



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

### Hydrology Report Unit of Management 23

### Final Report



# Document Control Sheet

BPP 04 F8

Project: Shannon CFRAM Study  
 Client: Office of Public Works  
 Document title: Unit of Management 23 Hydrology Report  
 Project No: 32103000

Originated by		Checked by	Reviewed by
<b>ORIGINAL</b>	NAME	NAME	NAME
	Keshav Bhattarai Kenny Samson	Elmar Torenga	Elmar Torenga
<b>Approved by</b>	NAME	As Project Manager I confirm that the above document(s) have been subjected to Jacobs' Check and Review procedure and that I <b>approve them for issue</b>	INITIALS
	Peter Smyth		P.S.
DATE	07 April 2014	<b>DRAFT revision 0</b>	

<b>REV 1_0</b>	NAME	NAME	NAME
	Keshav Bhattarai	Elmar Torenga	Elmar Torenga
<b>Approved by</b>	NAME	As Project Manager I confirm that the above document(s) have been subjected to Jacobs' Check and Review procedure and that I <b>approve them for issue</b>	INITIALS
	Peter Smyth		P.S.
DATE	23 April 2014	<b>DRAFT revision 1_0</b>	

<b>REVISION 2_0</b>	NAME	NAME	NAME
	Keshav Bhattarai	Elmar Torenga	Elmar Torenga
<b>Approved by</b>	NAME	As Project Manager I confirm that the above document(s) have been subjected to Jacobs' Check and Review procedure and that I <b>approve them for issue</b>	INITIALS
	Peter Smyth		P.S.
DATE	05 July 2016	<b>FINAL</b>	

## Copyright

Copyright Office of Public Works. All rights reserved.

No part of this report may be copied or reproduced by any means without prior written permission from the Office of Public Works. If you have received this report in error, please destroy all copies in your possession or control and notify the Office of Public Works.

## Legal Disclaimer

This report is subject to the limitations and warranties contained in the contract between the commissioning party (Office of Public Works) and Jacobs Engineering Ireland Limited.

## Executive Summary

As part of the Shannon Catchment Flood Risk Assessment and Management (CFRAM) study a series of Hydrology Reports has been produced, one for each unit of management within the Shannon River Basin District (RBD). The RBD consists of Units of Management (UoM) 23, 24, 25/26 and 27.

This Hydrology Report details the hydrological assessment for the CFRAM study in UoM 23. A review of the available hydrometric data for the unit of management was undertaken and is detailed in the Inception Report (September 2012, Chapters 3, 6 and 7). That report also describes the methodologies that were chosen for this unit of management.

The influence of soil types and geology was considered in deriving flood estimates. The dominant aquifer group in UoM 23 is the 'locally important aquifer' group. The lower Feale catchment consists of locally and regionally karstified aquifers. Some scattered poor aquifers are also observed near the periphery of the unit of management.

Soils in UoM 23 are dominated by the combination of poorly drained soil and peat. Some scattered well drained soil is found at the upstream reach of the River Feale as well as along the coastal areas. In addition to this, some alluvium is located along the river valley of the Feale.

As a consequence of the combination of the soils and aquifer geology karst is not considered to play a significant role in the hydrological flood response of the modelled catchments in UoM 23.

A review of historic flooding was undertaken during the Inception stage and the findings of this review are detailed in the Inception Report for this unit of management (Chapter 8). No significant floods have been experienced in this unit of management since the commencement of the Shannon CFRAM study in January 2011.

A rating review was undertaken for Station Ballymullen (23012) in this unit of management. This showed that the water levels at this gauge may be affected by the tide. It is recommended that this station is not used for flood flow estimation. No hydraulic model was completed for this station and no attempt was made to derive a set of rating equations following a request from OPW that work relating to this gauging station cease.

Due to a dearth of sub-daily rainfall data, Jacobs' approach to peak design flow estimation in the Shannon River Basin District (RBD) avoids the use of rainfall data, focussing instead on the use of gauged flow data, supplemented by Flood Study Update (FSU) techniques where no flow data is available. An index flood approach was adopted to determine the peak design flows at key points along the modelled watercourses. This approach involves the estimation of QMED, the median of the annual maxima (AMAX) flow series (which equals the 2-year return period [50% annual probability] peak flow), and using growth factors applied to QMED to estimate the peak flows for higher return periods up to 1000 years (0.1% annual probability). These growth factors were obtained by pooling group analysis and single site analysis. The results of these two methods were then compared and a view was taken on the best choice of method and distribution.

Estimates of QMED at key points along the model extents were derived from the FSU regression equation, which were adjusted using gauged data from key gauging station in the vicinity where available. This was done in accordance with implementation guidance in the FSU with respect to pivotal sites, with the determination of adjustment factors for any model length being guided by the number, quality and similarity of the gauging stations available for selection as pivotal sites.

The hydrograph shapes were estimated for watercourses from gauged data on the subject watercourse or at a hydrologically similar pivotal site if there were no gauged flows available on the subject watercourse.

The hydraulic model of the watercourse was then run with the inflow hydrographs and some reconciliation was carried out to ensure peak flows at key locations along the model extents were sufficiently close to the hydrological estimates at these points. A difference between anticipated total peak flow and hydraulic model peak flow of less than approximately 10% was normally sought.

Where gauged data and other historic flood information of sufficient quality was available, calibration and/or verification of the model was undertaken. Dependent on the available data this could result in re-evaluation of the hydraulic model, the hydrology or both.

The hydrological analysis resulted in a series of inflow hydrographs for each hydraulic model for a range of return periods (annual exceedance probabilities), at the upstream model boundaries and at key locations along the model extent to represent laterally contributing subcatchments. This report includes maps showing the catchment to a model extent, model inflow locations, a table and map showing river reaches for which the same hydrological parameters were adopted, tables with catchment descriptor ranges for each reach, tables with QMED adjustment factors, tables and graphs with flood frequency curves for each reach, tables with hydrological (target) peak flows and peak inflows, and graphs with design inflows for the 10-, 100- and 1000-year return period floods (i.e. 10%, 1% and 0.1% AEP). The flood estimates detailed herein were used in the hydraulic modelling to produce estimates of water level and flood extent throughout the modelled reaches.

The confidence in flood estimation can be increased by having more non-tidal gauging stations in the unit of management and by carrying out high flow check gaugings at the existing gauging stations. It is recommended that the Ballymullen gauging station (23012) is moved upstream to avoid the effects of the tidal cycle.

It is recommended that the flood hydrology be reviewed every 5 to 10 years as more annual maxima and flood event data become available.



## Contents

<b>Glossary</b>	<b>1</b>
<b>1 Introduction</b>	<b>1</b>
<b>2 Methodology</b>	<b>2</b>
2.1 Introduction	2
2.2 Rating Reviews	2
2.3 Design Hydrology	4
2.4 Determining QMED	5
2.5 Determining Flood Frequency Curves	7
2.5.1 General	7
2.5.2 Single Site Analysis	7
2.5.3 Pooled Analysis	8
2.6 Hydrograph Shape	9
2.7 Calibration	11
2.7.1 General	11
2.7.2 Hydrological Estimation Point (HEP) Calibration	11
2.7.3 Hydraulic Calibration	11
<b>3 Study Area</b>	<b>13</b>
3.1 Introduction	13
3.2 Shannon River Basin District	13
3.3 Units of Management	13
3.4 Feale – Tralee Bay (Unit of Management 23)	15
3.5 Geology	15
3.6 History of Flooding	22
3.6.1 Feale Catchment	22
3.6.2 Lee (Kerry) catchment	23
3.6.3 Tyshe Catchment	23
<b>4 Hydrological Analysis</b>	<b>24</b>
<b>5 Uncertainty in Design Flow Estimates</b>	<b>25</b>
5.1 Introduction	25
5.2 Confidence Quantified	28
<b>6 Future Environmental and Catchment Changes</b>	<b>30</b>

6.1	Introduction	30
6.2	Future Changes Quantified	31
<b>7</b>	<b>Conclusions and Recommendations</b>	<b>37</b>
7.1	Conclusions	37
7.2	Recommendations	37
<b>8</b>	<b>References</b>	<b>38</b>
<b>Appendix A Sub-catchment Hydrological Analysis</b>		
<b>Appendix B Model Specific Hydrological Analysis</b>		
<b>Appendix C Rating Review Summary Sheets</b>		
<b>Appendix D Gauging Station Information Sheets</b>		
<b>Appendix E Flood Frequency Curves</b>		
<b>Appendix F Calibration Strategy Sheets</b>		
<b>Appendix G Pooling Group Audit Trail</b>		
<b>Appendix H Geomorphology Assessment</b>		

## Glossary

AEP	Annual Exceedance Probability (%)
AFA	Area for Further Assessment
AMAX	Annual Maxima
ARTDRAIN2	% of the catchment river network included in drainage schemes (catchment descriptor)
BFIsoil	Baseflow index derived from soils data (catchment descriptor)
CFRAM	Catchment-based Flood Risk Assessment and Management
DEM	Digital Elevation Model (retains elevations of structures, vegetation, etc.)
DMF	Daily Mean Flow
DRAIN2	Drainage Density (catchment descriptor)
DTM	Digital Terrain Model (also referred to as bare earth model, level raster where structures and vegetation have been filtered out)
EPA	Environmental Protection Agency
ESB	Electricity Supply Board
EV1	Extreme Value Type 1 distribution (also referred to as Gumbel distribution)
FARL	Flood Attenuation by Reservoirs and Lakes (catchment descriptor)
fse	factorial standard error
FSU	Flood Studies Update
HEFS	High-End Future Scenario
HEP	Hydrological Estimation Point
HGF	Highest Gauged Flow (= highest check gauging)
HPW	High Priority Watercourse
IRR	Individual Risk Receptor
LN, LN2	2-parameter Log Normal distributions
LO	2-parameter Logistic distribution
MPW	Medium Priority Watercourse
MRFS	Mid-Range Future Scenario
NDHM	National Digital Height Model
NTCG	National Technical Coordination Group
OPW	Office of Public Works
PEAT	% of land area covered by peat bogs (catchment descriptor)
PFRA	Preliminary Flood Risk Assessment
QMED	Median Annual Flow (median of long-range annual maxima)
RBD	River Basin District
SAAR	Standard Annual Average Rainfall (mm) (catchment descriptor)
S1085	10-85% stream slope (m/km) (catchment descriptor)
UAF	Urban Adjustment Factor: $(1 + \text{URBEXT}/100)^{1.482}$
UoM	Unit of Management
URBEXT	Urban Extent (%) (catchment descriptor)
WFD	Water Framework Directive
WP	(FSU) Work Package

## 1 Introduction

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 Hydrology Reports, one covering each unit of management within the Shannon River Basin District (RBD). The RBD consists of Units of Management (UoM) 23, 24, 25/26 and 27. UoM 25/26 is the amalgam of two hydrometric areas (HA25 and HA26).

A requirement of the Hydrology Report is to detail the hydrological assessment that has been undertaken as part of the study. A review of the available hydrometric data for the unit of management was undertaken and is detailed in Chapters 3, 6 and 7 of the Inception Report of UoM 23 (September 2012). That report also describes the methodologies that were chosen for this unit of management.

A list of towns and villages that are thought to be susceptible to flooding was collated in the flood risk review stage. These towns and villages are referred to as Areas for Further Analysis (AFAs). Other important flood risk receptors (e.g. power stations and airports) are defined as Individual Risk Receptors (IRR). Section 3.4 specifies the AFAs and IRRs in this unit of management.

A review of historic flooding was undertaken during the Inception stage and the findings of this review are detailed in the Inception Report for this unit of management (Chapter 8).

During the Inception stage, the unit of management catchment boundaries were checked; refer to Chapter 5 of the Inception Report for more details.

This report assumes that the reader has read the Inception Report related to this unit of management, and that he or she has a good understanding of hydrology, in particular statistical methods for flood frequency analysis and the Flood Studies Update (FSU) documentation and calculation techniques.

Chapter 2 of this report outlines the methodology of the design flood hydrograph estimation process. Chapter 3 describes the study area including its flood history. Chapter 4 introduces the sub-catchment wide and model-specific hydrological analysis undertaken, which are detailed in Appendix A (in three chapters, one for each sub-catchment) and B (in six chapters, one for each hydraulic model). The sub-catchments and model extents are shown on Figure 3.2. Conclusions and recommendations are provided in Chapter 5. Chapter 6 gives the relevant references. The rating review summary sheets for reviews undertaken in UoM 23 are included in Appendix C. Appendix D presents gauging station information sheets with the original and revised AMAX series as used in the design flood hydrology for the sub-catchments within this unit of management. Appendix E shows the flood frequency curves for flow gauging stations which have been used for design flood estimation. Appendix F contains the calibration sheets for each model, and Appendix G presents pooled analysis audit trails for the unit of management.

## 2 Methodology

### 2.1 Introduction

This chapter outlines the general principles of the hydrological methodology employed in the design flood estimation process. It discusses briefly a rating review in the unit of management, the flood frequency analysis, the selection of a hydrograph shape along with hydrological and model calibration.

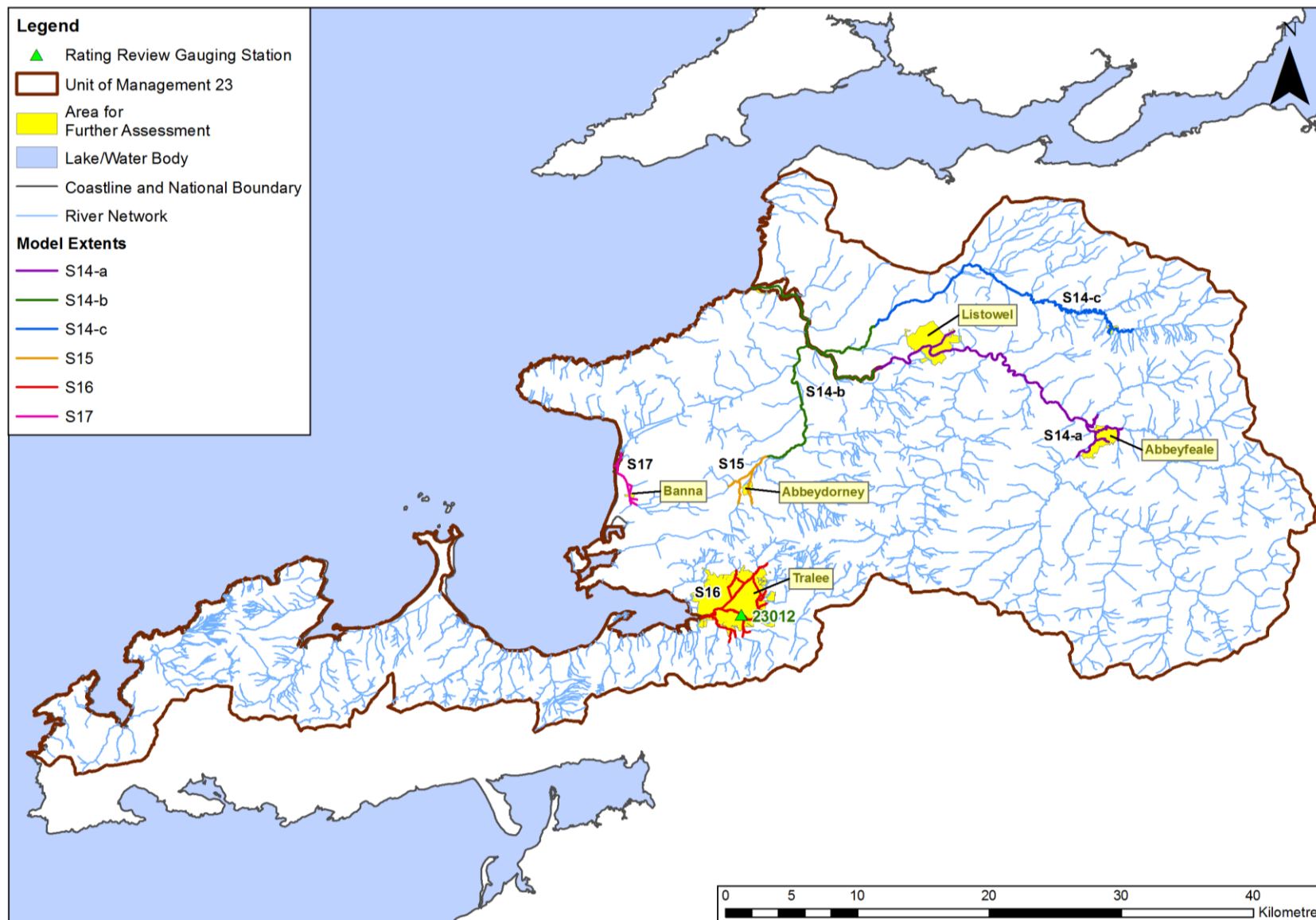
### 2.2 Rating Reviews

A rating review was undertaken for one station in this Unit of Management. The rating review gauging station is shown on Figure 2.1 below and on the model extent map in the sub-catchment section for the Tralee catchment in Appendix A. The rating review showed that the water levels at this gauge may be affected by the tide. It is recommended that this station is not used for flood flow estimation. No hydraulic model was completed for this station and no rating equations were produced following a request from OPW that work relating to this gauging station cease.. Therefore, the AMAX flows at this station were not used for the hydrological analysis.

The quality of all relevant flow stations in the modelled catchments (both the reviewed and not reviewed stations) within the unit of management is discussed in the respective sub-catchment sections in Appendix A.

Gauging Station Number	Gauging Station Name
23012	Ballymullen

**Table 2.1**      **UoM 23 Gauging Station Rating Review**



**Figure 2.1 Rating Review Stations in UoM 23**



## 2.3 Design Hydrology

Section 3.4 of Appendix B of the UoM 27 Inception Report discussed rainfall data from various sources. It concluded that there is a good network of daily-read raingauges (approximately 750 nation-wide), but there are not many raingauges that record rainfall at smaller intervals.

Met Éireann operate two radars for rainfall detection. However, rainfall depths and intensities estimated from radar data is not generally accurate enough for the purpose of flood estimation and was dismissed for this study.

Due to the dearth of sub-daily rainfall data, Jacobs' approach to peak design flow estimation in the Shannon River Basin District (RBD) avoids the use of such data, focussing instead on the use of gauged flow data, supplemented by Flood Study Update (FSU) techniques where no flow data is available.

The Gauging Station Information Sheets in Appendix D provide an overview of each gauging station used with the design hydrology and the existing and revised AMAX series.

The design hydrology approach is summarised below:

1. Gauging station rating reviews provide increased confidence in high flows gauged at specific gauging stations in the catchment. These gauging station reviews are critical in providing reliable information to be used as pivotal sites for hydrological adjustments to flood estimates at ungauged sites.
2. Rework the annual maxima series of flood flows as required at rating reviewed gauging stations.
3. Estimate the median of annual maxima flows (QMED) for key gauging stations (ideally ones that have been subject to a rating review or ones that are otherwise reliable) in or near the model domain from the gauged annual maxima at the site and compare this to the outcome of the FSU regression equation at the gauging station. Divide the two QMED estimates at these stations to obtain a QMED adjustment factor ( $QMED_{observed} / QMED_{synthetic}$ )
4. Estimate QMED at all ungauged HEPs using the FSU regression equation and adjust these using the QMED adjustment factor found in Step 3 for the key gauging station in the vicinity of the HEPs. This is done in accordance with implementation guidance in the FSU with respect to pivotal sites, with the determination of adjustment factors for any model length being guided by the number, quality and similarity of the gauging stations available for selection as pivotal sites.

To assess which river sections the QMED adjustment factors and the growth curves (see Step 5 below) should be applied to, **river reaches** were defined in the context of this study as sections of watercourse with similar hydrological characteristics, so that a single QMED adjustment factor and growth curve can be applied. The catchment is split up in river reaches based on a comparison of the catchment descriptors used in the regression equation to estimate QMED, e.g. AREA, BFIsoil, FARL, S1085, etc. and also an assessment of the availability and quality of gauging stations.

5. Produce flood frequency estimates at the key gauging stations by multiplying the observed QMED estimate with a suitable set of growth factors to obtain a range of AEP peak flows. The growth factors are obtained by pooling group analysis and single site analysis. The results of these two methods are then compared and a view is taken on the best choice of method and distribution. Refer to Section 2.5 for more detail on the choice between pooling and single site distributions.
6. Estimate the hydrograph shape for the watercourse from gauged data or a pivotal site, using the methodology described in Section 2.6 below.
7. Combine output from Steps 4, 5 and 6 above to estimate design flood hydrographs at each HEP.
8. Run hydraulic models (with appropriate amendments to the model inflows where required) to give consistency of design flows between the hydrological and hydraulic estimates, within a reasonable degree of accuracy (a difference between anticipated total flow and hydraulic model flow of less than approximately 10% is normally sought). The inflow hydrographs resulting from Step 7 above are timed in such a way that the peaks of all inflow hydrographs coincide with the peak of the flood wave moving down the river system.
9. Once calibrated, adjust the timings of the downstream tidal boundary such that the flood peak at the downstream end of the model coincides with the tidal peak, taking account of the Guidance Note on Joint Probability Analysis (GN20).

The adopted approach avoids the use of rainfall data, which has the advantage that it does not need to make assumptions about the spatial distribution of historical rainfall events which is only known at very few point locations. It also avoids having to make assumptions with regard to the runoff coefficients during design events. Instead, the approach relies on gauged flow and level data where these are available, and on the FSU regression equation for QMED where such data is not available (adjusted with pivotal data where appropriate).

Where level data but no flow data or reliable rating was available, it was sometimes possible to put this to good use by deriving design flood peak water levels (e.g. in lakes from AMAX levels if a sufficiently long record was available), or to determine a suitable initial water level. They were also occasionally used as downstream boundary conditions in lakes or river confluences. Such uses have been described in Appendices A and B for each subcatchment and/or model.

The different components of the design event flow estimation process (QMED, growth factors, hydrograph shape) are discussed in Sections 2.4 - 2.6 below.

## 2.4 Determining QMED

At a gauged site QMED was obtained as the median of the annual maximum flow series. At ungauged sites QMED was estimated using a regression equation based on seven catchment descriptors as detailed in FSU Work Package 2.3.

Where there is no gauged data the approximate 68% and 95% confidence intervals for an estimate of QMED based on the regression equation can be given as:

68% confidence interval = (QMED/fse, QMED x fse)

95% confidence interval = (QMED/fse<sup>2</sup>, QMED x fse<sup>2</sup>)

Where possible these estimates were improved by adopting a pivotal station, either in the same catchment, a neighbouring catchment, or in a hydrologically similar catchment.

Unless a pivotal station was in the same or a neighbouring catchment and hydrologically similar, typically no single station could be marked as much better than others. To avoid giving too much weight to one pivotal station, in most cases it was decided to derive a weighted mean QMED adjustment factor from the adjustment factors of these five stations.

An example calculation for a point in the S16 model is shown below (from Appendix A, Section A2.1).

The adjustment factors were estimated using a weighted geometric mean of the five hydrologically most similar gauged sites. The Dij parameter summarises the hydrological similarity between the subject site and the pivotal site and is a function of the AREA, BFIsoil and SAAR catchment descriptors. The weight of a pivotal site is the inverse of Dij divided by the sum of the inverses for all five pivotal sites (for Station 14033 below it is 1.83 divided by 6.32). The weights add up to 1. The geometric mean is the product of the site-specific adjustment factors to the power of the weight, for all five pivotal sites:

Final Adjustment Factor =  $\prod (\text{Adjustment Factor}^{\text{Weight}})$ . (where  $\prod$  is the product sign)  
 In Table 2.2 this is:  $1.17^{0.29} \times 1.42^{0.215} \times \dots = 1.11$ .

The adjustment factors for each station reflect the ratios of the gauged and statistical estimates and were provided by OPW as part of the FSU gauging station datasets.

Station Number	Station Name	Rank	Dij	1/Dij	Weight	Adjustment Factor
14033	MOUNTMELICK	1	0.545	1.83	0.290	1.17
35002	OWENBEG	2	0.735	1.36	0.215	1.42
34009	OWENGARVE	3	0.894	1.12	0.177	0.73
35004	OWENMORE	4	0.967	1.03	0.163	0.82
1041	DEELE	5	1.024	0.98	0.154	1.58
<b>Sum</b>				6.32	1.000	
<b>Final Adjustment Factor (Weighted Geometric Mean)</b>						<b>1.11</b>

**Table 2.2 QMED Adjustment Factor for HEP 23\_1520\_2 (Reach 1)**

The rainfall runoff response of a catchment can be altered by urbanisation where impervious surfaces inhibit infiltration and reduce surface retention, while increases in surface runoff result in an increase in the speed of response. The effect on the peak flow is accounted for in the hydrological analysis by an urban adjustment factor (UAF) applied to the rural estimate of QMED, as specified in Section 4 of FSU Work Package 2.3.

## 2.5 Determining Flood Frequency Curves

### 2.5.1 General

Growth factors may be determined from at-site data, if sufficient good quality data exists. This study includes the estimation of flood peaks with annual exceedance probabilities as low as 1% (1 in 100), 0.5% (1 in 200) and 0.1% (1 in 1000), and at-site data will not normally have long enough records for single site analysis to be appropriate. It is noted that OPW have intimated at the second NTCG meeting that the 1% (1 in 100) AEP event should be considered the target probability. For that target probability pooling group analysis was normally selected in preference over single site analysis, unless it was found that a representative pooling group could not be formed, or the at-site data showed that the pooled curve was not realistic. Where the available information was not decisive on the use of pooled or single site analysis, then when certain conditions (specified in FSU Work Package 2.2) were satisfied a combined approach was considered. A method of combining the two methods is specified in a technical note from OPW (*Combining Site and Pooled Analyses at the Subject Site* (M2.11), 10 December 2012).

