rosemarie Lawlor). We understand that manual corrections have been applied to 36 of the 216 catchments used in the FSU.
Automatic Ungauged Catchment Boundaries	Automatically generated outlines for the ungauged areas at FSU nodes.	Automatically derived from 20m H-DTM (the hydrologically corrected DTM).
OPW National Digital Height Model (NDHM, Intermap 2009)	Digital Terrain Model provided by OPW, 5m grid, IFSAR data with a vertical RMSE of approximately 0.7m on slopes smaller than 20 degrees.	Detailed but large amount of data and hence cumbersome. Not hydrologically corrected.

Table 5-A Catchment boundary and topographical data available for Shannon CFRAM study

The OPW also provided a river network shapefile. This network was also used to assess the local credibility of catchment boundaries.

In an email to Jacobs from OPW on 19th May 2011 Rosemary Lawlor explained the FSU (adjusted) dataset as follows:

"*As part of the Flood Studies Update 216 gauges were identified as being suitable for use in the FSU analysis (FSU Stations). The areas of the catchments that were delineated by Compass Informatics were compared with the catchments areas that the OPW had on file for all of the 216 catchments. Where it was found (that) the areas differed by more than 5% it was decided that the OPW catchment boundaries would be used in preference to the Compass Informatics boundaries. This was the case for 36 FSU stations. The OPW boundaries were digitised from paper maps for these 36 stations and were used to replace the compass informatics boundaries for these stations. The FSU end product was effectively a combination of 180*

catchment boundaries (from compass informatics) merged with the 36 OPW catchment outlines. This makes up the final FSU catchment outlines"

5.3 Methodology

It is important that the catchment areas are checked and a definitive set of catchment boundaries agreed with the OPW to allow:

- Accurate definition of catchment areas and hence design flows at each HEP;
- Interfaces with adjacent CFRAM Study project areas to be consistent;
- Allow FSU automated procedures to be used to derive design floods as appropriate (and allow any adjustments necessary to be properly documented).

We have undertaken a review of the catchment areas to the gauged locations as detailed below:

1. A map for Unit of Management 23 was produced to allow comparison of the Water Framework Directive (WFD) and Flood Studies Update (FSU) boundaries to the hydrometric gauging stations and identify discrepancies.
2. The WFD boundary (equivalent to the Unit of Management 23 boundary) was compared with the automatic gauged catchment outlines, paying particular attention to the areas where manual correction has been applied (as denoted by the manually adjusted gauged catchment boundaries).
3. Detailed plans were produced for areas where significant discrepancies were found. These maps present the WFD boundary where available, the automatic and manually adjusted (FSU) boundaries, and contours based on the OPW National Digital Height Model (NDHM, Intermap 2009).
4. An additional random check was undertaken to satisfy ourselves that the automatic ungauged catchment boundaries are reasonable compared to the NDHM.

This review has been undertaken with the aim of identifying differences in catchment areas of 10% or more as there is no one definitive catchment outline and all the datasets have some uncertainty associated with them. At the time of writing this Inception Report the process of defining the Areas of Flood Risk Review (AFRRs) had not been completed. This analysis is therefore only based on discrepancies of 10% or more in catchment sizes to hydrometric stations, Communities at Risk (CARs) and Individual Risk Receptors (IRRs). There is a risk that other discrepancies come to light as a result of additional sites requiring to be studied following the AFRR definition process. It is therefore recommended that the catchment boundary comparison is revisited once the AFRRs are defined.

5.4 Results of Analysis

Figure 7 overleaf shows a comparison of the Water Framework Directive (WFD) boundary, the automatic boundaries and the manually adjusted (FSU) boundaries in area UoM 23.

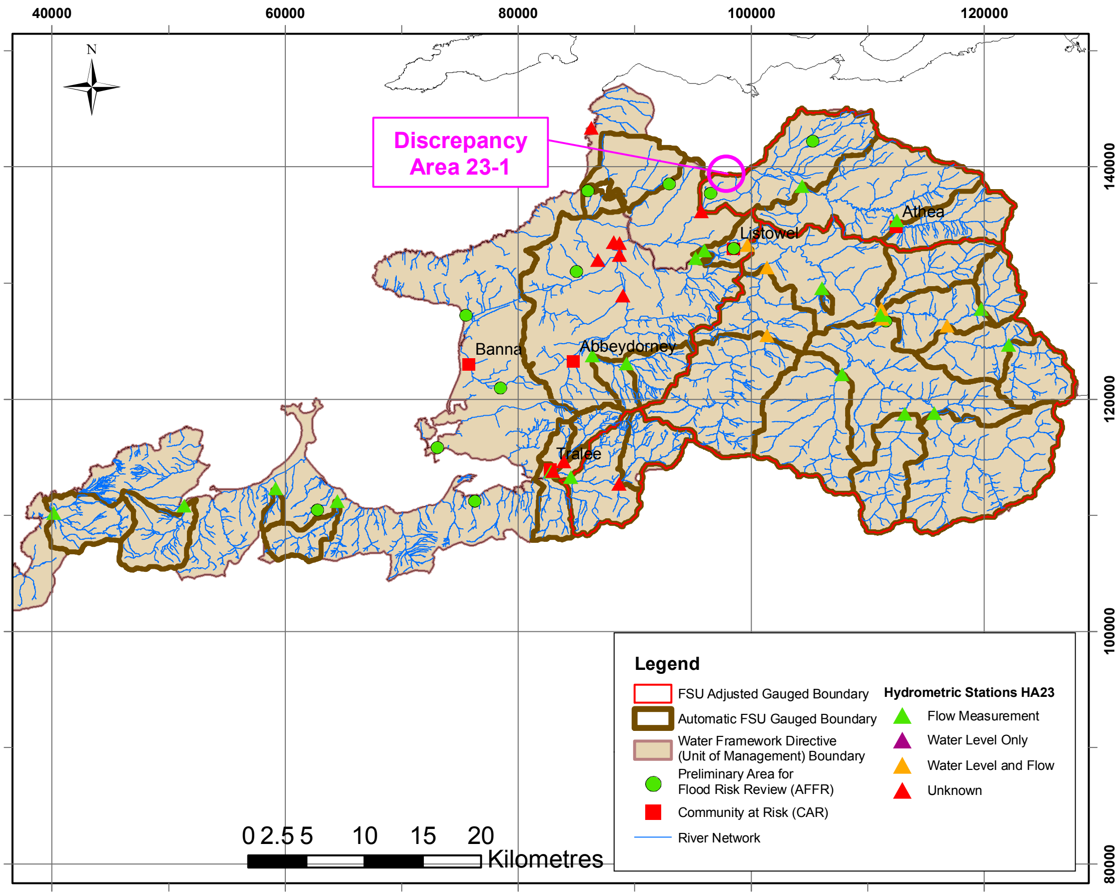
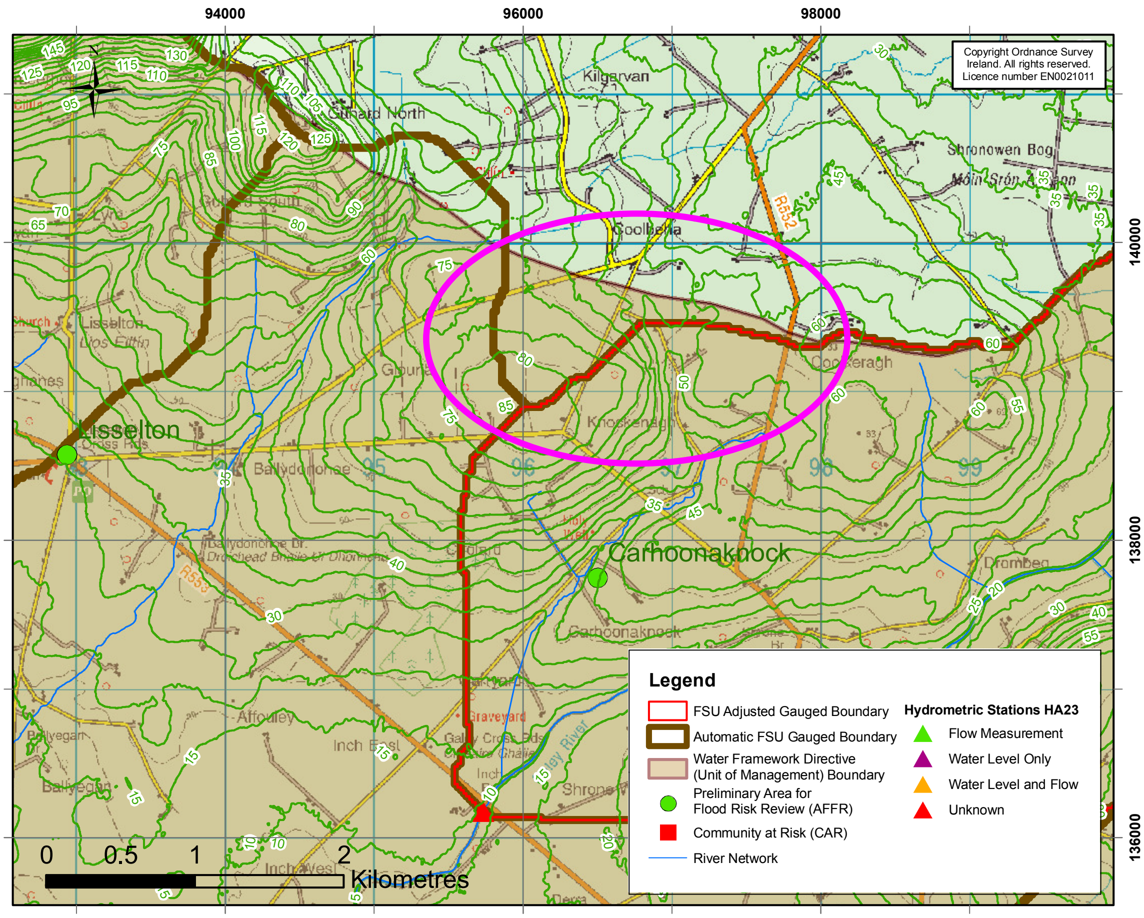


Figure 7 Unit of Management 23 – Comparison FSU and WFD Boundaries

There are no discrepancies which affect the area to gauging stations or CARs by 10% or more. However, there is one notable discrepancy which may have an effect on the flow estimation to the Area for Flood Risk Review of Carhoonaknock. This is shown in Figure 8 below. There are no Individual Risk Receptors in UoM 23.

This is a small discrepancy (0.6 km^2) where the automatic outline has not been adjusted (hence the automatic and adjusted (FSU) boundaries are identical). Figure 8 shows that the WFD boundary does not correspond with the two contour datasets shown (1:50,000 scale 10m-interval contours on the OSI mapping and NDHM 5m-interval contours). It is proposed that the automatic boundary is accepted.



The purple oval indicates the discrepancy

Figure 8 WFD Discrepancy Area

5.5 Conclusions

Based on an assessment of area UoM 23 alone, it can be concluded that:

1. No significant discrepancies were identified in the gauged catchment boundaries in Unit of Management UoM 23. The greatest discrepancy is that at Carhoonaknock, where the automatic FSU boundary appears to be more accurate than the WFD boundary when compared to NDHM contours;

2. Random checks were made to the ungauged boundaries, which did not reveal any significant discrepancies.

5.6 Way Forward

It is proposed that Jacobs and OPW have a discussion regarding the catchment boundary discrepancies after all Units of Management within the Shannon River Basin District have been analysed (UoM 23, 24, 25/26, 27, 28), so that the discrepancies can be addressed with a consistent approach for the whole River Basin District.

It is recommended that the discrepancy areas found in this analysis are investigated following the review of all discrepancies in the River Basin Districts. OPW is to

advise Jacobs of the catchment boundaries to be applied to identify the HEP catchments. If it is decided that adjustments have to be made to the automatic boundaries, then it is important that these adjustments are made consistently, i.e. that boundaries are correctly nested and that neighbouring catchments share one boundary. The manually adjusted (FSU) boundary dataset does not satisfy that requirement.

6 Review of Meteorological Data

6.1 Introduction

Rainfall analysis will focus on the daily rainfall data provided to Jacobs by Met Éireann, either through a direct data request or via the OPW (refer to Table 3-B).

6.2 Distribution of Raingauges within Tralee Bay - Feale

Daily read raingauges are fairly well evenly distributed across the Tralee Bay – Feale Unit of Management (ref. Figure 4). A cluster of gauges can be found in the centre of the unit of management between Tralee and Listowel; in the Brick, Feale and Lee catchments, and a further cluster in the upper reaches of the Feale catchment close to the southern boundary of the unit of management. There is a dearth of raingauges in the east of the catchment. Three raingauges are located along the Dingle Peninsula in the west and a single gauge in the lowlands close to Banna.

6.3 Data Review

To obtain some understanding of the completeness of the rainfall record and its long-term consistency, a brief review was undertaken on receipt of the data. Firstly, the number of missing days was counted. Subsequently, data for similar periods from adjacent stations were plotted against each other on double mass plots to highlight any obvious inconsistencies in the records.

A count of missing data reveals that gauges, 509 (Cloghane), 2010 (Listowel Inch), and 2610 (Athea Templeathea) have large portions of missing data, 33%, 26% and 33% respectively (Table 6-A). Stations 1509 (Tralee Lisaboula), 1809 (Castlegregory Rough Point), 2009 (Ardfert Ballymacquinn), 2310 (Listowel Grogeen), 2410 (Rockchapel), 2810 (North Kerry Landfill) and 3010 (Listowel Gurtocloghane) have either no or minimal missing data.

Raingauge no.	Name	Record start	Record end	Total number of days	Missing days	% of data missing
509	Cloghane	18/10/50	31/10/10	21928	7140	33
1209	Tralee U.D.C	01/05/75	31/08/10	12816	943	7
1509	Tralee (Lisaboula)	01/01/80	31/07/10	11139	348	3
1510	Lyreacrumpane (Reenagown)	10/11/47	31/08/10	22941	1289	6
1610	Brosna (Mt. Eagle)	11/11/47	31/03/04	20596	2398	12
1809	Castlegregory Rough Point	01/12/84	30/11/03	6939	147	2
1909	Dingle (Baile Na Ngall)	01/12/84	31/08/10	9405	1309	14
2009	Ardfert Ballymacquinn	01/05/85	31/08/10	9254	35	0.5
2010	Listowel (Inch)	01/08/82	31/08/10	20145	5273	26
2310	Listowel (Grogeen)	07/05/79	30/06/04	9187	1	0
2410	Rockchapel (Cappaphaudeen)	01/08/82	31/12/08	9650	94	0
2610	Athea (Templeathea)	01/07/85	31/08/10	9193	3048	33
2710	Knocknagoshel (Meinleitrim)	01/07/97	28/02/11	6538	289	4
2810	North Kerry Landfill	01/07/97	28/02/10	4991	72	1.5
3010	Listowel (Gurtocloghane)	01/02/01	28/02/11	3649	0	0

Table 6-A Summary of rainfall data, period of record and missing days

Double mass plots were created to ensure each raingauge was reviewed at least once (ref. Appendix B for plots). In general the plots confirmed that long term rainfall relationships between raingauges were fairly consistent across the catchment. However, it did serve to highlight the scale of missing data from records 509, 1209, 1610, 2010 and 2610. In many of the records the scale and frequency of missing data prevented the identification of any long-term trends. As a precaution those daily raingauges with significant missing data are assumed to be excluded further from this study, with the exception of raingauge 2010. For raingauge 2010, the majority of missing data is prior to 1998, therefore the record from 1998 will be used where necessary.

Cumulative totals for all raingauges between 1 February 2001 and 30 November 2003 (the only period for which data was available at all raingauges) were compared. This provided some indication of geographical variations in rainfall received throughout the unit of management. Medium-term rainfall totals are higher in the Dingle Peninsula and in the southeast of the area when compared to the northeast (Table 6-B), highlighting the influence of orographic rainfall on the region. The raingauge recording the highest total rainfall over the period was at Cloghane on the Dingle Peninsula (station 509) where a total of 5310.3 mm was recorded.

Station No.	Cumulative total rainfall (mm)
509	5310.3
1209	3172.9
1509	3773.8
1510	3888.2
1610	3444.1
1809	2716.0
1909	3290.1
2009	2595.5
2010	2481.4
2310	2876.3
2410	4501.9
2610	1934.5
2710	3583.1
2810	3934.4
3010	3223.0

Table 6-B Cumulative daily rainfall for stations in Tralee Bay – Feale between 1 February 2001 and 30 November 2003.

6.4 Raingauge Selection

Following the data review a selection of raingauges were chosen for further analysis, in which depth, duration and frequency estimates derived from local data were compared with the theoretical values derived for the FSU.

The following raingauges were selected based on location, completeness of data and quality of record:

- 1509 – Tralee (Lisaboula)
- 2009 – Ardfert Ballymacquinn
- 2010 – Listowel (Inch)
- 2310 – Listowel (Grogeen)

Despite the high proportion of missing data from the record before 1998, raingauge 2010 was included to supplement rainfall data post-June 2004, at which point the rainfall record at 2310 ends.

6.5 Rainfall Probability Plots

For the four raingauges selected in 6.4, 1 day total annual maxima and a 4 day total annual maxima series were created. To prevent bias of the annual maxima series with low rainfall depths, any years with greater than 30 days of missing data were excluded. This left station 1509, 2009, 2010 and 2310 with 24, 24, 10 and 24 years of data respectively. One exception to this rule was made for station 2009, where the annual maxima values for 1995, despite having 30 days missing data, were included in the AMAX series since the 4-day rainfall total was the maximum on record.

Each 1-day and 4-day annual maxima series were arranged in decreasing order of magnitude and ranked accordingly. The probability of exceedance was derived according to Gringorten, where *P(X)* is the probability of exceedance and is

calculated for each value of *X*, *r* is the rank and *N* is the total number of annual maxima values.

$$P(X) = \frac{r - 0.44}{N + 0.12} \tag{6.1}$$

The EV1 distribution was fitted to the observed annual maxima series of rainfall totals using the method of moments described in formulas 6.2 – 6.4 below, where F(X) is the probability of an annual maximum $Q \leq X$ and *a* and *b* are parameters with μ_Q being the mean and σ_Q the variance.

$$F(x) = \exp\left[-e^{-b(X-a)}\right] \tag{6.2}$$

$$a = \mu_Q - \frac{\gamma}{b} \tag{6.3}$$

$$b = \frac{\pi}{\sigma_Q \sqrt{6}} \tag{6.4}$$

The subsequent distribution fits (Appendix C) were used to derive estimates of annual exceedance probability for historic events to ensure a coherent relationship between estimates. However, note that the annual exceedance probabilities could have been estimated directly from the plotted local data. The actual fit with the chosen distribution has little relevance for this independent check of the FSU DDF method.

6.6 Events of Interest

Severe rainfall events were identified in conjunction with the annual maxima flow series. The four rainfall stations identified in Section 6.4 will be the focus for the analysis. For consistency the same events selected for fluvial analysis will be reviewed here also. Event selection is detailed in Section 7.6. The three events selected are:

- 6 August 1986;
- 28 October 1989;
- 19 November 2009

Due to missing data, the raingauges at 2310 and 2010 will be used conjunctively; 2310 will be used to analyse the 6 August 1986 and 28 October 1989 events and 2010 will be used to analyse 19 November 2009. These raingauges are located approximately 6.5 km apart and their cumulative totals between 1 February 2001 and 30 November 2003 only differed by 394.9 mm (ref. Table 6-B).

For each event the maximum depth of rainfall for a range of durations; 1 day, 2 days, 4 days and 10 days were obtained. Depths for each duration were produced by summing the daily rainfall total for the corresponding x number of preceding days. Maximum values were selected from within a 10 day period up to and including the date of the largest peak flow within the catchment. The results are presented below in Sections 6.6.1 to 6.6.3.

To put the rainfall depths into context annual exceedance probabilities were derived for the 1 day and 4 day rainfall totals based on the probability plots outlined in Section 6.5.

It is important to note that the availability of daily rainfall only is anticipated to significantly reduce the uncertainty with respects to the analysis of short duration rainfall events.

6.6.1 6 August 1986

Rainfall depths recorded between 28th July and 6th August 1986 present a consistent picture of rainfall intensity across the unit of management. A period of prolonged low intensity rainfall is followed by a period of high intensity short duration rainfall on the 5th August (Figure 9), the latter being consistent with a summer convective storm. Daily rainfall totals on the 5th August varied between 46.7 (2310) to 67.7 mm (1509). Flows gauged in the Feale, Galey and Lee catchments peaked early on the 6th August 1986 (equivalent to the rainfall day of the 5th August 1986). Gauging station 23022 on the Big at Tralee (ref. section 7.6.1), which is situated relatively close to raingauge 1509, has a gap in the recorded data during this event and can unfortunately not be used for analysis.

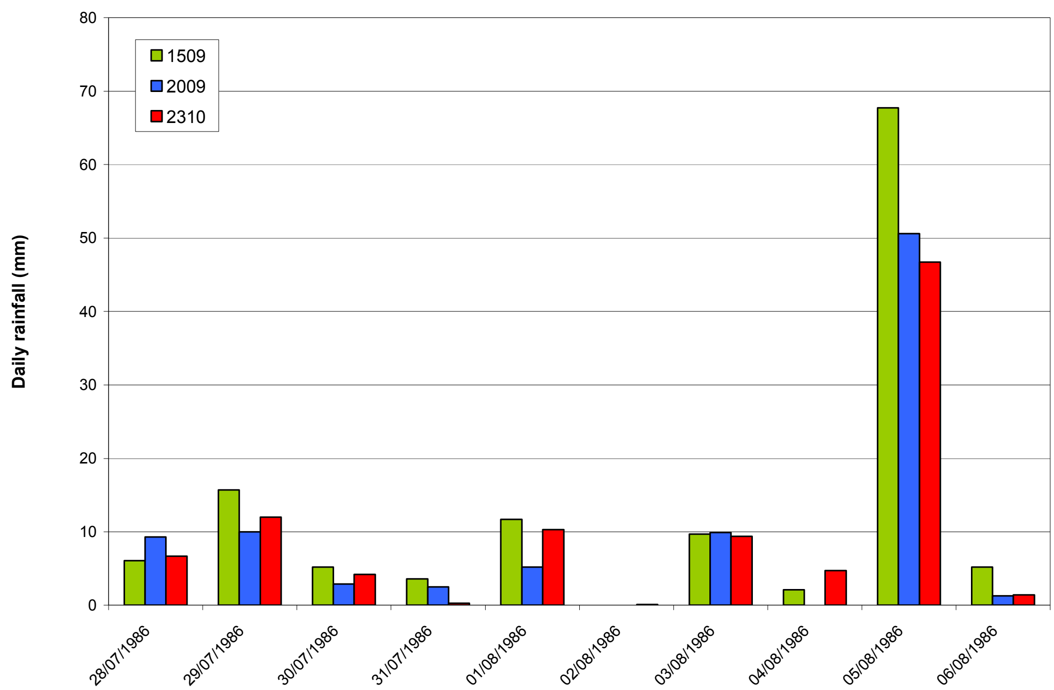


Figure 9 Daily rainfall – 28th July to 6th August 1986

Annual exceedance probabilities (AEPs) for the maximum rainfall depths over the event are presented in Table 6-C. AEPs estimated from the 1-day and 4-day rainfall probability plots indicate this was in general a rarer event for the 1 day duration when compared to the longer 4-day duration. Values derived for the 1 day duration at all three raingauges indicate that this event has an annual exceedance probability of around 4-6% making these rainfall depths over this duration a relatively rare occurrence.

Rainfall Duration	Aug-86 1509 Max. Rainfall depth (mm)	1509 AEP (%)	2009 Max. Rainfall depth (mm)	2009 AEP (%)	2310 Max. Rainfall depth (mm)	2310 AEP (%)
1 day	67.7	4	50.6	4	46.7	6
2 day	72.9		51.9		51.4	
4 day	84.7	55	61.8	40	62.2	44
10 day	127.0		91.7		98.0	

Table 6-C Maximum rainfall depths for 1 day, 2 day, 4 day and 10 day durations with corresponding AEP for 1 day and 4 day durations (August 1986)

6.6.2 28 October 1989

A review of the daily rainfall plotted in Figure 10 suggests that peak flows observed on all gauged rivers within the Tralee Bay-Feale Unit of Management on 28th October 1989, were the result of moderate but prolonged rainfall on 26th, 27th and 28th October. Daily rainfall recorded in the week prior is likely to have reduced any soil moisture deficit and in turn any storage capacity within the catchment.

Missing data on the 27th October 1989 is likely to result in the underestimation of 2-day, 4-day and 10-day rainfall depths recorded at raingauge 2009.

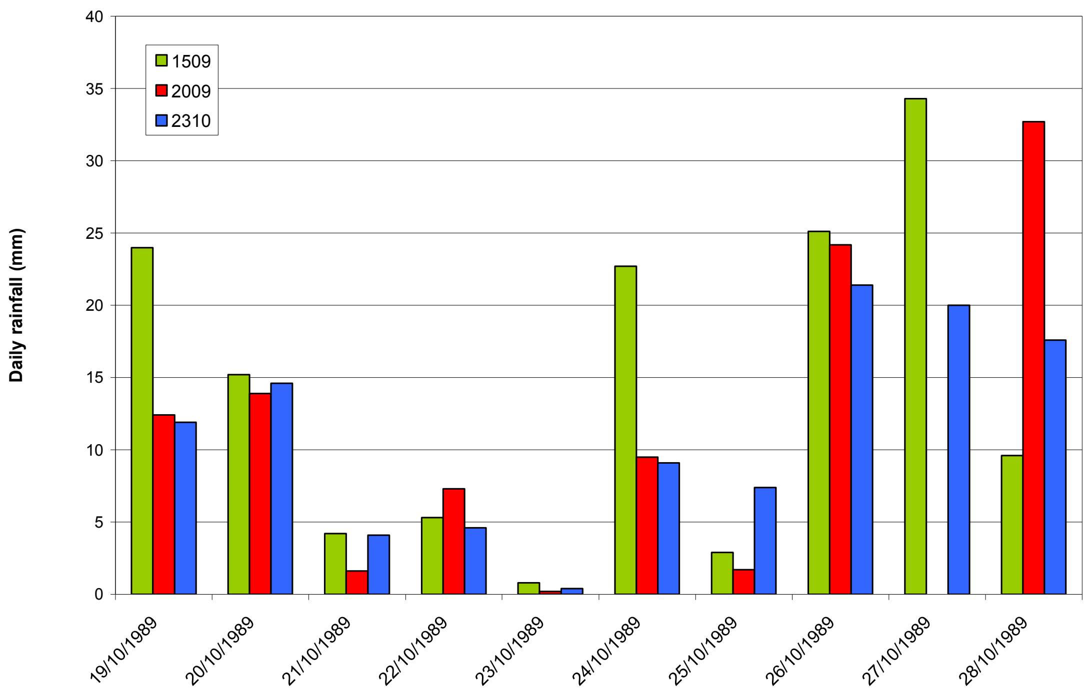


Figure 10 Daily rainfall - 19th October to 28th October 1989

Annual exceedance probabilities (AEPs) for the maximum rainfalls over the event are presented in Table 6-D. AEP estimates obtained from 1-day and 4-day rainfall probability plots (ref. Section 6.5) indicate this was in general a rarer event for the 4-day duration rainfall rather than the 1-day duration. The only variation from this pattern is at raingauge 2009, however, it is likely that rainfall depths for durations

greater than 1 day may be underestimated due to a missing daily rainfall value. 4-day rainfall AEP estimates range from 30% to 54%. Values derived for the 1 day duration indicate that statistically these rainfall depths occur on an annual or bi-annual frequency (47-91%).

	Oct-89					
Rainfall Duration	1509 Max. Rainfall depth (mm)	1509 AEP (%)	2009 Max. Rainfall depth (mm)	2009 AEP (%)	2310 Max. Rainfall depth (mm)	2310 AEP (%)
1 day	34.3	91	32.7	47	21.4	99
2 day	59.4		32.7		41.4	
4 day	85.0	54	58.6	50	66.4	30
10 day	114.1		103.5		113.9	

[Please note missing data on the 27th October will impact the maximum rainfall depths obtained for the 2-day, 4-day and 10-day rainfall totals at station 2009.]

Table 6-D Maximum rainfall depths for 1 day, 2 day, 4 day and 10 day durations with corresponding AEP for 1 day and 4 day durations (October 1989).

6.6.3 19 November 2009

Daily rainfall depths for the period 10th November to 19th November plotted in Figure 11 indicate spatially variable but prolonged rainfall across the unit of management. Daily rainfall depths peak on the 18th November 2009 at between 28.1mm (2009) and 39.6mm (1509). Flows gauged on the River Feale and River Galey peaked on 19th November 2009.

