NATIONAL CFRAM PROGRAMME
CATCHMENT FLOOD RISK ASSESSMENT AND MANAGEMENT
Clár Náisiúnta MBPTA
Measúnú agus Bainistiú Priacal Tuile Abhantraí

SHANNON CFRAM STUDY
CATCHMENT FLOOD RISK ASSESSMENT AND MANAGEMENT

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

Inception Report – Unit of Management 28

Draft Final Report

Appendix B: Preliminary Hydrological Assessment and Method Statement

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18 September 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 list of possible Areas of Potential Significant Risk (APSR) to which will be added any additional areas identified in the Flood Risk Review to form the final list of APSRs. It is noted that the Flood Risk Review may also lead to some CARs or IRRs not being designated as 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 17,800km^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.

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 (UoM) within the Shannon River Basin District (ref. 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 Mal Bay Unit of Management (UoM 28) only. Analysis and discussion for the remaining units of management will be presented in separate reports.

2.4 Unit of Management 28 - Mal Bay

The Mal Bay Unit of Management (or UoM 28) is shown in its wider context within the Shannon RBD in Figure 1, and in more detail in Figure 2. It covers part of West Clare (Figure 1).

The area is bounded to the west by the Atlantic Ocean. The boundary to the east is the topographic divide between those rivers and streams that eventually flow into the Shannon Estuary (located in UoM 27) and those which flow to the west discharging to the Atlantic Coast (located in UoM 28). To the south, the boundary is the generally low lying area that forms the divide between UoM 27 and 28. The total area of UoM 28 is approximately 850 km^2.

This unit of management is variable in nature comprising:

- the upland limestone area in the western part of The Burren in the north;
- the lowland area drained by the Inagh (or Cullenagh) River and the upland area between Ennis and Milltown Malbay in the centre; and
- low lying land towards the south.

The topography of these areas is apparent from the coloured shading on Figure 2.

UoM 28 is characterised by numerous small to medium sized catchments, with the rivers flowing predominantly east to west, also shown on Figure 2. The largest rivers in this unit of management, all discharging to the Atlantic Ocean, from north to south are:

- the Aille River - discharging near Doolin;
- the Aughyvackeen River and the Inagh (Cullenagh) River – discharging between Lehinch and Liscannor;
- the Doonbeg River – discharging at Doonbeg.

The coastal strip within this area is variable, including rocky steep, high cliffs as well as extensive sand dune systems and natural shingle ridges. Some inland areas behind the natural coastal defences are low lying, with extensive land drainage networks which can be tidally influenced.

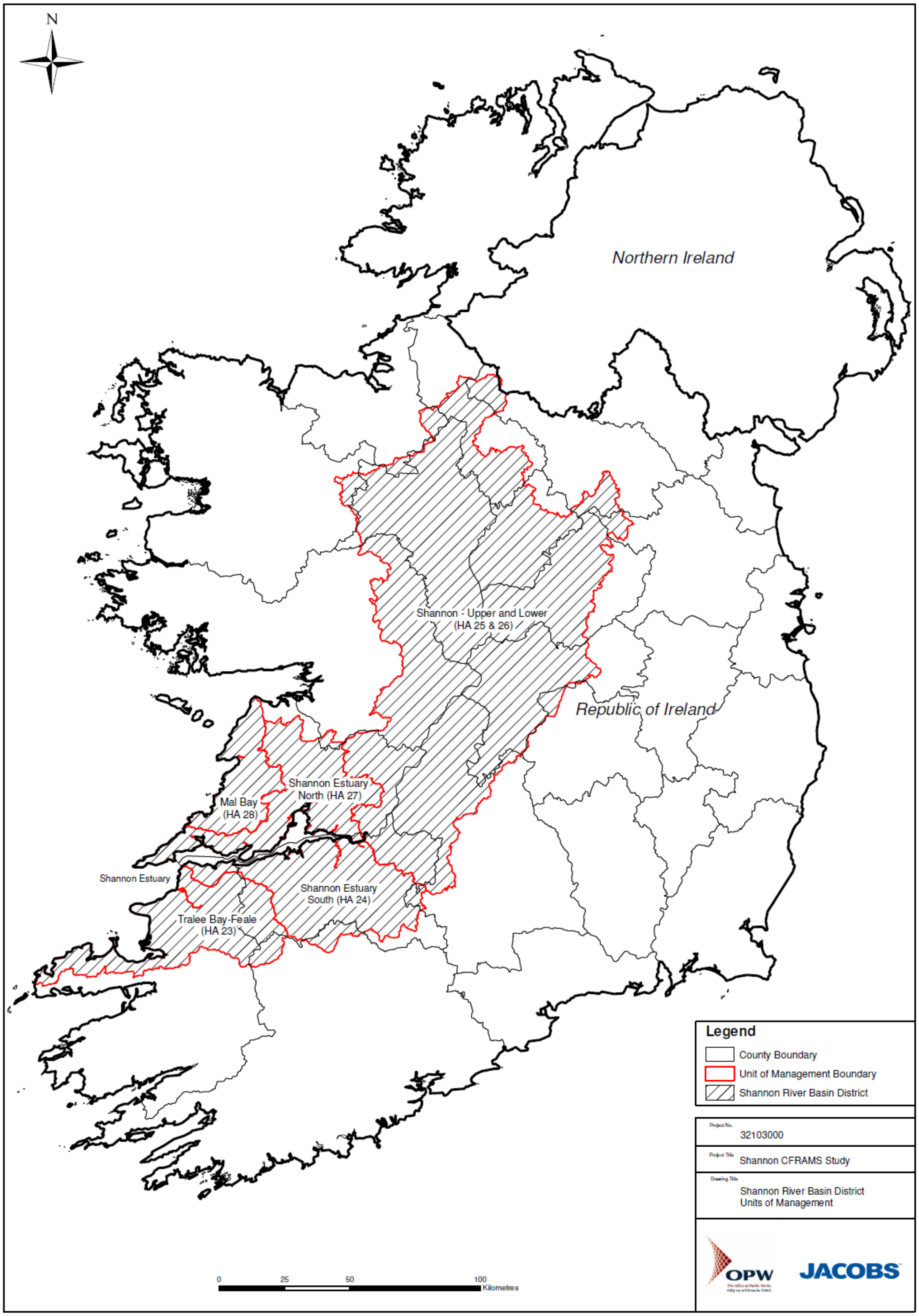

Figure 1 Shannon River Basin District and the five Units of Management

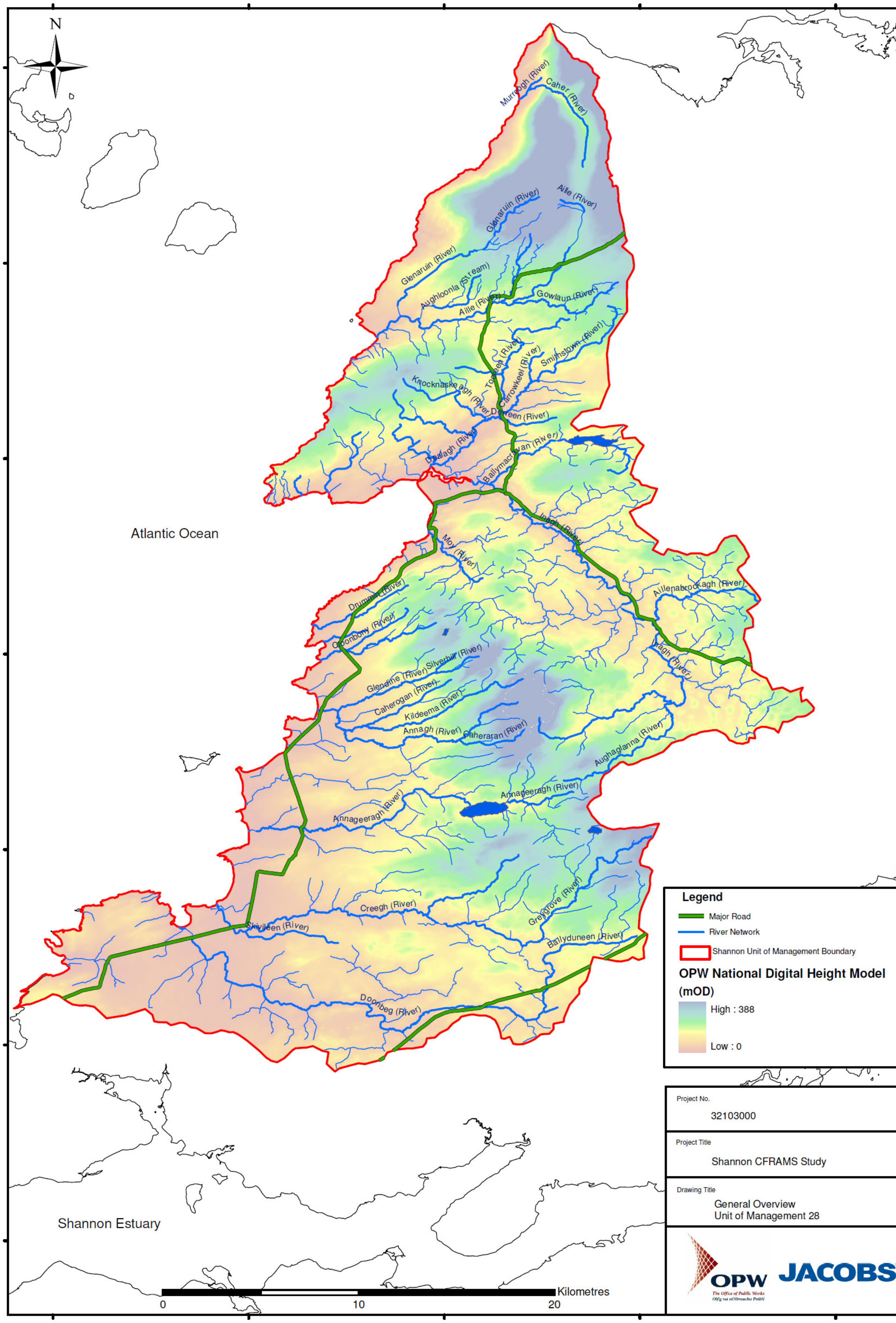

Figure 2 Mal Bay Unit of Management

2.4.1 Communities at Risk

Communities within UoM 28 are potentially at risk from tidal and/or fluvial flooding. Table 2-A outlines the single community identified by OPW as a Community at Risk (CAR) within UoM 28. The location of the Community at Risk (CARs) is shown in Figure 3.

No.	Location	Easting	Northing	Catchment	At risk of fluvial flooding?	At risk of tidal flooding?
CAR17	Carrowmore	98750	166750	Creegh	Yes	No

Table 2-A Community at Risk in* Mal Bay *(or UoM 28)

2.4.2 Individual Risk Receptors

A number of assets within the Shannon RBD have been identified as Individual Risk Receptors (IRRs). These assets are 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 28.

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 11 river and lake level, flow and tidal level gauging stations within UoM 28 (Appendix A), of which only two 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 28. 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-A);
- Whether a hydrometric station improved the spatial distribution of data throughout the UoM and sub-catchments (ref. Table 3-A).

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 ?
28001	Ennistymon	Inagh	Active	Data Logger			Yes
28002	Doonbeg	Doonbeg	Active	Data Logger	Carrowmore		
28008	Mountrivers Br.	Creegh	Inactive	Staff Gauge Only	Carrowmore		

Table 3-A Key hydrometric stations identified for Mal Bay (grey boxes indicate N/A)

3.3 Hydrometric Network in relation to CARs and IRRs

Carrowmore, the only Community at Risk (CAR) identified within UoM 28 does not have an active hydrometric gauging station located within the immediate locality. In the Doonbeg catchment, immediately to the south of Carrowmore, the River Doonbeg is gauged at Doonbeg (28002). This should be considered as a pivot site. In addition an inactive, staff gauge only station is located upstream of Carrowmore on the River Creegh at Mountrivers Bridge (28008). Note that the River Creegh is also referred to as the Skivilleen River at this location. Consideration should be given to improving the gauging network in these locations, for the benefit of future flood studies.

There are no IRRs in UoM 28.