The choice between a single site and pooling group analysis was made on a site by site basis. The decision was informed by the reliability of AMAX data, the record length, the presence of extreme floods in the AMAX series, the fit of different statistical distributions, and the homogeneity of the pooling group. The flood frequency curves at each gauging station comparing pooled distributions with at-site data are included within Appendix E. The pooling analysis audit trails are located in Appendix G.

### 2.5.2 Single Site Analysis

The required flood magnitude may be estimated from a single record of at-site data providing the AMAX series is sufficiently long in relation to the target return period. FSU Work Package 2.2 (Section 14.2) states:

*“The required flood quantile may be estimated from a single record of at-site data providing:*

- *the record length  $N$  is at least 10 years long*
- *the required quantile return period  $T$  is less than  $N$ , or not appreciably larger than  $N$  and certainly not more than  $2N$ ”*

As indicated in Section 2.5.1, the 1% (1 in 100) AEP storm can be considered the target design event for the hydrological analysis. FSU Work Package 2.2 (Section 14.6) states that: *“in ordinary circumstances a three parameter distribution should not be used with at-site data. An exception could be made if the data series is very long, say > 50 years, and the required return period is small, say 25 years.”* With a focus on a return period of 100 years, two parameter distributions have generally been selected in the Shannon CFRAM study. A few exceptions have been made where long records were available (> 50 years) and three parameter distributions could be shown to give a better fit with the AMAX flows and more realistic AEPs for the highest floods on record.

FSU Work Package 2.2 (Section 14.2) also states that: “*In the case of EV1 the parameters should be estimated by the method of probability weighted moments (or the L-moment equivalent).*” In the Shannon CFRAM study the method of (ordinary) moments was used to fit the EV1 distribution to the on-site data, in accordance with Shaw *et al* (2011). In the few occasions where three parameter distributions were chosen the more refined L-moments method was employed to fit a flood frequency curve to the observed data.

The selection of the (single site) distribution (EV1, LN2, etc) was done visually from a Gringorten plot showing the ranked AMAX series. Where estimates of the AEP of the highest recorded flood(s) was/were available, this was used to select the distribution that assigned an AEP to that event that was closest to the estimate.

### 2.5.3 Pooled Analysis

The 100 year event is considered the target return period for this study. If the 5T rule is applied to the 100 year flood estimation then a minimum of 500 station years of data should be included in the pooling group. FSU suggests that such a pooling group be used for all return periods rather than constructing a separate group for every return period of interest. Pooling groups were selected on the hydrological similarity between sites, although the criteria of nearness and presence in the same catchment may also play a role (the latter particularly in larger catchments).

The initial catchment descriptor limits for the acceptance of sites to the pooling group are shown in Table 2.2 below.

AREA	between 0.25 and 4 times the area of the subject site
BFIsoil	+/- 25% of subject site
SAAR	+/- 25% of subject site
FARL	+/- 10% of subject site
URBEXT	+/- 2.5
FLATWET	(FORMWET) +/- 0.10

**Table 2.2 Pooling Analysis Acceptable Ranges**

If no homogenous pooling group could be established within these limits, then the limits were relaxed as deemed appropriate for that subject site.

Consideration was given to the choice of using two parameter or three parameter distributions. Two parameter distributions were generally applied, but three parameter distributions were considered in the case of a particularly poor fit. In most cases variations in peak design flows were relatively small between the various pooled distributions.

If the single site analysis was based on sufficiently reliable data (with a relatively long record and a few extreme floods), the pooled distribution which matches closest with the single site growth curve was favoured as the latter is based on local flood data. The comparison of single site analysis with pooling group analysis allows a check on the validity of the design floods. Where single site analysis indicates that the pooled distribution may not be representative for the site (e.g. if the pooled 1% AEP [100 year return period] flood has been exceeded several times in a relatively short period of record), then a single site flood frequency curve may be more appropriate than the pooled flood frequency curve.

## 2.6 Hydrograph Shape

The method of determining the design event hydrograph shape was selected in order to make best use of the available gauged data.

For gauged sites with sufficiently reliable flow records, the highest gauged flows were determined using the AMAX and DMF data. For the majority of stations the four highest recorded floods were selected and the hydrograph that from a visual comparison best represented the median duration at 80% of the peak flow was used in the design hydrology. With typical record lengths of 30 to 60 years these four floods will have return periods roughly in the range of 7 to 200 years (14% AEP to 0.5% AEP) and therefore be representative of the return periods of events of interest to this study (2 to 1000 years, i.e. 50% to 0.1% AEP). For stations with very short AMAX records (up to 10 years) only the highest three events were considered as the return period of the fourth highest peak would be likely to be too low to be representative for the range of floods that is to be considered for this flood study.

When a hydrological or hydraulic model is calibrated double-peaked hydrographs are usually avoided as such events are notoriously difficult to calibrate to. Such a consideration was not relevant for the design event runs. The importance of considering realistic flood responses at a gauge was given preference over any concern with unusually shaped hydrographs. As an example of this it could happen that for a particular gauging station most events show a double peak as a consequence of the combined effect of a large rural catchment and a smaller urban tributary; in such a case it seems appropriate that the adopted design hydrograph reflects that shape. Therefore double-peaked hydrographs were not dismissed for this analysis.

The above method involving the hydrographs of real flood events was preferred over the use of the gauged  $n$ ,  $T_r$  and  $C$  parameters detailed in FSU Work Package 3.1 (WP 3.1, Hydrograph Width Analysis) which derives an average shape from the highest  $N$  events over a period of  $N$  years. That method is skewed towards higher frequency events as half of that set of events occurs more frequently than the 50% (1 in 2) AEP design event, events which are of lesser interest to this study.

On reaches where no gauged data was available (i.e. flows based on a rating) an appropriate hydrograph shape was selected from a gauged pivotal site. The pivotal sites were selected in the following order of preference:

1. A reliable gauging station in the same catchment (downstream or upstream of the subject site) with similar catchment descriptors (see Table 2.3 below); or
2. A reliable gauging station in a neighbouring catchment with similar catchment descriptors (see Table 2.3); or
3. A hydrologically similar site, based on the similarity measure  $D_{ij}$  which is a function of the three catchment descriptors BFIsoil (geology), FARL (routing) and S1085 (slope). The OPW Hydrograph Generator spreadsheet, (based on the FSU WP 3.1) was implemented for this analysis. The most similar site was compared with the subject site using a range of catchment descriptors to ensure that none of these descriptors were very different from the subject site, within the ranges shown in Table 2.3 below. If the most similar site didn't accord with the ranges in Table 2.3 then the second or third most similar site was compared.



AREA	between 0.25 and 4 times the area of the subject site
BFIsoil	+/- 25%
SAAR	+/- 25%
FARL	+/- 10%
URBEXT	+/- 2.5
S1085	+/- 50%
ARTDRAIN	+/- 10
ALLUV	+/- 3

**Table 2.3 Hydrograph Shape Acceptable Ranges**

At pivotal sites the design event hydrograph was determined with the FSU WP 3.1 hydrograph shape equations using the gauged  $n$ ,  $T_r$  and  $C$  parameters, or using the Top 3-4 of recorded flood peaks if such information was readily available (i.e. at reliable stations in the Shannon RBD). Given the uncertainty associated with the use of pivotal sites the use of the WP 3.1 method using gauged  $n$ ,  $T_r$  and  $C$  parameters was considered acceptable, notwithstanding the observations in the third paragraph of this section (see above).

A consistency check was undertaken to ensure that the synthetic hydrograph duration for a tributary was shorter than that of its main stem (gauged or pivotal), or another nearby larger watercourse, if (all other parameters being similar) the catchment was smaller. Where a pivotal site failed this consistency test, another pivotal site was considered if available.

The presence of karst features in the catchment was also taken into consideration. A site in a different geology with regard to karst than the subject site may not be considered a suitable pivotal site.

In small ungauged tributary catchments where no suitable pivotal site could be found, the FSU WP 3.1 regression equations were employed to derive a synthetic hydrograph shape. For larger catchments this is not generally the preferred approach because the correlation between the catchment descriptors and the shape parameters  $n$ ,  $T_r$ , and  $C$  is weak, and the regression equations do not feature the catchment area as an independent variable, whilst the catchment area can be expected to be one of the key parameters affecting the flood duration.

However, for small ungauged tributaries for which no suitable pivotal site was available, the synthetic FSU WP 3.1 method was considered acceptable. The synthetic FSU hydrograph was adopted if a consistency check between the subject catchment and other catchments showed that the resulting flood duration was reasonable. The consistency check ensured that the flood duration for a tributary was shorter than that of its main stem (gauged or pivotal), or another nearby larger watercourse, if (all other parameters being similar) the catchment was smaller.

At ungauged sites where no suitable pivotal station could be found and the synthetic hydrograph was considered unrealistic or inconsistent, the FSR (NERC 1975, Volume I, Section 6.8.2) method for producing a flood hydrograph shape was used as a last resort.

The required design flood hydrograph was calculated by linear scaling of the hydrograph's ordinates so that the peak agreed with the target peak flow obtained from the statistical analysis for each specified return period. The selected hydrograph shape was used for each HEP in a river reach as defined in Section 2.3 (Step 4) above. Following an initial hydraulic model run the modelled total flow

hydrograph at the subject site was compared with the selected design hydrograph to ensure that the resulting hydrograph has a similar volume.

## **2.7 Calibration**

### **2.7.1 General**

The dearth of sub-daily rainfall records for the catchment severely limits the application and accuracy of traditional rainfall-runoff techniques to simulate historical events. The uncertainty arising in the calibration of such models and the subsequent need to adjust the model flood flow predictions to align with the flood frequencies derived from local flow gauge records, renders rainfall-runoff modelling ineffective. Rainfall-runoff modelling of historical events has therefore been discounted. The use of radar rainfall data was dismissed for rainfall-runoff modelling due to known issues with the calibration of such data, and the relatively short radar record length. This data may still be useful for qualitative assessment of the distribution of rainfall during calibration events, where such information is required.

Hence a combination of Hydrological Estimation Point calibration and hydraulic calibration is proposed as detailed in the sections below. The Calibration Strategy Sheets for the hydraulic calibration of each model extent can be found in Appendix F.

### **2.7.2 Hydrological Estimation Point (HEP) Calibration**

Within the broader context of hydraulic model calibration, there was the need for consistency and continuity moving downstream through the catchments with regard to flows and flow frequency. Therefore, for a given AEP the peak flow at one HEP derived from the hydrological analysis should match broadly with the total flow in the model at that location, and there should be only a small discrepancy between the estimates. The accepted discrepancy for this study was 10%.

If a discrepancy greater than 10% was found, normally because the routing/storage effect in the catchment was greater than the hydrological flow estimation method predicts, then inflows were scaled to obtain a better match between modelled flows and anticipated flows based on the hydrological analysis. The scaling was done by multiplying each hydrograph ordinate with a constant factor. It should be noted that locally the discrepancy can be different for a wide range of physical reasons not represented by the hydrological methods, and that the inflows were only adjusted if the discrepancy was consistent over a range of HEPs and for a range of AEPs.

### **2.7.3 Hydraulic Calibration**

Where a flow gauge was located at a suitable location upstream or downstream of an AFA and suitable historic (anecdotal) flood information existed, we selected two in-bank events and two out of bank events, obtained the relevant hydrographs from the gauging station and applied it to the hydraulic model to allow the gauged reach through (or very close to) the AFA to be calibrated and verified. Intervening ungauged catchments contributing to the watercourse through the AFA were allowed for by scaled the inflow up by a factor determined by the ratio of QMED at the AFA and QMED at the gauged location. Clearly, the closer the gauge was to the AFA and the fewer the number of ungauged contributing catchments between the gauge and the AFA, the more successful the calibration was.

Where no historic (anecdotal) flood information existed, it was sometimes still possible to calibrate the model using gauged water levels instead. To calibrate the hydraulic model this level gauge should not normally be the same gauge as the one that provides the historic flows to the model, as such flows are derived from water levels at the gauge, and the model run would only provide a localised comparison of the model rating with the rating previously established at the gauge. Especially at rating review stations, where the rating used to establish the calibration event hydrograph may be based on a hydraulic model, this would be a completely circular argument and not actually test the modelled flood outlines. Where two or more gauging stations were close to each other (on the same main watercourse), the upstream flow gauge could be used to provide flow data to the model, and the observed water levels at the downstream gauge could be compared with the modelled water levels at the same location. This method was not normally successful if significant tributaries joined the main watercourse between the two stations, unless the tributary had a reliable flow gauge close to the confluence.

In areas without a nearby flow gauging station, anecdotal and historical flood information (if suitably reliable information was available) was compared to the flood outlines derived from the design events. This served as a reality check and helped determine whether the frequency of flooding experienced in the past was broadly replicated by the model.

Where reaches that were suitable for calibration were tidally influenced, and suitable historic tidal hydrographs existed, we applied these hydrographs to the models as part of the calibration process.

With regard to data gathering for use within the model calibration exercise, the focus was to draw on data included within [www.floodmaps.ie](http://www.floodmaps.ie) where this provides sufficient information, supplemented with additional data provided by Local Authorities where details were known.

The hydrology stage of the calibration is summarised for each model in Appendix B, and the calibration strategy development for each model is described in the Calibration Strategy Sheets in Appendix F.

## 3 Study Area

### 3.1 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.

### 3.2 Shannon River Basin District

The Shannon River Basin District is the largest River Basin District (RBD) in Ireland, covering approximately 17,800 km<sup>2</sup> and more than 20% of the island of Ireland. The Shannon RBD extends into Northern Ireland, although the part in Northern Ireland is very small (less than 3 km<sup>2</sup>) and does not include any areas identified as being at particular risk of flooding. 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 3.1).

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.

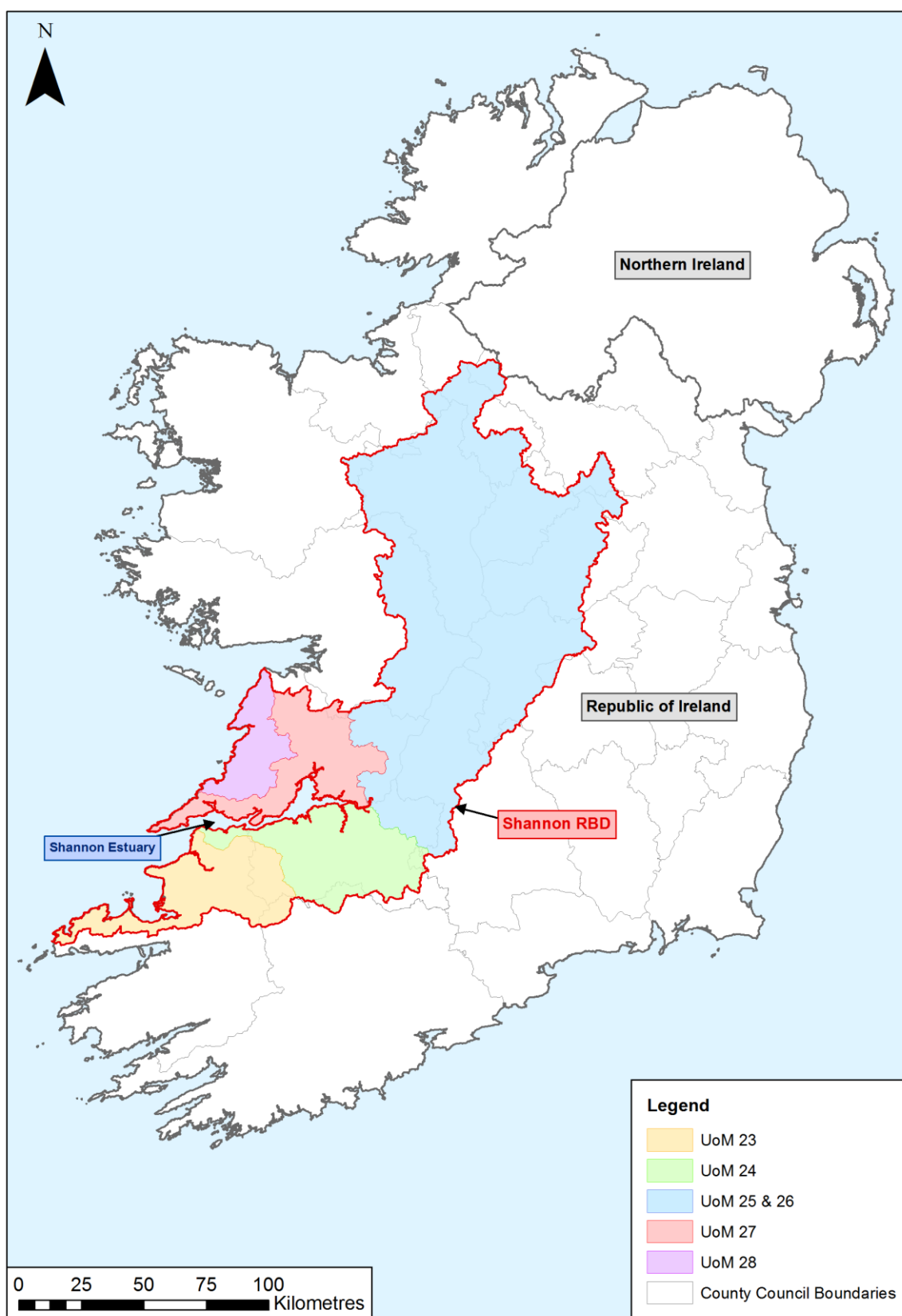
### 3.3 Units of Management

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

There are five units of management (UoM) within the Shannon River Basin District (see Figure 3.1):

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

This report appraises the Feale and Tralee Bay Unit of Management (UoM 23) only. Analysis and discussion for the remaining units of management are presented in separate reports. There is no hydrology report for UoM 28 as there are no AFAs within this UoM. For more details please refer to the Unit of Management 28 Inception Report (Chapter 9).



**Figure 3.1** *Shannon River Basin District and its Units of Management*

### 3.4 Feale – Tralee Bay (Unit of Management 23)

The Feale and Tralee Bay Unit of Management (or UoM 23) is located within three counties; Kerry, Limerick and Cork (Figure 3.1). The total area of UoM 23 is approximately 1800 km<sup>2</sup>. It is bounded on the northwest by the mouth of the Shannon Estuary and on the east and southeast by the Mullaghareirk Mountains, forming the catchment boundary between UoM 23 and 24 (Figure 3.2). Along the southern boundary from east to west are the Glanaruddery Mountains and the Slieve Mish Mountains which extend into the Dingle Peninsula.

UoM 23 is dominated by the Feale catchment in the central and eastern area. The River Feale drains into Cashen Bay in its lower reaches where it becomes tidally influenced. This catchment, with a total area to the mouth of the Cashen of 1155 km<sup>2</sup> makes up around 65% of the total area of UoM 23. Major tributaries to the Feale catchment include the Shannow, Brick, Galey, Smearlagh, Allaghaun, and Oolagh rivers. These typically drain the upland areas to the east and south of the area, with the exception of the Brick which predominantly drains a lowland area towards the west.

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

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

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

There are seven Areas for Further Assessment (AFAs) in Unit of Management 23:

Abbeydorney	Abbeyfeale	Athea	Banna
Listowel	Moneycashen	Tralee	

There are no Individual Risk Receptors (IRRs) in UoM 23.

To assist with the hydrological analysis, the unit of management has been divided into three sub-catchments, namely, the Feale, the Lee and the Tyshe. These sub-catchments are shown on Figure 3.2 and the hydrology for each of these catchments is discussed in detail in Appendix A, Chapters A1 to A3.

### 3.5 Geology

The spatial distribution of geological features of UoM 23 including the hydrological groupings of the aquifers, soil drainage types and Karst geological features are presented in Figures 3.2, 3.3 and 3.4 respectively. The classification of the aquifer groups are presented in Table 2.4. Figures 3.3 and 3.4 are based on the same data that is used in Figures 4.1 and 4.2 in FSU WP 5.2 (OPW 2009).



From Figure 3.3 and Table 3. it can be observed that the dominant aquifer group in UoM 23 is the locally important aquifer group (LI). The lower Feale catchment consists of locally and regionally karstified aquifers (Lk and Rkd). Some scattered poor aquifers (PI and Pu) are also observed near the periphery of the unit of management.

UoM 23 is dominated by the combination of poorly drained soil and peat, as observed in Figure 3.4. Some scattered well drained soil is found at the upstream reach of the River Feale as well as along the coastal areas. In addition to this, some alluvium is located along the river valley of the Feale.

The location of karst features and of geological strata that can exhibit karstic behaviour are shown on Figure 3.5. The Geological Survey of Ireland (GSI) has provided the base data for the information shown on this map, .The karst layer shown forms a detailed inventory of surveyed karst features in Ireland. However, this information is not complete and may not show the features in certain counties where no survey has taken place yet. Therefore the karstic aquifers have been added to the map, showing areas that have the potential for karstic catchment behaviour.

Karst is generally not considered to play a significant role in the hydrological flood response in the AFAs and modelled catchments in UoM 23.

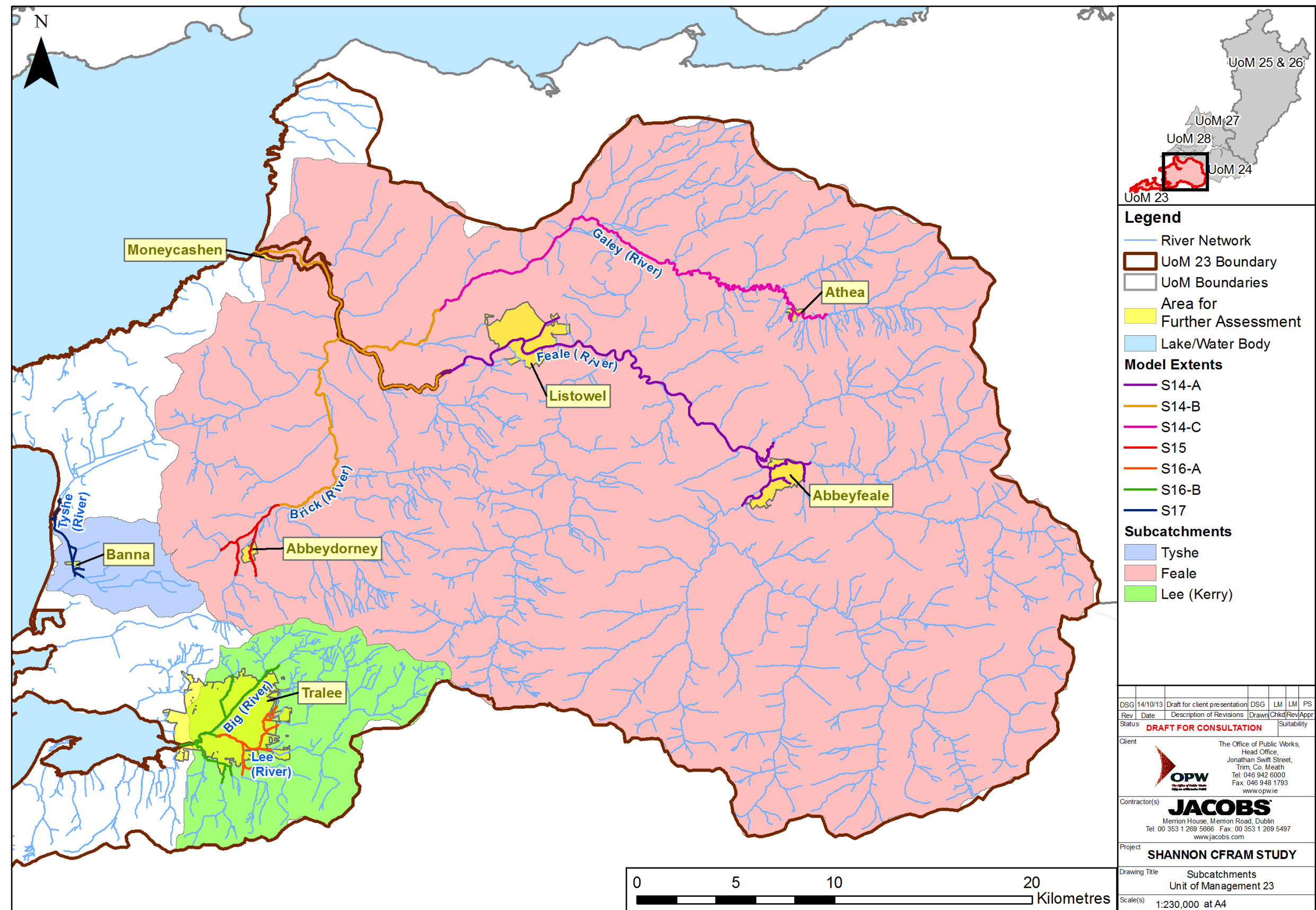


Figure 3.2 UoM 23 Sub-catchments

Aquifer Type	Class Code	Hydrological Grouping
Regionally important karstified aquifer dominated by conduit flow	Rkc	Rkc_Rk
Regionally important karstified aquifer	Rk	
Regionally important karstified aquifer dominated by diffuse flow	Rkd	Rkd_Lk
Locally important Aquifer karstified	Lk	
Locally important aquifer which is generally moderately productive.	Lm	Lm_Rf
Regionally important fissured bedrock aquifer	Rf	
Locally important aquifer – Bedrock which is moderately productive only in Local Zones	LI	LI
Poor Aquifer – Bedrock which is generally unproductive	Pu	Pu_Pl
Poor Aquifer – Bedrock which is generally unproductive except for Local Zones.	Pl	
Locally important sand gravel aquifer	Lg	Lg_Rg
Regionally important sand gravel aquifer	Rg	