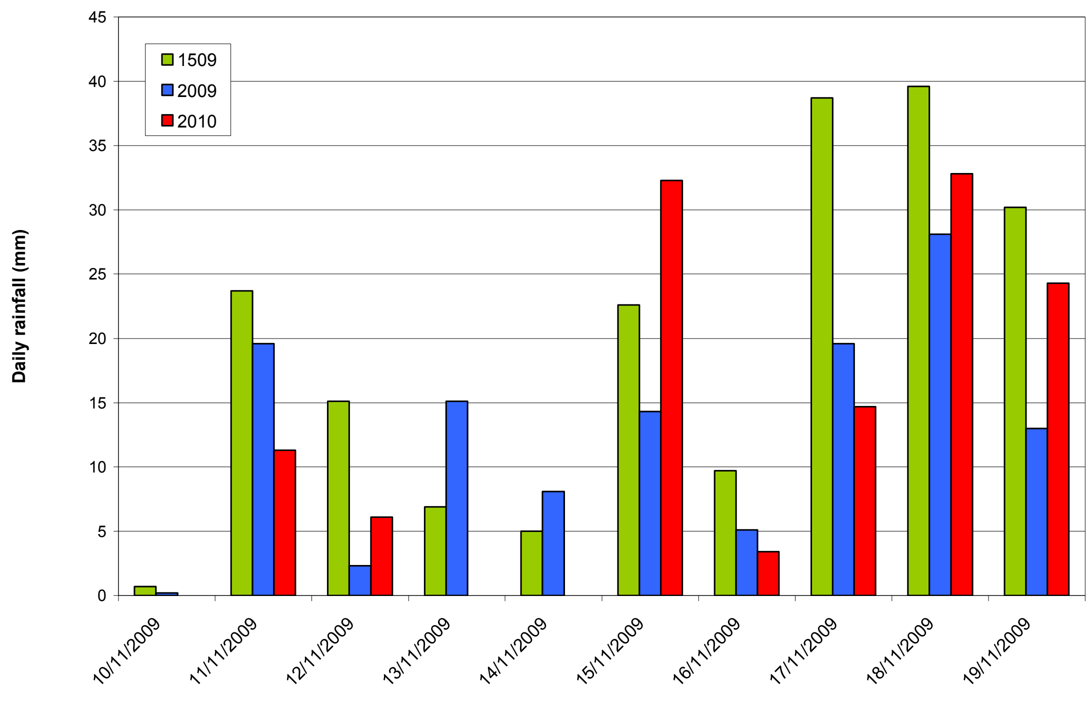


Figure 11 Daily rainfall - 10th November to 19th November 2009

Estimated annual exceedance probabilities, presented in Table 6-E indicate that this was a less frequent event for the 4-day duration as opposed to the 1-day duration rainfall. One-day duration rainfall probabilities estimated at a consistent 72-73%

indicate this depth of rainfall would be recorded on an almost annual basis, whilst the 4-day duration probabilities range between 6 and 26%. Rainfall recorded over 10 days duration prior to the 19th November, confirm the occurrence of considerable and prolonged rainfall with a rainfall depth of 192.2mm recorded at raingauge 1509 and 125.4 mm and 124.9mm recorded at raingauges 2009 and 2010 respectively.

	Nov-09					
Rainfall Duration	1509 Max. Rainfall depth (mm)	1509 AEP (%)	2009 Max. Rainfall depth (mm)	2009 AEP (%)	2010 Max. Rainfall depth (mm)	2010 AEP (%)
1 day	39.6	72	28.1	72	32.8	73
2 day	78.3		47.7		57.1	
4 day	118.2	6	67.1	26	83.2	8
10 day	192.2		125.4		124.9	

Table 6-E Maximum rainfall depths for 1 day, 2 day, 4 day and 10 day durations with corresponding AEP for 1 day and 4 day durations (November 2009)

6.7 Flood Studies Update Rainfall Comparison

Theoretical point rainfall depths, created for the Flood Studies Update were extracted from GIS rasters layers for a range of Annual Exceedance Probabilities between 50% and 0.5% at the 24 hour and 4 day durations. Output values are presented in Table 6-F.

Duration	Return Period	Annual Exceedance Probability (%)	1509	2009	2010	2310
24 hours	2	50	61.13	35.74	35.30	37.43
24 hours	5	20	74.74	44.41	43.19	46.31
24 hours	10	10	83.99	50.48	48.72	52.37
24 hours	20	5	93.62	56.70	54.30	58.72
24 hours	30	3	99.57	60.67	57.81	62.60
24 hours	50	2	107.43	65.87	62.45	67.85
24 hours	100	1	118.92	73.56	69.20	75.51
24 hours	200	0.5	131.57	82.06	76.67	84.04
4 day	2	50	100.68	60.56	60.70	64.64
4 day	5	20	118.38	71.76	71.56	76.42
4 day	10	10	130.22	79.21	78.81	84.29
4 day	20	5	142.10	86.74	86.15	92.26
4 day	30	3	149.28	91.32	90.58	97.09
4 day	50	2	158.70	97.37	96.41	103.43
4 day	100	1	172.34	106.10	104.84	112.55
4 day	200	0.5	187.01	115.60	113.90	122.47

Table 6-F Rainfall depths for a range of durations and frequencies obtained from grids corresponding to the locations of raingauges 4811, 4911 and 5111.

As stated previously, comparison of daily rainfall data and 24 hour data may not be a precise or even fair comparison due to the possible underestimation of maximum

daily rainfall values should an event straddle 09:00 hours, when daily storage raingauges are read.

Depth, duration and frequency estimates derived from actual data were compared with the theoretical values derived for the FSU (ref. Section 3.7.1). To assist, FSU rainfall depths for varying durations were plotted against Annual Exceedance Probabilities between 50% and 0.5% (ref. Appendix D). The resulting plots were used to estimate the FSU AEP of the actual rainfall depths. Results of this analysis are presented for each raingauge below (Tables 6-G, 6-H, 6-I and 6-J), with the FSU estimates of equal or less than 50% highlighted in bold for ease of reading.

As expected there is some difference between the two estimates of AEP for the same rainfall depth and duration. Just over half of the AEP estimates were above 50% AEP and therefore appear broadly to agree with the estimated AEP derived from the data.

FSU AEP estimates were greater than the AEP estimates derived from the annual maxima series at raingauges 1509, 2009 and 2310. The most notable difference was for the August 1986 event at 1509 (Table 6-G), where an AEP of 4% was estimated from the data and 35% from the FSU. This is a considerable disparity.

At raingauge 2010 (Table 6-I), the AEP estimates were similar for the November 2009 event, where the AEP estimated from the annual maxima series was 8% compared to the FSU AEP of 7%.

1509	1 day			4 day		
Event date	Maximum depth (mm)	Estimated AEP %	FSU AEP (%) (approx)	Maximum depth (mm)	Estimated AEP % (approx)	FSU AEP (%)
Aug-86	**67.7**	**4**	**35**	84.7	55	>50
Oct-89	34.3	91	>50	85.0	54	>50
Nov-09	39.6	72	>50	**118.2**	**6**	**21**

Table 6-G 1 day and 4 day rainfall and associated Annual Exceedance Probability (AEP) for raingauge 1509

2009	1 day			4 day		
Event date	Maximum depth (mm)	Estimated AEP %	FSU AEP (%) (approx)	Maximum depth (mm)	Estimated AEP % (approx)	FSU AEP (%)
Aug-86	**50.6**	**4**	**10**	**61.8**	**40**	**47**
Oct-89	32.7	47	>50	58.6	50	>50
Nov-09	28.1	72	>50	**67.1**	**26**	**32**

Table 6-H 1 day and 4 day rainfall and associated Annual Exceedance Probability (AEP) for raingauge 2009

2010	1 day			4 day		
Event date	Maximum depth (mm)	Estimated AEP %	FSU AEP (%) (approx)	Maximum depth (mm)	Estimated AEP % (approx)	FSU AEP (%)
Aug-86						
Oct-89						
Nov-09	32.8	73	>50	**83.2**	**8**	**7**

Table 6-I 1 day and 4 day rainfall and associated Annual Exceedance Probability (AEP) for raingauge 2010

2310	1 day			4 day		
Event date	Maximum depth (mm)	Estimated AEP %	FSU AEP (%) (approx)	Maximum depth (mm)	Estimated AEP % (approx)	FSU AEP (%)
Aug-86	**46.7**	**6**	**19**	62.2	44	>50
Oct-89	21.4	99	>50	**66.4**	**30**	**46**
Nov-09						

Table 6-J 1 day and 4 day rainfall and associated Annual Exceedance Probability (AEP) for raingauge 2310

6.8 Conclusions

Fifteen Met Éireann daily storage raingauges have been identified within the Tralee Bay - Feale Unit of Management, although four of these were immediately excluded from further study due to significant periods of missing data. In the absence of any Met Éireann sub-daily raingauges, the potential does exist to use a rainfall sensor installed and managed for the National Roads Authority, however, this will require further investigation to assess its suitability. The lack of sub-daily rainfall at this stage in the analysis has limited the durations analysed and subsequently the conclusions able to be drawn.

Three rainfall events have been studied across the unit of management, August 1986, October 1989 and November 2009. The events selected for analysis were the same events selected in the fluvial analysis. Rainfall depths were summed for four durations for each event, 1day, 2 day, 4 day and 10 day.

Cumulative rainfall depths from across the unit of management indicate rainfall totals are over the long-term highest at station 509 on the Dingle Peninsula. Rainfall events analysed in detail appear to reflect both winter depressions, characterised by a moderately intense rainfall event preceded by prolonged rainfall, and summer convective rainfall characterised by high intensity short duration rainfall.

Annual exceedance probabilities for the 1 day and 4 day duration rainfall depths were estimated based on probability plots developed from annual maxima series derived from the rainfall record. The annual maxima series was plotted according to Gringorten and fitted to the Gumbel distribution.

The lowest annual exceedance probabilities estimated for the 1-day duration were between 4-6% for all three raingauges (1509, 2009 and 2310) during the August

2009 event. While the lowest 4-day probabilities estimated for rainfall totals over a 4-day duration were during the November 2009 event, where AEPs of 6 and 8% were estimated for rainfall recorded at stations 1509 and 2010.

Annual exceedance probabilities estimated from actual data for the 1 day and 4 day durations compared to theoretical AEPs for the same durations derived for the Flood Studies Update typically varied. FSU AEP estimates were significantly higher at stations 1509, 2009 and 2310. The only value for which a lower FSU AEP was estimated was for the 4-day duration rainfall at station 2010 where 7% was estimated for the FSU compared to 8% from the annual maxima series. These differences appear to suggest that the FSU DDF estimates do not accurately reflect the DDF relationship at the four rainfall stations considered.

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7 Review of Fluvial Data

7.1 Introduction

Those gauging stations located within the Tralee Bay - Feale Unit of Management (UoM 23) and for which any instantaneous, daily mean or annual maxima (AMAX) flow or level data was received are listed previously (Tables 3-C, 3-D and 3-F). The subsequent review and analysis of fluvial data will be limited to these stations.

As outlined previously, the majority of flow and level gauges within the Tralee Bay – Feale Unit of Management are located on the Rivers Feale and Shannow and their tributaries. Of the 19 stations for which some fluvial flow and level data were provided, seven stations are located within the Feale catchment and eight within the Shannow catchment to their tidal limits. In addition to these, two flow measurement sites are located on the Lee River and one on the Big River within the vicinity of Tralee and a further gauge is located on the Galey.

The Shannon CFRAM study is primarily concerned with flooding, therefore good quality high flow and level data are required. The objective of this data review is to assemble the fluvial data available and understand its suitability for use in the CFRAM study.

Not all the data requested was issued promptly and a cut off date was required to ensure completion of the preliminary review. A cut off of 21 June 2011 was selected and any data received after this date will be acknowledged but excluded from any review or analysis presented in this report.

7.2 Distribution of Flow and Level Gauging Stations within UoM 23

The majority of hydrometric stations, 15 out of the 19 for which some data has been provided, are located within the Feale and Brick catchments and their tributaries, see Figure 5 in Section 3.5.3. The remaining stations are located in the Galey, Lee and Big catchments. The Feale, Brick and Galey rivers all drain into Cashen Bay.

Three hydrometric stations are located on the River Feale itself (23031, 23002, and 23006). Its tributaries are well represented with two located on the River Smearlagh (23008, 23017), one each on the River Oolagh (23007) and River Allaghaun (23005). This distribution fairly well represents the lower and mid Feale catchment, but the upper reaches of the River Feale are not well represented. If level stations are excluded, the distribution of stations becomes increasingly limited with one gauge each on the Feale (23002) and Smearlagh (23017).

The River Galey has one gauge located in its lower reaches measuring both flow and level.

Three gauges are located on the River Brick (23033, 23030 and 23034), whilst five are located on the Stream (23032, 23035, 23036, 23037 and 23038). All five gauges are clustered within the River Bricks lower reaches.

Outside of the Feale (Cashen) catchment, the River Lee and Big River drain Tralee located at the eastern end of the Dingle Peninsula. Two gauges (23011 and 23012) are located on the River Lee, whilst one gauge is located on the Big River (23022). Both rivers have one gauge providing flow measurements.

7.3 Data Review

It was assumed that data provided by the OPW or EPA had already been quality assured. In order to gain an understanding of the completeness and the quality of data at each gauged location, flows and level records were reviewed upon receipt of the data. This assessment was aimed at providing an overview of the quality of data based on a visual inspection of daily mean flow (or level) records, a count of quality codes (where available), completeness of record and a visual assessment of long-term trends which may impact on the confidence given to QMED. Daily mean flows were inspected in preference to instantaneous data to focus the review on gross errors and long-term trends. A summary of the review findings can be found in Table 7-A, whilst a more detailed summary is documented in Appendix E.

An example of a typical observed trend in peak flows is shown in Figure 12 below.

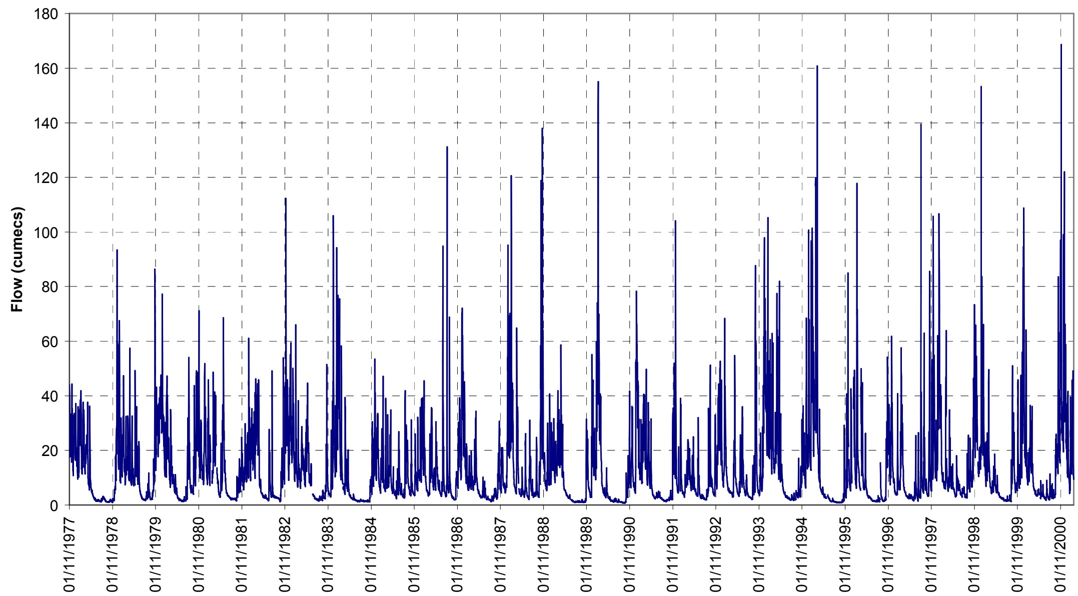

Figure 12 Example of Trend at Station 24082

All three daily mean flow and / or level records available were reviewed (ref. Table 3-C). Unfortunately, the level series at station 23012 was too short to enable any conclusions to be drawn. A trend in the water level and flow was observed at station 23001 between 1968 and 1978 following which the level and flow series stabilise. At station 23002 a rise in water levels leading to a step change in the record is evident between 1974 and 1976. Water levels and peak flows post-1976 appear to be generally higher. Any step change or trend in peak levels is problematic as it disproves the assumption of homogeneity of a flow series; an assumption routinely made when undertaking any hydrological statistical analysis. For these stations, the pre-1978 data (at 23001) and pre-1976 data (at 23002) will be used with caution.

In addition, a sudden and anomalous dip in water level was observed in the level record at 24001. Typically such anomalous values are removed from the record and will be excluded should they arise within further event analysis.

Analysis of the OPW quality codes (ref. Table 3-E) assigned to the data revealed that at the two sites with flow series, 23001 and 23002, 68% and 69% of the data was considered to be of 'good' quality.

The daily level series at 23012 had greater than 51% of the data series flagged as missing, reducing the utility of this short record.

For locations where both flow and level data were available (23001 and 23002) it was apparent that quality codes for the same site were, in general, not equivalent. This can partly be attributed to the differing classifications for flow and level series, but even where classifications were the same the counts for each were often dissimilar.

Station No.	Station name	River	UoM 23 sub-catchment	FSU class	Daily Flow data only				Daily Level data only				
					% good days	% poor or cautionary days	% missing days	Total number of days	% good days	% days cautionary	% days missing	Total number of days	Further investigation required
23001	Inch Br.	Galey	Feale	A2	68	7	3	16789	97	0	3	16789	No, declining trend in levels and flows 64-78. Post-78 flows and levels ok.
23002	Listowel	Feale	Feale	A1 (2 records both A1)	69	1	6	23339	94	0	6	22525	Step change in flows and levels 74-76. Post-76 levels and peak flows higher.
23012	Ballymullen	Lee (Kerry)	Lee (Kerry)	A2					45	0	51	2256	Record too short

Table 7-A Summary of daily mean flow and level data review (see also Appendix E) (Grey squares indicate no data)

7.4 Annual Maxima Flow and Level Series

Annual maxima (AMAX) data available for four fluvial stations in the Tralee Bay – Feale Unit of Management (ref. Table 3-F) were ranked to identify the top 10 of ranked events for each gauging station. In Table 7-B, the top 5 events at each location are identified by the letter A and yellow shading; those ranked 6-10 are identified by the letter 'B' and green shading. Due to the manual extraction of selected peak flows the rank of flow and level for a given event could differ at the same location. Therefore, where both flow and level annual maxima series were available, the flow series was used in preference. The subsequent matrix of annual maxima provided an overview of the most significant events across the catchment (Table 7-B). It is worth noting, however, that both the period of record and length of an annual maxima series can skew the data and therefore will be used as one of a series of approaches for assessing severe events.

As detailed in Section 7.3 the annual maximum flow series (AMAX) will only be considered from 1978-onwards at 23001 and 1976-onwards at 23002.

Dates	23001	23002	23031	23012
	Flow	Flow	Level	Flow
15 January 1975			B	
2 November 1980		A	B	
17 October 1982				B
31 March 1983		B		
16 January 1984			B	
14 August 1985			A	
6 August 1986		A	A	
25 August 1986	B			
21 September 1987			A	
18 January 1988			B	
19 March 1988				B
9 March 1989			A	
28 October 1989	B	B	A	
30 January 1990				A
1-5 January 1991			B	A
12 September 1992	A			
17 January 1995				A
22 February 1995	A	B		
10 February 1997				B
6 March 1998	B			
2 January 1999				B
24-25 December 1999				B
26-27 October 2000	B	A		
1-2 February 2002				A
8 January 2005	A	A		
3 December 2006		B		
10 March 2008				A
1 August 2008	A			
13 August 2008		B		
12 December 2008	B			
19 November 2009	A	A		

Table 7-B Top 5 (A) and Top 6-10 (B) AMAX flow or level for hydrometric gauging stations within UoM 23.

7.5 Flow and Level Flood Frequency Curves

Where an AMAX series was available for a continuous flow series with a period of record greater than 10 years a flood frequency plot was developed. Research documented in FSU guidance (Work package 2.2) concluded that no single distribution could be considered a 'best fit' to all locations across Ireland. However, it was reported that the use of either a lognormal or Extreme Value Type 1 (EV1 or Gumbel) distribution provided a reasonable fit for the majority of stations.

Based upon this recommendation and for the benefit of consistency, one distribution will be selected as the distribution to be fitted to all applicable AMAX series in this Inception reporting phase of the study. The most likely candidates for this distribution are the lognormal and EV1 distributions. The selection of the distribution will be carried out after the rating review phase when the reliability of the available AMAX data has been assessed and possibly improved.

As part of this preliminary hydrological analysis flood frequency curves were developed following the procedure outlined in Section 6.5 based on an EV1 distribution and plotted according to Gringorten.

The subsequent flood frequency curve was used to derive estimates of annual exceedance probability for historical events rather than from data directly to ensure a coherent relationship between estimates.

Flood frequency plots were derived for the four hydrometric gauging stations located in the Tralee Bay – Feale Unit of Management for which an AMAX series greater than 10 years was available.

Flood frequency plots can be found in Appendix F and on the Gauging Station Summary Sheets in Appendix H. The reasons for the shapes of the plots and the locations of any outliers, or extended "flat" rating curves, will be given due consideration following the completion of the gauging station reviews and the re-working of the AMAX series as necessary, recognising that an unusual shape can be a result of physical reasons, data limitations, or simply the statistical distribution of floods that has occurred over the data record.

7.6 Event Analysis

Three flood events have been selected and will form the basis of a detailed hydrological analysis of hydrograph shape, duration, volume of flow, runoff and estimated probability of the event.

Events were selected based on a review of the AMAX series from gauges across the catchment (ref. Table 7-B) in conjunction with the occurrence of historic flood events as documented on the floodmaps.ie website. Emphasis was initially placed on the selection of events which have occurred recently, within the past 15 years. However, the flow data provided for the River Lee at Ballymullen (23012) ends in 1994 so events within the past 25 years have been included to ensure the widest response across the unit of management.

The following events were selected to represent severe flood events within the Feale – Tralee Bay Unit of Management.

- 6 August 1986
- 28 October 1989;
- 19 November 2009.

The following gauging stations located on both the Feale and Galey rivers represent the instantaneous flow series available within this unit of management and are therefore used in the subsequent analysis;

23001 Galey at Inch Bridge
23002 Feale at Listowel
23012 Lee at Ballymullen
23017 Smearlagh at Trienearagh
23022 Big at Tralee Clonalour

Of these five stations only 23002 and 23017 are located within the same catchment.

7.6.1 6 August 1986

Flow data was extracted from the 15 minute series at four gauging stations between 5th August 1986 (00:00 hours) and 9th August (23:45 hours). A summary of the data is presented in Table 7-C below. Gauging station 23022 on the Big at Tralee has a gap in the recorded data during this event. It has therefore been excluded from any further event analysis.

Station No.	Peak flow (m^3/s)	Time of peak flow	Start time	End time	Volume of flow (m^3)	Duration (days, hours, minutes)
23001	109.5	06/08/1986 05:00	05/08/1986 16:45	06/08/1986 21:30	5,165,804	01:04:45
23002	764.8	06/08/1986 04:00	05/08/1986 16:00	09/08/1986 06:15	35,366,308	03:14:15
23012	31.8	06/08/1986 04:30	05/08/1986 16:00	07/08/1986 05:30	2,157,133	01:13:30
23017	213.4	06/08/1986 01:03	05/08/1986 14:44	06/08/1986 20:15	7,470,915	01:05:31
23022	0.6	08/08/1986 16:00				

Table 7-C Summary of timings and flows for the flood event 6 August 1986

All four hydrographs (Figure 13a, below Section 7.6.3) reflect the occurrence of a single event across the UoM.

Flows at 23002 and 23017 responded rapidly to the event as indicated by the steep rising limb of their hydrographs. The initial hydrograph response at 23002 mirrors that recorded upstream at 23017 and allows us to deduce the time to travel between the two stations is approximately 25 minutes. Hydrographs for the flow series at 23001 and 23012 reflect a slower runoff response to the rainfall event. Despite the significant difference in the shape of hydrograph and time to peak between 23001 and 23017, the event durations are similar.

Peak flows for the event were recorded on the Feale at Listowel (23002) at 754.8 m^3/s. This hydrometric station has by far the largest catchment area (646.8 km^2) of any of the gauged stations so this occurrence is not surprising. The data quality code of ‘254’ for the flow series indicates that between 5 August 1986 23:15 and 6 August 08:00 the flow series is classified as either ‘missing, erroneous or of unacceptable quality’ (ref.Table 3-E). From Table 3-C we can observe that this includes the peak flows.

The flat-topped hydrograph at 23017 could indicate the bank full-capacity of the channel at this location and therefore the truncation of the hydrograph peak.

Annual exceedance probabilities were estimated from the annual maximum series fitted with a Gumbel distribution and presented in Table 7-D. An AEP of 35% was estimated for the peak flow on the River Galey at Inch Bridge which indicates that the event was fairly unusual with only a probable tri-annual occurrence. On the River Feale at Listowel (23002) an AEP of 3% was estimated indicating that it is a much less frequent event, whilst the 1% AEP estimated for the peak flows recorded on the River Lee at Ballymullen (23012) suggest it was a rare event.

			Aug-86	
Station No.	Station Name	Watercourse	Peak flow (m^3/s)	Estimated Annual Exceedance Probability (%)
23001	Inch Bridge	Galey	109.5	35
23002	Listowel	Feale	764.8	3
23012	Ballymullen	Lee (Kerry)	31.8	1
23017	Trienearagh	Smearlagh	213.4	
23022	Tralee Clonalour	Big (Kerry)	0.6	

Table 7-D Estimated Annual Exceedance Probabilities for peak flows during August 1986 event

7.6.2 28 October 1989

Flow data was extracted from the 15 minute series at three gauging stations between 27th October 1989 (00:00 hours) and 31st October 1989 (23:45 hours). A summary of the data is presented in Table 7-E below and graphically in Figure 13b, below Section 7.6.3.

Station No.	Peak flow (m^3/s)	Time of peak flow	Start time	End time	Volume of flow (m^3)	Duration (days, hours, minutes)
23001	124.4	28/10/1989 18:45	28/10/1989 09:45	29/10/1989 19:45	7,129,997	01:10:00
23002	503.6	28/10/1989 18:00	28/10/1989 07:15	29/10/1989 19:00	31,275,726	01:11:45
23012	19.1	28/10/1989 18:45	28/10/1989 06:30	29/10/1989 12:30	1,378,098	01:06:00
23017	139.3	28/10/1989 10:16	28/10/1989 06:14	29/10/1989 11:13	5,177,482	01:04:59
23022	35.0	28/10/1989 10:51	28/10/1989 07:24	29/10/1989 01:10	509,497	00:17:46

Table 7-E Summary of timings and flows for the flood event 28 October 1989

Flow series from the five gauging stations all reflect the occurrence of a single hydrograph for this event; superimposed on flows receding after a smaller event which peaked on 27th October 1989.

Whilst the peak flow was again highest at station 23002 on the River Feale, a steep rising hydrograph limb, flattening off towards the peak was observed at stations 23002, 23017 and 23022. An equally steep recession was observed at 23002 and 23022, however the attenuated response at 23017 indicates the existence of a further rainfall event or storage within the catchment. A slower hydrograph response was recorded at both 23001 and 23012.

Estimated annual exceedance probabilities ranging between 20% and 27% were estimated for stations 23001, 23002 and 23012 (Table 7-F). This indicates that the impact for this fairly infrequent event was similar across the unit of management.

			Oct-89	
Station No.	Station Name	Watercourse	Peak flow (m^3/s)	Estimated Annual Exceedance Probability (%)
23001	Inch Bridge	Galey	124.4	20
23002	Listowel	Feale	503.6	27
23012	Ballymullen	Lee (Kerry)	19.1	27
23017	Trienearagh	Smearlagh	139.3	
23022	Tralee Clonalour	Big (Kerry)	35.0	

Table 7-F Estimated Annual Exceedance Probabilities for peak flows during October 1989 event

7.6.3 19 November 2009

Flow data was extracted from the 15 minute series at three gauging stations between 17th November 2009 (00:00 hours) and 21st November 2009 (23:45 hours). A summary of the data is presented in Table 7-G below and shown graphically in Figure 13c below. The hydrograph peak at station 23022 looks erroneous with a flat-topped peak which dips suddenly only to peak again. This behaviour is not consistent with the other hydrographs (or rainfall) and could be a result of a drowned weir. This station will therefore be excluded from any further analysis of this event.

Station No.	Peak flow (m^3/s)	Time of peak flow	Start time	End time	Volume of flow (m^3)	Duration (days, hours, minutes)
23001	158.5	19/11/2009 17:45	19/11/2009 04:00	21/11/2009 08:15	12,900,747	02:04:15
23002	670.1	19/11/2009 14:00	19/11/2009 03:45	21/11/2009 08:30	47,147,580	02:04:45
23012						
23017	133.0	19/11/2009 12:15	19/11/2009 03:15	21/11/2009 07:45	7,764,948	02:04:30
23022	30.0					

Table 7-G Summary of timings and flows for the flood event 19 November 2009

All four hydrographs (Figure 12c below) indicated a single peaked event, but superimposed on the reclining flows of the previous event. Analysis has focused on the portion of the hydrograph starting at the rising limb on the 19th November 2009 and ending at the start of the subsequent event as the hydrograph rises again (21st November 2009).

Timing of the peak flows indicates that flows peaked first in the Smearlagh tributary, which feeds into the River Feale not far upstream of Listowel, with flows on the Feale at Listowel peaking soon after.

The flatter hydrograph observed in the Galey catchment represents a slower responding catchment either with more attenuation or a great capacity for storage within the catchment.

Based on the annual maximum flow series fitted with a Gumbel distribution as detailed in Section 7.5 annual exceedance probabilities were estimated for flows at 23001 and 23002, an AMAX series was not available for stations 23017 or 23022. Results for the two gauges were very similar at 5% on the Galey at Inch Bridge and 6% on the Feale at Listowel (Table 7-H). The estimated AEPs indicate this was a relatively infrequent event.