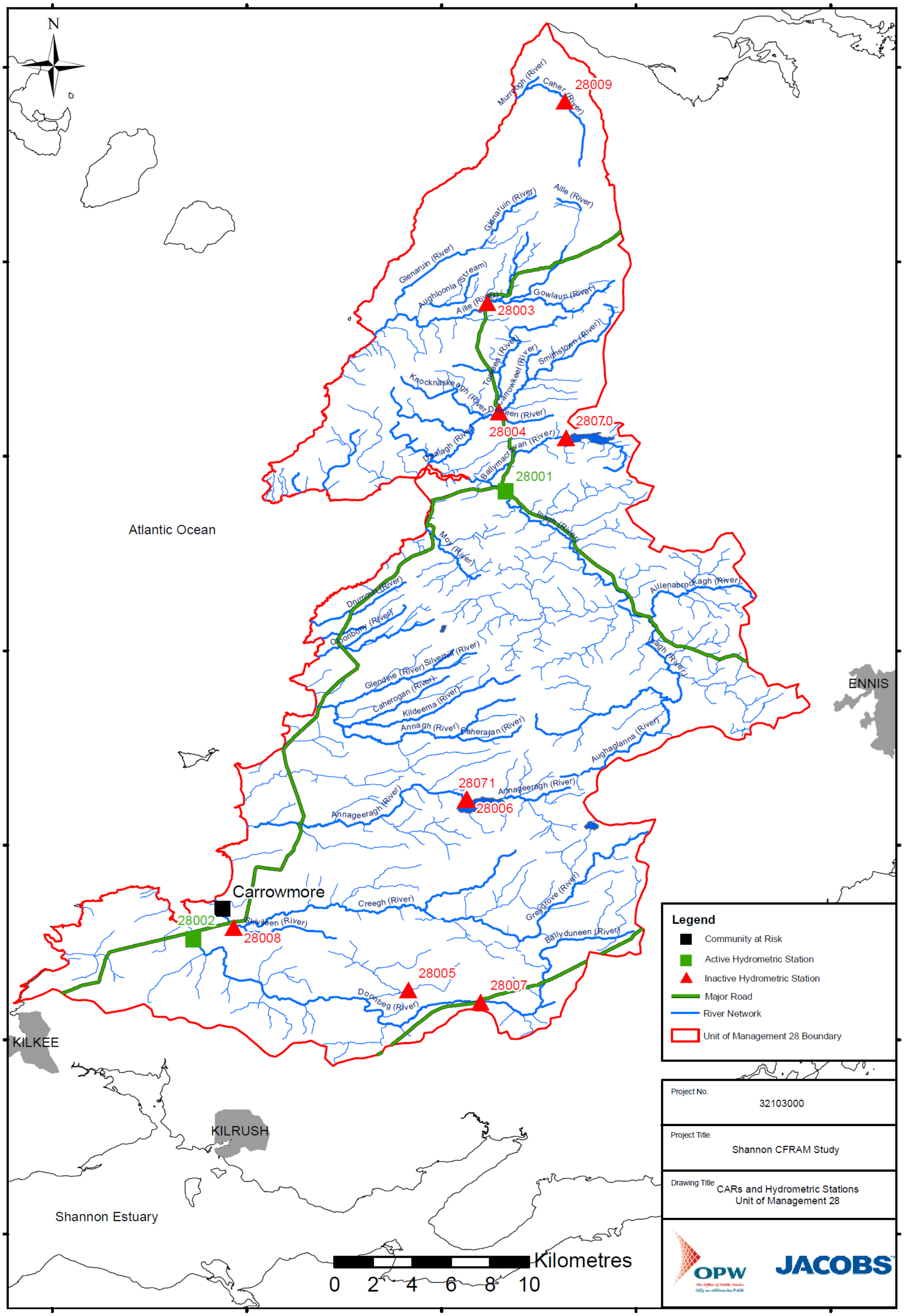

Figure 3 Location of hydrometric gauging stations in relation to the Communities at Risk within Mal Bay

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 read daily, 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. There are no NRA rainfall sensors located within the Mal Bay Unit of Management. 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 eight locations within the Mal Bay 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 Mal Bay and the availability of data. Figure 4 shows the distribution of the raingauge network.

Raingauge no.	Raingauge name	Data available?
417	Inagh (Mt Callan)	Yes
1117	Doo-Lough	Yes
1217	Doonbeg	Yes
1317	Kilmihil (Shyan)	Yes
1417	Mullagh (Carrowlagan)	Yes
1617	Lisdoonvarna (Cahermacnaghten)	Yes
1717	Ennistymon (Ballymacravan)	Yes
2017	Quilty	Yes

Table 3-B Daily rainfall data available within Mal Bay

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 is no Met Éireann hourly rainfall station located within the Mal Bay Unit of Management.

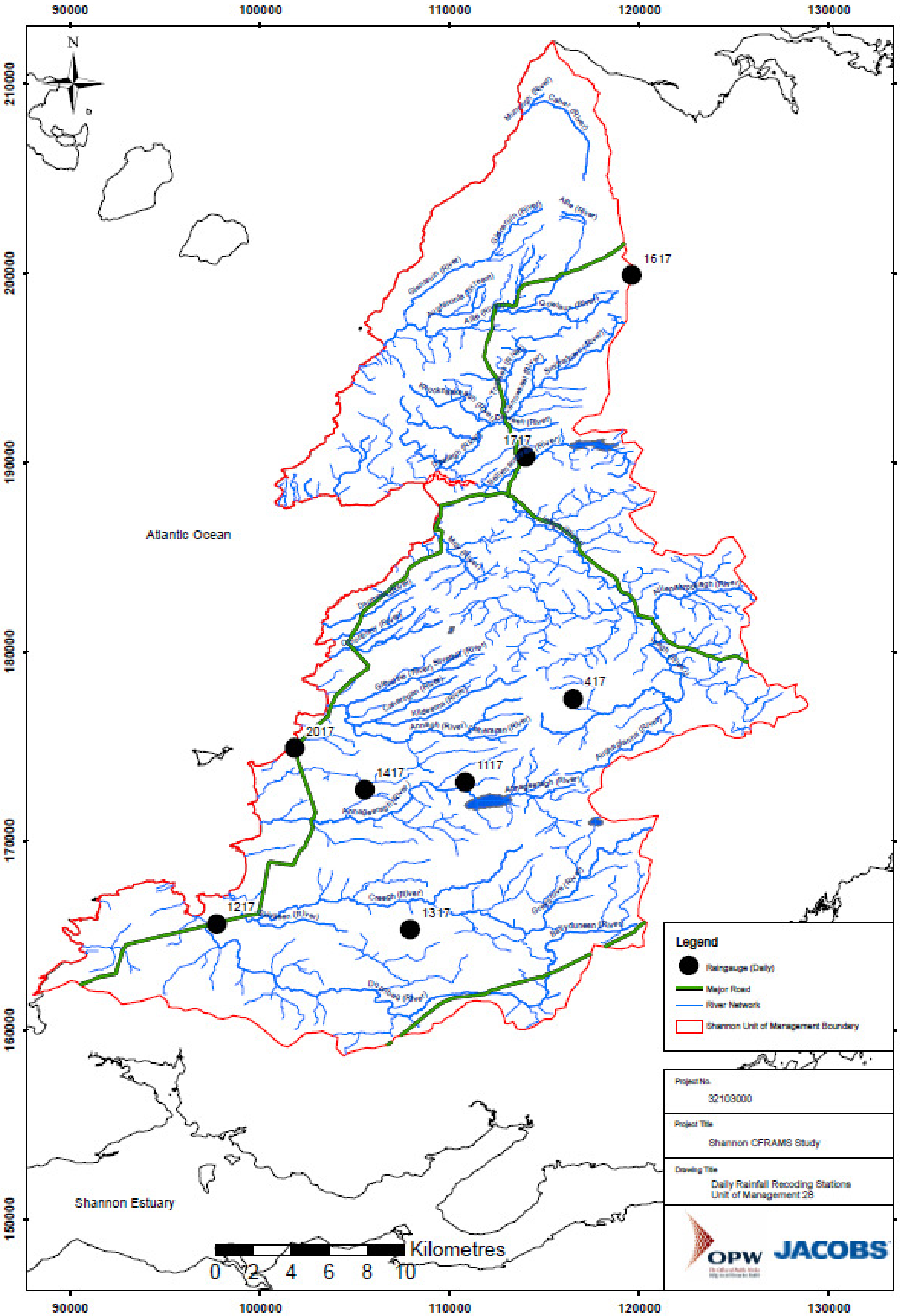

Figure 4 Location of daily raingauges within Mal Bay Unit of Management

3.5 Hydrometric Data

3.5.1 Background

The location of hydrometric stations in the Mal Bay is shown in Figure 3. The two active flow and level gauging stations within UoM 28 are located on the River Doonbeg and the River Inagh, located in the south and mid to north portion of the unit of management respectively. Dotted throughout the remainder of the unit of management, are locations where intermittent water levels have historically been taken.

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 regular intervals by a data logger will be collectively treated as instantaneous and continuous 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 three stations within UoM 28 (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, although if the data is important then the autographic recordings can be digitised. Data listed in Table 3-C outlines all the instantaneous 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 instantaneous 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 the 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.

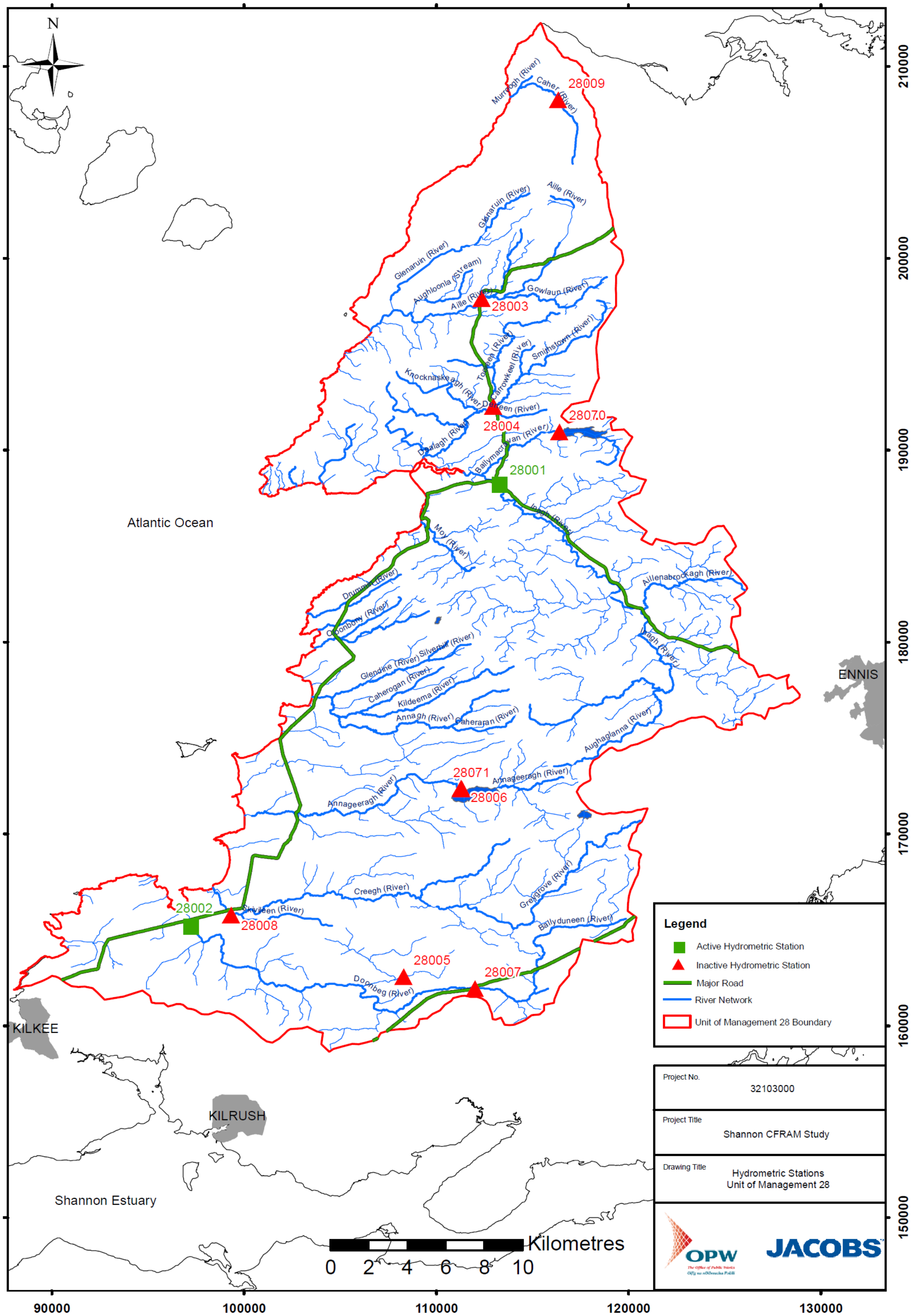

Figure 5 Location of hydrometric gauging stations within Mal Bay Unit of Management

Station number	Station name	Watercourse	Station status	15 min flow start	15 min flow end	15 min level start	15 min level end
28001	Ennistymon	Inagh	Active	01/10/1972	09/09/2010	01/10/1972	10/09/2010
28002	Doonbeg	Doonbeg	Active	01/10/1972	10/09/2010	01/10/1972	10/09/2010
28070*	Lickeen	Lickeen L.	Inactive			20/01/1976	24/08/2003

** 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 28 and their period of record

Station no.	Station name	River	Daily mean flow data		Daily mean level data	
			Record start	Record end	Record start	Record end
28001	Ennistymon	Inagh	01/10/1972	06/01/2004	01/10/1972	06/01/2004
28002	Doonbeg	Doonbeg			01/10/1972	21/10/2001

Table 3-D Daily mean flow and level data available within UoM 28 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

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 flow or level data series for a hydrometric year (1 October to 30 September).

Annual maxima (AMAX) data was provided by the OPW for two locations (28001 and 28002) located within UoM 28 (Table 3-F).

