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

Inception Report – Unit of Management 24

Final Report

Appendix B: Preliminary Hydrological Assessment and Method Statement

28 September 2012

Document control sheet — BPP 04 F8

Client: Office of Public Works
Project: Shannon CFRAM Study — Job No: 32103000
Document Title: Preliminary Hydrological Assessment and Method Statement – UoM 24

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Document Status Issued as part of Final Inception Report				

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DATE **28 Sep 2012**	SIGNATURE	SIGNATURE (PP)	SIGNATURE (PP)	SIGNATURE
Document Status: Re-issued as part of Final Inception Report				

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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 (17th March). The CARs and IRRs form the basic Areas of Potential Significant Risk (APSR) to which will be added the additional areas identified in the Flood Risk Review to form the final list of APSRs. The Flood Risk Review has been undertaken in parallel with this hydrological work.

2 Study Area

2.1 Introduction

The boundary of the Shannon CFRAM study area is delineated by the Shannon River Basin District (RBD) as defined for the Water Framework Directive. The Shannon RBD is designated an international RBD as a consequence of a small portion of the Shannon headwaters lying within County Fermanagh, Northern Ireland. No particular flood risk areas were identified in the Northern Irish portion, and this study will focus on the Shannon RBD within the Republic of Ireland.

2.2 Shannon River Basin District

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

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

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

2.3 Units of management

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

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

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

This report appraises the Shannon Estuary South Unit of Management (UoM 24) only. Analysis and discussion for the remaining units of management will be presented in separate reports.

2.4 Shannon Estuary South (Unit of Management 24)

The Shannon Estuary South Unit of Management (or UoM 24) is shown in its wider context within the Shannon RBD in Figure 1, and in more detail in Figure 2. It encompasses areas of four counties; Kerry, Limerick, Cork and Tipperary. It consists of a fertile limestone plain, known as the 'Golden Vale' bounded on the north by the Shannon Estuary and on the west and south and east by the Mullaghareirk Mountains, Ballyhoura Mountains, Galty Mountains and Slieve Felim Mountains. The total area of UoM 24 is approximately 2000 km^2.

The unit of management is dominated by two main river catchments, the Deel and the Maigue, which together cover 65% of the unit of management. The coastline extends along the Shannon Estuary from Limerick City in the east to where it meets the Atlantic Ocean between Loop Head (County Clare) and Kerry Head (County Kerry), west of this unit of management.

The River Deel rises in the Mullaghareirk Mountains near Dromina. It flows roughly in a north-westerly direction though the mountains, where it is joined by numerous tributaries, including the Finglasha River and the Ahavarragh Stream which drains the lands upstream of Dromcolliher. Downsteam of Newcastle West, the River Deel is joined by the rivers Arra, Dooally and Daar, which drain the steep topography of the Knockanimpaha Mountains which bound the west of the catchment. Downstream of the confluence the River Deel flows north east, through agricultural plains and roughly follows the direction of the N21 towards and through the centre of Rathkeale. Flowing north from Rathkeale the Deel flows through Askeaton, and on to the Shannon Estuary. Where the River Deel enters the Shannon Estuary, the catchment area is approximately 486.1 km^2.

The Deel catchment drainage scheme was completed in 1968 and focused on improved drainage for agricultural purposes. Arterial Drainage schemes have historically been undertaken at various locations within the Maigue and Deel catchments for agricultural purposes.

East of the Deel catchment, and bounded to the south by the River Blackwater catchment, lies the Maigue catchment. The River Maigue drains an area of approximately 806 km^2, from its source in the Ballyhoura Mountains (County Cork) to where it enters the Shannon Estuary approximately 10km north of Adare.

Rising north of Milford in North Cork, the River Maigue flows east to join the River Loobagh approximately 3km north of Charleville, and then flows north through Bruree. Just downstream of Bruree, the Maigue is joined by the significant tributary of the Morningstar River, which drains a catchment area of approximately 131.9 km^2. Continuing northwards, just upstream of Croom, the Maigue is joined by the third significant tributary of the River Camogue. From Croom, the River Maigue flows north-west towards Adare where the River Maigue becomes tidally influenced.

To assist with analysis of data, the unit of management has been divided into sub-catchments consisting primarily of the Maigue catchment to Adare Quay, the Deel catchment to Askeaton and all outstanding catchments classified as 'Other'. In accordance with the scope, the Ballinacura catchment, which includes Limerick, has been included within the Shannon Upper and Lower Unit of Management. Tidal gauges have been analysed separately.

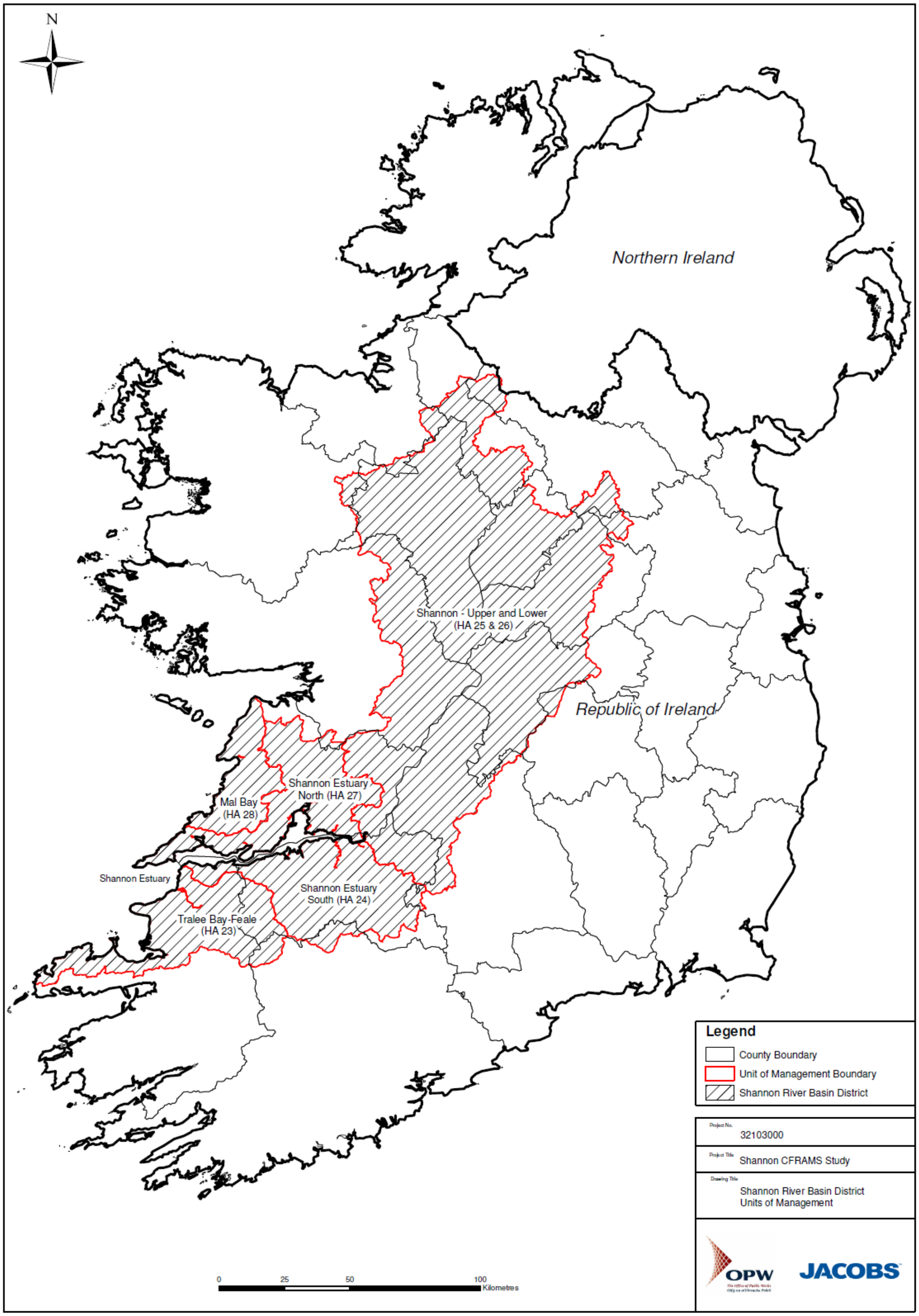

Figure 1 Shannon River Basin District and the five units of management

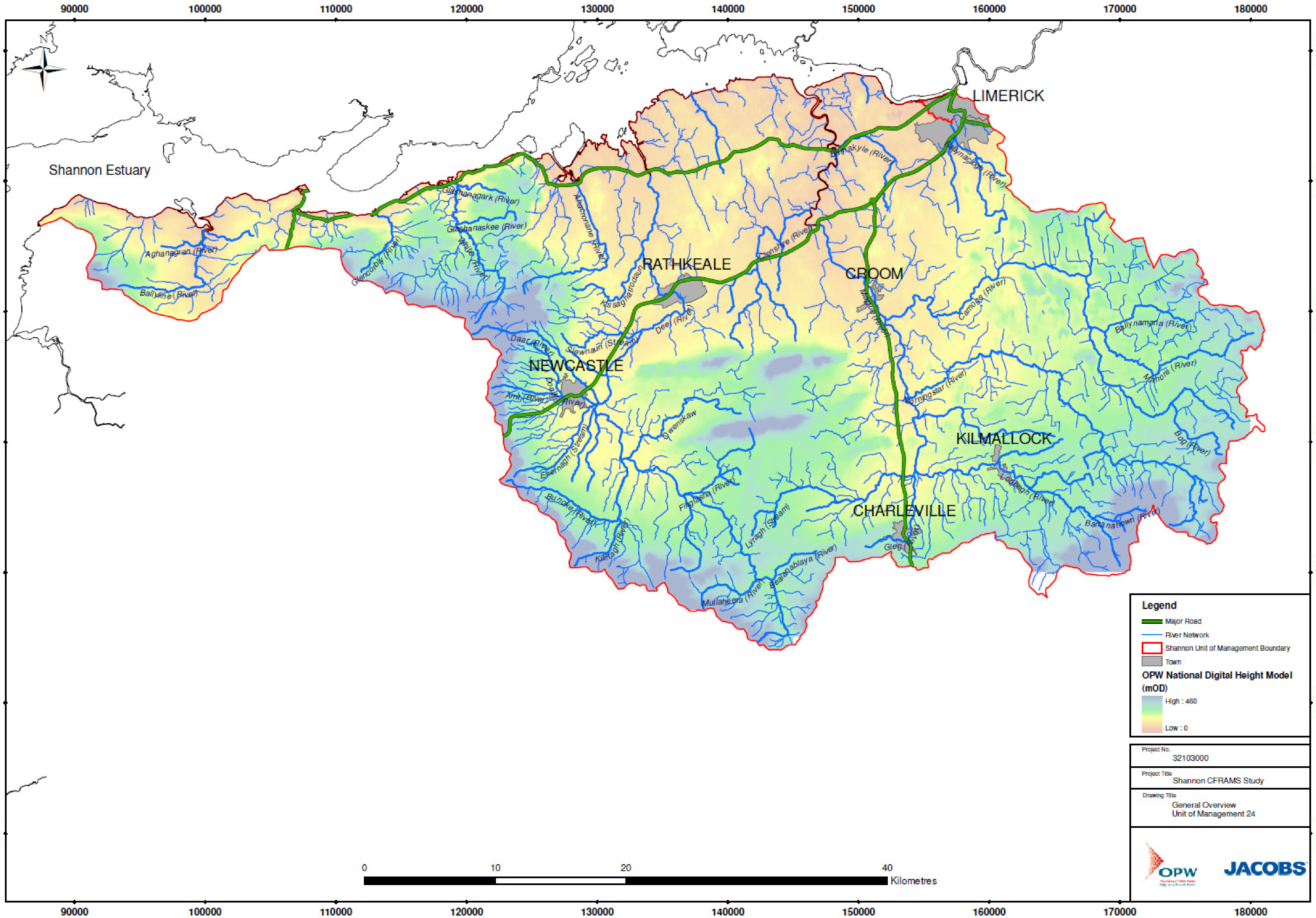

Figure 2 Shannon Estuary South Unit of Management (UoM 24)

2.4.1 Communities at Risk

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

No.	Location	Easting	Northing	Catchment	At risk of fluvial flooding	At risk of tidal flooding
CAR3	Adare	146500	146750	Maigue	Yes	Yes
CAR4	Askeaton	134000	150000	Deel	Yes	No
CAR9	Ballylongford	99500	144750	Other	Yes	Yes
CAR20	Charleville	152250	122500	Maigue	Yes	No
CAR22	Clarina	150000	154000	Other	Yes	Yes
CAR24	Croom	151000	141500	Maigue	Yes	No
CAR25	Dromcolliher	138231	121197	Deel	Yes	No
CAR29	Foynes	125000	151500	Other	Yes	Yes
CAR32	Kildimo New	145250	152750	Maigue	Yes	Yes
CAR35	Kilmallock	161126	127573	Maigue	Yes	No
CAR44	Newcastle West	129750	133000	Deel	Yes	No
CAR50	Rathkeale	136750	140750	Deel	Yes	No

Table 2-A Communities at Risk in* Shannon Estuary South *(UoM 24)

2.4.2 Individual Risk Receptors

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

One individual risk receptor (IRR) is located within the Shannon Estuary South as shown in Table 2-B and Figure 3.

No.	Location	Easting	Northing	Catchment	At risk of fluvial flooding	At risk of tidal flooding
IRR1	Tarbert Power Station	107750	149250	Other	No	Yes

***Table 2-B Individual Risk Receptors in* Shannon Estuary South**

3 Hydro-meteorological data 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:

- 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:

- river 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 flood peak 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 have a role with regard to the collection of flood peak 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 Study 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;
- Check gaugings (also referred to as spot flow gaugings);
- Annual Maximum (AMAX) flow and level series;
- Daily and sub-daily rainfall;
- Soil Moisture Deficit (SMD);
- All Flood Studies Update (FSU) reports and worksheets.

The EPA hydrometric register (dated January 2011) lists 59 river and lake level, flow and tidal level gauging stations within UoM 24 (Appendix A), of which only 31 locations are currently active. A further two OPW operated gauging stations, 24093 and 24094, not included on the EPA register were identified via an OPW GIS layer.

Within this preliminary data collection phase, all efforts were made to obtain a full record of all available hydrometric data within UoM 24. 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 or staff gauge 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. This may include, for example, station 24002 (Gray's Bridge on the River Camogue), station 24004 (Bruree on the River Maigue) and station 24022 (Hospital on the River Mahore), although none of these are close to any CARs.

Station No.	Station Name	Watercourse	Status	Station type	Proximity to CAR/IRR	Rating Review required?	Improve Spatial Coverage?
24001	Croom	Maigue	Active	Recorder	Croom	Yes	
24003	Garrose	Loobagh	Active	Recorder	Charleville	Yes	
24005	Athlacca	Morningstar	Active	Recorder			Yes
24006	Creggane	Maigue	Active	Recorder	Charleville	Yes	
24008	Castleroberts	Maigue	Active	Recorder	Adare	Yes	
24009	Adare Manor	Maigue	Active	Recorder	Adare		
24011	Deel Bridge	Deel	Active	Recorder	Newcastle West	Yes	
24012	Grange Bridge	Deel	Active	Recorder	Rathkeale	Yes	
24013	Rathkeale	Deel	Active	Recorder	Newcastle West	Yes	
24015	Dromcolliher	Ahavarragh	Active	Recorder	Dromcolliher	Yes	
24016	Kilmallock	Loobagh	Inactive	Recorder	Kilmallock		
24017	Robertstown	Robertstown	Inactive	Recorder	Foynes		
24029	Inchirouke More	Deel	Active	Recorder	Askeaton	Yes	
24030	Danganbeg	Deel	Active	Recorder		Yes	
24031	Newcastle West	Arra	Inactive	Staff gauge only	Newcastle West		
24033	Ballyhahill	White	Active	Recorder	Ballylongford		
24034	Riversfield Weir	Loobagh	Active	Recorder	Kilmallock	Yes	
24036	Golden Vale	Ballincolly	Inactive	Staff gauge only	Charleville		
24067	Normoyle's Bridge	Greanagh	Active	Recorder	Kildomo New		
24081	Currachase	Currachase	Inactive	Staff gauge only	Kildomo New		
24082	Islandmore	Maigue	Active	Recorder			Yes
24084	Kilmallock Creamery	Maigue	Inactive	Staff gauge only	Kilmallock		

Table 3-A Key hydrometric stations identified for Shannon Estuary South (grey boxes indicate no data available)

3.3 Hydrometric network in relation to CARs and IRRs

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

Of the 12 Communities at Risk (CARs), 7 have hydrometric gauging stations located within the immediate locality all of which are loggers operated either by the OPW or co-ordinated by the EPA. A further CAR (Charleville) is located on a tributary in the upper reaches of the River Maigue catchment and it could be assumed that a suitable pivotal gauge (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) could be identified. Four CARs (Ballylongford, Kildomo New, Clarina and Foynes) do not have any flow or level gauges located within their catchment, and their small catchment size could be a potential hurdle to finding a suitable pivotal gauging site within the unit of management or more widely. Consideration should be given to improving the gauging network in these locations for the benefit of future flood studies.

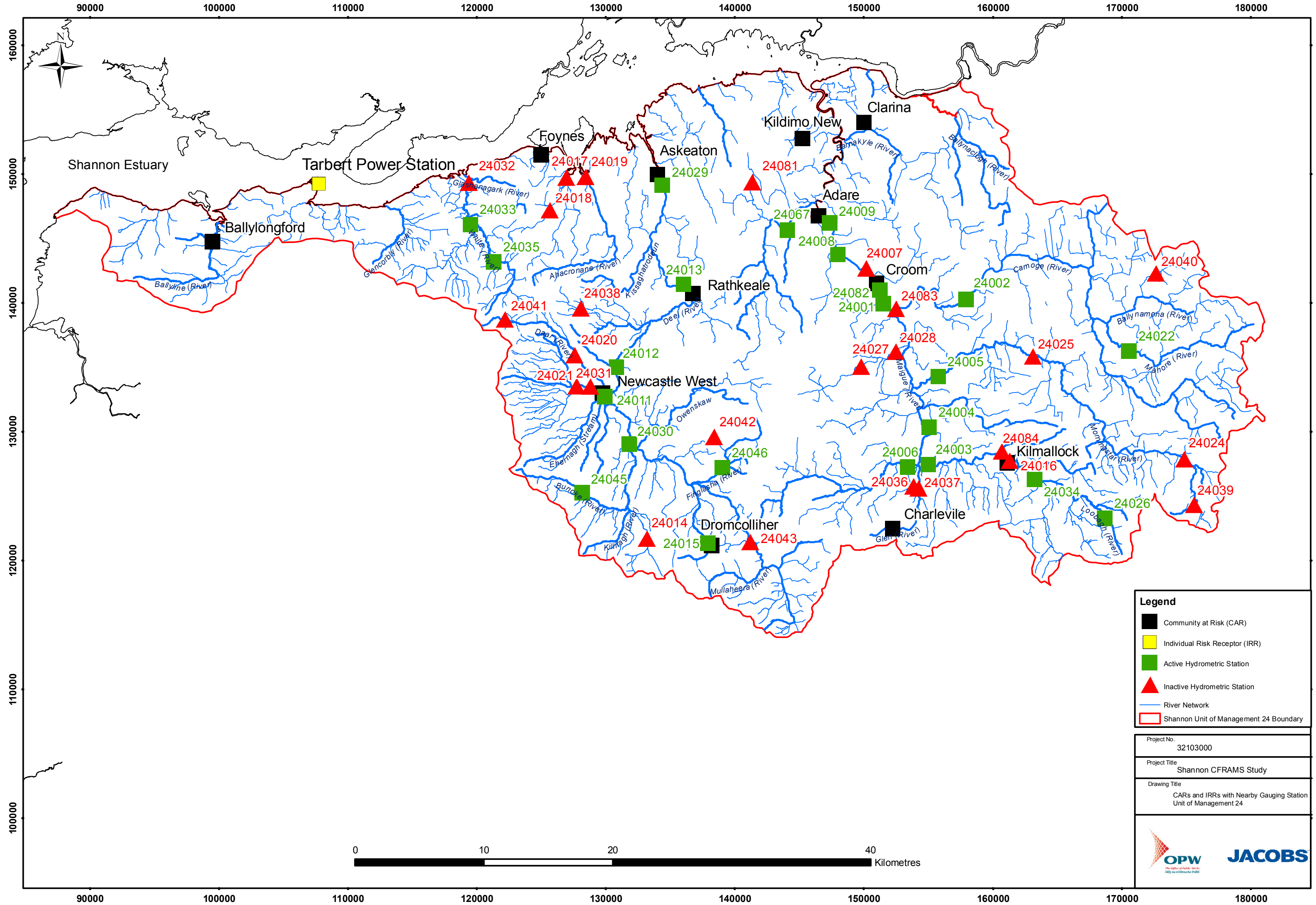

Figure 3 Location of hydrometric gauging stations in relation to Communities at Risk and Individual Risk Receptors within Shannon Estuary South

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 runs 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. This will be discussed in the Hydrological Report.

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 when 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 spatial extent of rainfall for particular events, when there are concerns about how widespread the event may have been.

The National Roads Authority (NRA) may be another potential source of sub-daily rainfall information. The NRA has recently established a network of sensors along major roads to measure and record the type and intensity of precipitation at 10 minute intervals. This information is used to help warn the NRA of extreme weather and warn drivers of road conditions. One NRA rainfall sensor is located within the Shannon Estuary South 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 raingauges. 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 depths are recorded at nine locations within the Shannon Estuary South 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 compared to a 24 hour rainfall depth obtained over no fixed time period.

Table 3-B summarises the raingauges located within Shannon Estuary South and the availability of data. Figure 4 shows the distribution of the raingauge network. Two further stations 6011 and 4111 are also located within UoM 24. Their use will be considered as necessary in the ongoing hydrological study.

It is noted that the use of rainfall data from other rainfall gauges outside UoM 24 (but close to it) could conceivably be useful. This may include sub-daily raingauges to the south in the Blackwater catchment. This will be done if considered appropriate, but its use is likely to be limited given the need to derive (and use) rainfall within the catchment.

Raingauge no.	Raingauge name	Data available
4611	Tarbert Island	Yes
4811	Patrickswell (Dooneen)	Yes
4911	Castlemahon	Yes
5111	Rathkeale Duxtown	Yes
5711	Newcastle West (Castle Demesne)	Yes
5811	Meanus	Yes
6205	(Unknown)	No
6111	Shanagolden (Old Abbey)	Yes
6311	Ballyhahill	Yes

Table 3-B Daily rainfall data available within Shannon Estuary South

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. The nearest synoptic station to UoM 24 is north of the Shannon Estuary at Shannon International Airport.

There are no Met Éireann hourly rainfall stations located within the Shannon Estuary South.

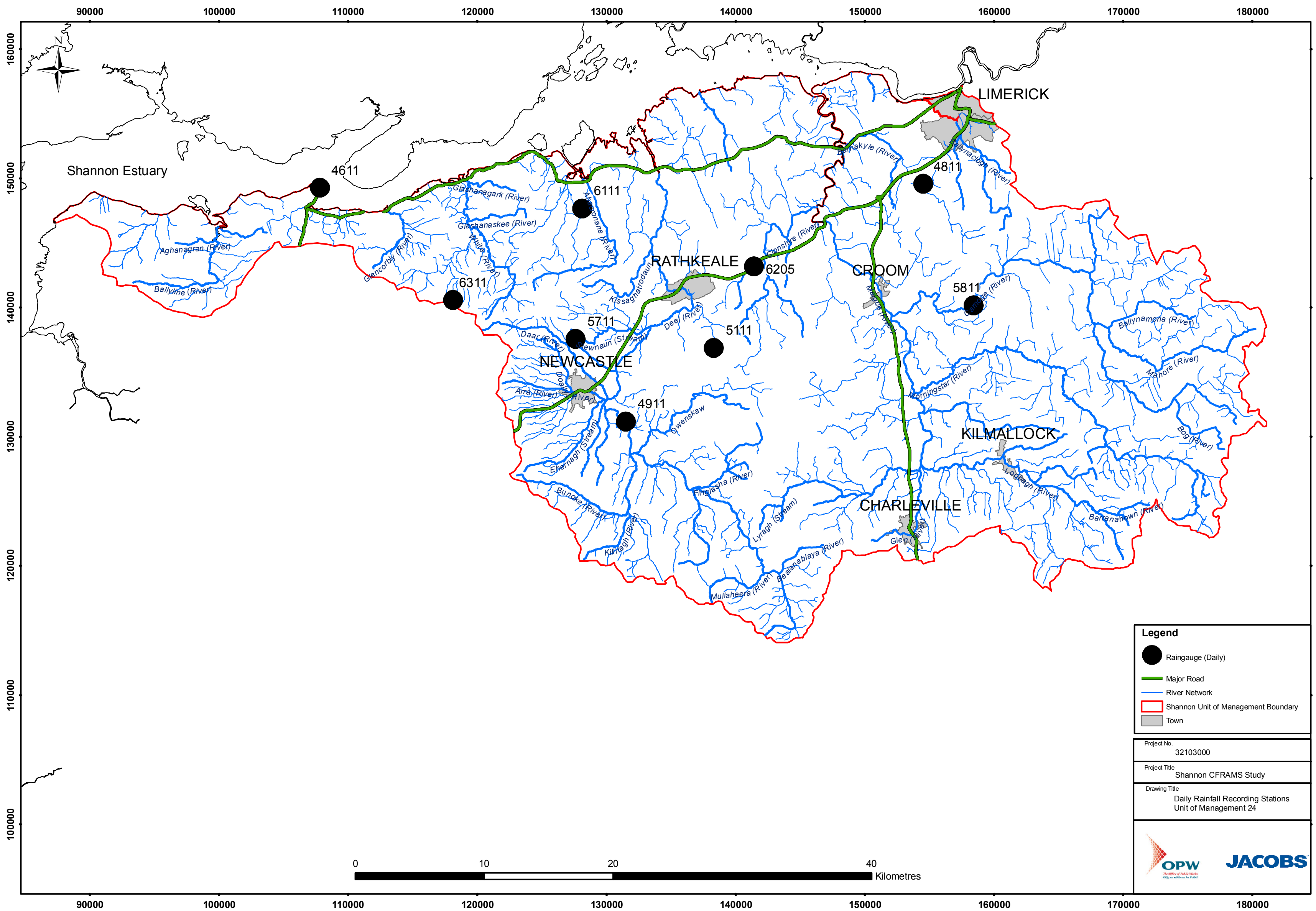

Figure 4 Location of daily raingauges within Shannon Estuary South

3.5 Hydrometric data

3.5.1 Background

The location of hydrometric stations in the Shannon Estuary South is shown in Figure 3. The majority of flow and level gauging stations within UoM 24 are located on the Rivers Deel and Maigue or their tributaries. A small cluster of flow measurement sites are located to the west of the River Deel on the River White and on the watercourses draining into the Robertstown River. Additional gauges are located on the Ballincurra Creek which drains Limerick City, however, in accordance with the scope these gauges will be considered along with Limerick City within the Shannon Upper and Lower Unit of Management (UoM 25/26).

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 estimation 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 to provide an instantaneous and (near-) continuous data record. 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 at regular intervals of time. Both types of recorder can be considered continuous for fluvial and tidal flood analysis 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 intanteneous 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 28 stations within UoM 24 (Table 3-C). These stations are located on Figure 5 along with their current status (active or inactive). Jacobs have been advised that not all data from autographic recorders has been digitised and uploaded onto the archives and will therefore not be readily available for this study. However, for specific events, such data may be of benefit (which will require digitising by OPW) and will be requested as the need for such data arises. Data listed in Table 3-C outlines all the 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.

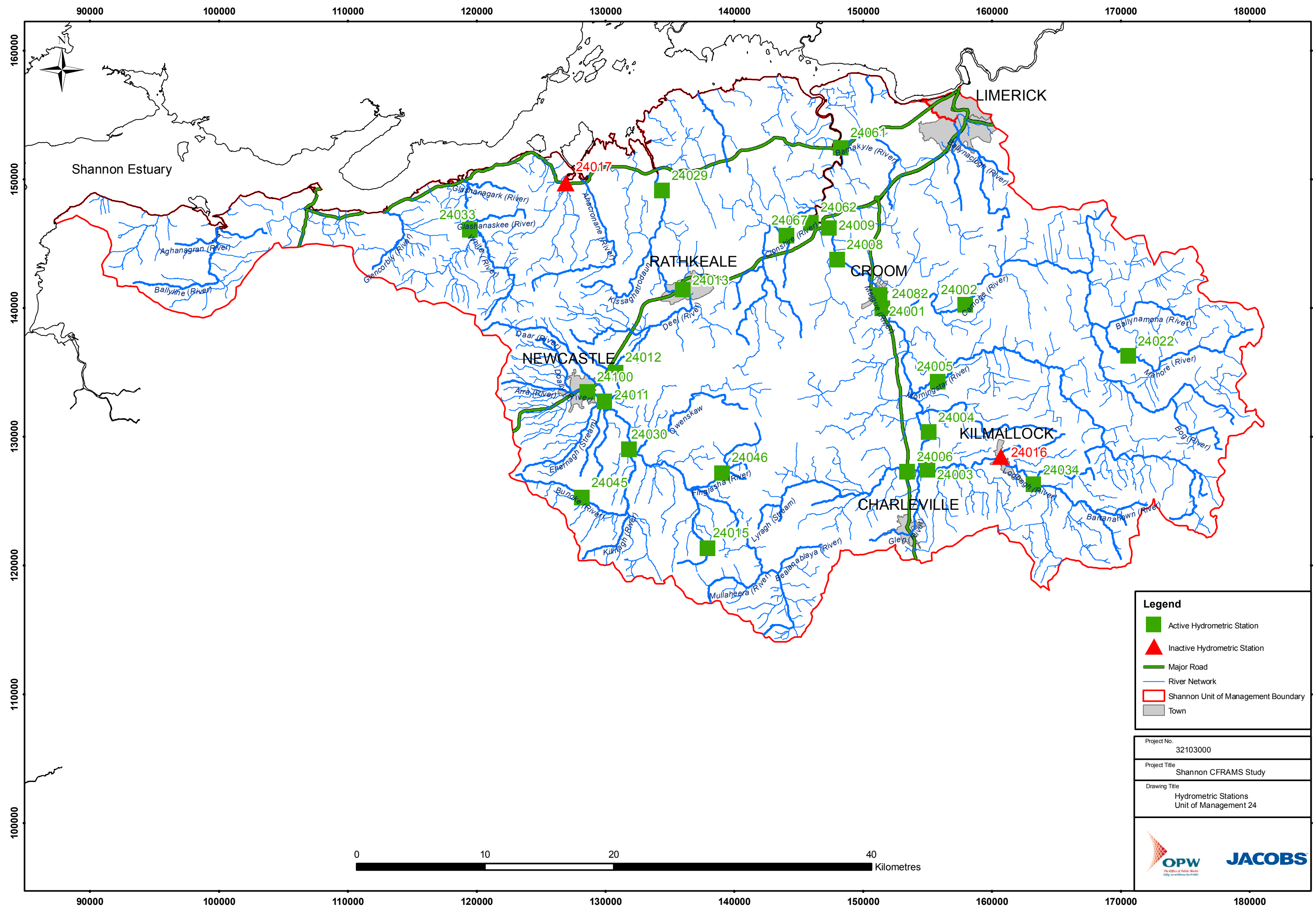

Figure 5 Location of hydrometric gauging stations within Shannon Estuary South Unit of Management

Station number	Station name	Watercourse	UoM24 sub-catchment	Station status	15 min flow start[3]	15 min flow end[3]	15 min level start	15 min level end
24001	Croom	Maigue	Maigue	Active	01/10/1972	09/09/2010	01/10/1972	09/09/2010
24002	Gray's Br	Camoge	Maigue	Active			01/10/1972	10/09/2010
24003	Garroose	Loobagh	Maigue	Active	01/10/1972	10/09/2010	01/10/1972	10/09/2010
24004	Bruree	Maigue	Maigue	Active	01/10/1972	10/09/2010	01/10/1972	10/09/2010
24005	Athlacca	Morningstar	Maigue	Active	01/10/1972	10/09/2010	01/10/1972	10/09/2010
24006	Creggane	Maigue	Maigue	Active			01/10/1972	10/09/2010
24008	Castleroberts	Maigue	Maigue	Active	01/01/1977	10/09/2010	28/11/1973	10/09/2010
24009	Adare Manor	Maigue	Maigue	Active			01/11/2007	10/09/2010
24011	Deel Br	Deel	Deel	Active	01/01/1989	10/09/2010	01/01/1989	10/09/2010
24012	Grange Br	Deel	Deel	Active	01/10/1954	09/09/2010	01/10/1954	09/09/2010
24013	Rathkeale	Deel	Deel	Active	01/10/1972	10/09/2010	01/10/1972	09/09/2010
24016 [1]	Kilmallock	Loobagh	Maigue	Inactive	24/07/1980	17/04/1984	24/07/1980	17/04/1984
24017 [1]	Robertstown	Robertstown	Other	Inactive	21/10/1981	15/05/2000	21/10/1981	15/05/2000
24022 [1]	Hospital	Mahore	Maigue	Active			12/06/1984	27/10/2010
24029 [1]	Inchirourke More	Deel	Deel	Active	12/10/1982	29/08/1995	12/10/1982	03/05/2011
24030 [1]	Danganbeg	Deel	Deel	Active	05/05/1980	03/05/2011	05/05/1980	05/01/2011
24033 [1]	Ballyhahill	White	Other	Active			28/07/1980	04/01/2011
24034	Riversfield Weir	Loobagh	Maigue	Active	16/07/2004	21/09/2010	16/07/2004	21/09/2010
24045 [1]	Cantogher	Bunoke	Deel	Active			09/07/2007	11/05/2010
24046 [1]	Gortnaluggin Br	Finglosha	Deel	Active			05/08/2004	07/10/2010
24047 [2]	Rossbrien Rly Br	Ballinacurra	Ballinacurra	Active			01/01/2000	23/07/2008
24048 [2]	Ballinacurra DS	Ballinacurra	Ballinacurra	Active			01/01/2000	01/08/2004
24049 [2]	Ballinacurra US	Ballinacurra	Ballinacurra	Active			01/01/2000	04/11/2006
24061	Ferry Br	Maigue Estuary	Tidal	Active			01/01/2000	31/08/2010
24062	Adare Quay	Maigue Estuary	Tidal	Active			30/11/2007	09/09/2010
24067	Normoyle's Br	Greanagh	Other	Active			30/11/2007	10/09/2010
24082	Islandmore	Maigue	Maigue	Active	03/11/1975	24/08/2010	03/11/1975	24/08/2010
24100	Gortboy Hotel	Deel	Deel	Active			29/10/2008	10/09/2010

[1] 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);
[2] Limerick City (and therefore the Ballinacurra catchment) have been scoped within the Upper and Lower Shannon Unit of Management (UoM 25/26);
[3] Grey boxes indicate no data available.

Table 3-C Instantaneous flow and level data available within UoM 24 and their period of record

Station no.	Station name	River	UoM 24 sub-catchment	Daily mean flow data		Daily mean level data	
				Record start	Record end	Record start	Record end
24001	Croom	Maigue	Maigue	01-Oct-71	09-Sep-10	01-Oct-72	09-Sep-10
24002	Gray's Bridge	Camoge	Maigue			01-Jan-79	05-Oct-03
24003	Garroose	Loobagh	Maigue	01-Oct-72	10-Sep-10	01-Oct-72	10-Sep-10
24004	Bruree	Maigue	Maigue	01-Oct-72	31-Dec-03	01-Oct-72	30-Jan-05
24005	Athlacca	Morningstar	Maigue			01-Jan-80	21-Dec-02
24006	Creggane	Maigue	Maigue	30-Dec-77	01-Jan-78	01-Oct-72	10-Sep-10
24008	Castleroberts	Maigue	Maigue	28-Nov-73	12-Jul-10	28-Nov-73	10-Sep-10
24011	Deel Bridge	Deel	Deel	02-Jan-89	31-Dec-03	02-Jan-89	10-Sep-10
24012	Grange Bridge	Deel	Deel	01-Oct-54	02-Apr-07	02-Oct-54	02-Apr-07
24013	Rathekeale	Deel	Deel	01-Oct-72	10-Sep-10	01-Oct-72	10-Sep-10
24034	Riversfield Weir	Loobagh	Maigue	16-Jul-04	10-Sep-10	16-Jul-04	10-Sep-10
24082	Islandmore	Maigue	Maigue	01-Nov-77	20-Feb-01	01-Nov-77	20-Feb-01

Table 3-D Daily mean flow and level data available within UoM 24 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 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 maximum (AMAX) data was provided from two sources, the OPW and the FSU (via the OPW). Where both sets of data were available for a location, the OPW advised that the former series be used in preference, due to the additional work undertaken to extract the peak flows. The FSU series was developed for the Flood Studies Update in 2005/6 and accordingly the series ends in 2004. AMAX data was available at 19 hydrometric stations, including 3 tidal gauges (24061, 24062 and 24067) located within UoM 24 (Table 3-F). The annual maximum flow series at 24100 is currently too short (3 years) to be of much use in subsequent statistical analysis, but has been included for completeness.