			Nov-09	
Station No.	Station Name	Watercourse	Peak flow (m^3/s)	Estimated Annual Exceedance Probability (%)
23001	Inch Bridge	Galey	158.5	5
23002	Listowel	Feale	670.1	6
23012	Ballymullen	Lee (Kerry)		
23017	Trienearagh	Smearlagh	133.0	
23022	Tralee Clonalour	Big (Kerry)	30.0	

Table 7-H Estimated Annual Exceedance Probabilities for peak flows during November 2009 event

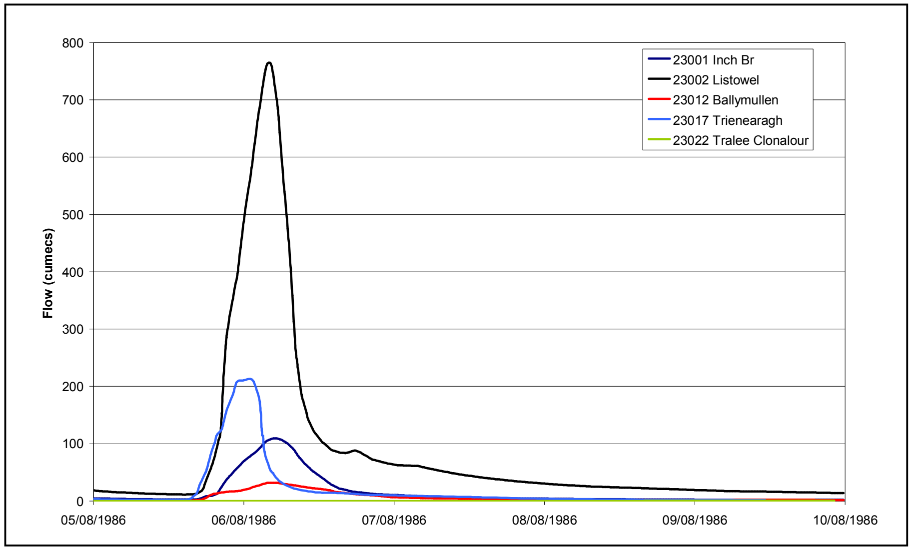

Figure 13a 6 August 1986

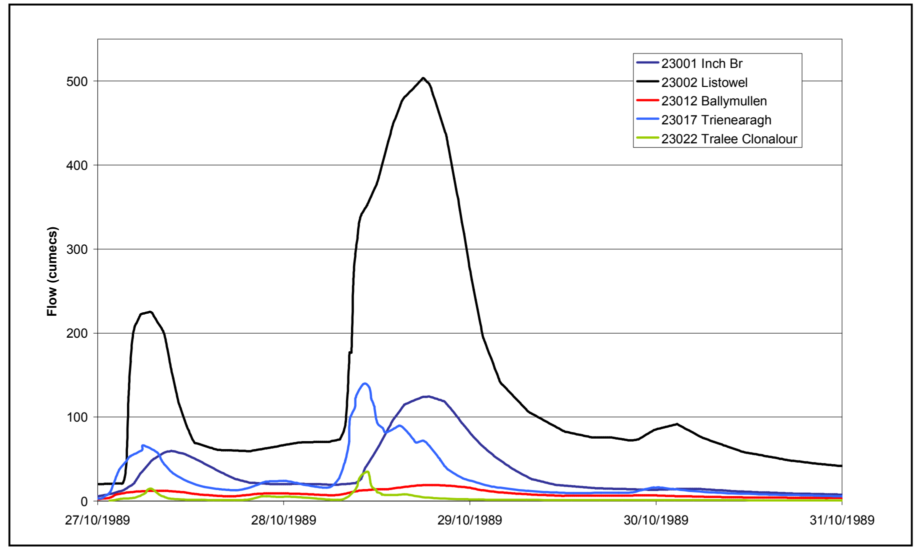

Figure 13b 28 October 1989

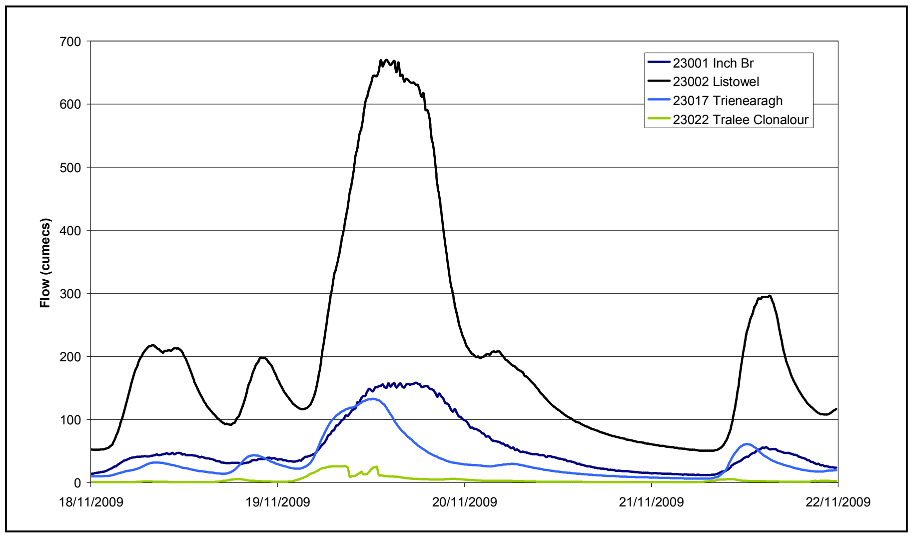

Figure 13c 19 November 2009

Figure 13 Hydrographs for the three events within the Tralee Bay – Feale Unit of Management

7.6.4 Event Discussion

Hydrographs from the three events highlight general trends in catchment response at given locations. Flows gauged at 23002, 23017 and 23022 were highly responsive as demonstrated in the hydrographs steep rising limbs and steep recessions. Flows gauged at 23001 and 23012 were much less responsive with gentler hydrograph rising limbs and recessions (ref. Table 7-I).

The highest runoff values (Table 7-I) obtained for all three events were on the River Feale at Listowel (23002) and on one of its tributaries upstream; the River Smearlagh at Trienearagh. Where data was available on the Big River at Tralee a comparable runoff value was noted there also. For the August 1986 event, the runoff on the Smearlagh was considerably greater than on the Feale giving us some indication of the distribution of the rainfall event. Runoff was not too dissimilar at all locations during the November 2009 event, possibly due to similar antecedent conditions. Runoff values ranged between 65 to 73 mm.

Headwaters for the River Lee and Big River are adjacent, both draining the southwestern slopes of the Stacks Mountains, however, their hydrograph responses are very different. For the October 1989 event - the only event for which data is available at both locations, the Big River at Tralee (23022), with a catchment area of 10.9 km^2 responds rapidly to rainfall peaking with a flow of 35.0 m^3/s. Conversely the River Lee at Ballymullen, which has a much larger catchment (61.6 km^2) responds much slower and flow peaks at only 19.1 m^3/s. Despite this difference in response the runoff values for the two catchments are similar at 22 mm and 23 mm.

Station No.	Catchment area (km^2)	Aug-86			Oct-89			Nov-09		
		Peak flow	Volume of flow (m^3)	Runoff (mm)	Peak flow	Volume of flow (m^3)	Runoff (mm)	Peak flow	Volume of flow (m^3)	Runoff (mm)
23001	191.7	109.5	5,165,804	27	124.4	7,129,997	37	158.5	12,900,747	67
23002	646.8	764.8	35,366,308	55	503.6	31,275,726	48	670.1	47,147,580	73
23012	61.6	31.8	2,157,133	35	19.1	1,378,098	22			
23017	119.1	213.4	7,470,915	63	139.3	5,177,482	43	133.0	7,764,948	65
23022	10.9	0.6			35.0	509,497	47			

Table 7-I Peak flow, volume of flow and runoff for 3 events within the Tralee Bay – Feale Unit of Management.

7.7 Conclusions

Fluvial data has been analysed across the Tralee Bay – Feale Unit of Management. Initially, daily mean flows, where available for three hydrometric stations, were reviewed for long-term errors or trends. Only two records were long enough to be conclusive. A trend in the water level and flow was observed at station 23001 between 1968 and 1978 after which the record stabilises. A rise in water levels is evident at station 23002 leading to a step change in 1974 – 1976. The older data will be used with caution, unless there is evidence of a real step change in the catchment characteristics, in which case it may be decided to ignore the older data completely.

Instantaneous flow data was provided for five gauging stations. Three flood events were selected across the unit of management to analyse series in detail. Limited data availability forced the selection of two events in the 1980s together with the 2009 flood:

- 6 August 1986
- 28 October 1989
- 19 November 2009

Hydrographs from gauges 23002, 23017 and 23022 indicated a highly responsive catchment, as demonstrated by steep rising limbs and steep recessions. Flows gauged at 23001 and 23012 were much less responsive with gentler hydrograph rising limbs and recessions.

Highest peak flow in the three events was 670.1 m^3/s recorded on 19th November 2009 at Listowel on the River Feale (23002).

Runoff within the Tralee Bay-Feale Unit of Management was consistently the highest at station 23002 on the River Feale. However runoff values were similarly high for the River Galey at Inch Bridge (23001), and the River Smearlagh at Trienearagh (23017) during the November 2009 event.

Annual exceedance probabilities estimated for each event suggested a range of values across the catchment. The lowest AEP estimated was 1% for the River Lee at Ballymullen for peak flows recorded during the August 1986 event. AEP estimates for the three events on the River Feale at Listowel ranged from 3% (August 1986) to 27% (October 1989); and for the River Galey at Inch Bridge between 5% (November 2009) to 35% (August 1986).

8 Historical Flood Risk Review

8.1 Introduction

A substantial amount of historical flooding information has been gathered using "floodmaps" (www.floodmaps.ie) which is a web-based flood hazard mapping resource managed by the Office of Public Works (OPW). It contains historical flood events in various areas of the Republic of Ireland, with links to archived reports, photographs and newspaper articles collected from local authorities, other state bodies and members of the general public.

The historical data from this website is related to flooding caused by fluvial, tidal and coastal factor within the past 120 years. It does not deal with flood events arising as a result of other causes such as burst pipes, surcharged or blocked sewers etc.

Quality codes have been assigned to define the reliability of the sources of information (Table 8-A). This, however, excludes the newspaper articles and information to which other quality assurance or coding processes apply e.g. the OPW hydrometric data. The reliability is classified and graded as follows:

Code	Description
1	Contains, for a given flood event at a given location, reliably sourced definitive information on peak flood levels and/or maximum flood extents.
2	Contains, for a given flood event at a given location, reliably sourced definitive information on flood levels and/or flood extents. It does not however fully describe the extent of the event at the location.
3	Contains, for a given location, information that, beyond reasonable doubt, a flood has occurred in the vicinity.
4	Contains flood information that, insofar as it has been possible to establish, is probably true.

Table 8-A Quality Codes assigned to data in floodmaps (OPW)

The quality codes have been considered when summarising the historical flooding information with the priority given to data with quality code 1. The data with quality code 1 where available provides reliable information on peak flood levels and/or maximum flood extents and used in the analysis of the historical flood events. The detailed summary of all the historical flooding information for all the Communities at Risk (CAR) and Individual Risk Receptors (IRRs), together with the quality code, is shown in Appendix I. This is précised in the text and tables presented below.

Wherever the information is available in "floodmaps.ie" the number and type of properties and infrastructure affected in a CAR by a historical flood event is stated in the sections below. However, due to the qualitative nature of most of the information available in "floodmaps" it has often been found impossible to quantify these factors from the historical records.

The OPW recognises that the website is not a comprehensive catalogue of all past flood events and may not cover all flood events. The information included depends on the available records of the source organisation and is uploaded at their

discretion. Therefore, the absence of any records of past flood events in any given location does not allow us to conclude that flooding has never occurred in that area.

8.2 Records of Historical Flood Risk

The list of the Communities at Risk (CARs) and Individual Risk Receptors (IRRs) in this unit of management (UoM) is shown in Section 2. The CARs in this unit of management are spread in five catchments namely the Brick, Feale, Galey, Lee and Big, and Tyshe catchments. No IRR has been identified in this UoM .

Where possible a representative gauging station for each of the CARs has been identified and flow or water level data of the gauging station have been used to estimate the Annual Exceedance Probability (AEP) of historical flood events obtained from the "floodmaps.ie" website. In the absence of any flow or level estimates from a gauging station the AEP is estimated based on the order of magnitude of similar events within the same catchment. This estimate can therefore be considered as indicative only and should be treated with caution.

The AEPs for particular events are derived using the flood frequency plots indicated on the gauging station information sheets (Refer to Appendix H).

Historical flood event records and the sources and cause of the event in each CAR are discussed on a catchment by catchment basis in the following sections.

8.3 Brick Catchment

Table 8-B below summarises the CARs and IRRs in this catchment and sources and causes of flood in each of the CARs and IRRs. As shown in the table below there is only one CAR in this catchment.

CAR/IRR	County	River	Mechanism of Flooding
CAR 01 Abbeydorney	Kerry	Brick	There is no information on the sources and cause of flood.

Table 8-B flooding mechanism in the Brick Catchment

8.3.1 Records of Historical Flood Risk

(a) CAR 01 Abbeydorney

The only available information on historical flood event in **Abbeydorney** is a hand written memo dated 23 November 1994. According to the memo flooding occurred in **Abbeydorney** on 11 October and 7 November 1994, although the sources of flooding are not stated.

8.3.2 Discussion

The memo does not give any detail of extent and cause of flooding.

8.4 Feale Catchment

Table 8-C below summarises the CARs in this catchment and sources and causes of flood in each of the CARs. As shown in the table below there is only one CAR in this catchment.

CAR/IRR	County	River	Mechanism of Flooding
CAR 39 Listowel	Kerry	Feale	Pluvial: No detail information on sources and causes of flooding. However, the localised nature of the recorded flood events may suggest the source of flooding is pluvial.

Table 8-C flooding mechanism in the Feale Catchment

8.4.1 Records of Historical Flood Risk

(a) CAR 39 Listowel

Five flood events have been recorded as occurring in Listowel. These are summarised in Table 8-D below. The representative gauging station for this area is Listowel Bridge (23002). The gauging station records flows from a catchment area of about 647 km^2.

The AEP of a given historical event as shown in Table 8-D was estimated based on annual maximum series flow data recorded at Listowel Bridge gauging station. However, in certain cases the date of the flood event and the annual maximum event might not match. Thus, where the dates are similar, an assumption has been made that the flow during the flood event was equivalent to the annual maximum flow of the hydrometric year in which the event occurred.

Event	Peak Flow (m^3/s)	Peak Level (mAOD_Malin)	Estimated Annual Exceedance Probability (AEP) (%)	Flood Extents & Damages	Ranking
12 August 2003	420.71 (Listowel)	19.10 (Listowel)	38	Land LIS 03/0419 at Coibee, Listowel flooded.	1
28 November 2002	271.70 (Listowel)	18.65 (Listowel)	>50	House LIS 02/1022 at Curraghatoosane, Listowel flooded.	2
11 November 2002	271.70 (Listowel)	18.65 (Listowel)	>50	Septic tank LIS 02/0988 at Gortnaminch, Listowel flooded.	2
25 July 2002	-	-		Field LIS 02/0737 at Greenville, Listowel flooded.	
22 February 2001	104.13 (Listowel)	12.19 (Listowel)		Field C3R C1/18/19 Feale Galey Tributary at Shrone West, Listowel flooded.	

Table 8-D Summary of historical recorded flood events in CAR 39 Listowel

8.4.2 Discussion

Flood events are recorded as having occurred in the Feale catchment that affected Listowel in February 2001, July 2002, November 2002 and August 2003.These flood events occurred in different locations of Listowel and do not appear to coincide with fluvial flood events recorded at the gauging station at the river (23002).

Though there is no detailed information on the sources and cause of these flood events, they appeared to be localised. Hence the cause and the source is anticipated to be a combination of a localised rainfall storm which might have generated high surface runoff beyond the capacity of the adjacent drainage system.

8.5 Galey Catchment

Table 8-E below summarises the CARs in this catchment and sources and causes of flood in each of the CARs. As shown in Table 8-E there is only one CAR in this catchment.

CAR/IRR	County	River	Mechanism of Flooding
CAR 05 Athea	Limerick	Galey	Fluvial: Events coincided with major weather events

Table 8-E Flooding Mechanism in the Galey Catchment

8.5.1 Records of Historical Flood Risk

(a) CAR 05 Athea

Four flood events are known to have occurred in Athea, according to the information obtained from “floodmaps.ie” website of OPW. Of those, two events occurred in August 2008 within one week. Table 8-F below summarises the recorded historical flood events and their corresponding flow and levels as recorded at Inch Bridge (23001) which is 25km downstream of Athea. The gauging station covers a catchment area of 191.7km^2.

Event	Peak Flow (m^3/s)	Peak Level (mAOD-Malin)	Estimated Annual Exceedance Probability (AEP) (%)	Flood Extents & Damages	Ranking
02 September 2009	158.37 (Inch Bridge)	12.76 (Inch Bridge)	13	Approximately 4 properties, The Avenue & Con Colbert (main street) flooded.	2
01 August 2008	138.29 (Inch Bridge)	12.56 (Inch Bridge)	22	At least 12 properties, R523, Wastewater treatment plant flooded.	3
06 August 2008	138.29 (Inch Bridge)	12.56 (Inch Bridge)	22	At least 14 properties flooded (2 additional properties compared to 01st August 2008 event)	3
April 2005	159.42 (Inch Bridge)	12.77 (Inch Bridge)	12	Area adjacent to the bridge in the village was affected by flooding. One resident's house was flooded.	1

Table 8-F Summary of historical recorded flood events CAR 05 in Athea

8.5.2 Discussion

Athea Flood Severity and Impact Report by JBA (October 2008) identified a significant difference between the AEP calculated based on the rainfall radar data

taken at Athea on 1 August 2008 and the AEP of the flow recorded at Inch Bridge gauging station (23001) on the same date. The AEP of the rainfall estimated to be 0.16% (1 in 645) whilst the AEP of the flow recorded at the Inch Bridge gauging station on the same date is 35.96%. Obviously the rainstorm AEP is expected to be lower than the flow AEP. However, the huge difference between the two in this case might be attributed to the localised nature of the rainstorm and the subsequent local flooding. In general the 2008 summer has been identified as a major metrological event due to heavy rain and subsequent flooding in Ireland. However, according to rainfall radar data the heavy rainfall which caused flooding in 1 August happened to be mainly centred in around Athea and areas east and south east of Athea (boundary of UoM 23 and 24). Thus the AEPs shown in Table 8-F are indicative only and should be used with caution.

Below is the brief description of the flood events recorded in Athea.

September 2009

The September 2009 event was a localised flood in Athea. The flood was caused due to inadequate capacity in an underground culvert south of the main street (Con Colbert St). The flood water first overflowed a small avenue and flowed down to the main street (Con Colbert St). This flood impacted about 4 properties and caused substantial damage on the road pavement.

August 2008

The 1 August 2008 flood event resulted from a period of prolonged wet weather which had saturated much of the Munster region and thus reduced the capacity of the ground to absorb rainfall. An exceptional intensive, localised rainfall on 31st July with a depth of approximately 85.9mm (in a six hour period) centred itself over the mountains of the Galey catchment causing localised flash flooding to Athea. This rainfall event was estimated to be a 0.16% AEP (1 in 645 years) from the previous Athea Flood Severity and Impact Report by JBA (October 2008).

It was reported that water levels at the bridge in Athea town centre rose rapidly over a period of around 25 minutes. Flood water overwhelmed the channel upstream of Athea and overflowed above the channel banks and flooded properties along the main road from the rear. The water flowed via the driveway of the house downstream of the bridge to rejoin the channel briefly before flowing overland again through the front house of the Coise na Gaile and on to the houses in Markievicz Park development. It then returned to the channel further downstream.

The hydraulic capacity of the River Galey was restricted due to overgrowth of vegetation on its bank and deposition of the river gravel within the river channel. The storm on 1st August exacerbated the situation and the channel and bridge capacities were significantly reduced.

As a result of the reduction in the channel capacity another flooding event occurred on 6 August 2008. Subsequent to this event, the OPW carried out emergency channel and bank clearance through a limited area of Athea at the request of Limerick County Council.

8.6 Lee and Big Catchment

Table 8-G summarises the CARs in this catchment and sources and causes of flood in each of the CARs. As shown in Table 8-G there is only one CAR in this catchment.

CAR/IRR	County	River	Mechanism of Flooding
CAR 56 Tralee	Kerry	Lee	Mainly fluvial but also groundwater flooding in areas around Pembroke/Rock St

Table 8-G Flooding mechanism in the Lee and Big Catchment

8.6.1 Records of Historical Flood Risk

(a) CAR 56 Tralee

The flood events in Tralee and its surrounding area are listed in Table 8-H below. The town centre used to be flooded more often before 1986. However, after a severe flood in August 1986 a major flood relief scheme was constructed to alleviate the problem. However, discussions with OPW indicate that some areas still appear to be at risk of flooding.

The main sources of flooding in Tralee and its surrounding area are the two tributaries of the River Lee, the Big and Balloonagh Rivers. These two tributaries drain the steeply sloping ground to the north of the town. Due to the underlying geology of limestone, small size and steepness of the catchments, storm flows in the Big and Balloonagh Rivers were characterised by short times to peak, short duration and high peak value resulting in flash flooding. For detailed information on causes of flooding and the extent of flood in August 1986 refer to a report "Tralee Flood & Development Study" prepared by M C O'Sullivan Consulting Engineers in October 1987.

There are two gauging stations in this catchment, one in the River Lee and the other in one of its tributaries, the Big River. The gauging station on the Big River is managed by the Environmental Protection Agency (EPA) whilst the gauging station on River Lee is managed by OPW. The data from Big River gauging station was not available at the time of preparing this report. Only 18 years (1975 to 1992-hydrometric year) annual maximum flow is available from Ballymullen (23012), the gauging station on River Lee. The Ballymullen gauging station records flow from a catchment area of about 62km^2. Because of the limited number of annual maximum flow records available, the flow of events that occurred outside the period of 1975 to 1992 hydrometric years and their associated AEP cannot be estimated.

Event	Peak Flow (m^3/s)	Peak Level (mAOD-Malin)	Estimated Annual Exceedance Probability (AEP) (%)	Flood Extents & Damages	Rank-ing
Recurrence			The recurrence of flood in these areas indicated to be almost annual	Ballinorig: Castleisland to Tralee Road, Caherleheen: N70- Tralee to Castlemaine Ardfert: R551	
18 Feb 2011				Karney's Rd Blennerville. Flooding due to tidal effect.	
19 November 2009		3.3 (1m deep) (flood level at Curragraigue)		Flooding occurred in Curragraigue TD and Ballymullen (Munster Bar Road U171) N70 from Army Barracks to Ballymullen roundabout. The flood affected 6 residential, 1 commercial-Public House in Ballymullen and Local GAA Clubhouse flooded to depth of 300mm in Curragraigue. The flood in Curragraigue disrupted road access to Blennerville.	
13 August 2008		6.3 (0.6m deep) (flood level at Caherweeshee)		Caherweesheen TD, Ballyard, 0.6m deep flood. One house and a farm building were flooded. Access to L6516 affected for a number of hours.	
01 December 2005				Flooding occurred in three areas Ballinorig, Caherleheen, Ardfert	
31 August 1997		3 feet (1.0m)- deep flood at Killarney Road		Tralee Killarney Road, Ardnabraher Ballinorig flooded	
24 Nov 1996				Flooding in Ballyseedy area	
05 August 1986	31.74 (Ballymullen)	7.24 (Ballymullen)	1	Entire business centre of Tralee flooded causing severe damage to shops, offices & private dwellings. Severe flooding in Ballymullen & Castlecountess areas. Roads impassable.	1
02 November 1980	16.94 (Ballymullen)	6.71 (Ballymullen)	42	Ballyseedy, Ballyard, Oakview and the railway yard near Ashe Street flooded. New Ring Road flooded due to surface water. Ballymullen areas – Killerisk, terrace of houses opposite Army Barracks and land near Castlemaine Road flooded.	3
December 1973	-	-	2 (1 in 49 years[1])	Entire business area of Tralee flooded.	2

May 1971	-	-		No flooding details available.	
01 March 1955				No flooding details available.	
25 November 1916				No flooding details available.	
30 November 1924 & 05 December 1924				No flooding details available.	
22-23 January 1925				No flooding details available.	

N.B: unless stated otherwise levels are mAOD-Malin.

[1] Source: McCarthy and Partners Jan 1974 report entitled: Tralee Flooding 1 Dec 1973

Table 8-H Summary of Historical Recorded Flood Events in CAR56 Tralee

8.6.2 Discussion

The recurrence of flood event in the town centre has improved after major drainage works following the severe flooding event of August 1986. However areas outside the town centre appear to be flooded regularly. Most of the floods in Tralee appear to have been caused due to overgrowth in the banks of the river channels, inadequate capacity of culverts along the River Lee and its two tributaries the Big and Balloonagh rivers. In the section below the historical recorded flood events and their causes and sources are described briefly.

Recurrent Flood

Flood events are known to have occurred quite often in two areas around Tralee, namely Ballinorig and Caherleheen, as well as Ardfert, several km northwest of Tralee.

The flooding problem in Ballinorig appears to have been caused by inadequate capacity of a culvert under the N21 Castleisland to Tralee road at Clashlane roundabout which causes a stream to overflow in the vicinity of houses at Ballinorig. The recurrence of flooding in this area is reportedly almost annual.

Flooding in Caherleheen occurs almost once per year, mainly along the N70 (Tralee to Castlemaine) road and the surrounding land. The cause of flooding appears to be heavy rainfall over a long period of time which results in the limestone subterranean caves and caverns overflowing. This is exacerbated in some cases by backwater effects caused by high tides.

In Ardfert the R551 road is flooded 3 to 4 times per year. The flood in this area affects 10 houses. The cause of the flood in this area is surface runoff from steep land at the south east of the village running into the road and lack of adequate drainage to safely collect the runoff. The flooding is not from the Tyshe River which flows just to the north of Ardfert.

February 2011

Flooding occurred in Kearney's Road in the Blennerville area on 18th February 2011 mainly due to tidal flooding in the River Lee Estuary.

November 2009
The flooding in Curragraigue started on 19th November and lasted until 26th November 2009. Exceptional high rainfall caused surface runoff. The existing culvert failed to cope with the excess surface runoff generated. The flood was level estimated to be about 3.3mAOD (1.0m deep).

On the same day the area from Army Barracks to Ballymullen roundabout in Balleymullen was flooded. The flood in this area lasted for a day. Similar to Curragraigue a rainstorm generated surface runoff beyond the capacity of the combined sewer system in the vicinity of this area. The flood affected 6 residential properties and 1 commercial or public property. It also caused major disruption to transport.

August 2008
South West of Tralee Caherweesheen, Ballyard a flooding event was reported on 13 August 2008. The flood lasted for two days. The source of the flood was surface water runoff during exceptionally heavy rainfall which caused overflow of river banks. The capacity of the river was restricted by culverts/pipes along the section of the river. This flood impacted 1 house and a farm building.

August 1997
On 31 August 1997 severe flooding occurred in Tralee area. The Tralee Killarney Road was flooded and closed to traffic at Ballycarthy cross and the Earl of Demon hotel was flooded. Flooding also occurred at Ardnabraher Ballinorig where 3 houses were flooded to a depth of 3 feet.

November 1996
On 24 November 1996 flooding occurred in Balleyseedy. The flooding problem in Ballyseedy area was mainly caused due to overgrowth on the river bank and the narrow nature of the river around this area.

August 1986
Excess rainfall on 5 August 1986 caused the Big River to overflow and burst its bank at a point in the vicinity of the railway station where the channel is culverted under the town. This caused severe flooding in Tralee. The peak flow at Princes Quay and Denny Street at the time of flooding was $10m^3/s$ and $27.5m^3/s$ compared against the design capacity of $9m^3/s$ and $18.2m^3/s$ respectively.

Severe flooding was also experienced in Ballymullen and Castlecountess areas along the main River Lee.

This flooding event coincided with the storm hurricane Charley, a major metrological event that occurred in Ireland in August 1986.

November 1980
On 2 November 1980 flooding occurred in Ballyseedy, Ballyard and on the Big River at Oakview and the railway road near Ashe Street. This event is recorded as a major weather event in http://www.met.ie (the Met Eireann website).

In addition flooding also occurred in Ballymullen at three locations. The first is Killerisk, areas opposite the Army Barrack and Castlemaine road. The flooding in Killerisk was caused due to inadequate capacity of the culvert that discharges runoff from the area to the River Lee. The area around the Trace House opposite the Army Barrack was flooded as a result of over bank flow.

JACOBS

There is a drain on the east side of the Castlemaine road. The drain is crossed by an access road to a private house and a filling station. The culverts under the access road appear to have restricted the capacity of the drain and hence caused flooding to the Castlemaine road.

December 1973

The 1 December 1973 flood event resulted from heavy rains in the previous days which saturated the ground and reduced its capacity to absorb water. The entire business area of Tralee was flooded in some areas the flood reached a depth of about 0.6m.

The coincidence of the heavy rain with a high tide exacerbated the flooding condition in the low lying areas of Tralee. However, the effect of the tide was for a short duration and not major when compared with the fluvial and groundwater flooding.

Detailed information about the 1973 flood in Tralee can be found in the flood study report titled "The Tralee 1st December 1973 Report" prepared by McCarthy & Partners Consulting Engineers January 1974. This report also discusses various options for alleviating flooding problems in the area.

8.7 Tyshe Catchment

8.7.1 Records of Historical Flood Risk

Table 8-I below summarises the CARs in this catchment and sources and causes of flood in each of the CARs. As shown in Table 8-I there is only one CAR in this catchment.

CAR/IRR	County	River	Mechanism of Flooding
CAR10 Banna	Kerry	Tyshe	There is no detail information about the source and cause of flooding in this catchment

Table 8-I Flooding mechanism in the Tyshe Catchment

(a) CAR 10 Banna

There is no major information on historical flooding events for Banna. The only event that has been recorded with its associated water level is shown in Table 8-J below. There is no gauging station in the catchment. Thus the AEP of the recorded flood event has not been estimated.

Event	Peak Flow (m^3/s)	Peak Level (mAOD-Malin)	Estimated Annual Exceedance Probability (AEP) (%)	Flood Extents & Damages	Ranking
03 November 1980	-	4.585 (Banna House)	-	Main Ballyheigue – Ardfert Road flooded.	

N.B: unless stated otherwise levels are mAOD-Malin.

Table 8-J Summary of historical recorded flood events in CAR 10 Banna

8.7.2 Discussion

The November 1980 event was the only recorded flood event in Banna. This flooding was due to the coincidence of the heavy rain with high tides. The main Ballyheigue – Ardfert Road was flooded to a depth of approximately 0.15m (0.5ft).