**Table 3.2**                      **Aquifer Hydrological Grouping as shown in Figure 3.3**

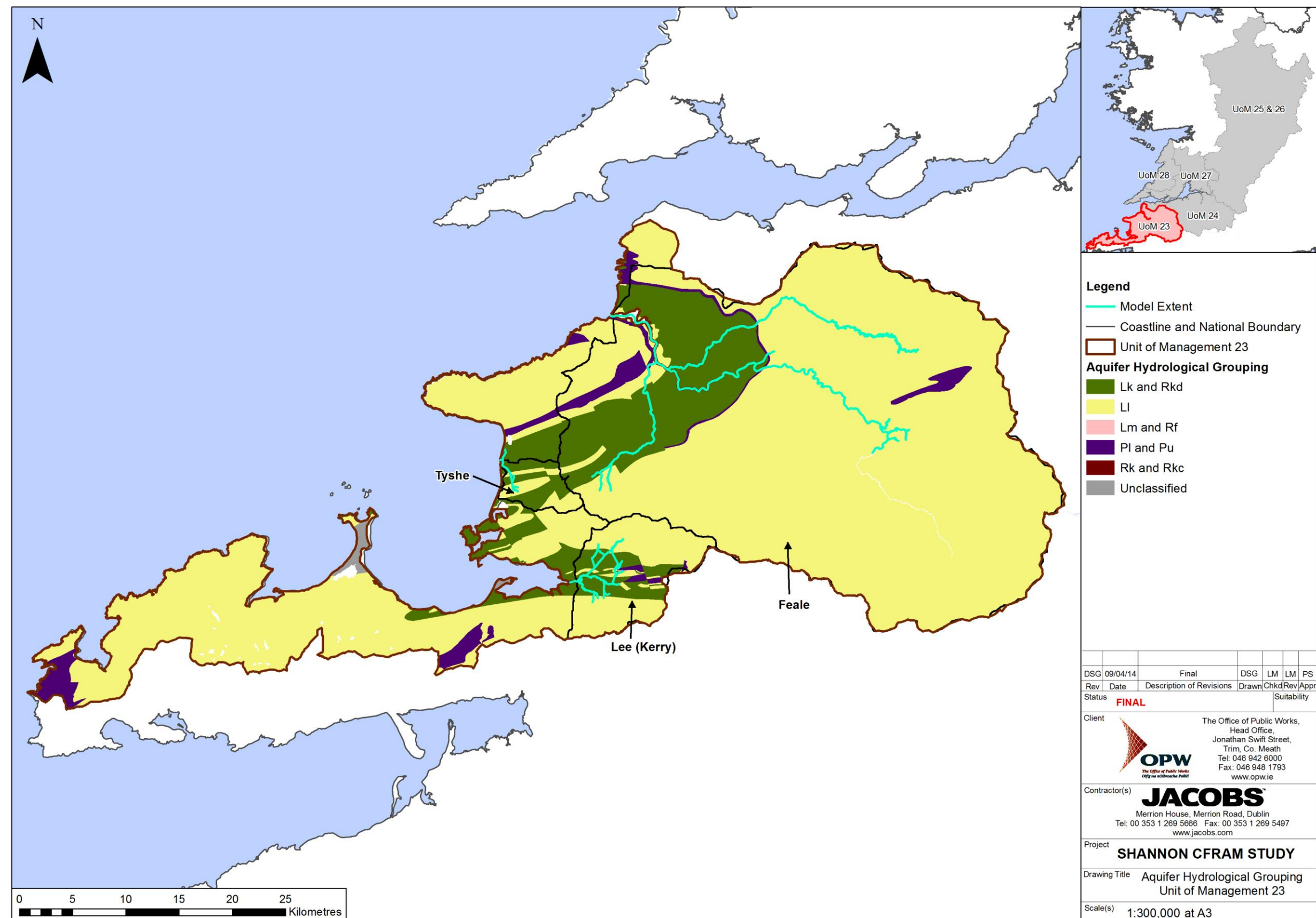


Figure 3.3 Aquifer Hydrological Groupings



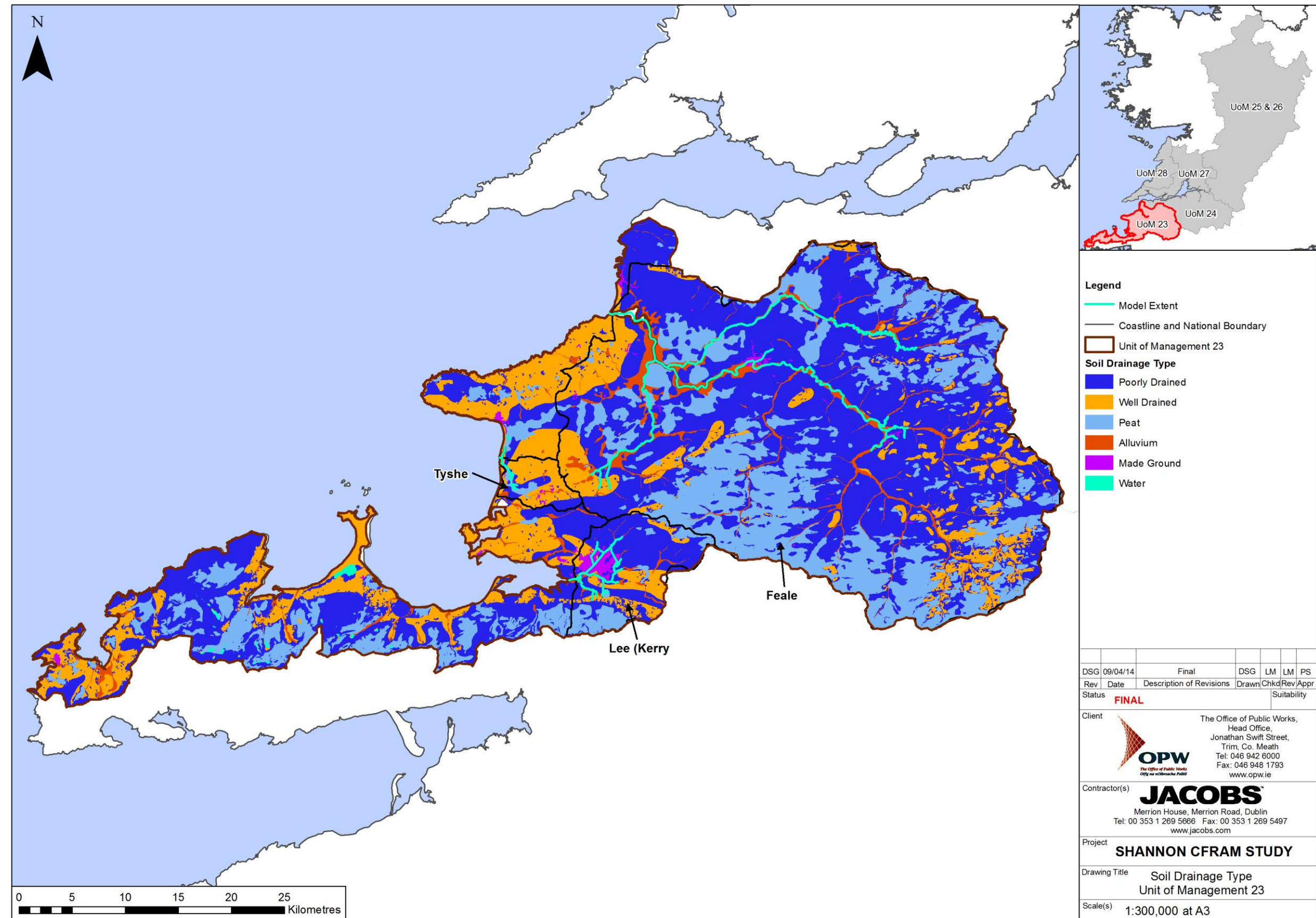


Figure 3.4 Soil Drainage Types

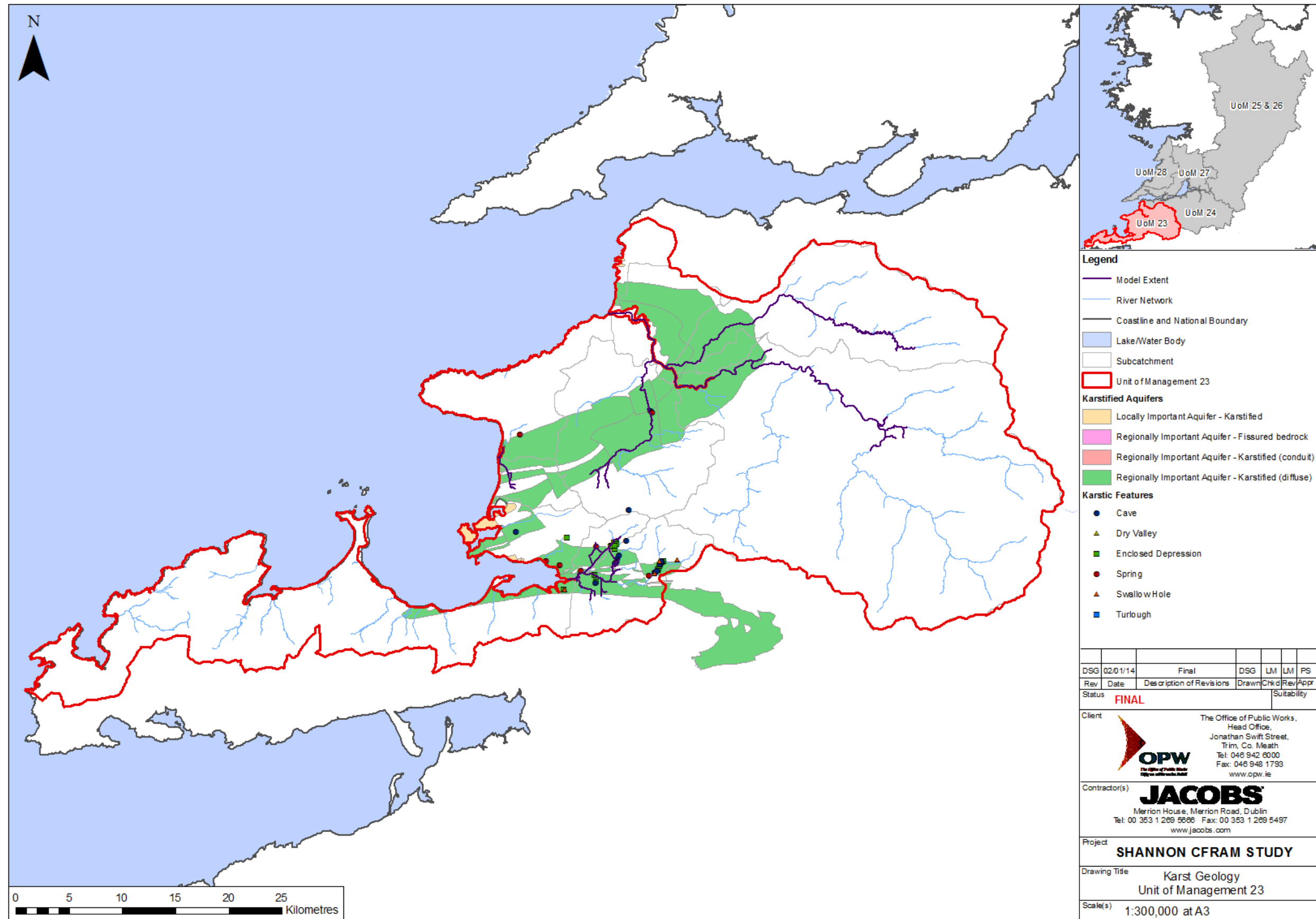


Figure 3.5 Karst Geological Features



### 3.6 History of Flooding

Flood records were studied as part of the Inception Study to determine a flood history for the sub-catchments making up UoM 23. The findings are summarised below. Further information on the flood events that were employed for calibration or verification of the hydraulic models, as well as details of the calibration for each of the hydraulic models can be found in Appendix B, Chapters B1 to B7. Calibration strategy summary sheets are provided in Appendix F.

#### 3.6.1 Feale Catchment

Five AFAs, namely Abbeyfeale (River Feale), Listowel (River Feale), Moneycashen (Feale Estuary), Athea (River Galey) and Abbeydorney (River Brick) are located in the Feale catchment. A brief review of the history of flooding in these five AFAs is presented below.

##### Listowel AFA

Major flood events that affected Listowel AFA were recorded in February 2001, July 2002, November 2002 and August 2003. The localised nature of the flood events and the fact that reported events do not appear to coincide with fluvial flood events recorded at the gauging station on the river (gauging station number 23002 - Listowel) suggest the potential source of the flooding being pluvial with the main mechanism of flood generation being a combination of localised storm events which may generate high surface runoff beyond the capacity of the drainage system.

##### Abbeyfeale AFA

The Abbeyfeale AFA located at the upper reach of the River Feale model extent was affected by the flood event of January 2005. As the 2005 flood event coincided with the high flow record at Station 23002 (Listowel), the cause of this flooding is considered to be fluvial.

##### Moneycashen

The Moneycashen AFA, located at the Feale Estuary, is susceptible to tidal/coastal flooding. This AFA was affected by a major tidal flood event in February 2002 (anecdotal evidence suggesting that tidal flood levels were at their highest in more than 80 years).

##### Athea AFA

The Athea AFA is located close to the upper boundary of the River Galey model (S14c). This AFA was affected by flooding in April 2005, in August 2008 and in September 2009. According to the Athea Flood Severity and Impact Report by JBA (October 2008), the main cause of the August 2008 flood in the Athea area was the extreme rainfall event, the AEP of which was estimated to be 0.16% (i.e. a return period of 650 years).

##### Abbeydorney AFA

The Abbeydorney AFA is located on the River Brick, close to the upper boundary of the S15 model. The Abbeydorney area was affected by local surface water related flooding in October/November 1994.

### 3.6.2 Lee (Kerry) catchment

Tralee AFA is located in the River Lee (or Kerry) catchment. The River Big is the major tributary of the Lee (Kerry). A brief review of the history of flooding in the Tralee AFA is presented below.

#### **Tralee AFA**

The main sources of flooding in this AFA and surrounding area are the two tributaries of the River Lee: the Rivers Big and Balloonagh. These two tributaries drain the steeply sloping ground to the north of the town. Due to the underlying geology and steepness of the catchments, storm flows in the Big and Balloonagh are characterised by short durations and high peak flows resulting in flash flooding.

The Tralee area was flooded several times. The major recorded flood events were in November 1916, November/December 1924, January 1925, March 1955, May/December 1973, November 1980, August 1986, November 1996, August 1997, December 2005, August 2008, November 2009 and February 2011. According to the National Flood Hazard Mapping website [www.floodmaps.ie](http://www.floodmaps.ie), the recurrence of flood events in the town centre has improved after major drainage works following the severe flooding of August 1986. However, areas outside the Tralee town centre appear to flood regularly. Most of the floods in Tralee are reported to have been caused by overgrowth in the banks of the river channels and inadequate capacity of culverts along the River Lee and its two tributaries the Big and Balloonagh.

### 3.6.3 Tyshe Catchment

#### **Banna AFA**

The Banna AFA is located in the Tyshe catchment. According to the records available on the website [www.floodmaps.ie](http://www.floodmaps.ie) this AFA was affected by flooding in November 1980. In addition, recurring flooding has been reported on the R551 road through the village of Ardfert, which is located to the southeast of Banna AFA.

## 4 Hydrological Analysis

The estimation of design event hydrographs for the model extents in the unit of management requires the analysis of the hydrological response of its sub-catchments. For this purpose three sub-catchments were defined, as shown on Figure 3.2. The analysis of each of the three sub-catchments is described in Appendix A, Chapters A1 to A3.

Subsequent to the sub-catchment analysis the hydrological analysis involves calibration of the seven individual models, and design event hydrograph estimation at HEPs in each of the models. The model-specific analysis is summarised in Appendix B, Chapters B1 to B6. Appendix B also discusses the calibration of each model.

## 5 Uncertainty in Design Flow Estimates

### 5.1 Introduction

Flood flow estimation is based on the interpretation of historical gauged flood data. In general, the more that is known about the flood history of a site, the better the design flow estimate can be. However, the uncertainty in most flood flow estimates is considerable, and may well be the largest contribution to the uncertainty in the flood maps.

There are several sources of uncertainty in the design flood flow estimates.

- (a) The length of gauged record and the extreme value analysis techniques
- (b) Data accuracy
- (c) Changes to the land use, drainage network and climate over the period of record
- (d) Model uncertainty

These sources of uncertainty are discussed in more detail below.

#### (a) Record Length and Extreme Value Analysis

The longer a gauging station record, the greater the confidence in the estimate of the design flows at the station. A short record length increases the uncertainty in a flood estimate, as there is a higher chance that the observed flows to date are atypical. This uncertainty is statistically quantifiable for a given annual exceedance probability, and FSU WP 2.2 (OPW 2009) reports that for Ireland the standard error (SE) for QMED is:

$$SE(QMED) = (0.36/\sqrt{N}) \times QMED$$

(where N is the number of years in the AMAX record length)

If the error can be assumed to be normally distributed on a log-scale, then the confidence intervals can be approximated by:

$$\begin{aligned} 68\% \text{ confidence interval: } & (QMED/FSE, QMED \times FSE) \\ 95\% \text{ confidence interval: } & (QMED/FSE^2, QMED \times FSE^2) \end{aligned}$$

(where FSE is related to SE as follows:  $FSE = 1 + SE/QMED = 1 + 0.36/\sqrt{N}$ )

For design peak flows greater than QMED single site or pooling group analysis is undertaken, dependent on the return period of interest. In this study the target return period is 100 years, and as this is generally longer than the period of record, pooling is preferred over single site analysis. In pooling the AMAX record is extended by including the data from stations that are hydrologically similar to the subject site. Section 13.4 of FSU Work Package 2.2 specifies that the uncertainty in flow estimates from pooling for return periods greater than 2 years is dominated by the uncertainty in QMED, suggesting that the standard error for a return period T ( $Q_T$ ) can be approximated using the same equation as that used for QMED above:

$$SE(Q_T) = (0.36/\sqrt{N}) \times Q_T$$

However additional sources of uncertainty are brought into the estimation of rarer events based upon the pooling group approach. These include:

- The assumption that hydrological similarity can be achieved in the selection of pooling group members. No catchment will have exactly the same mixture of characteristics as the target catchment and therefore cannot be considered an exact facsimile.
- Individual pooling group members are assumed to have independent flow records.
- The flood frequency analysis relies on the accuracy of all the data points within the AMAX series, including the highest floods which by virtue of their rareness and magnitude inevitably come with greater uncertainty. This is in contrast with the estimation of QMED for which the extreme AMAX values are irrelevant;
- The assumptions imposed upon the flood frequency relationship when fitting a statistical distribution to the data - the uncertainties of which are magnified when extrapolating the flood frequency curve beyond the magnitude of the largest events on record. This includes issues concerning the choice of what statistical distribution to use, and the choice of fitting procedures of the distribution to the data, etc.

It is difficult to quantify the magnitude of these uncertainties and no established and practical means of achieving this is available. Consequently the estimates based on the equation for SE ( $Q_T$ ) above should be considered to offer a lower limit measure of the uncertainty in the design flood estimates.

Some sense of the scale of the uncertainty related to the choice of statistical distribution can be obtained from Appendix A. There the growth curves from at-site data and from different statistical distributions used to fit the data to (generally EV1, LN2 and 2-parameter logistic distributions) are shown together with the Gringorten plotting position of the AMAX series. Although techniques exist to help judge which distribution best fits the data these often give a rather ambiguous steer and there can be little to choose between distributions that give different extrapolated estimates.

Similarly, the resulting growth factors related to the use of different statistical distributions in the pooling analysis are tabulated in the pooling group audit trails in Appendix G. These also give a sense to the scale of uncertainty related the flood frequency analysis.

## **(b) Data Accuracy**

Only a few gauging stations in the unit of management have a stage-discharge rating that is known to be reliable for high flows. Only when it has been possible to undertake check gaugings during several floods, and these are not scattered (i.e. they form a line on a stage-discharge plot), can one have confidence that a rating can be trusted for flood conditions.

Reasons for scatter in check gaugings are many and include: difficulty in undertaking a satisfactory gauging on the day (conditions can be challenging), poor performance of the equipment, weed-growth (seasonal variation), geomorphological changes at the gauge, transitory downstream backwater effects and hysteresis in the stage discharge relationship.

The extrapolation of the rating beyond the highest check gaugings (which is nearly always needed to estimate the biggest flows) is particularly prone to introducing errors. There is a reliance that the relationship based upon the check gaugings

holds – yet as the water rises there can be distinct changes in the cross sectional profile that the water is passing through (e.g. the transition from solely channel flow to a combination of channel flow and out-of-bank flow). Also depending on the local circumstances the high flow hydraulic control may change, also leading to a change in the stage-flow relationship.

Changes to a rating can occur as a consequence of: changes to the geomorphological characteristics of the channel, (seasonal) weed growth, drainage works, changes to the gauge structure if there is one, station datum changes, rating reviews based on new gauging data or refined understanding which may only be applicable to part of the record. Capturing these variations accurately within the station information database can be difficult, introducing additional uncertainty.

Rating uncertainty is largely station-specific and difficult to quantify. A qualitative appreciation of the uncertainty can be obtained from a stage-discharge plot showing the check gaugings with the rating, though this can be a non-trivial comparison as different check gaugings may attract different levels of confidence. For gauging stations that were subject to a CFRAM rating review in UoM 23, stage-discharge plots were produced and included in the rating review summary sheets in Appendix C.

### **(c) Land Use, Drainage Network and Climate Change**

The statistical analysis of floods assumes that the available flow records are formed in a stationary climate and from a catchment whose flood controlling characteristics are not changing. Some change is likely, though if the changes are small then the statistical analysis can still be considered to have sufficient validity.

Land-use changes do not generally have large effects on flood flows at a catchment scale. The exception to this may be in small catchments where there is more potential for extensive change to occur. For example the extensive urbanisation of a small rural catchment is likely to result in a marked change to the flood event runoff characteristics.

Drainage works were carried out throughout Ireland from the late 1940s to the early 1990s. These may have had some effects on the flood flows in the watercourses downstream of these works. In UoM 23 there is insufficient gauged data to infer any effects.

A non-stationary climate is another source of uncertainty. Climate change as a consequence of global warming is projected to increase the risk of flooding in the future. Such a long-term sustained change to climatic conditions has the distinct potential to alter the flood frequency relationship of a catchment, though some uncertainty exists as to the precise magnitude of these changes. It is also likely that climate change has already started to influence the hydrology to some extent meaning that the available flood records may already incorporate some non-stationarity. The influence of climate change therefore introduces further uncertainty.

Future climate change and future changes to the principal forms of land use in Ireland (urbanisation and afforestation) are discussed in more detail in Chapter 6.

### **(d) Model Uncertainty**

In ungauged watercourses QMED (the 2-year return period flow) is estimated from a regression equation developed from gauging station data that samples the range of catchment conditions across Ireland.



The FSU Work Package 2.2 (OPW 2009) reports a factorial standard error (FSE) of 1.37 for the estimate of  $QMED_{rural}$ , and confidence intervals as:

68% confidence interval:  $(QMED/FSE, QMED \times FSE)$

95% confidence interval:  $(QMED/FSE^2, QMED \times FSE^2)$

The regression estimate of QMED is often adjusted using one or more pivotal stations. In this study up to five pivotal stations were used. This should have a beneficial effect on the confidence intervals, but this cannot be quantified as the effect is different for each location dependent on the quality and suitability of a pivotal station.

Urban and permeable catchments are subject to more uncertainty than others. This is because urban and permeable sites are underrepresented in the list of gauging stations used to derive the QMED regression equation, and due to the added complexity of their runoff responses which are seen to exhibit greater variability between similar catchments compared to other types of catchment. In urban settings the interaction of the urban landscape and its particular location specific drainage system has a large effect on flood event runoff. In permeable catchments the location specific characteristics of the underground hydrogeology play an important role in determining the runoff.

Similarly, catchments affected by lakes and reservoirs can also be expected to yield larger errors than other catchments.

For ungauged sites that are on a gauged watercourse, upstream or downstream from it, the confidence in a peak flow estimate will become smaller with increasing distance to the gauging station. This uncertainty has not been studied in the FSU and is not quantified. However, it should be borne in mind when assessing the accuracy of flow estimates and flood outlines along the CFRAM model extents.

## 5.2 Confidence Quantified

Tables 5.1 and 5.2 provide a list of HEPs within the AFAs in UoM 23, one HEP for each modelled watercourse. For each of the 14 locations the tables summarise the method of flow estimation for QMED: 'statistical' where the FSU regression method was used (with or without a QMED adjustment from pivotal stations), or 'gauged' if it is based on a gauged reach. The tables provide the catchment, model extent, reach number and 68% confidence intervals for the 50% (1 in 2 year) and 1% (1 in 100 year) AEP design floods respectively. In all instances the 1% AEP design peak flow was determined with pooling group analysis. These confidence intervals are explained and caveated in Section 5.1.

On a gauged reach the confidence limits apply to the gauging station location. Moving away from the gauging station the uncertainty will increase.

It is worth bearing in mind that the uncertainty specified here is only that caused by the limited record length (at gauged locations) and the regression model inaccuracy (at ungauged locations). Other uncertainties are described in Section 5.1.