Station number	Station name	Waterbody	AMAX (Flows) (from OPW)	AMAX (Levels) (from OPW)	AMAX (Flow) (from FSU)*
24001	CROOM	MAIGUE	1977-2009	1953-2009	
24002	GRAY'S BR.	CAMOGE		1972-2009	
24003	GARROOSE	LOOBAGH		1980-2009	
24004	BRUREE	MAIGUE	1953-2009	1953-2009	
24005	ATHLACCA	MORNINGSTAR	1953-1969	1953-2009	
24006	CREGGANE	MAIGUE		1998-2009	
24008	CASTLEROBERTS	MAIGUE	1977-2009	1975-2009	
24009	ADARE MANOR	MAIGUE		1973-2009	
24011	DEEL BR.	DEEL	1972-2009	1972-2009	
24012	GRANGE BR.	DEEL	1964-2009	1964-2009	
24013	RATHKEALE	DEEL	1953-2009	1953-2009	
24022	HOSPITAL	MAHORE			1985-2004
24030	DANGANBEG	DEEL			1980-2004
24034	RIVERSFIELD WEIR	LOOBAGH	1985-2009	1985-2009	
24061**	FERRY BR.	MAIGUE ESTUARY		1960-2009	
24062**	ADARE QUAY	MAIGUE ESTUARY		1993-2009	
24067**	NORMOYLE'S BR.	GREANAGH		1993-2009	
24082	ISLANDMORE	MAIGUE	1977-2009	1977-2009	
24100	GORTBOY HOTEL	DEEL	2007-2009	2007-2009	

** Details of FSU AMAX only recorded if no flow or level annual maxima data is available from the OPW.*

*** Tidal stations*

Table 3-F Annual maximum flow and level data for hydrometric gauges located within UoM 24 (NB: FSU AMAX flow series only listed if AMAX flow series was not available from the OPW)

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.

Table 3-G and Figure 6 illustrate the gauging stations for which rating reviews are required. Table 3-G also details stations for which rating equations and check gaugings have been provided. No rating equations have been provided for stations requiring a rating review that are managed by the EPA, stations 24015, 24029 and 24030.

Station number	Station name	River	UoM 24 sub-catchment	Rating review required by the OPW?	Rating equations received?	Check flow gaugings received?
24001	Croom	Maigue	Maigue	**Yes**	**Yes**	**Yes**
24003	Garroose	Loobagh	Maigue	**Yes**	**Yes**	**Yes**
24004	Bruree	Maigue	Maigue	No	**Yes**	**Yes**
24005	Athlacca	Morningstar	Maigue	No	**Yes**	**Yes**
24006	Creggane	Maigue	Maigue	**Yes**	**Yes**	**Yes**
24008	Castleroberts	Maigue	Maigue	**Yes**	**Yes**	**Yes**
24009	Adare Manor	Maigue	Maigue	No	No	**Yes**
24011	Deel Br.	Deel	Deel	**Yes**	**Yes**	**Yes**
24012	Grange Br.	Deel	Deel	**Yes**	**Yes**	**Yes**
24013	Rathkeale	Deel	Deel	**Yes**	**Yes**	**Yes**
24015	Dromcolliher	Ahavarragh	Deel	**Yes**	No	No
24029	Inchirouke More	Deel	Deel	**Yes**	No	No
24030	Danganbeg	Deel	Deel	**Yes**	No	No
24034	Riversfield Weir	Loobagh	Maigue	**Yes**	**Yes**	**Yes**
24046	Gortnaluggin Br.	Finglosha	Deel	No	No	**Yes**
24067	Normoyle's Br.	Greanagh	Maigue	No	No	**Yes**
24082	Islandmore	Maigue	Maigue	No	**Yes**	**Yes**
24100	Gortboy Hotel	Deel	Deel	No	No	**Yes**

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

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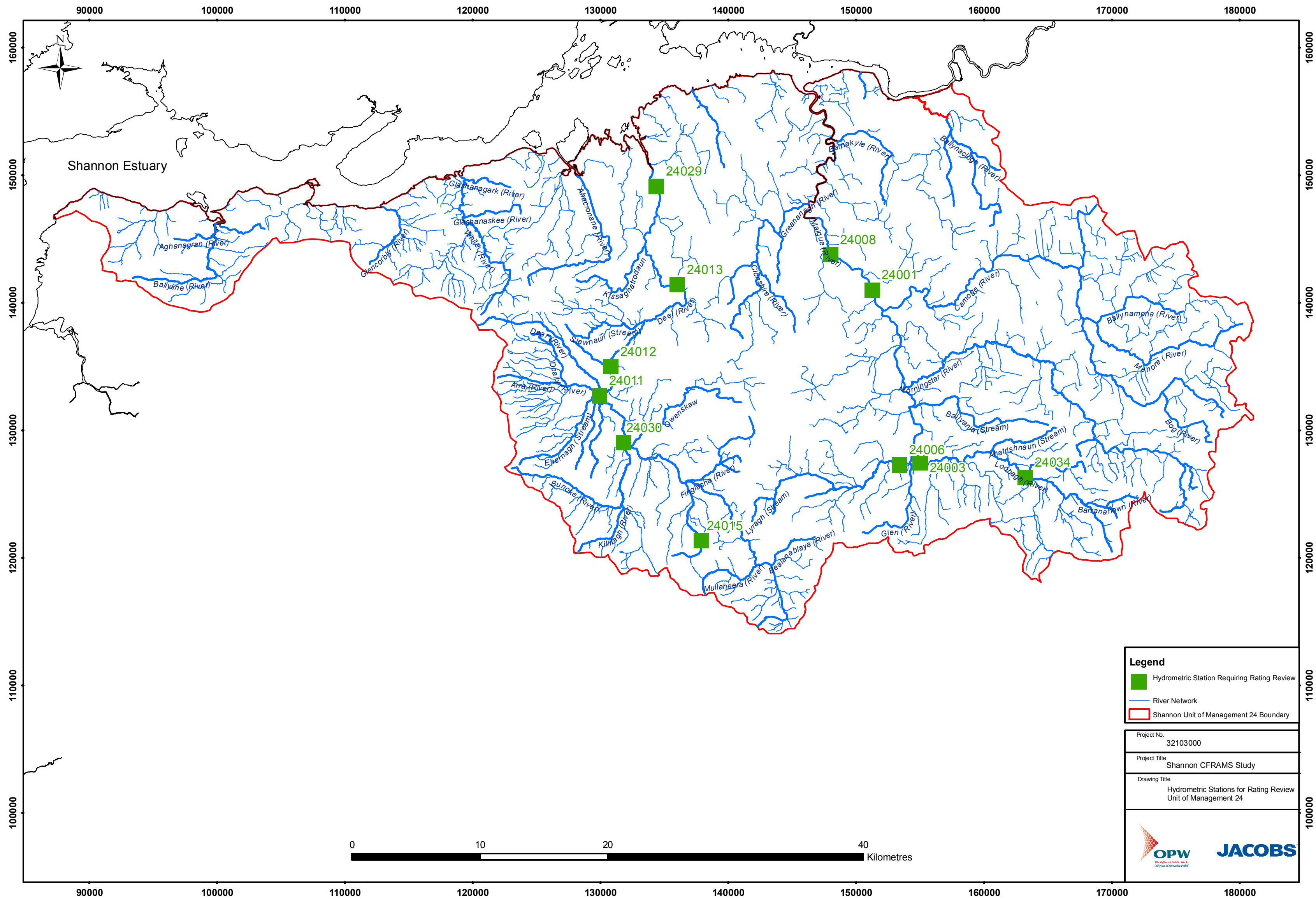


Figure 6 Hydrometric gauging stations within Shannon Estuary South requiring a rating review

3.5.7 Check gaugings

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

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

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

3.5.8 Gauging station visits

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

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 Annual Exceedance Probabilities (AEP) down to 0.002% (0.004% AEP for durations less than 24 hours). The model uses median rainfall as the index rainfall and log-logistic growth curves to determine rainfall with other frequencies. The associated software allows 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). This information has been used within this study to assess extreme rainfall events and to inform the assessment of flood events. At a sample of sites the output from the Depth Duration Frequency (DDF) software has been 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 median 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 station 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 24
A1	75	18	1
A2	119	22	4
Total A sites	*194*	*40*	*5*
B	103	11	4

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

This FSU classification has been borne in mind when reviewing flood flows and will form the basis of high flow quality assessments undertaken later in the project. Table 3-J summarises the eight FSU rating reviews and classifications for the separate periods of record within UoM 24.

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)
24001	Croom (Pre 28/07/76)	Maigue	A2	Rating history reviewed HL rating created for period. Insufficient confidence to extrapolated. Bankfull level will help. Limit of rating 0.2m - 3.5m (ASGZ). Some scatter at top end. More high flow gaugings needed to have confidence in extrapolation
	Croom (Post 26/10/77)	Maigue	A2	Rating history reviewed HL rating created for period. Insufficient confidence to extrapolated. Bankfull level will help. Limit of rating 0.5m - 3.5m (ASGZ). Some scatter at top end. More high flow gaugings needed to have confidence in extrapolation
24002	Gray's Bridge (Post 17/05/1978)	Camoge	A2	
	Gray's Bridge (Pre 17/05/1978)	Camoge	B	
24004	Bruree	Maigue	B	No major datum changes to account for large number of high flow ratings. Channel excavation on 16/4/81 doesn't seam to have had a significant impact on the channel ratings. Insufficient confidence to extrapolate past HGF (37 cumecs). Bankfull level will help confirm limit of extrapolation. Some scatter at top end. More high flow gaugings needed.
24008	Castleroberts	Maigue	A2	Use existing rating RC1 for POR. Extrapolate to 2.5m allows site to be A2 (Level assumed from site photo).
24011	Deel Bridge (post 01/10/1962)	Deel	B	HL high flow rating developed. Rating OK . Maximum extent of extrapolation 3.0m. More high flow gaugings needed to confirm top end. Minimum extrapolation 0.5m as a significant amount of scatter below this. Spring line of arches approx 3.2m and soffit of keystone approx 4.5mSG.
	Deel Bridge (pre 01/10/1962)	Deel	B	HL high flow rating developed. Rating OK but few gaugings. Maximum extent of extrapolation 3.0m. Minimum extrapolation 0.3m as no gaugings below this.
24012	Grange Bridge (post 28/09/1964)	Deel	B	Reasonable rating, scatter particularly at low flows. Minimum limit of rating 0.8m. Maximum extent of extrapolation 3.4m (bankfull).
	Grange Bridge (pre 28/09/1964)	Deel	B	Reasonable rating, few gaugings particularly at low flows. Maximum extent of extrapolation 2.84m (HGF).
24013	Rathkeale (post 01/01/68)	Deel	A1	Use RC12 post drainage in the range 1.0m to bankfull at 4.4m.
	Rathkeale (pre 01/01/64)	Deel	A1	Use RC3 pre drainage for POR in the range 1.0m to bankfull at 4.4m.
24082	Islandmore Weir	Maigue	A2	Use RC1 for POR. Bankfull levels need to be established before extrapolation can be assessed. Could be A1 if bankfull near 1.8m.

Table 3-J Summary of FSU Rating Classification for hydrometric stations within UoM 24.

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. 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 Historical flood events

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

3.9 Outstanding data and recommendations

Rating review histories and check gaugings are outstanding for three gauging stations identified by the OPW as requiring a rating review, these are 24015, 24029 and 24030.

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 results and HEP definitions for the trial area have been provided to OPW via Sharepoint.

4.3 Lessons learned

The HEP definition trial resulted in the following lessons learned:

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

4.4 Conclusions

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

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

4.5 Recommendations and Way Forward

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

5 Catchment Boundaries

5.1 Introduction

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

5.2 Data

The datasets in Table 5-A were compared.

Title	Description	Comments
WFD Areas	Water Framework Directive River Basin District boundaries. Used to define Units of Management.	Identical to Units of Management Boundaries. Derived from 20m H-DTM (the hydrologically corrected DTM) with some manual correction.
Automatic Gauged Catchment Boundaries	Automatically generated outlines for the gauged areas.	Automatically derived from 20m H-DTM (the hydrologically corrected DTM).
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 CFRAM Study project areas to be consistent;
- Allow FSU automated procedures to be used to derive design floods as appropriate (and allow any adjustments necessary to be properly documented).

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

1. A map for Unit of Management 24 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 24 boundary) was compared with the automatic gauged catchment outlines, paying particular attention to the areas where manual correction has been applied (as denoted by the manually adjusted gauged catchment boundaries).
3. Detailed plans were produced for areas where significant discrepancies were found. These maps present the WFD boundary where available, the automatic and manually adjusted (FSU) boundaries, and contours based on the OPW National Digital Height Model (NDHM, Intermap 2009).
4. An additional random check was undertaken to satisfy ourselves that the automatic ungauged catchment boundaries are reasonable compared to the NDHM.

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

5.4 Results of analysis

Figure 7 overleaf shows a comparison of the Water Framework Directive (WFD) boundary, the automatic boundaries and the manually adjusted (FSU) boundaries in UoM 24. The figure shows two discrepancy areas which affect the area to a gauging station by 10% or more. The effects of the discrepancies on the catchment area to the nearest defined CARs would be smaller than 10%. The only IRR in the catchment (Tarbert Power Station) is on a small island in the Shannon Estuary, without FSU nodes. The risk of tidal flooding is more relevant to this island than surface/fluvial flooding.

The discrepancy areas have been labelled 24-1 and 24-2 in Figure 7. Both areas show discrepancies between the automatic and the manually adjusted boundaries. Discrepancy Area 24-2 occurs in an internal subcatchment boundary, where no WFD boundary exists.

It is important to note that the manually adjusted boundaries were derived from the automatic boundaries, updating them for only a few gauged catchments, where the gauging station was found to be relevant for hydrological analysis. As a consequence, the manually adjusted boundaries are not consistent for nested and adjacent catchments, as the catchments nested in or adjacent to the manually adjusted catchments have not been amended.

The contours on the 1:50,000 scale OSi mapping have been compared with contours derived from the OPW National Digital Height Model (NDHM, Intermap 2009) and generally show a good correlation, particularly in relatively flat areas with little vegetation. The NDHM is based on IFSAR data, with a reported vertical root-mean-square error of approximately 0.7m on slopes smaller than 20 degrees, and greater on steeper slopes.

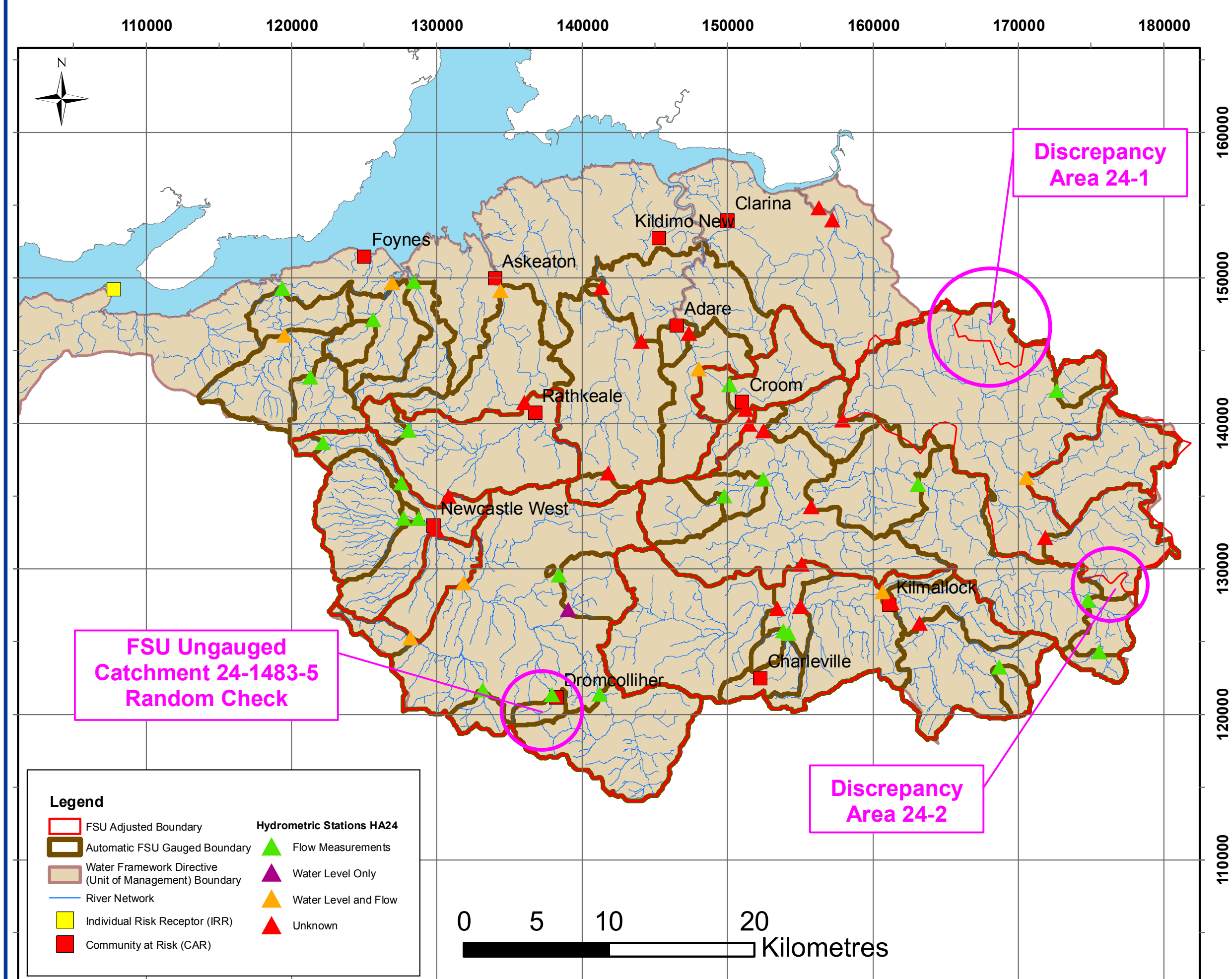


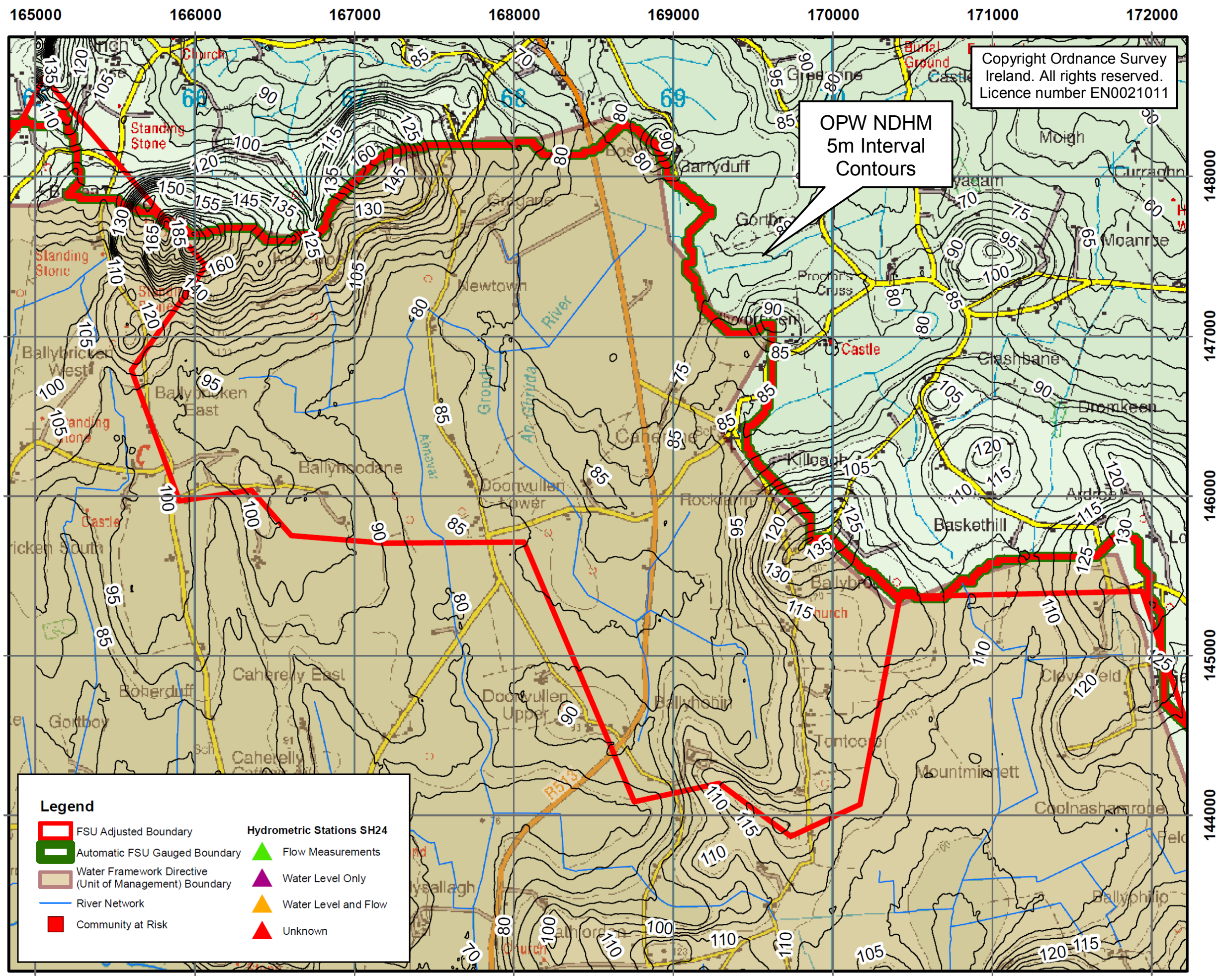
Figure 7 Catchment Boundaries Overview

5.4.1 Discrepancy Area 24-1 – Dunvullen (Doonvullen)

Discrepancy Area 24-1 (approximate size 10 km^2) is shown in detail in Figure 8 below. The figure shows a significant discrepancy between the automatic and the manually adjusted boundaries. The differences between the WFD boundary and the automatic boundary are negligible.

As described above, the adjusted boundaries are not consistent for nested and adjacent catchments, as the catchments nested in or adjacent to an adjusted catchment would not have been amended. In this particular area, the catchment boundaries to gauging stations 24001, 24008, 24082, etc. have not been corrected and follow the automatic boundary (see the red lines representing the automatic boundary). Only catchment 24002 was amended to exclude the discrepancy area based on historical OPW catchment boundary hardcopy maps.

In Figure 8 contours with a 5m vertical interval derived from the NDHM were superimposed on the OSi mapping. Analysis of the contours would suggest that some of the discrepancy area drains northwards. However, the figure includes the Shannon river network (in blue) and this shows that the manually adjusted boundary intersects a watercourse (Ahnavar/Groody River), which suggests that the adjusted boundary may not be accurate. The discrepancy may be caused by local errors in the river network dataset, errors in the NDHM (or the contours derived from this dataset), or the local rivers sloping against the general ground level gradient, draining southwards instead of northwards as the ground levels would suggest. This discrepancy may be resolved by a site visit possibly followed by a small topographic survey to confirm the gradients of the local river network.

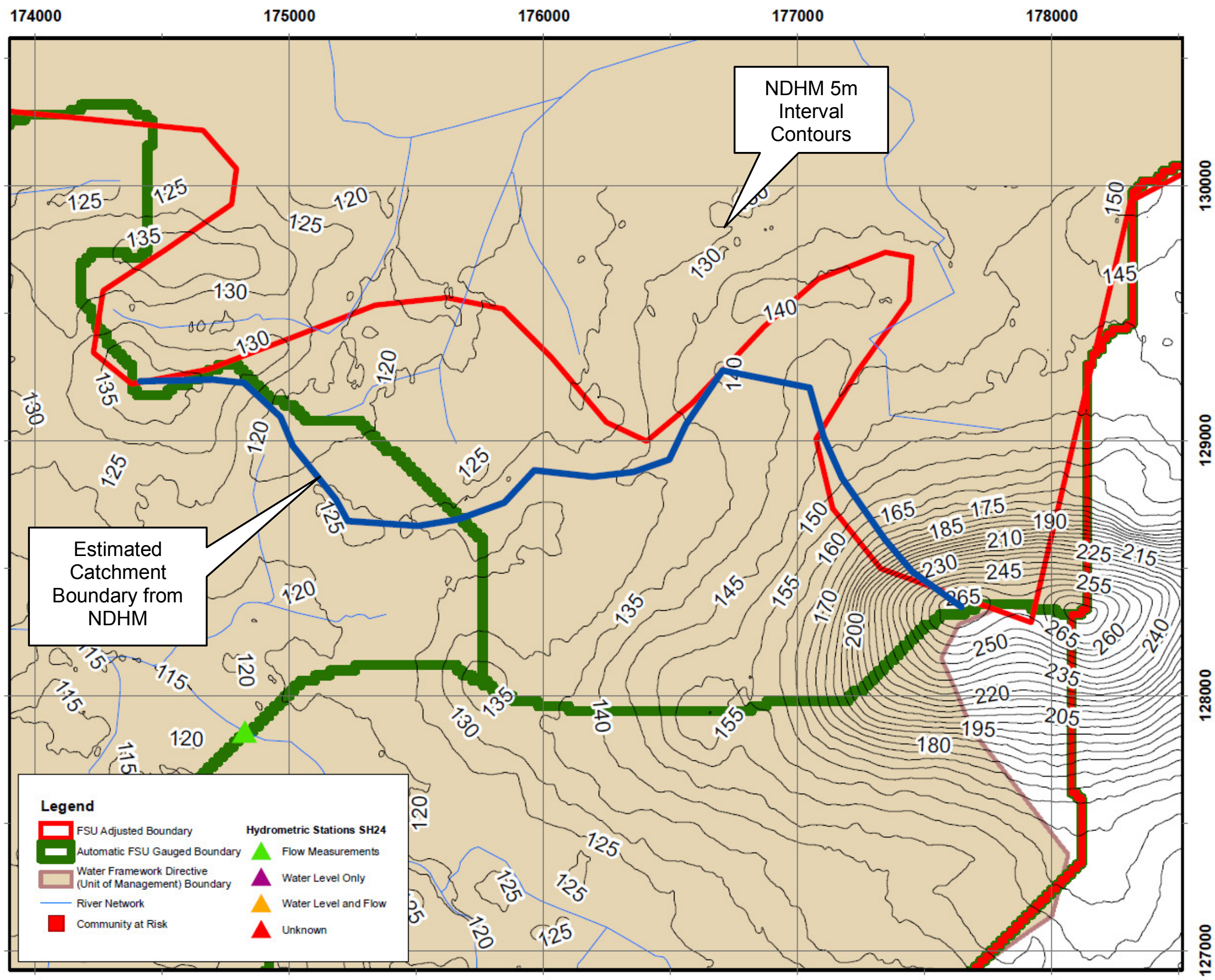


Approximate scale 1 : 40,000

Figure 8 Discrepancy Area 24-1 (Dunvullen)

5.4.2 Discrepancy Area 24-2 – Galbally

This is another discrepancy (of approximately 2 km^2) between the automatic and manually adjusted boundaries. Figure 9 shows the automatic boundary, manually adjusted (FSU) boundary, and an estimated boundary based on the NDHM (in blue). The manually adjusted boundary is intersected by rivers (as indicated by the river network dataset). Analysis of the NDHM contours suggests that this error is due to an error in the manually adjusted boundary. As this boundary discrepancy is at an 'internal' boundary within the unit of management, there is no WFD boundary available for comparison.



Approximate scale 1 : 25,000

Figure 9 Discrepancy Area 24-2 (Galbally)

5.4.3 Random check

For UoM 24 the catchment area to one CAR was checked against the NDHM contours with a 5m vertical interval. The area chosen was the catchment to Dromcolliher, at the nearest ungauged FSU node (node number: 24-1483-5, area 5.4 km2). The results are shown in Figure 10 below. There appears to be a good correlation between the automatic catchment boundary and the contours, particularly considering the location of watercourses as indicated by the river network dataset.

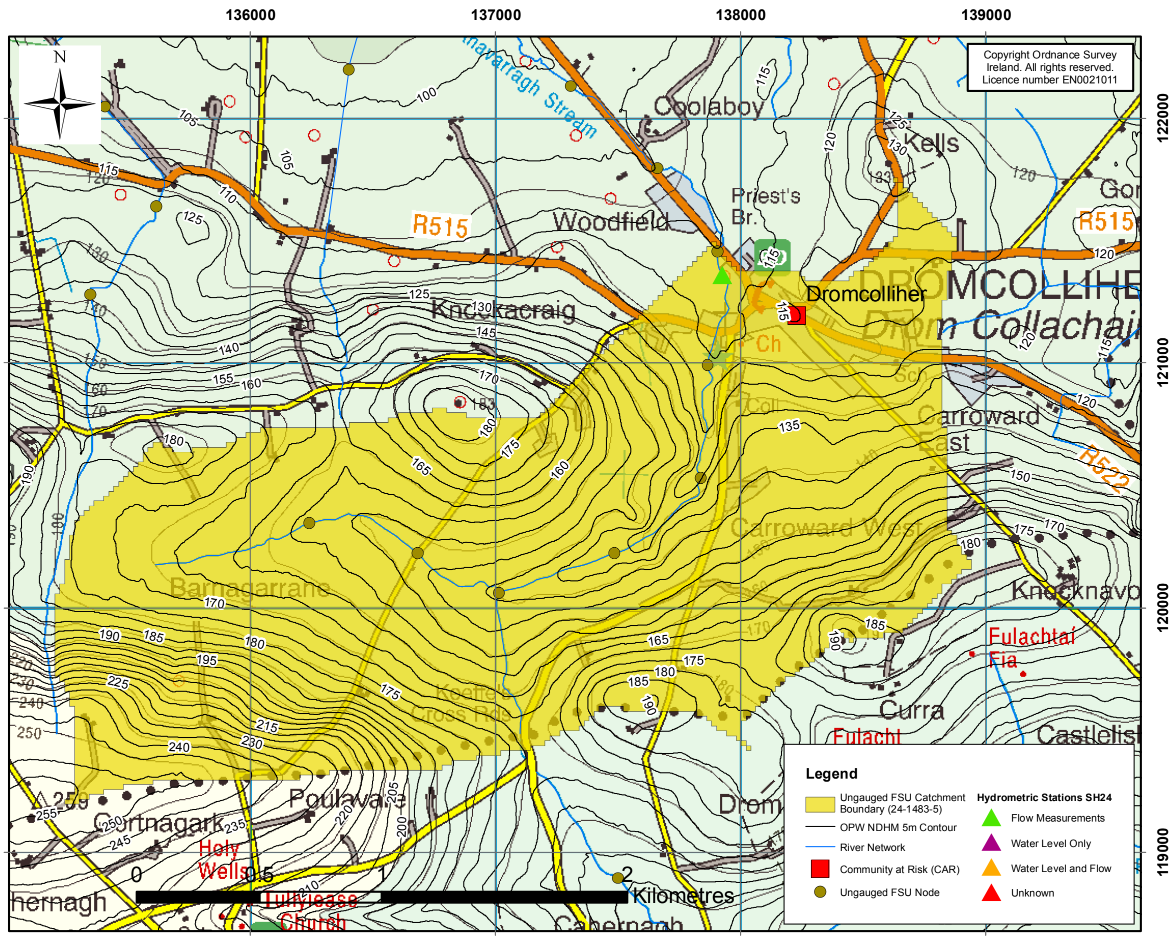


Figure 10 Random Check Area UoM 24 (Dromcolliher, FSU catchment 24-1483-5)

5.5 Conclusions

Based on the assessment of Unit of Management 24 alone, it was concluded that:

1. The manually adjusted (FSU) boundaries were derived from the automatic boundaries, revising them for only a few gauged catchments, where the gauging station was found to be relevant for hydrological analysis. As a consequence, the manually adjusted boundaries are not consistent for nested and adjacent catchments, as the catchments nested in or adjacent to the manually adjusted catchments would not have been amended.

2. The contours on the 1:50,000 scale OSi mapping have been compared with contours derived from the OPW National Digital Height Model (NDHM, Intermap 2009) and generally show a good correlation, particularly in relatively flat areas with little vegetation. The NDHM is based on IFSAR data, with a reported vertical root-mean-square error of approximately 0.7m on slopes smaller than 20 degrees, and greater on steeper slopes.

3. Inspection of the Water Framework Directive (WFD) boundary, the automatic boundaries and the manually adjusted boundaries shows two discrepancy areas which may affect the area to a gauging station by 10% or more. In both cases

the manually adjusted boundary intersects with watercourses defined in the River Network dataset and on the OSi mapping. It is understood that the WFD and automatic boundaries are both based on hydrologically corrected DTMs, which may explain why their boundaries differ from the boundaries found using contour maps alone (manually adjusted boundary and NDHM contours).

4. One additional random check was carried out in catchment UoM 24 to compare an automatic ungauged FSU catchment boundary to a Community at Risk (CAR) with the NDHM dataset. For the catchment checked the automatic boundary compared well with the contours with 5m vertical interval generated from the NDHM.

The data used for this comparison is provided electronically using the Sharepoint system, see Appendix G.

5.6 Recommendations

It is recommended that the two discrepancies detailed above are further investigated. A site visit, possibly followed by some topographic survey should provide conclusive evidence with regard to the correct catchment boundaries for each discrepancy area.

5.7 Way forward

It is proposed that Jacobs and OPW have a discussion regarding the catchment boundary discrepancies after all Units of Management within the Shannon River Basin District have been analysed (UoM 23, 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.

Jacobs suggests that OPW review the data provided herewith and, in discussion with Jacobs, 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). As a result of missing data, daily raingauge 6205 has been excluded from this phase of the study.

6.2 Distribution of raingauges within Shannon Estuary South

Daily read raingauges are not evenly distributed across the Shannon Estuary South (ref. Figure 4). Their distribution is clustered in the northern portion of the unit of management, and primarily within the lower reaches of the Deel and Maigue catchments. Three raingauges are located outside and to the west of these catchments, one each in the River Robertstown and River White catchments and one located on Tarbert Island.

6.3 Data review

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

A count of missing data reveals that gauges 4611 (Tarbert Island) and 5811 (Meanus) have large portions of missing data, 22% and 33% respectively (Table 6-A). Stations 4811 (Patrickswell), 6111 (Shanagolden) and 6311 (Ballyhahill) have either no or minimal missing data.

Raingauge no.	Name	Record start	Record end	Total number of days	Missing days	% of data missing
4611	Tarbert Island	13/02/1968	30/11/2009	15267	3310	22
4811	Patrickswell	01/09/1981	31/05/2010	10500	9	0
4911	Castlemahon	01/04/1982	31/12/2009	10137	68	1
5111	Rathkeale Duxtown	01/07/1984	31/12/2009	9315	316	3
5711	Newcastle West	08/02/1992	31/12/2009	6537	135	2
5811	Meanus	01/06/1993	31/10/2004	3955	1318	33
6111	Shanagolden	01/07/1994	31/05/2010	5814	3	0
6311	Ballyhahil	01/01/2001	31/12/2009	3287	0	0

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

Double mass plots were created to ensure each raingauge was reviewed at least once (ref. Appendix B for plots). In general the plots confirmed that long term rainfall relationships between raingauges were fairly consistent across the catchment. However, it did serve to highlight the scale of missing data from record

5811 and a potential change at raingauge 5711. When the cumulative record for 5711 was plotted against cumulative rainfall from stations 4911 and 6311 both plots revealed a change in the relationship in around May or June 2005. There is no scope for further investigation at this stage of the study; therefore out of caution, rainfall from station 5711 is assumed to be excluded from further use in this study. However, if there is merit in using the data post-2005, this will be considered.

Cumulative totals for all raingauges between 1 January 2001 and 29 March 2004 indicate geographical variations in rainfall received throughout the unit of management with higher medium-term rainfall totals in the west of Shannon Estuary South compared to the east (Table 6-B). The raingauge recording the highest total rainfall was 6311 at Ballyhahill with a total of 4101.0 mm for that period.

Station No.	Cumulative total rainfall (mm)
4611	3085.8
4811	2685.5
4911	2839.9
5111	3801.1
5711	3395.6
5811	2237.6
6111	3257.4
6311	4101.0

Table 6-B Cumulative rainfall for stations in Shannon Estuary South between 1 January 2001 and 29 March 2004.

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:

- 4611 – Tarbert Island
- 4811 – Patrickswell
- 5111 – Rathkeale Duxtown

Despite the high proportion of missing data, raingauge 4611 was included primarily due to its location as the furthest westerly raingauge in the area. A review of the time series identified that the majority of missing data was prior to 1993 and even excluding this data, the time series was still longer than the closest gauge, 6311 whose record commences 1 January 2001.

Raingauge 4611 is located on Tarbert Island within the 'Other' sub-catchment, as defined by this study to include catchments outside of the Maigue and Deel, whilst 4811 and 5111 are located in the Maigue and Deel sub-catchments respectively and collectively provide the best possible coverage across the unit of management.

6.5 Rainfall probability plots

For the three raingauges selected in Section 6.4, a 1-day total annual maxima and a 4-day total annual maxima series were created. Any years with more than 30 days of missing data were excluded and this left 4611, 4811, and 5111 with 16, 30 and 21 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.

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

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.

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

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

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

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 can also be estimated directly from the plotted local data. Therefore, the actual fit with the chosen distribution has little relevance for this independent check of the FSU DDF method.

6.6 Events of interest

Severe rainfall events were identified in conjunction with the annual maxima flow series. The three rainfall stations identified in 6.4 will be the focus for the analysis. For consistency the same events selected for fluvial analysis will be reviewed here also. Event selection is detailed in Sections 7.6 and 7.7. The five events selected are:

- 11 – 12 October 1988;
- 29 - 30 December 1998;
- 6 - 7 November 2000;
- 31 July – 1 August 2008;
- 31 January - 1 February 2009.