9 Proposed Methodologies for Future Work

9.1 Introduction

Within the scope of works for the Inception report, the OPW requested that a detailed method statement be provided which sets out the datasets to be used and the approaches to be followed for the hydrometric gauging station rating reviews and in the derivation of design flows. These are provided below.

9.2 Hydrometric Gauging Station Rating Reviews

The OPW have identified three stations (ref. Table 3-G), located within the Tralee Bay – Feale Unit of Management, for which rating reviews are required. For each of these gauging stations an assessment of the quality and limitations of the flood flow data will be made and where necessary the rating adjusted to reduce the uncertainty associated with it. The ratings will be extrapolated to beyond the highest recorded levels and if possible to the highest design flow (0.1% AEP). The methods used are likely to vary between sites depending on the availability of gaugings, survey data and local controls. Section 9.2.2 describes the techniques to be used. For all gauging stations for which a rating review is required, a 1D hydraulic model will be developed. Where the floodplain is too complex to be characterised in 1D a 2D representation will be used based on topographic survey data and 5m SAR data. The reach modelled will extend sufficiently downstream such that any backwater effects within the channel are accounted for, and upstream to take account of approach conditions that could influence the rating.

9.2.1 Data Required

All available data and information made available will be used to assess the quality and uncertainty associated with the high flow ratings. The analysis will build on the work undertaken by Hydro-Logic in 2007 using the information listed below:

- Check flow gaugings;
- Rating equations (historical and current) and associated dates;
- Cross sectional survey data.

9.2.2 Methodology

For all rated gauging stations, the upper range of the stage–discharge rating will be reviewed. A range of techniques will be employed to understand the quality and limitations of the high flow rating as detailed below:

A. An assessment of the quality of the spot flow gaugings, the range in levels over which they have been taken and the frequency of gaugings. This will determine the quality of the underlying data on which the rating is based.
B. Consideration of the limitations imposed by the gauging site i.e the cross section profile, stability, the presence of bypassing, backwater effects etc.
C. Goodness of fit of the rating (as measured by the standard error).
D. Identification of the upper limit in which reasonable confidence can be placed.
E. Identification of any recommendations made in previous review not yet completed.

The findings will be tabulated for each site and an overall classification given on a simple scale according to the confidence that can be placed in the high flow rating.

Extension of Ratings
For the three sites identified in the Brief, hydraulic modelling will be undertaken to extrapolate the stage-discharge relationship to approximately three times the site Qmed. Preliminary investigations of design flows suggests that extending the rating to three times the value of Qmed should ensure that the rating exceeds the 0.1% AEP design peak flow. At each target gauging station, extended cross sectional data will be input to the hydraulic modelling software to develop a representative hydraulic model of the reach and floodplain. The model will be calibrated against the higher check gaugings and then used to develop a high flow rating.

9.3 Design Events

This section describes the data required, the methodology and the outputs from the proposed work to define the hydrological design flows. The design flows will be used in the hydraulic models, developed later in the project, to estimate extreme flood water levels. The method by which the design flows are used in the hydraulic models is also detailed.

9.3.1 Data Required

The following data will be required to complete the design flood estimates in accordance with the methodology set out below:

- Gauging station surveys for the rating reviews (from Survey Contractors);
- Hydraulic models of the gauging stations for rating review (3 gauges in UoM23) (by Jacobs);
- Rating equations and spot flow gaugings for all gauges requiring rating review that are still outstanding (gauging stations 23012, 23014 and 24021) (from OPW and EPA);
- High flow rating reviews (by Jacobs);
- Agreement on the way forward with each of the catchment area boundary anomalies highlighted in this report (Jacobs/OPW);
- Hydrological Estimation Point definitions (by Jacobs).

9.3.2 Methodology

The dearth of sub-daily rainfall records for the catchment severely limit the application and accuracy of traditional rainfall runoff techniques. Rainfall runoff modelling has therefore been discounted. The uncertainty arising in the calibration of such models and the subsequent need to adjust the model flood flow predictions, to align with the flood frequencies derived from local flow gauge records, renders rainfall-runoff modelling ineffective.

The method to be employed will draw upon the techniques set out in the Flood Studies Update (FSU) reports making best use of the gauged data to improve upon the estimates of Qmed, growth curves and the hydrograph shape.

The Hydrological Estimation Points (HEPs) will be determined in accordance with Jacobs Technical Note 10 and the lessons learnt from the trial areas (see Section 4).

The data from the gauging stations detailed in Table 9 of the Stage II Tender Brief will be subjected to high flow rating reviews and on the basis of the review deemed suitable or otherwise for Qmed estimation, derivation of a flood frequency growth curve and dimensionless hydrograph. Cognisance will be given to the gauges used in the FSU to develop the Qmed equation (3 in UoM 23, 1 of which will also be subject to rating review in this project) together with others assessed as being of sufficient quality and/or others which become so after annual maximum flow series are reworked during the rating review (3 in UoM 23).

The reaches of watercourse to be modelled in the main catchments in UoM 23, the Feale, Brick (including the Stream), Galey, Lee (including the Big) are sparsely served by gauges with flow data. However, following the rating review, there should be at least one flow gauge in each of the main catchments able to provide flood flow data (the exception being the modelled section of the watercourse flowing through Aughacasla (if required) although this is not recommended to be designated as an APSR). These will be able to supply useful data to estimate Qmed and the dimensionless hydrograph shapes. The annual maximum flow series for the gauges are detailed on the summary sheets in Appendix H. Also detailed on these summary sheets are the preliminary estimates of Qmed and the dimensionless hydrographs for the highest recorded flows, prior to the rating review.

Specific details of the methodology proposed for each of the main items of the design hydrology are presented below:

Qmed

The objective is to define Qmed at each HEP, in a manner that it is consistent with reliable gauged Qmed data. The method should ensure that the Qmed estimate increases with increasing catchment area unless there is good hydrological justification for this not being the case.

The use of pivotal gauges to refine catchment descriptor Qmed estimates at ungauged sites is, where appropriate, one of the best ways of improving design flow hydrology and is a critical part of the flood frequency estimation process.

The Qmed equation from FSU will be employed to estimate Qmed at each HEP. At gauging stations where we have confidence in the Qmed estimate at the site, following the rating review, this will be compared to the synthetic FSU Qmed estimate and correction factors established for all such gauges. These correction factors will then be applied across the catchment, in the manner described in FSU Report Work Package 2.3 *Flood Estimation in Ungauged Catchments* but importantly employing hydrological knowledge to better judge how to make these adjustments.

Urban adjustments in Ireland will generally be very small in comparison with rural runoff from the catchments discharging to the modelled reaches. A standard approach to taking account of urbanisation is included within the equations for estimating Qmed. With regard to land use change over long time horizons, for large rural catchments the impact of increased urbanisation will generally be extremely small, and will therefore generally be ignored in the derivation of flood discharges for future scenarios. Where catchment areas are small and urbanisation is likely to be significant, urban adjustment to take account of future land use changes will be considered, and applied as necessary.

Growth Curves

The objective is to define a growth curve for each HEP, that is representative of growth curves derived from reliably gauged data, such that the extreme flood discharges increase with increasing catchment area unless there is a good hydrological justification for it not so doing.

Growth curves for Ireland are generally flat and consistent between areas, this reflects the wet nature of the catchments prior to large floods, which tend to be caused by the sequential passage of frontal rainfall systems over the catchments. The Flood Studies Report (UK, 1975) recommended a single growth curve for the whole of Ireland.

In UoM 23 the Gumbel (EV1) distribution fitted to the annual maximum series suggest growth factors to 1% AEP(Q100/Q2) of 2.1 to 2.5 for the Galey catchment, 2.2 for the Feale catchment and 2.0 for the River Lee catchment compared to that implied from the Flood Studies Report (FSR) of 2.06 (Q100/Q2). A growth factor of approximately 2 is very similar to that for the FSU rainfall estimates shown in Appendix D.

Two main approaches are considered to estimate suitable growth curves:

- Gauged annual maximum series fitted to a distribution which can then provide a growth curve for use in the catchment.
- A pooling group approach.

In a subsequent phase of this CFRAM study, Jacobs will decide on the most appropriate statistical distribution for design flood estimation for the unit of management (see Section 7.5). Based on FSU Work Package 2.2 the most likely candidates are the EV1 and lognormal distributions. We feel a consistent growth curve should be a priority for the area, as otherwise anomalies may arise in the magnitude of flood discharges for the more extreme floods as you move down the catchment. Such growth curve data would be examined on a catchment and sub-catchment wide basis to determine whether patterns exist to better inform the selection of an appropriate growth curve.

The procedures set out in FSU Work Package 2.2 will be followed for the pooling group approach. Following liaison with OPW it was decided that these pooling groups should typically contain approximately 500 years of AMAX data, based on the following two considerations:

1. the focus of the design hydrology should normally be on the 100-year design event (as specified by OPW on the National Technical Coordination Group Meeting of 19 June 2012); and
2. FSU Work Package 2.2 recommends that the number of years should be 5 times the design event return period.

Both methods will be trialled for the gauges in the first unit of management to be considered (UoM24). Based on the trial a decision will then be made as to which option to apply on the project.

Growth Curves will be developed to allow the peak flows for design events to be estimated at each HEP for the 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1% Annual Exceedance Probabilities (AEP).

Hydrograph Shape/Volume

The objective will be to use a hydrograph shape which is a reasonable representation of the gauged hydrograph shapes and volumes realised in the catchment. This will then be scaled to match the design flow for a given frequency, estimated as detailed above.

The options are to use a dimensionless hydrograph typical of the largest gauged floods, a non-parametric approach, or to employ a synthetic hydrograph shape where regression-based expressions are used to estimate the values of relevant hydrograph descriptors, following a parametric approach. Both methods are defined FSU in Report Work Package 3.1, Hydrograph Width Analysis.

Where gauged data exists, on the basis that it is better to use gauged data than synthetic data, the former approach will be employed. However, the prescriptive methods outlined in FSU for defining the typical hydrograph shape are rather involved and, given the uncertainties involved in the changing hydrograph shape throughout the catchment, a more subjective method of defining hydrograph shape is considered more appropriate.

On the Feale, Galey, Lee and Brick catchment modelled watercourses, where there is some gauged data the gauged dimensionless hydrographs will be employed. A dimensionless hydrograph shape will be derived for each gauge following the rating review. The typical hydrograph shape broadly being the mean hydrograph shape from a number of the largest floods recorded at the site (similar to those shown on the gauging station summary sheets (see Appendix H).

For smaller ungauged catchments the FSU synthetic hydrograph methodology will be considered but our preference would be to use a suitable transfer of hydrograph shape from gauged hydrographs from catchments with similar catchment descriptors (using FSU descriptors) where possible, as that way gauged data is used to its full potential.

9.3.3 Output

The outputs from the design flood hydrology will be peak flow estimates at each HEP for the 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1% Annual Exceedance Probabilities (AEPs) together with a defined typical flood hydrograph shape for each HEP.

9.3.4 Application to Hydraulic Models

The objective will be to produce a hydraulic model that reproduces the flood hydrographs estimated at each HEP within a reasonable degree of accuracy.

FSU Work Package 3.4, Guidance for River Basin Modelling, describes a method of estimating tributary inflows so as to preserve the flood frequency in the main watercourse when applying FSU techniques to a hydraulic model. However, this method, whilst no doubt appropriate for smaller scale models of a limited extent, will unavoidably lead to errors which will accumulate as different tributary flows contribute throughout a larger system.

We therefore propose an alternative method to preserve the flood frequency along the main watercourse to match the design hydrographs estimated at each HEP. This alternative method is described below and illustrated in Figure 14.

The reaches to be hydraulically modelled will be considered between tributary junctions or, where the space between these results in a difference in catchment area of more than 10%, at intermediate hydrological model nodes. These locations will be coincident with HEPs. Flood hydrograph estimates for the main watercourse immediately upstream of the tributary (Hydrograph B in Figure 14) and upstream of the next tributary/model node (Hydrograph D in Figure 14) will be established as described above (for Qmed, growth curve and hydrograph shape). The difference between the two hydrograph estimates, derived by subtracting the upstream flow estimate from the downstream flow estimate for each hydrograph ordinate, will form the inflow from the tributary/location (i.e. Hydrograph D minus Hydrograph B gives Hydrograph E in Figure 14). The hydraulic model is run with the tributary inflow (Hydrograph E) and inflow at the upstream node (Hydrograph A). The resulting hydrograph from the model (Hydrograph D') is then compared to the hydrograph originally estimated at the downstream nodel (Hydrograph D in Figure 14). The timing of the tributary inflow hydrograph (Hydrograph E in Figure 14) has to be adjusted by trial and error in running the hydraulic model to account for the travel time in the modelled reach. The target is that the peak flow differences are less than approximately 5% (Hydrograph D' compared to Hydrograph D) and that the timing is representative. Additional nodes can be inserted and lateral inflows added (with flows derived using the same method as described here for tributary inflows) to reduce the error between nodes where appropriate. In this manner the design hydrograph peak and shape are preserved within a reasonable degree of accuracy throughout the model. The system is then repeated for any other tributaries requiring inflows to be modelled.

The approach has been successfully applied to the Lower River Thames for the Thames Region of the Environment Agency in the UK.

JACOBS

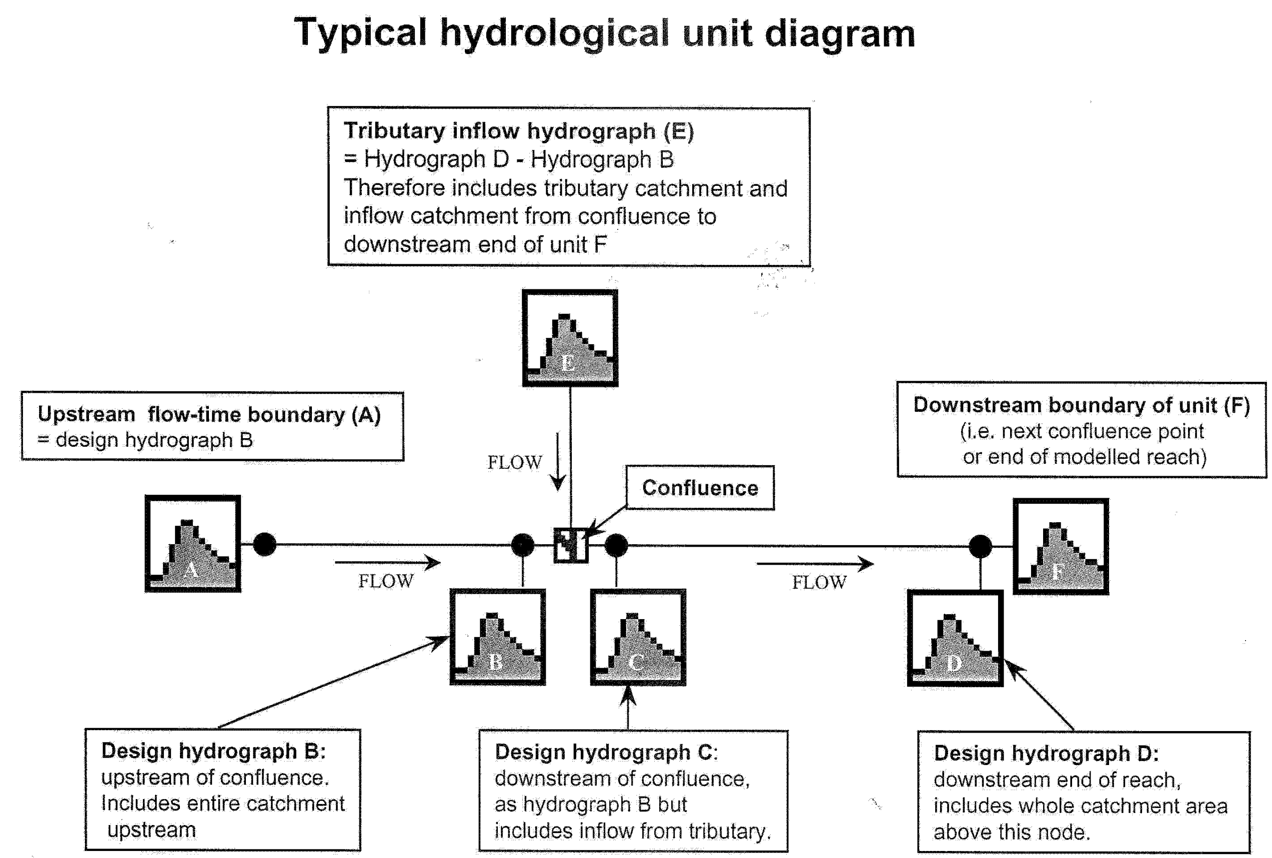

Figure 14 Typical Model Hydrograph Method

9.4 Joint Probability

Section 6.5.6 of the Brief requires a joint probability analysis. However, Section 7.5.2.1 requires mapping to indicate fluvially dominated extents and tidally dominated extents, and a merged map showing both.

Joint Probability is a complex issue that would benefit from the pooling of ideas and concepts from all members of the NTC Group. We therefore suggest that the most appropriate methodology is discussed and agreed through the NTC Group forum. This will ensure that a consistent approach is adopted. However, the Group is not yet fully developed and functioning. There remains a need to resolve the combinations of flows and sea levels to be run, as we have commenced modelling and require the information in order to proceed with the study.

Jacobs will therefore make use of the results of the Joint Probability Analysis carried out by Halcrow for the Lee Catchment study. Halcrow followed the Defra/EA guidance on joint probabilities and adopted a conservative approach, assuming a high level of dependence between surge and fluvial levels. The study resulted in a joint probability table, which gives design scenarios (in the form of pairs of fluvial and tidal exceedance probabilities) for each joint probability. For each joint probability two design scenarios are given, representing the fluvially dominated and the tidally dominated conditions. All tidally affected hydraulic models will be run with both design scenarios for each joint probability, and the highest water level will be adopted as the design level.

9.5 Hydraulic Model Calibration

A proposed approach to hydraulic model calibration was set out in Section 7.4.2 of the Jacobs Stage 1 Tender Response. We propose to follow this methodology.

The limited amount of short duration rainfall data available in the region indicates that rainfall-runoff modelling will not provide the required confidence in the temporal distribution of rainfall and hence flows. We shall therefore make best use of any reliable observed data to calibrate the hydraulic models, where this exists.

The hydraulic models will provide design flood flow and level frequency estimates that can be compared with gauged and observed data, and/or implied flood frequency, as a check on the modelled estimates. These comparisons are a vital reality check on the model, particularly where flood data is sparse.

9.6 Coastal Flood Modelling

9.6.1 Tide and Surge

OPW have provided the results from the Irish Coastal Protection Strategy Study (ICPSS). This gives extreme tidal peak levels for the following annual probabilities: 50%, 20%, 10%, 5%, 2%, 1%, 0.5%, 0.1% for the south western coast and the Shannon Estuary.

Tidal curves will be generated using mean spring tidal cycles obtained at Carrigaholt, Foynes and Limerick from the Shannon Foynes Port Company and the Admiralty Report. To develop the extreme tide/surge hydrographs, a surge event of 30 hrs will be assumed. Then ICPSS extreme peak levels together with the

assumed surge event profile and the mean spring tide levels will be used to create the tide/surge hydrographs associated with each annual probability event. This process is illustrated on Figure 15. The Mean High Water Springs (MHWS) tide levels will be chosen according to the geographic position of the sites under consideration relatively to the three tidal record locations mentioned above.

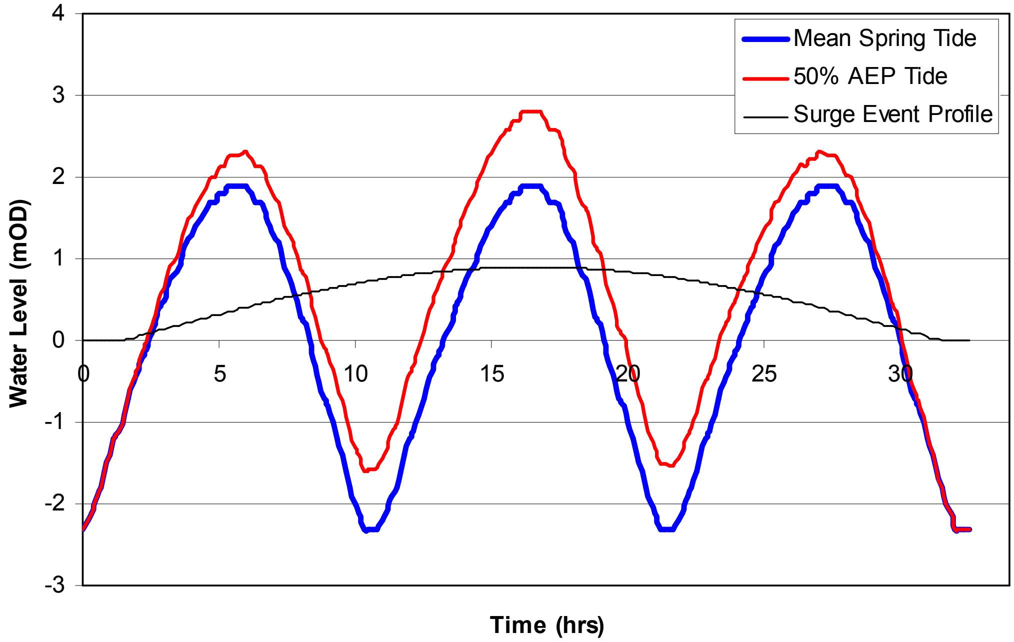

Figure 15 Tide/Surge Hydrograph

For model sections where both tidal levels and fluvial flows affect the risk of flooding, a joint probability approach will be needed. This is discussed above in Section 9.4.

9.6.2 Wave Overtopping

Wave overtopping will be considered separately from tidal overtopping for tide/surge events where the tide+surge levels for the design events under consideration do not cause overtopping of the coastal defences, but the additional wave action would cause a flow across the defences that has the potential to cause flooding.

OPW has provided results from the ICWWS (Irish Coastal Wave & Water Level Modelling Study) screening analysis which highlight coastal locations potentially vulnerable to wave overtopping for the south western coast and the Shannon estuary.

For these locations, detailed wave and still water level model outputs are available in the form of shoreline prediction points and their associated predicted water level and wave climate (wave height H_{mo}, period T_p and mean direction) combinations for a range of annual probabilities (50%, 20%,10%, 5%, 2%, 1%, 0.5% and 0.1%). These outputs include both the current condition and two future scenarios (Mid Range Future Scenario [MRFS] and High End Future Scenario [HEFS]).

ICWWS data will be used in the coastal flooding models developed for this study to simulate flooding from wave overtopping of coastal defences for the design flood events.

The following paragraphs detail the proposed methodology to simulate flooding from wave overtopping using the coastal flooding models developed for this study.

Site selection
OPW has supplied eight locations which are potentially vulnerable to wave overtopping, and where modelling has been requested to simulate flooding arising from wave overtopping of coastal defences. These sites are:

- AFAs: Limerick, Shannon, Kilrush, Kilkee, Foynes and Tralee
- IRRs: Shannon Airport and Tarbert Power Station

For those sites for which appropriate data ia provided, in agreement with OPW, we will undertake wave overtopping modelling. At each site, coastal defences are likely to vary in height, type and orientation relative to the mean direction of the incident waves. We will divide the coastal defences prone to wave overtopping in discrete reaches of similar characteristics and allocate a wave prediction point according to its geographic proximity and the mean direction of the incident waves.

Wave characteristics selection for the selected reaches of coastal defence
For each flood event annual probability, ICWWS data consists of six combinations of extreme coastal water levels with predicted significant wave heights (H_{mo}), peak wave period (T_p) and mean wave direction. We will choose one combination for which the extreme water level is the closest to the average elevation of the stretch of defence identified whilst remaining below it. We will then calculate the mean overtopping discharge (in m^3/s per m of coastal defence length) associated with the wave characteristics and the type of flood defence (sea dikes, embankments, vertical wall) involved. This calculation will be undertaken using the online tool available from the Overtopping Manual (EurOtop, 2007).

Generating a wave overtopping discharge hydrograph for the selected reaches of coastal defences
As quoted from the overtopping manual, "*in reality there is no constant discharge over the crest of a defence during overtopping. The process of wave overtopping is very random in time and volume*". A simplified approach is proposed here to generate a wave overtopping discharge hydrograph (flow vs. time) that will be input in the coastal flooding model at the landward side of the structure.

As illustrated in Figure 16 below, a wave overtopping discharge hydrograph will be generated assuming a 30-hour storm surge duration. Overtopping will occur when the selected wave height superimposed on the tide level exceeds the average elevation of the defence. During these overtopping periods, half of the mean overtopping discharge calculated above will be applied. This is because the wave height is at a maximum at the peak of the tide, but reduces to zero either side of the peak. On average, half the overtopping flow computed at peak tide can be assumed to flow over the defence, between the time of initial overtopping (some time prior to the peak tide) to the time overtopping ceases (some time after the peak tide). The time over which overtopping occurs is dependent on the tidal level and wave height selected.

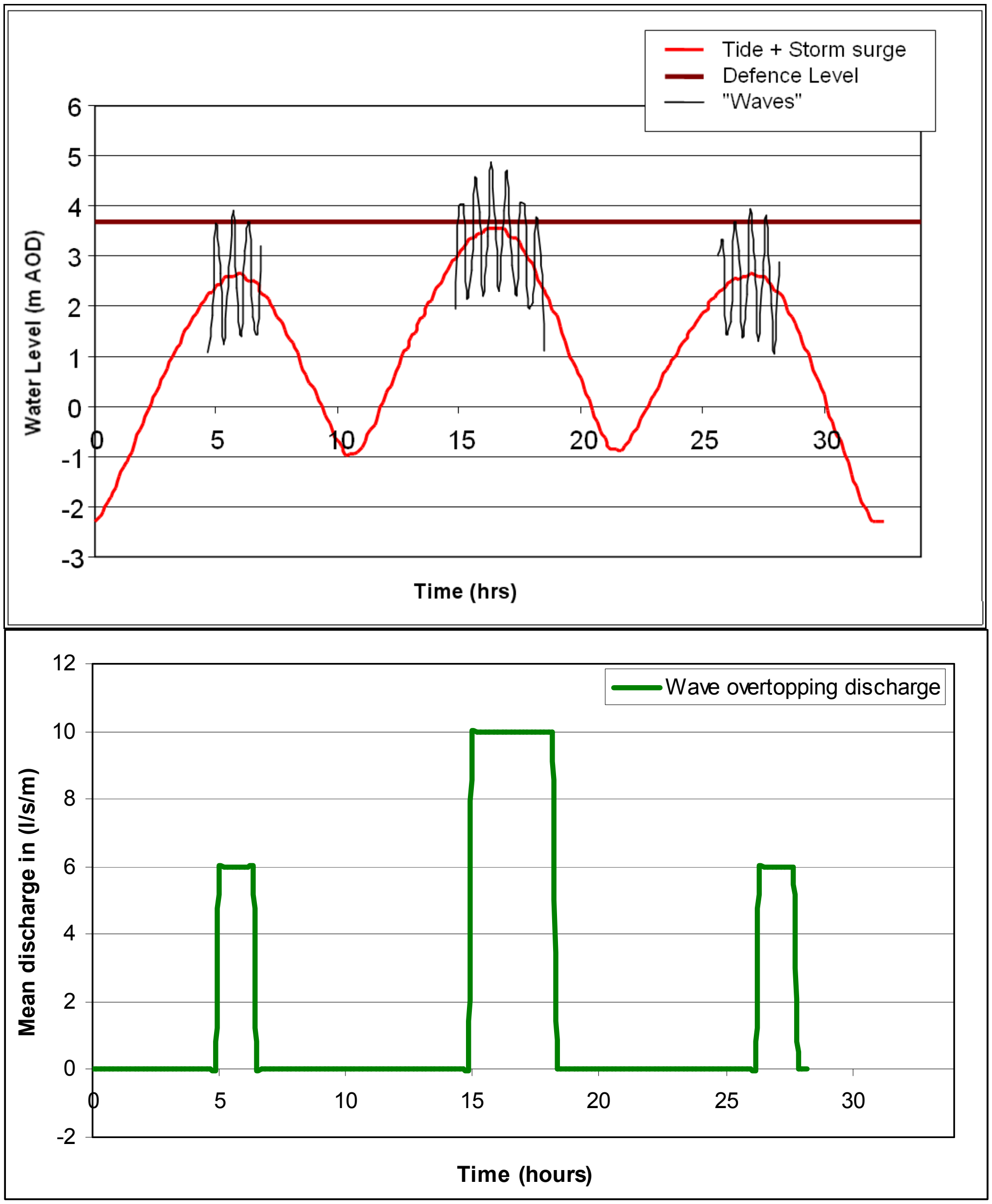

Figure 16 (a and b) Wave overtopping hydrograph

It should be noted that if, for a given annual probability event, the tidal levels for all six wave - water level combinations (as described above) exceed the average elevation of the coastal defence reach, no simulation of flooding arising from wave overtopping will be carried out for this event. This is because the results will be represented by the separate tidal inundation modelling.

10 Constraints, Data Problems and Other Issues

A complete list of gauging stations for which data is available can be found in Appendix A.

As outlined in Section 3.2 data collation at this stage has focused on the key hydrometric stations, but where data has not been provided for other stations, this may still be requested at a later stage in the project. Several daily and instantaneous flow and level series for the key hydrometric stations have not yet been received (Table 10-A). Confirmation of whether the relevant data series exists is requested in the first instance.

There is no cost implication associated with the lack of provision of the data below, however, any lack of data may have an impact on the uncertainty and quality of the derived flood flow estimates, hydraulic model calibration and validation and rating reviews, all of which are programmed to be undertaken in the next phases of the project.