Station number	Station name	Watercourse	AMAX (Flows) (from OPW)	AMAX (Levels) (from OPW)
28001	Ennistymon	Inagh	1957 - 2009	1957 - 2009
28002*	Doonbeg	Doonbeg	1972 - 2008*	1972 - 2009

** Data missing 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2004 and 2005.*

Table 3-F Annual maximum flow and level data for hydrometric gauges located within UoM 28

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) may 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 may change over time, making the rating equations invalid until new equations are established. Actual flows may vary for a given water level as a result of hysteresis, blockage, instability of the cross-section, or hydraulic backwater effects.

No stations within UoM 28 have been identified by the OPW as requiring a rating review. Table 3-G details stations for which rating equations and check gaugings have been provided.

Station number	Station name	Watercourse	Rating review required by the OPW?	Rating equations received?	Check flow gaugings received?
28001	Ennistymon	Inagh	No	**Yes**	**Yes**
28002	Doonbeg	Doonbeg	No	**Yes**	**Yes**

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

3.5.7 Check Gaugings

Frequent check gaugings or 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 do not need to be reviewed within the context of undertaking rating reviews within UoM 28, as no sites have been identified for rating review. If a rating review were needed, the check gaugings would be reviewed in association with the rating equations to assess the suitability of the rating equations at high flows.

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 Stage II Project Brief were visited by Jacobs staff. However, no hydrometric gauging stations require a rating review in the Mal Bay Unit of Management.

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 the quality and facility of flood estimation in Ireland. Since 2005, the OPW have been implementing 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% Annual Exceedance Probability (AEP) (1 in 500) (0.4% AEP (1 in 250) 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 will be compared to measured rainfall frequency (ref. 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 Hydrologic 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).

FSU Classification		Definition
A	Both	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
	A1	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.
	A2	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.
B		Flows can be estimated up to Q_{med} with confidence. Some high flow gaugings must be around the Q_{med} value.
C		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}.

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 28
A1	75	18	0
A2	119	22	0
Total A sites	*194*	*40*	*0*
B	103	11	1

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 (if necessary). Table 3-J summaries the FSU rating reviews and classifications for the one record within UoM 28.

Station Number	Station Name (period of record)	River Name	FSU Classification	Rating Remarks (limit of reliable extrapolation, stability, concerns over particular gaugings, assumptions made etc)
28001	Ennistymon (Pre 01/01/1977)	Inagh	B	Use RC2 for period from SOR to 01/01/1977. Rating OK up to HGF only.

Table 3-J Summary of FSU Rating Classification for hydrometric stations within UoM 28.

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 estimates from catchment characteristics can be significantly improved by using pivotal sites (i.e. a gauge that can be used to assist in deriving flood estimates based on the hydrological similarity between the gauged site and the site for which flows must be derived). 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

Outstanding data for the Mal Bay Unit of Management are staff gauge levels from station 28008.

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 (4 for this trial). Catchment descriptors for these HEPs will have to be attributed manually.

The trial HEPs for UoM 24 have been provided to OPW using the Sharepoint filesharing 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 on whether it represents one of the tributary catchments 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 lessons learned as described in Section 4.3 above.

5 Catchment Boundaries

5.1 Introduction

This chapter details the findings of the comparison of different catchment boundary datasets for Unit of Management 28, which was carried out using the methodology set out in Technical Note TD010.

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).
Adjusted Gauged Catchment Boundaries	Manually adjusted applied to catchments where area derived from the automated 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 CFRAMS 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 28 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 (equal to the Unit of Management 28 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 preliminary hydrological assessment the Flood Risk Review (FRR) had not been completed. This analysis is therefore only based on discrepancies of 10% or more in catchment sizes to hydrometric stations, and Communities at Risk (CARs) and Individual Risk Receptors (IRRs) identified in the Shannon CFRAM Study Stage II Brief. It is possible that the Flood Risk Review will recommend the inclusion of other locations to be designated as Areas of Potential Significant Risk (APSR) and this may lead to further discrepancies being identified. It is therefore advised that the catchment boundary comparison is revisited once the FRR has been completed.

5.4 Results of Analysis

Figure 6 overleaf shows a comparison of the Water Framework Directive (WFD) boundary, the automatic boundaries and the manually adjusted (FSU) boundaries in area UoM 28. There are some differences between the WFD and the automatic boundaries, but these differences are too small to be significant (for this study defined as smaller than a 10% difference to a catchment area).

Random checks were carried out to compare the ungauged automatic catchment boundaries with the NDHM dataset. No significant discrepancies were found.

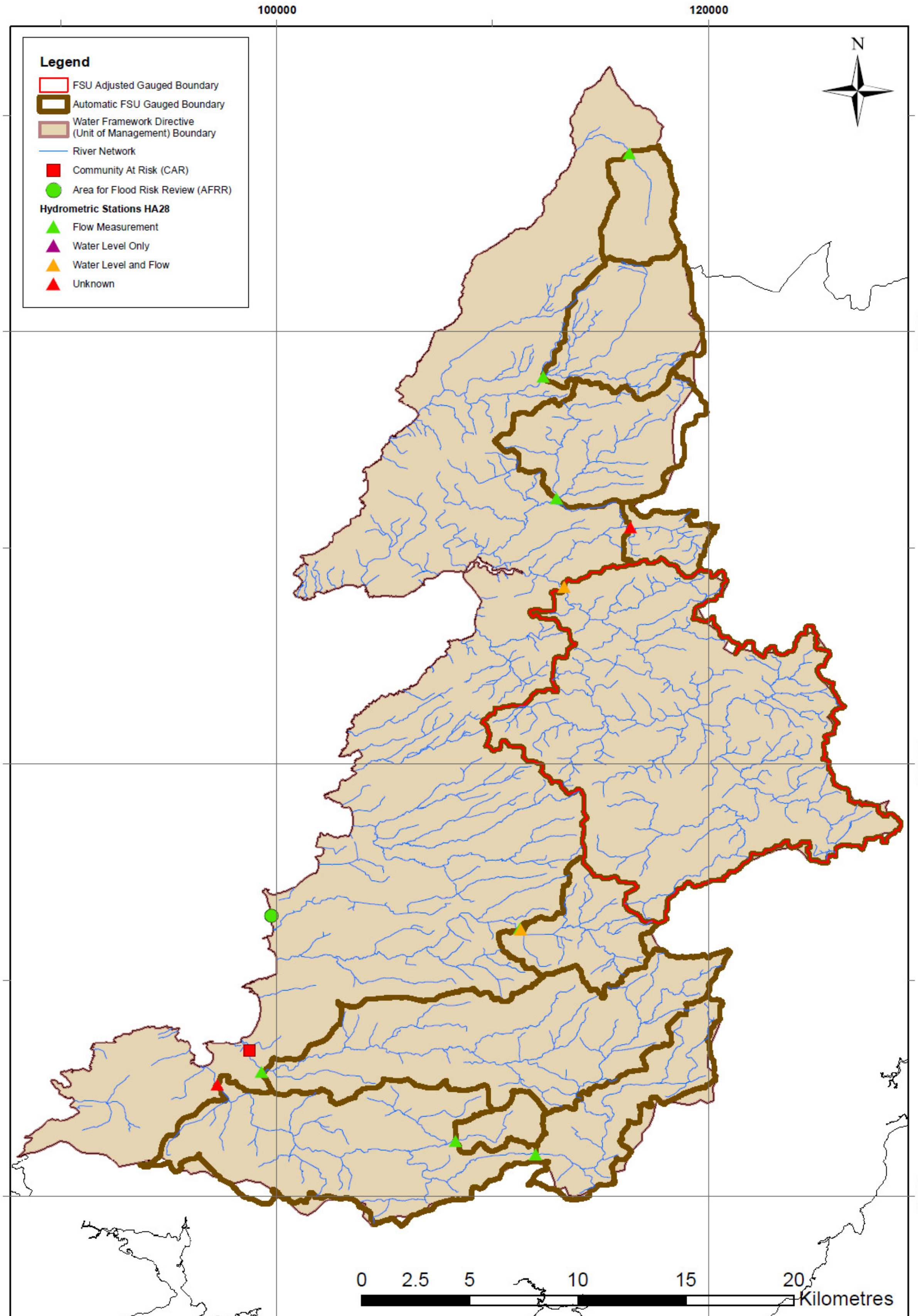

Figure 6 Unit of Management 28 – Comparison FSU and WFD Boundaries

5.5 Conclusions

Based on an assessment of Unit of Management 28 alone, it can be concluded that:

1. No significant discrepancies were found in the gauged FSU catchment and WFD boundaries of Unit of Management 28.

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

5.6 Recommendations

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, UoM 24, UoM 25-26, UoM 27, UoM 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 other Units of Management) 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 has focussed 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 Mal Bay Unit of Management

Daily read raingauges are not evenly distributed across the Mal Bay Unit of Management (ref. Figure 4) with six of the eight raingauges clustered within the southern portion of the unit of management, and the remaining two in the northern portion.

6.3 Data Review

It was assumed that rainfall data provided by Met Éireann was fully quality assured prior to being distributed. 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 gauge 1617 (Lisdoonvarna) has a large portion of missing data , 68% (Table 6-A). Stations 1117 (Doo-Lough), 1317 (Kilmihil), 1417 (Mullagh), 1717 (Ennistymon) and 2017 (Quilty) have either no or minimal missing data.

Raingauge no.	Name	Record start	Record end	Total number of days	Missing days	% of data missing
417	Inagh (Mt Callan)	01/01/41	31/07/10	25414	1093	4
1117	Doo-Lough	01/06/41	28/02/11	10500	8	0
1217	Doonbeg	01/06/84	31/10/01	6365	650	10
1317	Kilmihil (Shyan)	01/06/84	31/08/10	9588	304	3
1417	Mullagh (Carrowlagan)	01/06/84	31/08/10	9588	67	1
1617	Lisdoonvarna (Cahermacnaghten)	01/06/85	31/10/05	7458	5050	68
1717	Ennistymon (Ballymacravan)	01/12/84	28/02/11	8491	36	0
2017	Quilty	01/06/99	28/02/11	4291	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 across the entire record at station 1617 and at the end of the record at station 1217.

Cumulative totals for all raingauges between 1 June 1999 and 31 October 2001 (the only period for which data was available at all eight raingauges) indicate a possible geographical variation in rainfall received throughout the unit of management. A higher cumulative rainfall total was recorded furthest east (inland) within the Mal Bay Unit of Management (stations 417, 1117, 1317 and 1717) compared to the rainfall totals recorded at gauges located more centrally or to the west by the coast (stations 1417 and 2017) (see Table 6-B and Figure 4). The raingauge recording the highest total rainfall was 417 at Inagh (Mt Callan) with a total of 4316.8 mm for the given period. The lowest total rainfall recorded was 1617 (Lisdoonvarna), this can be attributed to missing data over the selected period.

Station No.	Cumulative total rainfall (mm)
417	4316.8
1117	3334.1
1217	1257.1
1317	3294.5
1417	3050.6
1617	197.3
1717	3309.0
2017	2778.7

Table 6-B Cumulative rainfall for stations in Mal Bay Unit of Management between 1 June 1999 and 31 October 2001.

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. Due to the close proximity of the raingauges within the unit of management, it was not deemed necessary to review all raingauge data. The following raingauges were selected based on location, completeness of data and quality of record:

- 1317 – Kilmihil (Shyan)
- 1717 – Ennistymon (Ballymacravan)

Raingauge 1317 is located within the Creegh catchment, upstream of Carrowmore, whilst 1717 is located in the Ballymacravan catchment, a tributary to the River Inagh, in the northern portion of the unit of management. Together the two raingauges provide a broad coverage of the unit of management.

6.5 Rainfall Probability Plots

For the two raingauges selected in Section 6.4, 1 day total annual maxima and a 4 day total annual maxima series were created. Any years with greater than 30 days of missing data were excluded and this left 1317 and 1717 with 21 and 23 years of data respectively.

The annual maxima series were ranked in decreasing order of magnitude. 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.

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

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.

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

$$a = \mu_Q - \frac{\gamma}{b} \quad (6.3)$$

$$b = \frac{\pi}{\sigma_Q \sqrt{6}} \quad (6.4)$$

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

A severe rainfall event was identified in conjunction with the annual maxima flow series. The two rainfall stations identified in 6.4 will be the focus for the analysis. For consistency the same event selected for fluvial analysis will be reviewed here also. Event selection is detailed in Sections 7.4 and 7.6. The event selected is:

- 6 January 1992;

For this 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 Section 6.6.1.

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 (and Appendix C).

It is important to note that the availability of daily rainfall only is anticipated to significantly increase the uncertainty in respect of the analysis of rainfall events with sub-daily durations, and hence the focus of the analysis is on durations of 1 day or more.

6.6.1 Event of 6 January 1992

High fluvial flows recorded on 6th January appear to have been the result of a rainfall event which commenced on the 2nd January through to the 6th January, peaking on the 4th January with daily rainfall totals of 47.3 mm and 58.0 mm recorded at

raingauges 1317 and 1717 respectively. Daily rainfall related to this event is shown in Figure 7.