For each event the maximum depth of rainfall for a range of durations; 1 day, 2 days, 4 days and 10 days were obtained. Depths for each duration were produced by summing the daily rainfall total for the corresponding x number of preceding days. Maximum values were selected from within a 10 day period up to and including the date of the largest peak flow within the catchment. The results are presented below in Sections 6.6.1 to 6.6.5 inclusive.

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

It is important to note that the availability of daily rainfall only is anticipated to significantly increase the uncertainty in respect of the analysis of rainfall events with sub-daily durations.

6.6.1 Event of 11 - 12 October 1988

High fluvial flows recorded on 11th and 12th October appear to have been the result of a high intensity and short duration rainfall event on 10th October, with daily rainfall totals of between 25.3 mm and 39.7 mm recorded at the selected raingauges. A plot of the daily rainfall for the 10 days preceding the event (Figure 11) indicates a period of prolonged rainfall, which is likely to have saturated the catchments. Daily rainfall totals were generally higher at raingauges 4811 and 5111.

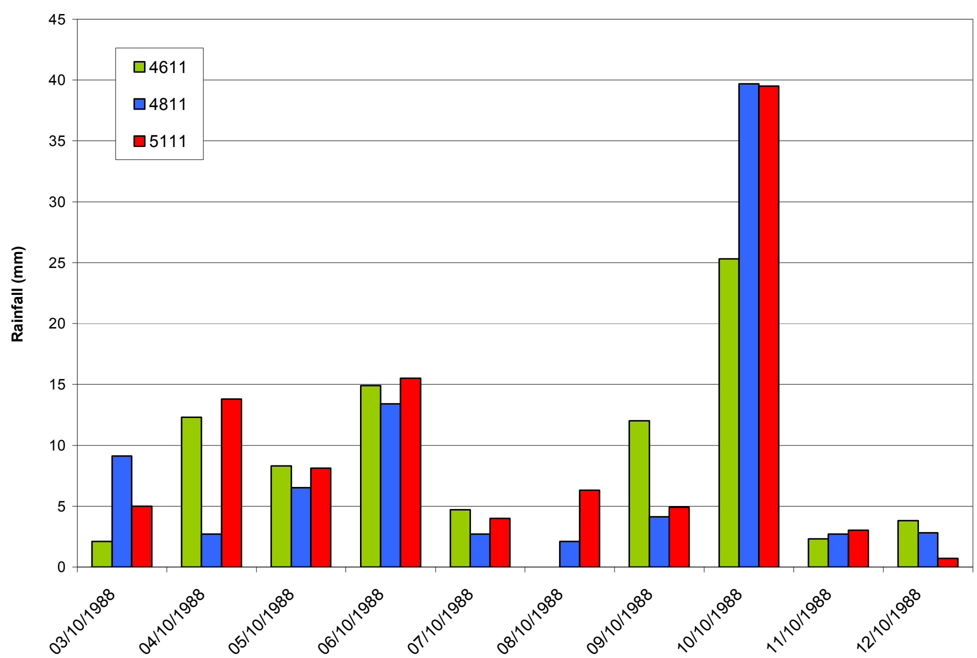


Figure 11 Daily rainfall – 3rd October to 12th October 2011 (NB: rainfall missing at 4611 on 8th October 1988)

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 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 4811 and 5111 indicate that this event has annual exceedance probability of 16% and 22% respectively

Rainfall Duration	Oct-88					
	4611 Rainfall depth (mm)	4611 AEP (%)	4811 Rainfall depth (mm)	4811 AEP (%)	5111 Rainfall depth (mm)	5111 AEP (%)
1 day rainfall (mm)	25.3	89	39.7	16	39.5	22
2 day rainfall (mm)	37.3		43.8		44.4	
4 day rainfall (mm)	43.4	90	49.3	55	54.7	55
10 day rainfall (mm)	85.9		85.8		104.4	

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 (October 1988)

6.6.2 Event of 29 - 30 December 1998

A review of the daily rainfall plotted in Figure 12 suggests that peak flows on both the River Maigue and River Deel were triggered by a rainfall event on 29th December 1998, following a period of prolonged lighter rainfall across the catchment. For the 10 days preceding the 31 December all three gauges recorded at least 7 out of 10 days with total daily rainfall exceeding 5mm.

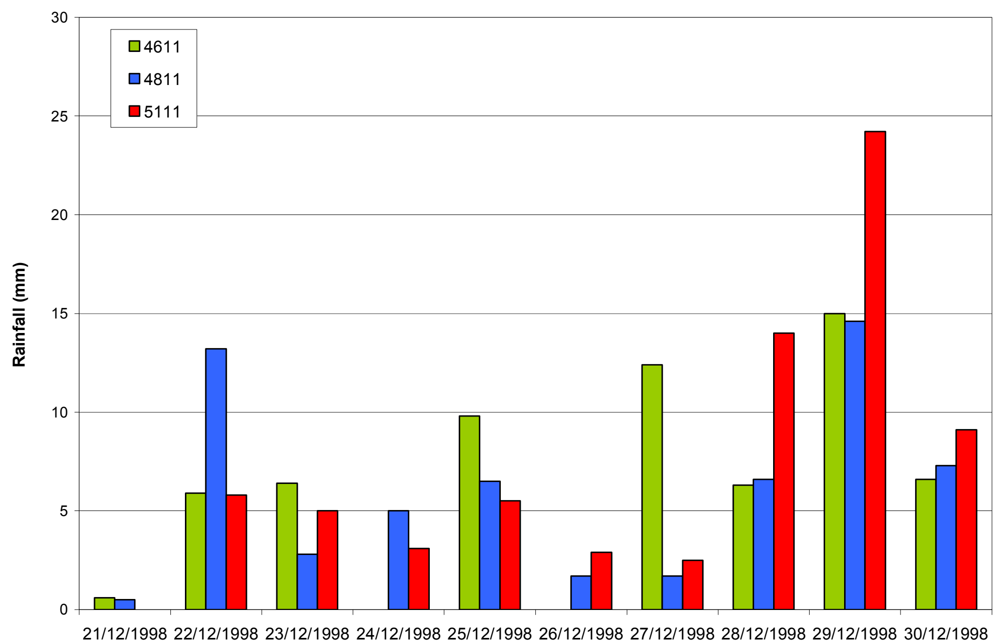


Figure 12 Daily rainfall – 21st December to 30th December 1998

Annual exceedance probabilities (AEPs) for the maximum rainfalls over the event are presented in Table 6-D. AEPs estimated for the maximum event rainfall at raingauges 4611, 4811 and 5111 indicate that for both the 1 day and 4 day durations this is a typical annual event. Only the AEP value for the 4 day rainfall total recorded at 5111 indicates a probability slight lower.

Rainfall Duration	Dec-98					
	4611 Rainfall depth (mm)	4611 AEP (%)	4811 Rainfall depth (mm)	4811 AEP (%)	5111 Rainfall depth (mm)	5111 AEP (%)
1 day rainfall (mm)	15	100	14.6	99	24.2	84
2 day rainfall (mm)	21.6		21.9		38.2	
4 day rainfall (mm)	40.3	100	30.2	97	49.8	67
10 day rainfall (mm)	63		59.9		72.1	

Table 6-D Maximum rainfall depths for 1 day, 2 day, 4 day and 10 day durations with corresponding AEP for 1 day and 4 day durations (December 1998)

6.6.3 Event of 6 - 7 November 2000

Daily rainfall of between 19.8 mm and 28.7 mm on 5th November following a period of prolonged low intensity rainfall (ref. Figure 13) across the area appear to be the origin of the high flows. The duration and widespread nature of the rainfall are consistent with a prolonged winter depression.

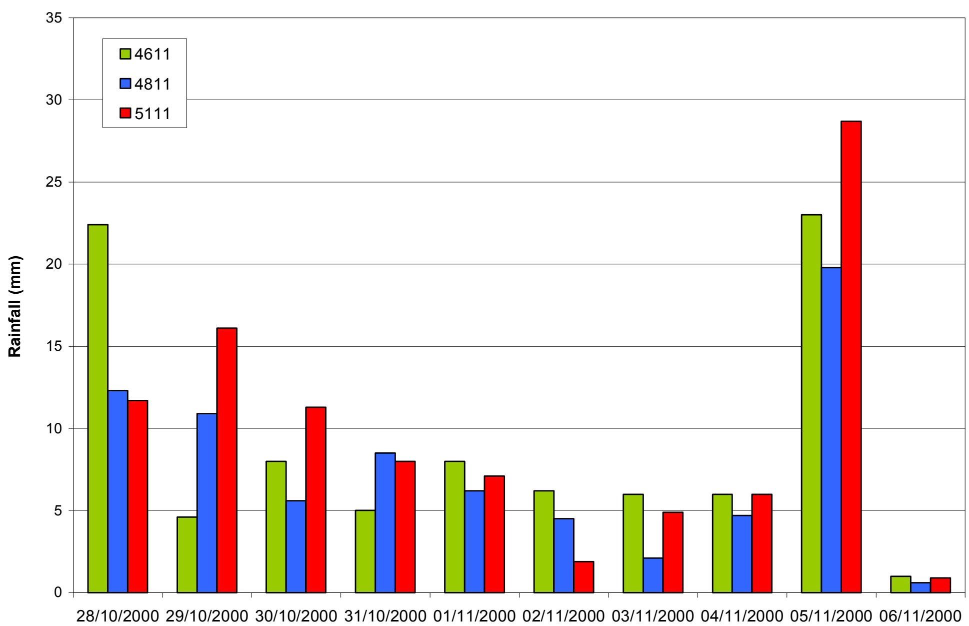


Figure 13 Daily rainfall – 28th October 6th November 2000

Annual exceedance probabilities (AEPs) for the maximum rainfalls over the event are presented in Table 6-E. Estimated AEPs indicate that this was a less frequent event for the 4-day duration as opposed to the 1-day duration rainfall, not surprising considering the nature of the event and highlighting the influence of antecedent rainfall on the catchment response. However, AEP estimates still associate it within the bounds of a typical annual event.

Rainfall Duration	Nov-00 4611 Rainfall depth (mm)	4611 AEP (%)	4811 Rainfall depth (mm)	4811 AEP (%)	5111 Rainfall depth (mm)	5111 AEP (%)
1 day rainfall (mm)	23	94	19.8	92	28.7	64
2 day rainfall (mm)	29		24.5		34.7	
4 day rainfall (mm)	57.8	64	45.1	66	59.4	45
10 day rainfall (mm)	97		76.7		105.2	

Table 6-E Maximum rainfall depths for 1 day, 2 day, 4 day and 10 day durations with corresponding AEP for 1 day and 4 day durations (November 2000)

6.6.4 Event of 31 July – 1 August 2008

Daily rainfall presented in Figure 14 reflects a short duration, high intensity rainfall event, consistent with a summer convective storm. Rainfall totals peak on the 31 July with 48.4 mm recorded at 4811 within the lower reaches of the Maigue catchment. A lower daily rainfall total of 29.3 mm is recorded at 4611, however, the preceding day a total of 37.4 mm of rain was recorded which this suggests that the storm event may have spanned 09:00 hours, when the raingauge is read and emptied daily.

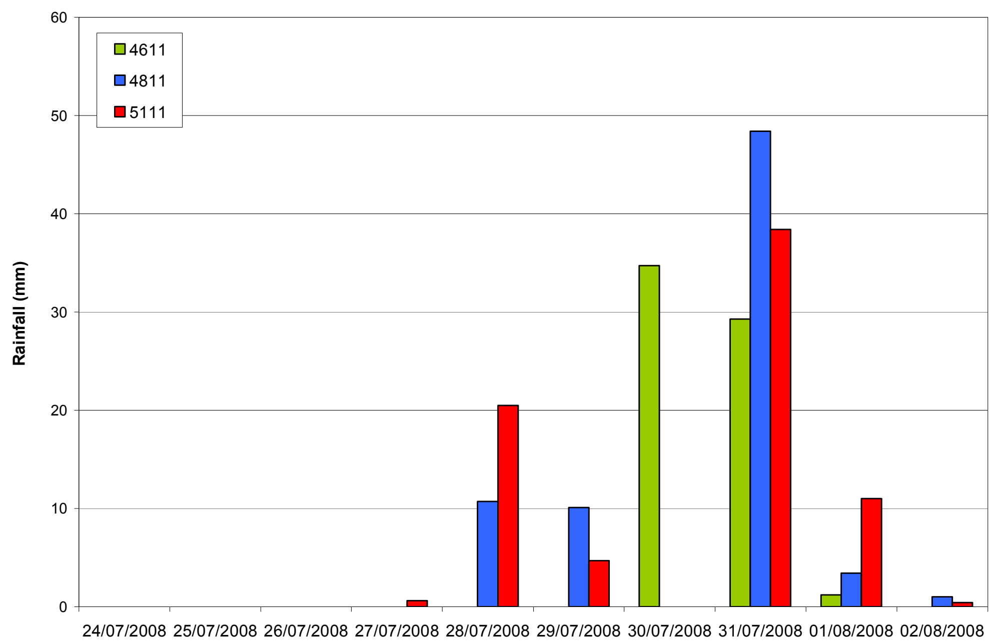


Figure 14 Daily rainfall – 24th July to 2nd August 2008

Annual exceedance probabilities (AEPs) for the maximum rainfalls over the event are presented in Table 6-F. Estimated AEPs indicate that the 1 day rainfall depth as recorded at 4811 was a relatively rare event with an AEP of 4%. If it is considered that the event spanned the 09:00 threshold of the raingauge being read and the daily rainfall recorded for 30th and 31st July would have been recorded in a 24-hour period, the revised AEP is 5%, similar to that of 4811.

Rainfall Duration	Jul-08					
	4611 Rainfall depth (mm)	4611 AEP (%)	4811 Rainfall depth (mm)	4811 AEP (%)	5111 Rainfall depth (mm)	5111 AEP (%)
1 day rainfall (mm)	34.7	60	48.4	4	38.4	25
2 day rainfall (mm)	64		51.8		49.4	
4 day rainfall (mm)	65.2	49	69.2	16	63.6	37
10 day rainfall (mm)	65.2		73.6		75.6	

Table 6-F Maximum rainfall depths for 1 day, 2 day, 4 day and 10 day durations with corresponding AEP for 1 day and 4 day durations (August 2008)

6.6.5 Event of 31 January - 1 February 2009

Daily rainfall ploted in Figure 15 for the period 22nd January to 31st January 2009, illustrates some variation in rainfall depths across the area. At raingauges 4811 and 5111 a period of fairly steady rainfall, peaking on 30 January is noted, whilst the rainfall at 4611 appears more intermittent.

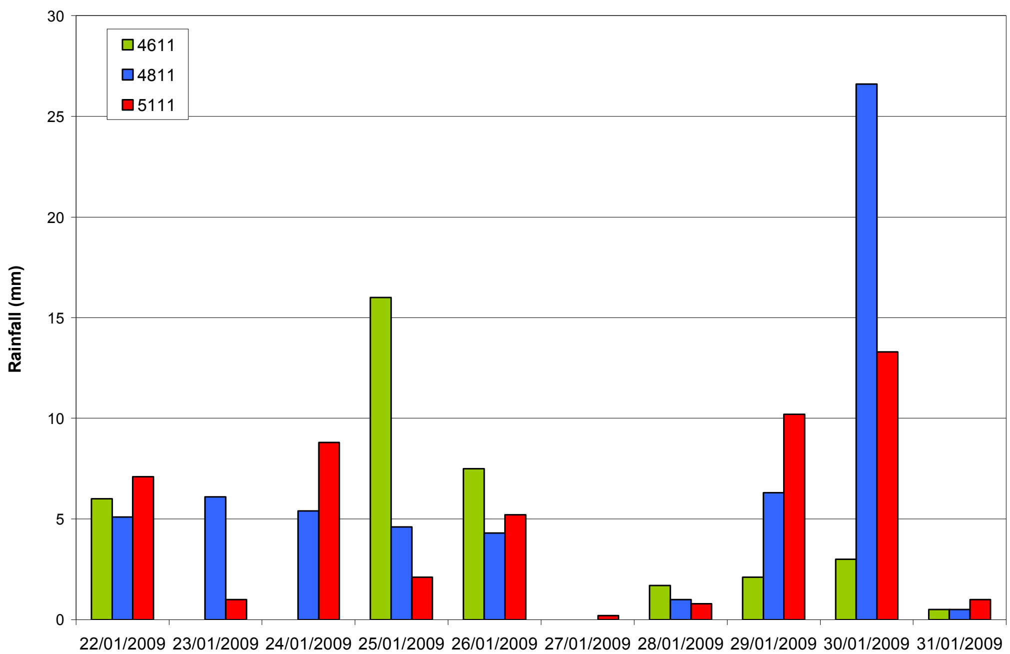


Figure 15 Daily rainfall – 22nd January to 31st January 2009

Table 6-G presents the AEPs estimated for the daily and 4-day durations. The figures for raingauges 4611 and 5111 suggest that it was a typical annual event. The AEP estimates for 4811 only indicate that the event occurs slightly more frequently than on an annual basis.

Rainfall Duration	Jan-09					
	4611 Rainfall depth (mm)	4611 AEP (%)	4811 Rainfall depth (mm)	4811 AEP (%)	5111 Rainfall depth (mm)	5111 AEP (%)
1 day rainfall (mm)	16	99	26.6	63	13.3	100
2 day rainfall (mm)	23.5		32.9		23.5	
4 day rainfall (mm)	40.3	94	34.4	91	26.2	99
10 day rainfall (mm)	98.8		66.2		77.2	

Table 6-G 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 2009)

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-H.

Duration	Return Period (years)	Annual Exceedance Probability (%)	4811 Rainfall Depths (mm)	4911 Rainfall Depths (mm)	5111 Rainfall Depths (mm)
24 hour	2	50	34.3	37.9	37.3
24 hour	5	20	47.3	47.2	50.6
24 hour	10	10	57.1	53.7	60.5
24 hour	20	5	67.9	60.4	71.3
24 hour	30	3	74.9	64.6	78.3
24 hour	50	2	84.6	70.2	87.9
24 hour	100	1	99.7	78.5	102.6
24 hour	200	0.5	117.3	87.7	119.6
4 day	2	50	54.0	68.0	63.5
4 day	5	20	70.4	80.6	80.9
4 day	10	10	82.4	88.9	93.2
4 day	20	5	95.1	97.4	106.2
4 day	30	3	103.1	102.6	114.4
4 day	50	2	114.0	109.3	125.4
4 day	100	1	130.6	119.1	141.8
4 day	200	0.5	149.3	129.7	160.3

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

As stated previously, comparison of daily rainfall data and 24 hour data may not be a precise or even fair comparison due to the possible underestimation of maximum daily rainfall values should an event straddle 09:00 hours.

Depth, duration and frequency estimates derived from local 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-I, J and K), with the FSU estimates of equal or less than 50% highlighted in bold for ease of reading.

4611	1 day			4 day		
Event date	Maximum depth (mm)	Estimated AEP (%)	FSU AEP (%) (approx)	Maximum depth (mm)	Estimated AEP (%) (approx)	FSU AEP (%)
Oct-88	25.3	89	> 50	43.4	90	> 50
Dec-98	15	100	> 50	40.3	100	> 50
Nov-00	23	94	> 50	**57.8**	**64**	**42**
Jul-98	**34.7**	**60**	**50**	**65.2**	**49**	**29**
Jan-99	16	99	> 50	40.3	94	> 50

Table 6-I 1 day and 4 day rainfall and associated Annual Exceedance Probability (AEP) for raingauge 4611

4811	1 day			4 day		
Event date	Maximum depth (mm)	Estimated AEP (%)	FSU AEP (%) (approx)	Maximum depth (mm)	Estimated AEP (%) (approx)	FSU AEP (%)
Oct-88	**39.7**	**16**	**43**	49.3	55	> 50
Dec-98	14.6	99	> 50	30.2	97	> 50
Nov-00	19.8	92	> 50	45.1	66	> 50
Jul-98	**48.4**	**4**	**16**	**69.2**	**16**	**47**
Jan-99	26.6	63	> 50	34.4	91	> 50

Table 6-J 1 day and 4 day rainfall and associated Annual Exceedance Probability (AEP) for raingauge 4811

5111	1 day			4 day		
Event date	Maximum depth (mm)	Estimated AEP (%)	FSU AEP (%) (approx)	Maximum depth (mm)	Estimated AEP (%) (approx)	FSU AEP (%)
Oct-88	**39.5**	**22**	**46**	54.7	55	> 50
Dec-98	24.2	84	> 50	49.8	67	> 50
Nov-00	28.7	64	> 50	59.4	45	> 50
Jul-08	**38.4**	**25**	**48**	**63.6**	**37**	**50**
Jan-09	13.3	100	> 50	26.2	99	> 50

Table 6-K 1 day and 4 day rainfall and associated Annual Exceedance Probability (AEP) for raingauge 5111

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

For the three rainfall depths which fell below the 50% FSU AEP threshold on raingauge 4611 (Tarbert Island), the FSU AEP estimates were consistently lower than those derived from the actual data, suggesting that the events were rarer than estimated from actual data.

At raingauges 4811 and 5111, the opposite was observed, whereby the FSU AEP estimates were consistently higher than the estimates obtained from actual data. This is most notable for the July 1998 event at raingauge 4811, where the AEP estimated from the data was 4% compared to 16% estimated by FSU methods. This is a considerable disparity.

Comparing the FSU estimated depths and frequencies with the plotted historical local data as presented in the graphs in Appendix C shows that the FSU DDF estimates do not appear to accurately reflect the local conditions at the three rainfall stations considered here.

One contributory factor to the discrepancy may be the use of fixed-duration rainfall (09:00-09:00 UTC data) rather than the sliding-duration used or adjusted for by the FSU (2007). For 1-day duration data this can lead to an underestimation of fixed-duration rainfall by up to 13%. This effect diminishes with increasing duration. It would appear that this contribution alone cannot explain the entire discrepancy.

6.8 Conclusions

Nine Met Éireann daily storage raingauges have been identified within the Shannon Estuary South Unit of Management, however, data was only provided for eight. 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, suggest that events were the result of both winter depressions, characterised by a moderately intense rainfall event preceded by prolonged rainfall, and a summer convective event characterised by high intensity short duration rainfall.

Annual exceedance probabilities for the 1 day and 4 day duration rainfall depths were estimated based on probability plots developed from annual maxima series derived from the rainfall record.

Subsequent annual exceedance probabilities estimated indicate that the majority of rainfall events were typical annual events with an AEP of 50% or greater. The lowest annual exceedance probability estimated was 4% for a 1 day rainfall depth at station 4811 during the July 2008 event.

Annual exceedance probabilities estimated from actual data for the 1 day and 4 day durations and compared to theoretical AEPs for the 24 hour and 4 day durations created for the Flood Studies Update varied. FSU AEPs were lower AEPs at station 4611 and higher AEPs at stations 4811 and 5111. 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 Shannon Estuary South Unit of Management (UoM 24) 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.

As outlined previously, the majority of flow and level gauges within the Shannon Estuary South Unit of Management are located on the Rivers Maigue and Deel and their tributaries. Of the 24 stations for which some fluvial flow and level data were provided, 12 stations are located within the River Maigue catchment down to its tidal limit, 9 within the River Deel catchment, and 1 each on the Robertstown, White and Greanagh rivers. To assist in the review of catchment response the unit of management has been divided into the following sub-catchments, the Deel, the Maigue and 'Others' (ref. Figure 16).

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 in this report.

7.2 Distribution of flow and level gauging stations within UoM 24

Within the Maigue catchment, five hydrometric gauging stations are located on the River Maigue (24004, 24001, 24082, 24008 and 24000), three on the River Loobagh (24034, 24016 and 24003) and one each on the Rivers Camoge (24002), Morningstar (24005) and Mahore (24022). This distribution ensures that all significant tributaries are gauged in at least one location. There is some clustering of flow gauges along the River Maigue in the lower reaches, downstream of the last major tributary (River Camoge) where the river is gauged in three locations. The River Maigue can be considered tidal from Adare Quay.

There are nine gauging stations located within the Deel catchment, six are located on the River Deel (24030, 24011, 24100, 24012, 24013 and 24029), and are fairly evenly distributed spatially along its length. The Ahavarragh Stream (24015) and Rivers Bunoke (24045) and Finglosha (24046) are each gauged at one location. No data is currently available for recently installed gauges on the watercourses which drain the steep topography of the Knockanimpaha mountain area to the west of Newcastle West.

Outside of the Deel and Maigue catchments in the 'Others' catchment, the River Greanagh is gauged at Normoyle's Bridge (24067) and discharges into the tidal River Maigue. Two further gauges are located on the Robertstown and White Rivers (24017 and 24033 respectively) located to the west of the Deel catchment, each draining a small catchment which discharges directly into the Shannon Estuary at the Robertstown inlet.

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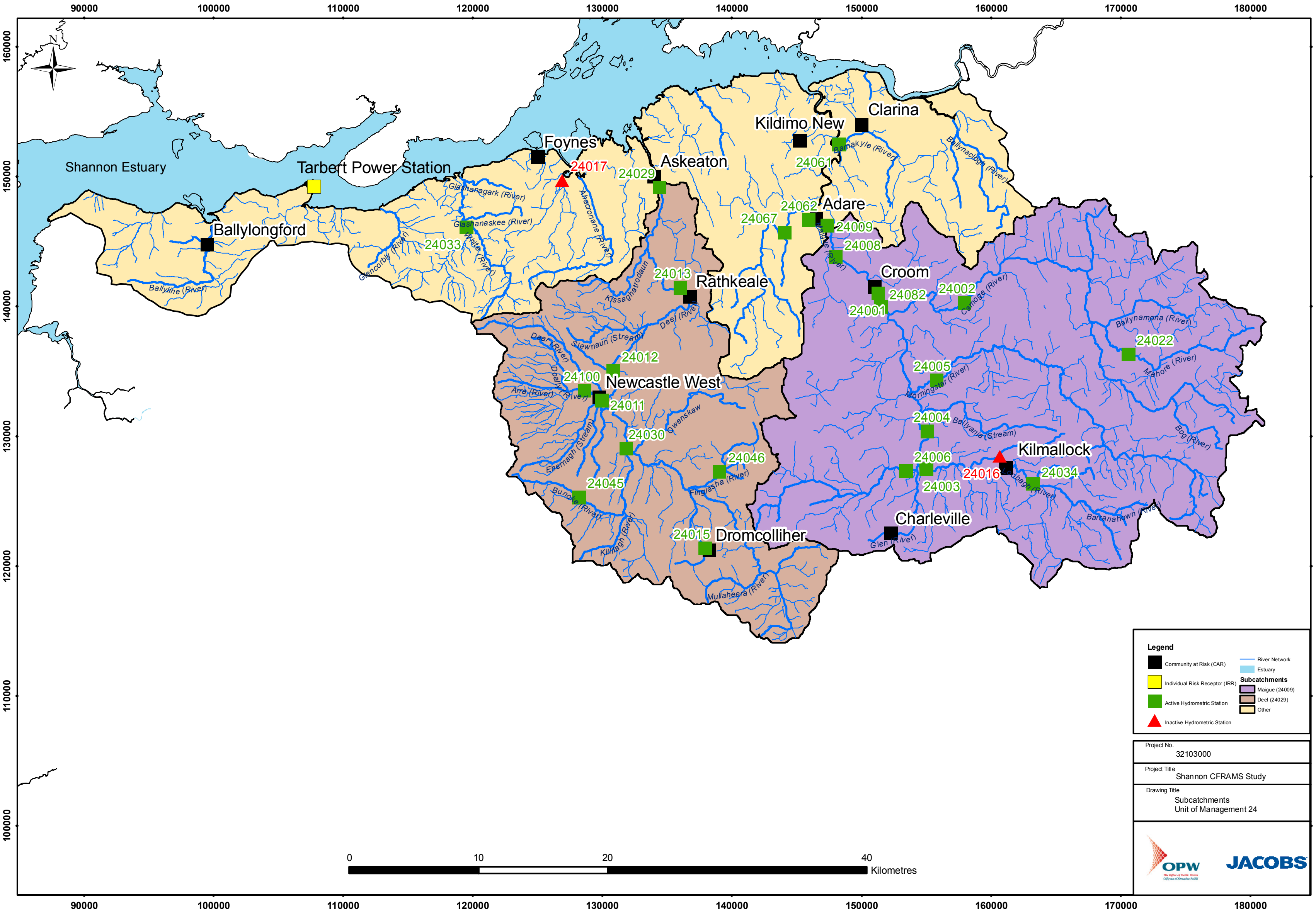


Figure 16 Shannon Estuary South Unit of Management with the Maigue, Deel and Other sub-catchments delineated

7.3 Data review

It was assumed that data was provided by the OPW or EPA quality assured. In order to gain an understanding of the completeness and the quality of data at each gauged location, flows and level records were reviewed upon receipt of the data. This assessment was aimed at providing an overview of the quality of data based on a visual inspection of daily mean flow (or level) records, a count of quality codes (where available), completeness of record and any 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.

All 12 daily mean flow and / or level records available were visually reviewed (ref. Table 3-D). Only three stations were identified as not having any obvious trends or consistencies, whilst 8 stations (24001, 24003, 24005, 24008, 24011, 24012, 24013 and 24082) indicated trends of rising levels and/or flows over the period of record. In some of the records (24001, 24003 and 24011), a trend was evident in the level series but not in the flow, which suggests a change to the gauged cross-section possibly accounted for in the flow record by a revision of the rating. Trends in peak flows, either rising or declining are problematic as they disprove the assumption of homogeneity of a flow series; an assumption routinely made when undertaking any hydrological statistical analysis.

An example of a typical observed trend in peak flows is shown in Figure 16a below.

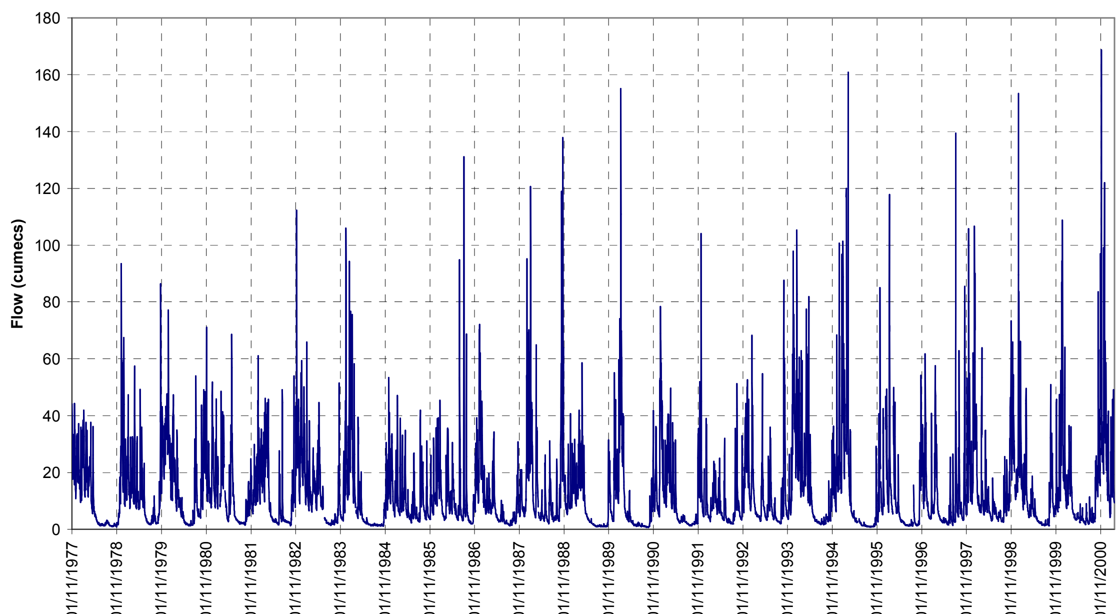


Figure 16a Example of trend at station 24082

It is possible that the trends are indicative of climatological trends rather than site specific, although an analysis of the long term rainfall time series did not identify any such trends. Further investigation by OPW into the flow and level series is recommended to determine whether this is actually the case. Land use change is another potential contributing factor although this has not been considered in detail in this Preliminary Hydrological Assessment.

					Daily Flow data only				Daily Level data only				
Station no.	Station name	River	UoM 24 sub-catchment	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
24001	Croom	Maigue	Maigue	A2	38	7	4	13858	96	0	4	13858	Yes - trend in water level, flows ok
24002	Gray's Bridge	Camoge	Maigue	A2/B					92	0	4	9044	No
24003	Garroose	Loobagh	Maigue		83	0	16	13859	83	0	16	13859	Yes - rising trend in water level, flows ok
24004	Bruree	Maigue	Maigue	B	69	1	6	11414	87	0	6	11810	No
24005	Athlacca	Morningstar	Maigue						45	0	51	16761	Yes - rising trend in water level
24006	Creggane	Maigue	Maigue						21	0	78	13859	Yes - irregularities in water level
24008	Castleroberts	Maigue	Maigue	A2	70	1	5	12939	89	0	3	13436	Yes - trend in water level, flow ok.
24011	Deel Bridge	Deel	Deel	B	2	16	4	5477	97	0	1	7923	Yes - trend in water level, flow ok
24012	Grange Bridge	Deel	Deel	B	24	27	5	19177	97	0	3	19174	Yes - trend of increasing flows
24013	Rathekeale	Deel	Deel	A1	0	12	8	13859	94	0	5	13858	Yes - trend of increasing flows
24034	Riversfield Weir	Loobagh	Maigue		61	4	7	2248	89	1	7	2259	No
24082	Islandmore	Maigue	Maigue	A2	2	0	2	8513	98	0	2	8513	Yes - trend of increasing peak flows

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

Sudden and anomalous dips in water level were observed in two of the records, 24003 and 24008. Typically such anomalous values are removed from the record and will be excluded should they arise within further event analysis.

Analysis of the OPW quality codes (ref. Table 3-E) assigned to the data revealed that at two sites, 24011 and 24082 only 2% of the daily flow series was considered to be of ‘good’ quality. One station, 24012, had 27% of the daily flow series data flagged as poor or cautionary.

Two daily level series had greater than 50% of the data series flagged as missing, these were stations 24005 (51%) and 24006 (78%). This percentage of missing data can greatly reduce the utility of a data series.

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

7.4 Annual maxima flow and level series

Annual maxima (AMAX) data for the 16 fluvial stations in UoM 24 (excluding the short record of 24100) (ref. Table 3-F) were ranked to identify the top 5 and top 10 ranked events for each gauging station. In Table 7-B, the top 5 events at each location are identified by the letter A and yellow shading; those ranked 6-10 are identified by the letter ‘B’ and green shading. Due to the manual extraction of selected peak flows the rank of flow and level for a given event could differ at the same location. Therefore, where both flow and level annual maxima series were available, the flow series was used in preference. The subsequent matrix of annual maxima provided an overview of the most significant events across the catchment (Table 7-B). It is worth noting, however, that both the period of record and length of an annual maxima series can skew the data and therefore should be used as one of a series of approaches for assessing severe events.

Dates	Hydrometric Gauging Station														
	Maigue											Deel			
	24001	24002	24003	24004	24005	24006	24008	24009	24022	24034	24082	24011	24012	24013	24030
27-Feb-1954					B										
01-Jan-1955					B										
3-4 Dec 1960					B										
20-Mar-1964					A										
17-Jan-1965					A										
17-Nov-1965				B											
10-Dec-1965					A										
23-Feb-1967					A										
18-Oct-1967					B										
02-Nov-1968													A		
15-Dec-1968					A										
10-Jan-1969				A											
20-Jan-1970					B										
07-Dec-1972		A													
1-3 Dec 1973		A						A				A	A	A	
27-30 Jan 1975		A													
30 Jan - 1 Feb 1976		B						B							
19-Feb-1977		B													
02-Nov-1980												A	B	A	A
22-May-1981			B												
08-Nov-1982	A														A
31-Jan-1983												B	B		
16-Dec-1983	A			A			A	B			B	B			A
06-Aug-1986	A		B	B			B				B	A	B		A
08-Dec-1986	B														
01-Feb-1988	A														
11-12 Oct 1988		B						A	B	A		A	A		
21-22 Oct 1988	A		A	A			A				A			A	A
6-7 Feb 1990	B	A	A	A			A	A	B	A	A	B		B	
15- 16 Jan 1994												B		B	B
19-Feb-1994										B					
25-26 Jan 1995												A	B	B	
22-23 Feb 1995									A	A	A				
9-10 Mar 1995	B	A		B			A								

Dates	Hydrometric Gauging Station														
	Maigue											Deel			
	24001	24002	24003	24004	24005	24006	24008	24009	24022	24034	24082	24011	24012	24013	24030
24-Nov-1995									B	B					
28-Oct-1996														B	
05-Aug-1997	B		A	B			B			A	B				B
17-18 Oct 1997								B							
29-30 Dec 1998	B		A	A		A	A	A	A	B	A		B	A	B
18-Dec-1999									B						
24-25 Dec 1999								A							
6-7 Nov 2000		B	B	B		A	B		A		A			B	
26-Nov-2000															B
30-Nov-2000										B					
21-23 Jan 2002						B									B
01-Feb-2002								B							
26-Feb-2002									A						
27-Nov-2002						B				B					
14-Nov-2003						B			B						
27-29 Oct 2004						A			A	A	B				
28-Nov-2004			A												
08-Jan-2005													A		
20-Feb-2006								B							
22-May-2006						B									
01-Jan-2008												B			
10-Jan-2008							B				B				
10-Mar-2008															
31 Jul- 1 Aug 2008													A	A	
10-Oct-2008			B			A									
31 Jan -1 Feb 2009		B				B	B								
01-Nov-2009			B												
14-Nov-2009															
20-Nov-2009						A									

Table 7-B Top 5 (A) and Top 6-10 (B) AMAX flow or level for hydrometric gauging stations within UoM 24.