Station number	Data holder	Daily mean flows outstanding	Instantaneous flow data outstanding	Staff gauge readings outstanding	Check gaugings outstanding	Rating equations outstanding
23011	OPW	Yes	Yes			
23012	OPW			Yes		
23014	EPA	Yes		Yes	Yes	Yes
23021	EPA	Yes		Yes	Yes	Yes
23022	EPA	Yes				
23030	OPW	Yes	Yes			

Table 10-A Outstanding hydrometric data for Tralee Bay – Feale Unit of Management (UoM 23)

The lack of sub daily rainfall data for the Unit of Management precludes the use of rainfall-runoff modelling. Alternative methods are proposed, as set out in Section 9 of this report. These may give rise to difficulties in future use to examine the potential impacts of land use change, although sensitivity analysis could be used to overcome these difficulties.

11 Conclusions

In order to avoid abortive work the definition of Hydrological Estimation Points (HEPs) has been postponed until the Flood Risk Review has been completed and the final list of Areas of Potential Significant Risk agreed with OPW. However, the results of a trial application of the proposed method to define HEP are presented herein together with lessons learned.

Catchment areas, defined using a range of datasets, have been compared and the comparison reported where catchment areas to gauging stations and Communities at Risk exceed 10%. No significant discrepancies were identified for Unit of Management 23.

A review of rainfall and flow gauges in the catchment has been undertaken and specific flood events studied to better understand the data and provide a hydrological understanding of the data for use in subsequent phases of the project.

Fifteen Met Éireann daily storage raingauges have been identified within the Tralee Bay - Feale Unit of Management, although four of these were immediately excluded from further study due to significant periods of missing data. In the absence of any Met Éireann sub-daily raingauges, the potential does exists to use a rainfall sensor installed and managed for the National Roads Authority, however, this will require further investigation to assess its suitability. The lack of sub-daily rainfall at this stage in the analysis has limited the durations analysed and subsequently the conclusions able to be drawn.

Three rainfall events have been studied across the unit of management, August 1986, October 1989 and November 2009. The events selected for analysis were the same events selected in the fluvial analysis. Rainfall depths were summed for four durations for each event, 1 day, 2 day, 4 day and 10 day.

Cumulative rainfall depths from across the unit of management indicate rainfall totals are over the long-term highest at station 509 on the Dingle Peninsula. Rainfall events analysed in detail appear to reflect both winter depressions, characterised by a moderately intense rainfall event preceded by prolonged rainfall, and summer convective rainfall characterised by high intensity short duration rainfall.

Annual exceedance probabilities for the 1 day and 4 day duration rainfall depths were estimated based on probability plots developed from annual maxima series derived from the rainfall record. The annual maxima series was plotted according to Gringorten and fitted to the Gumbel distribution.

The lowest annual exceedance probabilities estimated for the 1-day duration were between 4-6% for all three raingauges (1509, 2009 and 2310) during the August 2009 event. While the lowest 4-day probabilities estimated for rainfall totals over a 4-day duration were during the November 2009 event, where AEPs of 6 and 8% were estimated for rainfall recorded at stations 1509 and 2010.

Annual exceedance probabilities estimated from actual data for the 1 day and 4 day durations compared to theoretical AEPs for the same durations derived for the Flood Studies Update typically varied. FSU AEP estimates were significantly higher at stations 1509, 2009 and 2310. The only value for which a lower FSU AEP was estimated was for the 4-day duration rainfall at station 2010 where 7% was

estimated for the FSU compared to 8% from the annual maxima series. These differences may reflect the fit of the EV1 distribution selected here compared to the log logistic growth curve assumed in the FSU.

Fluvial data has been analysed across the Tralee Bay – Feale Unit of Management. Initially, daily mean flows, where available for three hydrometric stations, were reviewed for long-term errors or trends. Only two records were long enough to be conclusive. A trend in the water level and flow was observed at station 23001 between 1968 and 1978 after which the record stabilises. A rise in water levels is evident at station 23002 leading to a step change in 1974 – 1976. Hence, the older annual maximum series for both gauges will only be considered cautiously.

Instantaneous flow data was provided for five gauging stations. Three flood events were selected across the unit of management to analyse series in detail. Limited data availability forced the selection of two events in the 1980s together with the 2009 flood:

- 6 August 1986
- 28 October 1989
- 19 November 2009

Hydrographs from gauges 23002, 23017 and 23022 indicated a highly responsive catchment, as demonstrated by steep rising limbs and steep recessions. Flows gauged at 23001 and 23012 were much less responsive with gentler hydrograph rising limbs and recessions.

Highest peak flow in the three events was 670.1 m^3/s recorded on 19th November 2009 at Listowel on the River Feale (23002).

Runoff within the Tralee Bay-Feale Unit of Management was consistently the highest at station 23002 on the River Feale, however runoff values were similarly high for the River Galey at Inch Bridge (23001), River Smearlagh at Trienearagh (23017) during the November 2009 event.

Annual exceedance probabilities estimated for each event suggested a range of values across the catchment. The lowest AEP estimated was 1% for the River Lee at Ballymullen for peak flows recorded during the August 1986 event. AEP estimates for the three events on the River Feale at Listowel ranged from 3% (August 1986) to 27% (October 1989); and for the River Galey at Inch Bridge between 5% (November 2009) to 35% (August 1986).

Methodologies for the hydrometric gauging station rating reviews procedure to be applied to three gauges in the catchment and for the design flow estimation methods have been proposed together with the design event hydrological methodology to be adopted for the study. A traditional rainfall-runoff modelling approach is not considered practical due to the lack of short duration rainfall data within the catchment.

Consideration of the tidal issues has concluded that Joint Probability is a complex issue that would benefit from the pooling of ideas and concepts from all members of the NTC Group. We therefore suggest that the most appropriate methodology is discussed and agreed through the NTC Group forum. This will ensure that a consistent approach is adopted.

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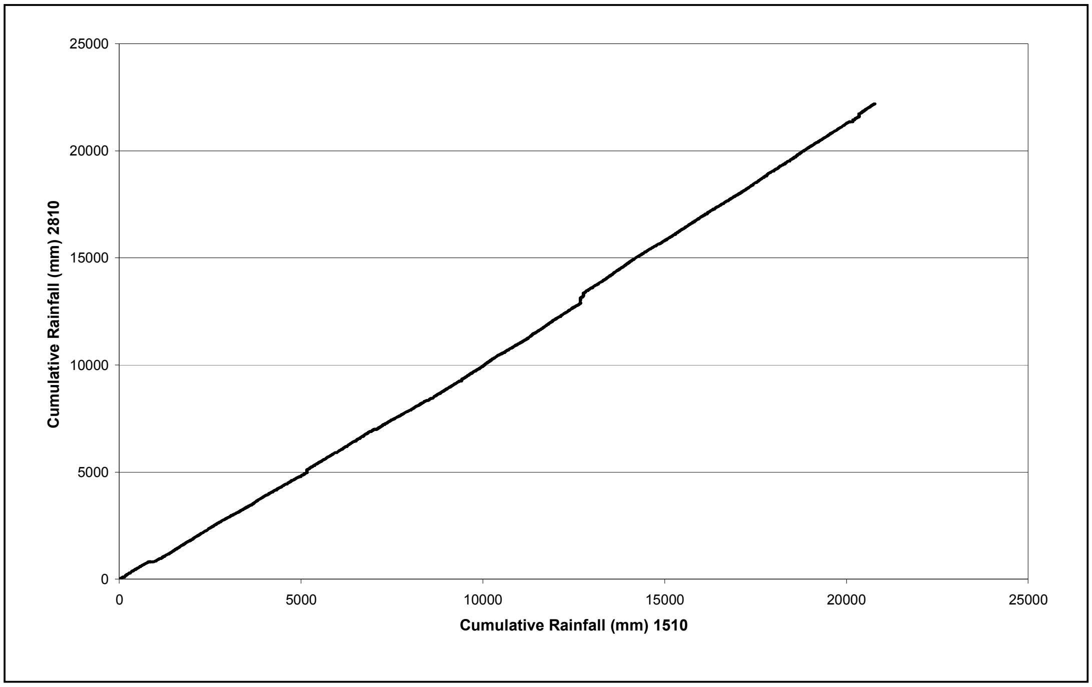
Appendix A - All Hydrometric Stations listed in EPA Register

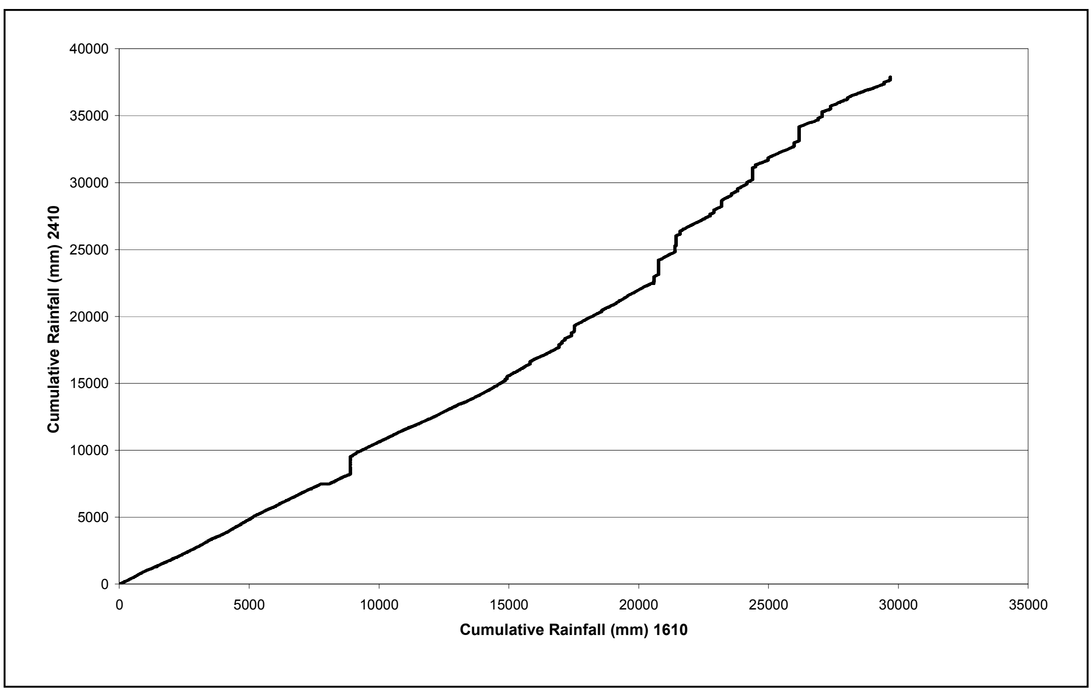
Station number	Station name	Waterbody	Catchment Area (km2)	Station status	Station type	Available data	BDS	Easting	Northing	Type	Record start	Record End	Telemetry
23001	Inch Br.	Galey	191.7	Active	Recorder	Water Level and Flow	Office of Public Works	95729	136181	River	01/03/1949		Yes
23002	Listowel	Feale	646.8	Active	Recorder	Water Level and Flow	Office of Public Works	99700	133295	River	01/10/1946		Yes
23004	Galey Br.	Galey	124.1	Inactive	Staff Gauge Only	Flow Measurements	Office of Public Works	104397	138385	River			No
23005	Goulburn	Allaghaun	62.1	Inactive	Recorder	Water Level and Flow	Limerick County Council	116842	126378	River	08/03/1976	18/09/2007	No
23006	Neodata	Feale	303.7	Active	Recorder	Water Level and Flow	Limerick County Council	111311	126860	River	23/03/1976		Yes
23007	Oolagh Rly. Br.	Oolagh	33.1	Active	Recorder	Water Level and Flow	Limerick County Council	111179	127783	River	26/02/1976		Yes
23008	Knockaunbrack	Smearlagh	80.6	Inactive	Recorder	Water Level and Flow	Kerry County Council	101375	125495	River	12/07/1977	17/07/2008	No
23009	Listowel Weir	Feale	657.7	Inactive	Staff Gauge Only	Flow Measurements	Kerry County Council	96017	132857	River	02/07/1975	13/09/1977	No
23010	Abbeyfeale	Feale	417.3	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	111106	127255	River	11/06/1975	04/09/1981	No
23011	Ballycarty	Lee (Kerry)	23.3	Inactive	Recorder		Office of Public Works	88682	112716	River	01/10/1959	01/07/1991	No
23012	Ballymullen	Lee (Kerry)	61.6	Active	Recorder	Water Level and Flow	Office of Public Works	84512	113339	River	01/04/1974		Yes
23013	Oakview	Big (Kerry)	83.6	Inactive	Staff Gauge Only	Flow Measurements	Office of Public Works	82832	113777	River			No
23014	Athea	Galey	36.2	Active	Staff Gauge Only	Flow Measurements	Limerick County Council	112498	135418	River	26/04/1978		No
23015	Tour Br.	Allaghaun	29.3	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	122129	124703	River	14/09/1977	12/02/1998	No

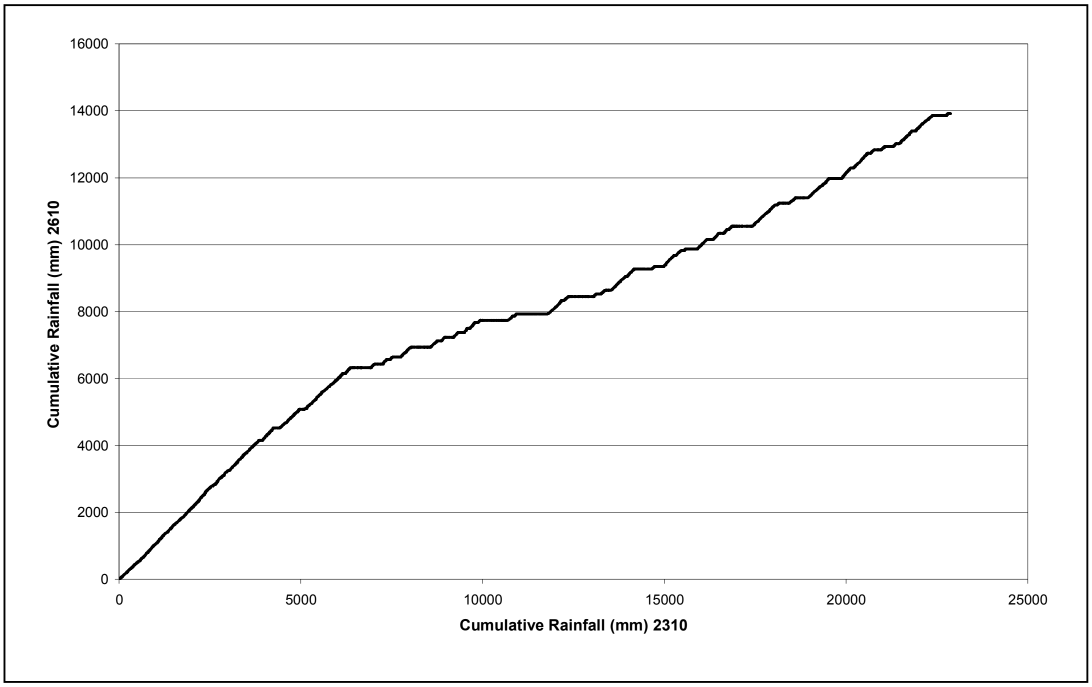
Station number	Station name	Waterbody	Catchment Area (km2)	Station status	Station type	Available data	BDS	Easting	Northing	Type	Record start	Record End	Telemetry
23016	Mountcollins	Feale	101.7	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	115735	118818	River	08/07/1975	17/04/1984	No
23017	Trienearagh	Smearlagh	119.1	Active	Recorder	Water Level and Flow	Kerry County Council	101355	131340	River	10/06/1981		No
23018	Brosna	Clydagh (Kerry)	39.1	Active	Staff Gauge Only	Flow Measurements	Kerry County Council	113209	118766	River	21/07/1981		No
23019	Beheenagh	Owveg	72.2	Inactive	Staff Gauge Only	Flow Measurements	Kerry County Council	107830	122184	River	23/07/1981	17/11/1994	No
23020	Kilflynn	Shannow	19.2	Inactive	Staff Gauge Only	Flow Measurements	Kerry County Council	89313	123089	River	04/07/1984	07/01/1997	No
23021	Shannow Br.	Shannow	30.0	Active	Staff Gauge Only	Flow Measurements	Kerry County Council	86372	123773	River	27/01/1966		No
23022	Tralee Clonalour	Big (Kerry)	10.9	Active	Recorder	Water Level and Flow	Tralee Urban District Council	83918	114672	River	15/11/1985		No
23023	Stradbally	Stream	3.8	Active	Staff Gauge Only	Flow Measurements	Kerry County Council	59178	112360	River	06/09/1985		No
23024	Duagh	Glosha	1.3	Inactive	Staff Gauge Only	Flow Measurements	Kerry County Council	106066	129568	River	23/10/1985	15/04/1996	No
23025	Listowel S.W	Feale	658.9	Inactive	Staff Gauge Only	Flow Measurements	Kerry County Council	95216	132159	River	31/05/1990	22/10/1997	No
23026	Cloghane	Owenmore	29.8	Inactive	Staff Gauge Only	Flow Measurements	Kerry County Council	51297	110858	River	30/05/1990	13/02/2008	No
23027	Ballyganneen	Feohanagh	28.4	Inactive	Staff Gauge Only	Flow Measurements	Kerry County Council	40131	110208	River	30/05/1990	05/07/2007	No
23028	Aghacasla	Owencashla	16.2	Inactive	Staff Gauge Only	Flow Measurements	Kerry County Council	64507	111260	River	30/05/1990	19/10/2000	No
23029	Temple Glentan	Eeghanun Stream	18.5	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	119737	127789	River	16/06/2003	20/02/2007	No
23030	Sleveen Main Channel	Brick		Active	Recorder	Water Level Only	Office of Public Works	88716	132448	River	19/03/1998		Yes

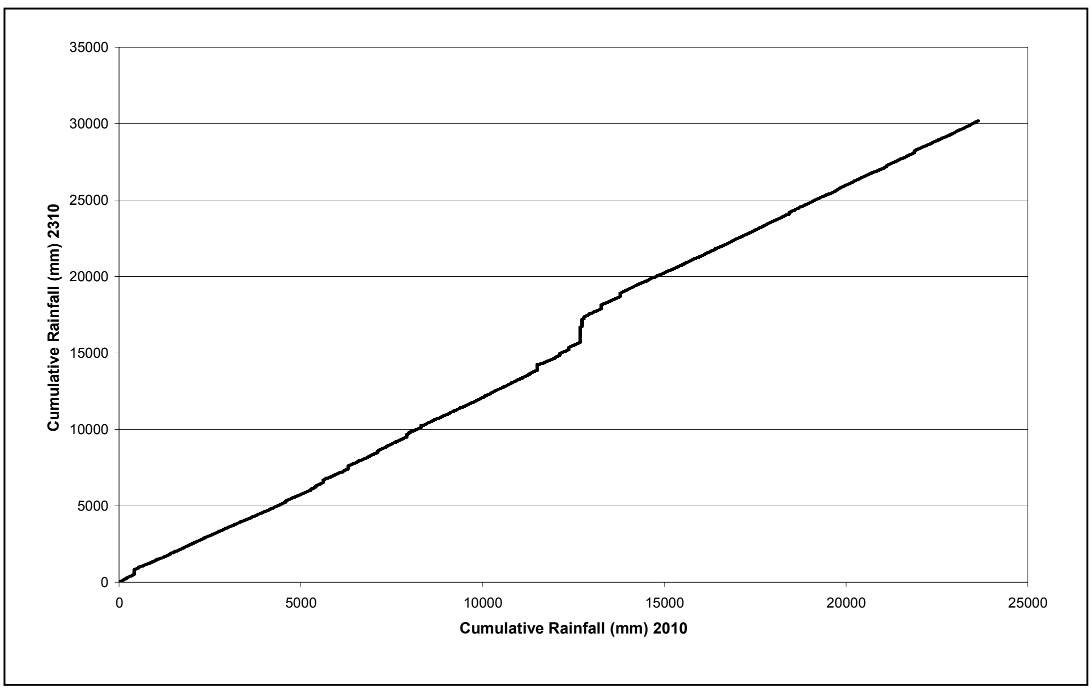
Station number	Station name	Waterbody	Catchment Area (km2)	Station status	Station type	Available data	BDS	Easting	Northing	Type	Record start	Record End	Telemetry
23031	Poulnahaha	Feale		Inactive	Recorder		Office of Public Works	93453	131151	River	26/03/1998	30/10/2009	No
23032	Lisnagoneeny	Stream		Inactive	Recorder		Office of Public Works	86842	132009	River	12/03/1998	08/03/2005	No
23033	Sleveen Back Channel	Brick		Inactive	Recorder	Water Level Only	Office of Public Works	88707	132455	River	19/03/1998	08/03/2005	No
23034	Lixnaw	Brick		Inactive	Recorder	Water Level Only	Office of Public Works	89015	128926	River	19/03/1998	08/03/2005	No
23035	Ratoo Road	Stream		Inactive	Recorder	Water Level Only	Office of Public Works	88207	133546	River	01/09/2002	08/03/2005	No
23036	Ratoobank	Stream		Inactive	Recorder	Water Level Only	Office of Public Works	88728	133478	River	01/09/2002	08/03/2005	No
23037	Drumroe	Stream		Inactive	Recorder	Water Level Only	Office of Public Works	85300	130900	River	19/03/1998	11/07/2002	No
23038	Cloneen	Stream		Inactive	Recorder	Water Level Only	Office of Public Works	84400	130400	River	19/03/1998	11/07/2002	No
23061	Ferry Br.	Feale Esty	1,116.7	Active	Recorder	Water Level Only	Office of Public Works	89068	136468	Tidal	01/10/1946		Yes
23062	Blennervillw	Lee Esty	99.1	Active	Recorder	Water Level Only	Office of Public Works	81288	113043	Tidal	01/06/1960		Yes
23063	Ballyard	Lee Esty	17.7	Active	Recorder	Water Level Only	Office of Public Works	82997	113818	Tidal	01/04/1974		Yes
23064	Akeragh Sluice D/S	Akeragh		Inactive	Recorder	Water Level Only	Office of Public Works	75130	124889	Tidal	01/03/1980	01/02/1983	No
23065	Akeragh Sluice U/S	Akeragh		Inactive	Recorder	Water Level Only	Office of Public Works	75139	124900	Tidal	01/03/1980	01/02/1983	No
23067	Doon Bay	Sea		Inactive	Recorder	Water Level Only	Office of Public Works	86300	143400	Tidal	01/09/1950	01/06/1969	No
23068	Moneycashen	Feale Esty	2.2	Active	Recorder	Water Level Only	Office of Public Works	85850	138096	Tidal	01/10/1980		Yes

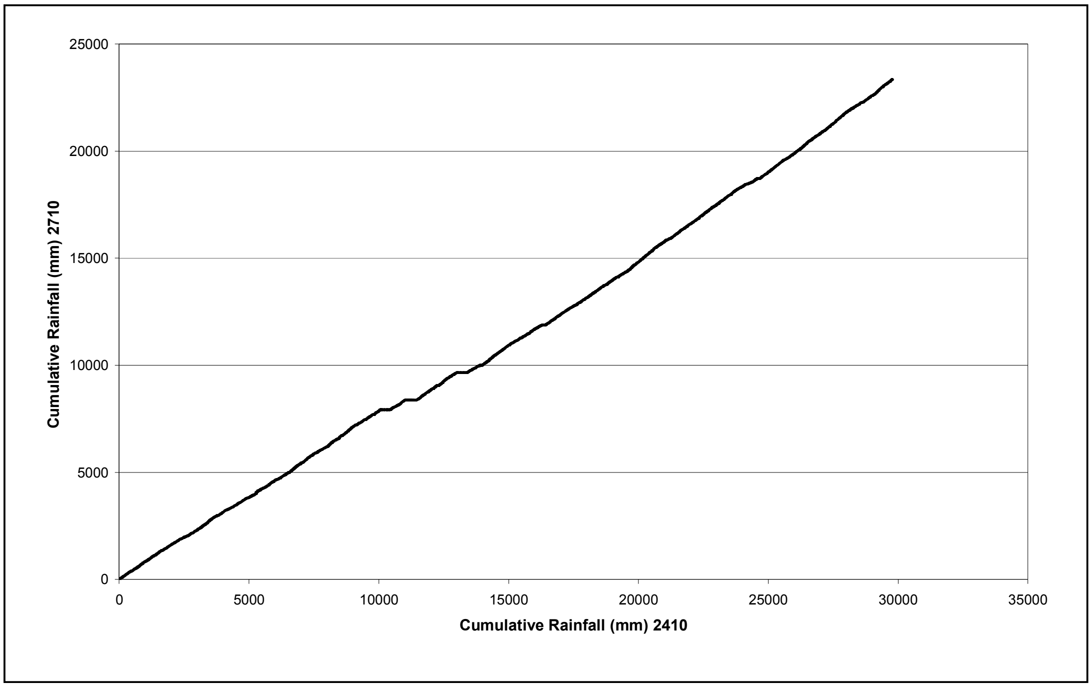
Appendix B - Double Mass Rainfall Plots

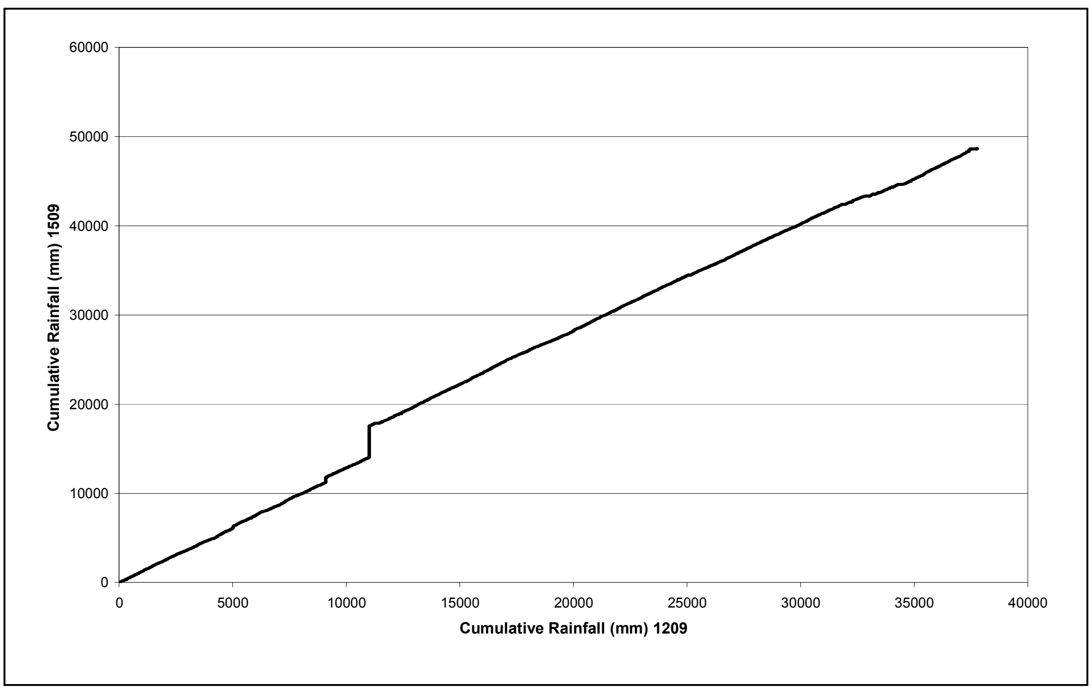


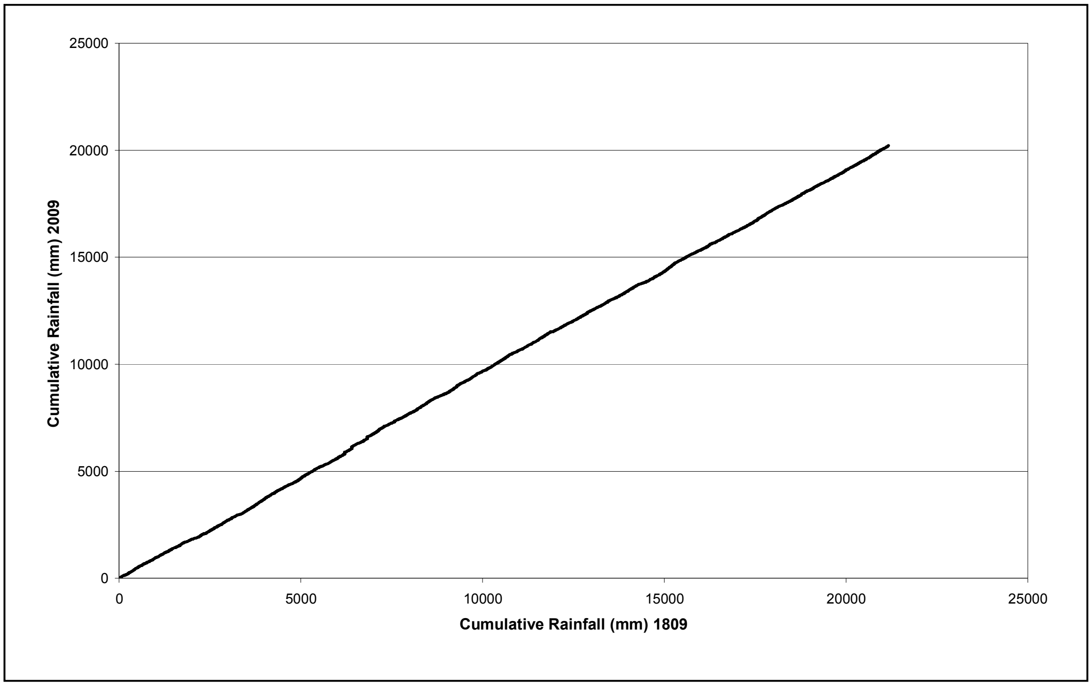



Cumulative Rainfall (mm) 2610
Cumulative Rainfall (mm) 2310
0
2000
4000
6000
8000
10000
12000
14000
16000
0
5000
10000
15000
20000
25000