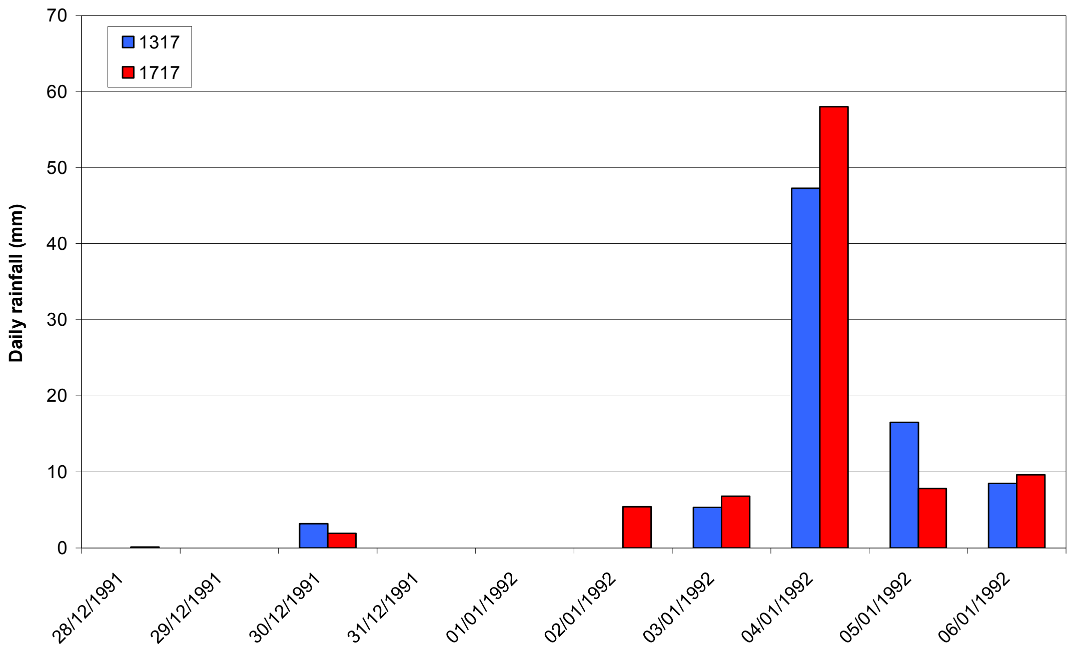

Figure 7 Daily rainfall –28th December 1991 to 6th January 1992

Annual exceedance probabilities (AEPs) for the maximum rainfalls over the event are presented in Table 6-C. AEPs estimated from the 1-day and 4-day rainfall probability plots (in Appendix C) indicate this was in general a rarer event for the 1-day duration compared to the longer 4-day duration. Values derived for the 1-day duration at raingauges 1317 and 1717 indicate that this event had an annual exceedance probability of 11% and 4% respectively, compared to around a 25% AEP for the 4-day duration.

	Jan-92			
Rainfall Duration	1317 Rainfall depth (mm)	1317 AEP (%)	1717 Rainfall depth (mm)	1717 AEP (%)
1 day rainfall (mm)	47.3	11	58.0	4
2 day rainfall (mm)	63.8		65.8	
4 day rainfall (mm)	77.6	26	82.2	25
10 day rainfall (mm)	80.8		89.6	

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 (January 1992)

6.7 Flood Studies Update Rainfall Comparison

Theoretical point rainfall depths, created for the Flood Studies Update were extracted from GIS raster layers for a range of Annual Exceedance Probabilities between 50% and 0.5% at the 24 hour and 4 day durations. GIS rasters were not available for the 10 day duration rainfall. Output values are presented in Table 6-D.

Duration	Return Period (years)	Annual Exceedance Probability (%)	1317	1717
24 hour	2	50	39.92	39.03
24 hour	5	20	47.21	49.37
24 hour	10	10	52.10	56.69
24 hour	20	5	57.03	64.42
24 hour	30	3	59.99	69.25
24 hour	50	2	63.92	75.68
24 hour	100	1	69.61	85.32
24 hour	200	0.5	75.70	96.09
4 day	2	50	69.06	69.06
4 day	5	20	79.75	83.62
4 day	10	10	86.74	93.57
4 day	20	5	93.77	103.79
4 day	30	3	98.00	110.04
4 day	50	2	103.46	118.29
4 day	100	1	111.29	130.43
4 day	200	0.5	119.68	143.62

Table 6-D 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 1 day 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.

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-E and F), 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. However, this difference is primarily at the one day duration. At both locations AEP values estimated from the data and FSU for the 4-day duration, are remarkably similar, all at around the 25% AEP event.

At the 1-day duration, the FSU AEP values are both higher than estimated from the data, with values of 20% and 9% compared to the estimated AEPs of 11% and 4% respectively. This is a considerable disparity with FSU estimates suggesting the frequency is approximately double the frequency estimated directly from the source data.

1317	1 day			4 day		
Event date	Maximum depth (mm)	Estimated AEP %	FSU AEP (%) (approx)	Maximum depth (mm)	Estimated AEP % (approx)	FSU AEP (%)
Jan-92	**47.3**	**11**	**20**	**77.6**	**26**	**25**

Table 6-E 1 day and 4 day rainfall and associated Annual Exceedance Probability (AEP) for raingauge 1317

1717	1 day			4 day		
Event date	Maximum depth (mm)	Estimated AEP %	FSU AEP (%) (approx)	Maximum depth (mm)	Estimated AEP % (approx)	FSU AEP (%)
Jan-92	**58.0**	**4**	**9**	**82.2**	**25**	**23**

Table 6-F 1 day and 4 day rainfall and associated Annual Exceedance Probability (AEP) for raingauge 1717

6.8 Conclusions

Eight Met Éireann daily storage raingauges have been identified within the Mal Bay Unit of Management. No sub-daily rainfall data was available and this has limited the rainfall durations analysed and the conclusions that were able to be drawn.

Rainfall depths calculated for four durations, 1-day, 2-day, 4-day and 10-day over the selected period in January 1992 suggest the event was the result of high intensity rainfall preceded and followed by low intensity more prolonged 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 analysis indicates that the 1-day rainfall depths recorded during the January 1992 event were relatively infrequent at both raingauge locations, with annual exceedance probabilities estimated at 4% (1717) and 11% (1317).

Annual exceedance probabilities estimated from actual data for the 1 day and 4 day durations were compared to theoretical AEPs for the 24 hour and 4 day durations created for the Flood Studies Update varied. For the 4-day durations, the FSU AEPs were almost identical to the estimated AEPs at both locations. However, for the 1-day duration, the FSU AEPs were higher. These differences appear to suggest that the FSU DDF estimates do not accurately reflect the DDF relationship at the three rainfall stations considered.

7 Review of Fluvial Data

7.1 Introduction

Those gauging stations located within the Mal Bay Unit of Management (UoM 28) and for which any instantaneous, daily mean or annual maxima (AMAX) flow or level data was received are listed previously (Tables 3-A, 3-C and 3-F). The subsequent review and analysis of fluvial data has been limited to these stations.

Flow and level gauges within the Mal Bay Unit of Management are distributed throughout the unit of management but primarily in two clusters; in the south and in the middle to north. Of the 11 fluvial flow and level gauging stations listed by the EPA as located within UoM 28 only two are currently active with 15-minute flow or level data provided (ref. Appendix A).

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 the 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 herein.

7.2 Distribution of Flow and Level Gauging Stations within UoM 28

Two hydrometric gauges are currently active within the Mal Bay Unit of Management with one each located within the Inagh and Doonbeg catchments.

The River Doonbeg, located in the south of UoM 28 is gauged at Doonbeg (28002) just upstream of where the river drains into the Atlantic Ocean.

Towards the north of UoM 28, the River Inagh (or Cullenagh) flows from the uplands dividing UoM 27 and UoM 28, through Inagh and Ennistymon and into the Atlantic Ocean. The River Inagh is gauged at Ennistymon (28001).

7.3 Data Review

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.

Two daily mean flow and / or level records were available for review (ref. Table 3-D). No trends were observed in either record, however the highest flow on record at station 28001 appears dubious as it is considerably larger than the next highest peak flow on record (231m^3/s versus 72 m^3/s). Further investigation by OPW into the flow and level series is recommended to determine whether this peak value is genuine.

The AMAX series for 28001 show a maximum flow for that hydrological year of 47 m^3/s indicating that the daily mean flow data is probably in error (ref. Section 7.5).

Although the flow series at 28002 appears to extend until 2004, with the exception of three values, the record ends in 2001.

				Daily Flow data only				Daily Level data only				
Station no.	Station name	River	FSU Class	% of good days	% of poor or cautionary days	% of missing days	Total number of days	% of good days	% of cautionary days	% of missing days	Total number of days	Further investigation recommended
28001	Ennistymon	Inagh	B	46	28	2	11420	90	0	2	11420	Highest peak on record (3/12/1979) considerably higher than any other peaks on record. OPW Review recommended.
28002	Doonbeg	Doonbeg						89	0	8	11425	No obvious step or trend.

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 data for the two fluvial stations in the Mal Bay Unit of Management (ref. Table 3-F) were ranked and the top 5 and top 6-10 events at each location identified by the letter A and yellow shading and 'B' and green shading, respectively. 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 should be used as one of a series of approaches for assessing severe events.

Date of Event	28001	28002
24 December 1968	A	
5 August 1971		
14 November 1972		B
02 December 1973		A
2 December 1975		B
19 June 1982		A
10 October 1983	B	
10 December 1983		B
15-16 August 1985	B	A
6-7 August 1986	B	A
28 October 1989	B	
6 January 1992	A	A
28 December 1994	A	
8 January 2005	B	
22 September 2006	A	
29 December 2007		B
25 August 2009		B
24 November 2009	A	

Table 7-B Top 5 (A) and Top 6-10 (B) AMAX flow or level for hydrometric gauging stations within UoM 28.

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 two hydrometric gauging stations located in the Mal Bay Unit of Management for which an AMAX series greater than 10 years was available. The fit for station 28002 is acceptable, whilst a high flow at station 28001 prevents a fit at the upper end of the flows. A questionable peak flow identified in the daily mean flow sequence at 28001 (234.1 m^3/s) was not present in the AMAX series, casting doubt on the daily mean flow data.

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

One flood event has 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.

Event selection was based a review of the AMAX series from gauges across the catchment (ref. Table 7-B). No data on historic flooding was available on floodsmap.ie for Carrowmore, the only CAR identified within UoM 28 in the Shannon CFRAM Study Stage II Brief. Emphasis was initially placed on the selection of events which have occurred recently, within the past 15 years. However, to ensure the widest response across the unit of management was obtained, events within the past 25 years have been considered.

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

28001 Inagh at Ennistymon
28002 Doonbeg at Doonbeg

The flood event of January 1992 is the only event that is ranked in the top 5 events for both gauges (2nd at 28002 and 3rd at 28001). Given the geographic separation of the gauges (one in the north and one in the south of UoM 28) it represents a catchment wide event. Therefore, this event was selected as representative of severe flood events within the Mal Bay Unit of Management.

7.6.1 Event of 6 January 1992

Flow data was extracted from the 15 minute series at the two gauging stations between 3rd January 1992 (00:00 hours) and 17th January 1992 (23:45 hours). These flows are in reasonable agreement with the respective values detailed in the AMAX series (ref. Appendix H). A summary of the data is presented in Table 7-C below.

Station No.	Peak flow (m^3/s)	Time of peak flow	Start time	End time	Volume of flow (m^3)	Duration (days, hours, minutes)
28001	79.1	06/01/1992 02:00	04/01/1992 22:15	07/01/1992 12:45	12,128,209	02:14:30
28002	74.8	06/01/1992 08:30	04/01/1992 22:30	07/01/1992 15:15	9,665,497	02:16:45

Table 7-C Summary of timings and flows for the flood event 6 January 1992

Both hydrographs (Figure 8) indicated a double-peaked event, with the first peak being the largest. Analysis has therefore focused on the first portion of the hydrograph ending at the start of the second rising limb of the hydrograph.

Both hydrographs are similar in their response with steep rising limbs and steep recessions indicating responsive catchments.

Based on the annual maximum flow series fitted with a Gumbel distribution as detailed in Section 7.5 annual exceedance probabilities were estimated for the event at each location. Results vary from 4% on the Doonbeg at Doonbeg (28002) to 7% on the Inagh at Ennistymon (28001) (Table 7-D). Both estimates suggest it was an infrequent event.