AFA	Model	HEP	QMED Estimation Method	50% AEP Design Peak Flow (m <sup>3</sup> /s)		
				68% Lower Limit	Central Estimate	68% Upper Limit
Listowel	S14A	23_2556_2	Gauged	353	369	386
Abbeyfeale	S14A	23_1973_3	Statistical	2.26	3.10	4.25
Abbeyfeale	S14A	23_1733_5	Statistical	47.3	64.8	88.8
Abbeyfeale	S14A	23_121_3	Statistical	153	210	288
Athea	S14C	23_2579_1	Statistical	21.9	30.0	41.1
Abbeydorney	S15	23_988_8	Statistical	3.21	4.40	6.03
Tralee	S16A	23_2921_2	Statistical	21.0	28.8	39.5
Tralee	S16A	23_1563_2	Statistical	6.06	8.30	11.4
Tralee	S16A	23_2750_2	Statistical	7.45	10.2	14.0
Tralee	S16A	23_2698_6	Statistical	2.34	3.20	4.38
Tralee	S16B	23_2376_5	Statistical	2.63	3.60	4.93
Tralee	S16B	23_2727_7	Statistical	8.10	11.1	15.2
Tralee	S16B	23_2612_3	Statistical	12.6	17.3	23.7
Banna	S17	23_497_2	Statistical	2.34	3.20	4.38

**Table 5.1 AFAs with 50% AEP Design Peak Flow Confidence Intervals (in m<sup>3</sup>/s)**

AFA	Model	HEP	QMED Estimation Method	1% AEP Design Peak Flow (m <sup>3</sup> /s)		
				68% Lower Limit	Central Estimate	68% Upper Limit
Listowel	S14A	23_2556_2	Gauged	780	815	852
Abbeyfeale	S14A	23_1973_3	Statistical	5.04	6.90	9.45
Abbeyfeale	S14A	23_1733_5	Statistical	104	143	196
Abbeyfeale	S14A	23_121_3	Statistical	339	464	636
Athea	S14C	23_2579_1	Statistical	51.5	70.5	96.6
Abbeydorney	S15	23_988_8	Statistical	8.18	11.2	15.3
Tralee	S16A	23_2921_2	Statistical	39.4	54.0	74.0
Tralee	S16A	23_1563_2	Statistical	11.8	16.2	22.2
Tralee	S16A	23_2750_2	Statistical	14.3	19.6	26.9
Tralee	S16A	23_2698_6	Statistical	4.45	6.10	8.36
Tralee	S16B	23_2376_5	Statistical	5.18	7.10	9.73
Tralee	S16B	23_2727_7	Statistical	15.9	21.8	29.9
Tralee	S16B	23_2612_3	Statistical	24.7	33.9	46.4
Banna	S17	23_497_2	Statistical	4.96	6.80	9.32

**Table 5.2 AFAs with 1% AEP Design Peak Flow Confidence Intervals (in m<sup>3</sup>/s)**

## 6 Future Environmental and Catchment Changes

### 6.1 Introduction

The CFRAM study considers how design floods may change in the future by the use of two scenarios that combine climate change and land-use change allowances. The two scenarios are referred to as the Mid-Range Future Scenario (MRFS) and the High-End Future Scenario (HEFS), as described below (from OPW CFRAM brief):

- The MRFS is intended to represent a 'likely' future scenario, based on the wide range of predictions available and with the allowances for increased flow, sea level rise, etc. within the bounds of widely accepted projections.
- The HEFS is intended to represent a more extreme potential future scenario, but one that is nonetheless not significantly outside the range of accepted predictions available, and with the allowances for increased flow, sea level rise, etc. at the upper the bounds of widely accepted projections.

The allowances provided by OPW to be used across the CFRAM studies for a time horizon of 100 years are provided in Table 6.1 below.

Parameter	MRFS	HEFS
Extreme Rainfall Depths	+20%	+30%
Flood Flows	+20%	+30%
Mean Sea Level Rise	+500mm	+1000mm
Land Movement <sup>1</sup>	-0.5mm/year	-0.5mm/year
Urbanisation	Review case-by-case	Review case-by-case
Afforestation <sup>2</sup>	-1/6 Tp	-1/3 Tp +10% SPR <sup>3</sup>

<sup>1</sup> Applicable to southern part of the country only (Dublin-Galway and south of this)

<sup>2</sup> Reduce the time to peak (Tp) by a sixth or third. This allows for potential accelerated runoff that may arise as a result of drainage of afforested land

<sup>3</sup> Add 10% to the Standard Percentage Runoff (SPR) rate: This allows for increased runoff rates that may arise following felling of forestry.

**Table 6.1 Allowances for Future Scenarios (Time Horizon 100 Years)**

Given that the hydrological approach applied to the Shannon RBD is based solely on river flows and does not use rainfall the rainfall allowance has not been used in the Shannon work. Mean sea-level rise and land movement are considered in the hydraulic modelling (see the hydraulic modelling report for UoM 23 for more details) and are therefore not discussed here.

The flow allowances for climate change, urbanisation and afforestation are discussed in more detail in the following section.

## 6.2 Future Changes Quantified

### (a) Flood Flows and Climate Change

The potential future effects of increases in flood flows due to climate change have been incorporated in the hydraulic modelling by undertaking separate runs in which the original design inflows are scaled up proportionally by a factor 1.2 and 1.3 for the MRFS and HEFS respectively. As per the CFRAM brief, flood maps have been produced for the MRFS runs, whereas the HEFS model results are provided in GIS format but not mapped.

### (b) Urbanisation

The process of urbanisation and the associated increase in impervious surfaces can be expected to typically result in higher runoff rates and faster catchment response times. Kjeldsen (2010) reports that *'it is well established in the literature that the effect of urbanisation can be detected in the magnitude of individual annual maximum series of peak flow (Packman, 1980; Sheng and Wilson, 2009), and thereby lead to changes in the flood frequency characteristics.'* There is evidence that urbanisation tends to affect low return period flows more than high return period flows (Kjeldsen, 2010).

Most methods that quantify the effect of urbanisation on design flows, including the adjustment for QMED in the FSU, are based on the analysis of flood data from existing urbanised catchments. These catchments include a wide range of development types, from all eras. Many existing developments have no or limited systems in place to limit the runoff from developed areas. Planning authorities now generally require new developments to limit their runoff rates to the pre-development rates for a range of design storms, and the downstream impacts on flood flows of future development should be lower than in the past. Extrapolation of the effects of urbanisation from the past is therefore likely to overestimate the real effect of future change.

As the locations of future urbanisation and their effects on flood risk are highly uncertain, they have not been accounted for in the flood mapping for this study. However the potential effects of urbanisation on design flows at AFAs in the unit of management are considered in more detail below.

The Environmental Protection Agency (EPA) reports in their CORINE Land Cover updates for 2000, 2006 and 2012 that 'artificial surfaces' ('urban' areas) increased by 31% in the period 1990-2000 throughout Ireland, by another 15% in the period 2000-2006 and by approximately 4% from 2006 to 2012 (Section 5.2.1 in EPA 2014). These figures are subject to some uncertainty due to changes in the methodologies and technologies used, though attempts were made to compare like for like, and as such they represent the best available data.

The recent CORINE datasets suggest that the high growth rate seen in the period 1990-2006 has slowed down. The 4% growth over 6 years (2006 to 2012) comes down to an annual (compound) growth rate of approximately 0.7% per year. Assuming that this growth rate will be sustained into the future this suggests an increase of 100% (i.e. a doubling) of the urban extents over the 100 year time horizon of the future scenarios considered in this study. Because of planning rules (as discussed above) increases in runoff rates from future development can be expected to be mitigated for (in attenuation tanks, detention basins, soakaways, swales, etc.) more than in the past, and an effective increase in urban extent of about 50% or less seems more appropriate for the prediction of future river flows.

To assess the sensitivity of the design flows to increased urban extent, increases of 25% (for the MRFS) and 50% (for the HEFS) in the URBEXT catchment descriptor have been applied to points in AFAs that have relatively high URBEXT values already. Where the present day URBEXT value contributes less than 5% to the peak flow rates (i.e. results in an FSU Urban Adjustment Factor [UAF] smaller than 1.05, with  $UAF = (1 + URBEXT/100)^{1.482}$ ) it is assumed that future changes in the urban extent will not have a significant effect on the catchment runoff response.

The same increase in URBEXT, and therefore the same UAF, has been applied to all return periods, thus ignoring any variation of the effect with return period, as this is difficult to quantify and no method was proposed in the FSU research. As the effect of urbanisation is thought to decrease for higher return periods the allowances may be conservatively high for such floods.

A list of AFAs with present day URBEXT values (ranked by the URBEXT descriptor) is presented in Table 6.2 below. One HEP was selected for each watercourse within an AFA, at a location close to the urban centre. Where multiple HEP nodes were situated in or close to the urban centre, then the downstream point was selected. Where multiple watercourses flow through an AFA, Table 6.2 presents multiple HEP nodes. Where a tributary joined a river in an AFA, the HEP at the most downstream node of the tributary was selected.

The HEP node numbers are shown on the model extent maps in Chapters B1 to B6 in Appendix B for Models S14A, S14B, S14C, S15, S16 and S17 respectively.

AFA	Model	HEP	URBEXT (%)	UAF
Tralee	S16B	23_2376_5	27.91	1.44
Tralee	S16B	23_2612_3	25.27	1.40
Tralee	S16B	23_2727_7	16.17	1.25
Tralee	S16A	23_2750_2	4.47	1.07
Tralee	S16A	23_2921_2	2.6	1.04
Abbeydorney	S15	23_988_8	2.07	1.03
Banna	S17	23_497_2	2.02	1.03
Abbeyfeale	S14A	23_1973_3	1.38	1.02
Tralee	S16A	23_1563_2	1.13	1.02
Listowel	S14A	23_2556_2	0.57	1.01
Abbeyfeale	S14A	23_121_3	0.49	1.01
Abbeyfeale	S14A	23_1733_5	0.19	1
Athea	S14C	23_2579_1	0.22	1
Tralee	S16A	23_2698_6	0.05	1

**Table 6.2 AFAs with Present Day URBEXT and Urban Adjustment Factor**

There are four locations in UoM 23 with a UAF greater than 1.05 (i.e. a greater than 5% increase in statistical peak flows due to the present day urbanisation). For these

four locations Table 6.3 tabulates the present-day design (target) flows as reported in Appendix B, whilst Tables 6.4 and 6.5 present the effects on the design flows when the urban extent (URBEXT) is increased by 25% for the MRFS and by 50% for the HEFS conditions.

AFA (and Model)	HEP	Annual Exceedance Probability (%)							
		50	20	10	5	2	1	0.5	0.1
Tralee (S16B)	23_2376_5	3.6	4.5	5.2	5.7	6.5	7.1	7.7	9.0
Tralee (S16B)	23_2727_7	11.1	14	15.8	17.7	20	21.8	23.5	27.6
Tralee (S16B)	23_2612_3	17.3	21.7	24.7	27.5	31.2	33.9	36.7	43.0
Tralee (S16A)	23_2750_2	10.2	12.8	14.4	16.0	18.1	19.6	21.2	24.7

**Table 6.3** *Present Day Design Flows*

AFA (and Model)	HEP	Annual Exceedance Probability (%)							
		50	20	10	5	2	1	0.5	0.1
Tralee (S16B)	23_2376_5	3.9	4.9	5.6	6.2	7.0	7.7	8.3	9.7
Tralee (S16B)	23_2727_7	11.7	14.7	16.6	18.6	21.0	22.9	24.7	29.0
Tralee (S16B)	23_2612_3	18.6	23.3	26.6	29.6	33.6	36.5	39.5	46.3
Tralee (S16A)	23_2750_2	10.4	13.0	14.6	16.3	18.4	19.9	21.5	25.1

**Table 6.4** *Design Flows for Future Urbanisation – MRFS (URBEXT+25%)*

AFA (and Model)	HEP	Annual Exceedance Probability (%)							
		50	20	10	5	2	1	0.5	0.1
Tralee (S16B)	23_2376_5	4.2	5.3	6.1	6.7	7.6	8.3	9.0	10.5
Tralee (S16B)	23_2727_7	12.3	15.5	17.5	19.6	22.1	24.1	26.0	30.5
Tralee (S16B)	23_2612_3	20.0	25.0	28.5	31.7	36.0	39.1	42.3	49.6
Tralee (S16A)	23_2750_2	10.5	13.2	14.9	16.5	18.7	20.2	21.9	25.5

**Table 6.5** *Design Flows for Future Urbanisation – HEFS (URBEXT+50%)*

Although the National Spatial Strategy and county-level core strategies include details of national and local government intentions with regard to the quantities and location of housing and industrial development, these tend to only look to the near future, up to 20 years or less. It is considered likely that areas that are not currently favoured for development may become favoured in the future (e.g. when the areas currently favoured have been filled), and that there may be considerable differences between the target growth numbers and those realised. It was not considered appropriate to use the details of these strategies for the 100-year time horizon adopted here.



### (c) Afforestation

Ireland is seeing an increase in forest cover, which is expected to continue into the future. The majority of this increase is related to the expansion of commercial forestry.

Converting the land use to forest (afforestation) or its opposite (deforestation) has the potential to affect the runoff response from a catchment if the changes cover a large proportion of the catchment. The effects of an increase in forest cover on peak flows in the catchment may be positive or negative.

It is generally assumed (Nisbet et al 2006) that replacing grass cover with tree cover will serve to reduce peak flows due to a combination of:

- a. an increase in the infiltration rates and storage capacity in the soils which tend to be more open-structured than grassed soils.
- b. Interception of water by the trees
- c. Increased roughness and local attenuation in floodplains, e.g. by wooden debris dams within stream channels, the presence of trees, shrubs and deadwood on the floodplain and greater unevenness of the ground surface

Although these effects are the subject of continued research, they are thought to be relatively small in the case of extreme floods (EA/Defra 2004) and may be counteracted if land preparation includes a network of extensive drainage ditches designed in such a way as to convey water more quickly to the natural watercourses. Table 6.1 includes a reduced time-to-peak to allow for the effects of these drainage systems. Newly afforested land with young trees will not show much of the advantages listed above, and if a dense network of drainage ditches is installed may well see an increase in peak runoff rates. Over the following decades, as the drainage ditches fall into disrepair and become less effective and the trees get bigger, the positive effects on reducing flood runoff are likely to manifest themselves more strongly – redressing the balance and possibly reducing peak flood flows compared to the original state.

Defra/EA (2004) concludes at the time of writing that: ‘Overall, no clear evidence has emerged to show that forests either mitigate or increase flooding to a significant extent.’

In addition, it may be assumed that the commercial use of forests means that after several decades trees are felled and young trees re-planted in a cyclical fashion, with different areas at different stages of the cycle, potentially cancelling out significant effects on runoff rates.

It is pertinent to note that during the FSU research the FOREST catchment descriptor was not found to exert a significant influence on describing variation in floods in relation to QMED, growth curve or hydrograph shape.

The pragmatic approach followed in this study to investigate the possible peak flow sensitivity to afforestation in the AFA catchments is described below.

The proportion of forest in the catchments to all AFAs was determined, and the sensitivity to a doubling of the amount of forest considered, in which it was assumed that the effect of afforestation is that peak runoff rates from the new forest areas will increase by 10% in the MRFS and 20% in the HEFS.

The present-day proportion of forest cover in the catchments to the AFAs was determined, as captured in the FSU catchment descriptor FOREST<sup>1</sup>. The ranked present-day forest proportions for each AFA are presented in Table 6.6. The locations considered are the same as those in Table 6.2. The node numbers are shown on the model extent maps in Chapters B1 to B6 in Appendix B for Models S14A, S14B, S14C, S15, S16 and S17 respectively.

Projections of the increase in future forestry were not available. It was assumed that forestry doubles over the 100-year horizon considered in this chapter. However for catchments with less than 25% forest cover it was assumed that changes to flow at the AFA due to afforestation would not be significant. Where more than 25% of a catchment is currently covered a doubling of the forest surface area is considered as having more of a possibility of significantly affecting the flood flows. Noting that the research discussed above suggests that changes in flood runoff due to afforestation are generally small, an increase in peak flows of 10% and 20% was applied for the MRFS and HEFS conditions over the proportion of new forest in the catchments to the AFAs. As an example, if 25% of a catchment is covered by forest, then it is assumed that the forest cover will increase by another 25%, and the design flow at the AFA is increased by 10% (MRFS) and 20% (HEFS) of 25%, i.e. by 2.5% and 5%.

There are three locations where the proportion of forest in the upstream catchment is greater than 25%. For these locations the effects of afforestation on design flows have been assessed in the above mentioned manner. Refer to Tables 6.7-6.9 for the present day, MRFS and HEFS peak design flows.

AFA	Model	HEP	FOREST (%)
Athea	S14C	23_2579_1	45
Abbeyfeale	S14A	23_121_3	29
Listowel	S14A	23_2556_2	26
Abbeyfeale	S14A	23_1733_5	19
Tralee	S16A	23_2921_2	6
Abbeydorney	S15	23_988_8	5
Tralee	S16B	23_2376_5	4
Tralee	S16B	23_2727_7	2
Tralee	S16B	23_2612_3	2
Tralee	S16A	23_1563_2	0.5
Tralee	S16A	23_2698_6	0.5
Tralee	S16A	23_2750_2	0.3
Banna	S17	23_497_2	0.3
Abbeyfeale	S14A	23_1973_3	0

<sup>1</sup> This parameter is produced from a composite of the CORINE dataset for the year 2000 with the Coillte Teoranta forestry database and the Forest Inventory Parcel System from the Forest Service of 1998 (Compass Informatics, 2009).

**Table 6.6 AFAs and Present Day FOREST Catchment Descriptors**

AFA (and Model)	HEP	Annual Exceedance Probability (%)							
		50	20	10	5	2	1	0.5	0.1
Listowel (S14A)	23_2556_2	369	500	576	649	744	815	886	1050
Abbeyfeale (S14A)	23_121_3	210	284	328	370	424	464	504	598
Athea (S14C)	23_2579_1	30	41.3	48.3	55.1	63.9	70.5	77	92.2

**Table 6.7 Present Day Design Flows**

AFA (and Model)	HEP	Annual Exceedance Probability (%)							
		50	20	10	5	2	1	0.5	0.1
Listowel (S14A)	23_2556_2	379	513	591	666	764	837	909	1078
Abbeyfeale (S14A)	23_121_3	216	293	338	380	436	478	519	615
Athea (S14C)	23_2579_1	31.4	43.2	50.5	57.6	66.8	73.7	80.5	96.4

**Table 6.8 Design Flows for Future Afforestation – MRFS (FOREST+10%)**

AFA (and Model)	HEP	Annual Exceedance Probability (%)							
		50	20	10	5	2	1	0.5	0.1
Listowel (S14A)	23_2556_2	389	526	606	683	783	858	932	1105
Abbeyfeale (S14A)	23_121_3	223	301	347	391	448	491	534	633
Athea (S14C)	23_2579_1	32.7	45.0	52.7	60.1	69.7	76.9	84.0	101

**Table 6.9 Design Flows for Future Afforestation – HEFS (FOREST+20%)**

## 7 Conclusions and Recommendations

### 7.1 Conclusions

The influence of soil types and geology was considered in deriving flood estimates. The dominant aquifer group in UoM 23 is the 'locally important aquifer' group. The lower Feale catchment consists of locally and regionally karstified aquifers. Some scattered poor aquifers are also observed near the periphery of the unit of management.

Soils in UoM 23 are dominated by the combination of poorly drained soil and peat. Some scattered well drained soil is found at the upstream reach of the River Feale as well as along the coastal areas. In addition to this, some alluvium is located along the river valley of the Feale.

Karst is not considered to play a significant role in the hydrological flood response of the modelled catchments in UoM 23.

A rating review was undertaken for Station Ballymullen (23012) in this unit of management. This showed that the water levels at this gauge may be affected by the tide. It is recommended that this station is not used for flood flow estimation. No hydraulic model was completed for this station and no attempt was made to derive a set of rating equations following a request from OPW that work relating to this gauging station cease.

Due to a dearth of sub-daily rainfall data, Jacobs' approach to peak design flow estimation in the Shannon River Basin District (RBD) avoids the use of rainfall data, focussing instead on the use of gauged flow data, supplemented by Flood Study Update (FSU) techniques where no flow data is available.

The hydrological analysis resulted in a series of inflow hydrographs for each hydraulic model for a range of design events at the upstream model boundaries and at key locations along the model extent to represent laterally contributing subcatchments. The flood estimates detailed in this report were used in the hydraulic modelling to produce estimates of water level and flood extent throughout the modelled reaches.

### 7.2 Recommendations

The confidence in flood estimation can be increased by having more non-tidal gauging stations in the unit of management and by carrying out high flow check gaugings at the existing gauging stations. It is recommended that the Ballymullen gauging station (23012) is moved upstream as it is affected by the tidal cycle.

It is recommended that the flood hydrology be reviewed every 5 to 10 years as more annual maxima and flood event data become available.

8

## References

An Foras Taluntais (1978), Peatland Map of Ireland

Compass Informatics (2009), *Preparation of Digital Catchment Descriptors*, Flood Studies Update, Work Package 5.3, January 2009

Dunsmore, S.J. (2007), River Thames Flood Hydrology Design Curves. Water and Environment Journal. Vol. 11 (1), pp 67-71

EPA (2011), *Register of Hydrometric Stations in Ireland*,  
Website: [http://www.epa.ie/downloads/pubs/water/flows/name\\_12745.en.html](http://www.epa.ie/downloads/pubs/water/flows/name_12745.en.html)  
(Accessed March 2011)

EPA Envision (<http://gis.epa.ie/Envision/>)

EPA Hydronet Website  
Website: <http://hydronet.epa.ie/introduction.htm> (Accessed March - June 2011)

Geological Survey of Ireland (GSI); Bedrock 1:500,000 Solid Geology  
(<http://www.gsi.ie/mapping.htm>)

Geological Survey of Ireland (GSI); National Draft Bedrock Aquifer and Groundwater Vulnerability maps (<http://www.gsi.ie/mapping.htm>)

Geological Survey of Ireland (GSI); National Groundwater Recharge map  
(<http://www.gsi.ie/mapping.htm>)

Hydro-Logic Ltd (2006), *Review of flood flow ratings for Flood Studies Review*, Work Package 2.1, Flood Studies Update

JBA Consulting (2008), Athea Flood Severity and Impact Report, 31<sup>st</sup> July 28 – 6<sup>th</sup> August 2008, Final Report, October 2008 (prepared for Limerick Co. Co).

JBA Consulting (2009), *IBIDEM (Interactive Bridge Invoking the Design Event Method)*, Flood Studies Update, Work Package 3.5, July 2009

JBA Consulting (2010), *Guidance for River Basin Modelling* (Revised Final Report), Flood Studies Update, Work Package 3.4, June 2010

Kiely, G., Leahy, P., Fenton, M., Donovan, J. (2008), *Flood event analysis*, Flood Studies Update, Work Package 3.2, University College Cork, Hydromet Research Group, Centre for Hydrology, Micrometeorology and Climate Change

Met Éireann (2007), *Estimation of point rainfall frequencies*, Flood Studies Update, Work Package 1.2

Murphy, C. (2009), *Flood Estimation in Ungauged Catchments*, Flood Studies Update, Work Package 2.3, Irish Climate Analysis and Research Units (ICARUS), Department of Geography

National University of Ireland (2009), *Frequency analysis*, Flood Studies Update, Work Package 2.2, Department of Engineering Hydrology and The Environmental Change Institute, Galway

Office of Public Works (2009), *Base Flow Index derived from soils* (Draft Final Report), Flood Studies Update, Work Package 5.2, August 2009

Office of Public Works National Flood Hazard Mapping  
Website: <http://www.floodmaps.ie/> (Accessed March to July 2011)

Office of Public Works *Hydro- Data* Website  
Website: <http://www.opw.ie/hydro/> (Accessed March to July 2011)

O'Connor, K., Goswami, M. (2009), *Hydrograph Width Analysis*, Flood Studies Update, Work Package 3.1, National University of Ireland (2009), Department of Engineering Hydrology Environmental Change Institute

Reed, D.W. (2007), *PROPWET for Ireland: a dimensionless index of typical catchment wetness*, Flood Studies Update, Work Package 5.4, May 2007

Shaw, E.M., Beven, K.J., Chappell, N.A., Lamb, R. (2011), *Hydrology in Practice*, 4<sup>th</sup> Edition, ISBN 13: 978-0-415-37041-7

University College Dublin (2006), *Scoping Study of Urban Flooding Issues*, Flood Studies Update, Work Package 4.1, Centre for Water Resources Research, October 2006

Teagasc/EPA (2009), *Soils and Subsoils Mapping*, Final Report,



## Appendix A      Sub-catchment Hydrological Analysis

### Table of Content

A1	Feale catchment
A2	Lee catchment
A3	Tyshe catchment

## A1 Feale Catchment

### A1.1 Catchment Description

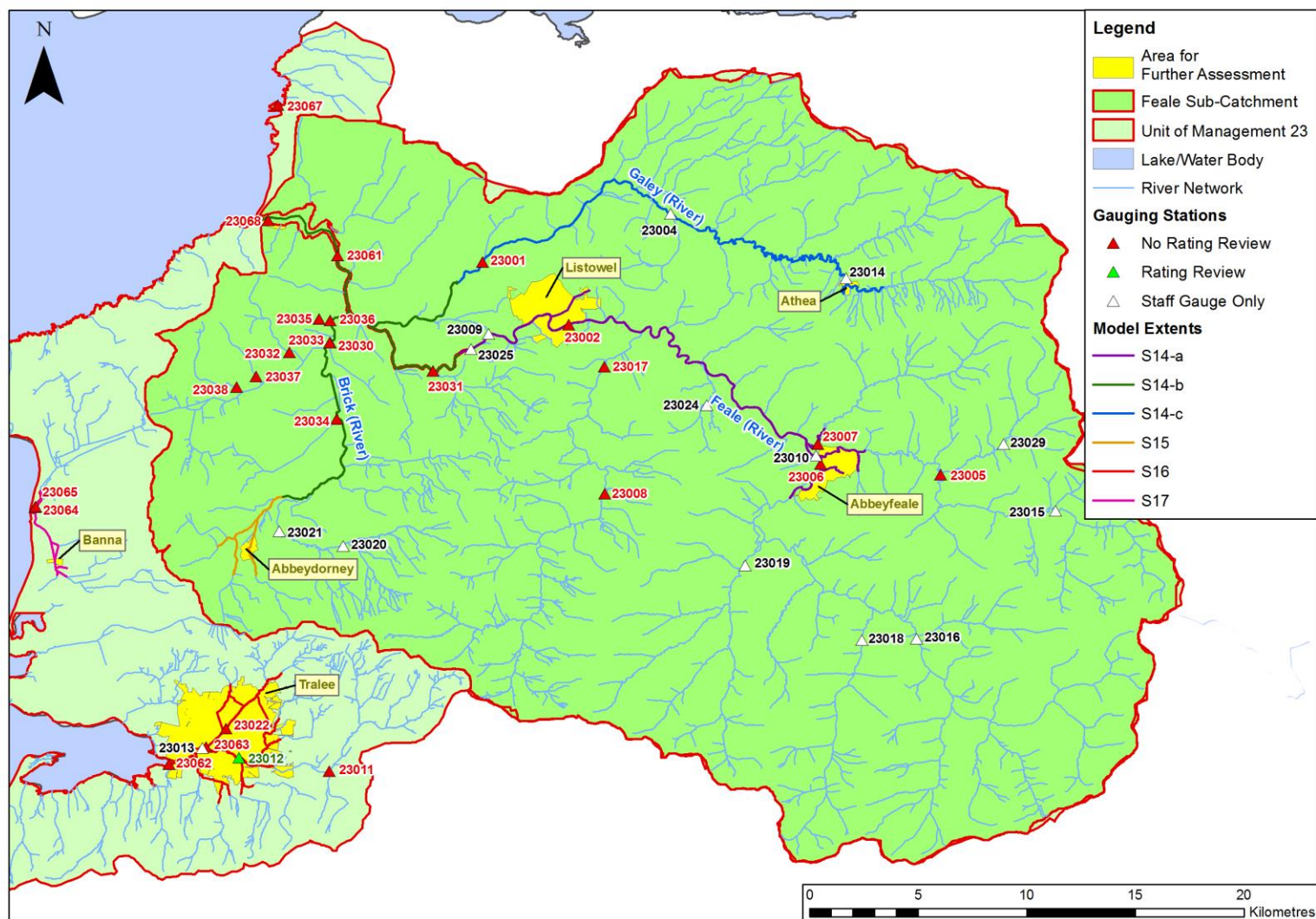
The general description of the Feale catchment (Figure A1.1) is given in Table A1.1.