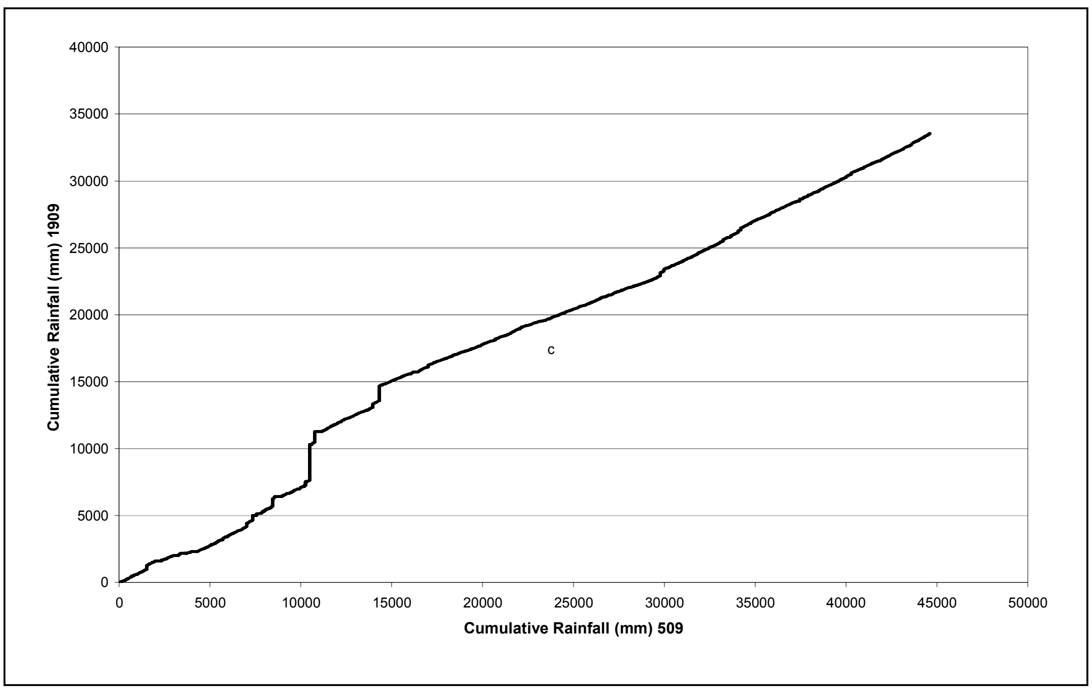

Cumulative Rainfall (mm) 2310
Cumulative Rainfall (mm) 2010
0
5000
10000
15000
20000
25000
30000
35000
0
5000
10000
15000
20000
25000


25000
20000
15000
10000
5000
0
Cumulative Rainfall (mm) 2710
0
5000
10000
15000
20000
25000
30000
35000
Cumulative Rainfall (mm) 2410

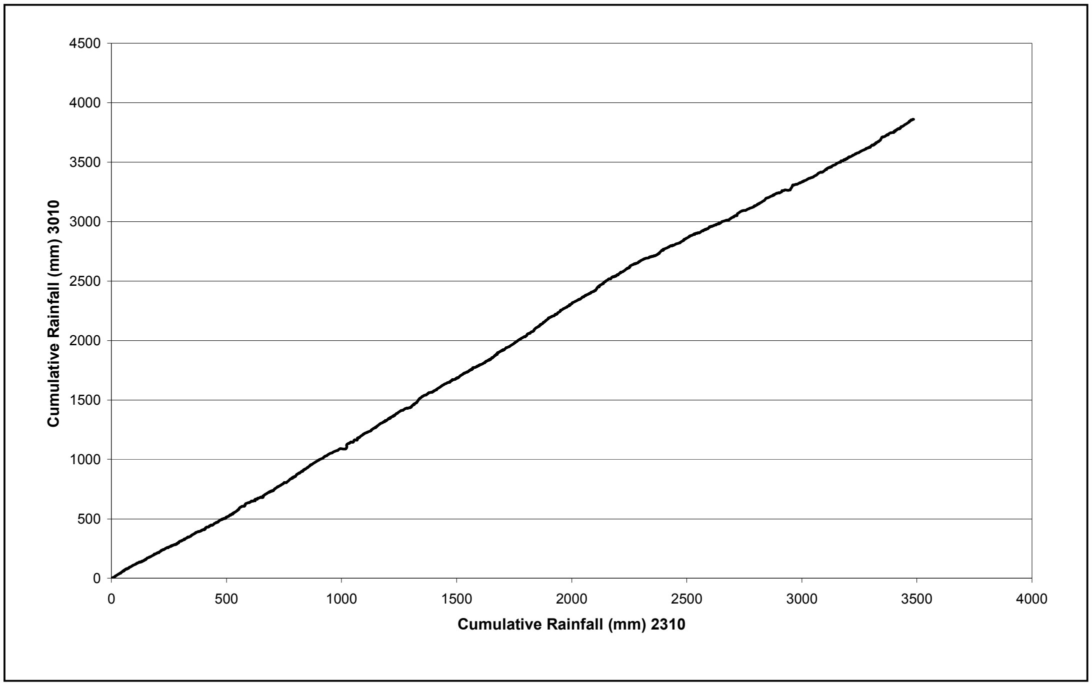

60000
50000
40000
30000
20000
10000
0
Cumulative Rainfall (mm) 1509
0
5000
10000
15000
20000
25000
30000
35000
40000
Cumulative Rainfall (mm) 1209

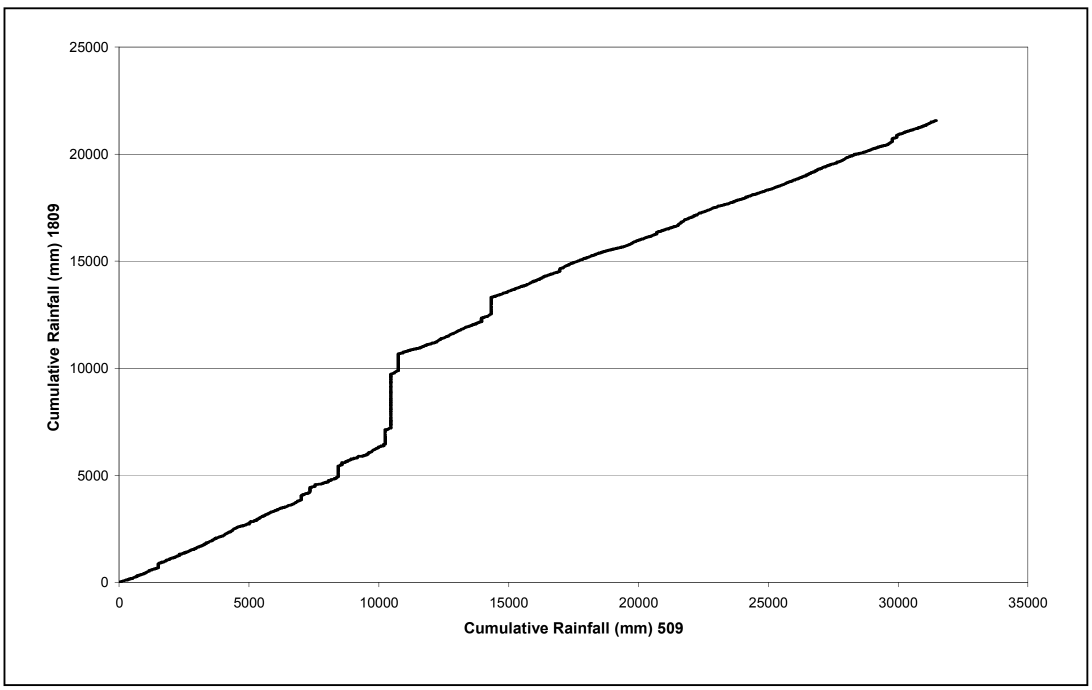


Cumulative Rainfall (mm) 2009
Cumulative Rainfall (mm) 1809

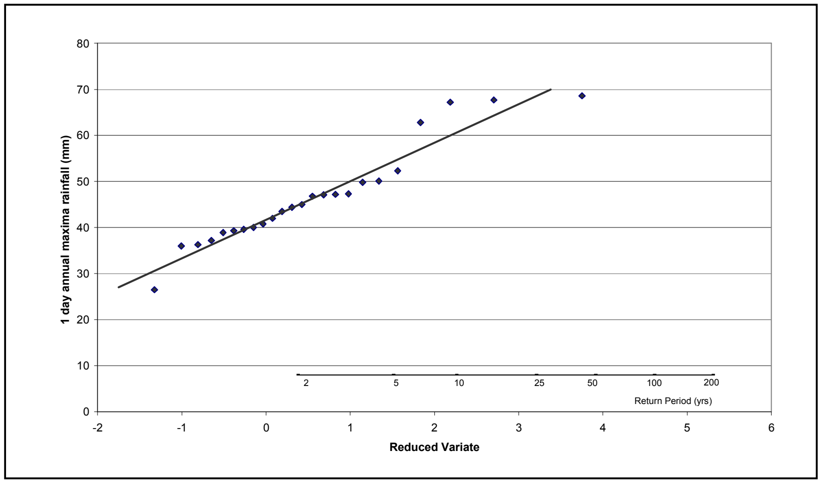


Cumulative Rainfall (mm) 1909
c
Cumulative Rainfall (mm) 509

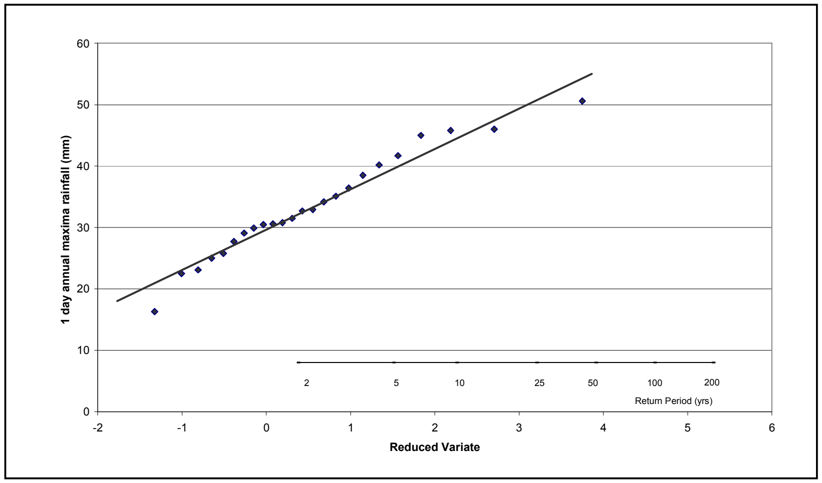

4500
4000
3500
3000
2500
2000
1500
1000
500
0
Cumulative Rainfall (mm) 3010
0
500
1000
1500
2000
2500
3000
3500
4000
Cumulative Rainfall (mm) 2310


25000
20000
15000
10000
5000
0
Cumulative Rainfall (mm) 1809
0
5000
10000
15000
20000
25000
30000
35000
Cumulative Rainfall (mm) 509

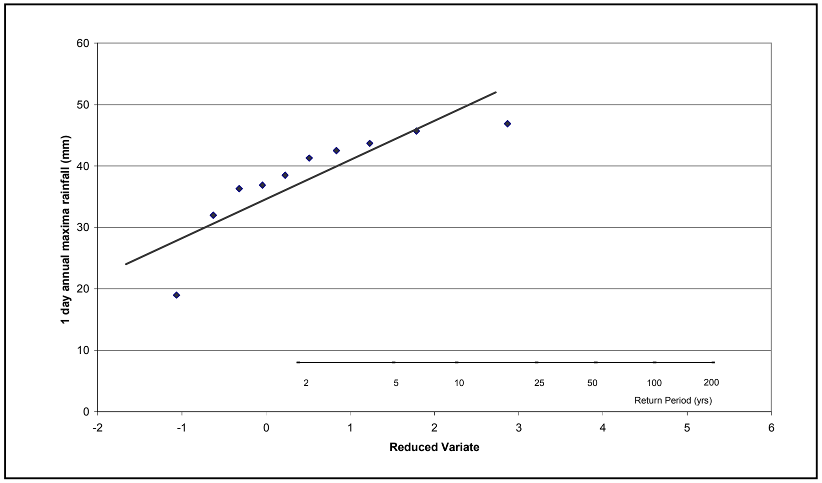
Appendix C - 1 day and 4 day Rainfall Probability Plots



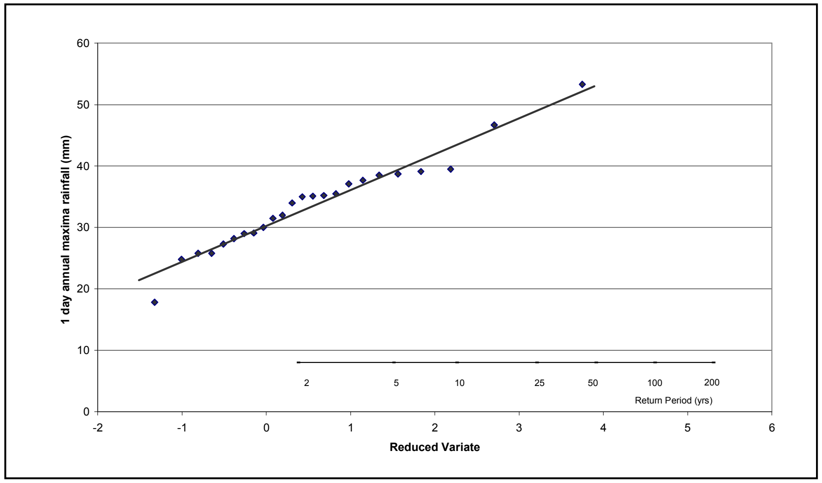
a) Raingauge 1509 – Tralee (Lisaboula)



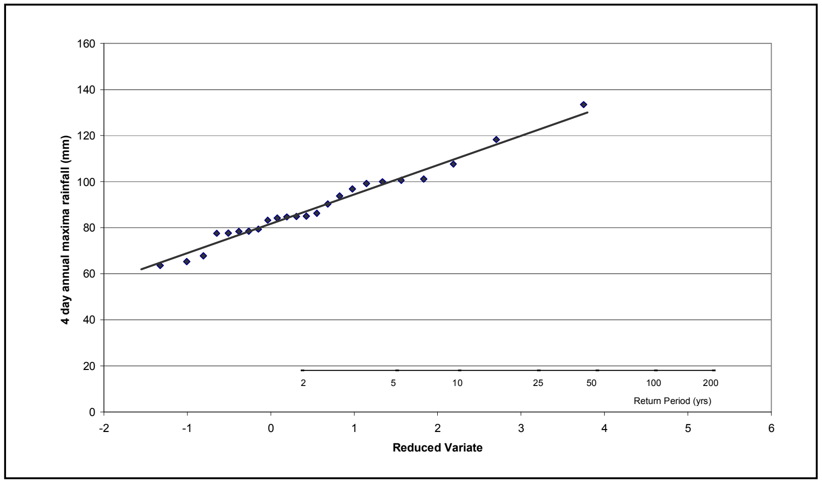
b) Raingauge 2009 – Ardfert Ballymacquinn



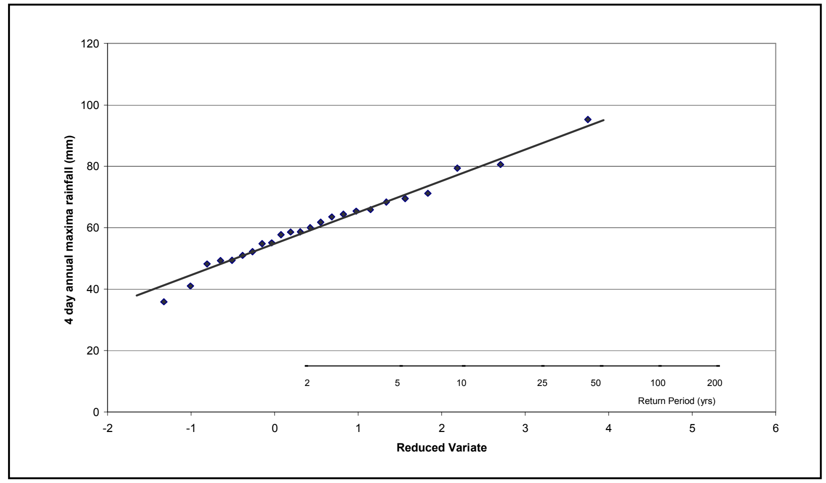
c) Raingauge 2010 – Listowel (Inch)



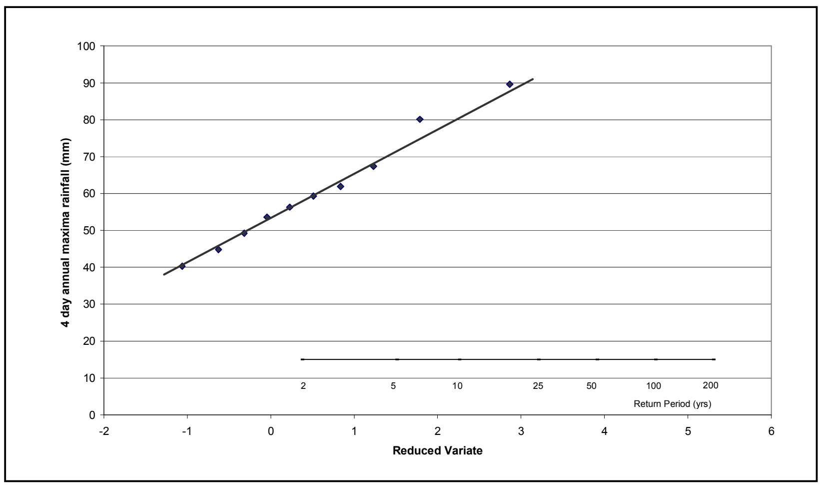
d) Raingauge 2310 – Listowel (Grogeen)



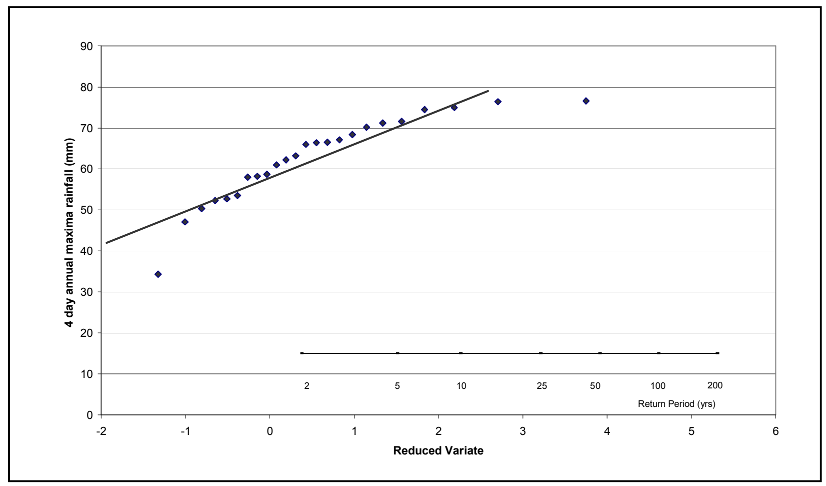
a) Raingauge 1509 – Tralee (Lisaboula)



b) Raingauge 2009 – Ardfert Ballymacquinn



c) Raingauge 2010 – Listowel (Inch)



d) Raingauge 2310 – Listowel (Grogeen)

Appendix D - FSU Depth Duration Frequency Plots

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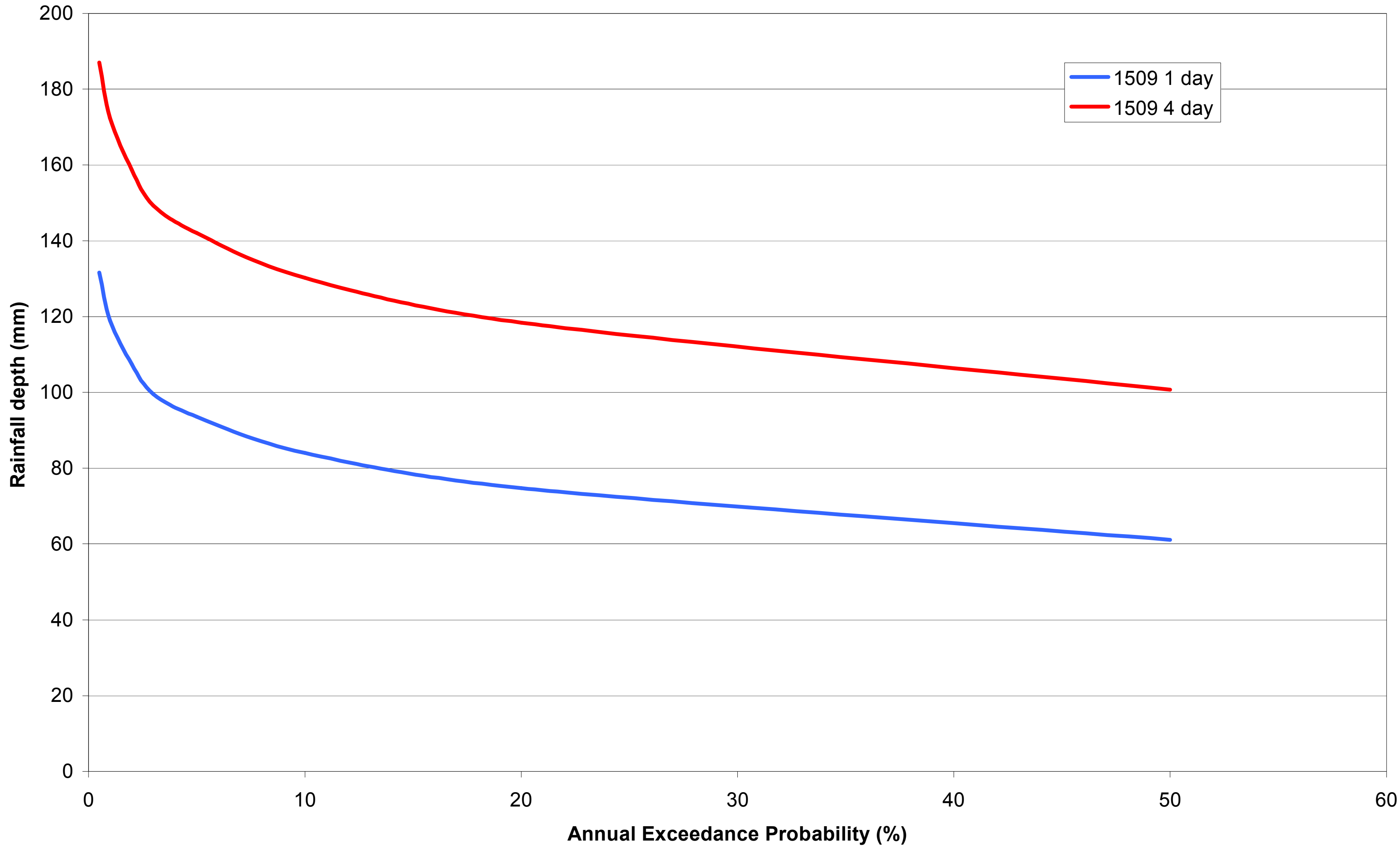
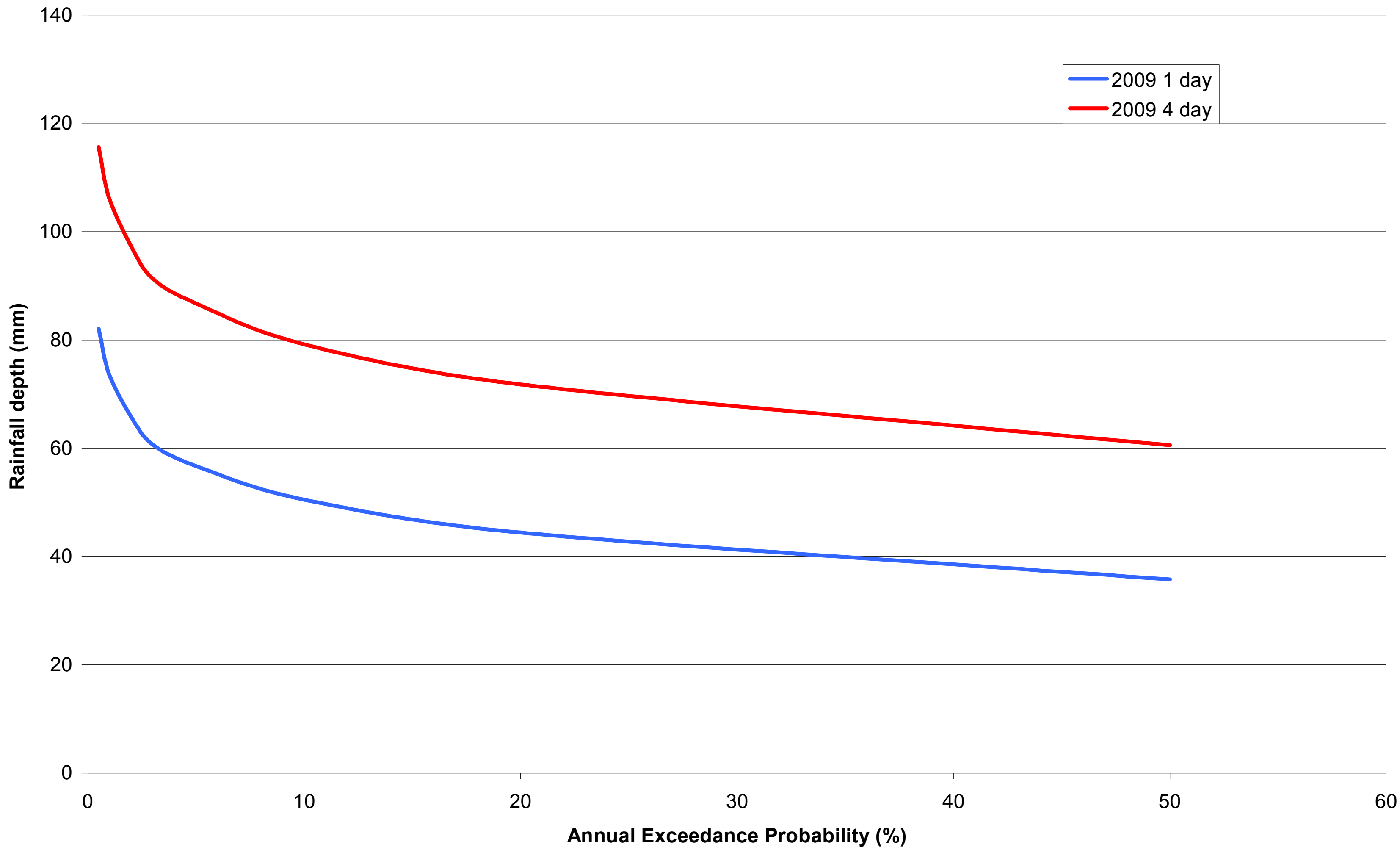
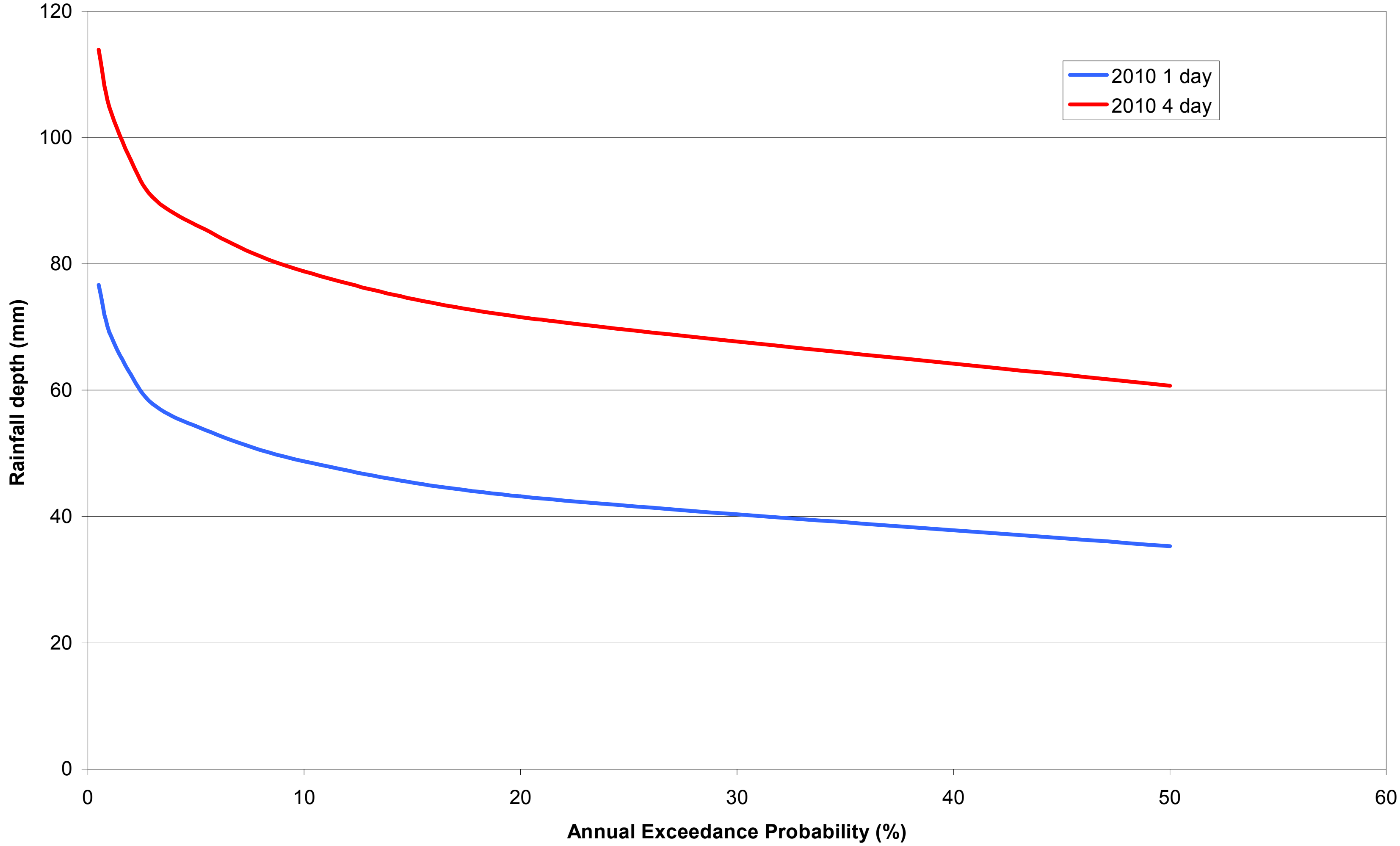
Depth Duration Frequency Curves for raingauge 1509 (derived from outputs of FSU Workpackage 2.2)