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 completion of the rating review process 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 15 hydrometric gauging stations located in the Shannon Estuary South Unit of Management for which an AMAX series greater than 10 years was available.

The 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

For each gauged sub-catchment, three flood events have been selected and will form the basis of a detailed hydrological analysis of hydrograph shape, duration, volume of flow, runoff and estimated probability of the event.

Events were selected based a review of the AMAX series from gauges across the catchment (ref. Table 7-B) in conjunction with the occurrence of historical flood events as documented on the floodmaps.ie website. Emphasis has been placed on the selection of events which have occurred in the past 15 years primarily to increase the chance of data availability.

It is expected that the comparison of three events is sufficient to derive the characteristic hydrograph shape. However, where three events do not give a consistent picture, additional events may be considered, provided there is data of appropriate quality that will significantly improve the analysis.

7.7 Maigue catchment

The following events were selected to represent severe flood events within the Maigue catchment:

- 29 - 30 December 1998;
- 6 - 7 November 2000;
- 31 January - 1 February 2009.

The following gauging stations located across the catchment were selected to represent the catchment response:

24001 Maigue at Croom
24003 Loobagh at Garroose
24004 Maigue at Bruree
24005 Morningstar at Athlacca
24008 Maigue at Castleroberts
24082 Maigue at Islandmore

The catchment areas of gauges 24001 and 24082 differ only by 7.4 km^2 but have both been included due to their differing hydrograph responses. A review of mean daily flow series (reported in Section 7.3) suggests that flows at station 24082 are suspect and flows at station 24001 appear reasonable.

7.7.1 Event of 29 - 30 December 1998

Flow data was extracted from the 15 minute series at four gauging stations between 29th December 1998 (00:00 hours) and 1st January 1999 (23:45 hours). Data was not available for station 24005 (Morningstar at Athlacca) and due to missing data (between 00:45 and 09:00 on 31st December 1998) at station 24082, it was also excluded. 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)
24001	161.1	30/12/1998 02:45	29/12/1998 07:30	31/12/1998 01:45	19,233,552	01:18:15
24003	60.5	29/12/1998 21:00	29/12/1998 06:30	31/12/1998 02:00	6,955,086	01:19:30
24004	100.1	30/12/1998 03:15	29/12/1998 06:30	31/12/1998 02:45	10,754,941	01:20:15
24005						
24008	166.7	30/12/1998 06:45	29/12/1998 07:45	31/12/1998 03:15	19,078,823	01:19:30
24082						

Table 7-C Summary of timings and flows for the flood event 29 - 30 December 1998

All four hydrographs (Figure 17 a) 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.

Timing of the peak flows indicates that flows peaked first in the Loobagh tributary in the upstream reaches of the catchment and last on the Maigue at Castleroberts, the furthest downstream gauging station included in this analysis.

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 3% at the Maigue at Bruree (24004) to 17% on the Maigue at Croom. The 3% AEP estimated at Bruree suggests it was a relatively infrequent event.

			Dec-98	
Station No.	Station Name	Watercourse	Peak flow (m^3/s)	Estimated Annual Exceedance Probability (%)
24001	Croom	Maigue	161.1	17
24003	Garroose	Loobagh	60.5	10
24004	Bruree	Maigue	100.1	3
24005	Athlacca	Morningstar		
24008	Castleroberts	Maigue	166.7	8
24082	Islandmore	Maigue		

Table 7-D Estimated annual exceedance probabilities for peak flows during December 1998 event

7.7.2 Event of 6 - 7 November 2000

Instantaneous flow data was available at six gauging stations between 4th November 2000 (00:00 hours) and 10th November 2000 (23:45 hours). A summary of the data is presented in Table 7-E 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)
24001	147.4	06/11/2000 14:15	05/11/2000 11:45	09/11/2000 00:30	27,329,098	03:12:45
24003	59.7	06/11/2000 01:30	05/11/2000 12:45	08/11/2000 10:00	9,577,524	02:21:15
24004	82.9	06/11/2000 11:00	05/11/2000 10:30	08/11/2000 22:30	12,615,482	03:12:00
24005	30.1	06/11/2000 04:45	05/11/2000 08:00	08/11/2000 23:15	5,204,473	03:15:15
24008	158.0	06/11/2000 12:45	05/11/2000 11:45	09/11/2000 12:45	28,088,204	04:01:00
24082	185.1	06/11/2000 10:30	05/11/2000 15:45	09/11/2000 00:45	29,949,604	03:09:00

Table 7-E Summary of timings and flows for the flood event 6 – 7 November

All hydrographs (Figure 17 b) reflect the occurrence of a single event across the catchment.

Both the peak flow and the greatest volume of flow logged for the event was recorded at 24082 and exceeded the flows and volumes estimated just downstream at 24001 and 24008, casting some doubt on the 24082 record as flows at 24001 and 24008 appear consistent.

The timing of peak flows in the lower catchment are also irregular considering there are no significant inflows between gauges 24082, 24001 and 24008, whereby the upstream gauge (24082) peaks first and the middle gauge (24001) peaks last.

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 (ref. Table 7-F). Results vary from 3% on the Morningstar tributary at Athlaccaa (24005) to 85% on the adjacent tributary Loobagh at Garroose (24003). This disparity in adjacent tributaries suggests that high intensity rainfall may have been localised. In the lower reaches of the River Maigue, estimated AEPs are similar ranging between 8 % to 11% suggesting that in the lower reaches an event on this scale would be expected once in every 10 years.

			Nov-00	
Station No.	**Station Name**	**Watercourse**	**Peak flow (m3/s)**	**Estimated Annual Exceedance Probability (%)**
24001	Croom	Maigue	147.4	27
24003	Garroose	Loobagh	59.7	85
24004	Bruree	Maigue	82.9	10
24005	Athlacca	Morningstar	30.1	3
24008	Castleroberts	Maigue	158	11
24082	Islandmore	Maigue	185.1	8

Table 7-F Estimated annual exceedance probabilities for peak flows during November 2000 event

7.7.3 Event of 31 January - 1 February 2009

Instantaneous flow data was available at six gauging stations between 29th January 2009 (00:00 hours) and 4th February 2009 (23:45 hours). A summary of the data is presented in Table 7-G 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)
24001	123.7	31/01/2009 04:00	29/01/2009 19:00	03/02/2009 03:45	26,733,810	04:08:45
24003	51.2	31/01/2009 04:15	29/01/2009 19:00	01/02/2009 23:00	8,911,677	03:04:00
24004	58.1	31/01/2009 06:30	29/01/2009 18:45	01/02/2009 20:15	9,902,498	03:01:30
24005	29.2	31/01/2009 10:45	29/01/2009 20:15	01/02/2009 22:15	5,009,748	03:02:00
24008	134.8	31/01/2009 04:45	29/01/2009 20:30	03/02/2009 03:45	28,840,791	04:07:15
24082	146.5	31/01/2009 03:15	29/01/2009 19:00	03/02/2009 03:45	28,922,422	04:08:45

Table 7-G Summary of timings and flows for the flood event 31 January – 1 February 2009

Hydrographs (Figure 17 c) plotted for this event display a runoff response to more than one rainfall event. This is particularly evident on the Loobagh tributary at

Garroose (24003) where three peaks can be identified, but is less evident further down the catchment and on the Morningstar tributary.

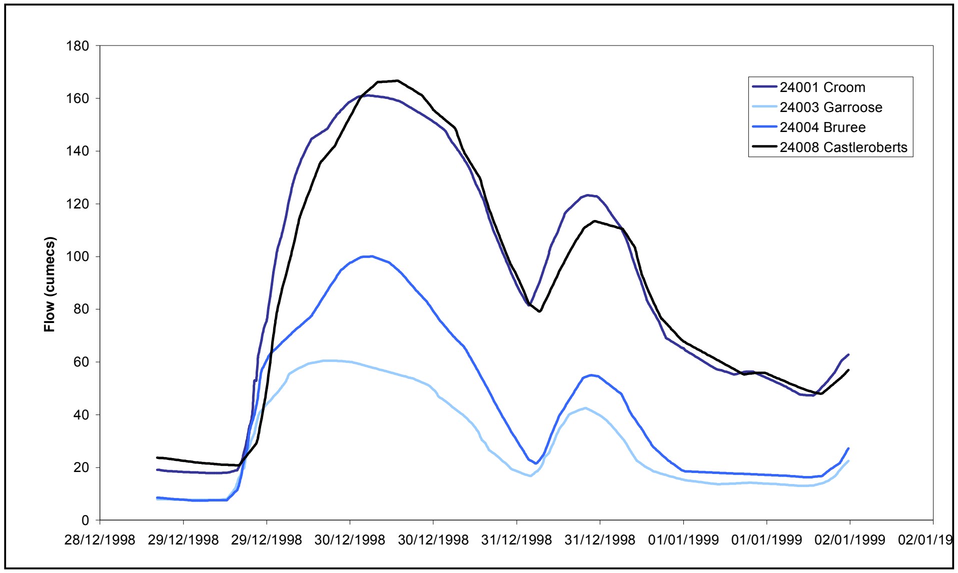
Timings of peak flow indicates that all gauges, with the exception of 24005 on the Morningstar tributary, peaked almost simultaneously suggesting a widespread rainfall event.

As noted for the November 2000 event, both the peak and volume of flow was greater on the Maigue at Islandmore (24082) when compared to the downstream gauges of 24008 and 24001.

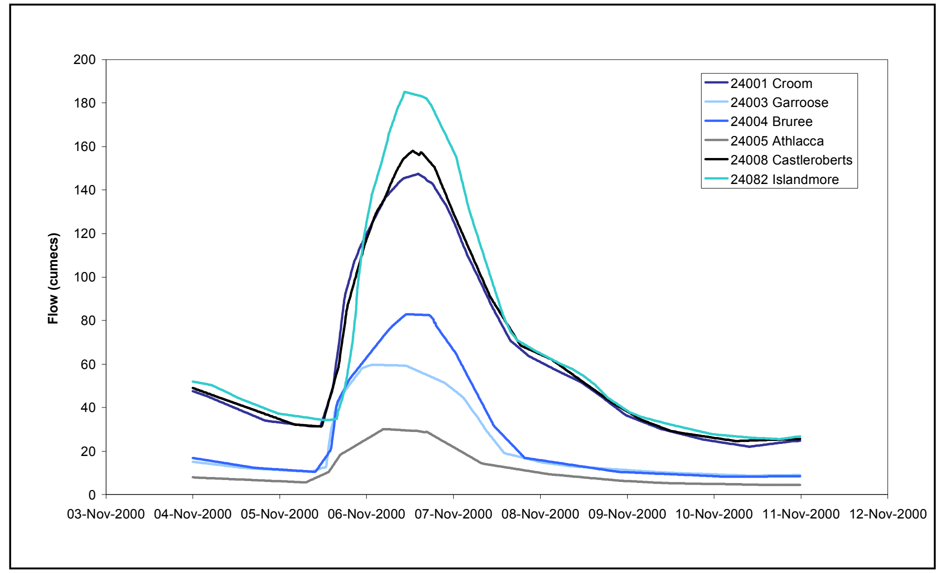
Annual exceedance probabilities estimated from the annual maximum flow series indicate that at Islandmore (24082) and Castleroberts (24008) on the lower River Maigue the event was of a similar probability of occurrence ~30%, but further downstream this value increases to around 50%.

			Jan-09	
Station No.	**Station Name**	**Watercourse**	**Peak flow (m3/s)**	**Estimated Annual Exceedance Probability (%)**
24001	Croom	Maigue	123.7	53
24003	Garroose	Loobagh	51.2	100
24004	Bruree	Maigue	58.1	38
24005	Athlacca	Morningstar	29.2	28
24008	Castleroberts	Maigue	134.8	27
24082	Islandmore	Maigue	146.5	31

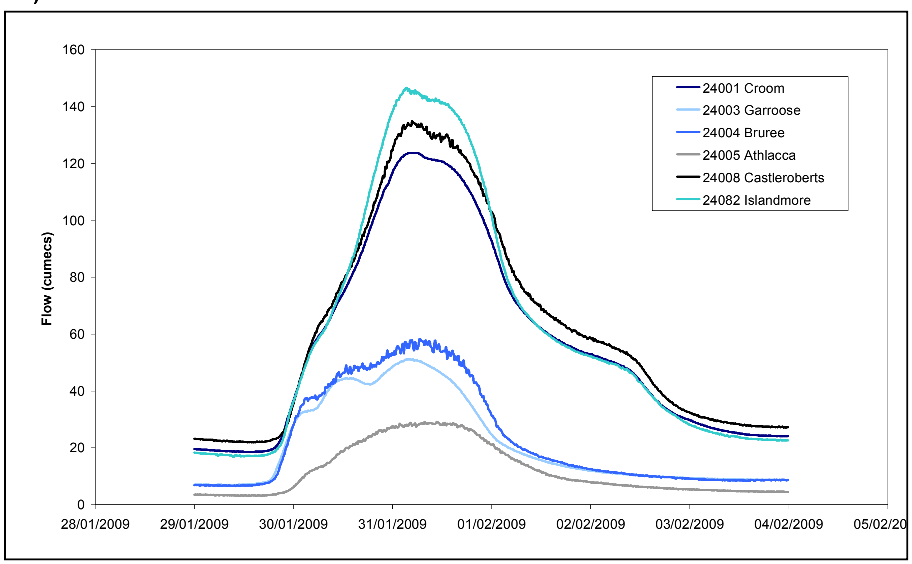
Table 7-H Estimated annual exceedance probabilities for peak flows during January 2009 event



a) Event of 29 – 30 December 1998



b) Event of 6 – 7 November 2000



c) Event of 31 January to 1 February 2009

Figure 17 Hydrographs for the three events on the River Maigue

7.7.4 Maigue catchment discussion

Of the three events reviewed, peak flow values were consistently the greatest in the December 1998 event (excluding 24082 for which there was no data available).

The hydrographs for all three events all indicate a steep rising limb and an initial steep recession which appears to flatten out. The shape of the hydrograph is indicative of a fast responding catchment.

Of the two gauged tributaries, the Loobagh and Morningstar, the Loobagh appears to consistently peak first. These tributaries drain adjacent areas and are of a similar size and the difference in time to peak can be attributed to the shape of their catchments, whereby the longer, narrower catchment of the Morningstar has a longer time-to-peak.

A feature of the hydrographs worthy of further investigation is the relationship between the peak flows at 24082, 24001 and 24008. The hydrographs indicate a consistent reduction in the peak flow and volume of flow between gauges 24082 and 24001 and 24008. Referring back to the review of daily data, the possibility of a trend of increasing peak flows was raised and this in conjunction with the inconsistent relationship between the gauges indicates an error is likely in the gauged data at 24082.

Further analysis of the catchment response in terms of the peak flow, volume of flow and runoff (Table 7-I) reveals that runoff for all three events is significantly greater at 24003 on the Loobagh tributary. This correlates with the steepest topography of the Maigue catchment, where the Loobagh drains the Ballyhoura Mountains. The Morningstar tributary (24005) which also drains the Ballyhoura Mountains has a lower runoff value, which suggests that a potentially higher runoff value in its upper reaches is diminished by lower runoff in other parts of the Morningstar catchment. As would be expected runoff values are lowest at the flatter downstream end of the catchment.

		Dec-98			Nov-00			Jan-09		
Station No.	Catchment area (km^2)	Peak flow	Volume of flow (m^3)	Runoff (mm)	Peak flow	Volume of flow (m^3)	Runoff (mm)	Peak flow	Volume of flow (m^3)	Runoff (mm)
24001	770.2	161.1	19,233,552	25	147.4	27,329,098	35	123.7	26,733,810	35
24003	129.2	60.5	6,955,086	54	59.7	9,577,524	74	51.2	8,911,677	69
24004	242.1	100.1	10,754,941	44	82.9	12,615,482	52	58.1	9,902,498	41
24005	131.9				30.1	5,204,473	39	29.2	5,009,748	38
24008	806.0	166.7	19,078,823	24	158.0	28,088,204	35	134.8	28,840,791	36
24082	762.8				185.1	29,949,604	39	146.5	28,922,422	38

Table 7-I Peak flow, volume of flow and runoff for 3 events in the Maigue catchment.

7.8 Deel catchment

The following events were selected to represent severe flood events within the Deel catchment:

Events selected were:
- 11 – 12 and 21 – 22 October 1988;
- 29 - 30 December 1998;
- 31 July – 1 August 2008.

Throughout this study, emphasis has been placed on the selection of events which have occurred in the past 15 years primarily to increase the chance of data availability. However, hydrometric gauging station 24029 has significant periods of missing data in the past decade, therefore one event has been selected from 1988 to ensure the broadest picture of catchment response can be obtained.

The following gauging stations located across the catchment were selected to represent the catchment response:

- 24011 Deel at Deel Bridge;
- 24012 Deel at Grange Bridge;
- 24013 Deel at Rathkeale;
- 24029 Deel at Inchirourke More;
- 24030 Deel at Danganbeg.

7.8.1 Events of 11 – 12 and 21 – 22 October 1988

Instantaneous flow data was available at four gauging stations between 10th October 1988 (00:00 hours or first record of the day for digitised chart records) and 25th October 1988 (23:45 hours or last record of the day for digitised chart records). No data was available at station 24011. The data is summarised in Table 7-J.

Station No.	Peak flow (m^3/s)	Time of peak flow	Start time	End time	Volume of flow (m^3)	Duration (days, hours, minutes)
24030	49.9	11/10/1988 12:05	11/08/1988 00:23	14/10/1988 00:48	5,339,153	03:00:25
24011						
24012	139.2	11/10/1988 11:15	11/08/1988 00:30	14/10/1988 00:30	12,256,223	03:00:00
24013	129.0	12/10/88 01:15	11/10/1988 04:00	14/10/1988 03:00	16,558,548	02:23:00
24029	44.9	12/10/1988 04:04	11/10/1988 07:46	14/10/1988 03:56	7,680,509	02:20:10

Table 7-J Summary of timings and flows for the flood event 11 – 12 October 1988

Hydrographs (Figure 18a) covering the period 10th October to 24th October 1988 demonstrate the occurrence of four events, two of which 11th-12th and 21th-22th October were of a similar magnitude. The annual maxima peak flow for all gauges rests with either event, but for ease of comparison, Table 7-J and subsequent analyses will focus on the flows between 11th – 14th October.

A review of the timing of peak flows indicates that flow peaked first at station 24012, located mid-catchment, downstream of the River Arra confluence. The River Arra and its tributaries drain the steep area (Knockanimpaha) to the West of Newcastle West. The steep gradient combined with the short distance to travel makes this source area likely to be responsible for the initial peak response at 24012.

There is a significant lag, of approximately 14 hours, between the peak in flow at 24012 and 24013.

The volume of flow and hydrograph peak at 24029 looks undersized considering that this station should capture all the flows. This could indicate by-passing of flows or be the result of the approach taken to calculate the volume which is an adequate approach for data with a 15 minute time step but may underestimate flows over larger time steps (for example digitised chart data).

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 three locations, unfortunately an annual maxima series was not available for flows at 24029 (Ref. Table 7-K). The AEP estimates for gauges mid-catchment on the River Deel (24012 and 24013) denote a similar probability of occurrence. The higher probability of occurrence of 59% derived for station 24030 located within the upper reaches of the River Maigue supports the theory that runoff primarily originated from the River Arra and to the west of the catchment.

Peak flows at 24030 and 24029 seem to flatten out at flows of ~50 m^3/s and ~45 m^3/s respectively. This may be indicative of problems with the out-of-bank rating.

			Oct-88	
Station No.	Station Name	Watercourse	Peak flow (m^3/s)	Estimated Annual Exceedance Probability (%)
24030	Danganbeg	Deel	49.9	59
24011	Deel Br.	Deel		
24012	Grange Br.	Deel	139.2	8
24013	Rathkeale	Deel	129	12
24029	Inchirouke More	Deel	44.9	

Table 7-K Estimated Annual Exceedance Probabilities for peak flows in the Deel catchment during October 1988 event

7.8.2 Event of 29 - 30 December 1998

Instantaneous flow data was available at four gauging stations between 29th December 1998 (00:00 hours) and 31st December 1998 (23:45 hours) (Ref. Table 7-L). Flow data was not available for 24029 Deel at Inchirourke More.

Station No.	Peak flow (m^3/s)	Time of peak flow	Start time	End time	Volume of flow (m^3)	Duration (days, hours, minutes)
24030	49.4	30/12/1998 12:45	29/12/1998 18:30	31/12/1998 15:00	6,172,866	01:20:30
24011	89.1	29/12/1998 23:00	29/12/1998 07:15	31/12/1998 00:15	7,969,141	01:17:00
24012	125.8	29/12/1998 23:30	29/12/1998 06:15	31/12/1998 00:30	12,166,949	01:18:15
24013	137.8	30/12/1998 19:00	29/12/1998 15:00	31/12/1998 08:30	16,677,755	01:17:30
24029						

Table 7-L Summary of timings and flows for the flood event 29 – 30 December 1998

All four hydrographs (Figure 18b) point towards a double-peaked event, with the initial peak being the largest. Analysis has therefore focused on the first portion of the hydrograph ending at the inflection point for the second peak. However, this double peak does complicate the analysis and in particular the volume of flow due to the superposition of the two events on peak flows at 24013.

The lag in hydrographs between the locations is more evident on this shorter-duration plot. As observed in October 1988, flows at station 24012 peak early on but with the flow data from 24011 it is possible to observe a similar response just upstream. The response recorded in the upstream reaches at 24030 is much delayed by over 12 hours and may be more indicative of the location of rainfall within the catchment than of any general catchment response.

Annual exceedance probabilities presented in Table 7-M indicate that peak flows at 24011 and upstream at 24030 were a typical annual occurrence. However, peak flows downstream at 24012 and especially 24013 appear to be less frequent. From this we can deduce that peak flows at 24012 and 24013 were primarily the result of runoff from the catchment contributing to flows downstream of 24011. This includes the tributaries that drain the mountains bordering the west of the catchment, including the River Arra, River Daar and River Doally.

The flow record for 24030 again flattens out at peak flow ~50 m^3/s indicative of a problem with the rating as bank full flow transitions to out-of-bank flow.

			Dec-98	
Station No.	Station Name	Watercourse	Peak flow (m^3/s)	Estimated Annual Exceedance Probability (%)
24030	Danganbeg	Deel	49.4	62
24011	Deel Br.	Deel	89.1	50
24012	Grange Br.	Deel	125.8	19
24013	Rathkeale	Deel	137.8	9
24029	Inchirouke More	Deel		

Table 7-M Estimated annual exceedance probabilities for peak flows in the Deel catchment during the December 1998 event

7.8.3 Event of 31 July – 1 August 2008

Instantaneous flow data was available at three gauging stations between 31st July 2008 (00:00 hours) and 4th August 2008 (23:45 hours) (Ref. Table 7-N). Flow data was not available at stations 24029 and 24030.

Station No.	Peak flow (m^3/s)	Time of peak flow	Start time	End time	Volume of flow (m^3)	Duration (days, hours, minutes)
24030						
24011	118.7	01/08/2008 04:30	31/07/2008 20:15	02/08/2008 22:45	9,781,073	02:02:30
24012	153.6	01/08/2008 05:00	31/07/2008 19:45	03/08/2008 03:15	14,495,010	02:07:30
24013	131.0	01/08/2008 23:00	31/07/2008 22:30	04/08/2008 10:00	19,132,945	03:11:30
24029						

Table 7-N Summary of timings and flows for the flood event 31 July – 1 August 2008

Without flow data from the upper (24030) or lower (24029) reaches of the catchment, it is difficult to gain a broader picture of catchment response.

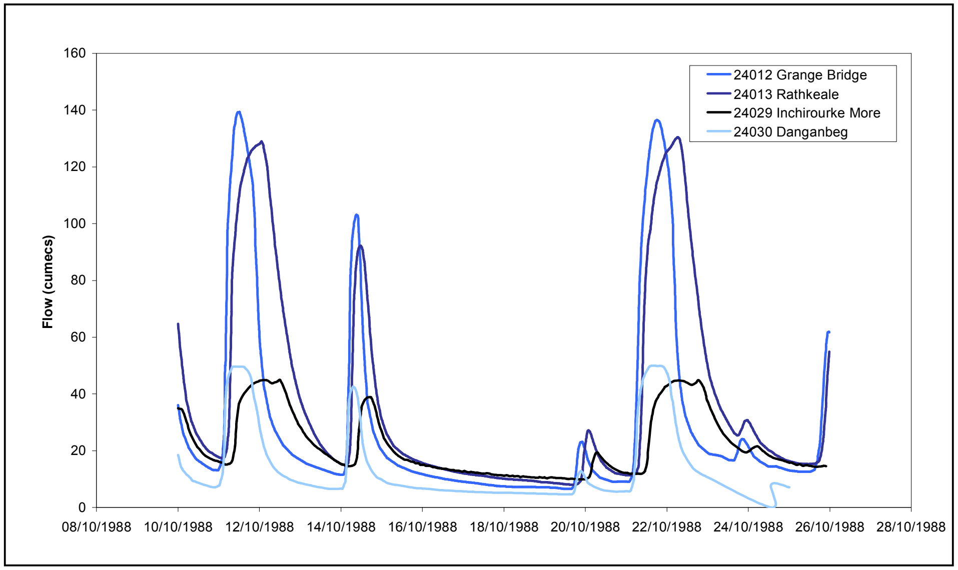
Hydrographs of this event (Figure 18 c) suggest a shorter lag between the rising limb of the hydrograph between 24012 and 24013 than that noted in the December 1998 event. This can be attributed to the high intensity short duration rainfall identified in Section 6.6.4.

A peak flow of 154 m^3/s was recorded for the event mid-catchment at station 24012, considerably greater than the peak flow recorded at 24011. By the time flows peaked downstream at 24013, the peak had apparently been reduced to 131 m^3/s due to attenuation storage. From this we can infer either that the most significant source of runoff contributing flows to the River Maigue was from the portion of the catchment draining into the River Maigue between gauges 24011 and 24012 or that gauge 24013 is underestimating peak flows or that gauge 24012 may be overestimating peak flows.

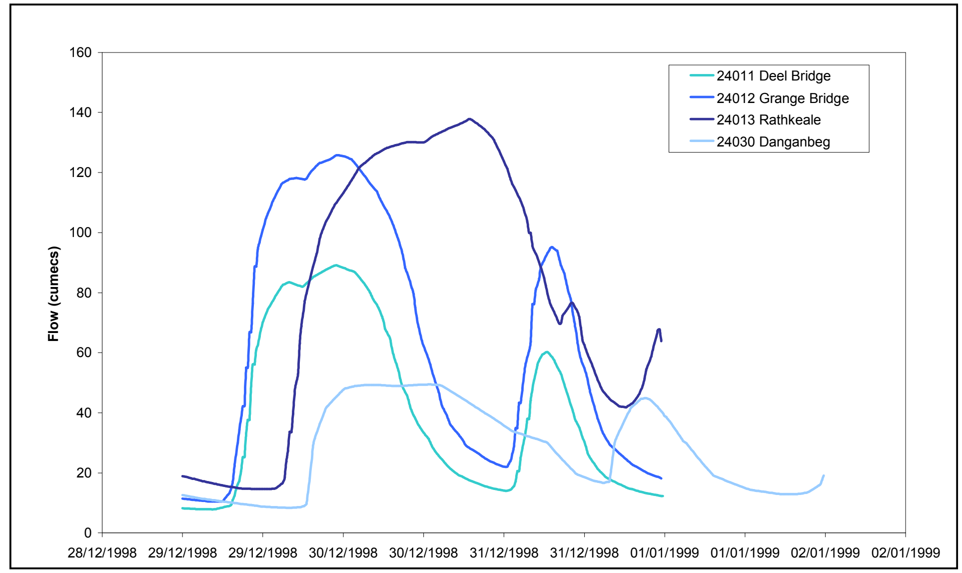
The annual exceedance probability estimated for the peak flow at 24012 was 3% indicating that this was an infrequent event (Table 7-O). AEP estimates for peak flows recorded at the gauging stations upstream (24011) and downstream (24013) were higher at 13% and 11% and support the observation that this was a relatively isolated event on a catchment-scale.

			Aug-08	
Station No.	Station Name	Watercourse	Peak flow (m^3/s)	Estimated Annual Exceedance Probability (%)
24030	Danganbeg	Deel		
24011	Deel Br.	Deel	118.7	13
24012	Grange Br.	Deel	153.6	3
24013	Rathkeale	Deel	131	11
24029	Inchirouke More	Deel		

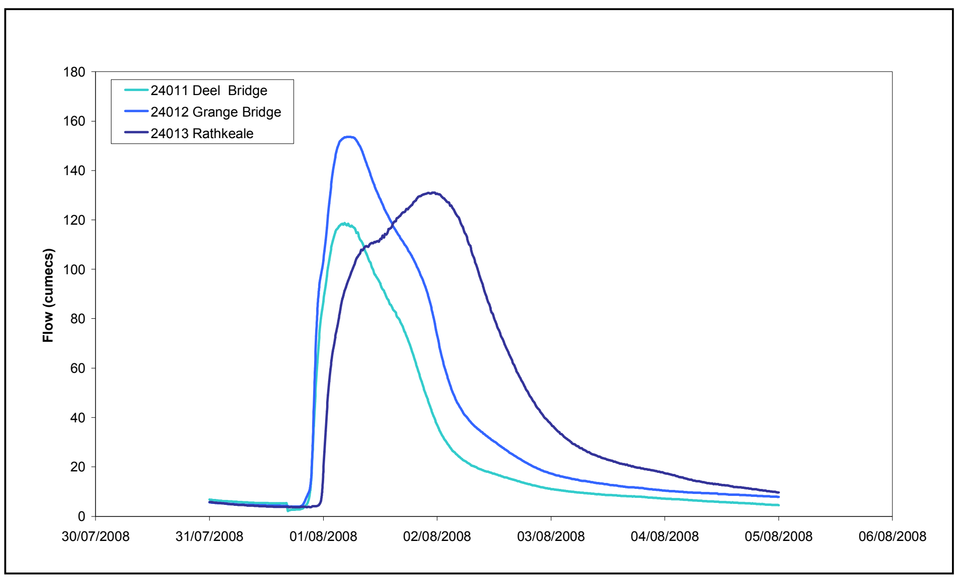
Table 7-O Estimated annual exceedance probabilities for peak flows in the Deel catchment during the August 2008 event



a) Events of October 1988



b) Event of 29 – 30 December 1998



c) Event of 31 July – 1 August 2008

Figure 18 Hydrographs for gauging station in the Deel catchment for
a) October 1988
b) 29–30 December 1998 and
c) 31 July to 1 August 2008

7.8.4 Deel catchment discussion

The hydrographs for all three events reflect a steep rising limb at all locations but, as to be expected, the recession is more prolonged in the lower reaches of the Deel catchment at gauging station 24029.

All three events highlight the significance of runoff contributions on peak flow from the area draining steep topography at the western boundary of the Deel catchment. This area drains into tributaries of the River Arra and eventually the River Deel between gauges 24011 and 24012. Rapid runoff from this area is thought to be the origin of the highest peak flow recorded from the three events, a flow of 153.6 m^3/s recorded during August 2008 on the River Deel at Grange Bridge (24012). Following the 2008 event, flow gauges have been installed on the River Arra and further analysis of flows at this location is recommended.

The events analysed indicate an apparent attenuation in the peak flows down the catchment between 24012, 24013 and 24029. This could be attributed to an underestimation of flows at 24013, an overestimation of flows at 24012 or some form of storage effect between the two gauges.

Further analysis of the catchment response in terms of the peak flow, volume of flow and runoff (Table 7-P) reveals that runoff for all three events is greatest at 24013 within the lower reaches of the Deel catchment. Based on the runoff value from one event, it appears that runoff is lowest at 24029, at the base of the catchment and just upstream of where the River Deel becomes tidal.

Station No.	Catchment area (km²)	Oct-88			Dec-98			Aug-08		
		Peak flow	Volume of flow (m³)	Runoff (mm)	Peak flow	Volume of flow (m³)	Runoff (mm)	Peak flow	Volume of flow (m³)	Runoff (mm)
24030	258.9	49.9	5,339,153	21	49.4	6,172,866	24			
24011	281.2				89.1	7,969,141	28	118.7	9,781,073	35
24012	366.3	139.2	12,256,223	33	125.8	12,166,949	33	254.0	14,495,010	40
24013	438.8	130.4	16,558,548	38	137.8	16,677,755	38	131.0	19,132,945	44
24029	486.1	44.9	7,680,509	16						

Table 7-P Peak flow, volume of flow and runoff for 3 events in the Deel catchment

7.9 Other catchments

This sub-catchment is a collection of smaller catchments located along the north of the unit of management and that discharge directly into the Shannon Estuary. No instantaneous flow data was available for any gauging stations located within this sub-catchment.

7.10 Conclusions

A review of daily mean flow data highlighted the possibility of long-terms trends in several flow and/or level series. Trends such as this in the flow series can reduce certainty in the index flood, QMED. Of those stations highlighted with a trend in the flow series the majority of stations will be revisited during the next phase through a high flows rating review, enabling further investigation and improvement in the confidence of QMED. Only gauging station 24082 will not be revisited.

To assist in the analysis of fluvial data, gauging stations were grouped according to their sub-catchment location; in either the River Maigue or River Deel. Three events were selected for each sub-catchment with instantaneous data.

Hydrographs produced for the Maigue catchment indicate a steep rising limb and an initial steep recession which appears to flatten out, indicative of a fast responding catchment. Another feature worth noting is the relationship between the peak flows at 24082, 24001 and 24008. The hydrographs indicate a consistent reduction in the peak flow and volume of flow between gauges 24082 and 24001, the consistency in the peak and volume of flood flows, casts some doubt on the record at 24082 but may also be the result of storage or flows by-passing the channel at 24001 and 24008.

Runoff within the Maigue catchment is significantly greater at 24003 on the Loobagh tributary. This correlates with the steepest topography of the Maigue catchment, where the Loobagh drains the Ballyhoura Mountains.

Annual exceedance probabilities estimated for each event on the Maigue suggested a range of values across the catchment. The lowest AEP estimated was 3% at two separate locations for two events; the River Maigue at Bruree (24004) in December 1998 and Athlacca on the River Morningstar during November 2000. AEP estimates for the three events analysed on the River Maigue, varied between 3% and 53%.

Hydrographs plotted for flood events on in the River Deel catchment reflect a steep rising limb and a prolonged recession in the lower reaches of the Deel catchment at gauging station 24029. Flattening of the peak at 24030 indicates some issue with the rating as flows transition to out-of-bank.

Significant runoff contributions to peak flows appear to originate from the River Arra and its tributaries draining the catchment at the western boundary of the Deel catchment.

A range of annual exceedance probabilities were estimated for the events and gauges analysed within the River Deel catchment. The lowest AEP estimated was 3% on the River Deel at Grange Bridge during the August 2008 event. Estimates for that event ranged between 3% and 13%, confirming it was a fairly infrequent event. AEP estimates for the three events analysed on the River Deel, varied between 3% and 62%.

8 Historical Flood Risk Review

8.1 Introduction

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

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

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

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

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

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

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

The OPW recognises that the website is not a comprehensive catalogue of all past flood events and may not cover all flood events. The information included depends on the available records of the source organisation and is uploaded at their discretion. Therefore, the absence of any records of past flood events in any given location does not allow us to conclude that flooding has never occurred in that area.

8.2 Records of historical flood risk

The list of the Communities at Risk (CARs) and Individual Risk Receptors (IRRs) in this unit of management is shown in Tables 2-A and 2-B. Twelve CARs and one IRR have been identified in this area. Six of the CARs are in the Maigue catchment, 4 in the Deel catchment and the remaining two are found to the west of these two main catchments.

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

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

8.3 Maigue catchment

The historical floods known to have occurred in the CARs within the Maigue catchment and the corresponding flows estimated at a representative gauging station are summarised below.

8.3.1 Records of historical flood risk

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

The AEP of flood events that occurred in Adare have been calculated based on the gauged water level record at Adare Manor gauging station (24009). The gauging station at Croom (24001) was used to calculate the AEP of floods that occurred at Croom.