Attribute	Description
Unit of Management (UoM)	23
Main water courses	River Feale, River Galey, River Brick
Outflow point	Cashen Bay
Total catchment area	1155 km <sup>2</sup> up to the mouth of the Feale Estuary at Cashen Bay
Areas for Further Assessment (AFAs)	Listowel, Abbeyfeale, Abbeydorney, Athea, Moneycashen
Individual Risk Receptors (IRRs)	None
Model Extents*	S14-a, S14-b, S14-c, S15
General topography	Min altitude = 0 mAOD Max altitude = 451 mAOD Gently undulating hills in the north-east giving way to flatter ground towards the west. The tidal limit is shown on the flood extent maps for Model S16.
Average annual rainfall**	1034mm to 1462mm.
Soils and Geology	Soils: Predominantly poorly drained soils with some well drained soils to the far west, south of Moneycashen. Peat deposits occur extensively throughout the catchment. Refer to Figure 3.4 in the main report for the distribution of the soil drainage types. Geology: Peat and low to moderate permeable glacial tills, Palaeozoic sandstone, shale and limestone bedrock. Limestone is limited to the far west of the catchment and is a regionally important (karstified) bedrock aquifer. The predominant sandstone and shale bedrock are locally important bedrock aquifers (occasionally poor aquifers) with extensive surface outcrops to the east. Alluvial deposits occur along major watercourses including the River Feale between Listowel and Abbeyfeale where the deposits form a highly permeable gravel aquifer. Refer to Figure 3.3 in the main report for the hydrogeological characteristics of the underlying rock formations.
Urban areas	The most significant urban areas in the catchment are the five AFAs listed above. The highest URBEXT value of 32% is on a tributary branch flowing through the settlement of Listowel (Model S14-a). Elsewhere, URBEXT values are comparatively low with maximum values of 1.3; 3.9; and 2.7 for Models S14-b; S14-c; and S15 respectively.

\* Specific hydrological details for the models are provided in Appendices B1 to B4

\*\* Range of SAAR values taken from the FSU catchment descriptors covering the extent of modelling

**Table A1.1 Feale Catchment description**



**Figure A1.1 Feale Catchment with both model extents and hydrometric stations indicated**

## A1.2 Hydrometric Stations in the Feale Catchment

Details of the gauging stations in the Feale catchment are tabulated in Table A1.2. They are also shown on Figure A1.1. Gauging Stations shown on Figure A1.1 that do not appear in Table A1.2 are not on the model extent and were found not to be relevant for the design flood estimates.

Model	Gauging Station	Name	Record Data Range	AMAX Available	FSU Quality Class or HGF/QMED	CFRAMS Rating Review	Quality Comments
S14-a	23002	Listowel Bridge	1946 - 2010	levels & Flows	A1	No	1
	23006	Neodata	2001 - 2011	N/A	N/A	No	2
	23007	Oolagh Rly. Bridge	1976 – 2000	N/A	N/A	No	2
	23009	Listowel weir	N/A	N/A	N/A	No	2
	23010	Abbeyfeale	N/A	N/A	N/A	No	
	23025	Listowel SW	N/A	N/A	N/A	No	
S14-b	23030	Sleeven Main Channel	1998 - 2010	Level Only	N/A	No	3
	23031	Poulnahaha	1998 - 2009	Level Only	N/A	No	
	23033	Sleeven Back Channel	1998 - 2005	Level Only	N/A	No	
	23034	Lixnaw	1998 - 2005	Level Only	N/A	No	
	23036	Ratoobank	2002 - 2005	Level Only	N/A	No	
	23061	Ferry Br.	1997 - 2010	level only	N/A	No	
	23068	Moneycashen	1997 - 2010	Level Only	N/A	No	
S14-c	23001	Inch Bridge	1960- 2010	levels & Flows	A2 HGF/QMED =1.1	No	4
	23004	Galey Br.	N/A	Staff gauge only	N/A	N/A	2
	23014	Athea	N/A	Staff gauge only	N/A	N/A	

**Table A1.2 Feale Catchment Gauging Stations**

**Table A1.2 Hydrometric Data Quality Comments:**

1. Listowel Bridge (23002) is the only appropriate station for flood estimation within the S14-a model extent. The gauge has an A1 FSU quality rating, having a reliable high flow rating of up to  $1.3 \times Q_{MED}$  pre-1974 and up to  $Q_{MED}$  post-1974 (following the relocation of the gauge 200metres upstream on 18/11/1974. The full AMAX series (1946 to 2009) at the station is used in the analysis.
2. No data was available for these stations.
3. Only level data but no flow data available for these gauges.
4. Inch Bridge (23001) is the only station appropriate for flood estimation within the S14-c model extent. The OPW operated gauge has an A2 FSU quality rating, with a high flow rating up to  $1.1 \times Q_{med}$ . The rating fits quite well with the three check gaugings of Nov 1997 ( $27 \text{ m}^3/\text{s}$ ), Jan 1998 ( $51 \text{ m}^3/\text{s}$ ) and Mar 1998 ( $116 \text{ m}^3/\text{s}$ ). The period of AMAX data used in the analysis is from 1960 to 2009.

### A1.3 Catchment River Reaches

River reaches are defined as sections of watercourse with similar hydrological characteristics, so that a single QMED adjustment factor and growth curve can be applied. The catchment is split up into river reaches based on the catchment geometry, geology and an assessment of the availability and quality of data at the gauging stations listed in Table A1.2 above. The river reaches are tabulated in Table A1.3 and shown on Figure A1.2. The variation in catchment descriptors for each reach is tabulated in Tables A1.4 to A1.6 below.

Reach	Description	Model Extent
1	Entire S14a model extent and a portion of the S14b model extent from HEP 23_2941_3 to the point of discharge into the Feale Estuary (refer to Appendices B1 and B2 for the HEP node numbering).	S14a, S14b
2	River Galey (from HEP 23_1853_1, upstream of Athea, to downstream HEP 23_2929_5) and a portion of the S14b model extent from HEP 23_2929_5 to the confluence of the Rivers Feale and Galey.	S14c, S14 b
3	Entire S15 model extent and a portion of the S14b model extent (from HEP 23_806_2 to HEP 23_2945_4).	S15, S14b

**Table A1.3 River Reaches in the Catchment**

Reach 1 *		
Catchment Descriptor	Lower Limit (HEP node)	Upper Limit (HEP node)
AREA (km <sup>2</sup> )	32.4 (23_114_6)	659 (23_2941_3)
BFIsoil	0.31 (23_2548_2)	0.35 (23_1732_3)
SAAR (mm)	1169 (23_114_6)	1462 (23_584_3)
FARL	1.00 (all)	1.00 (all)
DRAIN2	1.04 (23_121_3)	1.22 (23_114_10)
S1085 (m/km)	3.7 (23_2823_3)	14.69 (23_114_6)
ARTDRAIN2 (%)	0.0 (23_2388_4)	0.95 (23_2941_3)
URBEXT (%)	0.0 (23_114_6)	0.61 (23_2288_3)

\*Two urban tributaries (23\_2557\_0 to 23\_2557\_2 and 23\_001\_1 to 23\_001\_2) are excluded from Table A1.4

**Table A1.4 Reach 1 Catchment Descriptor Range**



Reach 2		
Catchment Descriptor	Lower Limit (HEP node)	Upper Limit (HEP node)
AREA (km <sup>2</sup> )	30.3 (23_1853_1)	203 (23_2929_9)
BFIsoil	0.31 (23_1756_1)	0.33 (23_2517_2)
SAAR (mm)	1083 (23_2929_9)	1135 (23_1919_2)
FARL	1.0 (all)	1.0 (all)
DRAIN2	1.32 (23_2929_9)	1.79 (23_2579_1)
S1085 (m/km)	3.3 (23_2929_1)	13.9 (23_1853_1)
ARTDRAIN2 (%)	0 (23_1853_1)	19 (23_2929_9)
URBEXT (%)	0.0 (23_1853_1)	0.69 (23_2580_2)

*\*Tributary branch at Athea (HEP 23\_2579\_00a & 23\_2579\_00b) excluded from Table A1.5*

**Table A1.5 Reach 2 Catchment Descriptor Range**

Reach 3		
Catchment Descriptor	Lower Limit (HEP node)	Upper Limit (HEP node)
AREA (km <sup>2</sup> )	5.1 (23_195_1)	178 (23_2945_4)
BFIsoil	0.332 (23_699_7)	0.642 (23_195_1)
SAAR (mm)	1034 (23_436_3)	1143 (23_699_2)
FARL	1.0 (all)	1.0 (all)
DRAIN2	0.56 (23_195_1)	2.04 (23_699_2)
S1085 (m/km)	0.1 (23_195_2)	26.5 (23_988_4)
ARTDRAIN2 (%)	0 (23_436_1)	90 (23_195_2)
URBEXT (%)	0.0 (23_436_1)	2.7 (23_195_2)

**Table A1.6 Reach 3 Catchment Descriptor Range**

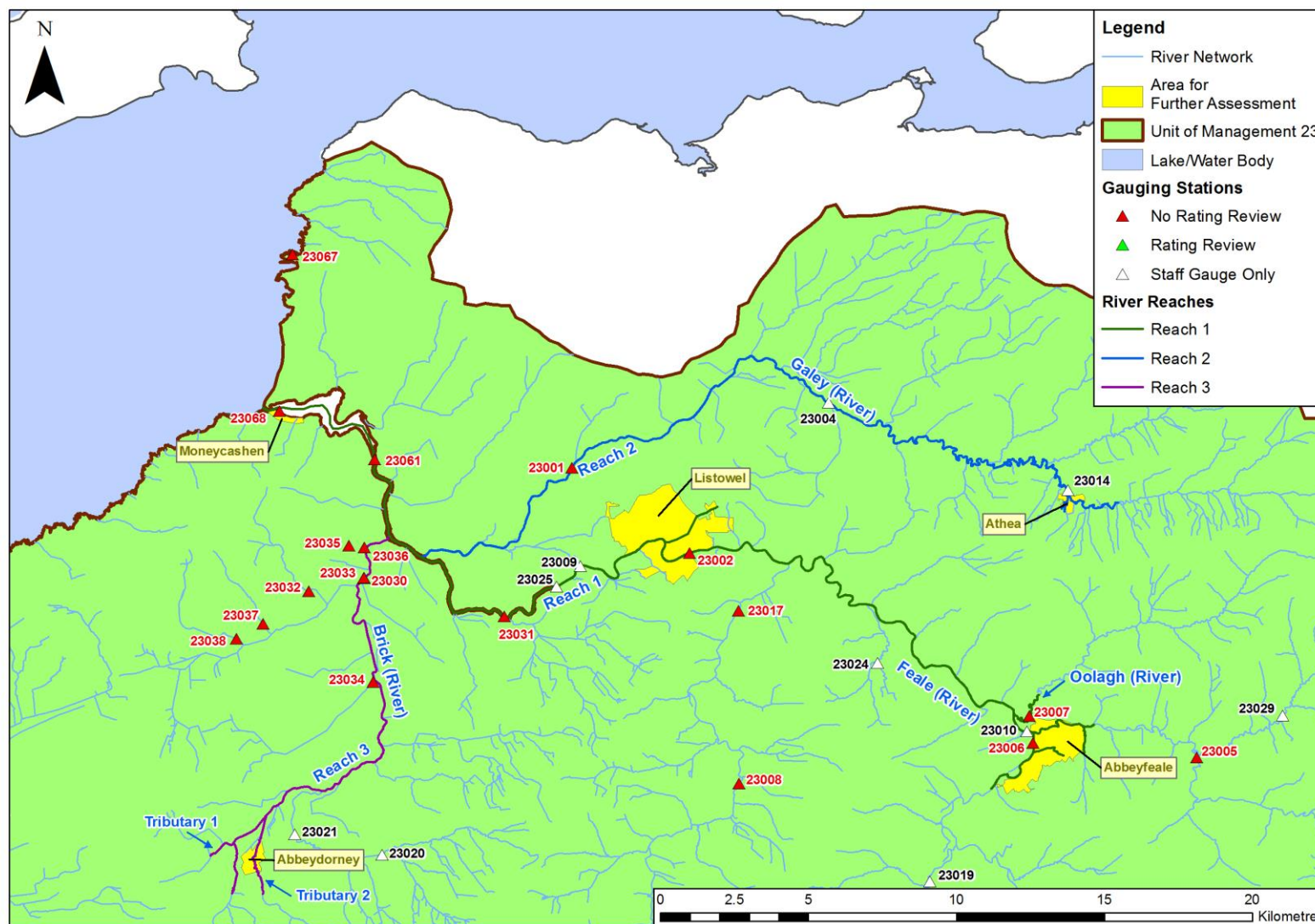


Figure A1.2 Feale Catchment River Reaches

## A1.4 QMED Adjustment Factors

Table A1.7 below gives the QMED adjustment factors at the available flow gauging stations in the catchment. The table specifies for each gauging station the QMED estimate based on AMAX data and a synthetic estimate based on the FSU regression equation including an urban adjustment (refer to FSU Work Package 2.3). The QMED adjustment factor is the observed QMED divided by the synthetic QMED.

Reach	Gauging Station Number	QMED Observed (m <sup>3</sup> /s)	QMED (urban) Synthetic (m <sup>3</sup> /s)	Adjustment Factor (-)	Model Extent	Note
1	23002	369.4	259.8	1.42	S14a	1
2	23001	103.5	66.5	1.56	S14c	2

**Table A1.7 Available QMED Adjustment Factors in each reach**

Notes:

1. Station 23002 has an A1 FSU classification and a reliable high flow rating up to 1.3\*Qmed (pre-1974) and 1.0\*Qmed (post-1974). The full AMAX series from 1946 to 2009 has been used to derive the estimate of observed Qmed shown in Table A1.7.
2. Station 23001 has an A2 FSU classification and a reliable high flow rating up to 1.1\*Qmed. The AMAX series from 1961 to 2009 has been used in the estimate of observed Qmed in Table A1.7.

Table A1.8 shows the final QMED adjustment factor applied to each reach in the catchment, each with a justification for selection.

Reach	QMED adjustment factor	Station or HEP Node	Justification
1	1.42	23002	<p>Station 23002 is the only station suitable for flood estimation within the reach. The gauge has an A1 FSU classification with a reliable rating up to QMED.</p> <p>The adjustment factor at 23002 has been applied at all HEPs within Model S14a and at HEP 23_2941_3 within Model S14b immediately downstream.</p>
2	1.56	23001	<p>Station 23001 is the only gauge within the reach suitable for flood estimation. The station has an A2 FSU classification, with check gaugings up to 1.1* QMED.</p> <p>The adjustment factor at 23001 has been applied at all HEPs within Model S14c and at HEPs 23_2929_5 and 23_2929_9 within Model S14b immediately downstream.</p>
3	1.56	23001	<p>The QMED adjustment derived at Station 23001 has been applied to the whole of Reach 3 (River Brick) which comprises Models S15 and the left branch of Model S14b. As no hydrometric station is present within the reach, an adjustment derived from a nearby pivotal gauge was favoured over the use of a QMED adjustment based on hydrological similarities.</p> <p>Of the two nearby stations mentioned above (23001, 23002), Station 23001 has been adopted for the following reasons:</p> <p>(i) The catchment area of the S15 Model (35 km<sup>2</sup>) is closer to that of Station 23001 (192 km<sup>2</sup>) than that of Station 23002 (647 km<sup>2</sup>).</p> <p>(ii) Other catchment descriptors at Station 23001 are relatively similar to the target site.</p> <p>It is noted that the BFIsol values in the extreme upstream part of this reach are higher than that of the pivotal station (up to 0.64 compared to 0.32 at Station 23001). However, a comparison of the five most similar pivotal sites throughout the country (with BFIsol values between 0.45 to 0.60) shows that they would produce Qmed adjustment factors varying between about 1 to 2.3, showing that the factor of 1.56 from Station 23001 falls centrally within that range. In addition, the BFIsol value in the AFA (Abbeydorney) is 0.43, much closer to that at Station 23001.</p>

**Table A1.8 Final QMED Adjustment Factors Applied to Each Reach**

## A1.5 Flood Frequency Curves

### Gauging Station Flood Frequency Curves

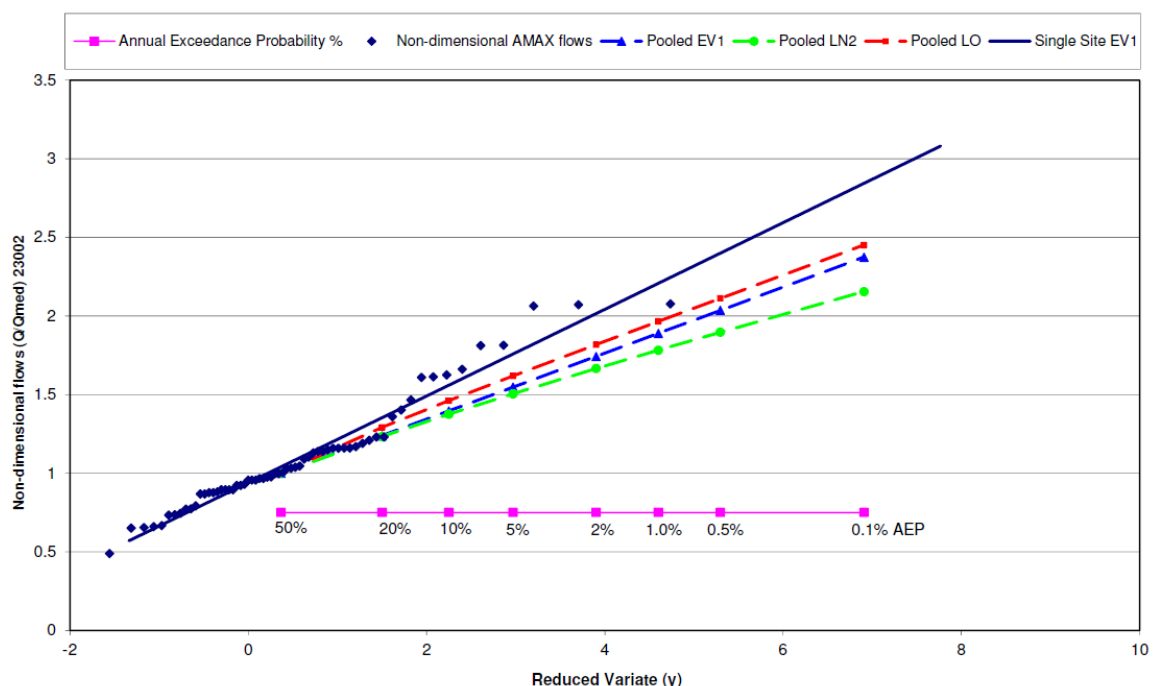
Two stations suitable for flood frequency analysis were identified in the catchment: 23001 (Inch Bridge on the River Galey) and 23002 (Listowel Bridge on the River Feale). The flood frequency curves (or growth curves) are plotted in Figures A1.3 and A1.4 below. The below figures show the at-site AMAX series (made dimensionless by dividing the flows by QMED, and plotting positions based on the Gringorten formula), an EV1 distribution based frequency curve fitted to the AMAX data, and three frequency curves based on pooling group results plotted against the reduced variate and an AEP scale. The growth curve selection is explained in the main report in Section 2.5. Pooling group audit trails for the relevant sites are included in Appendix G.

### Listowel Bridge Gauging Station

The Listowel Bridge gauge (Station 23002) has an A1 FSU quality rating and is reported to have a reliable high flow rating with check gaugings up to  $1.0 \times Q_{MED}$ . No rating review for this station has been undertaken as part of the Shannon CFRAM Study.

There is 64 years of annual maxima (AMAX) data at Station 23002, between 1946 and 2009. This data can be used to directly estimate growth factors with reasonable confidence for return periods up to approximately 32 years ( $1/2 N$  with  $N=64$ ), i.e. the ~3% AEP flood.

Figure A1.3 shows the at-site growth curve alongside those derived from pooled analysis. Despite relaxing the criteria for homogeneity in catchment descriptors (e.g. BFIsoil); a pooling group of only 360 years was achievable (refer to Appendix G).



**Figure A1.3 23002 Feale – Flood Frequency Curves (N=64)**

It is observed from Figure A1.3 that the at-site derived growth curve has a closer fit to the AMAX values than the pooled growth curves which are much flatter than the frequency curve obtained using only at-site data.

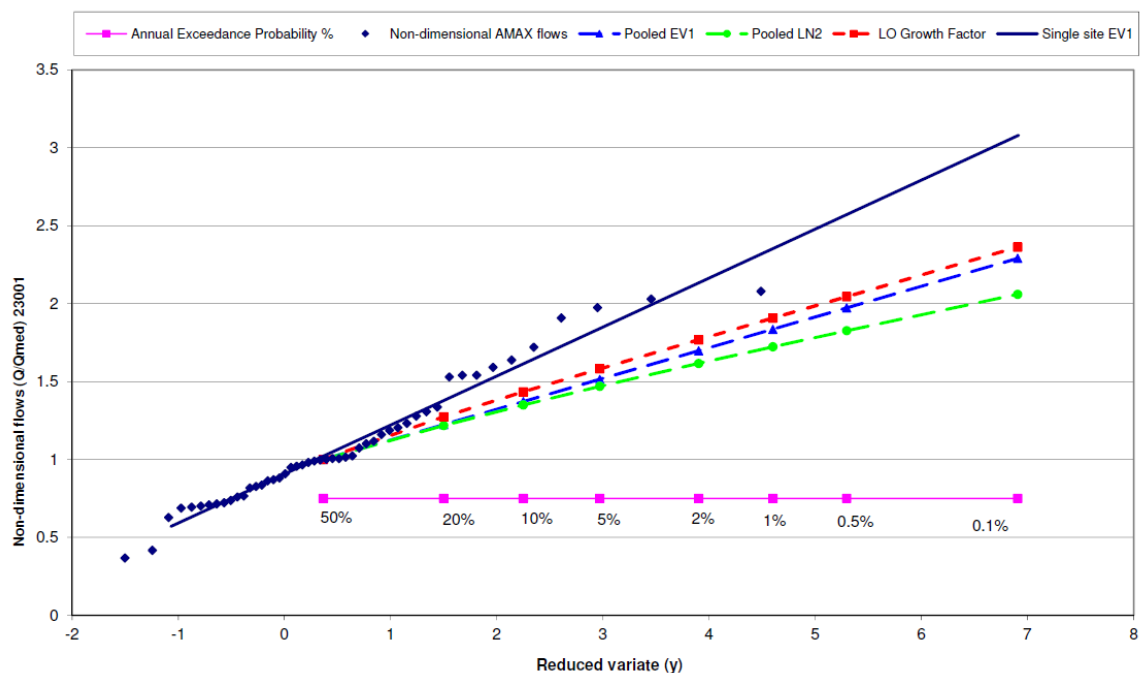
If the curves obtained by pooling of station data had been adopted the 1% (1 in 100) AEP (and even the 0.5% [1 in 200] AEP for EV1 and LN2) peak flows would have been exceeded three times in the period from 1946 to 2009. This suggests that the pooled group based growth curves underestimate the design flood at this site.

### Inch Bridge Gauging Station

The Inch Bridge gauge (Station 23001) has an A2 FSU quality class and is reported to have a reliable high flow rating with check gaugings up to  $1.1 \times Q_{MED}$ . No rating review for this station has been undertaken as part of the Shannon CFRAM Study.

50 years of AMAX data, from 1960 to 2009, have been used to derive the at-site growth curve shown in Figure A1.4. With 50 years of useable data a reasonably robust estimate of growth factors up to return periods of 25 years ( $1/2N$  with  $N=50$ ) i.e. the 4% AEP can be made.

Figure A1.4 shows the at-site growth curve alongside those derived from pooled analysis.