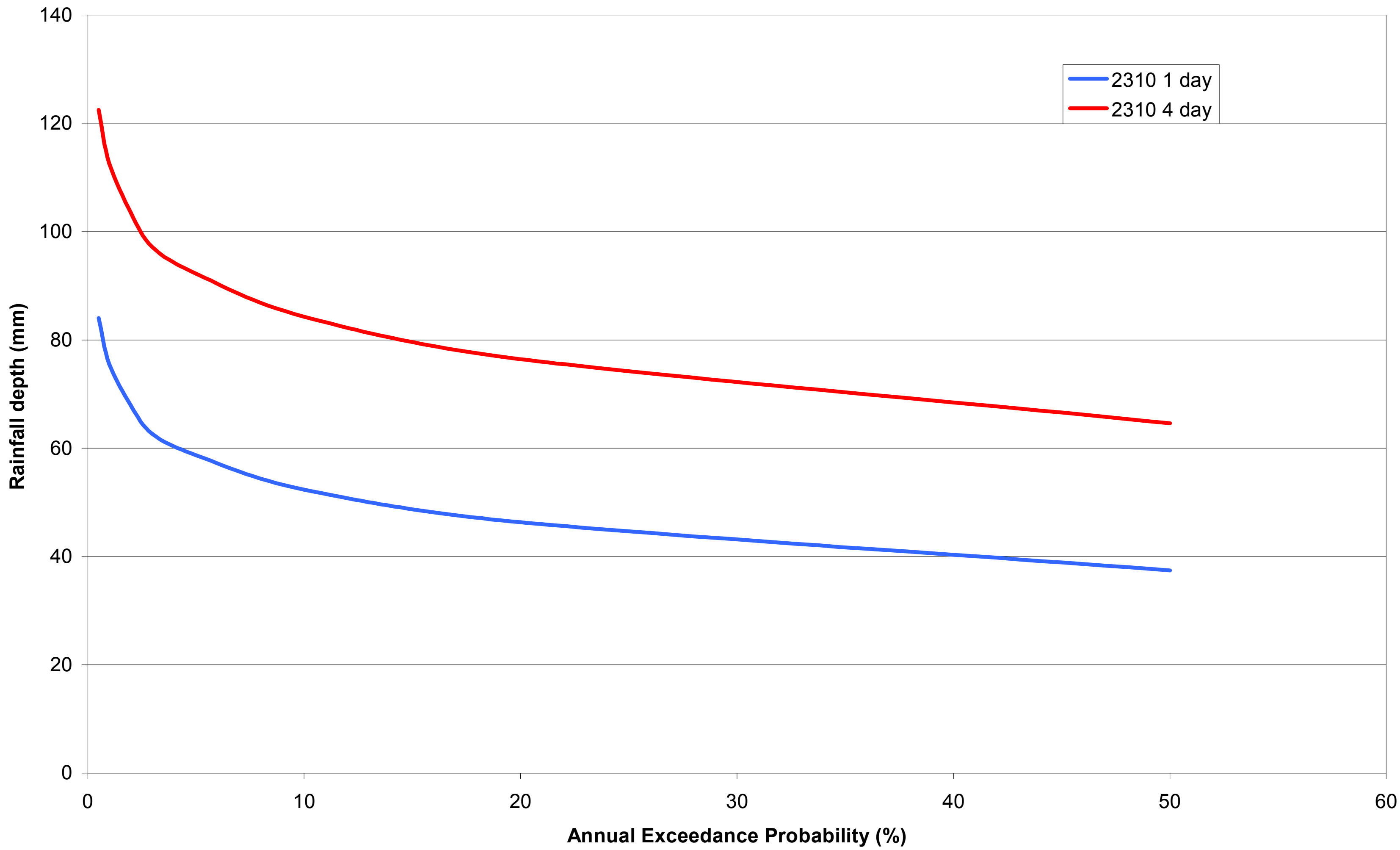
Depth Duration Frequency Curves for raingauge 2009 (derived from outputs of FSU Workpackage 2.2)



Depth Duration Frequency Curves for raingauge 2010 (derived from outputs of FSU Workpackage 2.2)



Depth Duration Frequency Curves for raingauge 2310 (derived from outputs of FSU Workpackage 2.2)

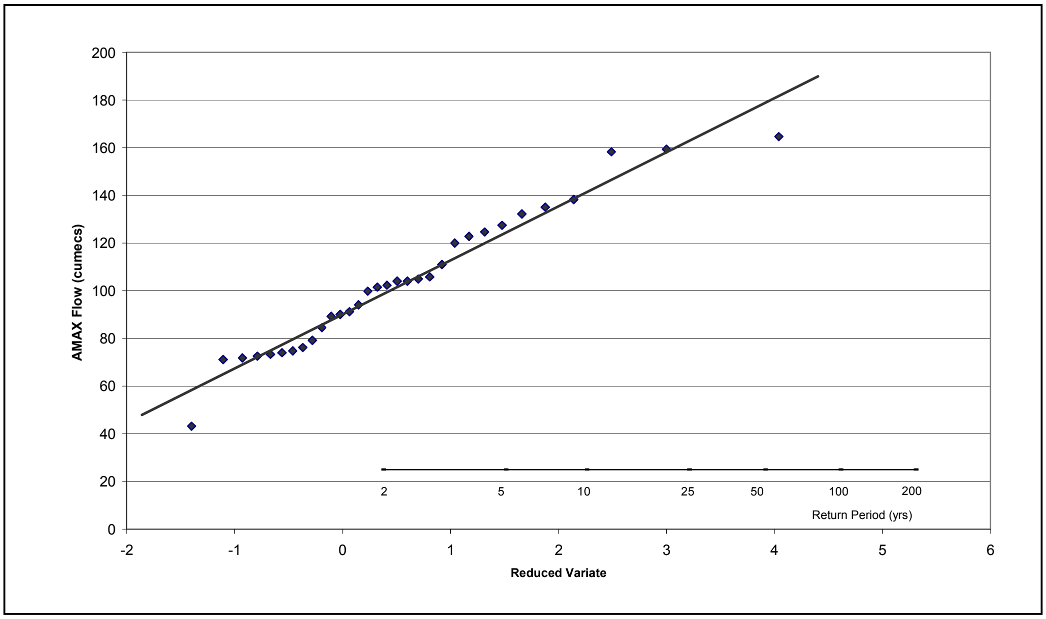


Appendix E - Daily Mean Flow Review

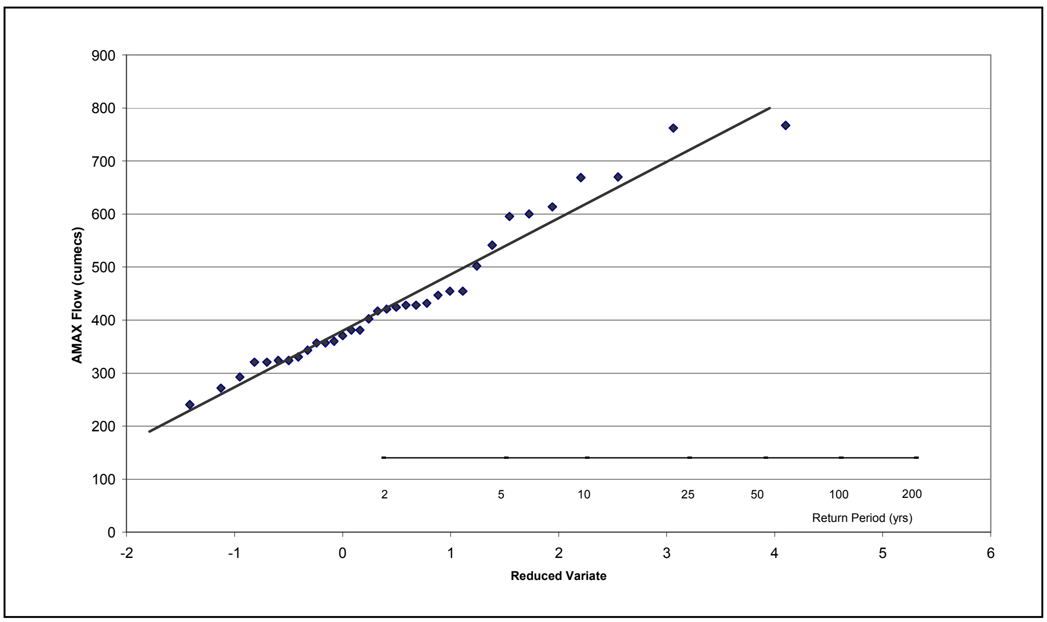
							Daily Flow data only									Daily Level data only							
Station No.	Station name	River	Daily mean flow start	Daily mean flow end	Daily mean level start	Daily mean level end	No. of good days	No. of fair days	No. of poor days	No. of beyond limit days	No. of unchecked days	No. of cautionary days	No. of missing days	Quality code not known	Total number of days	No. of good days	No. of beyond limit days	No. of unchecked days	No. of cautionary days	No. of missing days	Quality code not known	Total number of days	Comment on visual inspection of record
23001	Inch Br.	Galey	01/01/1960	18/12/2005	01/01/1960	18/12/2005	11443	3343	997	0	279	186	541	0	16789	16271	0	13	3	502	0	16789	Spurious 10m drop in level on 2/2/01. Gradual decline in low water levels from 1964 and from aprroximately 1978 a gradual trend of increasing lowest water levels. Drop in frequency and value of peak flows recorded post 1974 (drainage scheme?). Post-1978 flows and levels ok.
23002	Listowel	Feale	18/10/1946	10/09/2010	01/11/1946	02/07/2008	15994	5821	0	0	0	199	1288	37	23339	21188	0	0	1	1336	0	22525	Post 1974 record - rising trend in water levels at start of record. No obvious trend in flows. Post-76 levels and peak flows higher. No obvious trend in flows.
23012	Ballymullen	Lee (Kerry)			08/07/2004	10/09/2010	5723									1005	0	103	0	1148	0	2256	Data doesn't really start until July 2008.

NB: Grey squares indicate no data.

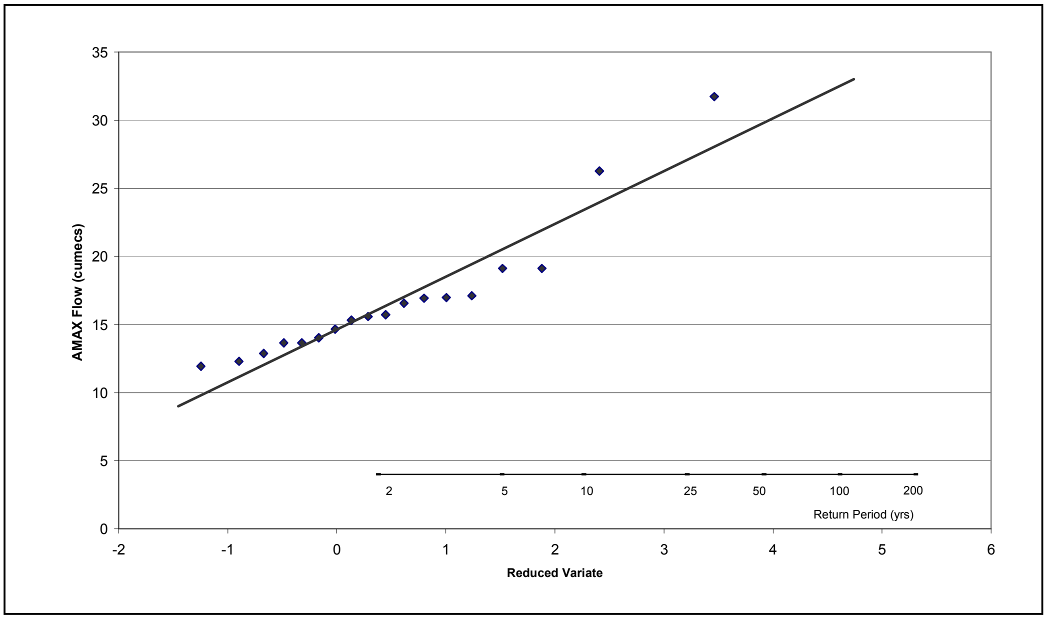
Appendix F - Flood Frequency Probability Plots



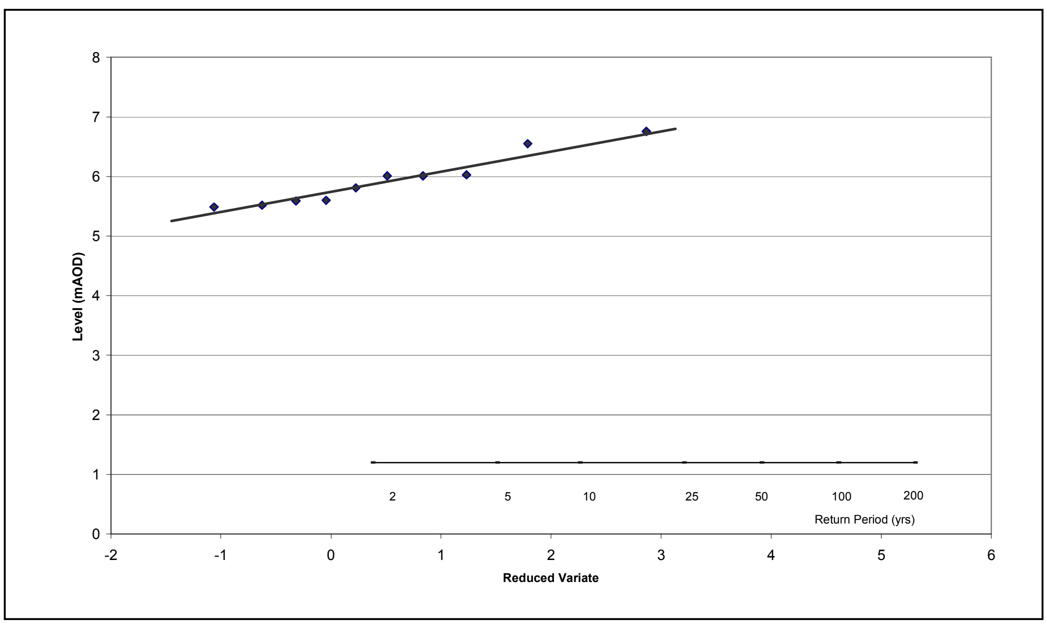
Hydrometric station 23001 (Post 1/10/1978, refer to Section 7.3)



Hydrometric station 23002 (Post 1/1/1976, refer to Section 7.3)



Hydrometric station 23012



Hydrometric station 23031

Appendix G - Catchment Boundary Discrepancies

The data used to assess the catchment boundary discrepancies is provided to OPW using the Sharepoint file sharing system.

Appendix H - Gauging Station Summary Sheets

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Shannon Catchment Flood Risk Assessment and Management (CFRAM) Study
Gauging Station Information Sheet

23001 – GALEY AT INCH BR.

Annual Maxima Series (Source: OPW)

Hydrological Year	Flow (m^3/s)	Date
1946		
1947		
1948		
1949		
1950		
1951		
1952		
1953		
1954		
1955		
1956		
1957		
1958		
1959		
1960		
1961		
1962		
1963		
1964		
1965		
1966		
1967		
1968		
1969		
1970		
1971		
1972		
1973		
1974		
1975		
1976		
1977		
1978	71.2	10/05/1979
1979	76.3	26/12/1979
1980	104.1	02/11/1980
1981	71.9	18/06/1982
1982	90.1	31/01/1983
1983	105.8	09/12/1983
1984	74.1	14/08/1985
1985	120.1	25/08/1986
1986	79.2	18/11/1986
1987	84.6	18/03/1988
1988	111.1	11/10/1988
1989	124.7	28/10/1989
1990	99.9	24/02/1991
1991	135.2	12/09/1992
1992	43.2	13/01/1993
1993	105.0	07/01/1994
1994	**164.7**	**22/02/1995**
1995	72.6	26/10/1995
1996	94.1	29/11/1996
1997	127.5	06/03/1998
1998	89.3	15/01/1999
1999	102.4	28/11/1999
2000	122.8	26/10/2000
2001	104.1	23/01/2002
2002	73.3	21/10/2002
2003	74.8	14/11/2003
2004	159.4	08/01/2005
2005	101.6	02/12/2005
2006	91.3	07/10/2006
2007	138.3	01/08/2008
2008	132.3	12/12/2008
2009	158.4	19/11/2009

Length of AMAX series: 32 years

Gauging Authority: Office of Public Works

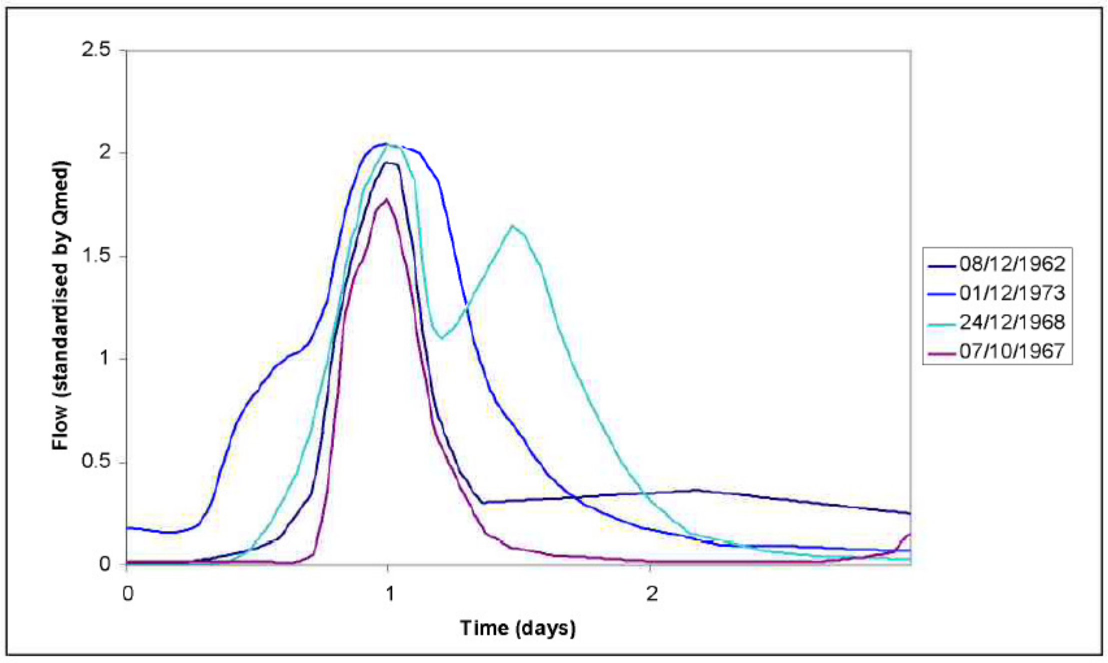
Easting: 95729	**Northing:** 136181
Catchment: Feale	**Telemetry:** Yes
Station Type: Recorder	**Catchment Area:** 191.70 km^2
QMED (gauged): 103.49 m^3/s	**AREA (FSU):** 191.74 km^2
QMED (FSU): 99.05 m^3/s	**SAAR (FSU):** 1084.01
QMED (predicted): 65.57 m^3/s	**FARL (FSU):** 1.00
BFIsoils (FSU): 0.33	**S1085:** 3.29
URBEXT: 0.30	**ARTDRAIN2:** 19.00
DRAIND: 1.39	

Comments: Automated velocity-area station installed in 1939 and automated in 1949. Unstable gravel bed and natural channel with bridge and fish pass as partial control. Some backwatering effects from the bridge at high flows.

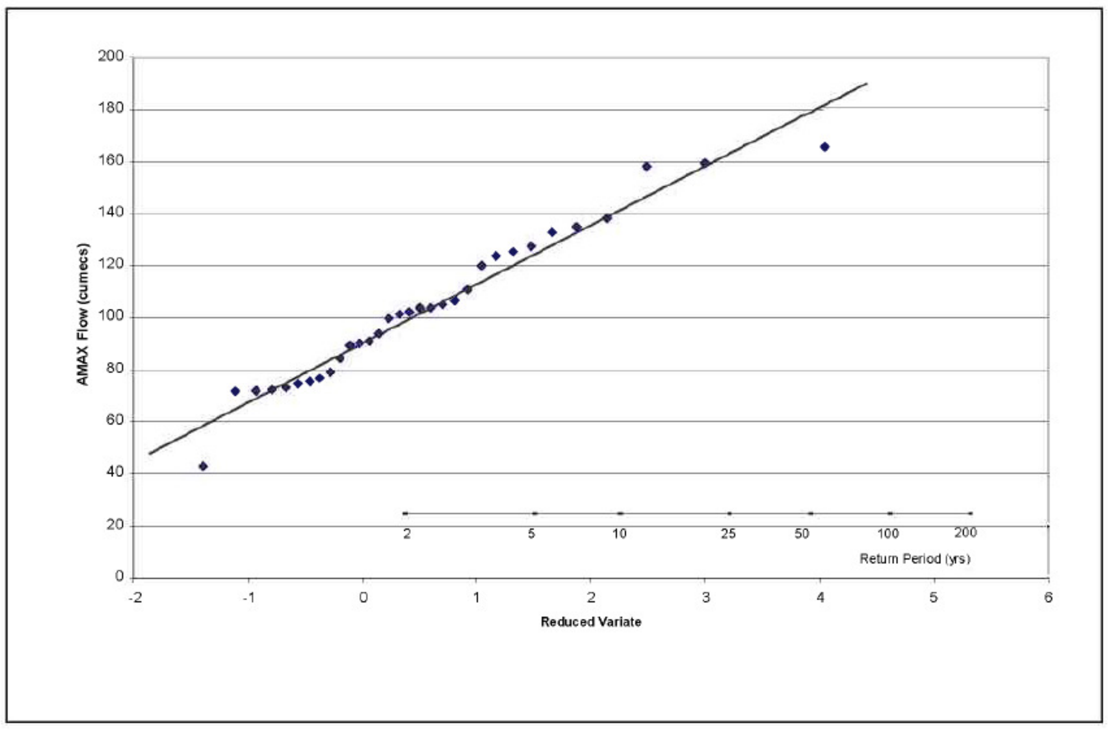
Nearby APSRs: To be confirmed

Jacobs Rating Review required: No | **OPW Station Classification:** A2

Normalised Hydrographs



Flood Frequency (EV1 with Gringorten plotting positions)



23002 – FEALE AT LISTOWEL

Annual Maxima Series (Source: OPW)

Hydrological Year	Flow (m^3/s)	Date
1946		
1947		
1948		
1949		
1950		
1951		
1952		
1953		
1954		
1955		
1956		
1957		
1958		
1959		
1960		
1961		
1962		
1963		
1964		
1965		
1966		
1967		
1968		
1969		
1970		
1971		
1972		
1973		
1974		
1975		
1976	240.5	12/10/1976
1977	357.0	20/04/1978
1978	323.9	07/12/1978
1979	381.1	24/10/1979
1980	762.3	02/11/1980
1981	320.7	28/09/1982
1982	454.7	31/01/1983
1983	428.1	16/01/1984
1984	323.9	14/08/1985
1985	**767.3**	**06/08/1986**
1986	360.4	18/11/1986
1987	343.6	01/02/1988
1988	447.0	14/10/1988
1989	502.2	28/10/1989
1990	357.0	01/01/1991
1991	330.4	12/11/1991
1992	292.6	18/05/1993
1993	370.7	15/01/1994
1994	600.2	22/02/1995
1995	320.7	09/02/1996
1996	381.1	31/08/1997
1997	424.4	06/03/1998
1998	431.9	30/12/1998
1999	454.7	28/11/1999
2000	613.7	27/10/2000
2001	417.0	23/01/2002
2002	271.7	21/10/2002
2003	420.7	14/11/2003
2004	669.2	08/01/2005
2005	402.4	01/12/2005
2006	595.7	03/12/2006
2007	541.5	13/08/2008
2008	428.1	05/10/2008
2009	670.1	19/11/2009

Length of AMAX series: 34 years

1974 - minor relocation u/s

Gauging Authority: Office of Public Works

Easting: 99700	**Northing:** 133295
Catchment: Feale	**Telemetry:** Yes
Station Type: Recorder	**Catchment Area:** 646.80 km^2

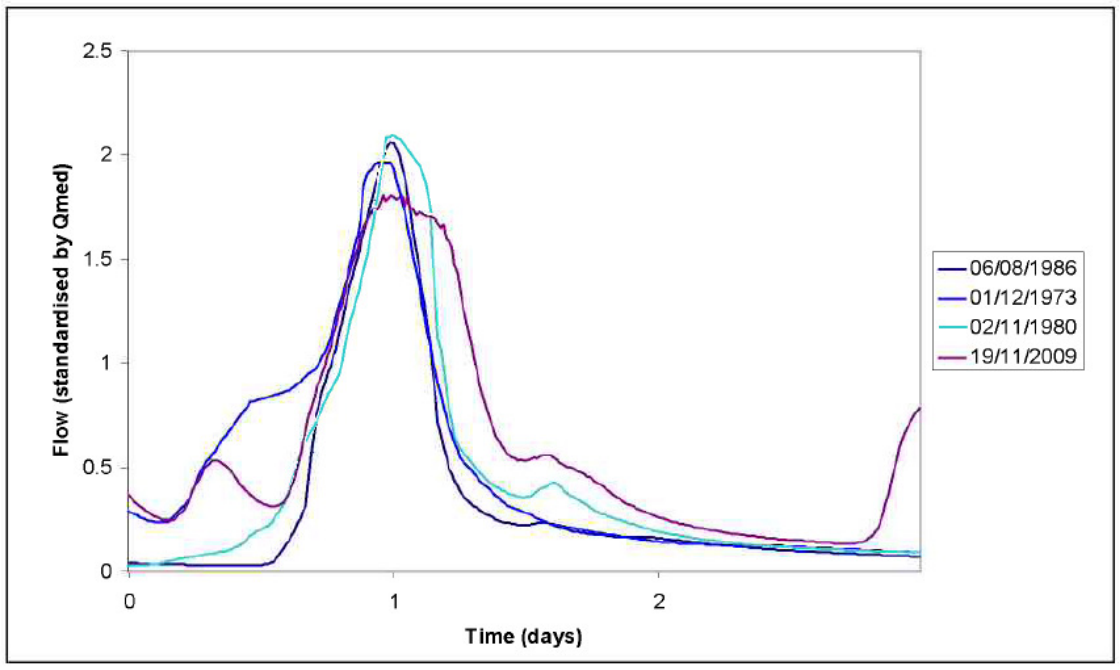
QMED (gauged): 369.42 m^3/s	**AREA (FSU):** 646.85 km^2
QMED (FSU): 381.10 m^3/s	**SAAR (FSU):** 1345.00
QMED (predicted): 248.75 m^3/s	**FARL (FSU):** 1.00
BFIsoils (FSU): 0.32	**S1085:** 4.31
URBEXT: 0.36	**ARTDRAIN2:** N/A
DRAIND: 1.11	

Comments: Automated velocity-area station installed in 1940 and automated in 1946. Unstable gravel bed and natural channel with bridge as partial control, acting like a flume.