			Jan-92	
Station No.	Station Name	Watercourse	Peak flow (m^3/s)	Estimated Annual Exceedance Probability (%)
28001	Ennistymon	Inagh	79.1	7
28002	Doonbeg	Doonbeg	74.8	4

Table 7-D Estimated Annual Exceedance Probabilities for peak flows during January 1992 event

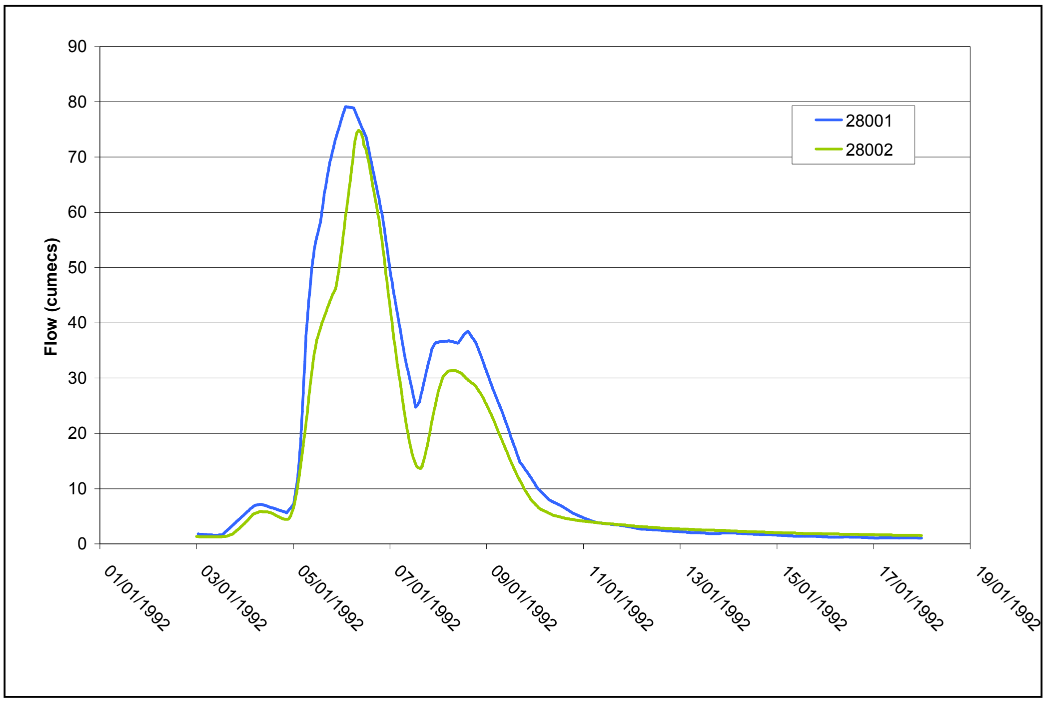

Figure 8 Hydrographs for the January 1992 event in Mal Bay Unit of Management

7.6.2 Mal Bay Discussion

Hydrographs at both locations indicate a steep rising limb and an equally steep recession, indicative of fast responding catchments. The rising limb of the hydrograph at 28002 is not entirely smooth and may represent a feature of the catchment response, although a firm conclusion can not be drawn based on this single event.

Despite the large difference in catchment area between the two catchments, the peak flows only differed by a small amount. The difference in catchment areas is offset by runoff (Table 7-E), which is higher for the catchment at 28002 in comparison to 28001. The lower runoff deduced for 28001 probably reflects the

more permeable geology of the catchment compared to 28002, FSU BFIsoils being 0.33 and 0.42 respectively..

		Jan-92		
Station No.	Catchment area (km^2)	Peak flow (m^3/s)	Volume of flow (m^3)	Runoff (mm)
28001	169.4	79.1	12,128,209	72
28002	108.2	74.8	9,665,497	89

Table 7-E Peak flow, volume of flow and runoff for one event in the Mal Bay Unit of Management

The hydrographs for the two events are remarkably similar, given that they are in different catchments and separated by nearly 30km (between the main watercourses in each catchment). This is a reflection of the catchment-wide nature of the rainfall event, demonstrated by the rainfall patterns shown in Figure 7. The catchment responses also show the peak flow occurring on 6th January 1992, approximately two days after the peak rainfall.

7.7 Conclusions

A review of daily mean flow data highlighted no long-terms trends in the two flow and / or level series. However, a questionable peak flow is present in the daily mean flow series, which warrants further investigation by the OPW or removal from the daily mean flow series. The questionability of the high flow is further emphasised by the presentation of a lower peak flow for the same event in the OPW AMAX series.

One flood event, 6 January 1992 was reviewed in detail. Hydrographs produced for the event at two gauges indicate a steep rising limb and an equally steep recession indicative of fast responding catchments. The event is seen to be a large catchment-wide event.

Runoff within the Mal Bay Unit of Management is greater at 28002 on the River Doonbeg, in comparison to 28001, based on the analysis of the single event. This may reflect the less permeable soils of the catchment compared to 28002.

Annual exceedance probabilities estimated for the January 1992 event within the Mal Bay Unit of Management indicate slightly differing event probabilities between catchments. An AEP of 4% was estimated at 28002 on the River Doonbeg, whilst an estimate of 7% was estimated on the River Inagh (28001).

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8 Historical Flood Risk Review

8.1 Introduction

A substantial amount of historical flooding information has been gathered using "floodmaps" (www.floodmaps.ie), 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. 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 in Table 8-A:

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.

Wherever the information is available in "floodmaps" 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 qualitative nature of most of the information available in "floodmaps" it has often been found difficult 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 bodies 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

Only one Community at Risk (CAR), Carrowmore has been identified in this unit of management (ref. Section 2). No records of historical flood risk have been identified for Carrowmore on floodsmap.ie or in discussion with the Local Authority (Clare County Council).

9 Proposed methodologies for future work

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. However, following the completion of the Flood Risk review in September 2011 UoM 28 has been excluded from modelling. No rating reviews or model extents are defined in this unit of management. Please refer to the inception reports for the other units of management in the Shannon RBD for a detailed discussion on the approach to modelling in the RBD.

10 Constraints, Data Problems and Other Issues

A daily mean flow series has not been received for the key station (ref. Section 3.2) 28002 (Table 10-A). Confirmation of whether the relevant data series exists is requested in the first instance. In addition staff gauge levels from station 28008 have been identified as information required but not yet supplied.

There is not expected to be any significant 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
28001	OPW					
28002	OPW	Yes				
28008	EPA			Yes		

Table 10-A Outstanding hydrometric data for Mal Bay Unit of Management (UoM 28) (Grey squares are equivalent to N/A)

As no rating review or modelling is proposed in UoM 28, we do not expect to need any further data.

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 discrepancies of this magnitude have been identified within UoM 28.

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

Eight Met Éireann daily storage raingauges have been identified within the Mal Bay Unit of Management. No sub-daily rainfall data was available and this has limited the rainfall durations analysed and the conclusions that are able to be drawn.

One rainfall event across the unit of management has been studied; January 1992. Rainfall depths calculated for four durations, 1-day, 2-day, 4-day and 10-day over the selected period in January 1992 suggest the event was the result of high intensity rainfall preceded and followed by low intensity more prolonged 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 analysis indicates that the 1-day rainfall depths recorded during the January 1992 event were relatively infrequent at both raingauge locations, with annual exceedance probabilities estimated of 4% (1717) and 11% (1317).

Annual exceedance probabilities estimated from actual data for the 1 day and 4 day durations, and the theoretical AEPs for the 24 hour and 4 day durations created for the Flood Studies Update varied. For the 4-day durations, the FSU AEPs were almost identical to the AEPs estimated from the actual data at both locations. However, for the 1-day duration, the FSU AEPs were approximately double those estimated from the data. These differences may reflect the fit of the EV1 distribution selected here compared to the log logistic growth curve assumed in the FSU.

Instantaneous flow data was provided for two gauging stations. One flood event was selected across the unit of management to analyse the series in detail. The event selected was that of 6th January 1992

A review of daily mean flow data highlighted no long-terms trends in the two flow and / or level series. However, a questionable peak flow is present in the daily mean flow series, which warrants further investigation by the OPW or removal from the daily mean flow series. The questionability of the high flow is further emphasised by the presentation of a lower peak flow for the same event in the OPW AMAX series.

Hydrographs produced for the event at two gauges indicate a steep rising limb and an equally steep recession indicative of fast responding catchments. Both

catchments show very similar hydrograph responses, in terms of their peak values (each one exhibiting a double peak) and the timing of the peak flows. The geographic separation of the two catchments demonstrates that the event was a large catchment-wide event.

Runoff within the Mal Bay Unit of Management is greater at 28002 on the River Doonbeg in the south, in comparison to 28001 on the River Inagh towards the north, based on the analysis of this single event. This may reflect the less permeable soils in catchment 28002.

Annual exceedance probabilities estimated for the January 1992 event within the Mal Bay Unit of Management indicate slightly differing event probabilities between catchments. An AEP of 4% was estimated at 28002 on the River Doonbeg, whilst an estimate of 7% was estimated on the River Inagh (28001).

A review of data available on the floodsmap website, yielded no historic flood information on Carrowmore, the only CAR identified within UoM 28.

There are no gauging stations in UoM 28 that are subject to a rating review.

Following the completion of the Flood Risk review in September 2011, no modelling is proposed for UoM 28. It is therefore not expected that any further data will be required for this unit of management.

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Appendix A - All Hydrometric Stations listed in EPA Register