**Figure A1.4 23001 Inch Bridge – Flood Frequency Curves**



It is observed that the pooling based growth curves are much flatter than that derived from an at-site analysis. Figure A1.4 shows that the EV1 100-year growth factor derived from the pooling group method is 1.84 compared with 2.35 from an EV1 single site analysis.

If the curves obtained by pooling of station data had been adopted the 1% (1 in 100) AEP peak flows would have been exceeded four times over the 50 year period of record, and the 0.5% (1 in 200) AEP peak flows three times. This indicates that the pooled group based growth curves would underestimate the design flood at this site.

In addition, the growth factors derived from a single site analysis of station data at 23001 is favoured over those derived from pooling as the single site derived growth curve is more closely matched with that derived for the River Feale at the Listowel Bridge gauge (station 23002).

### River Reach Flood Frequency

The growth curve distributions applied to the relevant reaches are shown in Table A1.9. Growth factors generated for a range of AEPs have been detailed in Table A1.10. Pooling group audit trails for the relevant locations are included in Appendix G.

Reach	Station	Single Site or Pooled	Selected distribution
1	23002 – Listowel Bridge	Single Site	EV1
2	23001 – Inch Bridge	Single Site	EV1
3	HEP 23_757_2	Pooled	EV1

**Table A1.9 Final Growth Curves Selected**

Annual Exceedance Probability (%)	Growth Factors Reach 1	Growth Factors Reach 2	Growth Factors Reach 3
50%	1.00	1.00	1.00
20%	1.35	1.38	1.42
10%	1.56	1.61	1.69
5%	1.76	1.84	1.95
2%	2.01	2.13	2.29
1%	2.21	2.35	2.55
0.5%	2.40	2.57	2.80
0.1%	2.84	3.08	3.39

**Table A1.10 Final Growth Factors Applied to the Feale Catchment**

## A1.6 Hydrograph Shape

Section 2.6 of the main hydrology report describes the selection of the design hydrograph shape. The design flood hydrograph shape is derived from flood events recorded at flow gauges.

Where the absence of hydrometric data prevents deriving actual event hydrographs as is the case for Reach 3, a hydrograph shape has been generated for a pivotal station that is hydrologically similar to the target site.

Table A1.11 summarises the gauging stations used to produce the typical flood hydrograph shapes for the catchment reaches.

Reach	Gauging Station
1	23002 – Listowel Bridge
2	23001 – Inch Bridge
3	N/A

**Table A1.11 Gauging Stations used to derive the Typical Hydrograph Shape in each Reach**

As no other observed data is available, and for consistency, one hydrograph shape was adopted for each entire reach. As in Reaches 1 and 2 the adopted hydrographs are derived from observed events at gauging stations in the lower part of the reach, this has the potential to give a cautiously long hydrograph in the upstream part. The effect on modelled flood depths is low, as flooding in the upstream sections was found to be dominated by flood peaks instead of volume.

Tables A1.12–13 and Figures A1.5–6 identify the highest and most representative flood events chosen for comparison at the gauges. The figures present the hydrographs in a non-dimensional manner by dividing flows by their respective flood peaks. The hydrograph that best represents a typical/median flood response has then been selected as the representative design hydrograph shape.

Date	Peak Flow (m <sup>3</sup> /s)	Comments
06/08/1986	767	
01/12/1973	765	
02/11/1980	762	
19/11/2009	670	
28/10/1989	502	Hydrograph width at 80% of the peak is the second widest and considered representative.

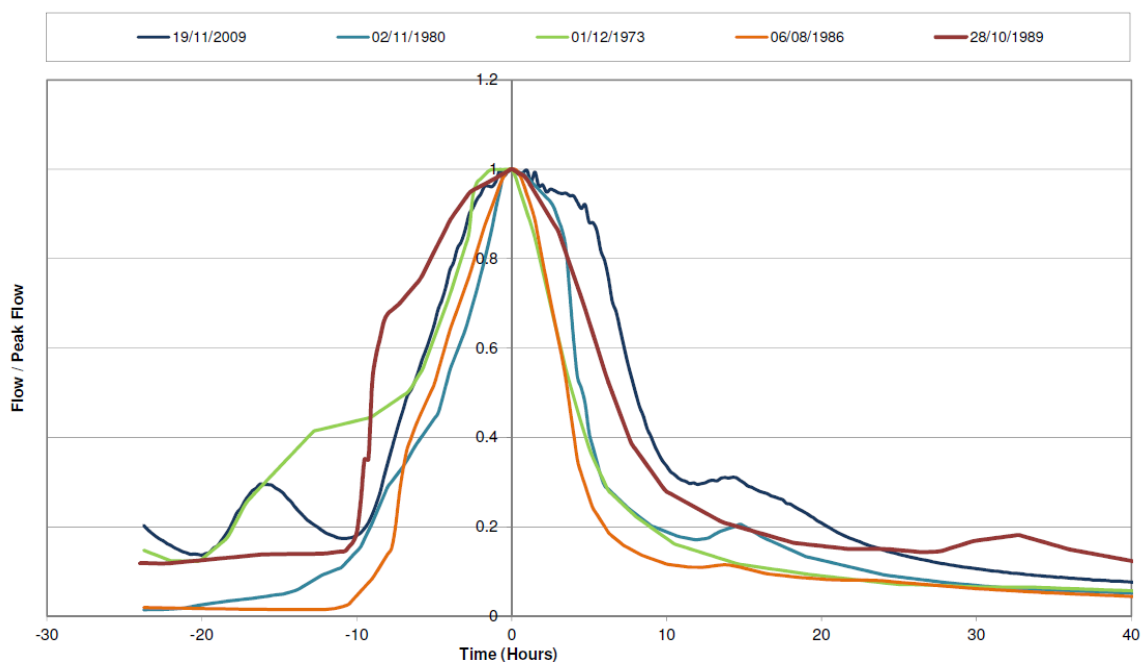
**Table A1.12 Highest Flood Peaks for Gauging Station 23002**

Date	Peak Flow (m <sup>3</sup> /s)	Comments
08/12/1962	215	
01/12/1973	210	Hydrograph width at 80% of the peak is the second widest and considered representative.
24/12/1968	204	
07/10/1967	197	
19/11/2009	158	

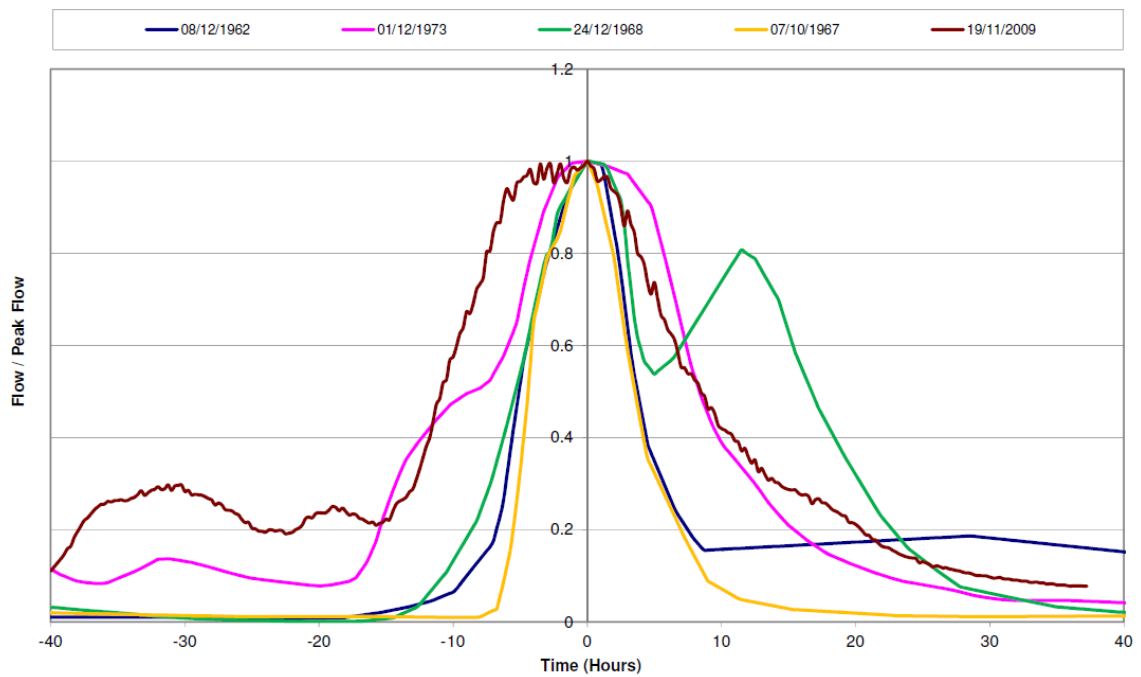
**Table A1.13 Highest Flood Peaks for Gauging Station 23001**

As no gauging stations are located on Reach 3, hydrograph shapes were derived using the gauged Tr, n, and C data of hydrologically similar pivotal stations, using the hydrograph generator spreadsheet. The generated hydrograph shape deemed most appropriate for the main stem of Reach 3 is shown in Figure A1.7. It adopts pivotal station 23012, which matches well with the catchment descriptors for BFIsoil, FARL, S1085, URBEXT, SAAR and AREA (considered on the River Brick approximately 3km downstream of Abbeydorney). It is noted that the hydrograph from Station 23012 is longer than that for Station 23001 which has a larger catchment. Because of the good hydrological similarity with Station 23012 its more conservative hydrograph shape was adopted nevertheless.

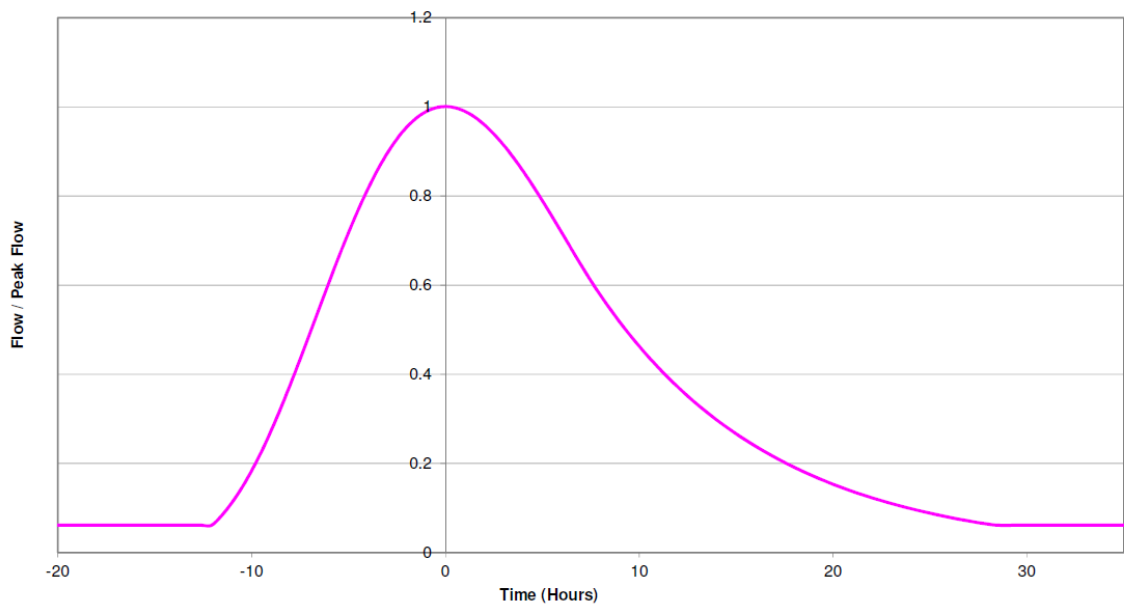
Figure A1.8 shows synthetic hydrograph shapes generated at hydrologically similar pivotal stations to represent the modelled sub-tributary branches which feed the larger watercourses within the Feale catchment. The gauged Tr, N and C parameters from Station 19001 were adopted for the tributaries west of Abbeydorney. This had a good hydrological similarity with the subject watercourse, and of the Top 7 of hydrologically similar stations had the lowest Tr parameter (which is a measure for the time to peak). The station's C value results in an uncharacteristically slow flood recession, but this does not affect the peak water levels in this watercourse.



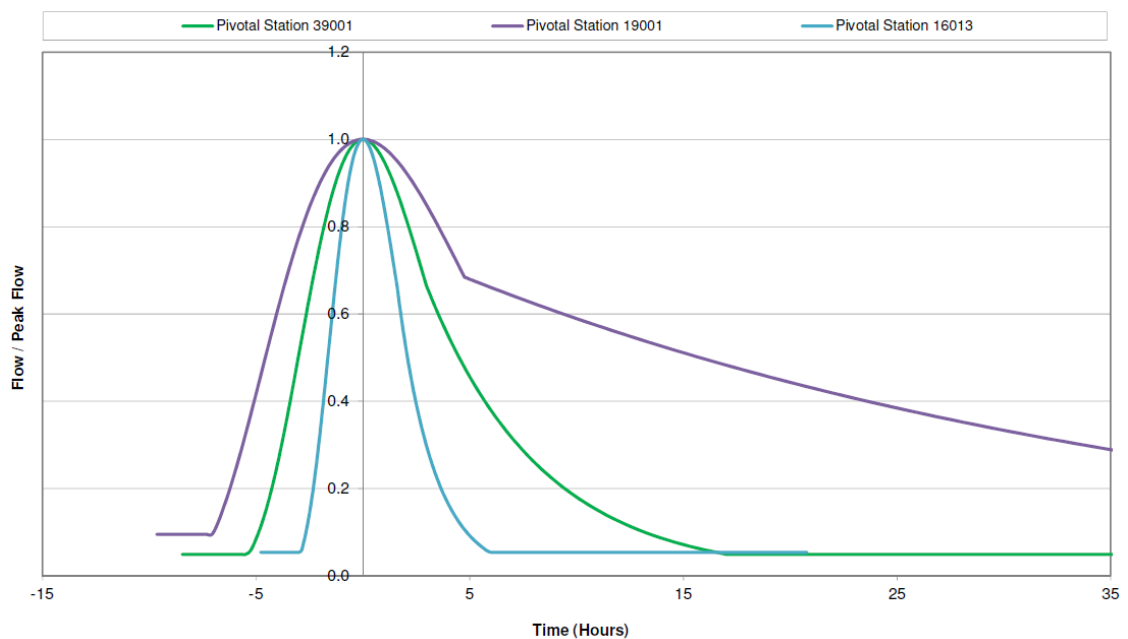
**Figure A1.5 Non-dimensional Hydrographs for Gauging Station 23002**



**Figure A1.6 Non-dimensional Hydrographs for Gauging Station 23001**



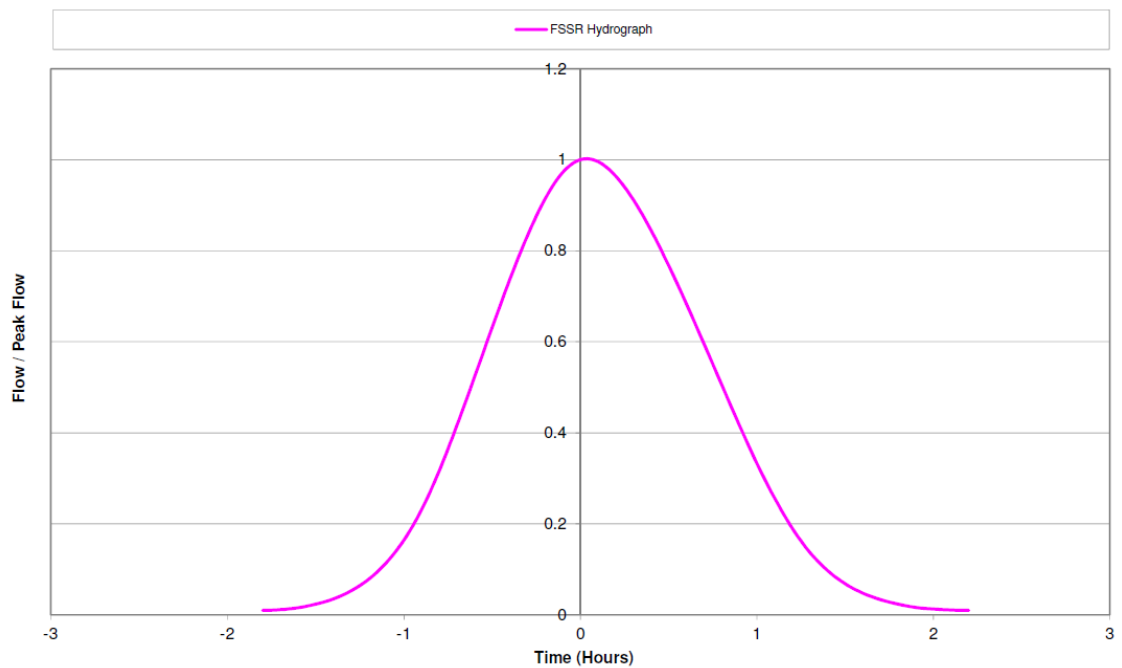
**Figure A1.7 Non-dimensional Hydrograph for Reach 3 – Main Stem (Pivotal Station 23012)**



**Figure A1.8 Non-dimensional Hydrograph used for tributaries**

The hydrograph shapes shown in Figure A1.8 above, have been adopted for the following watercourses (refer also to Appendix B):

- Pivotal Station 39001 - Oolagh River (Tributary 2, Model S14a)
- Pivotal Station 19001 - Tributary 1 (West of Abbeydorney, Model S15)
- Pivotal Station 16013 - Tributary 2 (Abbeydorney Tributary, Model S15)



**Figure A1.9** *Non-dimensional FSSR Hydrograph adopted for tributary branch at Athea (Model S14c)*

## A1.7 Flows and Hydrological Estimation Points

The peak flow estimation process is described in Sections 2.3-2.5 and Section 2.7.2 of the main report. The resulting peak flows at individual HEPs for each model are detailed in Appendix B.

## A1.8 Calibration

The calibration and verification of hydraulic models is discussed in Section 2.7.3 of the main report. Model specific information is provided in Appendix B.



## A2 Lee Catchment

### A2.1 Catchment Description

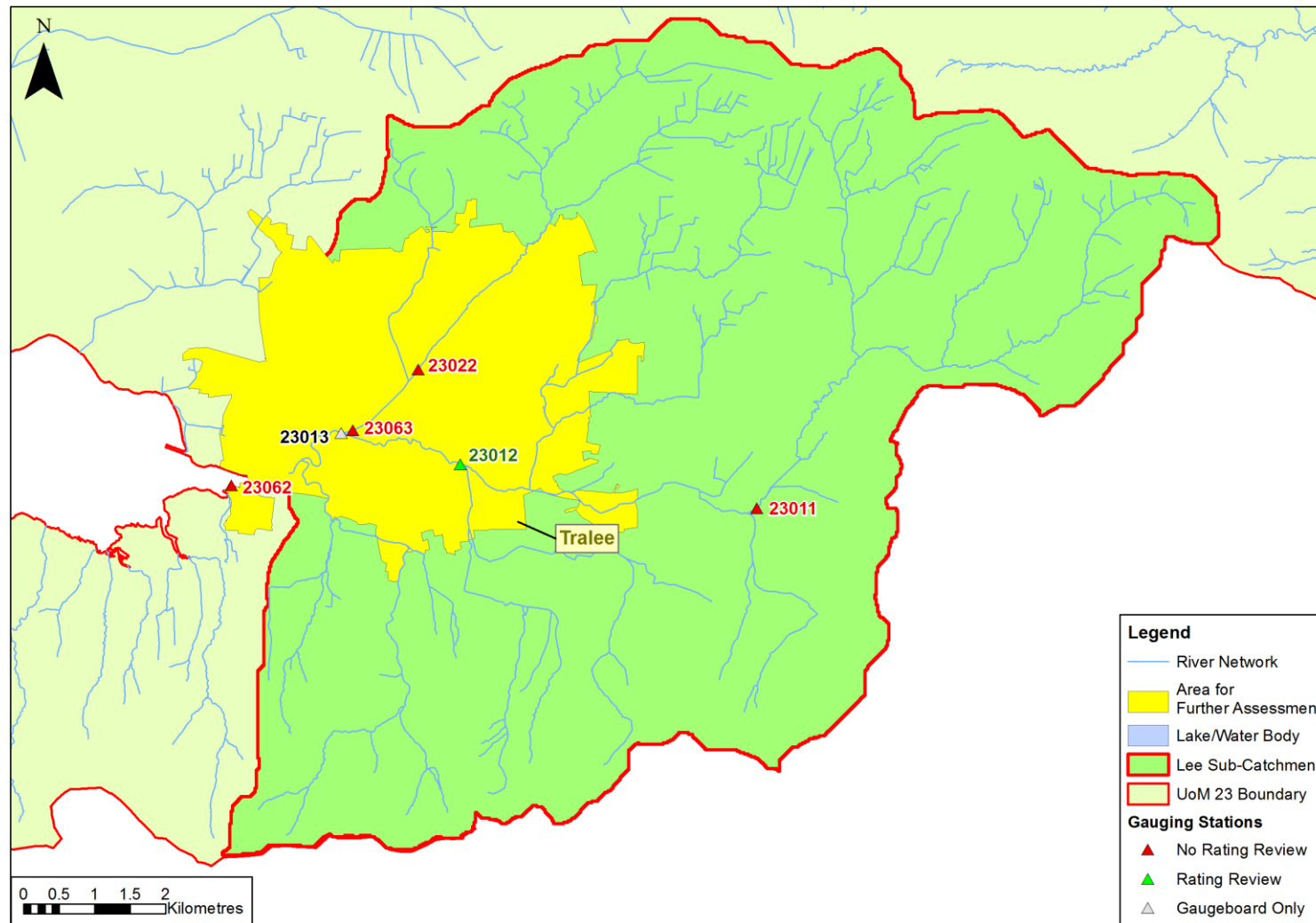
The general description of the Lee catchment (Figure A2.1) is given in Table A2.1.

Attribute	Description
Unit of Management (UoM)	23
Main water courses	River Lee and its tributaries including River Big and four unnamed watercourses
Outflow point	Shannon Estuary
Total catchment area	98.6 km <sup>2</sup> up to mouth of River Lee
Areas for Further Assessment (AFAs)	Tralee
Individual Risk Receptors (IRRs)	None
Model Extents*	S16
General topography	<p>Topography ranges from mountainous in the north-east and south-west. Elsewhere, slopes are generally much gentler.</p> <p>Min altitude = 0 mAOD</p> <p>Max altitude = 467 mAOD</p> <p>The tidal limit is shown on the flood extent maps for Model S16.</p>
Average annual rainfall**	1117mm to 1424mm.
Soil and Geology	<p>Soils: Poorly drained soils and extensive peat deposits predominate, associated with the higher ground of Beennageeha Mountain to the north and Slieve Mish mountains to the south. Well drained soils are limited to the areas of lower ground between Tralee and Castleisland. Made ground is limited to the area around Tralee.</p> <p>Geology: Subsoils comprise primarily peat and moderate permeability glacial tills over limestone, sandstone, shale and siltstone bedrock with some alluvial deposits occurring along watercourses. Shale, sandstone and siltstone bedrocks form the higher ground of Beennageeha Mountain and Slieve Mish mountains where bedrock occurs at or close to surface and forms a locally important (occasionally poor) aquifer. Limestone bedrock forms a regionally important karstified aquifer between Tralee and Castleisland where it occurs close to surface or as isolated surface outcrops within the till and contains many karst features.</p> <p>Refer to Figures 3.3, 3.4 and 3.5 in the main report for details.</p>
Urban areas	<p>The catchment is largely rural. The only significant urbanised area being Tralee AFA at the lower reach of the Lee.</p> <p>The highest URBEXT value (27.9 %) is found at the most downstream node on a tributary branch feeding the River Big.</p>

\* Specific hydrological details for the model is provided in Appendix B5

\*\* Range of SAAR values taken from the FSU catchment descriptors covering the extent of modelling

**Table A2.1 Lee Catchment description**



**Figure A2.1 Lee Catchment with hydrometric stations indicated**

## A2.2 Hydrometric Stations in the Lee Catchment

Details of the gauging stations in the Lee catchment are tabulated in Table A2.2. They are also shown on Figure A2.1.

Model	Gauging Station	Name	Record Data Range	AMAX Available	FSU Quality Class or HGF/QMED	CFRAMS Rating Review	Quality Comments
S16	23011	Ballycarty	1959 - 1991	Levels & Flows	N/A	No	1
	23012	Ballymullen	1974 - 2009	Levels & Flows	A2	Yes	2
	23013	Oakview	Not Stated	N/A	N/A	No	3
	23022	Tralee Clonalour	1985 - 2012	Levels & Flows	N/A	No	4
	23062	Blennerville	1960 - 2010	Level Only	N/A	No	5
	23063	Ballyard	1974 - 2010	Level Only	N/A	No	

**Table A2.2 Lee Catchment Gauging Stations**

### Table A2.2 Hydrometric Data Quality Comments:

1. Station 23011 (Ballycarty) is located upstream beyond the model extent of S16; Irish Hydrometric Register (2011) shows this station to be inactive. Station record extends up until 1991.
2. Station 23012 (Ballymullen) is located on the main branch of the River Lee. Although initially identified as a CFRAMS Rating Review station, no rating equations were derived following discussion with the OPW. Refer to Appendix C for details of the rating review.  
  
Flood relief works that took place between 1992 and 1996 make the check gaugings from before 1996 unsuitable for calibrating a rating post-1996. Since 1996, only very few mid-range check gaugings have been undertaken. In addition, the high flow water levels recorded at this gauge can be affected by the tide; therefore AMAX levels may not represent a fluvial influence alone. For these reasons the flood flow record from this site was not recommended for flood flow estimation.
3. Station 23013 is an inactive staff-gauge only station. The station is not suitable for flood flow estimation and has not been considered further.
4. EPA operated gauge. QMED (as calculated from provided data) at this station is significantly higher (28.2 m<sup>3</sup>/s) than the highest gauged flow (3.8 m<sup>3</sup>/s). Gauge not recommended for high flow estimates.
5. AMAX data for water level only. Both gauges are tidal level recorders.