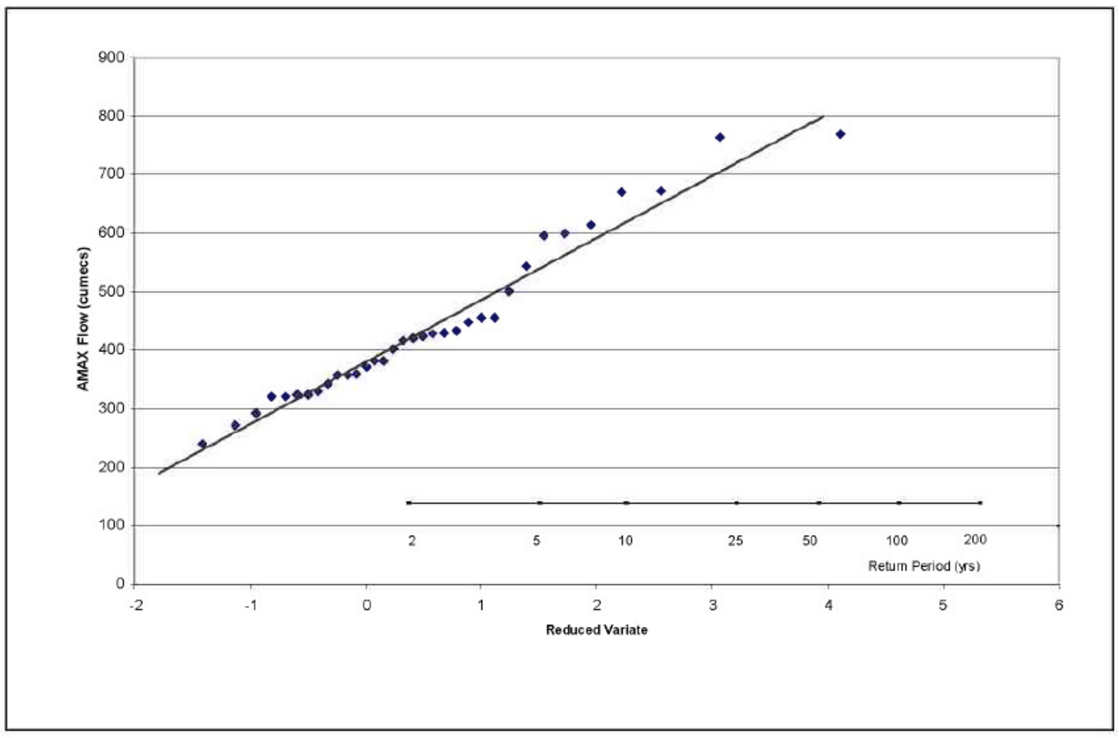
Nearby APSRs: To be confirmed

Jacobs Rating Review required: No | **OPW Station Classification:** A1

Normalised Hydrographs



Flood Frequency (EV1 with Gringorten plotting positions)



23012 – LEE (KERRY) AT BALLYMULLEN

Annual Maxima Series (Source: OPW)

Hydrological Year	Flow (m^3/s)	Date
1946		
1947		
1948		
1949		
1950		
1951		
1952		
1953		
1954		
1955		
1956		
1957		
1958		
1959		
1960		
1961		
1962		
1963		
1964		
1965		
1966		
1967		
1968		
1969		
1970		
1971		
1972		
1973		
1974	15.7	15/01/1975
1975	14.0	01/12/1975
1976	13.7	03/02/1977
1977	11.9	16/03/1978
1978	12.3	07/12/1978
1979	15.3	15/12/1979
1980	16.9	02/11/1980
1981	13.7	24/02/1982
1982	14.7	17/10/1982
1983	15.6	16/01/1984
1984	26.3	14/08/1985
1985	**31.7**	**06/08/1986**
1986	17.1	21/09/1987
1987	17.0	18/01/1988
1988	19.1	09/03/1989
1989	19.1	28/10/1989
1990	16.6	01/01/1991
1991	12.9	06/01/1992
1992	N/A	N/A
1993	N/A	N/A
1994	N/A	N/A
1995	N/A	N/A
1996	N/A	31/08/1997
1997	N/A	15/11/1997
1998	N/A	20/10/1998
1999	N/A	24/12/1999
2000	N/A	27/10/2000
2001	N/A	23/01/2002
2002	N/A	01/12/2002
2003	N/A	11/11/2003
2004	N/A	08/01/2005
2005	N/A	01/12/2005
2006	N/A	20/07/2007
2007	N/A	13/08/2008
2008	N/A	24/10/2008
2009	N/A	19/11/2009

Length of AMAX series: 18 years

Flood relief scheme developed 1992-1996. No rating post scheme.

Gauging Authority: Office of Public Works

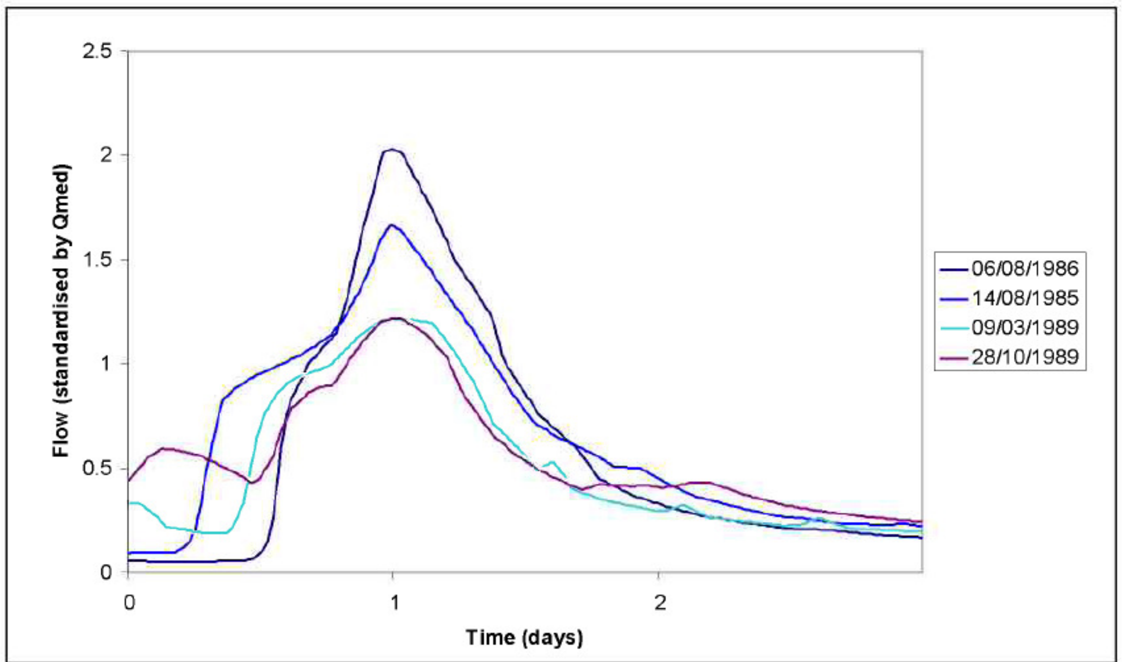
Easting: 84512	**Northing:** 113339
Catchment: Feale	**Telemetry:** Yes
Station Type: Recorder	**Catchment Area:** 61.60 km^2
QMED (gauged): 15.66 m^3/s	**AREA (FSU):** 61.63 km^2
QMED (FSU): 15.66 m^3/s	**SAAR (FSU):** 1264.00
QMED (predicted): 27.05 m^3/s	**FARL (FSU):** 1.00
BFIsoils (FSU): 0.43	**S1085:** 11.67
URBEXT: 2.43	**ARTDRAIN2:** N/A
DRAIND: 1.65	

Comments: Velocity-area station installed in 1947 and automated in 1947. Drainage works 92 to 96. Natural channel control at all flows, some tidal influence. Unstable gravel bed. Seasonal weed growth.

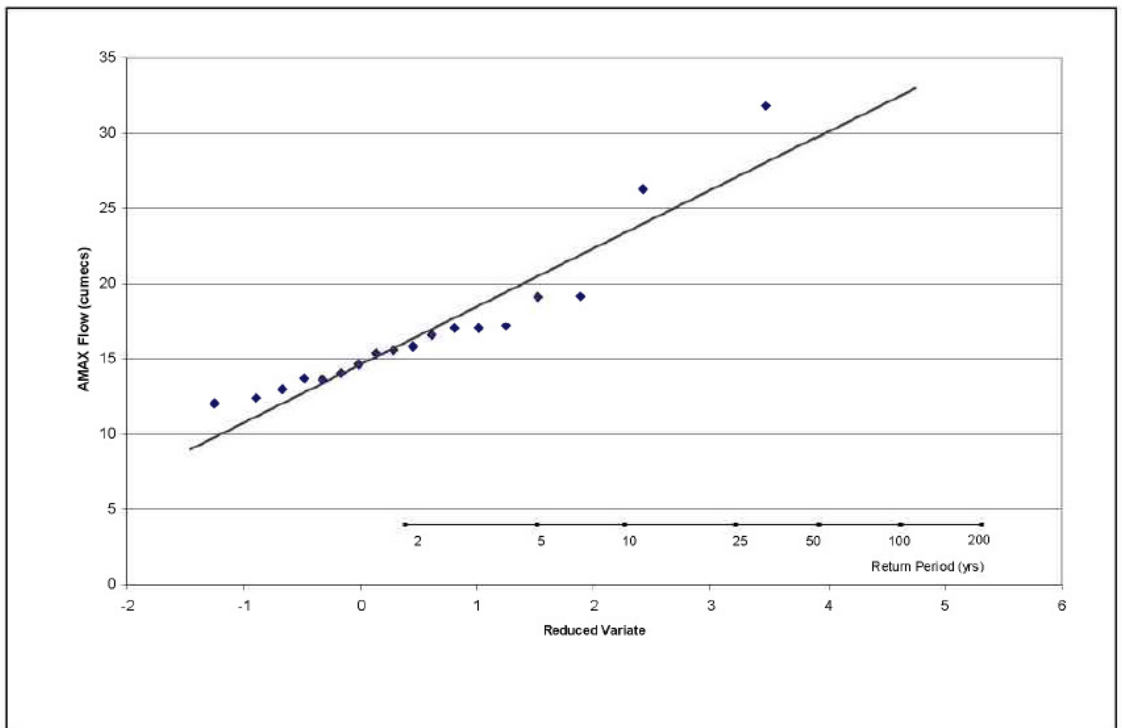
Nearby APSRs: To be confirmed

Jacobs Rating Review required: YES	**OPW Station Classification:** A2

Normalised Hydrographs



Flood Frequency (EV1 with Gringorten plotting positions)



Appendix I - Historical Flood Risk Review Details

Ref	Where?					When?			Magnitude?					Impact?							Flood
	River Basin	Tributary	CAR/IRR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused	Ranking	Estimated AEP	Source		Date	Authenticity	Quality Code
CAR 01 ABBEYDORNEY																					
01-1a	Feale	Brick	Abbeydorney			1994	October	11						Mentioned problem of flooding in Abbeydorney but no details given.	-		OPW memo	floodmaps	23/11/1994	Mentioned OPW drain at Abbeydorney	4
01-1a	Feale	Brick	Abbeydorney			1994	October	7						Mentioned problem of flooding in Abbeydorney but no details given.	-		OPW memo	floodmaps	23/11/1994	Mentioned OPW drain at Abbeydorney	4
CAR 05 ATHEA																					
05-1a	Feale	Galey	Athea	South of Con Colbert St		2009	September	2			158.37 (Inch Bridge-23001)	Flooded small avenue that leads to Con Colbert St	Culvert overwhelmed by floodwaters resulting in overland flows along the small avenue & down to Con Colbert St	Circa 4 properties, the avenue and Con Colbert St (main street) flooded.	2	7 based on flow at Inch Bridge-23001)	Flood Report OPW	floodmaps	18/01/2010		3
05-2a	Feale	Galey	Athea	Athea, R523		2008	August	1	Water level 300mm below soffit of central arch of Athea Bridge	85.9mm Circa in 6hours	138.29 (Inch Bridge - 23001)	Map showing flood extent and flow path is provided in the report	"Localised flooding" due to persistent rainfall with saturated catchment. Overgrown bank and channel sediment deposition resulted in banks overtopped	At least 12 properties (Bridge House 1.1m), R523, WWTP flooded. School on R523, petrol station, offices at Scanlon Construction & ESB substation not flooded.	3	>1:650yrs (0.15%) based on 6hrs rainfall and 14% based on annual maximum flow at Inch Bridge (23001)	JBA Consulting, Oct 2008. Athea Flood severity and impact Report. Prepared for Limerick Council.	floodmaps	10/2008		3
05-2a	Feale	Galey	Athea	Athea, R523		2008	August	6				Map showing flood extent and flow path is provided in the report	"Localised flooding" due to persistent rainfall with saturated catchment. Overgrown bank and channel sediment deposition resulted in banks overtopped	2 additional properties flooded compared to 01/08/2008 event. Bridge House to 0.6m.	3	>1:650yrs (0.15%) based on 6hrs rainfall and 14% based on annual maximum flow at Inch Bridge (23001)	JBA Consulting, Oct 2008. Athea Flood severity and impact Report. Prepared for Limerick Council.	floodmaps	10/2008		3
05-3a	Feale	Galey	Athea	Athea		-						map showing extent of flood	Heavy rain		-	7 (Based of Flow at Inch Bridge 23001)	Minutes of meeting Limerick CC	floodmaps	04/2005		4
CAR 10 BANNA																					
56-4a	Akeragh		Banna	Ballyheigue - Ardfert Rd		1980	November	3	Banna House: water level reached 4.585m's OD (1.20m staff gauge reading)			Ballyheigue/Rdfert road flooded up to a depth of 15cm.	Heavy rain	Main Ballyheigue - Ardfert Rd was flooded in 3 places to a depth of 15 cm			OPW memos	floodmaps	11/1980		1
CAR 39 LISTOWEL																					
39-1b	Feale		Listowel	Coibee (LIS 03/0419)		2003	August	12	420.71			Land		Land flooded	1	38 (based on Listowel - 23002)	OPW memo	floodmaps	07/10/2003		4

Ref	Where?					When?			Magnitude?					Impact?							Flood
	River Basin	Tributary	CAR/IRR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused	Ranking	Estimated AEP	Source		Date	Authenticity	Quality Code
39-1b	Feale		Listowel	Curraghatoosane (LIS 02/1022)		2002	November	28	271.7			House		House flooding	2	88 (based on Listowel - 23002)	OPW memo	floodmaps	07/10/2003		4
39-1b	Feale		Listowel	Gortnaminch (LIS 02/0988)		2002	November	11	271.7			Septic tank		Septic tank flooding	2	88 (based on Listowel - 23002)	OPW memo	floodmaps	07/10/2003		4
39-1b	Feale		Listowel	Greenville (LIS 02/0737)		2002	July	27				Field		Field flooding			OPW memo	floodmaps	07/10/2003		4
39-1b	Feale		Listowel	Shrone West (C3R C1/18/19)		2001	February	22	104.13			Field		Field flooded C3R C1/18/19 Feale Galey Trib	3	100 (based on Listowel - 23002)	OPW memo	floodmaps	07/10/2003		4
CAR 56 TRALEE																					
56 -kry1	Lee		Tralee	blennerville	81812, 112984	2011	February	18	2.9			Kearney's Rd Blenneriville	Tidal flooding in the River Lee Estuary	Road L6513 (Kearney's Road and adjacent agricultural land was flooded.			Flood Event Report	Floodmaps	02/2011		3
56-kry2	Lee		Tralee	Curragraigue TD and Ballymullen	81674, 112753 (Curragraigue TD)	2009	November	19	3.3 (Curragraigue)			Flooding occurred in Curragraigue TD and Ballymullen (Munster Bar Road U171) N70 from Army Barracks to Ballymullen roundabout.	Pluvial flood caused duet to lack of capacity in existing drainage	The flood affected 6 residential, 1 commercial-Public House in Ballymullen and Local GAA Clubhouse flooded to depth of 300mm in Curragraigue. The flood in Curragraigue disrupted road access to Blennervile.			Flood Event Report	Floodmaps	11/2009		3
56-kry03	Lee		Tralee	Caherweesheen TD, Ballyard	84008, 112123	2008	August	13	6.3			Caherweesheen TD, Ballyard, 0.6m deep flood.	Pluvial flood caused due to lack of capacity in existing drainage	One house and a farm building were flooded. Access to L6516 affected for a number of hours.			Flood Event Report	Floodmaps	08/2008		3
56-kry04	Lee		Tralee	Ballinorig, Caherleheen, Ardfert		2005	December	1				Flooding occurred in three areas Ballinorig, Caherleheen, Ardfert	Fluvial				Flood Study Group University College Cork, Oct 2005. N22 Tralee Bypass-Ballinorig Floodstudy. Prepared for Kerry National Road Design Office, Kerry Council.	Floodmaps	10/2005		3
56-kry5	Lee		Tralee	Killarney Road		1997	August	31				Tralee Killarney Road, Ardnabraher Ballinoring flooded	Fluvial	Tralee Killarney Road, Ardnabraher Ballinoring flooded			Letter(Note) prepared by OPW South West Drainage Maintenance.	Floodmaps	19/09/1997		3
56-kry5	Lee		Tralee	Ballyseedy		1996	November	24				Flooding in Ballyseedy area	Fluvial: caused due to overgrouth of vegetation on the river channel.				OPW	Floodmaps	14/04/1997		3

Ref	Where?					When?			Magnitude?					Impact?							
	River Basin	Tributary	CAR/IRR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused	Ranking	Estimated AEP	Source		Date	Authenticity	Flood Quality Code
56-2a, 3a	Lee	-	Tralee	-		1986	August	5				Tralee town centre	Fluvial: due to reduction in hydraulic capacity of the tributary of river Lee due to deposition and overgrowth of vegetation	Extensive flooding in the town of Tralee was reported			OPW Hydrometric review report	floodmaps	16/09/1986		3
56-2b	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1986	August	5	Ballyard - 2.76m, 3.32 (tide); Ballymullen - 3.00m; Blennervilla - 2.82m (6pm 05/08), 3.00m (6am 06/08); Ballyearty - 1.91m				Heavy rain with the Big River and River Lee overflowed as a result of restriction by culvert				OPW Hydrometric Report	floodmaps	08/1986		2
56-2b	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1986	August	5	Recorded level at Ballycarty is 0.25m higher than 1973			Properties	Big River overflowed and burst its bank near railway station when the channel is culverted.	Entire business centre of Tralee flooded causing severe damage to shops, offices and private dwellings. Severe flooding in the Ballymullen and Castlecountess areas along Lee River.			OPW Hydrometric review report	floodmaps	16/09/1986		3
56-2c, 5a, 6a	Lee	Lee - Balloonagh & Big Rivers	Tralee			1986	August	5			$10m^3/s$ at Princes Quay and $27.5m^3/s$ at Denny St culvert	Most of the business centre of the town was flooded	Heavy rain with restrictions caused by culverts	Major flooding in the centre of Tralee town			M.C O'Sullivan Consulting Engineers, Oct 1987. Tralee Flooding and Development Study- Summary Report. Prepared for Tralee Urban District Council	floodmaps	10/1987	Derived flows for Q10, Q25 & Q100.	3
56-2d	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1986	August	5	5ft -deep	4" (25% higher than 1916 event)		Properties & roads	Heavy rain and restriction caused by culvert.	Major flooding in Tralee town and the southern half of the county, where sections of roadway disappeared and bridges were seriously damaged. 50% of business houses were flooded in Tralee.			Cork Examiner	floodmaps	19/08/1986		-
56-2e	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1986	August	5	4ft-deep	4" (100mm)		Roads	Heavy rain and gale force winds	Tralee was flooded and roads through Macroom, Bantry, Killarney and Tralee were impassable.			Evening Herald	floodmaps	06/08/1986		-

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Ref	Where?					When?			Magnitude?					Impact?							
	River Basin	Tributary	CAR/IRR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused	Ranking	Estimated AEP	Source		Date	Authenticity	Flood Quality Code
56-2f, 3g	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1986	August	5		53.6mm over 6hrs & 86mm over 12hrs			Heavy rain	Tralee was flooded.			Irish Times	floodmaps	06/08/1986		-
56-2g	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1986	August	5	>3ft deep			Properties	Heavy rain	Business in Tralee, Ash St, Castle St and The Mall were flooded.			Evening Echo (Cork)	floodmaps	06/08/1986		-
56-2h	Lee			Tralee		1986	August	5									Kerry's Eye	floodmaps	21/08/1986		-
56-2i	Lee			Tralee		1986	August	5									Kerry's Eye	floodmaps	21/08/1986		-
56-2j	Lee			Tralee		1986	August	5									Kerry's Eye	floodmaps	21/08/1986		-
56-2k				Tralee		1986	August	5									Kerry's Eye	floodmaps	21/08/1986		-
56-2l	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1986	August	5	5ft - deep	"Highest rainfall recorded "		Properties	Heavy rain	"Worst floods" quoted. Extensive damage to shops and homes - 50 to 60% of business houses were flooded. Tralee was the worst hit part of the county.			Kerryman	floodmaps	22/08/1986		-
56-3b	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1986	August	5				Roads	Heavy rain	"worst floods" in over a decade, 1st serious flooding since 1973". Traffic disruption, telephone lines cut off.			Cork Examiner	floodmaps	06/08/1986		-
56-3c	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1986	August	5				Business	Heavy rain	Business in Tralee affected, telephone links cut off.			Cork Examiner	floodmaps	07/08/1986		-
56-3d	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1986	August	5	4ft -deep	4" (100mm)		Tralee & roads	Heavy rain and gale force winds	Tralee was flooded and roads through Macroom, Bantry, Killarney and Tralee were impassable.			Evening Herald	floodmaps	06/08/1986		-
56-3e	Lee					1986	August	5				Tralee		Tralee was flooded.			Evening Herald	floodmaps	06/08/1986		-
56-3f	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1986	August	5		53.6mm over 6hrs & 86mm over 12hrs		Properties & roads	River in the town failed to cope with the high tide and downpour; culvert restriction	"Worst flooding" since 1974. Severe damage to shops in Tralee, particularly in Castle St, Ashe St, Russell St and The Mall. Residential homes at Ballymullen flooded. Roads impassable			Irish Times	floodmaps	06/08/1986		-
56-3h	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1986	August	5	6ft -deep			Tralee	Heavy rain	Tralee was flooded.			Irish Independent	floodmaps	07/08/1986		-
56-3i	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1986	August	5	4ft (later mentioned 6ft in the paper)			Tralee & roads	Heavy rain	Tralee was badly affected with thousands of tourists stranded as roads became impassable			Irish Independent	floodmaps	07/08/1986		-
56-3k	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1986	August	5	>3ft deep			Business & roads	Heavy rain	Business in Tralee, Ash St, Castle St and The Mall were flooded.			Evening Echo (Cork)	floodmaps	06/08/1986		-

Ref	Where?					When?			Magnitude?					Impact?							Flood
	River Basin	Tributary	CAR/IRR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused	Ranking	Estimated AEP	Source		Date	Authenticity	Quality Code
56-3l	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1986	August	5						Phone system affected			Evening Echo (Cork)	floodmaps	07/08/1986		-
56-3m	NO DATA ATTACHED		Tralee	Tralee		1986	August	5									Kerry's Eye	floodmaps	06/08/1986		-
56-3n	Lee		Tralee	Tralee		1986	August	5									Kerry's Eye	floodmaps	06/08/1986		-
56-3o	Lee		Tralee	Tralee		1986	August	5									Kerry's Eye	floodmaps	06/08/1986		-
56-3p	Lee		Tralee	Tralee		1986	August	5									Kerry's Eye	floodmaps	06/08/1986		-
56-3q, 3r	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee, Castlecountess		1986	August	5		80mm		Tralee	Heavy rain and failure of a flood defence scheme designed in the mid 70s (only designed to cope with 1:27yrs event).	Massive flooding in Tralee with 5 bridges partially destroyed and roads damaged around the county. Serious damage to turf cope.			Kerryman	floodmaps	08/08/1986		-
56-3s	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee, Balloonagh, Ballymullen, Castlecountess		1986	August	5	Castlecountess - 2ft, Siamsa Tire area - 3ft, Ashe St - 3ft, Dr Arthur Spring's Surgery - 6"			Ashe St, Castle St, The Mall, Bridge St, Russell St, Lower Rock St, Pembroke St, Princess St	Heavy rain	Ashe St, Castle St, The Mall, Bridge St, Russell St, Lower Rock St, Pembroke St, Princess St flooded.			Kerryman	floodmaps	08/08/1986		-
56-3t	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1986	August	5				Tralee	Heavy rain	Tralee town flooded. Phone lines cut off, roads into Tralee impassable (except) Listowel Rd.			Kerryman	floodmaps	08/08/1986		-
56-3u	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1986	August	5				Tralee		Photos showing flooding at Russell St, Castle St, Rock St and Ashe St.			Kerryman	floodmaps	08/08/1986		-
56-3v	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1986	August	5				Tralee		Photo showing flooding at Ulster Bank, Tralee			Kerryman	floodmaps	08/08/1986		-
56-4a	Lee	Lee - Balloonagh & Big Rivers	Tralee	Ballyseedy, Ballyard, Oakview, Ashe St, Castlecountess, Castlemaine Rd		1980	November	2				Map showing extent of flooding	Heavy rain with restriction by culvert causing backwater effect	Flooding at Ballyseedy, Ballyard and on the Big River at Oakview and the railway yard nr Ashe St. Surface runoff flooding at the New Ring Rd. The town centre was not affected. 3 locations at Ballymullen area was flooded - Killerisk (houses not flooded); Terrace of houses opp. Army Barracks were flooded; land nr Castlemaine Rd.			OPW memos	floodmaps	11/1980		1

Ref	Where?					When?			Magnitude?					Impact?							Flood
	River Basin	Tributary	CAR/IRR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused	Ranking	Estimated AEP	Source		Date	Authenticity	Quality Code
56-1a	Lee	Lee - Balloonagh & Big Rivers	Tralee	Ashe St, Lower Castle St, Denny St, The Mall, The Square, Bridge St, Rock St, Pembroke St, Russell St, Staughton Row, Princes Quay, Ivy Terrace, Castle Countess, Castlemaine Rd		1973	December	1	4	Clash (Tralee) 28/11 - 22.7mm 29/11 - 13.5mm 30/11 - 62.5mm	Estimated ~ 14m3/s at Ashe St	Business premises	Heavy rain with saturated catchment and restriction caused by the culvert especially The Mall. Bridge St culvert	Entire business area of Tralee was flooded. Depth of flooding ranges btw 0.3 to 0.6m		1:49yrs	M.c Carthy and Partners Consulting Engineers and charter Planners, Jan 1974. Tralee Flooding 1 Dec 1973	floodmaps	01/01/1974		1
56-1a	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1973	December	1		Caherweesheen (Tralee) 28/11 - 24.4mm 29/11 - 13.2mm 30/11 - 82.2mm			fluvial - capacity of the rivers constrained by culverts				M.c Carthy and Partners Consulting Engineers and charter Planners, Jan 1974. Tralee Flooding 1 Dec 1973	floodmaps	01/01/1974		1
56-1b	Lee	Lee - Balloonagh & Big Rivers	Tralee	Ballymullen area		1973	Nov - Dec	30-2					fluvial - capacity of the rivers constrained by culverts				Cork Examiner	floodmaps	07/12/1973		
56-1d, 6b	Lee	Lee - Balloonagh & Big Rivers	Tralee	Castle St, The Mall, Castlecountess, Ballymullen, Gas Terrace, Rock St, Ashe St, Denny St		1973	Nov - Dec	30-2	Ballymullen - Water several ft high	28/11 - 1 1/2" 29/11 - 2 3/4" 30/11 - 0.30"/hr over 7hrs rainfall		Footpaths, properties, roads	fluvial - capacity of the rivers constrained by culverts	Footpaths in Castle St, The Mall. Castlecountess, Ballymullen - water several feet high, cars almost totally submerged. sewage seeped through premises. Gas Terrace. Rock St, Ashe Sy & The Mall - 3ft of water in shops. Denny St flooded.			Kerryman	floodmaps	07/12/1973		

Ref	Where?					When?			Magnitude?					Impact?							Flood
	River Basin	Tributary	CAR/IRR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused	Ranking	Estimated AEP	Source		Date	Authenticity	Quality Code
56-1e, 6c	Lee	Lee - Balloonagh & Big Rivers	Tralee	Rock St, Dominick St, The Mall, Bridge St, The Square, Russell St, James St, Gas Terrace, Skehanagh, The Casherlee, Pembroke St.		1973	Nov - Dec	30-2	Known flood depth: Bridge Inn in Bridge St 8ft; Denny St 15ft - Margaret Heffernan flat 4ft; Mr James Martin property at Gas Terrace 2ft; Mrs Betty Raggin property 3ft; Russell St - Parklands Hotel 2.5 ft; Brandon Hotel 0.5".			Properties		"Worst in memory". Premises in The Mall, Bridge St, Dominick St, The Square, Russell St, James' St, Castle St, Ashe St, Gas Terrace, Denny St, The Casherlee, Pembroke St flooded.			Kerryman	floodmaps	07/12/1973		
56-1c	Lee	Lee - Balloonagh & Big Rivers	Tralee	Shamrock Mills, Town Arch		-											Kerryman	floodmaps	07/12/1973		
56-6d	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee Town: The Mall, Listowel Rd., The Square, Staughton's Row, Rock Street, Castle Countess, Ivy Terrace, Boherbue		1973	November	30									Evening Echo (Cork)	floodmaps	01/12/1973		
56-1a	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1971	May										M.c Carthy and Partners Consulting Engineers and charter Planners, Jan 1974. Tralee Flooding 1 Dec 1973	floodmaps	01/01/1974		1
56-6e	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee		1955	March	1									Kerryman	floodmaps	05/03/1955		

Ref	Where?					When?			Magnitude?					Impact?							Flood
	River Basin	Tributary	CAR/IRR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused	Ranking	Estimated AEP	Source		Date	Authenticity	Quality Code
56-6i	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee Town: Ashe St, Lower Castle St, Denny St, the Mall, Boherbee, Moyderwell, Strand St, Rock St, Bridge St, and Pembroke St, The Square		1925	January	22-23									Kerryman	floodmaps	24/01/1925		
56-6h	Lee	Lee - Balloonagh & Big Rivers		Tralee Town: Boherbee, Moyderwall, Upper Strand St., Upper Rock St		1924	Nov & Dec	30&05									Kerryman	floodmaps	06/12/1924		
56-6g	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee Town: Boherbee, Rock St, Upper Rock St, Oakpark		-											Kerryman	floodmaps	06/12/1924		
56-2c, 5a	Lee	Lee - Balloonagh & Big Rivers	Tralee			1916	Oct/Nov	-									M.C O'Sullivan Consulting Engineers, Oct 1987. Tralee Flooding and Development Study-Summary Report. Prepared for Tralee Urban District Council	floodmaps	10/1987	Castlecountess & James St subject to tidal flooding	3

Ref	Where?					When?			Magnitude?					Impact?							
	River Basin	Tributary	CAR/IRR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused	Ranking	Estimated AEP	Source		Date	Authenticity	Flood Quality Code
56-6f	Lee	Lee - Balloonagh & Big Rivers	Tralee	Tralee (Kerry): Nelson Street, Castle Street, The Mall, The Square, Lower Rock Street, Russell Street, The Market, Pembroke Street, Stand Street, James Street, Moyderwell, Ballymullen Boherbee, Brogue Lane, Blackpool, Church Street.		1916	November	25									Kerry Weekly Reporter	floodmaps	25/11/1916		
56-2c, 5a	Lee	Lee - Balloonagh & Big Rivers	Tralee			1916	Oct/Nov	-									M.C O'Sullivan Consulting Engineers, Oct 1987. Tralee Flooding and Development Study- Summary Report. Prepared for Tralee Urban District Council	floodmaps	10/1987	Castlecountess & James St subject to tidal flooding	3