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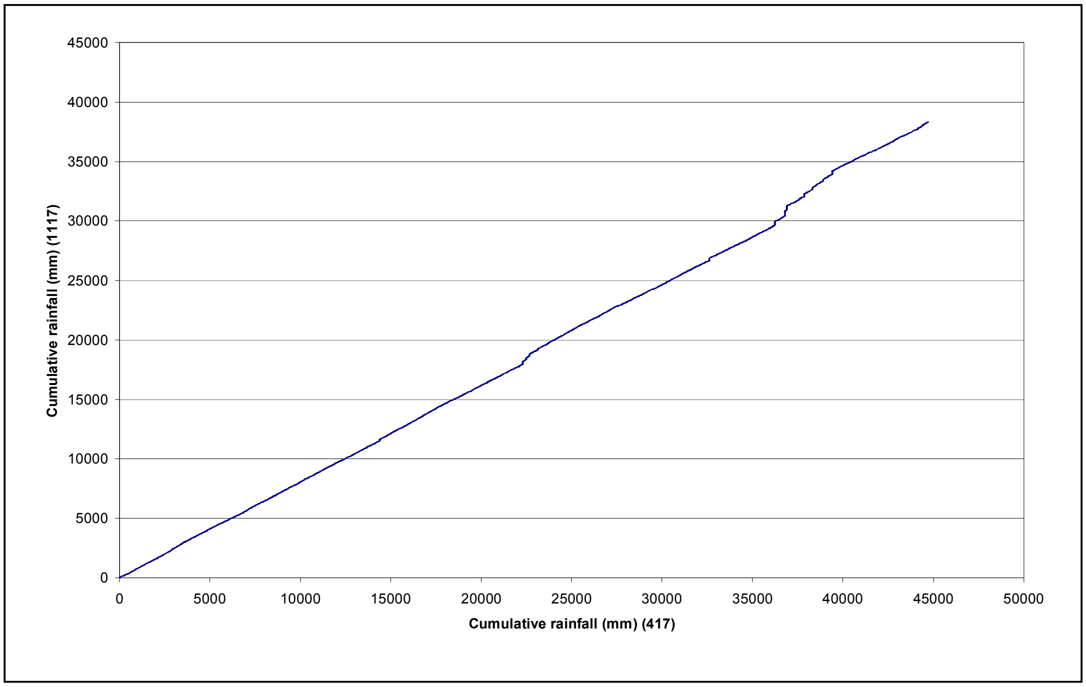
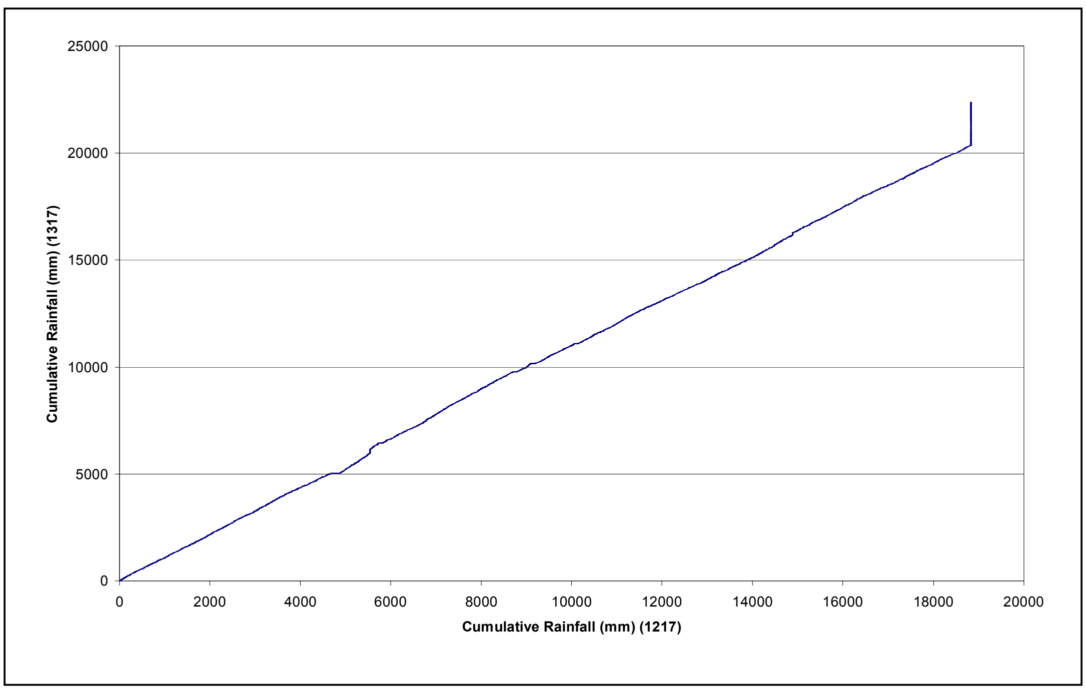
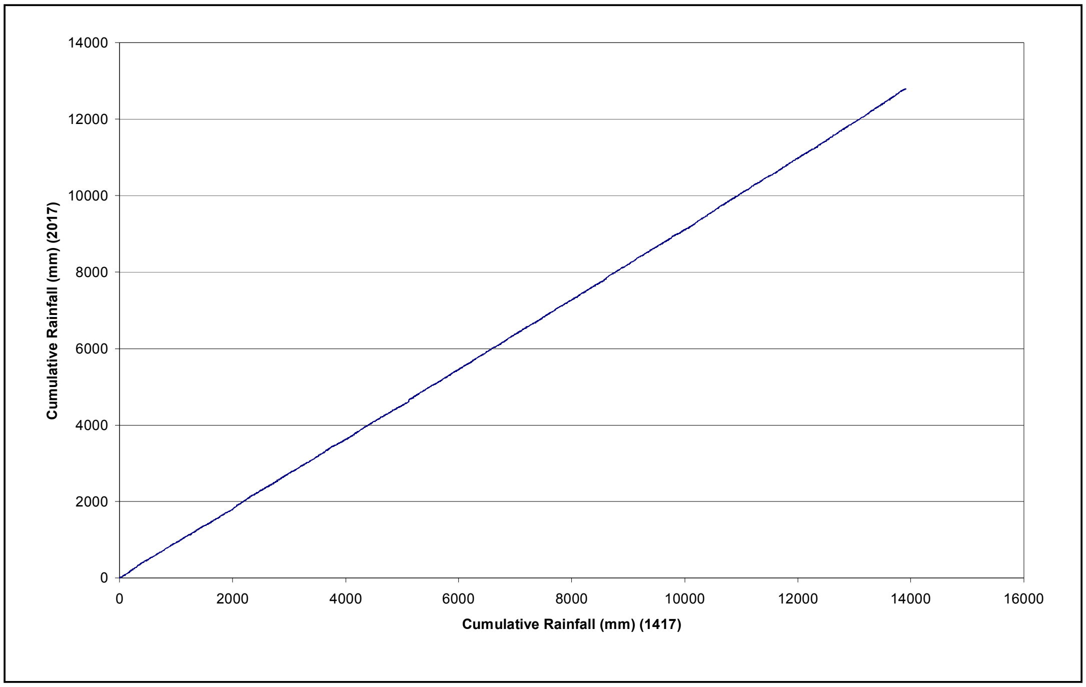
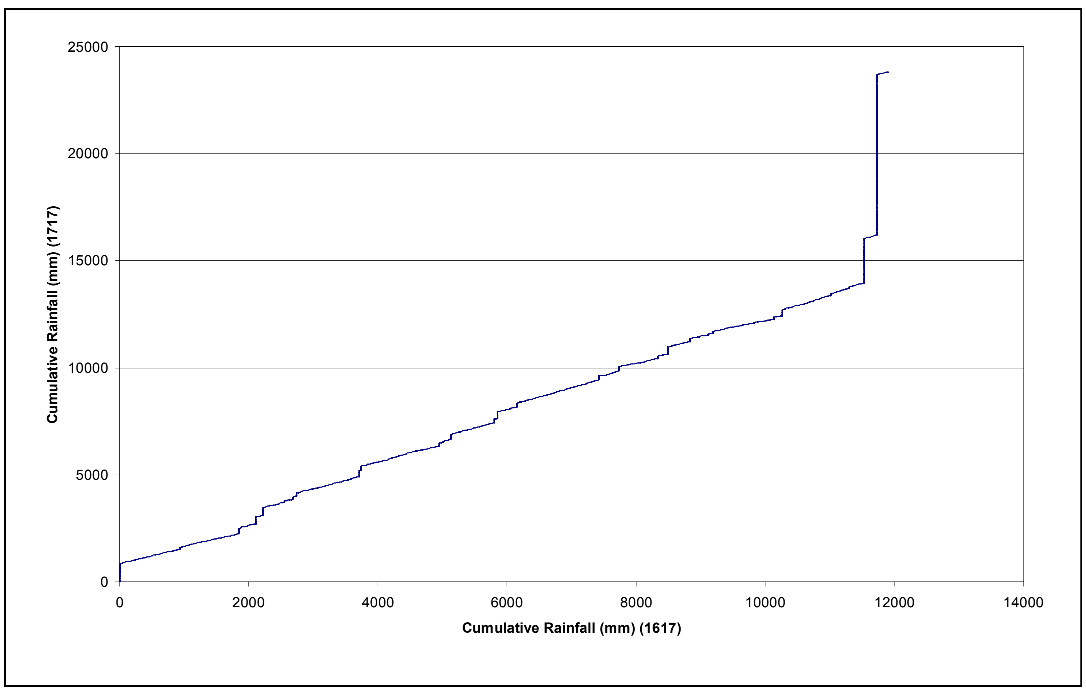
Station Number	Station Name	Waterbody	Catchment Area (km^2)	Station Status	Station Type	BDS	Catchment	Easting	Northing	Type	Records Start	Records End	Telemetry
28001	Ennistymon	Inagh	169.4	Active	Recorder	Office of Public Works	Inagh	113299	188191	River	01-Oct-57		Yes
28002	Doonbeg	Doonbeg	108.2	Active	Recorder	Office of Public Works	Doonbeg	97248	165180	River	01-Oct-57		Yes
28003	Spectacle Bridge	Aille (Clare)	33.5	Inactive	Staff Gauge Only	Clare County Council	Aille-Caher-Coastal	112339	197908	River	31-Aug-78	04-Dec-97	No
28004	Kilshanny	Derreen	37.5	Inactive	Staff Gauge Only	Clare County Council	Inagh	112941	192286	River	30-Oct-80	15-Nov-94	No
28005	Kilmihil	Doonbeg Trib.	7.3	Inactive	Staff Gauge Only	Clare County Council	Doonbeg	108281	162568	River	06-Dec-80	12-Feb-92	No
28006	D/S Doo Lough	Creevagh	22.9	Inactive	Staff Gauge Only	Clare County Council	Annageeragh-Annagh-Creegh-Coastal	111254	172391	River	05-Dec-80	08-Feb-83	No
28007	Goolburne Br	Doonbeg	29.5	Inactive	Staff Gauge Only	Clare County Council	Doonbeg	111977	161953	River	28-Jun-84	09-Dec-97	No
28008	Mountrivers Br.	Creegh	82.9	Inactive	Staff Gauge Only	Clare County Council	Annageeragh-Annagh-Creegh-Coastal	99302	165776	River	23-Aug-84	09-Dec-97	No
28009	Fermoyle	Fermoyle Stream	15	Inactive	Staff Gauge Only	Clare County Council	Aille-Caher-Coastal	116315	208253	River	29-Aug-90	04-Dec-97	No
28070	Lickeen	Lickeen L.	9.1	Inactive	Recorder	Clare County Council	Inagh	116371	190946	Lake	20-Jan-76	07-Jan-03	No
28071	Creevagh	Doo L.	22.8	Inactive	Staff Gauge Only	Clare County Council	Annageeragh-Annagh-Creegh-Coastal	111291	172344	Lake	03-Aug-77	19-Oct-82	No

Appendix B - Double Mass Rainfall Plots






Cumulative Rainfall (mm) (2017)
Cumulative Rainfall (mm) (1417)
0
2000
4000
6000
8000
10000
12000
14000
16000


Cumulative Rainfall (mm) (1717)
Cumulative Rainfall (mm) (1617)
0
5000
10000
15000
20000
25000
2000
4000
6000
8000
12000
14000

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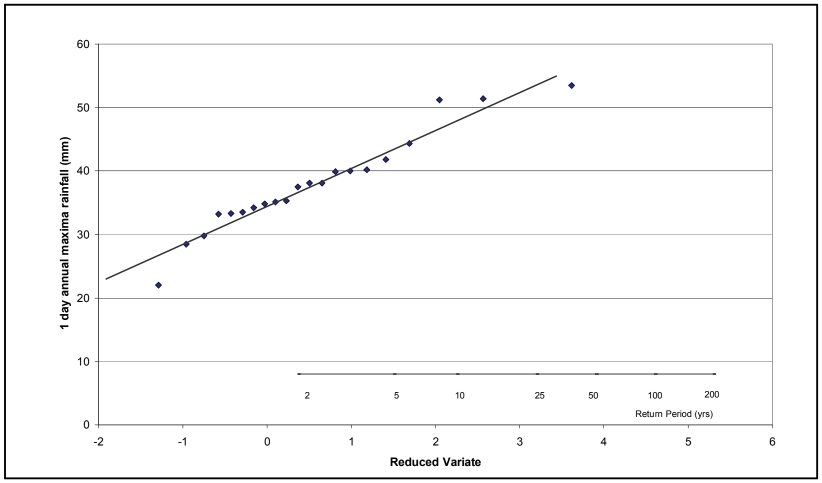
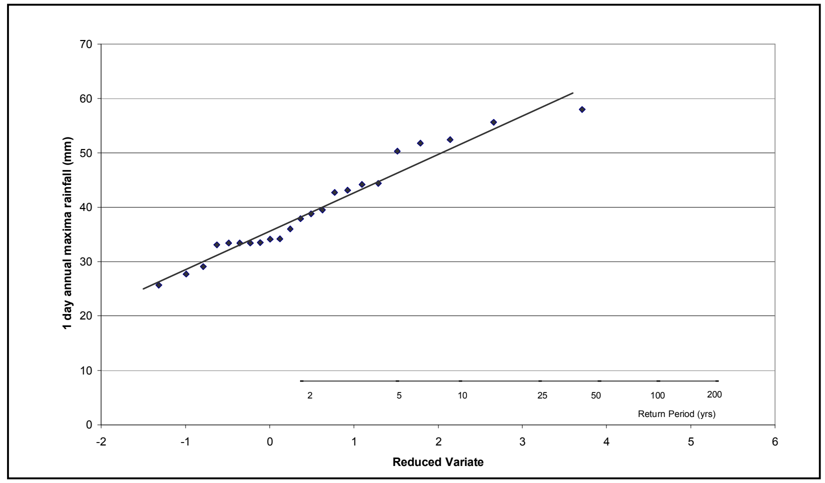
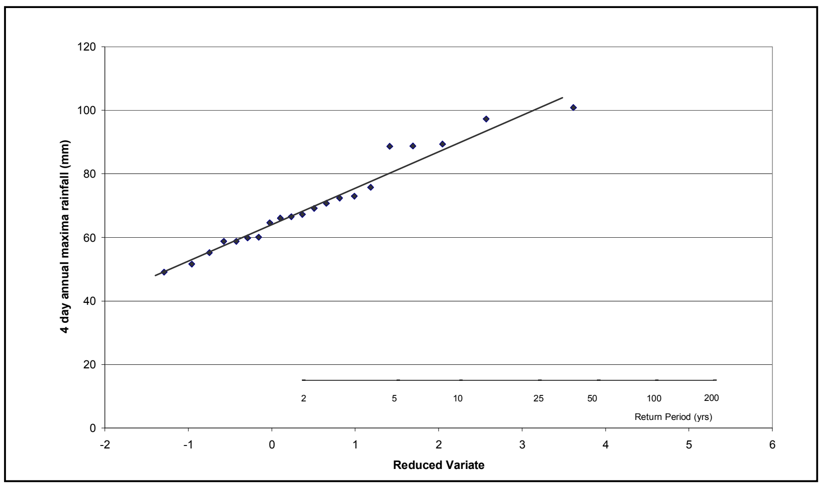
Appendix C - 1-day and 4-day Rainfall Probability Plots