## A2.3 Catchment River Reaches

River reaches are defined as sections of watercourse with similar hydrological characteristics, so that a single QMED adjustment factor and growth curve can be applied. The catchment is split up into river reaches based on the catchment geometry, geology and an assessment of the availability and quality of hydrometric data. The Lee catchment is covered by six reaches, as tabulated in Table A2.3 and shown on Figure A2.2. The variation in catchment descriptors for each river reach is tabulated in Tables A2.4 to A2.9 below.

Reach	Description	Model Extent
1	River Lee Main Stem (from HEP 23_1521_1 to 23_2919_1)	S16
2	Unnamed Right-Bank Tributary of River Lee (from HEP 23_1556_2 to 23_2750_3)	S16
3a	Unnamed Upper Left-Bank Tributary of River Lee (from HEP 23_2728_5 to 23_1563_2)	S16
3b	Minor Branch of Upper Left-Bank Tributary of River Lee (HEP 23_1551_3 to 23_1551_4)	S16
4	River Big Main Stem (from HEP 23_2349_2 to 23_2612_3) and Unnamed Right-Bank Tributary (HEP 23_2375_1 to 23_2376_5)	S16
5	Unnamed Lower Left-Bank Tributary of River Lee (from HEP 23_673_3 to 23_2648_3)	S16

**Table A2.3 River Reaches in the Lee Catchment**

Reach 1		
Catchment Descriptor	Lower Limit (HEP node)	Upper Limit (HEP node)
AREA (km <sup>2</sup> )	34.3 (23_1521_1)	98.6 (23_2919_2)
BFIsoil	0.41 (23_2647_3)	0.47 (23_1521_1)
SAAR (mm)	1234 (23_2647_3)	1264 (23_23012_1)
FARL	1.0 (all)	1.0(all)
DRAIND	1.6 (23_1521_1)	1.7 (23_1520_2)
S1085 (m/km)	8.7 (23_2919_2)	13.6 (23_1521_1)
ARTDRAIN2 (%)	0.0 (all)	0.0 (all)
URBEXT (%)	0.6 (23_1521_2)	10.8 (23_2647_3)

**Table A2.4 Reach 1 Catchment Descriptor Range**

Reach 2		
Catchment Descriptor	Lower Limit (HEP node)	Upper Limit (HEP node)
AREA (km <sup>2</sup> )	4.0 (23_2698_5)	12.2 (23_2750_3)
BFIsoil	0.30 (23_1556_2)	0.35 (23_2698_6)
SAAR (mm)	1165 (23_1556_2)	1238 (23_2698_6)
FARL	1.0 (all)	1.0 (all)
DRAIND	1.3 (23_2698_5)	2.6 (23_2649_2)
S1085 (m/km)	15.0 (23_2698_6)	20.4 (23_1556_2)
ARTDRAIN2 (%)	0.0 (all)	0.0 (all)
URBEXT (%)	0.01 (23_2698_5)	6.2 (23_2649_2)

**Table A2.5 Reach 2 Catchment Descriptor Range**

Reach 3a		
Catchment Descriptor	Lower Limit (HEP node)	Upper Limit (HEP node)
AREA (km <sup>2</sup> )	7.5 (23_2728_5)	13.5 (23_1563_2)
BFIsoil	0.46 (all)	0.46 (all)
SAAR (mm)	1331 (23_2728_6)	1346 (23_1563_2)
FARL	1.0 (all)	1.0 (all)
DRAIND	1.0 (23_2728_6)	1.4 (23_1563_2)
S1085 (m/km)	25.2 (23_1563_2)	35.6 (23_2728_5)
ARTDRAIN2 (%)	0.0 (all)	0.0 (all)
URBEXT (%)	0.0 (23_2728_5)	1.1 (23_1563_2)

**Table A2.6 Reach 3a Catchment Descriptor Range**

Reach 3b		
Catchment Descriptor	Lower Limit (HEP node)	Upper Limit (HEP node)
AREA (km <sup>2</sup> )	4.4 (23_1551_3)	4.6 (23_1551_4)
BFIs <sub>soil</sub>	0.36 (all)	0.365 (all)
SAAR (mm)	1388 (23_1551_4)	1395 (23_1551_3)
FARL	1.0 (all)	1.0 (all)
DRAIND	2.2 (all)	2.2 (all)
S1085 (m/km)	67.8 (23_1551_4)	75.4 (23_1551_3)
ARTDRAIN2 (%)	0.0 (all)	0.0 (all)
URBEXT (%)	0.0 (all)	0.0 (all)

**Table A2.7 Reach 3b Catchment Descriptor Range**

Reach 4		
Catchment Descriptor	Lower Limit (HEP node)	Upper Limit (HEP node)
AREA (km <sup>2</sup> )	1.01 (23_2375_1)	17.7 (23_2612_3)
BFIs <sub>soil</sub>	0.34 (23_2727_7)	0.35 (23_2375_2)
SAAR (mm)	1117 (23_2375_1)	1166 (23_2349_2)
FARL	1.0 (all)	1.0 (all)
DRAIND	1.7 (23_2612_3)	3.3 (23_2375_1)
S1085 (m/km)	20.5 (23_2612_3)	36.3 (23_2375_1)
ARTDRAIN2 (%)	0.0 (all)	0.0 (all)
URBEXT (%)	0.0 (23_2375_1)	25.3 (23_2612_3)

**Table A2.8 Reach 4 Catchment Descriptor Range**

Reach 5		
Catchment Descriptor	Lower Limit (HEP node)	Upper Limit (HEP node)
AREA (km <sup>2</sup> )	1.04 (23_673_1)	13.7 (23_2648_3)
BFIs <sub>soil</sub>	0.35 (23_587_3)	0.43 (23_673_2)
SAAR (mm)	1348 (23_673_2)	1424 (23_587_3)
FARL	1.0 (all)	1.0 (all)
DRAIND	1.5 (23_587_3)	2.4 (23_673_1)
S1085 (m/km)	43.0 (23_2648_3)	89.6 (23_673_1)
ARTDRAIN2 (%)	0.0 (all)	0.0 (all)
URBEXT (%)	0.0 (23_587_3)	0.9 (23_2409_2)

**Table A2.9 Reach 5 Catchment Descriptor Range**



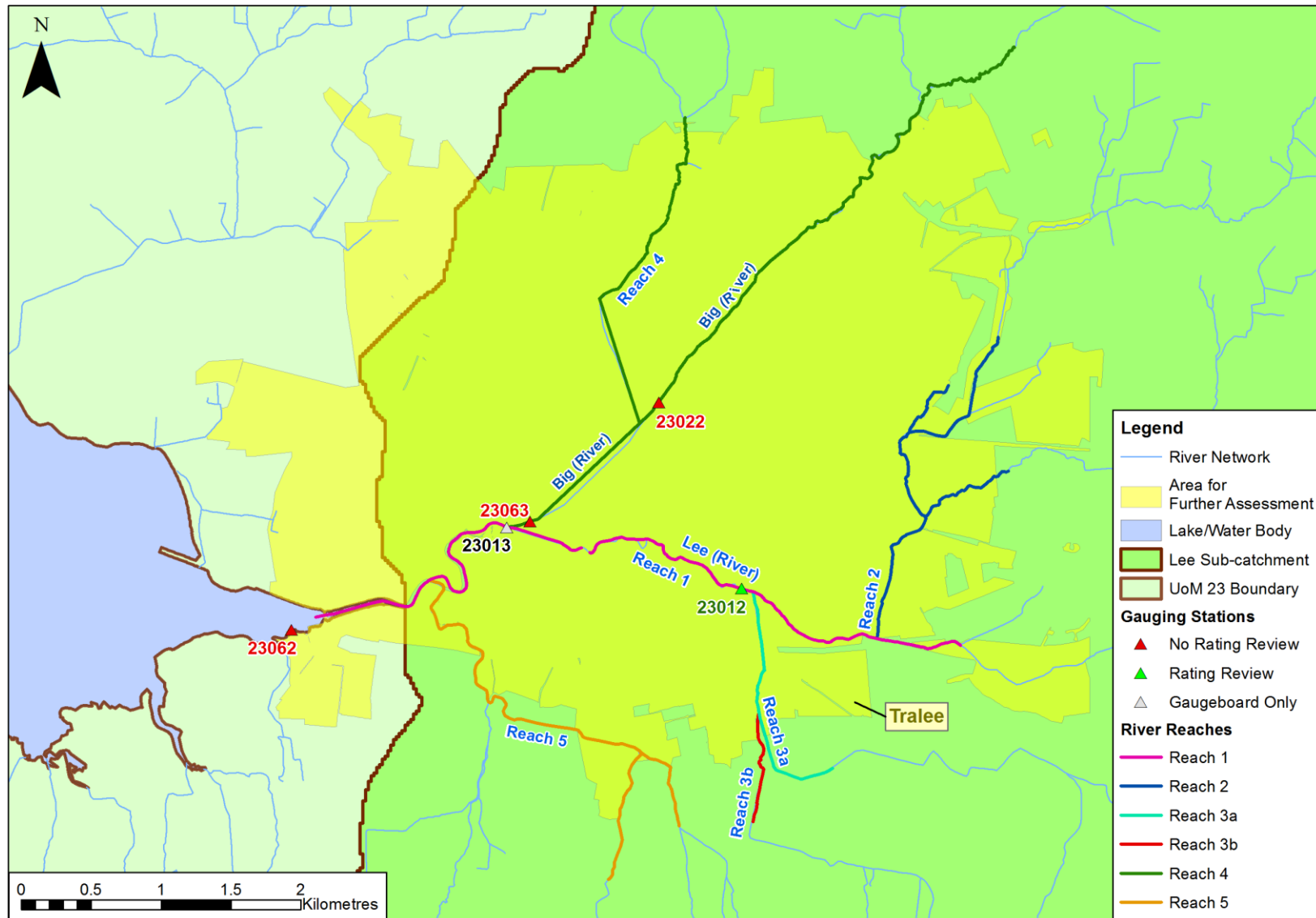


Figure A2.2 Lee Catchment River Reaches

## A2.4 QMED Adjustment Factors

Despite a number of stations located within the S16 model extent (see Figure A2.2), none were deemed suitable for adjusting the estimate of QMED. Station records are either tidally influenced or poorly rated for flood frequency analysis.

The adjustment factors were estimated using a weighted geometric mean of the five hydrologically most similar gauged sites in the country (see Tables A2.10 to A2.13). The Dij parameter summarises the hydrological similarity between the subject site and the pivotal site and is a function of the AREA, BFIsoil and SAAR catchment descriptors. The weight of a pivotal site is the inverse of Dij divided by the sum of the inverses for all five pivotal sites. The weights add up to 1. The geometric mean is the product of the site-specific adjustment factors to the power of the weight, for all five pivotal sites:

Final Adjustment Factor =  $\prod (\text{Adjustment Factor}^{\text{Weight}})$ . (where  $\prod$  is the product sign)

The adjustment factors for each station reflect the ratios of the gauged and statistical estimates and were provided by OPW as part of the FSU datasets.

Reaches 1 and 3a have a similar range of BFI values and the adjustment factor calculated for Reach 1 was assumed for 3a. Similarly Reaches 2 and 3b have similar ranges of BFI and the adjustment factor for Reach 2 was assumed for Reach 3b.

Station Number	Station Name	Rank	Dij	Weight	Adjustment Factor
14033	MOUNTMELICK	1	0.545	0.290	1.17
35002	OWENBEG	2	0.735	0.215	1.42
34009	OWENGARVE	3	0.894	0.177	0.73
35004	OWENMORE	4	0.967	0.163	0.82
1041	DEELE	5	1.024	0.154	1.58
Final Adjustment Factor (Weighted Geometric Mean)					1.11

**Table A2.10 QMED Adjustment Factor for HEP 23\_1520\_2 (Reach 1)**

Station Number	Station Name	Rank	Dij	Weight	Adjustment Factor
6030	BALLYGOLY	1	1.062	0.278	2.32
36021	YELLOW	2	1.290	0.229	1.22
27001	CLAUREEN	3	1.671	0.177	0.66
8007	BROADMEADOW	4	1.844	0.160	1.02
14033	MOUNTMELICK	5	1.905	0.155	1.17
Final Adjustment Factor (Weighted Geometric Mean)					1.26

**Table A2.11 QMED Adjustment Factor for HEP 23\_2750\_2 (Reach 2)**

Station Number	Station Name	Rank	Dij	Weight	Adjustment Factor
6030	BALLYGOLY	1	1.208	0.268	2.32
36021	YELLOW	2	1.542	0.210	1.22
8007	BROADMEADOW	3	1.741	0.186	1.02
27001	CLAUREEN	4	1.805	0.179	0.66
14033	MOUNTMELICK	5	2.053	0.157	1.17
Final Adjustment Factor (Weighted Geometric Mean)					1.25

**Table A2.12 QMED Adjustment Factor for HEP 23\_2727\_7 (Reach 4)**

Station Number	Station Name	Rank	Dij	Weight	Adjustment Factor
36021	YELLOW	1	0.863	0.284	1.22
6030	BALLYGOLY	2	1.118	0.220	2.32
10004	LARAGH	3	1.333	0.184	2.12
27001	CLAUREEN	4	1.525	0.161	0.66
35002	OWENBEG	5	1.631	0.151	1.42
Final Adjustment Factor (Weighted Geometric Mean)					1.44

**Table A2.13 QMED Adjustment Factor for HEP 23\_2648\_3 (Reach 5)**

Table A2.14 gives the final QMED adjustment factor applied to each reach in the catchment with a justification for selection.

Reach	QMED adjustment factor	Station or HEP Node	Justification
1	1.11	23_1520_2	QMED adjustment calculated upstream of station 23012 (beyond tidal limit) based on top-5 hydrologically similar sites
2	1.26	23_2750_2	No gauging station on reach. QMED adjustment factor based on top-5 hydrologically similar sites
3a	1.11	23_1520_2	Ungauged site. Similar range in BFI as Reach 1
3b	1.26	23_2750_2	Ungauged site. Similar range in BFI as Reach 2
4	1.25	23_2727_7	No suitable gauge for QMED adjustment. Adjustment factor based on top-5 hydrologically similar sites
5	1.44	23_2648_3	No suitable gauge for QMED adjustment. Adjustment factor based on top-5 hydrologically similar sites

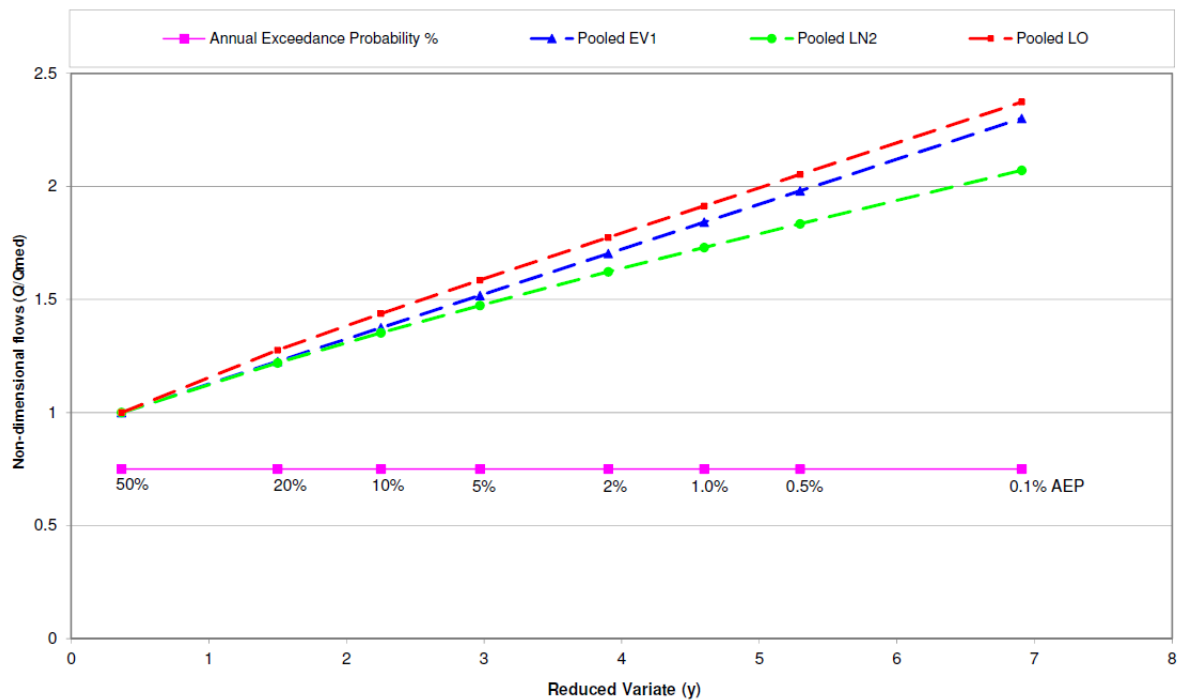
**Table A2.14 Final QMED Adjustment Factor Applied to Each Reach**

## A2.5 Flood Frequency Curves

None of the gauging stations are recommended for flood frequency analysis (Section A2.2). Therefore the flood frequency curves for all of the reaches have been derived using pooling group analysis. The resulting curves are presented in Figures A2.3 to A2.7.

### River Lee Main Stem (Reach 1)

The flood frequency curves for Reach 1 are shown in Figure A2.3. The flood frequency curves have been derived from a pooled analysis at HEP 23\_23012\_1 (the site of the Ballymullen gauging station [Stn No. 23012]). The final pooling group was found to be suitably homogenous and utilises a cumulative total of 482-years of station data.

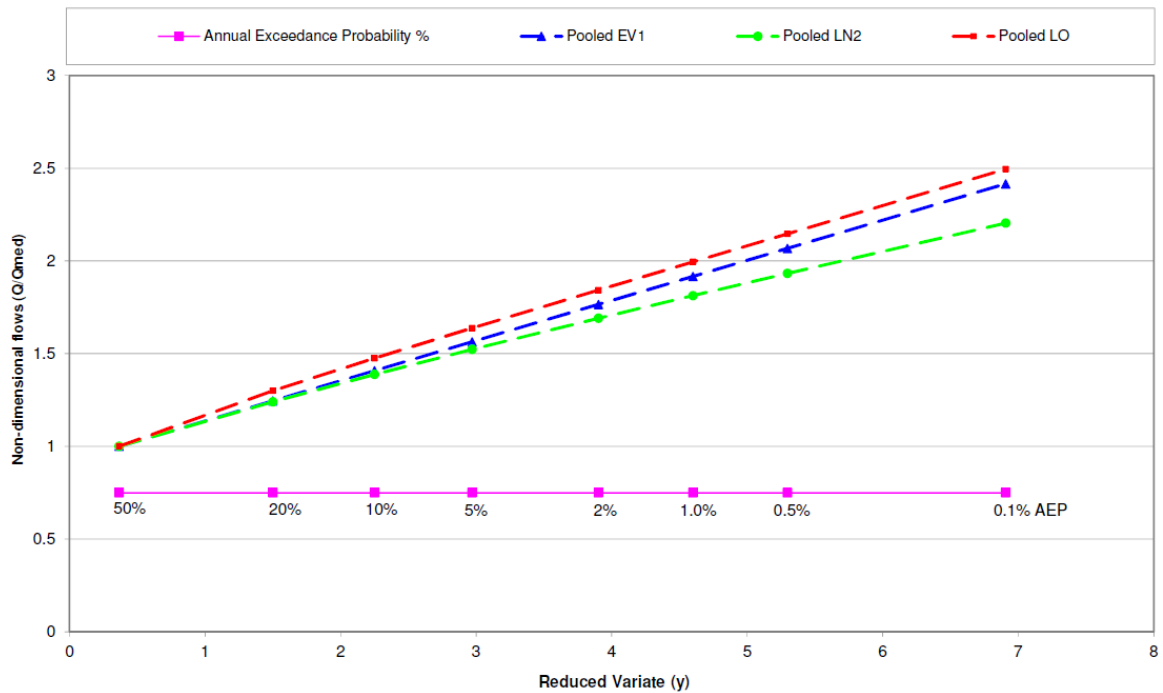


**Figure A2.3 Reach 1 – Flood Frequency Curves**



## Right-Bank Tributary of River Lee (Reach 2)

The flood frequency curves for Reach 2 are shown in Figure A2.4. The flood frequency curves have been derived from a pooled analysis at HEP 23\_2750\_2.

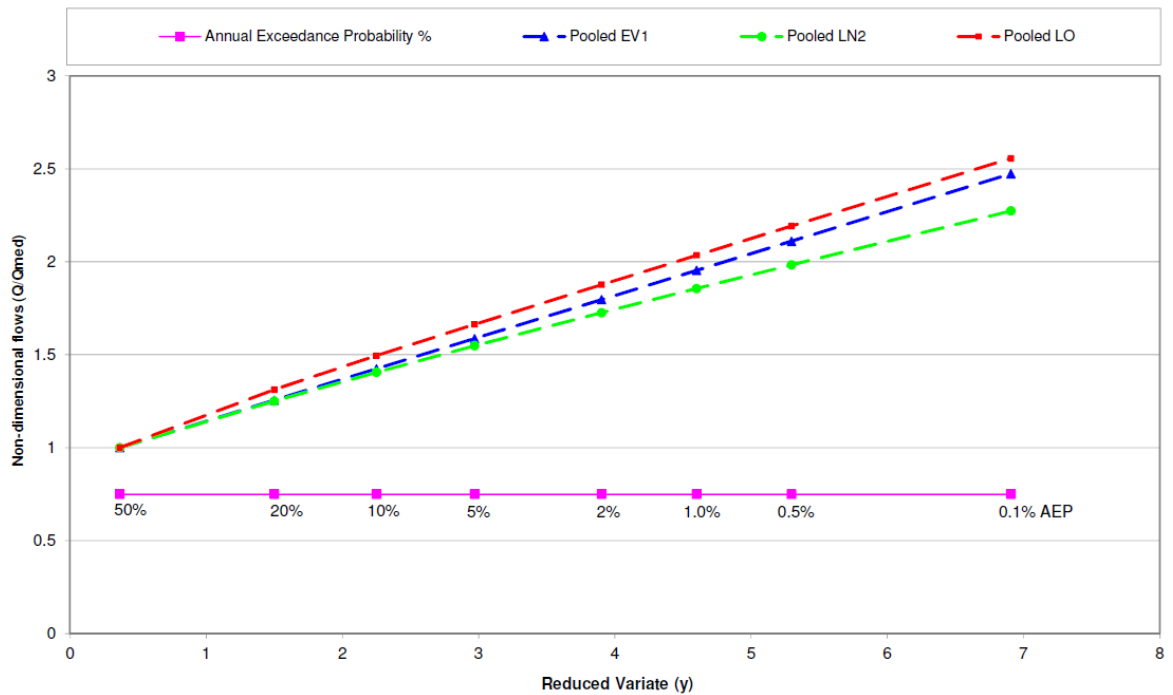


**Figure A2.4 Reach 2 – Flood Frequency Curves**

The pooled frequency curves plotted in Figure 2.4 have been derived from 512-years of station data. In order to obtain a sufficient number of years to satisfy the 5T rule, it was necessary to relax the criteria for station selection to allow sites with catchment areas up to 12x that of the target site, and BFI and SAAR values up to 55% and ~50% (respectively) greater. Refer to Appendix G for details of the pooling group analysis.

### Left-Bank Tributary of River Lee (Reaches 3a & 3b)

The flood frequency curves for Reaches 3a and 3b are shown in Figure A2.5. The curves have been derived from a pooled analysis at HEP 23\_1563\_2.

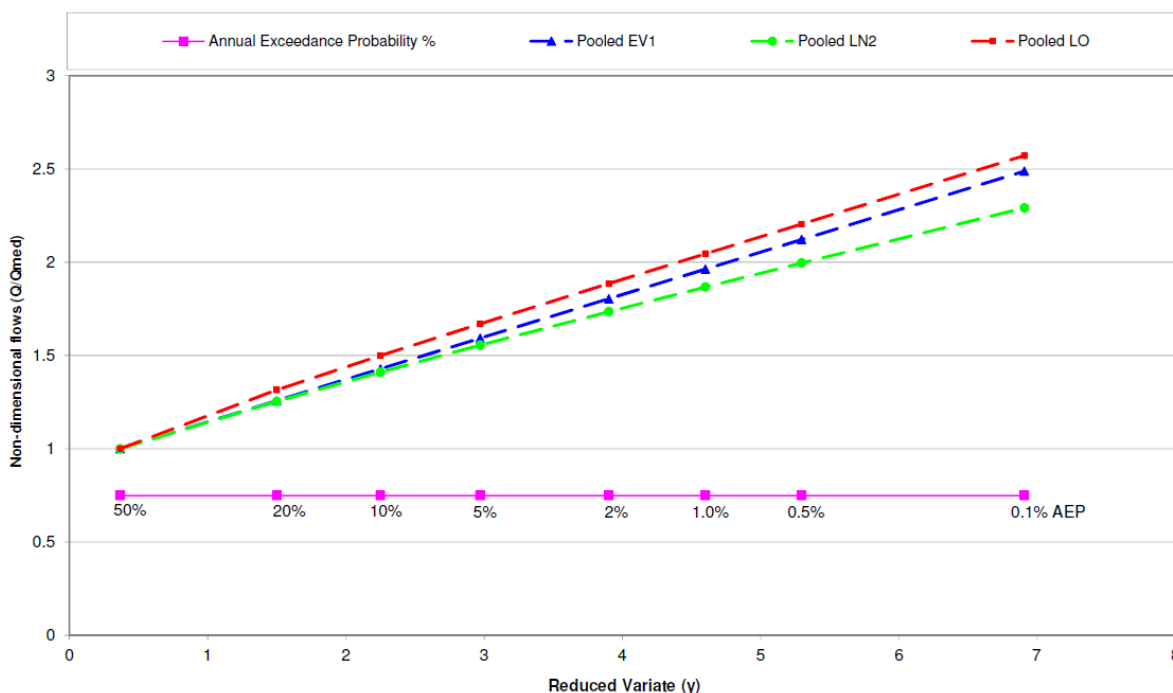


**Figure A2.5 Reach 3a & 3b – Flood Frequency Curves**

The pooled frequency curves plotted in Figure 2.5 have been derived from 500-years of station data. In order to obtain a sufficient number of years to satisfy the 5T rule, it was necessary to relax the criteria for station selection to allow sites with catchment areas up to 10x that of the target site, BFI values  $\pm 32\%$  and SAAR values  $\pm 30\%$ . Refer to Appendix G for details of the pooling group analysis.