Event	Peak Flow (m^3/s)	Peak Level (mOD -Malin)	Estimated Annual Exceedance Probability (AEP) (%)	Flood Extents & Damages	Ranking
CAR 03 Adare					
01/02 Feb 2002	-	6.57 (Adare Manor)	80	Land & road near Adare Station flooded.	4
07 Jan 1999	-	7.14 (Adare Manor)	12	Station Road area affected by flooding.	2
26 Feb 1996	-	6.89 (Adare Quay)	43	N21 road flooded.	4

Event	Peak Flow (m^3/s)	Peak Level (mOD -Malin)	Estimated Annual Exceedance Probability (AEP) (%)	Flood Extents & Damages	Ranking
Jan 1995		6.81 (Adare Quay)	32	Land & road flooded.	3
01 Dec 1973	-	7.40 (Adare Manor)	4	No flooding details available.	1
11 Aug 1946	-	-		Agricultural land & roads flooded.	
CAR 20 Charleville					
11 Aug 1946	-	-	-	Houses & agricultural land flooded.	
CAR 22 Clarina					
Sep 1992	-		?	Fields flooded. The flood depth estimated to be 0.30m (1ft)	
CAR 24 Croom					
05/06 Aug 1986	190.86 (Croom)	19.83 (Croom)	6	Croom-Bruff Road (C1/31/4/2) & north of the road (C1/31/4) flooded.	
Dec 1983	192.46 (Croom)	19.85 (Croom)	6	No flooding details available.	
Dec 1973	133.12 (Croom)	20.31 (Croom)	41	No flooding details available.	
CAR 32 Kildimo New					
-	-	-	-	No flooding details available.	-
CAR 34 Kilmallock					
Aug 1946	-	-	-	Roads & one house flooded.	

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

Table 8-B Summary of historical flood events in CARs within the Maigue catchment

8.3.2 Discussion

The major cause of flood in the CARs of the Maigue catchment appeared to be fluvial and high tide. The historical flooding event record in this catchment goes back to 1946. The latest recorded flood was February 2002 which mainly affected areas around Adare.

Recurrence

A local news paper edited on 9 January 1999 indicated a recurrent flooding problem in Croom, during the 1990s. There is no information on whether any improvements have been made to alleviate flooding problems in the area.

February 2002

The February 2002 event was a combined fluvial and tidal event which affected **Adare** only.

January 1999

The Station Road area of **Adare** was reported to have been flooded on 7 January 1999. Minutes of a meeting that took place on 3 June 2005 indicated that this area is prone to flooding caused by surface runoff and tide. Low lying areas around Station Road are protected by embankments. The meeting minutes also noted that a new sewer would be laid in 2006 or 2007 to alleviate the problem. However, there is no information to confirm that this sewer has been laid.

February 1996

On 26 February 2011 the N21 road around **Adare** was flooded.

January 1995

Adare and Croom were flooded during the January 1995 event. It was reported that high tide combined with low barometric pressure caused this flood.

September 1992

On 15 September 1992 an area called Corcamore to the south west of **Clarina**, close to the mouth of the river Maigue, was flooded.

August 1986

Flooding affecting various part of the Limerick County occurred on 5 and 6 August 1986. One of those areas was **Croom**. This flooding event coincided with the storm-hurricane Charley, a major meteorological event that occurred in Ireland in August 1986.

December 1973

The data obtained from the "floodmaps" website indicated that **Adare** and **Croom** areas were flooded on 1 December 1973. A major rainfall that lasted for 5 days from 27 November to 1 December 1973 caused major flood events in the south and south west of Ireland. This flood event was identified as a Major Weather Event by Met Éireann on their website www.met.ie.

According to a record at Croom gauging station (24001) the flow on 1 December 1973 was 133m^3/s with a peak flood level of 20.31mOD. The flood event corresponds with the annual maximum flow for that year. Its AEP was estimated to be 41% (approximately a 1 in 2 year event). However, the AEP estimated based on the water level at gauging station at Adare Manor (24009) was 4% (Equivalent to a 1 in 20 year event).

August 1946

On 11 August 1946 major floods occurred in **Adare, Charleville, Croom and Kilmallock**.

8.4 Deel catchment

The historical flood events known to have occurred in the CARs within the Deel catchment and the corresponding flows as estimated at a representative gauging station are summarised below.

8.4.1 Records of historical flood risk

The nearest gauging station to Askeaton is Inchirouke More (24029), but that does not have an associated annual maximum series. The gauging station 24015 at Dromcolliher also does not have an associated annual maximum series. Station Danganbeg (24030) is located about 10km downstream of Dromcolliher and about 4.5km upstream of Newcastle West on the River Deel. The main cause of flooding in Dromcolliher village is the limited capacity of the two streams flowing through the village. Therefore the flood event at Dromcolliher cannot be analysed based on flow data from a gauging station on the River Deel.

Similarly there is no gauging station on the River Arra, a tributary of the river Deel. The river Arra passes through Newcastle West and is a source of flooding there.

Absence of a representative gauging station for each CAR means the AEP of historical flood events that occurred in each of the four CARs in the Deel catchment has not been estimated. The table below summarises the historical flood events that are known to have occurred in the Deel catchment.

Event	Peak Flow (m^3/s)	Peak Level (mAOD- Malin)	Estimated Annual Exceedance Probability (AEP) (%)	Flood Extents & Damages	Ranking
CAR 04 Askeaton					
Recurring	-	-	50%	Deel over-flowed and flooded factory car park and L1236 Road. No premises affected. Frequency of the event indicated to be 1:2yr	-
CAR 25 Dromcolliher					
26 Aug 1997				Houses & roads flooded.	
12 Jul 1997				Houses & roads affected.	
30 Jun 1995				Houses & church flooded.	
22 Feb 1995				Roads flooded.	
25 Jan 1995				Roads flooded.	
17 Jan 1995				Roads flooded.	
30 Dec 1994				Roads flooded.	
27 Dec 1994				Roads flooded.	
14 Jan 1994				Roads flooded.	
15 Jan 1994				Roads flooded.	
08 Dec 1993				Roads flooded.	
09 Sep 1993				Roads flooded.	
17 Jan 1993				Roads flooded.	

Event	Peak Flow (m^3/s)	Peak Level (mAOD- Malin)	Estimated Annual Exceedance Probability (AEP) (%)	Flood Extents & Damages	Ranking
12 Nov 1991				Roads flooded.	
06 Feb 1990				Roads flooded.	
28 Dec 1990				Roads flooded.	
11 Jan 1989				Roads flooded.	
21 Oct 1988				Roads flooded.	
01 Feb 1988				Houses at Pike St & roads flooded.	
22 Jan 1988				Roads flooded.	
25 Aug 1986				Roads flooded.	
06 Aug 1986				Houses, church & roads flooded.	
28 Jul 1986				Roads flooded.	
22 Jan 1986				Roads flooded.	
16 Jan 1984				House at Pike St flooded	
CAR 44 Newcastle West					
Aug 2008				143 residential, 87 commercial properties & roads flooded.	
CAR 50 Rathkeale					
Jan 1969	-	-	-	No flooding details available.	-
23-24 Dec 1968	-	-	-	No flooding details available.	-
11-13 Dec 1968	-	-	-	No flooding details available.	-

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

Table 8-C Summary of historical flood events in CARs within the Deel catchment.

8.4.2 Discussion

Major events are known to have occurred in the Deel catchment that affected **Askeaton, Dromcolliher, Newcastle West or Rathkeale** in the winter of 1968, August 1997 and August 2008. The 1968 winter flood affected **Rathkeale** area. In August 1997 **Dromcolliher** was flooded. Heavy rainfall and flood affected many parts of Ireland in the summer of 2008. One of the areas that is known to have been affected by this weather condition in the Deel catchment was **Newcastle West**.

Below is a brief summary of major historical flood events that are known to have occurred in the Deel Catchment.

August 2008

On 1 August 2008 persistent rainfall in the previous days saturated the Arra catchment and caused a major flood in **Newcastle West**. The village is situated on the downstream reach of the River Arra. There is no gauging station on the River Arra. Therefore the flood flow during this flood event is not known. However, the annual exceedance probability (AEP) of the rainfall is estimated to be 0.15% (1 to 650 year) according to the "Newcastle West Flood Severity and Impact Report 1 August 2008" report prepared by JBA following this event.

In general the 2008 summer has been identified as a major meteorological event due to heavy rain and subsequent flooding in Ireland. However, there is no report that indicates that there was flooding in other CARs in the Deel catchment.

August 1997

On 26 and 27 August 1997 heavy rainfall caused flooding in different parts of **Dromcolliher** village. The village is located at the bottom of a mountain with two streams (Ahavarraga and the stream from Carroward) with steep catchments draining through the village. These streams are known to have caused flooding in different parts of the village. The AEP of the 1997 flood event was estimated to be 2% (1 in 50 years) , which is reported to exceed the capacity of the existing flood protection works.

An interim report compiled by Gibson O'Connor in September 1997 describes the impact of the 1997 flood on the village. The report also highlighted historical flood events prior to 1997. The major cause of flooding in the village appears to be inadequate hydraulic capacity of the streams which in most cases is exacerbated by the backwater effect of the downstream river. This is confirmed by the feasibility report prepared by ESB International carried out on behalf of Limerick County Council. The report also lists the historical flood events that occurred in **Dromcolliher** prior to 1997. These events are replicated in Table 8-C above.

The feasibility report investigated options for alleviating the flooding problem by enhancing the flood protection system in the village to cope with AEP of 1% (1 in 100 years) flow. However, no information has been found confirming that the preferred option has been implemented.

Winter 1968

The winter 1968 event resulted from prolonged heavy rain. There was heavy rain from 11 to 13 December (56mm), 23rd to 24th December (62mm) and 9th to 12th January (43mm) causing flooding in the Deel valley upstream of **Rathkeale**, at Deel Bridge and on the latter two occasions, at **Balliniska – Bunoke**. The duration of flooding on all occasions was about 24 hours.

8.5 Other catchments

The two CARs identified in UoM 24 outside the Maigue or Deel catchments, Ballylongford and Foynes are both found to the west side of the two main catchments. The historical flood records that are known to have occurred in these two CARs are summarised in the following table.

8.5.1 Records of historical flood risk

Event	Peak Flow (m^3/s)	Peak Level (mAOD - Malin)	Estimated Annual Exceedance Probability (AEP) (%)	Flood Extents & Damages	Source
CAR 09 Ballylongford					
01 Feb 2002	-	-	-	Kerry STW, street & some 10 houses flooded.	Tidal
21 Aug 2001	-	-	-	Carrig Island LIS01/769 flooded.	Tidal
07 Dec 2001	-	-	-	Land Commission Embankment LIS01/1584 flooded.	Tidal
08 Mar 2002	-	-	-	Land Commission Embankment LIS02/1993 flooded.	Tidal
08 Apr 2008	-	-	-	Land Commission Embankment LIS02/2104 flooded.	Tidal
15 Jan 2004	-	-	-	Gortnacooka Bridge area flooded.	Tidal
06 Jan 2002	-	-	-	At least 12 houses at Bridge St, R551, R522, LA water treatment plant flooded.	Tidal & Rainfall Runoff
22 Oct 1961	-	-	-	Streets at Ballylongford flooded.	Tidal
28 Oct 1927	-	-	-	A number of houses & streets flooded.	Tidal
CAR 29 Foynes					
01 Feb 2002	-	6.28	-	Domestic & commercial properties, main street & N69 flooded.	-
23 Jan 2002	-	-		N69 & a number of premises flooded.	-
08 Jan 2005	-	-		At least 4 residential & 2 commercial properties flooded.	-
23 Feb 1995	-	-		N69 flooded for days.	-
30 January 1995	-	-	-	Flooding in the Railway Road area.	-

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

Table 8-D Summary of historical flood events in Ballylongford and Foynes

8.5.2 Discussion

February 2002

Both **Ballylongford** and **Foynes** are within the Shannon tidal regime. They were both affected by the February 2002 event, reportedly caused by high tides, low pressure and strong south westerly winds.

In **Ballylongford** the high tide/surge level during this event reached 6.3m O.D which was estimated to have an AEP of 2% (1 in 50 year event). Kerry County Council Sewage Treatment Works (STW) was submerged below the tide level causing a backflow in the sewage pipes which backed up the toilets of some houses. The main street drainage system around the STW was also backed up and caused flooding as it is connected to the sewerage system by two gullies.

In **Foynes** a combination of high spring tide and high runoff in the Shannon, resulting from heavy rainfall over a prolonged period, increased the high tide level significantly on 1 February 2002. The tide overflowed the quay wall in the harbour area, flowed across the railway line and into the rear of a number of properties along the Main Street causing severe flooding to properties. The high tide recorded on this date was 6.28m O.D.

Other minor flooding was documented in **Ballylongford** e.g. October 1927, October 1961, August 2001, January 2002, March 2002, April 2002, January 2004, December 2007.

Other flood events in **Foynes** occurred in January 1995, February 1995, January 2002 and January 2005. These floods were caused by the rainfall runoff combined with inadequate culvert capacity. There is a small stream which runs from Cogrig along the side of the N69 road near Durnish and travels along the front gardens of a number of houses before discharging into the harbour area. The stream is culverted through the main street in Foynes. This flooding caused partial or complete blockage of the N69 road and flooding of the front gardens of the houses along the main street.

8.6 IRR 1 Tarbert Power Station

There is no record of flooding at the Tarbert Power Station and its immediate surroundings. However, minutes of a meeting organised by OPW which aimed at collecting flood data on 1 December 2005 suggested that the N67 road, which connects Tarbert village to the car ferry, floods at least twice a year.

9 Proposed Methodologies for Future Work

9.1 Introduction

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

9.2 Hydrometric gauging station rating reviews

The OPW have identified 11 stations (ref. Table 3-G), located within the Shannon Estuary South, for which rating reviews are required. For each of these gauging stations an assessment of the quality and limitations of the flood flow data will be made and where necessary the rating adjusted to reduce the uncertainty associated with it. The ratings will be extrapolated to beyond the highest recorded levels and if possible to the highest design flow (0.1% AEP). The methods used are likely to vary between sites depending on the availability of gaugings, survey data and local controls. Section 9.2.2 describes the techniques to be used. For all gauging stations for which a rating review is required, a 1D hydraulic model will be developed. Where the floodplain is too complex to be characterised in 1D a 2D representation of the floodplain will be included in the model based on 5m SAR data of LiDAR data as available. The modelled reach will extend sufficiently downstream such that any backwater effects within the channel are accounted for, and upstream to take account of approach conditions that could influence the rating.

9.2.1 Data required

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

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

9.2.2 Methodology

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

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

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

Extension of ratings
For the 11 sites identified in the Brief, hydraulic modelling will be undertaken to extrapolate the stage discharge relationship to approximately 3 times the Qmed. Preliminary investigations of design flows suggest that the extended rating will include and exceed the 0.1% AEP design peak flow. At each target gauging station, extended cross sectional data will be input to the hydraulic modelling software to develop a representative hydraulic model of the reach and floodplain. The hydraulic model will be calibrated against higher flow check gaugings and then used to develop one or more high flow rating equations.

9.3 Design events

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

9.3.1 Data required

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

- Gauging station surveys for the rating reviews (from survey contractors);
- Hydraulic models of the gauging stations for rating review (11 gauges in UoM24) (by Jacobs);
- Rating equations and check gaugings for all gauges requiring rating review that are still outstanding (gauging stations 24015, 24029 and 24030) (from OPW);
- High flow rating reviews (by Jacobs);
- Agreement on the way forward with each of the catchment area boundary anomalies highlighted in this report (Jacobs/OPW);
- Hydrological Estimation Point definitions (by Jacobs).

9.3.2 Methodology

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

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

The method to be employed will still enable testing of the effects of the hydrograph shape and peak to hydrological parameters like landuse change (e.g. urbanisation) or rainfall patterns, if this is required in the future. This can be done by creating a rainfall runoff model for a specific or typical catchment using the approach laid out in Work Package 3.5 (IBIDEM). Such a rainfall runoff model can be fitted to the synthetic hydrograph shape produced by FSU. The sensitivity of the flood hydrograph shape to changes in catchment parameters or rainfall can then be tested by adjusting these within the method used to simulate the runoff.

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

The data from the gauging stations detailed in Table 9 of the Stage II Tender Brief will be subjected to high flow rating reviews and on the basis of the review deemed suitable or not for Qmed estimation, derivation of a flood frequency growth curve and dimensionless hydrograph. Cognisance will be given to the gauges used in the FSU to develop the Qmed equation (10 in UoM 24, 6 of which will also be subject to rating review in this project) together with others assessed as being of sufficient quality and others which become so if annual maximum flow series are reworked following the rating review (potentially 11 in UoM 24, 6 which were employed in Qmed estimation for the FSU).

The reaches of watercourse to be modelled in the two main catchments in UoM 24, the Deel and Maigue, are both well served by flow gauges which ultimately, following the rating review, will be able to supply useful data to estimate Qmed and the dimensionless hydrograph shapes. The annual maximum flow series for the gauges are detailed on the summary sheets in Appendix H. Also detailed on these summary sheets are the preliminary estimates of Qmed and the dimensionless hydrographs for the highest recorded flows, prior to the rating review.

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

Qmed

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

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

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

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

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

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

In UoM 24 the Gumbel (EV1) distribution fitted to the annual maximum series suggest growth factors to 1% AEP of 1.5 to 1.9 (Q100/Q2) for the Deel catchment and 1.6 to 2.3 for the Maigue catchment compared to that implied from the Flood Studies Report (FSR) of 2.06 (Q100/Q2). A growth factor of approximately 2 is very similar to that for the FSU rainfall estimates shown in Appendix D.
Two main approaches are considered to estimate suitable growth curves:

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

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

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

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

Both methods will be trialled for the gauges in the first sub-catchment area to be considered in UoM 24. Based on the trial a decision will then be made as to which option to apply on the project in the remaining sub-catchment areas.

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

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

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

Jacobs is concerned that the approach outlined in FSU for defining a typical hydrograph shape has a bias to small and less relevant storm events, as about half of the calibration events are smaller than the 2-year design event. OPW has also indicated that they identified issues with using the parametric approach of Work Package 3.1 for ungauged catchments. Given the uncertainties involved in the changing hydrograph shape throughout the catchment, a more subjective method of defining hydrograph shape is considered more appropriate.

Where sufficient gauged data exists, e.g. on the rivers Deel and Maigue, a dimensionless hydrograph approach will be employed on the basis that it is better to use gauged data than synthetic data. A dimensionless hydrograph shape will be derived for each gauge using the more extreme gauged flood data. The typical hydrograph shape will broadly be the mean hydrograph shape from a number (usually three) of the largest floods recorded at the site (similar to those shown on the gauging station summary sheets in Appendix H). This method has the benefit that it focuses on the largest observed events at a gauging station only, and is therefore not biased towards smaller, less relevant events, which is the case for the method laid out in Work Package 3.1.

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

9.3.3 Output

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

9.3.4 Application to hydraulic models

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

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

We therefore propose an alternative method to preserve the flood frequency along the main watercourse to match the design hydrographs estimated at each HEP. This alternative method is described below and illustrated in Figure 19.

The reaches to be hydraulically modelled will be considered between tributary junctions or, where the space between these results in a difference in catchment area of more than 10%, at intermediate hydrological model nodes. These locations will be coincident with HEPs. Flood hydrograph estimates for the main watercourse immediately upstream of the tributary (Hydrograph B in Figure 19) and upstream of the next tributary/model node (Hydrograph D in Figure 19) will be established as described above (for Qmed, growth curve and hydrograph shape). The difference between the two hydrograph estimates, derived by subtracting the upstream flow estimate from the downstream flow estimate for each hydrograph ordinate, will form the inflow from the tributary/location (i.e. Hydrograph D minus Hydrograph B gives Hydrograph E in Figure 19). The hydraulic model is run with the tributary inflow (Hydrograph E) and inflow at the upstream node (Hydrograph A). The resulting hydrograph from the model (Hydrograph D') is then compared to the hydrograph originally estimated at the downstream nodel (Hydrograph D in Figure 19). The timing of the tributary inflow hydrograph (Hydrograph E in Figure 19) has to be adjusted by trial and error in running the hydraulic model to account for the travel time in the modelled reach. The target is that the peak flow differences are less than approximately 5% (Hydrograph D' compared to Hydrograph D) and that the timing is representative. Additional nodes can be inserted and lateral inflows added (with flows derived using the same method as described here for tributary inflows) to reduce the error between nodes where appropriate. In this manner the design hydrograph peak and shape are preserved within a reasonable degree of accuracy throughout the model. The system is then repeated for any other tributaries requiring inflows to be modelled.

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

Typical hydrological unit diagram

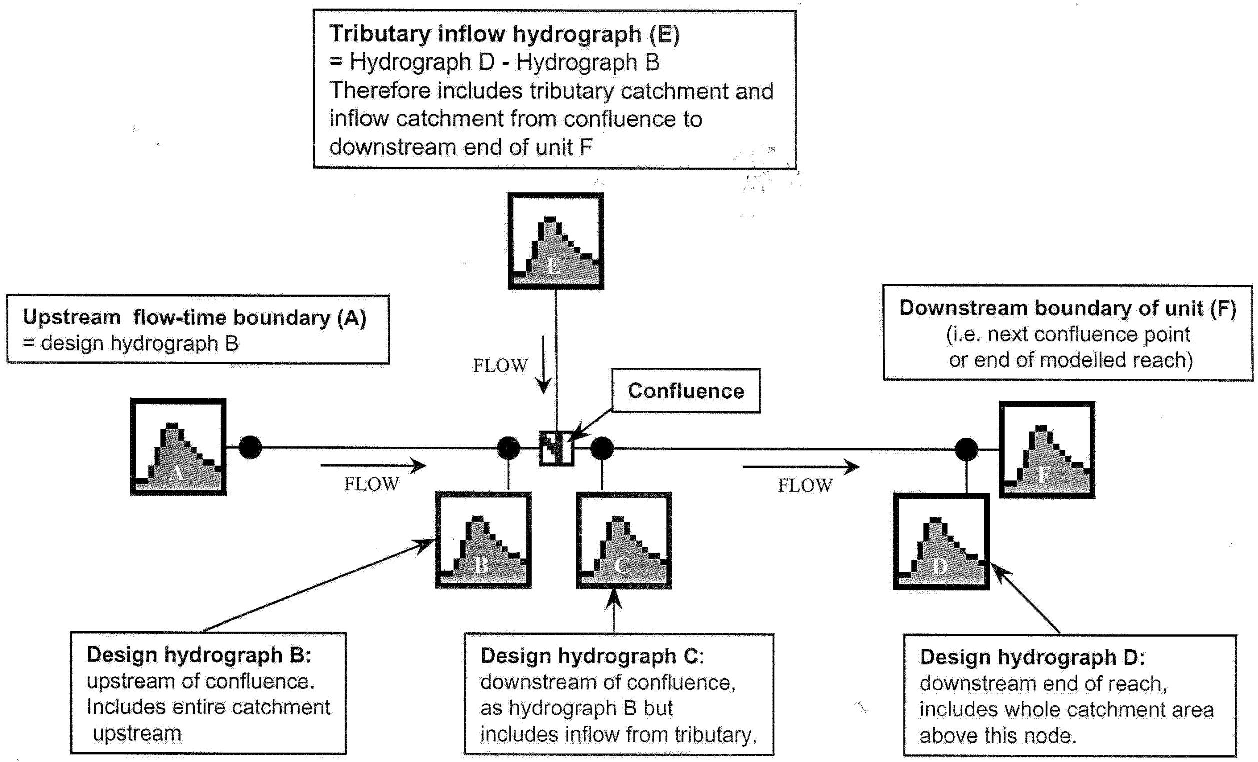


Figure 19 Typical model hydrograph method

9.4 Joint probability

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

Joint Probability is a complex issue that would benefit from the pooling of ideas and concepts from all members of the National Technical Coordination Group (NTCG). We therefore suggest that the most appropriate methodology is discussed and agreed through the NTCG forum. This will ensure that a consistent approach is adopted, making best use of data available along the Irish west coast. There remains a need to resolve the combinations of flows and sea levels to be run. However, the following broad principles will apply:

- Consideration of dependence based on review of the coincidence or otherwise of extreme tide and high fluvial events for which concurrent datasets are readily available.
- A broad consideration of catchment size as this is likely to influence the degree of dependence.
- The availability of coastal data on which to base an assessment of joint probability and the influence this may have on accuracy and method adopted (it is understood that less data may be available for the Irish west coast compared with other parts of the coastline).

9.5 Hydraulic model calibration

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

The limited amount of short duration rainfall data available in the region indicates that rainfall-runoff modelling will not provide the required confidence in the temporal distribution of rainfall and hence flows. There are no sub-daily rainfall gauges within Unit of Management 24. We shall therefore make best use of any reliable observed data to calibrate the hydraulic models, where this exists.

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

9.6 Coastal flood modelling

9.6.1 Tide and surge

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

Tidal curves will be generated using mean spring tidal cycles obtained at Carrigaholt, Foynes and Limerick from the Shannon Foynes Port Company and the Admiralty Report. To develop the extreme tide/surge hydrographs, a surge event of 30 hrs will be assumed. Then ICPSS extreme peak levels together with the assumed surge event profile and the mean spring tide levels will be used to create the tide/surge hydrographs associated with each annual probability event. This process is illustrated on Figure 20. The Mean High Water Springs (MHWS) tide levels will be chosen according to the geographic position of the sites under consideration relatively to the three tidal record locations mentioned above.

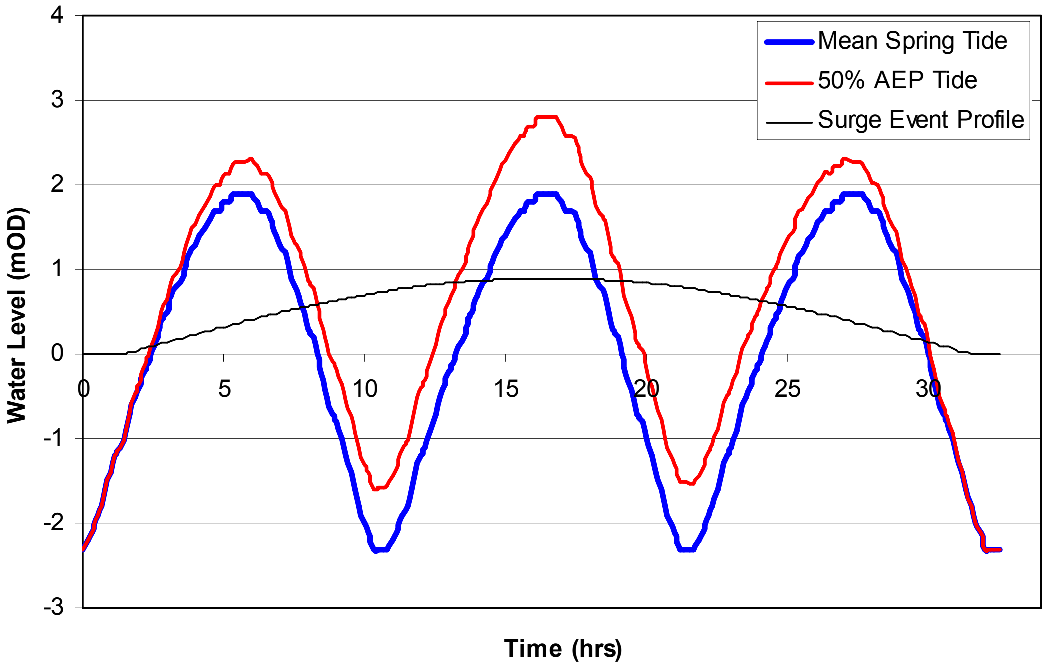


Figure 20 Tide/Surge Hydrograph

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

9.6.2 Wave overtopping

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

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

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

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

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

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

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

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

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

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

As illustrated in Figure 21 below, a wave overtopping discharge hydrograph will be generated assuming a 30-hour storm surge duration. Overtopping will occur when the selected wave height superimposed on the tide level exceeds the average elevation of the defence. During these overtopping periods, half of the mean overtopping discharge calculated above will be applied. This is because the wave height is at a maximum at the peak of the tide, but reduces to zero either side of the peak. On average, half the overtopping flow computed at peak tide can be assumed to flow over the defence, between the time of initial overtopping (some time prior to the peak tide) to the time overtopping ceases (some time after the peak tide). The time over which overtopping occurs is dependent on the tidal level and wave height selected.

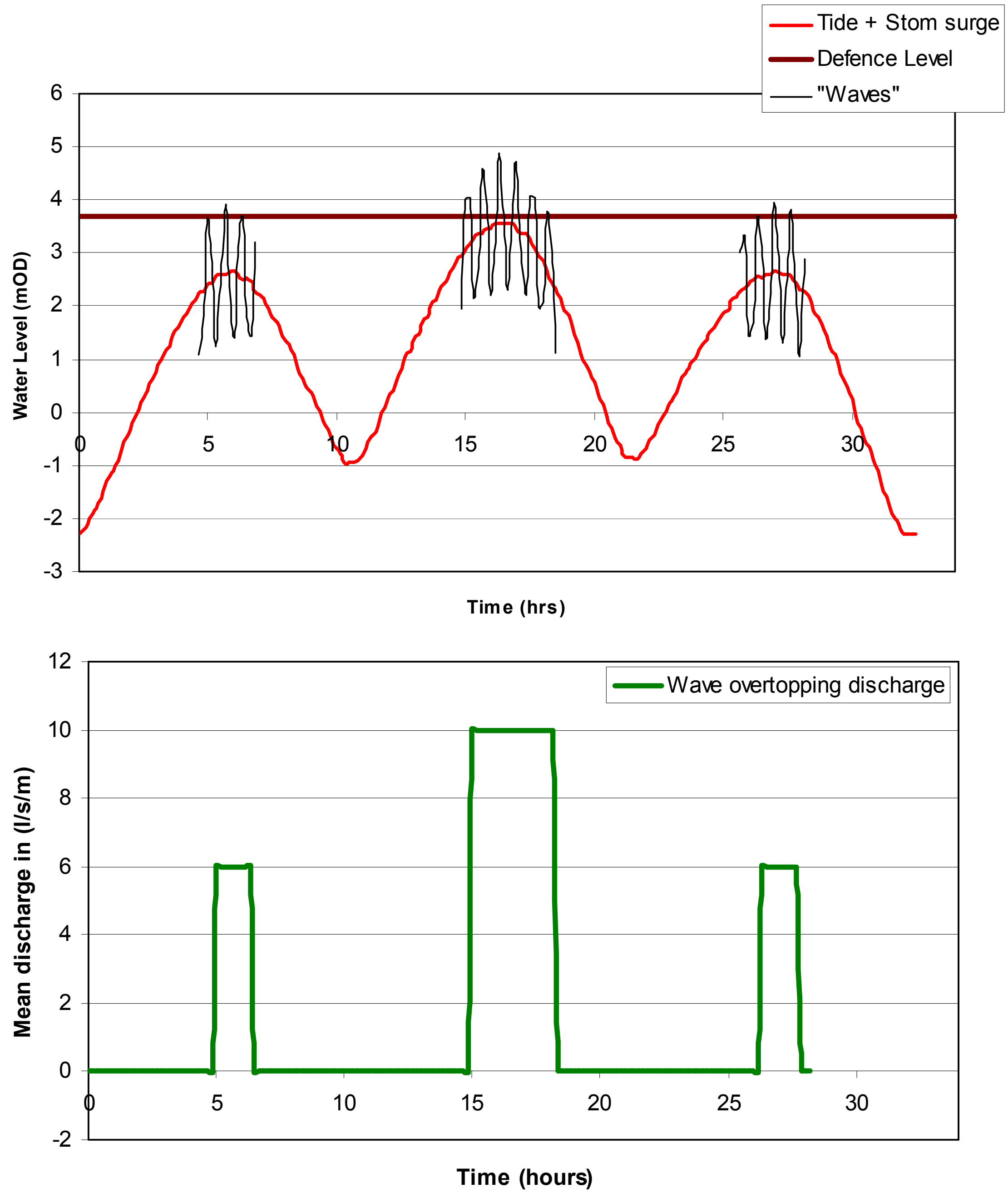


Figure 21 (a and b) Wave overtopping hydrograph

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

10 Constraints, Data Problems and Other Issues

Several daily and instantaneous flow and level series for the key hydrometric stations identified in Section 3.2 have not been received (Table 10-A). Confirmation of whether the relevant data series exists is requested in the first instance.

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

Station number	Data holder	Daily mean flows outstanding	Instantaneous flow data outstanding	Staff gauge readings outstanding	Check gaugings outstanding	Rating equations outstanding
24006	OPW		Yes			
24009	OPW		Yes			
24015	EPA	Yes	Yes		Yes	Yes
24029	EPA				Yes	Yes
24030	EPA				Yes	Yes
24031	EPA			Yes		
24033	EPA		Yes			
24036	EPA			Yes		
24067	OPW		Yes			
24081	OPW			Yes		
24084	OPW			Yes		

Table 10-A Outstanding hydrometric data for Shannon Estuary South (UoM 24)

In the process of reviewing the available daily mean flow and level series, trends in the data series were identified at eight out of the twelve stations (see Section 7.3), these were stations 24001, 24003, 24005, 24008, 24011, 24012, 24013 and 24082. These trends may be indicative of external factors or reflect actual trends in the flow and/or level series. Any feedback from the data managers of the OPW would be useful to ensure maximum confidence in using the associated flows in future work.

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

11 Conclusions

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

Catchment areas, defined using a range of datasets, have been compared and the comparison reported where catchment areas to gauging stations and Communities at Risk exceed 10%. The discrepancies identified have been documented herein such that the way forward can be agreed with OPW before the design hydrology commences.

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

Nine Met Éireann daily storage raingauges have been identified within the Shannon Estuary South Unit of Management, however, data was only provided for eight. No sub-daily rainfall data was available and this has limited the rainfall durations analysed and the conclusions that were able to be drawn.

Historical rainfall depths for these events have been studied for a range of durations. The results suggest that events were the result of both winter depressions, characterised by a moderately intense rainfall event preceded by prolonged rainfall, and a summer convective event characterised by high intensity short duration rainfall.

Annual exceedance probabilities (AEPs), for these selected rainfall events, have been estimated from actual data. These indicate that the majority of rainfall events studied were typical annual events with an AEP of 50% or greater. However, the lowest annual exceedance probability estimated was 4% for a 1 day rainfall depth at station 4811 during the July 2008 event. These AEPs have been compared to theoretical AEPs derived from the Flood Studies Update (FSU). FSU AEPs were lower AEPs at station 4611 and higher AEPs at stations 4811 and 5111. These differences appear to suggest that the FSU Depth Duration Frequency (DDF) estimates do not accurately reflect the DDF relationship at the three rainfall stations considered. However, as rainfall runoff modelling is not proposed (see below), this finding will not affect the proposed future work for this Unit of Management.

A review of daily mean flow data highlighted the possibility of long-terms trends in several flow and / or level series. Trends such as this in the flow series can reduce certainty in the index flood, QMED. Of those stations highlighted with a trend in the flow series the majority of stations will be revisited during the next phase through a high flows rating review, enabling further investigation and improvement in the confidence of QMED. Only gauging station 24082 will not be revisited.

To assist in the analysis of fluvial data, gauging stations were grouped according to their sub-catchment location; in either the River Maigue or River Deel. Three events were selected for each sub-catchment and the instantaneous flow data studied for these events.

Hydrographs produced for the Maigue catchment indicate a steep rising limb and an initial steep recession which appears to flatten out, indicative of a fast responding catchment. The hydrographs indicate a consistent reduction in the peak flow and volume of flow between hydrometric gauges 24082 and 24001, the consistency in the peak and volume of flood flows, casts some doubt on the record at hydrometric gauge 24082 but may also be the result of storage or flows by-passing the channel at 24001 and 24008.

Runoff within the Maigue catchment is significantly greater than the Deel catchment. This correlates with the steepest topography of the Maigue catchment, where the Loobagh drains the Ballyhoura Mountains.

Annual exceedance probabilities estimated for each event on the Maigue suggested a range of values across the catchment. For the three events analysed on the River Maigue, the AEP estimated at the hydrometric gauges varied between 3% and 53%.

Hydrographs plotted for flood events on in the River Deel catchment reflect a steep rising limb and a prolonged recession in the lower reaches of the Deel catchment. Flattening of the peak flows at hydrometric gauge 24030 indicates some issue with the rating as flows transition to out-of-bank.

Significant runoff contributions to peak flows appear to originate from the River Arra and its tributaries draining the catchment at the western boundary of the Deel catchment.

A range of annual exceedance probabilities were estimated for the events and gauges analysed within the River Deel catchment. Estimates for the three events analysed on the River Deel, varied between 3% and 62%.

Methodologies for the hydrometric gauging station rating reviews procedure to be applied to 11 gauges in the catchment and for the design flow estimation methods have been proposed together with the design event hydrological methodology to be adopted for the study. A traditional rainfall-runoff modelling approach is not considered practical due to the lack of short duration rainfall data within the catchment.

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

Where possible each CAR has been associated with a flow gauging station, which will provide essential information to derive local flood estimates. However, CARs Ballylongford, Kildomo New, Clarina and Foynes did not have such local data. It is recommended that consideration is given to improving the flow gauging network in the vicinity of these CARs for the benefit of future flood studies.