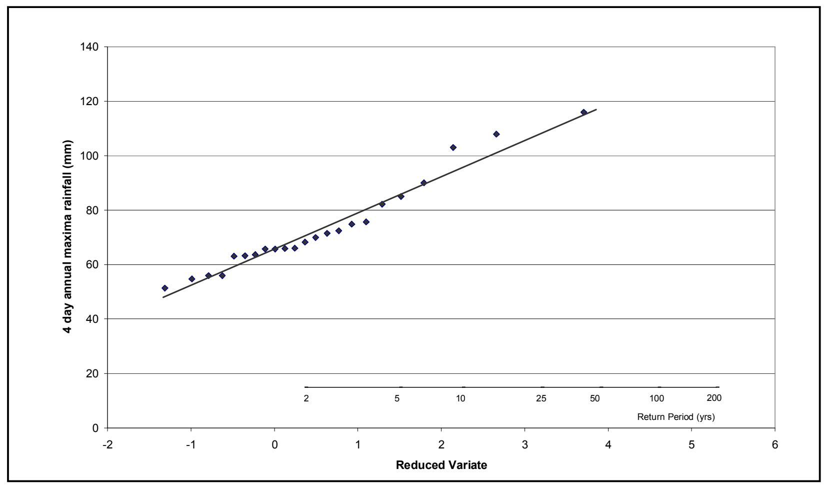
a) Raingauge 1317 – Kilmihil (Shyan) – 1 day



b) Raingauge 1717 – Ennistymon (Ballymacravan) – 1 day



a) Raingauge 1317 – Kilmihil (Shyan) – 4 day



b) Raingauge 1717 – Ennistymon (Ballymacravan) – 4 day

Appendix D - FSU Depth Duration Frequency Plots

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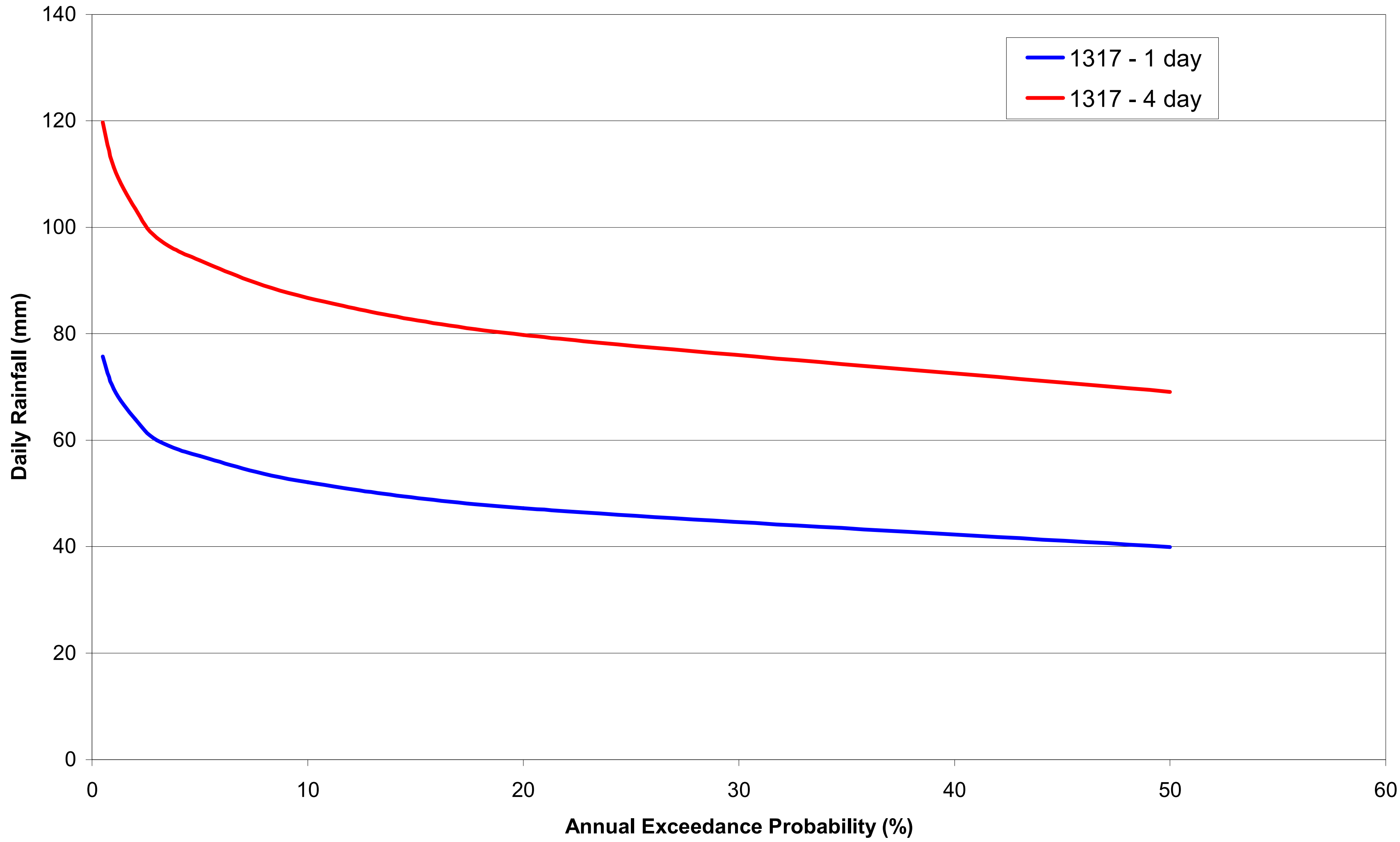
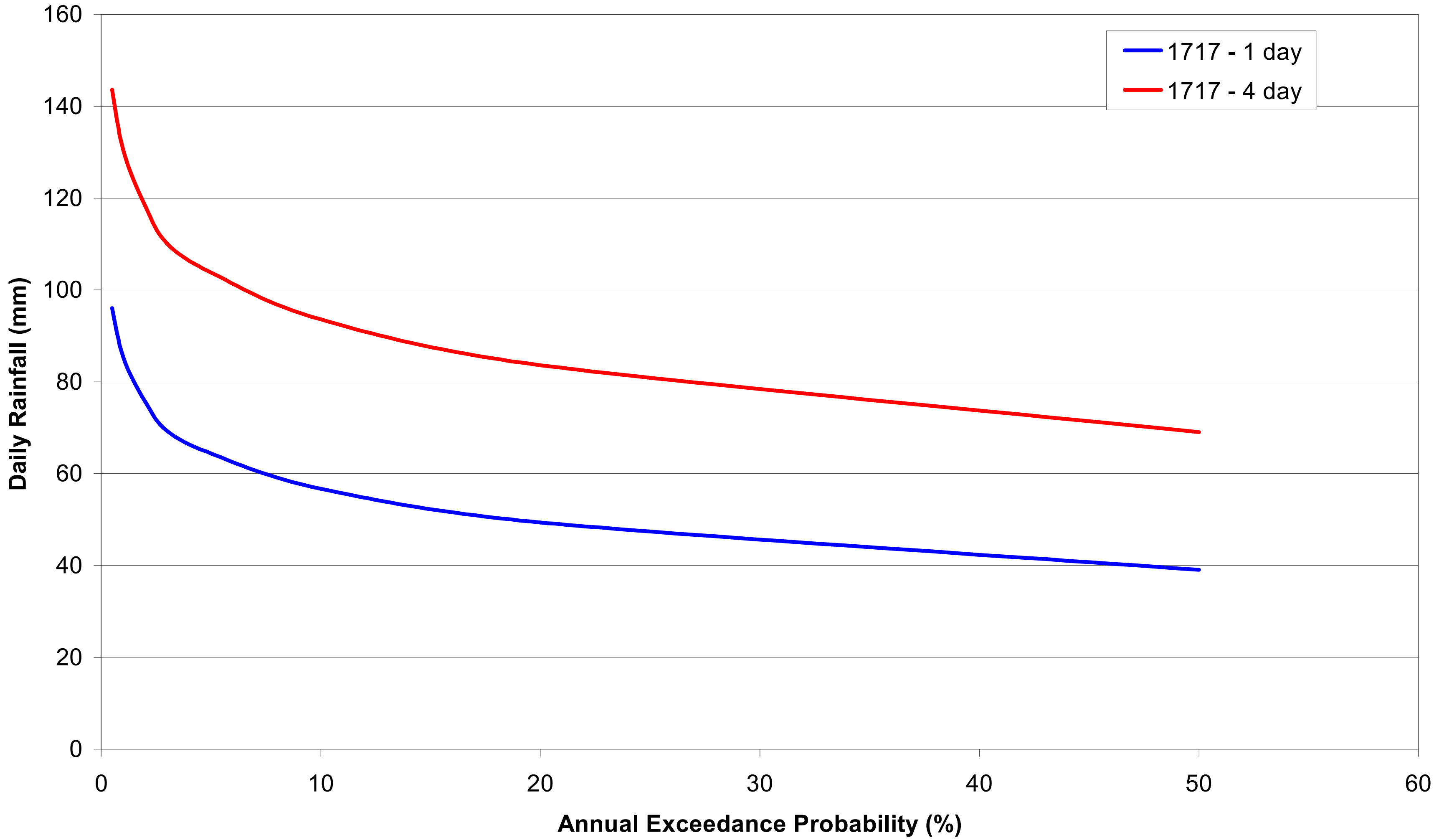
Depth Duration Frequency Curves for raingauge 1317 (from FSU Workpackage 2.2)



Depth Duration Frequency Curves for raingauge 1717 (from FSU Workpackage 2.2)



Appendix E - Daily Mean Flow Review

							Daily Flow data only									Daily Level data only							
Station number	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 no. 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 no. of days	Comment on visual inspection of record
28001	Ennistymon	Inagh	01/10/72	06/01/04	01/10/72	06/01/04	5258	2225	2558	0	109	676	280	314	11420	10311	0	913	0	196	0	11420	Highest peak on record considerably greater than next highest (231 vs 72 m^3/s). Remainder of flow record looks ok. Level record displays a trend of declining flows from start of record (1972) to around 1980.
28002	Doonbeg	Doonbeg			01/10/72	21/10/01										10196	0	262	0	967	0	11425	No obvious step or trend in record. Record ends in October 2001 except for 3 values in 2004.

NB: Grey squares indicate no data.

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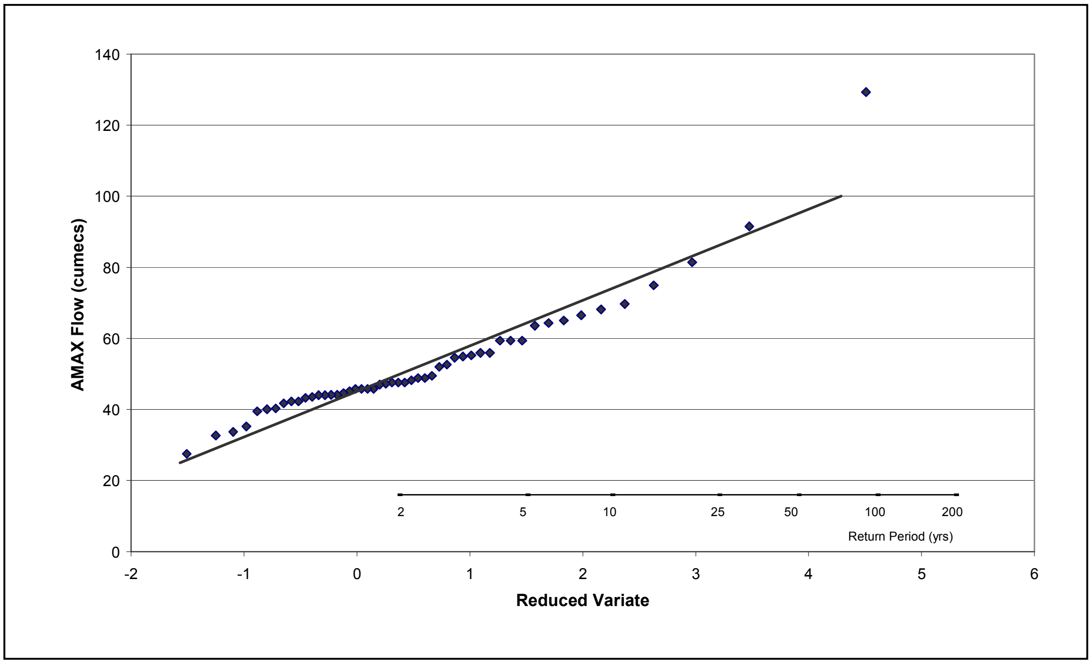
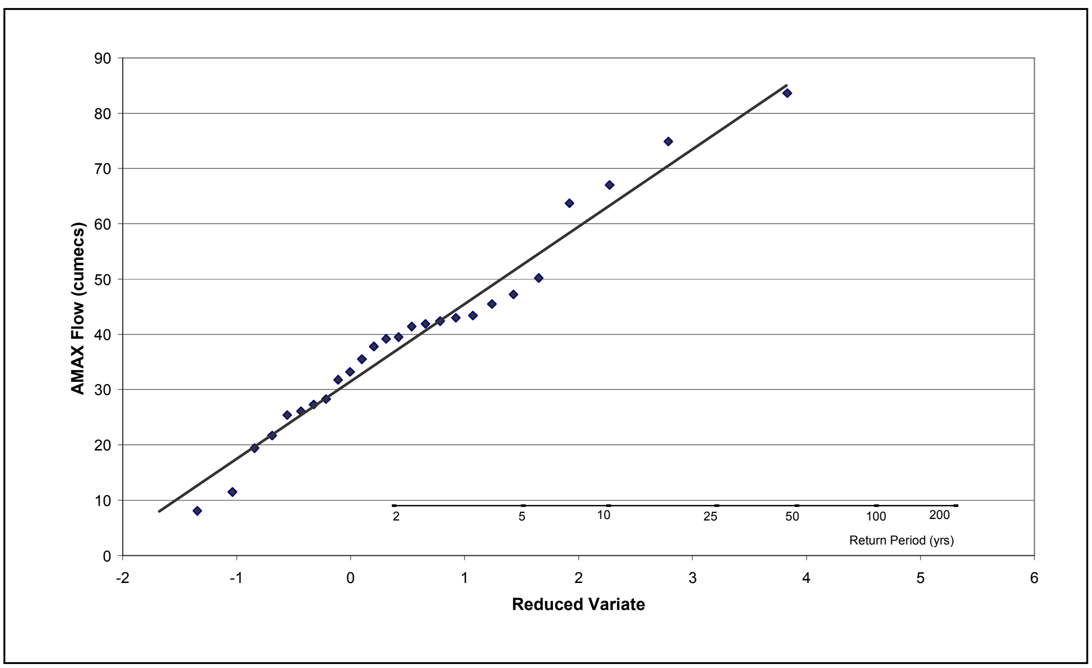
Appendix F - Flood Frequency Probability Plots