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Appendix A - All hydrometric stations listed in EPA register

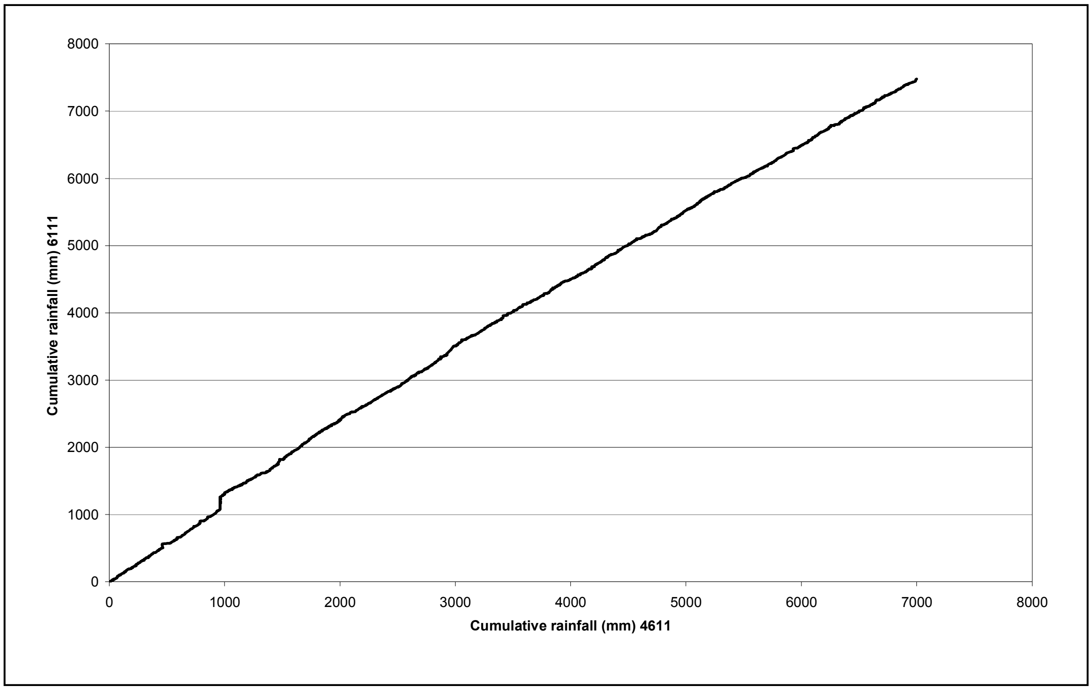
Station number	Station name	Waterbody	Station status	Station type	Available data	Operating Authority	Easting	Northing	Type	Record start	Record End
24001	CROOM	MAIGUE	Active	Data Logger		Office of Public Works	151274	141001	River	01/10/1953	
24002	GRAY'S BR.	CAMOGE	Active	Autographic Recorder		Office of Public Works	157932	140276	River	01/10/1953	
24003	GARROOSE	LOOBAGH	Active	Autographic Recorder		Office of Public Works	155008	127458	River	01/10/1956	
24004	BRUREE	MAIGUE	Active	Data Logger		Office of Public Works	155078	130369	River	01/10/1953	
24005	ATHLACCA	MORNINGSTAR	Active	Autographic Recorder		Office of Public Works	155782	134290	River	01/10/1953	
24006	CREGGANE	MAIGUE	Active	Autographic Recorder		Office of Public Works	153408	127284	River	01/101956	
24007	CAHERASS	MAIGUE	Inactive	Staff Gauge Only	Flow Measurements	Office of Public Works	150156	142678	River		
24008	CASTLEROBERTS	MAIGUE	Active	Autographic Recorder	Water Level and Flow	Office of Public Works	148000	143779	River	01/11/1973	
24009	ADARE MANOR	MAIGUE	Active	Autographic Recorder		Office of Public Works	147355	146220	Tidal	01/11/1973	
24011	DEEL BR.	DEEL	Active	Data Logger		Office of Public Works	129938	132738	River	01/09/1954	
24012	GRANGE BR.	DEEL	Active	Data Logger		Office of Public Works	130810	135013	River	01/09/1954	
24013	RATHKEALE	DEEL	Active	Data Logger		Office of Public Works	136009	141444	River	01/09/1953	
24014	BROADFORD	BUNOKE TRIB	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	133158	121701	River	10/05/1978	31/07/2003
24015	DROMCOLLIHER	AHAVARRAGH	Active	Data Logger	Flow Measurements	Limerick County Council	137926	121362	River	22/09/1977	28/01/1999
24016	KILMALLOCK	LOOBAGH	Inactive	Autographic Recorder	Water Level and Flow	Limerick County Council	160670	128462	River	24/07/1980	17/04/1984
24017	ROBERTSTOWN	ROBERTSTOWN	Inactive	Autographic Recorder	Water Level and Flow	Limerick County Council	126908	149709	River	02/10/1981	15/05/2000
24018	SHANAGOLDEN	ROBERTSTOWN	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	125626	147179	River	20/03/1978	12/12/2007
24019	BARRIGONE	AHACRONNANE	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	128407	149779	River	15/09/1977	12/09/1983
24020	DAAR BR	DAAR	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	127561	135948	River	10/07/1975	16/02/2009
24021	CULLENAGH HOUSE	DEEL	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	127705	133527	River	09/02/1978	15/08/1984

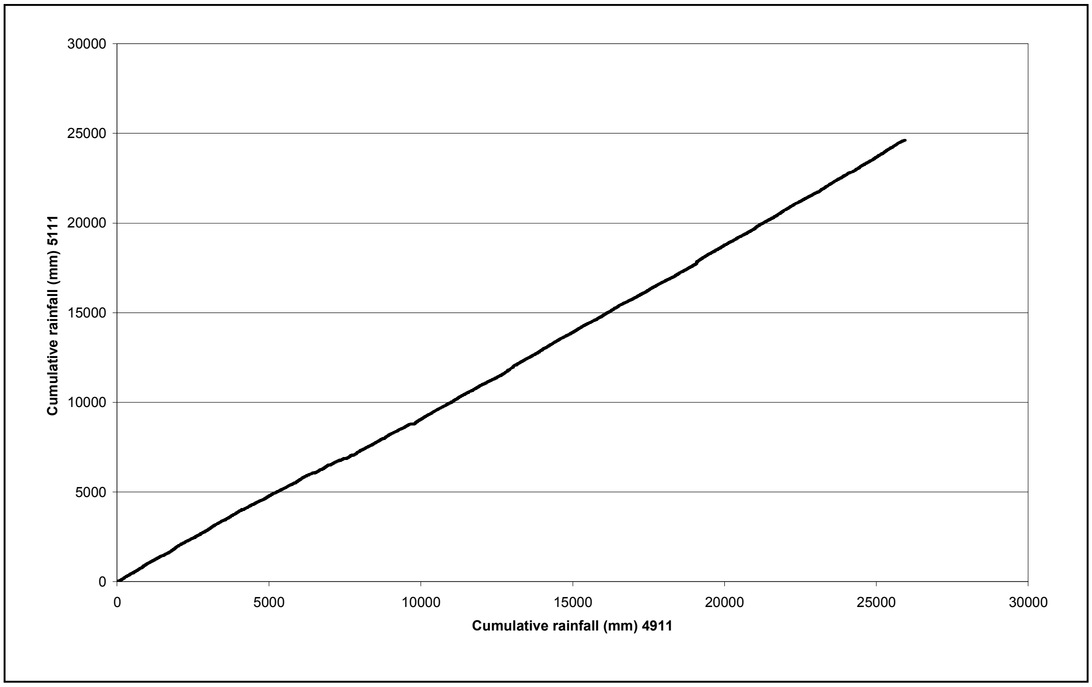
Station number	Station name	Waterbody	Station status	Station type	Available data	Operating Authority	Easting	Northing	Type	Record start	Record End
24022	HOSPITAL	MAHORE	Active	Data Logger	Water Level and Flow	Limerick County Council	170565	136283	River	12/06/1984	
24023	KNOCKLONG	DRUMCAMOGE	Proposed	Data Logger		Limerick County Council	171883	132196	River		
24024	GARRYSPILLANE	MORNINGSTAR	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	174823	127860	River	01/05/1978	06/12/1993
24025	BRUFF	MORNINGSTAR	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	163101	135832	River	30/05/1978	21/07/2009
24026	KILFINNANE	LOOBAGH	Active	Staff Gauge Only	Flow Measurements	Limerick County Council	168690	123293	River	04/05/1979	
24027	DOORLUS	MAIGUE TRIB	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	149779	135055	River	16/02/1978	23/05/1984
24028	BALLYNABANOGE	MAIGUE TRIB	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	152463	136197	River	04/05/1978	27/09/1990
24029	INCHIROURKE MORE	DEEL	Active	Data Logger	Water Level and Flow	Limerick County Council	134386	149141	River	12/10/1982	
24030	DANGANBEG	DEEL	Active	Data Logger	Water Level and Flow	Limerick County Council	131830	129038	River	05/05/1980	
24031	NEWCASTLE WEST	ARRA	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	128764	133488	River	12/12/1991	28/09/2004
24032	LOGHILL	WHITE [LIMERICK]	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	119350	149326	River	19/09/1977	15/09/1988
24033	BALLYHAHILL	WHITE [LIMERICK]	Active	Data Logger	Water Level and Flow	Limerick County Council	119497	146092	River	28/07/1980	
24034	RIVERSFIELD WEIR	LOOBAGH	Active	Data Logger		Office of Public Works	163231	126306	River	31/10/1985	
24035	GORTADROMA	WHITE [LIMERICK]	Active	Staff Gauge Only	Flow Measurements	Limerick County Council	121311	143196	River	19/02/1987	
24036	GOLDEN VALE	BALLINCOLLY	Inactive	Staff Gauge Only	Flow Measurements	Golden Vale Foods	154210	125589	River		
24037	HELENA'S BRIDGE	BALLINCOLLY TRIB	Inactive	Staff Gauge Only	Flow Measurements	Golden Vale Foods	153835	125759	River		
24038	ARDAGH	STREAM	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	128052	139570	River	25/07/1989	25/10/1995
24039	BALLYLANDERS	MORNINGSTAR	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	175597	124313	River	07/09/1989	11/11/1992
24040	KILTEELY	BALLYNAMONA	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	172640	142268	River	19/02/1990	12/11/1993

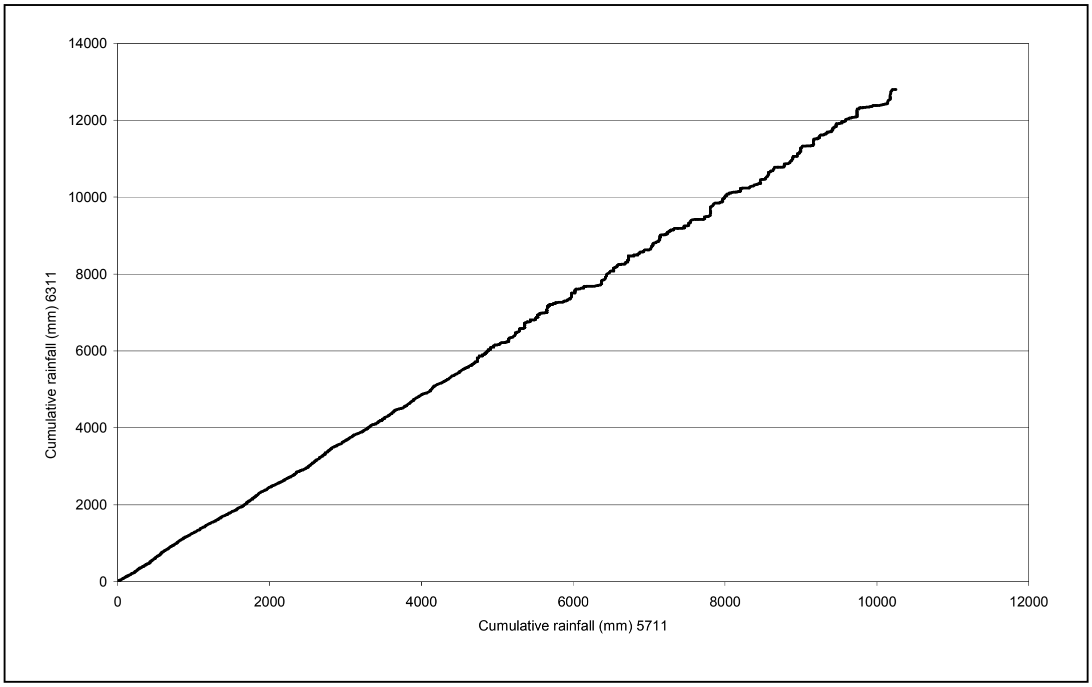
Station number	Station name	Waterbody	Station status	Station type	Available data	Operating Authority	Easting	Northing	Type	Record start	Record End
24041	CARRIGKERRY	DAAR	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	122140	138705	River	12/09/1989	30/10/1997
24042	KILMEEDY	KILMEEDY STREAM	Inactive	Staff Gauge Only	Flow Measurements	Limerick County Council	138383	129610	River	19/02/1990	19/02/1990
24043	COOLNAGOUR	DEEL	Inactive	Staff Gauge Only	Flow Measurements	Cork County Council	141186	121415	River		
24044	RYLANES	CLONSHIRE	Proposed	Data Logger		Limerick County Council	141797	136606	River		
24045	CANTOGHER	BUNOKE	Active	Data Logger	Water Level and Flow	Limerick County Council	128170	125280	River	09/07/2007	
24046	GORTNALUGGIN BR.	FINGLOSHA	Active	Data Logger	Water Level Only	Limerick County Council	139041	127219	River	05/08/2004	
24047	ROSSBRIEN RLY BR	BALLINACURRA	Active	Recorder	Water Level and Flow	Office of Public Works	157220	154018	River	16/12/1998	
24048	BALLINACURRA D_S	BALLINACURRA	Active	Recorder	Water Level Only	Office of Public Works	156279	154846	River	18/12/1998	
24049	BALLINACURRA U_S	BALLINACURRA	Active	Recorder	Water Level Only	Office of Public Works	156305	154843	River	17/12/1998	
24050	BALLINACURRA GARDENS	STREAM	Inactive	Recorder	Water Level Only	Office of Public Works	157300	154900	River	23/11/1998	09/06/2000
24051	HUNTSFIELD	DOORADOYLE	Inactive	Recorder	Water Level Only	Office of Public Works	157300	154900	River	23/11/1998	09/06/2000
24060	TARBERT	SHANNON ESTY	Inactive	Recorder	Water Level Only	ESB	108400	149400	Tidal		
24061	FERRY BR.	MAIGUE ESTUARY	Active	Recorder	Water Level Only	Office of Public Works	148256	152469	Tidal	01/01/1940	
24062	ADARE QUAY	MAIGUE ESTUARY	Active	Recorder	Water Level Only	Office of Public Works	145935	146661	Tidal	01/08/1966	
24067	NORMOYLE'S BR.	GREANAGH	Active	Autographic Recorder		Office of Public Works	144057	145659	Tidal	01/11/1963	
24081	CURRACHASE	CURRACHASE	Inactive	Staff Gauge Only		Office of Public Works	141334	149352	Lake		
24082	ISLANDMORE	MAIGUE	Active	Autographic Recorder		Office of Public Works	151496	139971	River	03/11/1975	
24083	TOOREEN	CAMOGE	Inactive	Autographic Recorder		Office of Public Works	152497	139531	Lake	01/10/1977	01/10/1987
24084	KILMALLOCK CREAMERY	MAIGUE	Inactive	UNKNOWN		Office of Public Works	161298	127727	Lake		
24093	ROSSBRIEN RLY BR	BALLINACURRA	Active	Data Logger		Office of Public Works	157220	154018	River	16/12/1998	

Station number	Station name	Waterbody	Station status	Station type	Available data	Operating Authority	Easting	Northing	Type	Record start	Record End
24094	BALLINACURRA D_S	BALLINACURRA	Active	Data Logger		Office of Public Works	156279	154846	River	18/12/1998	
24100	GORTBOY HOTEL	DEEL	Active	Recorder	Water Level and Flow	Office of Public Works	128600	133493	River	21/11/2008	

Appendix B - Double mass rainfall plots



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12000
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6000
8000
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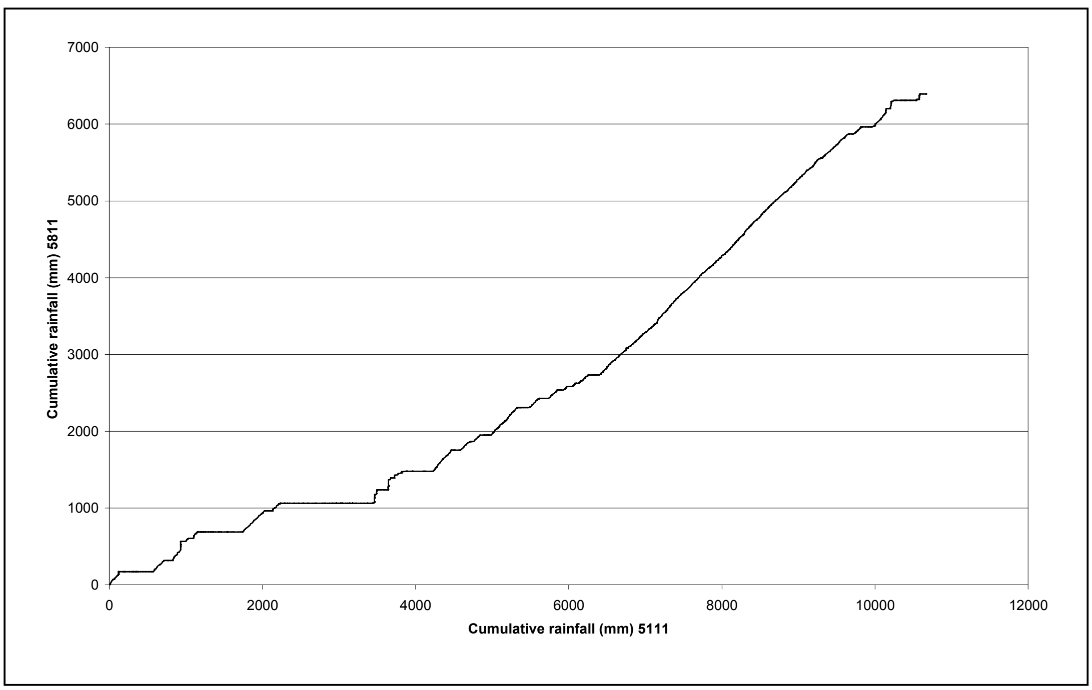
12000
Cumulative rainfall (mm) 5711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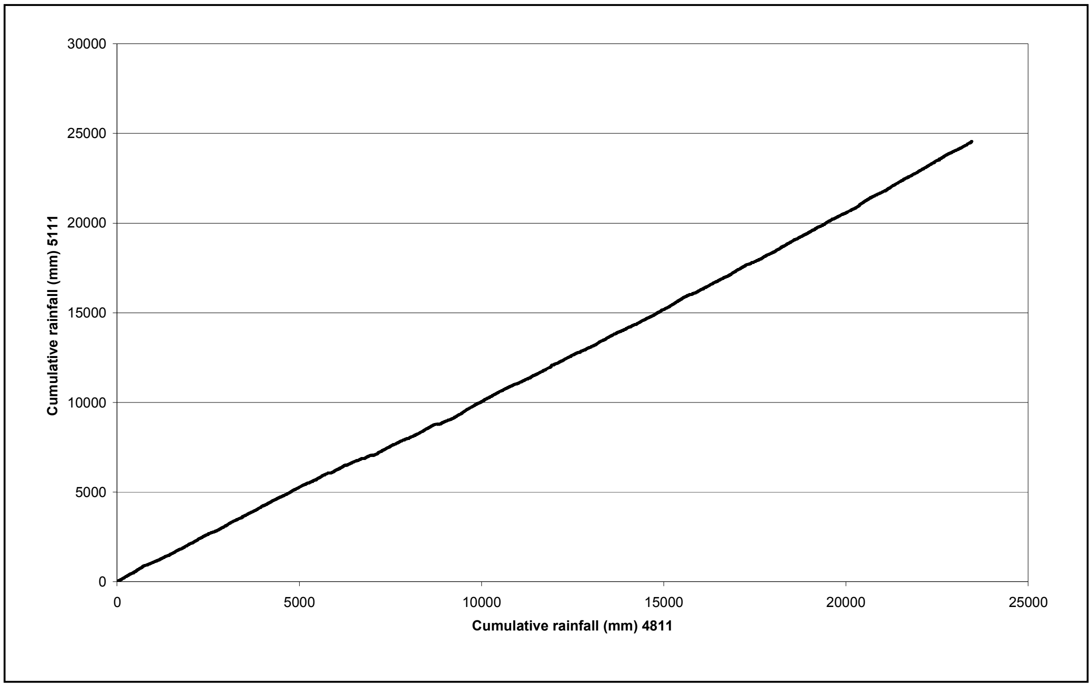
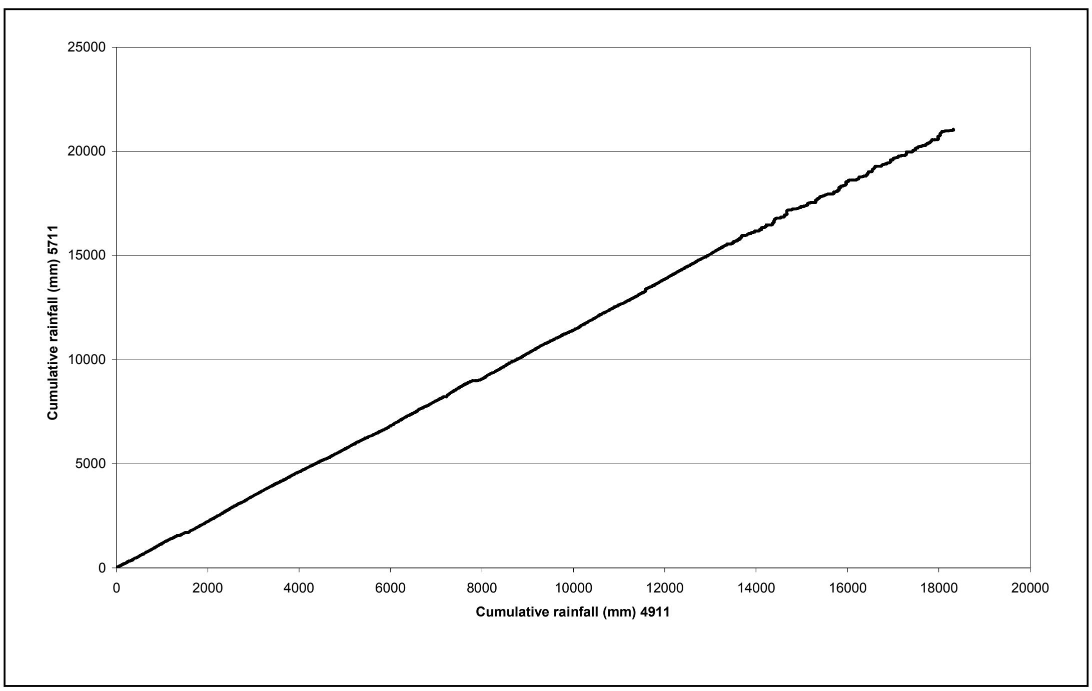
Cumulative rainfall (mm) 5111

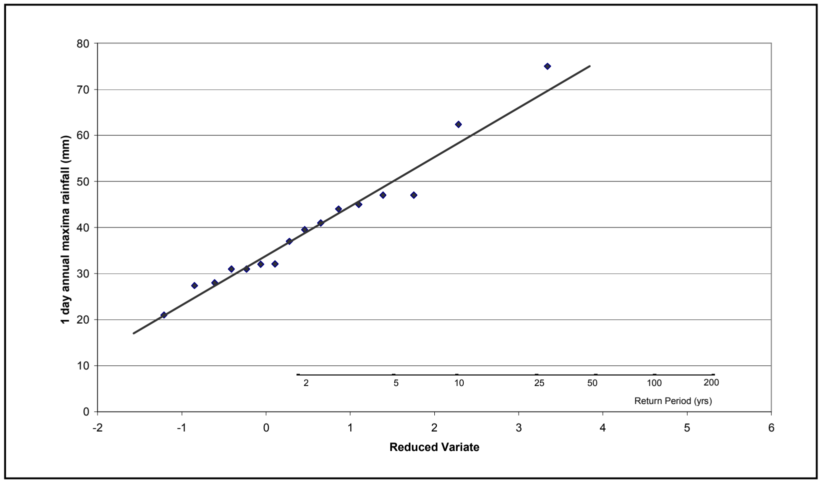
JACOBS

The Office of Public Works
Oifig na nOibreacha Poiblí

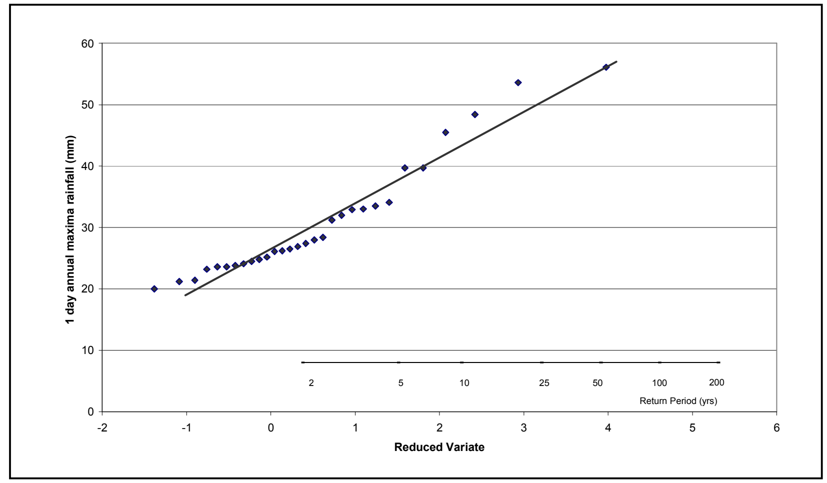




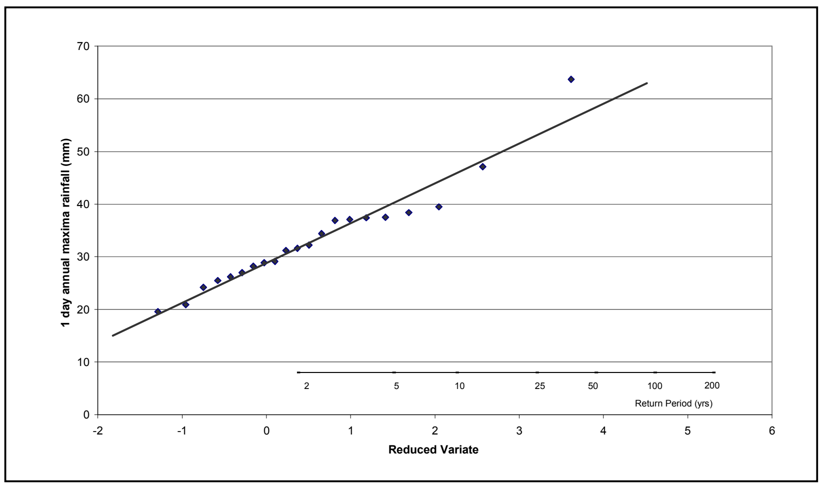
Appendix C - 1-day and 4-day rainfall probability plots



a) Raingauge 4611 – Tarbert Island

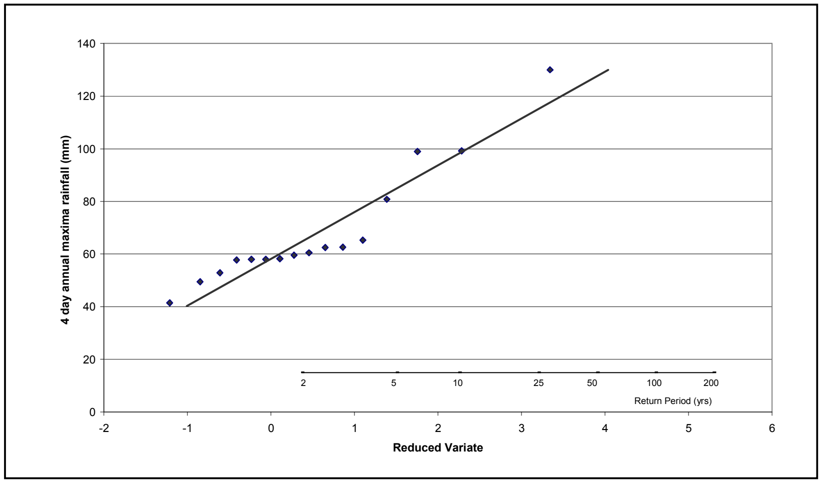


b) Raingauge 4811 – Patrickswell

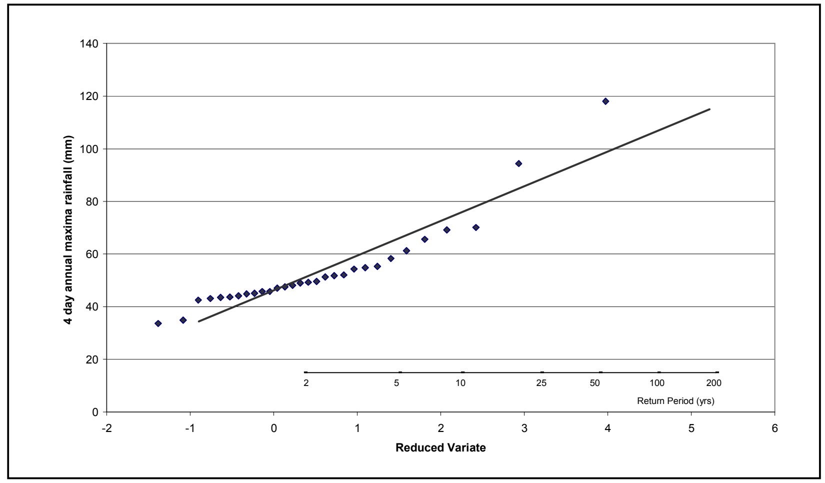


c) Raingauge 5111 – Rathkeale

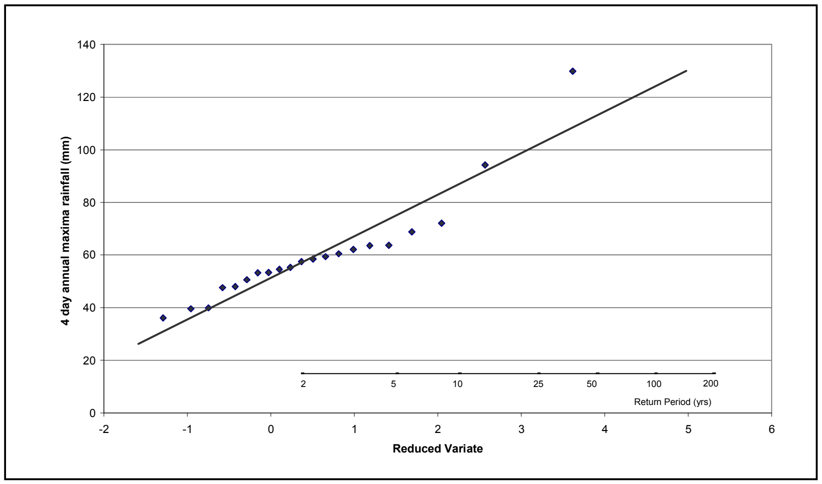
Figure C-1 (a-c) 1-day rainfall probability plots



a) Raingauge 4611 – Tarbert Island



b) Raingauge 4811 – Patrickswell

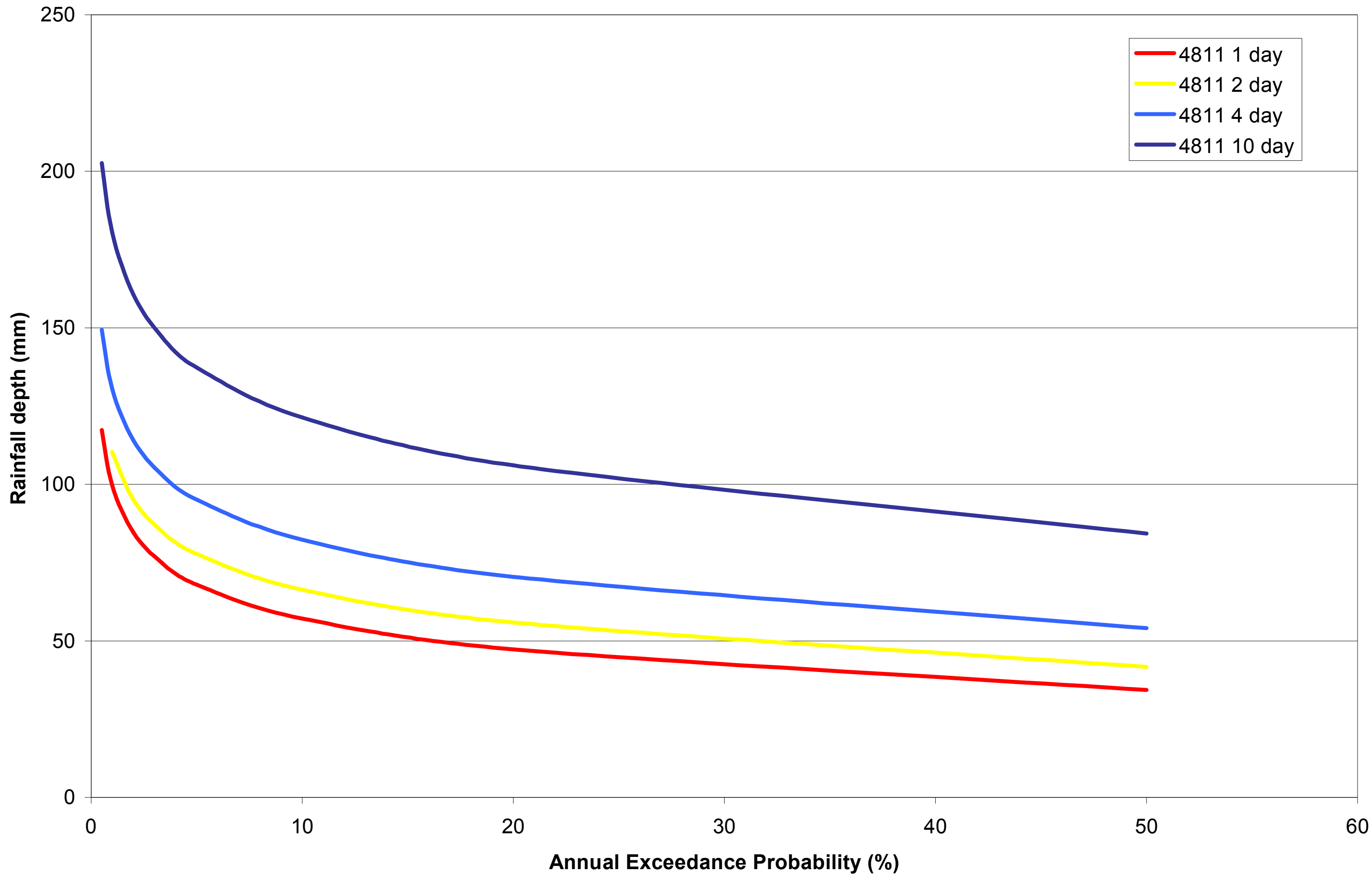


c) Raingauge 5111 – Rathkeale

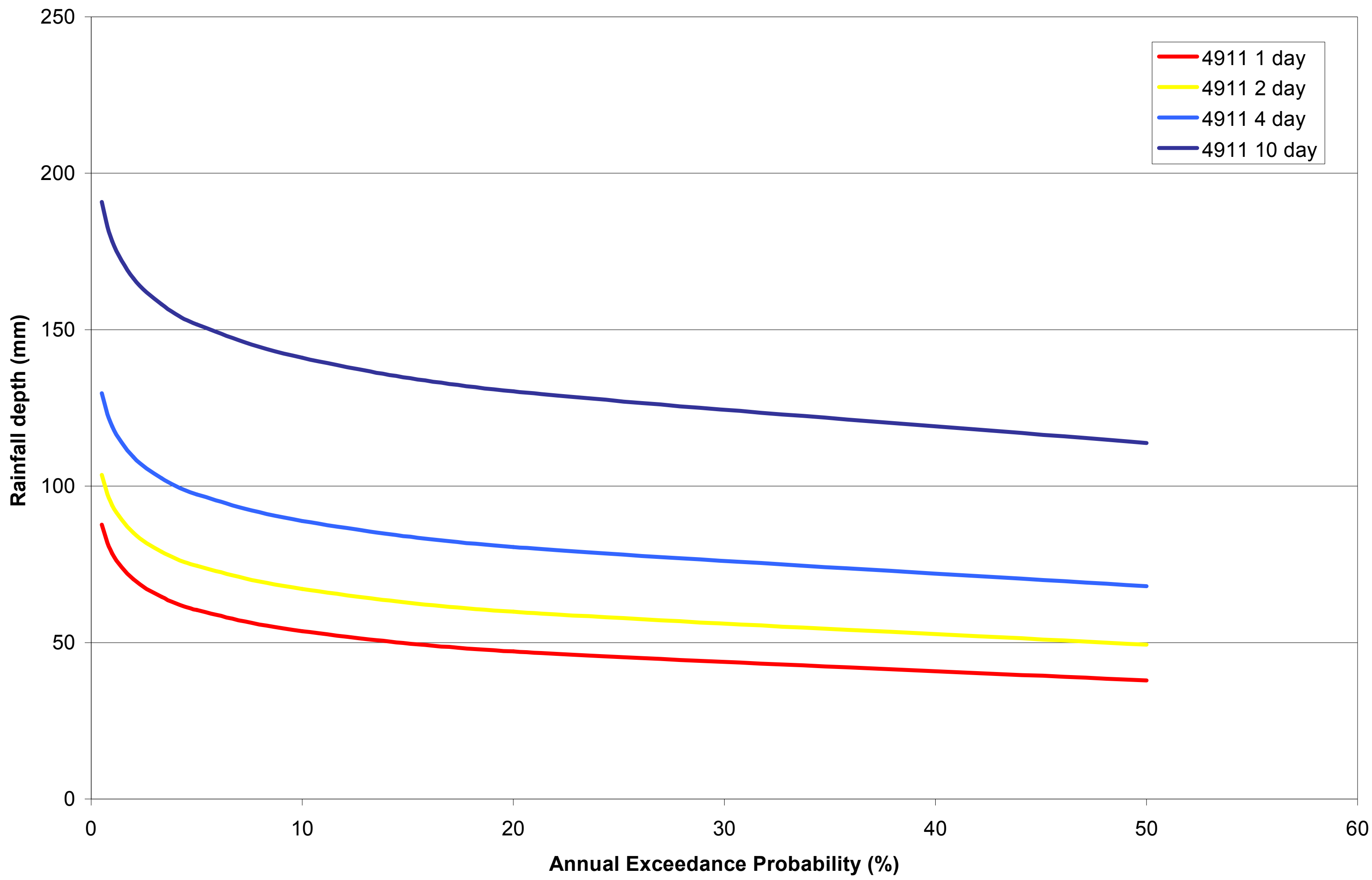
Figure C-2 (a-c) 4-day rainfall probability plots