Hydrometric station 28001



Hydrometric station 28002

Appendix G - Catchment Boundary Discrepancies

Appendix H - Gauging Station Summary Sheets

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28001 – INAGH AT ENNISTYMON

Annual Maxima Series (Source: OPW)

Hydrological Year	Flow (m^3/s)	Date
1946		
1947		
1948		
1949		
1950		
1951		
1952		
1953		
1954		
1955		
1956		
1957	45.8	30/10/1957
1958	27.5	26/04/1959
1959	49.4	27/12/1959
1960	59.3	04/12/1960
1961	N/A	N/A
1962	N/A	N/A
1963	47.6	11/05/1964
1964	55.2	07/10/1964
1965	45.8	10/12/1965
1966	42.3	28/02/1967
1967	47.6	09/10/1967
1968	**129.3**	**24/12/1968**
1969	48.8	18/09/1970
1970	47.6	28/10/1970
1971	44.0	21/11/1971
1972	55.9	13/11/1972
1973	59.3	29/11/1973
1974	45.8	22/01/1975
1975	44.6	10/01/1976
1976	40.3	07/02/1977
1977	54.9	08/11/1977
1978	47.0	15/11/1978
1979	47.3	15/12/1979
1980	59.3	17/12/1980
1981	52.6	18/06/1982
1982	48.8	15/12/1982
1983	66.5	10/10/1983
1984	63.6	15/08/1985
1985	64.3	06/08/1986
1986	41.7	27/03/1987
1987	54.6	02/01/1988
1988	32.7	22/10/1988
1989	65.0	28/10/1989
1990	45.8	23/12/1990
1991	81.4	06/01/1992
1992	39.5	22/11/1992
1993	42.3	19/12/1993
1994	74.9	28/12/1994
1995	35.2	13/03/1996
1996	52.0	05/08/1997
1997	45.2	07/03/1998
1998	44.0	27/10/1998
1999	55.9	27/12/1999
2000	33.7	06/11/2000
2001	48.2	04/02/2002
2002	40.0	22/10/2002
2003	43.5	14/01/2004
2004	68.1	08/01/2005
2005	69.6	22/09/2006
2006	44.1	26/10/2006
2007	43.2	24/12/2007
2008	44.1	10/10/2008
2009	91.5	20/11/2009

Length of AMAX series: 51 years

1968, 1971 & 1979 WL estimated

Gauging Authority: Office of Public Works	
Easting: 113299	**Northing:** 188191
Catchment: Doonbeg	**Telemetry:** Yes
Station Type: Recorder	**Catchment Area:** 169.40 km^2

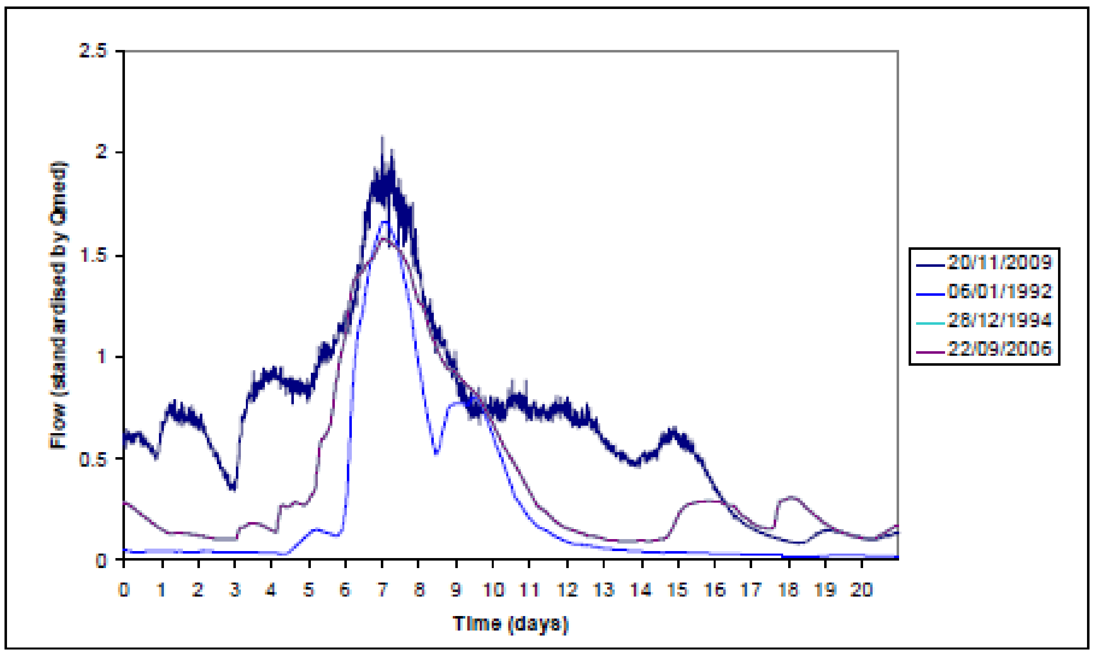
QMED (gauged): 47.58 m^3/s	**AREA (FSU):** 169.42 km^2
QMED (FSU): 42.84 m^3/s	**SAAR (FSU):** 1422.50
QMED (predicted): 62.55 m^3/s	**FARL (FSU):** 0.94
BFIsoils (FSU): 0.33	**S1085:** 2.20
URBEXT: 0.05	**ARTDRAIN2:** N/A
DRAIND: 1.41	

Comments: Automated velocity area station installed in 1940 and automated 1957. Stable rock bed. Natural channel control.

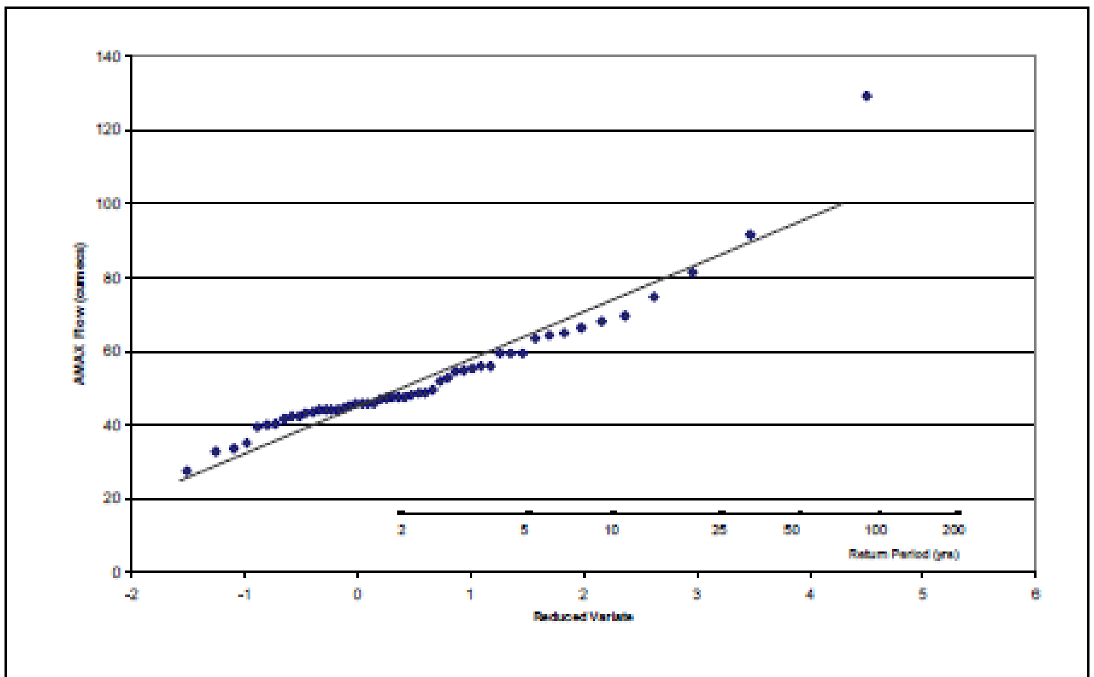
Nearby APSRs: To be confirmed

Jacobs Rating Review required: No	**OPW Station Classification:** B

Normalised Hydrographs



Flood Frequency (EV1 with Gringorten plotting positions)



28002 – DOONBEG AT DOONBEG

Annual Maxima Series (Source: OPW)

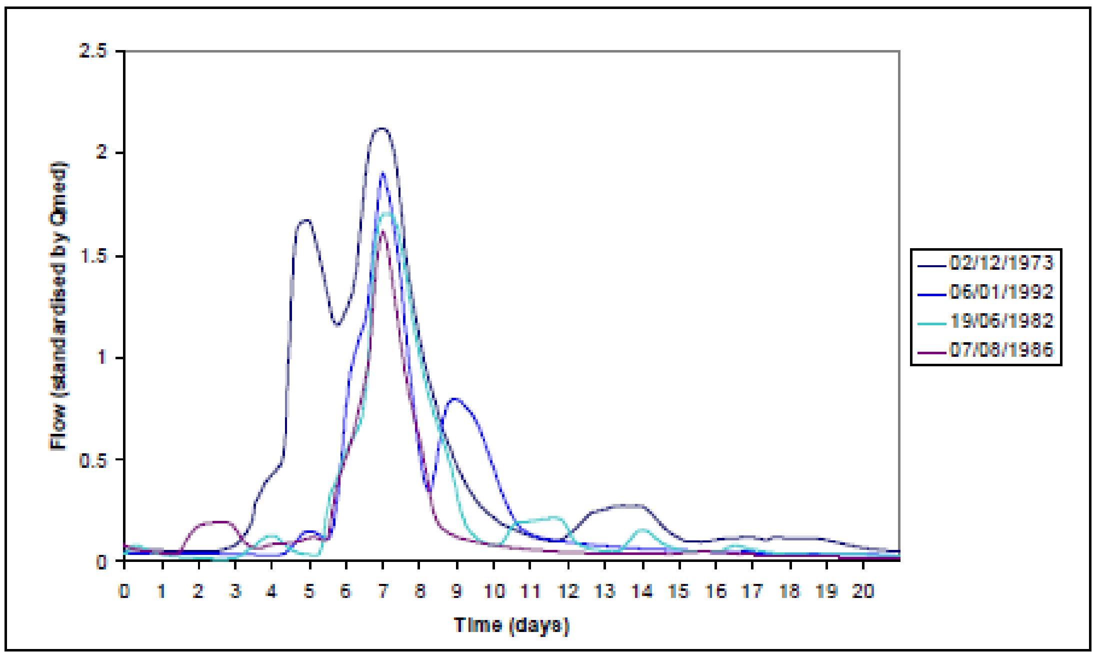
Hydrological Year	Flow (m^3/s)	Date
1946		
1947		
1948		
1949		
1950		
1951		
1952		
1953		
1954		
1955		
1956		
1957		
1958		
1959		
1960		
1961		
1962		
1963		
1964		
1965		
1966		
1967		
1968		
1969		
1970		
1971		
1972	42.4	14/11/1972
1973	**83.6**	**02/12/1973**
1974	27.3	29/09/1975
1975	43.0	02/12/1975
1976	19.4	08/02/1977
1977	26.1	22/04/1978
1978	41.4	16/11/1978
1979	35.5	07/11/1979
1980	39.5	20/09/1981
1981	67.0	19/06/1982
1982	39.2	16/12/1982
1983	45.5	10/12/1983
1984	50.2	16/08/1985
1985	63.7	07/08/1986
1986	25.4	20/11/1986
1987	37.8	19/03/1988
1988	33.2	12/04/1989
1989	41.9	29/10/1989
1990	31.8	24/12/1990
1991	74.9	06/01/1992
1992	28.3	22/11/1992
1993		
1994		
1995		
1996		
1997		
1998		
1999		
2000		
2001		
2002	11.5	01/07/2003
2003	21.7	16/11/2003
2004		
2005		
2006	8.1	06/08/2007
2007	47.2	29/12/2007
2008	43.4	25/08/2009
2009	N/A	20/11/2009

Length of AMAX series: 26 years

Data from automated WISKI extraction, to be confirmed prior to use PN 09/08/2010

Gauging Authority: Office of Public Works	
Easting: 97248	**Northing:** 165180
Catchment:	**Telemetry:** Yes
Station Type: Recorder	**Catchment Area:** 108.20 km^2
QMED (gauged): 39.35 m^3/s	**AREA (FSU):** N/A km^2
QMED (FSU): N/A m^3/s	**SAAR (FSU):** N/A
QMED (predicted): N/A m^3/s	**FARL (FSU):** N/A
BFIsoils (FSU): N/A	**S1085:** N/A
URBEXT: N/A	**ARTDRAIN2:** N/A
DRAIND: N/A	
Comments:	
Nearby APSRs: To be confirmed	
Jacobs Rating Review required: No	**OPW Station Classification:** None

Normalised Hydrographs



Flood Frequency (EV1 with Gringorten plotting positions)