Appendix D - FSU depth duration frequency plots

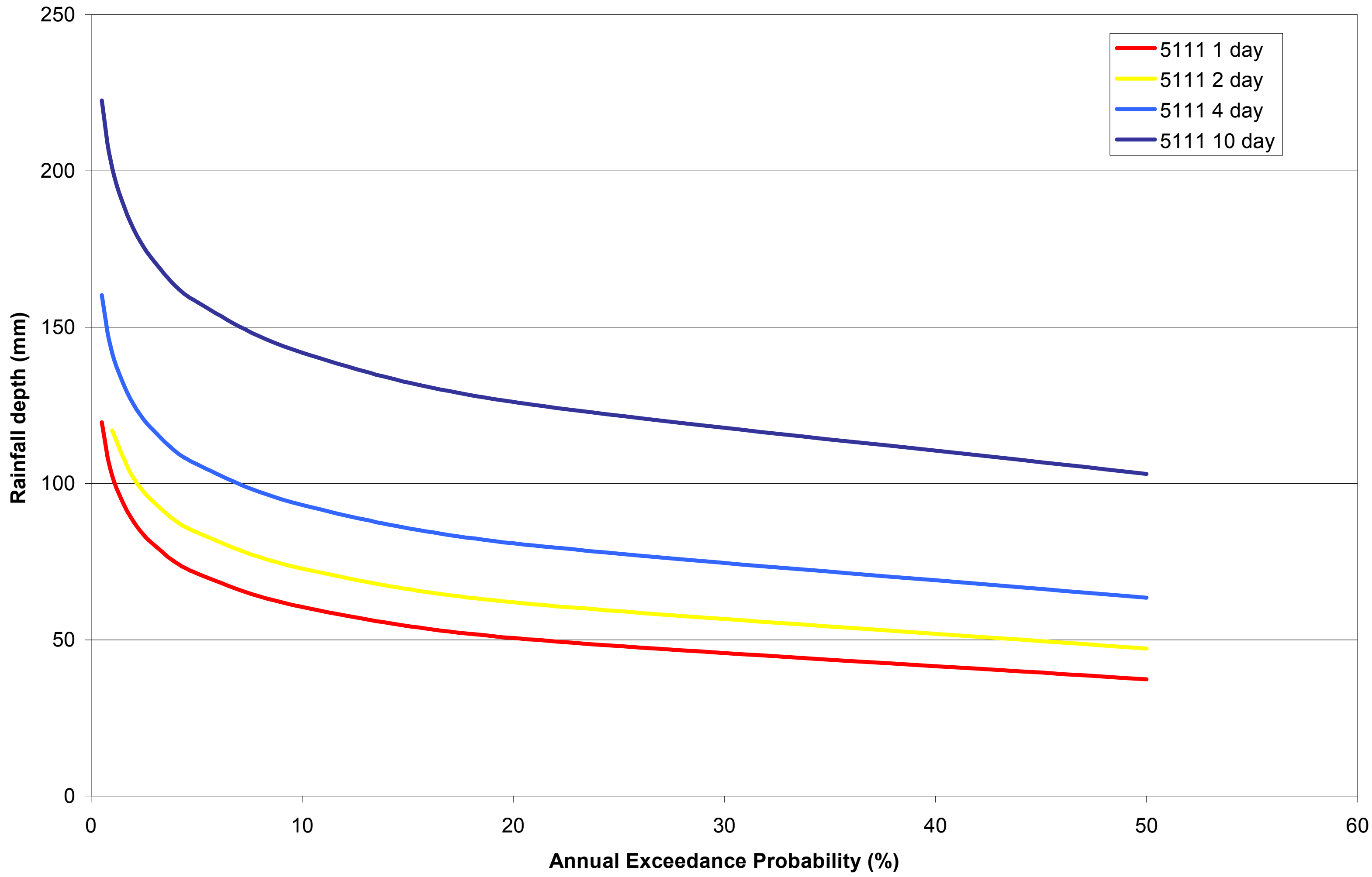
Depth Duration Frequency Curves for raingauge 4811 (from FSU Workpackage 2.2)



Depth Duration Frequency Curves for raingauge 4911 (from FSU Workpackage 2.2)



Depth Duration Frequency Curves for raingauge 5111 (from FSU Workpackage 2.2)

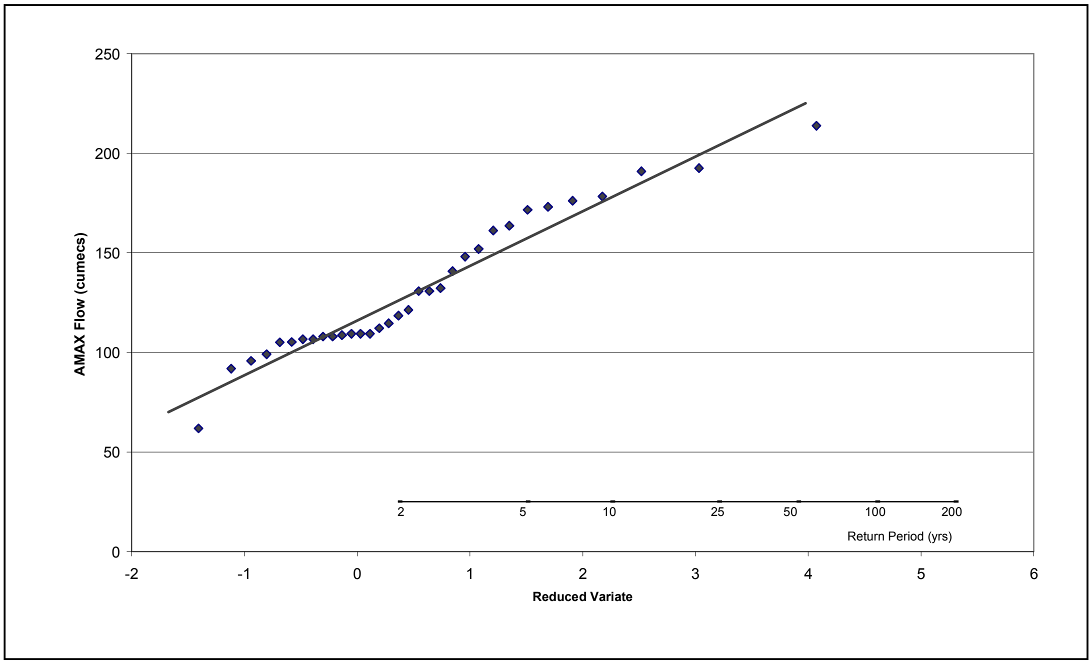


Appendix E - Daily mean flow review

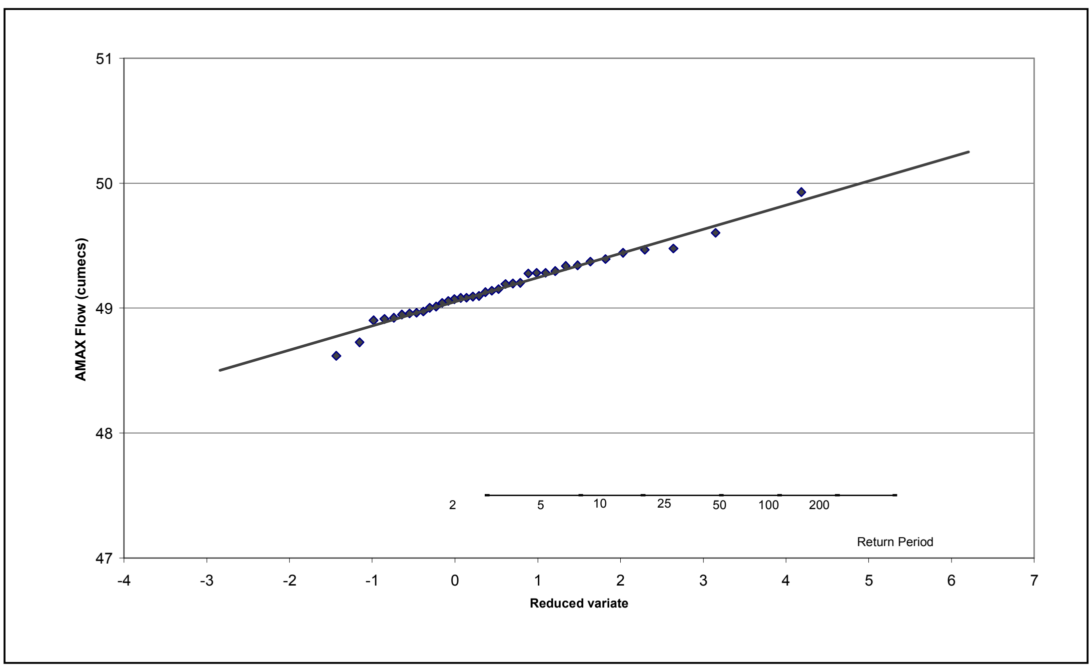
						Daily flow data only									Daily level data only							
Station no.	Station name	Waterbody	UoM 24 Sub-catchment	Record start	Record End	No. of good days	No. of fair days	No. of poor days	No. of beyond limit days	No. of unchecked days	No. of cautionary days	No. of missing days	Quality code not known	Total number of days	No. of good days	No. of beyond limit days	No. of unchecked days	No. of cautionary days	No. of missing days	Quality code not known	Total number of days	Comment on visual inspection of record
24001	CROOM	Maigue	Maigue	01/10/1953		5304	7076	904	0	0	27	526	21	13858	13305	0	27	0	526	0	13858	Clear rising trend in water level record. Flows ok.
24002	GRAY'S BR.	Camoge	Maigue	01/10/1953											8345	0	359	0	333	7	9044	No obvious inconsistencies or trends.
24003	GARROOSE	Loobagh	Maigue	01/10/1956		11568	0	0	0	0	26	2265	0	13859	11568	0	26	0	2265	0	13859	31/5/81 - sudden drop in level. Trend of gradually rising water level from May 1981. Flows ok.
24004	BRUREE	Maigue	Maigue	01/10/1953		7858	2348	0	0	293	155	634	126	11414	10276	0	785	0	749	0	11810	
24005	ATHLACCA	Morningstar	Maigue	01/10/1953											7559	0	596	0	8606	0	16761	Trend of gradually rising water level over period of record
24006	CREGGANE	Maigue	Maigue	01/10/1956											2878	0	27	0	10866	88	13859	Level data shows irregularities and missing values- poor record. No flow data
24008	CASTLE-ROBERTS	Maigue	Maigue	01/11/1973		9060	2422	0	0	0	68	696	0	12939	11974	0	155	0	340	2	13436	Anomalous dip in water levels Mar-Aug 86. Trend of gradually rising water level over period of record in both level and flow record. Most recent import has no flow flags assigned. Post 1979 WL data looks ok. Flow looks ok
24011	DEEL BR.	Deel	Deel	01/09/1954		98	4259	825	0	2	61	232	0	5477	7684	0	1	0	69	169	7923	Slight trend of gradually rising water level over period of record. No flags on data.
24012	GRANGE BR.	Deel	Deel	01/09/1954		4677	8351	4724	0	89	437	899	0	19177	18542	0	87	1	544	0	19174	Declining flows between Sept-1964 and May 1965. Trend of flows gradually increasing since May 1965.
24013	RATHKEALE	Deel	Deel	01/09/1953		0	11039	1664	0	0	24	1050	82	13859	13027	0	0	24	737	70	13858	Trend of gradually rising water levels from approx. Sept 1990, also evident in flow series.
24034	RIVERSFIELD WEIR	Loobagh	Maigue	31/10/1985		1362	632	0	0	0	79	156	19	2248	2012	0	74	16	156	1	2259	
24082	ISLANDMORE	Maigue	Maigue	03/11/1975		128	8226	0	0	0	8	151	0	8513	8356	0	6	0	151	0	8513	Trend of increasing peak flows throughout period of record. Water levels suggest an gradual increase in low flows also.

NB: Grey squares indicate no data.

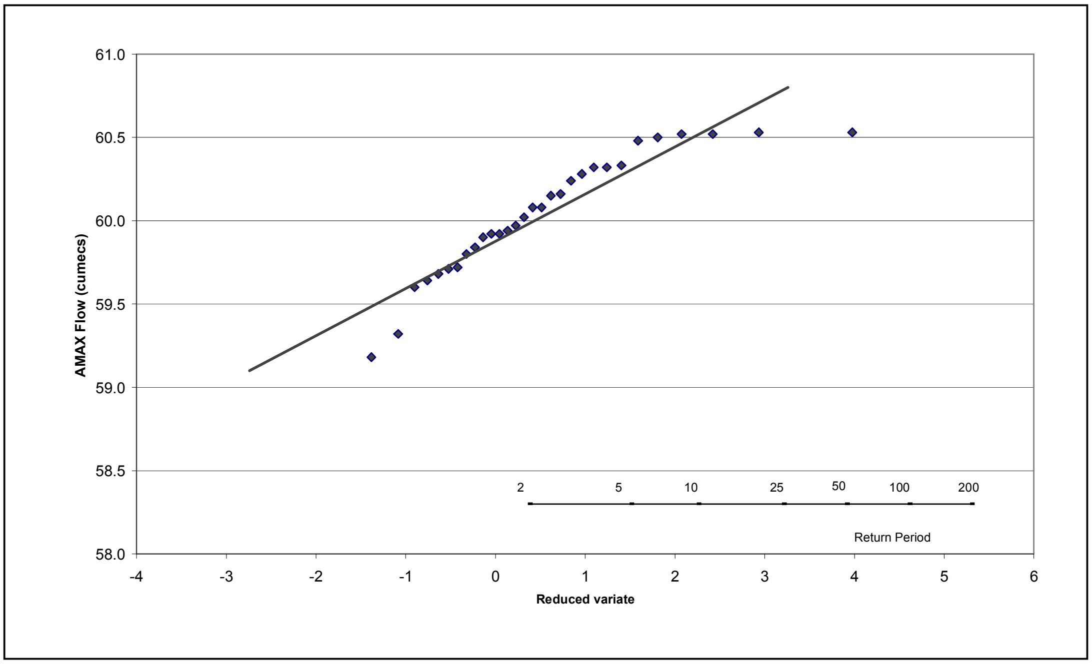
Appendix F - Flood frequency probability plots



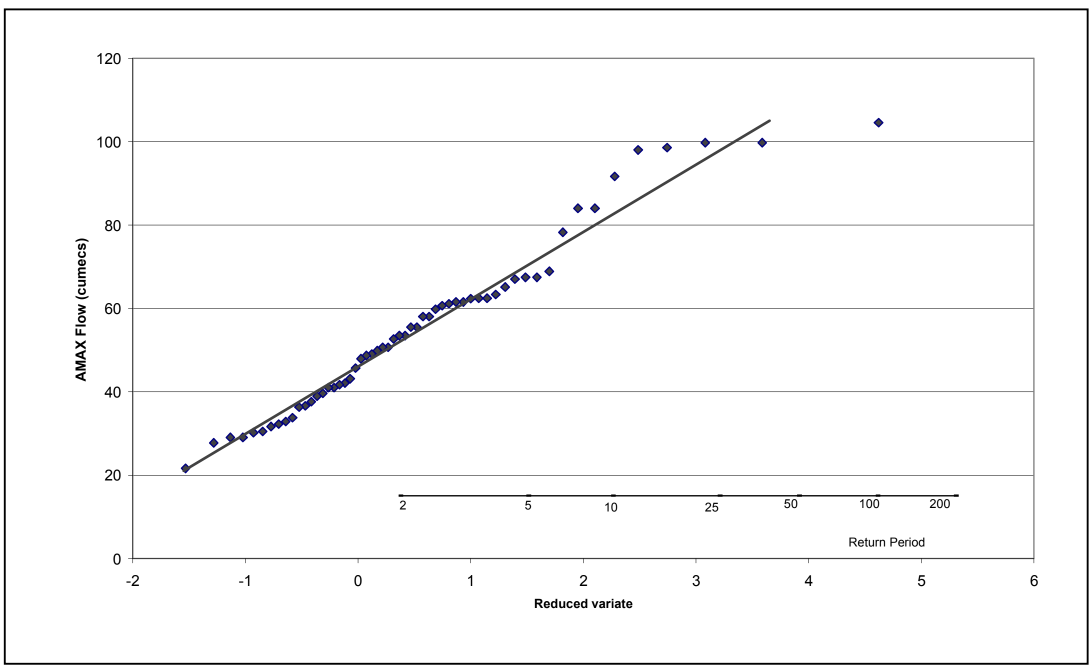
Hydrometric station 24001



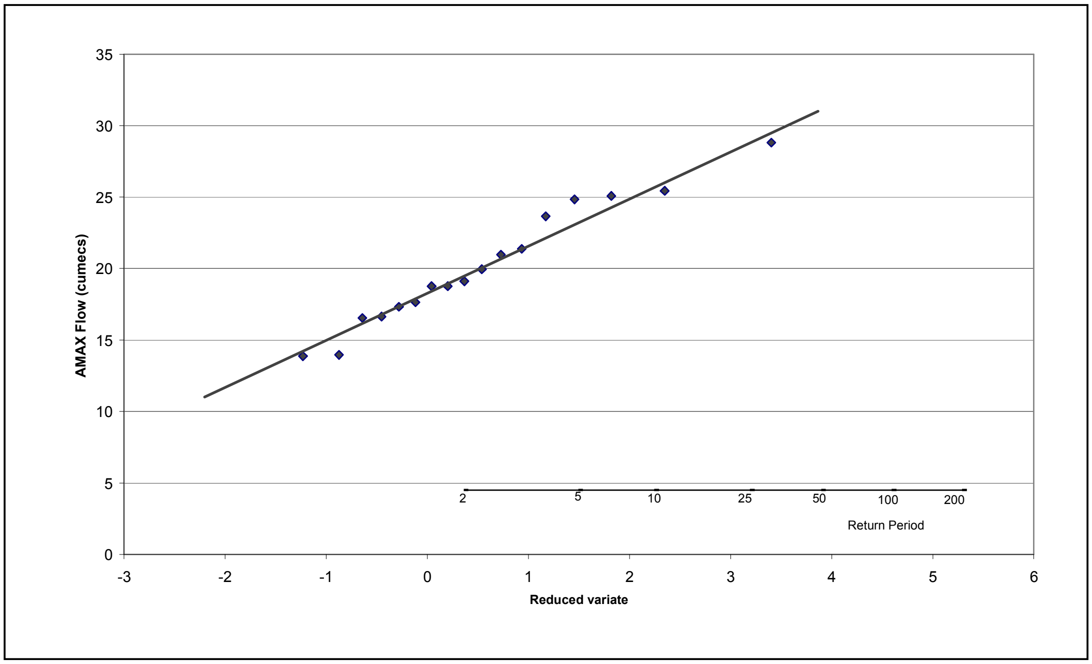
Hydrometric station 24002



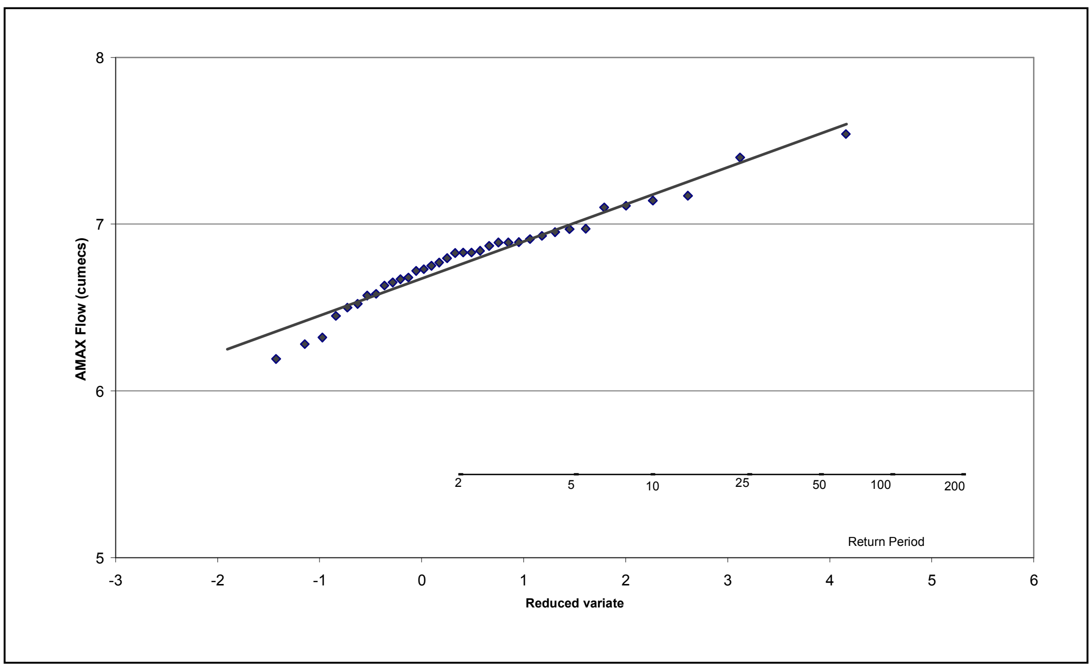
Hydrometric station 24003



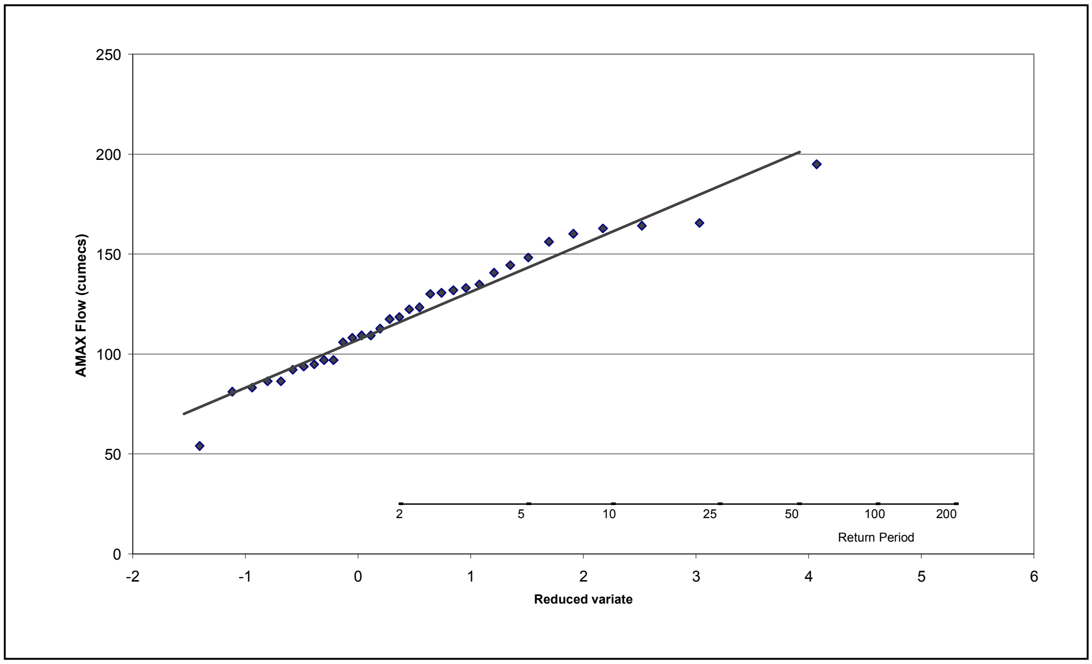
Hydrometric station 24004



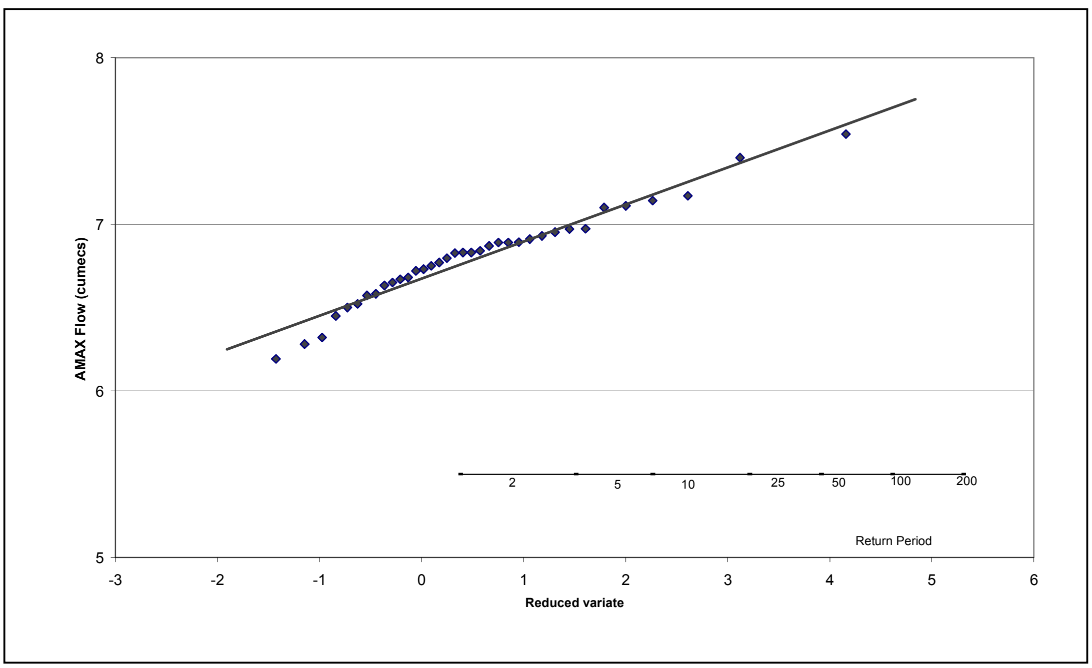
Hydrometric station 24005



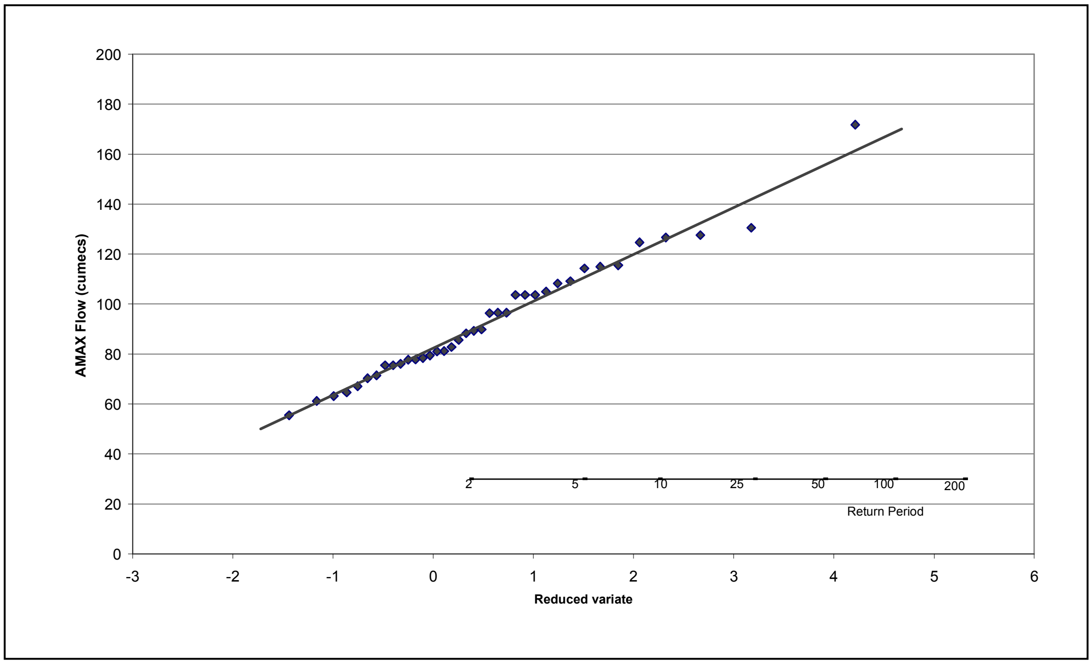
Hydrometric station 24006



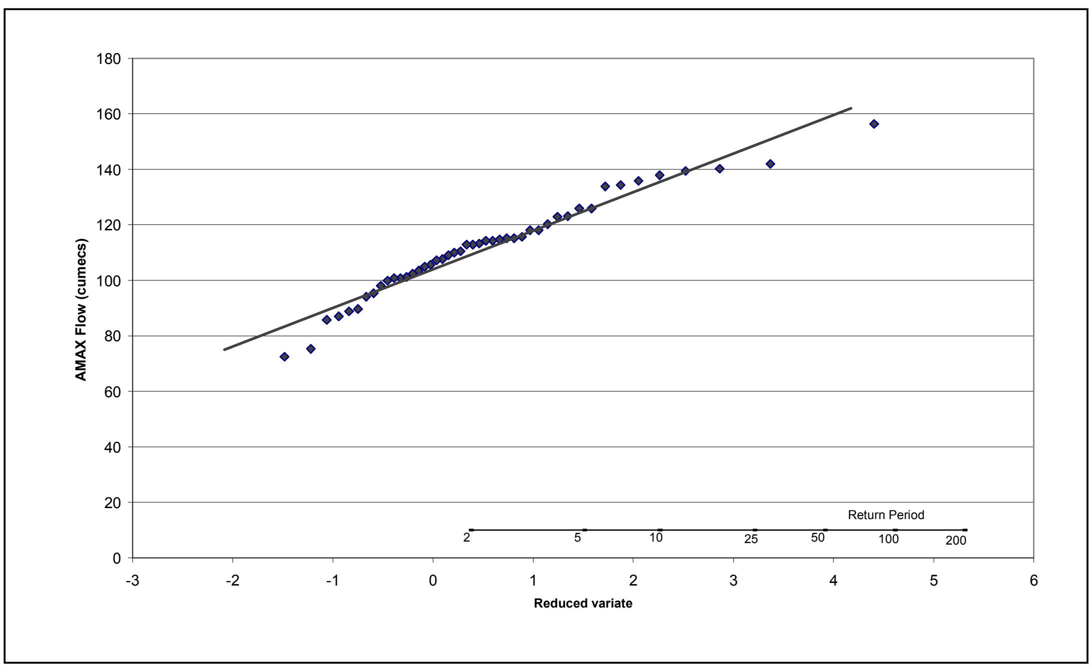
Hydrometric station 24008



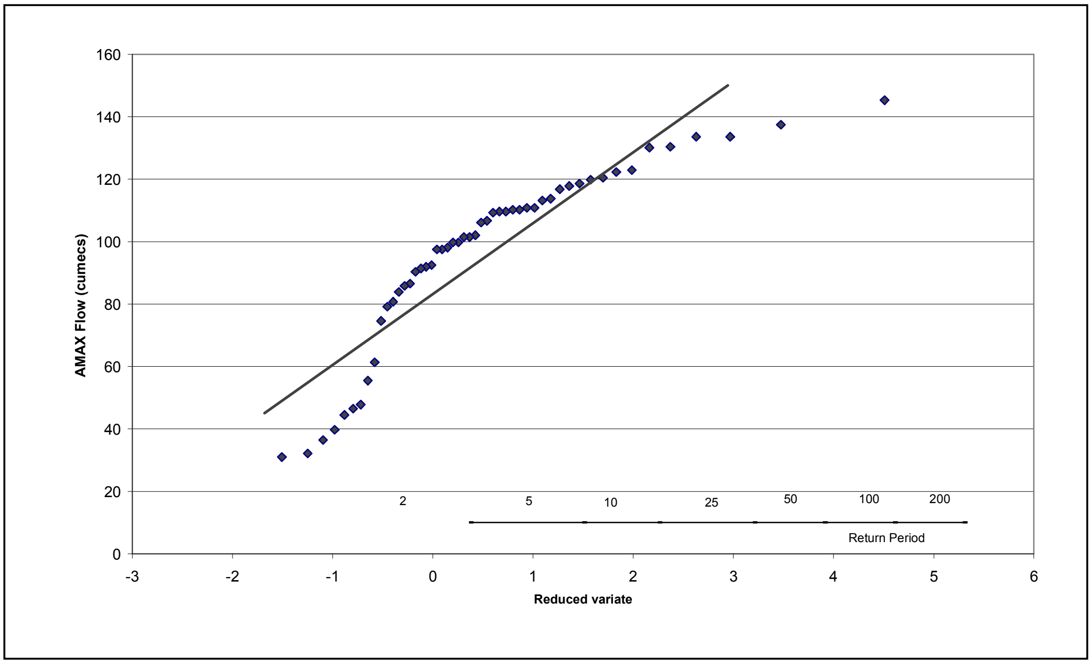
Hydrometric station 24009



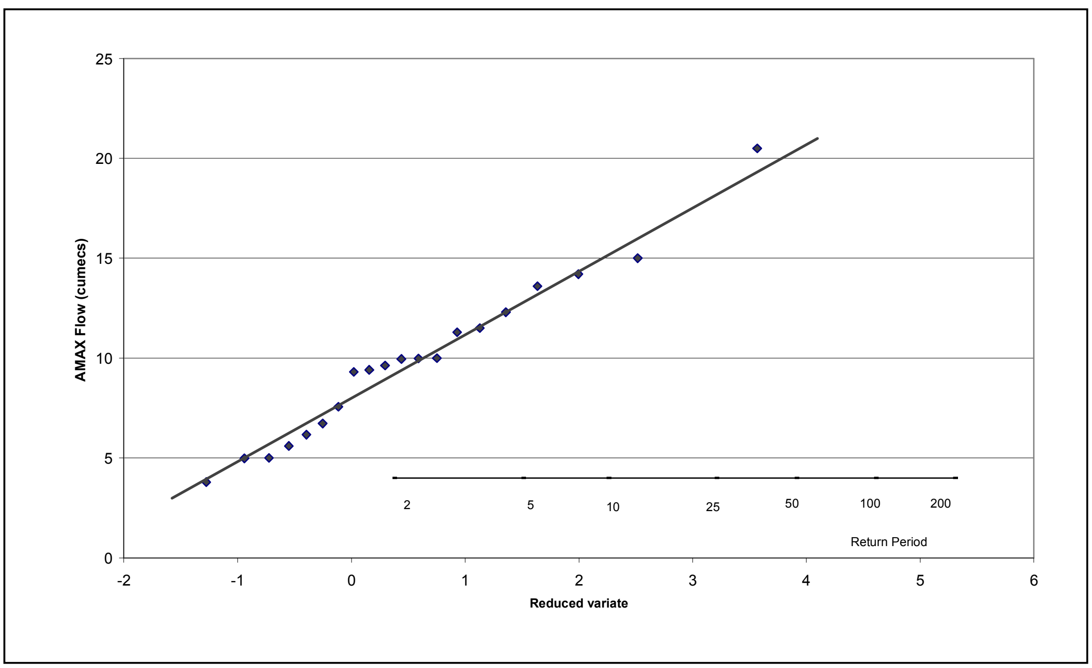
Hydrometric station 24011



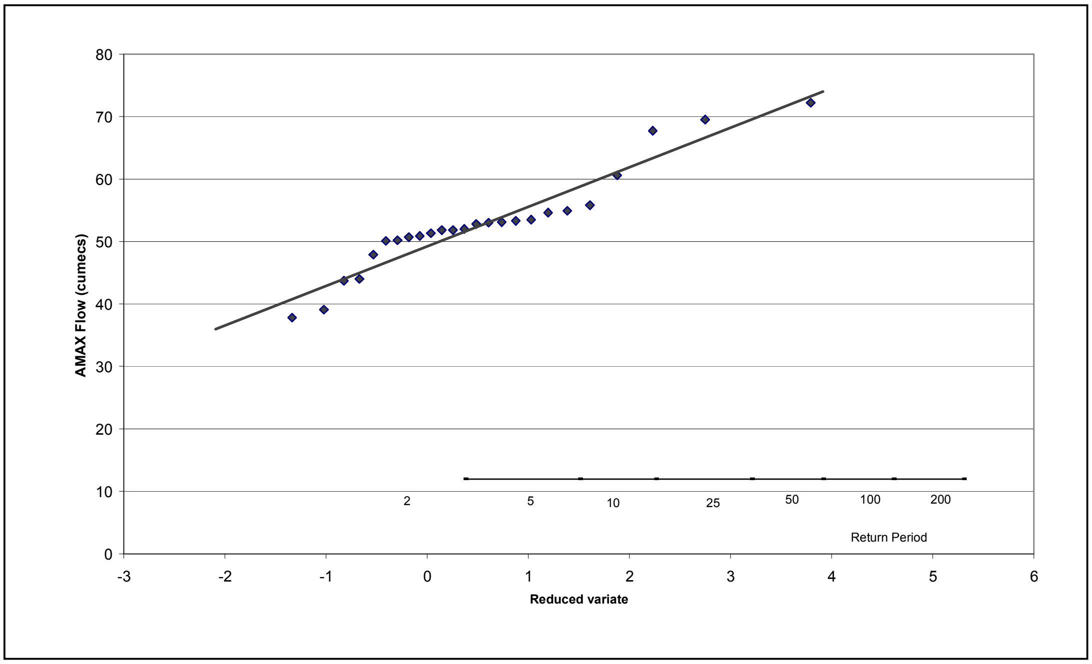
Hydrometric station 24012



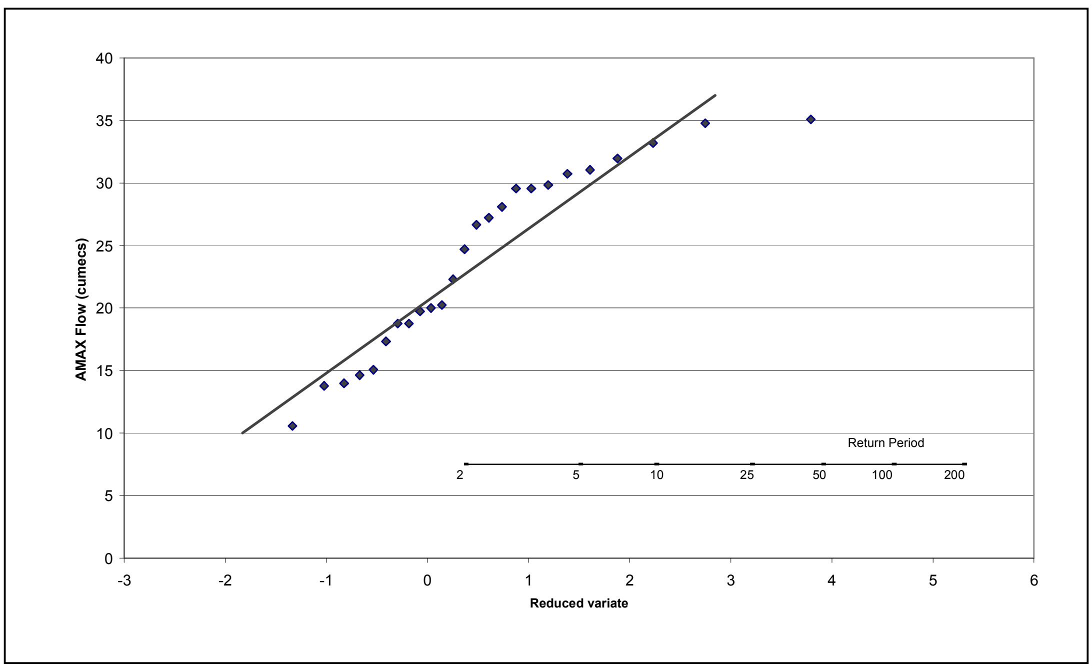
Hydrometric station 24013



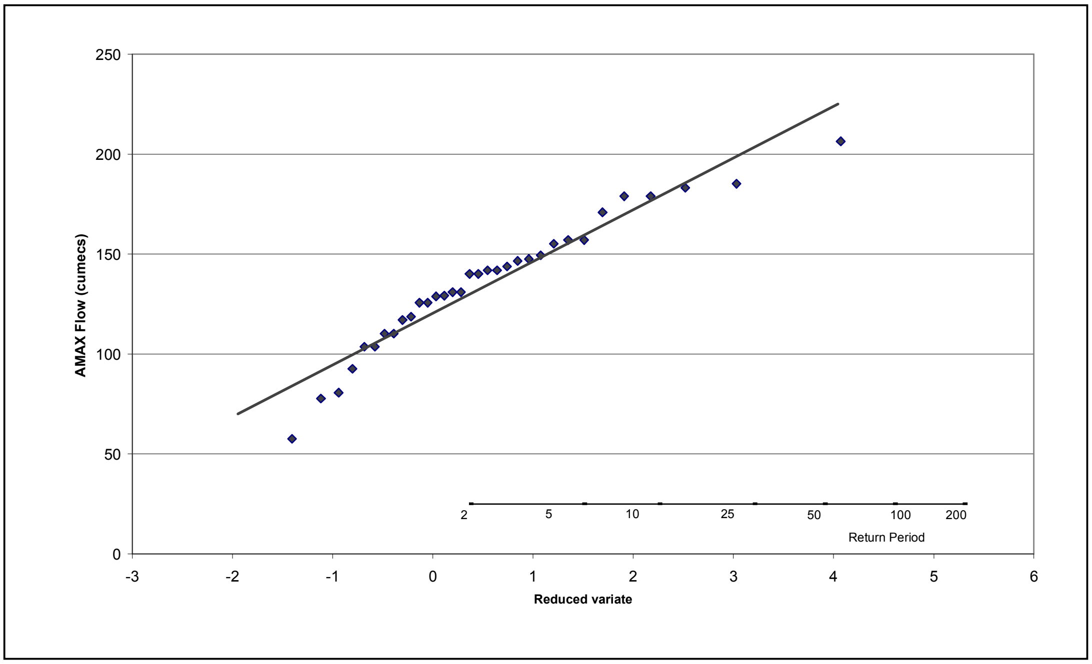
Hydrometric station 24022



Hydrometric station 24030



Hydrometric station 24034



Hydrometric station 24082

Appendix G - Catchment boundary discrepancies

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

Appendix H - Gauging station summary sheets

Appendix I - Historical flood risk review details

Ref	Where					When			Magnitude				Flooding mechanism	Impact	Ranking	Estimated AEP					Flood
	River Basin	Tributary	APSR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused			Source		Date	Authenticity	Quality Code
CAR 03 ADARE																					
03-1a	Maigue	Maigue	Adare	Road between town and station flooded. No further location detail given.	-	1946						Land & road	Breached embankment. Low neap tides.	Embankments breached, inundated agricultural land, road flooded.	4		Engineer report	floodsmap	01/12/1946	External Engineer visiting area with local Engineers.	3
03-1b	NO DATA ATTACHED					1946	August	12							4		Limerick Leader	floodsmap	17/08/1946		-
03-1c	NO DATA ATTACHED					1946	August	11							4		Evening Echo (Cork)	floodsmap	13/08/1946		-
03-1d	NO DATA ATTACHED					1946	August	11							4		Evening Echo (Cork)	floodsmap	14/08/1946		-
03-1e	NO DIRECT RELEVANT INFO.					1946	August	11					Heavy rain		4		Cork Examiner	floodsmap	15/08/1946		-
03-1f	NO DIRECT RELEVANT INFO.					1946	August	11							4		Guardian (Nenagh)	floodsmap	17/08/1946		-
03-1g	NO DIRECT RELEVANT INFO.					1930	January	11/ 12							?		Limerick Chronicle	floodsmap	14/01/1930		-
03-2a	Maigue	Maigue	Adare	Adare	-	1999	January		Photocopy of levels from notebook. Location and date unclear.						3		OPW Mungret	floodsmap	07/01/1999		2
03-2b	NO DIRECT RELEVANT INFO - CROOM				-	-									-		Limerick Leader	floodsmap	09/01/1999		
03-3a	REFER TO REPORT 27/02/1996 ?					1997	February	10				N21	Tidal	N21 flooded	-		OPW memo	floodsmap	10/02/1997		3
03-4a	Maigue	Maigue	Adare	Adare	-	1995	January		Tide Level of 6.89mOD (22.6ft) @ Adare			Road	Overtopping embankment. High tide due to low barometric pressure.	Overtopping of embankment, flooding the road, a national primary route. Embankment in many instances in excess of 300mm below design crest of 24ft OD.	5		Report to Regional Engineers	floodsmap	09/02/1995		3
03-4b	Maigue	Maigue	Adare	Only mentioned Limerick. Adare is not specifically mentioned	-	1995	January					Land & road		Land waterlogged in parts of the Maigue catchment. Road flooding.	5		Reports from Regional Hydrometric Technicians	floodsmap	07/02/1995	Other	3
03-5a	Maigue	Maigue	Adare		-	1973	December	1				Photographs of flooding. Location unclear.			1		OPW Dublin Hatch St	floodsmap	01/12/1973		2
03-6a	Maigue	Maigue	Adare	Likely to be Station Road?	-	-						Undated photograph of flooding. Location unclear.			-		OPW Mungret	floodsmap			2
03-6b	Maigue	Maigue	Adare	Adare Bridge	-	-						Undated photograph of flooding.			-		OPW Mungret	floodsmap			3
03-6c	Maigue	Maigue	Adare	Station Road	-	-						Undated Photograph of flooding.			-		OPW Mungret	floodsmap			3

Ref	Where					When			Magnitude					Impact	Ranking	Estimated AEP					Flood
	River Basin	Tributary	APSR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused			Source		Date	Authenticity	Quality Code
03-6d	Maigue	Maigue	Adare	Station Road	-	1999	January	7	Level data based on flood debris marks ~10.40m?					Station Rd area affected by flooding.	3		OPW Mungret	floodsmap			2
03-6e	Maigue	Maigue	Adare	Road	-	2002	February	01/02					Combined tidal and fluvial	150mm of road flooding.	6		OPW Mungret Memo	floodsmap	-		3
03-6f	Maigue	Maigue	Adare	Land near Adare Station, Limerick-Tarbert road west of Ferry Bridge, townland of Islandea.	-	-			Land, Limerick-Tarbert Rd, Islandea townland			Map shows the extent of flooding.	Breached left embankment a short distance below the Railway Bridge at Adare Station.	Land near Adare Station, Limerick-Tarbert road west of Ferry Bridge, townland of Islandea flooded.	-		OPW Dublin Hatch St	floodsmap	-		3
03-6g	Maigue	Maigue	Adare	Station Road	-	-						Doc Ref 2A showing Adare flooding is not attached within the doc.	Combined tidal and rainfall/runoff		-		Minute of Meeting Limerick CC	floodsmap	14/03/2005		4
03-7a	Maigue	Maigue	Adare	Curragh Bridge Islandea	-	-						Undated photograph and location map of flooding.			-		OPW Mungret	floodsmap	-		3
03-7b	Maigue	Maigue	Adare	Islandea	-	-						Undated photographs of flooding.			-		OPW Mungret	floodsmap	-		3
CAR 04 ASKEATON																					
04	Deel	Deel	Askeaton	factory car park and L1236	-	-						factory car park and L1236	Deel overflows on left bank, feeds into a stream to the west of L1236 and overflows before draining back into Deel.	Factory car park and L1236. No premises flooded.	-	frequency one or two times per annum.	OPW Flood Mapping Phase 1	floodsmap	12/04/2005		4
CAR 09 BALLYLONGFORD																					
9-1a, 3a	Ballyline	Ballyline	Ballylongford	Kerry STW	-	2002	February	1	High Tide 6.3mOD. "Highest tide" for 50 years according to locals. Tide level reached the underside of the bridge. 2 to 3ft (street flooding).			Kerry STW, street	High tide and overtopped of embankment on the northern side of the bridge. No flap valves on outfalls where some houses with no sewage system connected to.	Kerry STW were submerged causing a backflow in pipe and back up toilets in some houses. Street drainage connected to sewage system also backed up. Street flooded and some 10 houses flooded.	1		Engineers report OPW Mungret	floodmaps	26/04/2002		3
9-1b, 3b	Ballyline	Ballyline	Ballylongford		-	2002	February						Tidal	c. 10? properties affected	1		OPW Mungret	floodmaps	15/02/2002		3
9-1c	Ballyline	Ballyline	Ballylongford	Carrig Island	LIS01/769	2001	August	21							?		OPW Mungret memo - Flood history database	floodmaps	07/10/2003		4
9-1c	Ballyline	Ballyline	Ballylongford	Land Commission Embankment	LIS01/1584	2001	December	7							?		OPW Mungret memo - Flood history database	floodmaps	08/10/2003		4

Ref	Where					When			Magnitude					Impact	Ranking	Estimated AEP					Flood
	River Basin	Tributary	APSR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused			Source		Date	Authenticity	Quality Code
9-1c	Ballyline	Ballyline	Ballylongford	Land Commission Embankment	LIS02/ 1993	2002	March	8							?		OPW Mungret memo - Flood history database	floodmaps	09/10/2003		4
9-1c	Ballyline	Ballyline	Ballylongford	Land Commission Embankment	LIS02/ 2104	2002	April	8							?		OPW Mungret memo - Flood history database	floodmaps	10/10/2003		4
9-1d, 3d	Ballyline	Ballyline	Ballylongford	Only mentioned Ballylongford but no details given.	-	2002	February	1							2		Irish Times	floodmaps	06/02/2002		-
9-2a	Ballyline	Ballyline	Ballylongford	Gortnacooka Bridge	-	2004	January	15				Photograph of flood extent - road & land			?		Kerry CC	floodmaps	15/01/2004		2
9-2b	Ballyline	Ballyline	Ballylongford	Gortnacooka Bridge	-	2004	January	15				Photograph of flood extent - road & land			?		Kerry CC	floodmaps	15/04/2004		2
9-2c, 3c	Ballyline	Ballyline	Ballylongford	Bridge St	-	2002	January	6	Probably the "worst" flooding problem.			Large scale map of village with flood area (NOT PROVIDED)	High tide with rainfall runoff, wind direction and low pressure. It is not known whether the poor state of the river channel of Ballyline River helps or hinders the flooding.	At least 12 houses at Bridge St flooded up to window cill level. R551 impassable. LA water treatment plant was flooded during last event but remedial works safeguard it in this event. Probably the "worst" flooding in Kerry (at time of minutes).	1		OPW Flood Mapping Phase 1	floodmaps	01/12/2000		4
9-2c, 3c	Ballyline	Ballyline	Ballylongford	Gortnacooka Bridge	-	2002	January	6	900 to 1200mm on R552			Photographs (NOT PROVIDED)	Rainfall /Runoff and poor state of the river channel and exaverbated by tide. Restriction of bridge may be a contributory factor.	R552 is flooded and impassible two or three times per yr. Max depth 900 to 1200mm. No houses affected. (Some flooding at O'Brien's Bridge on a minor road also).	1		OPW Flood Mapping Phase 1	floodmaps	01/12/2000		4
9-3d	Ballyline	Ballyline	Ballylongford	Carrig Island	-	1990?						Carrig Island		Farmer from Carrig Island claimed that he stood to lose 15 acres of land	-		Cork Examiner	floodmaps	17/02/1990		-
9-3f	NO DIRECT RELEVANT INFO. TRALEE ONLY					1973	December	01/ 02									Kerryman	floodmaps	07/12/1973		-
9-3g	NO DATA ATTACHED																Kerryman	floodmaps	07/12/1973		-
9-3h	Ballyline	Ballyline	Ballylongford	Ballylongford	-	1961	October	22	2ft depth at Street of Ballylongford			Streets	High tide	Flooded streets of Ballylongford up to 2ft depth.	4		Kerryman	floodmaps	28/10/1961		-
9-3i	Ballyline	Ballyline	Ballylongford	Ballylongford	-	1927	October	28				Houses, streets	Intense storm - high tide and gale	Flooded a number of houses, streets with slates flying and trees falling. "one of the worst in memory".	3		Kerryman	floodmaps	05/11/1927		-
CAR 20 CHARLEVILLE																					
20	NO DATA ATTACHED																				
03-1e	Maigue	Maigue	Charleville	Houses on Smith's Lane, Baker's Lane and Clanchy Terrace flooded. Road into town flooded.		1946	August	11					Heavy rain	Houses flooded at Smith's Lane (kitchens & rooms were flooded), Baker's Lane & Clanchy Terrace. Agricultural land damaged. Roads leading to the town were flooded.			Cork Examiner	floodsmaps	15/08/1946		-
CAR 22 CLARINA																					

Ref	Where					When			Magnitude					Impact	Ranking	Estimated AEP					Flood
	River Basin	Tributary	APSR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused			Source		Date	Authenticity	Quality Code
22-1a	Maigue	Maigue	Clarina		-							Undated photograph of flooding. Location unknown.			-		OPW Mungret	floodmaps	-		3
22-1b	Maigue	Maigue	Clarina		-							Undated photograph of flooding. Location unknown.			-		OPW Mungret	floodmaps	-		3
22-1c	Maigue	Maigue	Clarina		-							Undated photograph of flooding. Location unknown.			-		OPW Mungret	floodmaps	-		3
22-1d	Maigue	Maigue	Clarina		-	1992	September					Map showing extent of flooding	1 ft depth of flooding		1		OPW Mungret	floodmaps	15/09/1992		3
22-2a, 3a	Maigue	Maigue	Clarina	Clarina Village	-	-			One event in recent years. Exceptional rainfall.			Houses	Water travelled from North West, across Ballybrown Rd, through village	Flooded a number of houses.	-		OPW Flood Mapping Phase 1	floodmaps	14/03/2005		4
22-2a, 3a	Maigue	Maigue	Clarina	Massey's Bridge	-	-			Tidal			Toe of embankment	High tide flows through bridge side wall and over the embankment downstream of the bridge on the RH bank.	No houses affected. Area flooded is over a length of 700 to 800m at toe of embankment.	-		OPW Flood Mapping Phase 1	floodmaps	15/03/2005		4
CAR 24 CROOM																					
24-1a, 2a	Maigue	Maigue	Croom		-	1986	August	05/06	2.82m (19.866 Poolbeg Datum)			Photographs of flooding at gauge & allyway.		Gauge reader who lives at the bridge stated that water had not entered her kitchen.	2		Report OPW Headford	floodmaps	-		2
24-1a, 2a	Maigue	Maigue	Croom		-	1983	December		2.86m (19.906 Poolbeg Datum)						1						2
24-1a, 2a	Maigue	Maigue	Croom		-	1973	December		2.28m (20.307 Poolbeg Datum)						3						2
24-1b	Maigue	Maigue	Croom	Cappamore (not relevant?)	-	1986	August	5									Limerick Leader		09/08/1986		-
24-1c	Mulcair?	Mulcair?	Croom?	Cappamore (not relevant?)	-	1986	August	5									Limerick Leader		16/08/1986		-
24-1d	Mulcair?	Mulcair?	Croom?	Newport, Ballymackeogh (not relevant?) - No info attached	-	1986	August	5									Guardian (Nenagh)		16/08/1986		-
24-2b	Maigue	Maigue	Croom		C1/31/4/2 & C1/31/4	1986	August	5				C1/31/4/2 & C1/31/4		Flooding along Croom-Bruff Road (along C1/31/4/2) and north of the road (along C1/31/4).	2		Report OPW Headford	floodmaps			3
24-3a	Maigue	Maigue	Croom	Caherass	-							Undated photograph of flooding						floodmaps			3
24-3b	Maigue	Maigue	Croom	Caherass	-							Undated photograph of flooding						floodmaps			3
24-3c	Maigue	Maigue	Croom	Caherass	-							Undated photograph of flooding						floodmaps			3

JACOBS

OPW

Ref	Where					When			Magnitude					Impact	Ranking	Estimated AEP					Flood
	River Basin	Tributary	APSR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused			Source		Date	Authenticity	Quality Code
24-3d	Maigue	Maigue	Croom	Caherass	-	-						Map showing area affected	Flooding caused by the blockage or lack of discharge capacity of a culverted section discharging into channel No. C1/19/2				Repot OPW Mungret	floodmaps	28/04/1995		4
24-4a	Maigue	Maigue	Croom	Dollas	-							Map showing source of flooding	Heavy rain				Minutes of meeting Limerick CC	floodmaps	04/2005		4
24-5a	Maigue	Maigue	Croom	RH bank d/s of road bridge	-							Undated photograph of flooding					OPW Mungret	floodmaps	-		3
24-5b	Maigue	Maigue	Croom	D/s of road bridge	-							Undated photograph of flooding					OPW Mungret	floodmaps	-		3
24-5c	Maigue	Maigue	Croom	RH bank u/s of road bridge	-							Undated photograph of flooding					OPW Mungret	floodmaps	-		3
24-5d	Maigue	Maigue	Croom	LH bank u/s of road bridge	-							Undated photograph of flooding					OPW Mungret	floodmaps	-		3
24-5e	Maigue	Maigue	Croom	LH bank d/s of road bridge	-							Undated photograph of flooding					OPW Mungret	floodmaps	-		3
03-1e	Maigue	Maigue	Croom			1946	August	11	"Worst flood in living memory". Worse than 1916.				Maigue overflowed banks	15 houses flooded. Banogue (Croom) Cremery was flooded.			Cork Examiner	floodsmap	15/08/1946	Newspaper report.	-
03-2b	Maigue	Maigue	Croom			1990	February							Houses flooded.			Limerick Leader	floodsmap	09/01/1999		-
03-2b	Maigue	Maigue	Croom			1995	January							Houses flooded.			Limerick Leader	floodsmap	09/01/1999		-
03-2b	Maigue	Maigue	Croom			1995	February							Houses flooded.			Limerick Leader	floodsmap	09/01/1999		-
03-2b	Maigue	Maigue	Croom			1995	March							Houses flooded.			Limerick Leader	floodsmap	09/01/1999		-
03-2b	Maigue	Maigue	Croom			1997	August							Houses flooded.			Limerick Leader	floodsmap	09/01/1999		-
03-2b	Maigue	Maigue	Croom			1998	December	29	Within 6 ft of top of new bridge. Up to windows of Riverside properties.				Overflowed defences	Houses flooded.			Limerick Leader	floodsmap	09/01/1999		-
CAR 25 DROMCOLLIHER																					
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher	Pike St	-	1984	January	16				Pike St	Rain and snow	House at Pike St flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/1997		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1986	January	22				Roads		Houses not flooded. Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/1998		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1986	July	28				Roads		Houses not flooded. Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/1999		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher	Church	-	1986	August	6				houses, church & roads		Houses and church flooded. Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2000		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1986	August	25				roads		Houses not flooded. Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2001		2

Ref	Where					When			Magnitude					Impact	Ranking	Estimated AEP					Flood
	River Basin	Tributary	APSR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused			Source		Date	Authenticity	Quality Code
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1988	January	22				Roads		Houses not flooded. Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2002		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1988	February	1				Roads		Houses not flooded. Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2003		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher	Pike St	-	1988	October	11				houses & roads		Houses flooded at Pike St. Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2004		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1988	October	21				Roads		Houses not flooded. Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2005		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1989	January	11				Roads		Houses not flooded. Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2006		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1990	February	6				Roads		Houses not flooded. Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2007		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1990	Decemb er	28				Roads		Houses not flooded. Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2008		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1991	Novemb er	12				Roads		Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2009		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1993	January	17				Roads		Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2010		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1993	Septemb er	9				Roads		Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2011		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1993	Decemb er	8				Roads		Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2012		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1994	January	14				Roads		Minor flooding - roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2013		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1994	January	15				Roads		Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2014		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1994	Decemb er	27				Roads		Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2015		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1994	Decemb er	30				Roads		Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2016		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1995	January	16				Roads		Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2017		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1995	January	17				Roads		Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2018		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1995	January	25				Roads		Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2019		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1995	February	22				Roads		Roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2020		2

Ref	Where					When			Magnitude					Impact	Ranking	Estimated AEP					Flood
	River Basin	Tributary	APSR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused			Source		Date	Authenticity	Quality Code
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher	Church	-	1995	June	30				Houses & church		Houses and church flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2021		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher		-	1997	July	12				houses & roads		Houses and roads flooded.	?		Flood Study Report OPW Dublin	floodmaps	12/2022		2
25-1a, 2b	Deel	Ahavarragh and Carroward	Dromcolliher	Pike St, Church, Pound St	-	1997	August	26	Flood levels along Pike St and Pound St ranges btw 93.50 to 117.81mOD (See table in the report for various level information).	57.5mm of rainfall in 4hr period.	Flood estimation provided. (Catchment 1 - 1:50 = 5.5m3/s, 1:100 = 6.3m3/s; Catchment 2 - 1:50 = 2.9m3/s, 1:100 = 3.4m3/s)	Map showing properties affected and the associated depths.	Heavy rainfall with insufficient capacity of the river channel. Overloaded combined sewers, raw sewage overflowed onto streets and houses. Bridges and culverts backed up along Ahavarraga Stream. Also, major channel capacity problem downstream of Dromcolliher causing a backwater effect.	Houses and roads flooded. Eastern village - several houses in Pike St area looded to 0.5m deep. Flooding of Pike St and Pound St. Western village - Ahavarraga Stream overflowed causing flooding to roads in the vicinity of church. Lands flooded. Refer to Appendix 2 of the report.	1	1:50	Flood Study Report OPW Dublin	floodmaps	12/2023		2
25-1b, 2a	Deel	Ahavarragh and Carroward	Dromcolliher	Liscarrol Rd (R522), Pound St	-	1997	August	26					Flooding caused by insufficient capacity of the Carroward Stream. Culverted crossings (especially the County Bridge on Liscarrol Rd (R522) and culvert under Pound St) restrict the flow and surcharging causing road flooding on a regular basis. Insufficient capability of channel downstream of the Ahavarragh River confluence with the Carroward Stream.		1	1:40	Dromcollihe r Localised Flood Relief Work Feasibility Study	floodmaps	10/1999		3
25-1c	Deel	Ahavarragh and Carroward	Dromcolliher	Village & sewage plant	-	1997						Village & sewage plant		Village flooded 3 times in 1997 and sewage plant was flooded.			River Deel Dromcollihe r Flooding	floodmaps	25/11/1997		3
44-2a	Deel	Ahavarragh and Carroward	Dromcolliher		-									Ref 44-2a stated "there was a serious flooding problem in Dromcolliher but remedial works was completed 3 year prior & problem eliminated.	-		OPW Flood Mapping Phase 1	floodmaps	25/04/2005		4
CAR 29 FOYNES																					
29-1a	Other		Foynes	Foynes	-	2002	February	1	19.62' OD (5.98m). Road flooded (road level 13.6' OD (4.39m) to 14.4' OD (4.15m)).			Properties	High tide overtopping embankment (level 19' OD (5.79m) to 22.53' OD (6.87m)). Possibly flooding via gullies and surface water drains without flap valve.	Domestic and commercial property flooding.	1		Resident Engineer Report OPW Mungret	floodmaps	18/09/2002		1
29-1b, 5a	Other		Foynes	Main Street & Denish	-	2002	January	23				N69, properties	Heavy rain and capacity of stream along Main St is unable to cope with the flow causing backing up of water	N69 at Dernish and a number of premises flooded	2		Limerick CC Letter	floodmaps	25/02/2002		2
29-1b, 5a	Other		Foynes	Main Street	-	2002	February	1	"more serious flooding" than 23/01/2002 event. Tide level 6.28m (compared to predicted level of 5.4m)			Properties	High tide with high floods in the Shannon.	Overtopped quay wall in the harbour area and water flowed across railway line into the rear of a number of preperties on Main St causing severe flooding.	1		Limerick CC Letter	floodmaps	25/02/2002		2
29-1c	Other		Foynes		-	2002	February					Properties	Tidal	c. 20? Properties affected to a depth of <300mm	3?	1:5?	OPW memo	floodmaps	15/02/2002		3
29-1c	Other		Foynes		-	1997?	February										OPW memo	floodmaps	15/02/2002		3

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Ref	Where					When			Magnitude					Impact	Ranking	Estimated AEP					Flood
	River Basin	Tributary	APSR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused			Source		Date	Authenticity	Quality Code
29-1d	Other		Foynes	Agricultural land to the east of Foynes	-	-						Agricultural land	High tide - flow out across the port entrance and thence up the village. May be an element of floodwater backing up the surface water sewers	Some flooding of agricultural land to the east of Foynes due to overtopping of a Land Commission Embankment. Overtopping at one location caused the capacity of the d/s drainage system to be exceeded.			OPW memo	floodmaps	05/02/2002		4
29-1e	Other		Foynes	Foynes	-	2002	February	1	Spring tide rose 1.8m higher than predicted due to strong winds			Properties	Heavy rainfall & high tide	A shop, a pub and a number of houses were flooded.	1		Irish Times	floodmaps	05/02/2005		-
29-1f	Other		Foynes	Foynes	-	2002	February	1						Flooding in Foynes.			Irish Times	floodmaps	06/02/2002		-
29-2a	Other		Foynes	Foynes	-	2005	January	8				Properties	Fluvial with tide locked condition. Previous storage area is occupied by residential development according to a resident.	At least 4 dwellings and 2 businesses	5		OPW memo	floodmaps	25/01/2005		3
29-3a, 5c	Other		Foynes	N69, Corgrigg	-	1995	February		"worst case flooding" in recent memory			N69 (Flood map not attached)	Fluvial with tide locked condition.	N69 flooded for days	4?		Limerick CC Letter	floodmaps	23/07/2003	Proposed partial stream divertion - carried out?	4
29-4a, 6a	Other		Foynes	Shanagolden area	-							Properties & road	High tides, with very intense rainfall and south westerly winds and lack of channel capacity	Main Foynes to Limerick , two houses along N69 flooded. Road and a commercial garage premises also flooded in Shanagolden area.	-		OPW memo & Limerick CC letters	floodmaps	18/05/1999		3
29-5b	Other		Foynes	Corgrig	-	-						N69 & properties		6 properties and N69 shown as flooded.	-		Limerick CC map	floodmaps	07/2003		3
29-5d, 6b, 7a	Other		Foynes	Durnish, Corgrig and Robertstown	-							Map showing locations of flooding	Heavy rain and storm/tidal flooding		-		Limerick CC map	floodmaps	04/2005		4
29-5e, 6c	Other		Foynes	N69	-	2005	January					N69	Rainfall/runoff combined with inadequate culvert capacity/storage and flooding due to high tides	Partial or complete blockage of the N69 and flooding of front gardens to houses and rarely flood the houses.	5		OPW Flood Mapping Phase 1	floodmaps	12/04/2005		4
29-5e, 6c	Other		Foynes		-	2002	January	23							2		OPW Flood Mapping Phase 1	floodmaps	13/04/2005		4
29-5e, 6c	Other		Foynes		-	1995	February	23							4?		OPW Flood Mapping Phase 1	floodmaps	14/04/2005		4
29-5e, 6c	Other		Foynes	Foynes Main Street, N69	-	2002	February	1				Properties & roads	High tides, low pressure & strong south westerly winds	Tide overflows the port quay wall, flows south westward across the railway line and into the rear of a number of properties along main street causing severe flooding to premises. Also flood main street and N69.	1		OPW Flood Mapping Phase 1	floodmaps	15/04/2005		4
29-7b	NO RELEVANT INFO				-												Minutes of meeting Cork CC	floodmaps	27/04/2005		4
37-25b	Shannon	Shannon, Abbey / Tidal	Limerick City	Foynes		1995	January	30					Heavy rain	Flooding in the Railway Rd area in particular. Foynes brigade was called out to help pumping operations at the Grotto end of Foynes.			Limerick Chronicle	floodmaps	31/01/1995		-
CAR 32 KILDINO NEW																					
32	NO DATA/SITE FOUND FROM DATABASE																				

Ref	Where					When			Magnitude					Impact	Ranking	Estimated AEP					Flood
	River Basin	Tributary	APSR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused			Source		Date	Authenticity	Quality Code
CAR 35 KILMALLOCK																					
35	NO DATA ATTACHED																				
03-1e	Maigue	Maigue	Kilmallock			1946	August	11					Rainstorm	Some of the roads were flooded, the house at the end of Wolle Tune St, Kilmallock was flooded.			Cork Examiner	floodsmap	15/08/1946	Newspaper report.	-
CAR 44 NEWCASTLE WEST																					
44-1a	Deel	Arra	Newcastle West	Newcastle West town	-	2008	August	1		Predicted 79.8mm, (7 hrs duration), 84.9mm (14 hrs)					1	>1:250yrs (0.4%)	Report on 2008 Summer Rainfall in Ireland	floodmaps	12/2008		1
44-1b	Deel	Arra	Newcastle West	Newcastle West town	-	2008	August	1	48.71 to 57.23mOD (d/s of bridge of Tears to street entrance @ Bllygowan plant)	85.9mm average rainfall.		Properties, WTW, WWTP, ESB substation & roads. (Flood Map (Figure 8.1))	"Localised flooding" due to presistent rainfall with saturated catchment	143 residential and 87 commercial properties, WTW, WWTP, ESB substation and several roads in the town were flooded.	1	>1:210yrs (0.47%)	Flooding Report, JBA	floodmaps	01/08/2008	Detailed flooding information in report	1
44-1c	Deel	Arra	Newcastle West	Newcastle West town	-	2008	August	1	Station 24030 Danganbeg (located on Deel u/s): Peak @ 03.00 with debris mark ~ 4.1m (gauge reading 3.63m)		64.9m3/s				1		EPA Report	floodmaps	05/08/2008		2
44-1c	Deel	Arra	Newcastle West	Newcastle West town	-	2008	August	2	Station 24029 Inchirourke More (located on Deel d/s): Peak @ 04.15 with level of 2.54m		46m3/s				1		EPA Report	floodmaps	05/08/2008		2
44-1c	Deel	Arra	Newcastle West	Newcastle West town	-	2008	August	1	Station 24025 Cantogher (located on tributary to Maigue): Peak @ 00.45 with level of 2.17m		Outside rating curve				1		EPA Report	floodmaps	05/08/2008		2
44-1c	Deel	Arra	Newcastle West	Newcastle West town	-	1995	February	3	Station 24029 Inchirourke More: Peak level of 2.56m		47.7m3/s				2		EPA Report	floodmaps	05/08/2008		2
44-1c	Deel	Arra	Newcastle West	Newcastle West town	-	1998	December	30	Station 24029 Inchirourke More: Peak level of 2.56m		47.6m3/s				3		EPA Report	floodmaps	05/08/2008		2
44-1d	Deel	Arra	Newcastle West	Lower Maiden St, New Rd to South Quay	-	2008	August	1	Range between 47.50 to 58.16mOD from Lower Maiden St, New Rd to South Quay						1		Flood Map OPW Mungret	floodmaps	01/08/2008		3
44-1e	Deel	Arra	Newcastle West		-										-		Other	floodmaps	01/08/2008	Video footage - not attached	
44-2a	Deel	Arra	Newcastle West	Main Road R520	-	-						Roads & land	River Deel.	Main road (R520) between Killmallock and Newcastle West flooded and impassable and adjacent land flooded. Flooding has historically occurred every 1 to 3 yrs.	-		Minutes of meeting Limerick CC	floodmaps	25/04/2005		4
44-2a	Deel	Arra	Newcastle West	Grange	-							Road	River Deel.	Road impassable roughly 2 times per annum.	-		Minutes of meeting Limerick CC	floodmaps	25/04/2005		4
44-2b	Deel	Arra	Newcastle West	Newcastle West	-							Map showing locations of flood hazard.			-		Minutes of meeting Limerick CC	floodmaps	21/06/2005		4
44-3	Deel	Arra	Newcastle West	Newcastle West	-							Map showing the type of flooding cause	Heavy rain		-		Limerick CC	floodmaps	04/2005		4

Ref	Where					When			Magnitude					Impact	Ranking	Estimated AEP					Flood
	River Basin	Tributary	APSR	Location	Grid Ref	Year	Month	Day	Peak level	Rainfall	Flow	Flood Extent	Flooding mechanism	Any damage caused			Source		Date	Authenticity	Quality Code
CAR 50 RATHKEALE																					
50-1a	Deel	Deel	Rathkeale	Deel Bridge & Balliniska - Bunoke	-	1969	January	09-12	Rainfall - 43mm (~96hrs) @ Deel				Losts of rain during Dec & Jan & saturated catchment	Flooding in Deel Valley u/s of Rathkeale at Deel Bridge & at Balliniska - Bunoke. Duration of flooding ~ 24 hours.	3		OPW Hydrometric Report	floodmaps	07/02/1969		3
50-2a	Deel	Deel	Rathkeale	Deel Bridge & Balliniska - Bunoke	-	1968	December	23-24	Rainfall - 62mm (~48hrs) @ Deel				Losts of rain during Dec & Jan & saturated catchment	Flooding in Deel Valley u/s of Rathkeale at Deel Bridge & at Balliniska - Bunoke. Duration of flooding ~ 24 hours.	1		OPW Hydrometric Report	floodmaps	07/02/1969		3
50-3a	Deel	Deel	Rathkeale	Deel Bridge	-	1968	December	11-13	Rainfall - 56mm (~72hrs) @ Deel				Losts of rain during Dec & Jan & saturated catchment	Flooding in Deel Valley u/s of Rathkeale at Deel Bridge. Duration of flooding ~ 24 hours.	2		OPW Hydrometric Report	floodmaps	07/02/1969		3
50-4a	Deel	Deel	Rathkeale	Graigue	-	-						Land & Roads	Flooding caused by feeder streams feeding the Deel backing up.	Graigue between Rathkeale & Ballingarry - land flooded on average once every 4/5 yrs. Area affected is btw the R518 and L1213. Roads not flooded.	-		Minutes of meeting Limerick CC	floodmaps	12/04/2005		4
50-5a	Deel	Deel	Rathkeale	Ballinlyny	-	-						Flooding map	Heavy rain				Minutes of meeting Limerick CC	floodmaps	04/2005		4
50-6a	Deel	Deel	Rathkeale	Knockaunavad	-	-								Knockaunavad - NW of Rathkeale - lands to east of L1219 flooded every winter.			Minutes of meeting Limerick CC	floodmaps	12/04/2005		4
50-7a	Deel	Deel	Rathkeale	Rathkeale	-	-						Flooding map	Heavy rain				Minutes of meeting Limerick CC	floodmaps	04/2005		4