## River Big (Reach 4)

The flood frequency curves for Reaches 4 are shown in Figure A2.6. The curves have been derived from a pooled analysis at HEP 23\_2727\_7 (the site of the Tralee Clonalour gauging station [Stn No. 23022])



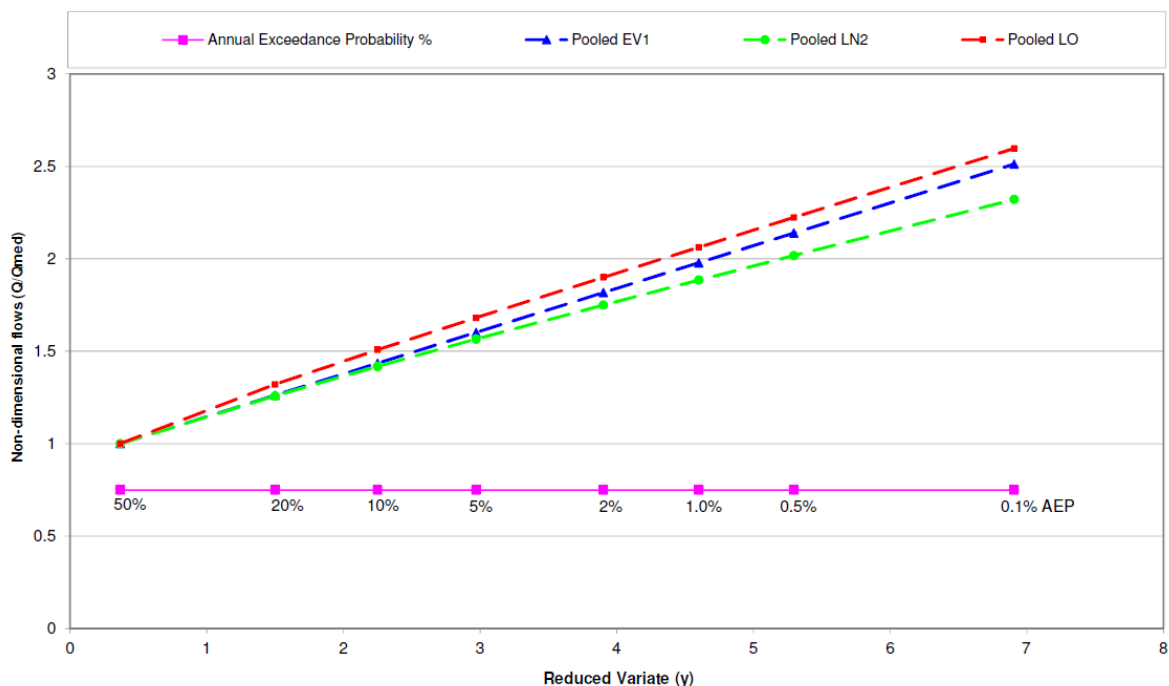
**Figure A2.6 Reach 4 – Flood Frequency Curves**

It should be noted that the catchment area draining to HEP 23\_2727\_7 is heavily urbanised and establishing a homogenous pooling group has proven problematic due to a high URBEXT and relatively low BFI value (relative to the stations in the pooling group).

The pooled frequency curves plotted in Figure A2.6 have been derived from just 430-years of station data.

### River Lee Lower Tributary (Reach 5)

The flood frequency curves for Reaches 5 are shown in Figure A2.7. The flood frequency curves have been derived from a pooled analysis at HEP 23\_2648\_3.



**Figure A2.7 Reach 5– Flood Frequency Curves**

The pooled frequency curves plotted in Figure 2.7 have been derived from 509-years of station data. In order to obtain a sufficient number of years to satisfy the 5T rule, it was necessary to relax the criteria for station selection to allow sites with catchment areas up to 25x that of the target site. The upper and lower thresholds for BFI and SAAR values were relaxed to allow the inclusion of sites with values  $\pm 30\%$  and  $\pm 43\%$  respectively. The URBEXT parameter was also relaxed to allow the inclusion of sites with values  $\pm 3.0x$  the target site. Refer to Appendix G for full details of the pooling group analysis.

Selection of the most suitable distribution shown in Figures A2.3 - A2.7 has been based on interpretation of the L-Moment Ratio Diagrams included in the OPW Pooled Growth Curve Analysis spreadsheet. The selected distribution for each river reach is tabulated in Table A2.15.

## River Reach Flood Frequency

The growth curve distribution applied to each reach is shown in Table A2.15. Growth factors generated for a range of AEPs have been detailed in Table A2.16.

Reach	Station	Single Site or Pooled	Selected distribution
1	HEP 23_23012_1	Pooled	EV1
2	HEP 23_2750_2	Pooled	EV1
3a	HEP 23_1563_2	Pooled	EV1
3b	HEP 23_1563_2	Pooled	EV1
4	HEP 23_2727_7	Pooled	EV1
5	HEP 23_2648_3	Pooled	EV1

**Table A2.15 Final Growth Curves Selected**

Annual Exceedance Probability (%)	Growth Factors Reach1	Growth Factors Reach2	Growth Factors Reach 3	Growth Factors Reach 4	Growth Factors Reach 5
50%	1.00	1.00	1.00	1.00	1.00
20%	1.24	1.25	1.26	1.26	1.26
10%	1.39	1.41	1.42	1.43	1.44
5%	1.54	1.56	1.59	1.59	1.60
2%	1.73	1.77	1.80	1.80	1.82
1%	1.88	1.92	1.95	1.96	1.98
0.5%	2.02	2.07	2.11	2.12	2.14
0.1%	2.36	2.42	2.47	2.49	2.51

**Table A2.16 Final Growth Factors Applied across the Lee Catchment**

## A2.6 Hydrograph Shape

Section 2.6 of the main hydrology report describes the selection of the design hydrograph shape. The design flood hydrograph shape is preferably derived from flood events recorded at flow gauges. Although the annual maximum peak flows from gauging station 23012 (Ballymullen) are not considered sufficiently accurate to undertake flood frequency analysis on, it is judged suitable for providing a useful steer upon the general shape and width of the typical flood event. Consequently this station has been used to identify a typical hydrograph shape. Similarly the record at station 23022 (Tralee Clonalour) has also been used.

Where the absence of hydrometric data prevents deriving actual event hydrographs as is the case for Reach 2, 3a, 3b, and 5; a hydrograph shape has been generated for a pivotal station that is hydrologically similar to the target site.

Table A2.17 summarises the gauging stations used to produce the typical flood hydrograph shapes for the catchment reaches.

Reach	Gauging Station
1	23012 – Ballymullen
2	N/A
3a	N/A
3b	N/A
4 (main stem)	23022 – Tralee Clonalour
5	N/A

**Table A2.17 Gauging Stations used to derive the Typical Hydrograph Shape in each Reach**

Tables A2.18–19 and Figures A2.8 and A2.11 identify the most representative flood events chosen for comparison at the gauges. The hydrograph that best represents a typical/median flood response has then been selected as the representative design hydrograph shape. Figures A2.9, A2.10, A2.12, and A2.13 present the hydrograph shapes adopted for all other river reaches. The Figures A2.8 – A2.13 present the hydrographs in a non-dimensional manner by dividing flows by their respective flood peaks.

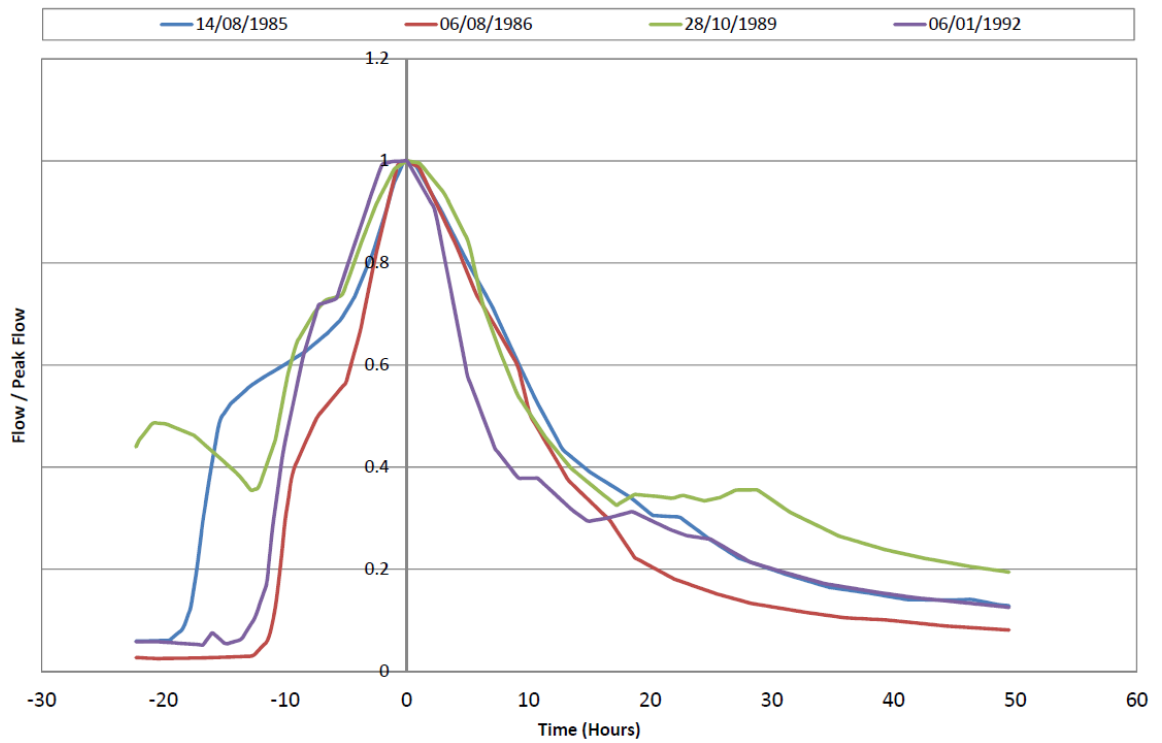
Date	Peak Flow (m <sup>3</sup> /s)	Comments
14/08/1985	26.1	
06/08/1986	31.8	
28/10/1989	19.1	
06/01/1992	21.2	Most representative shape

**Table A2.18 Highest Flood Peaks for Gauging Station 23012**

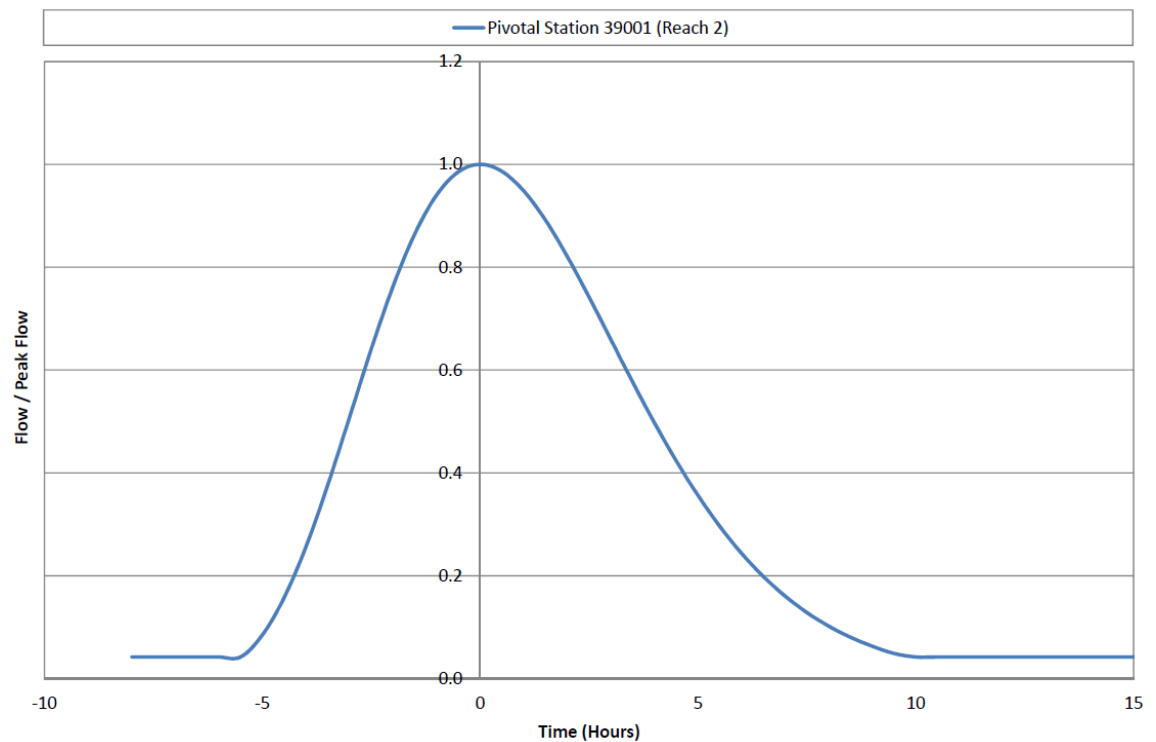


Date	Peak Flow (m <sup>3</sup> /s)	Comments
11/10/2000	32.9	
02/12/2005	59.7	
07/01/2005	57.6	
02/12/2006	28.3	Most representative shape

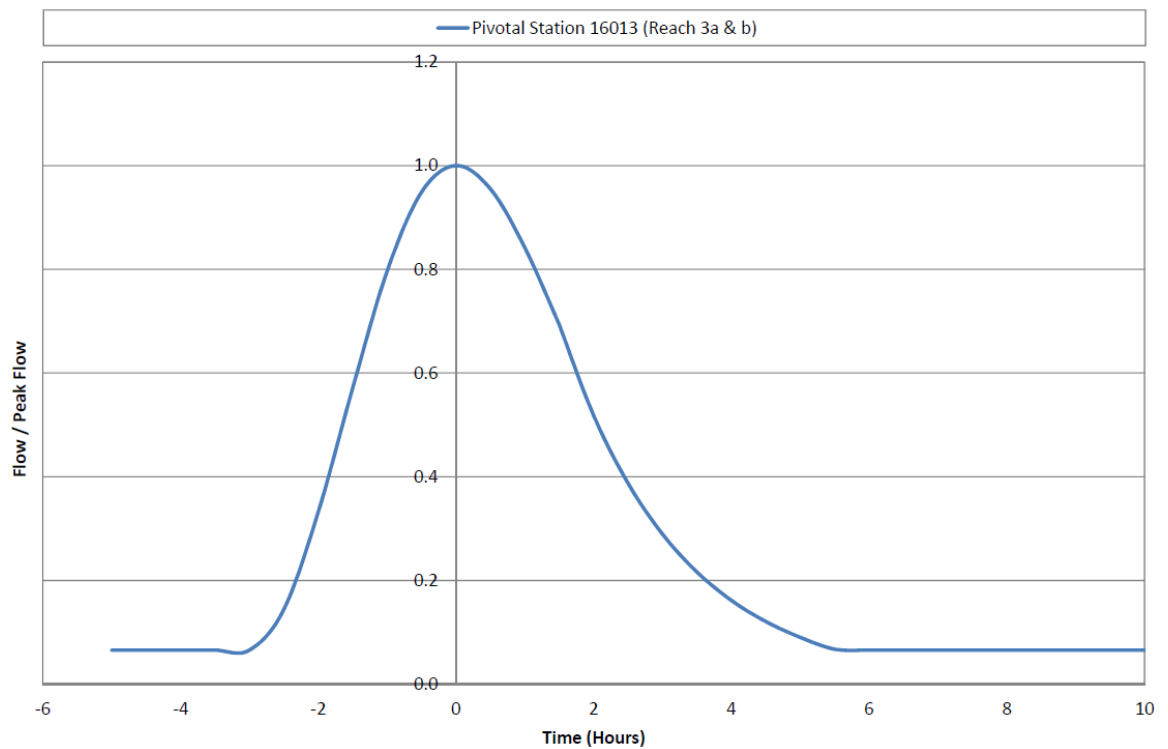
***Table A2.19 Highest Flood Peaks for Gauging Station 23022***



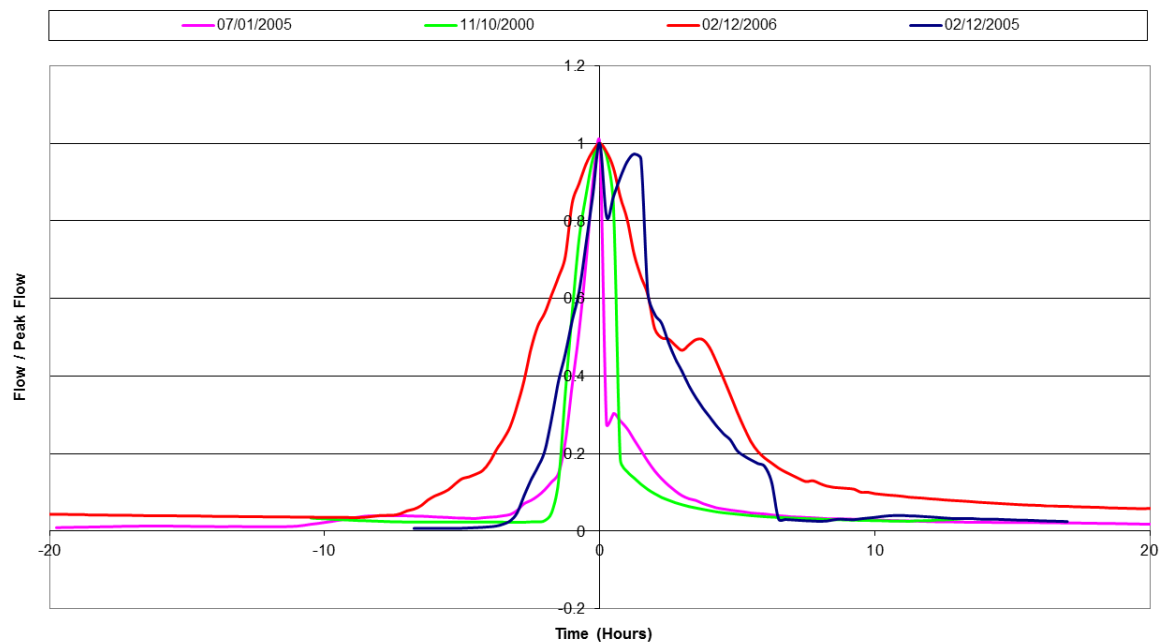
**Figure A2.8 Non-dimensional Hydrographs for Gauging Station 23012**



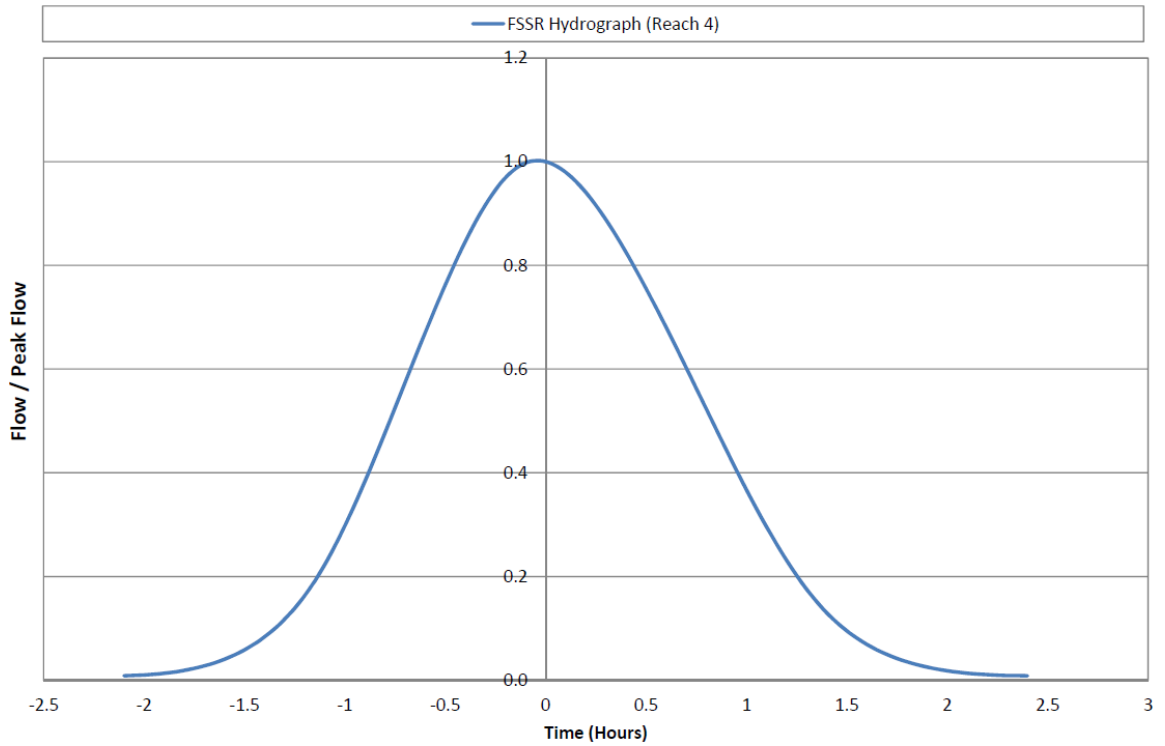
**Figure A2.9 Non-dimensional Hydrograph for Reach 2 (Pivotal Station 39001)**



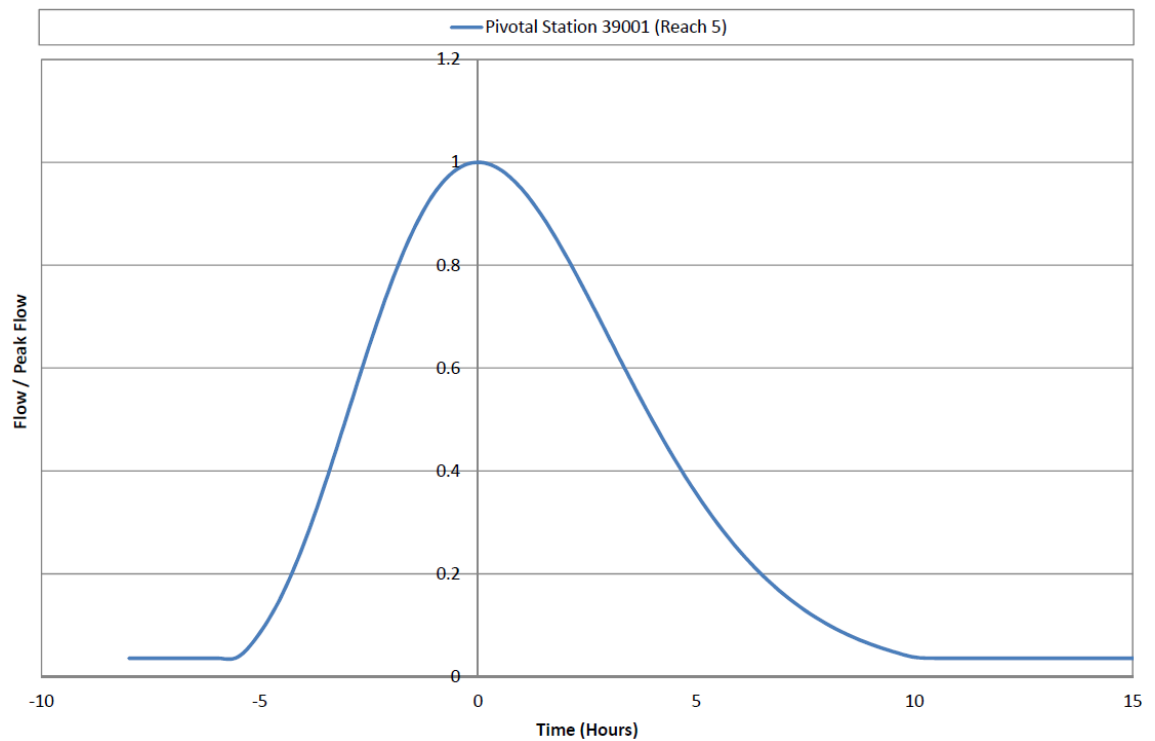
**Figure A2.10**      **Non-dimensional Hydrograph for Reach 3a & b (Pivotal Station 16013)**



**Figure A2.11**      **Non-dimensional Hydrographs for Gauging Station 23022**



**Figure A2.12 Non-dimensional Hydrograph for Reach 4 (Tributary of River Big)**



**Figure A2.13 Non-dimensional Hydrograph for Reach 5 (Lower Tributary of River Lee)**

## **A2.7 Flows and Hydrological Estimation Points**

The peak flow estimation process is described in Sections 2.3-2.5 and Section 2.7.2 of the main report. The resulting peak flows at individual HEPs for each model are detailed in Appendix B.

## **A2.8 Calibration**

The calibration and verification of hydraulic models is discussed in Section 2.7.3 of the main report. Model specific information is provided in Appendix B.

## A3 Tyshe Catchment

### A3.1 Catchment Description

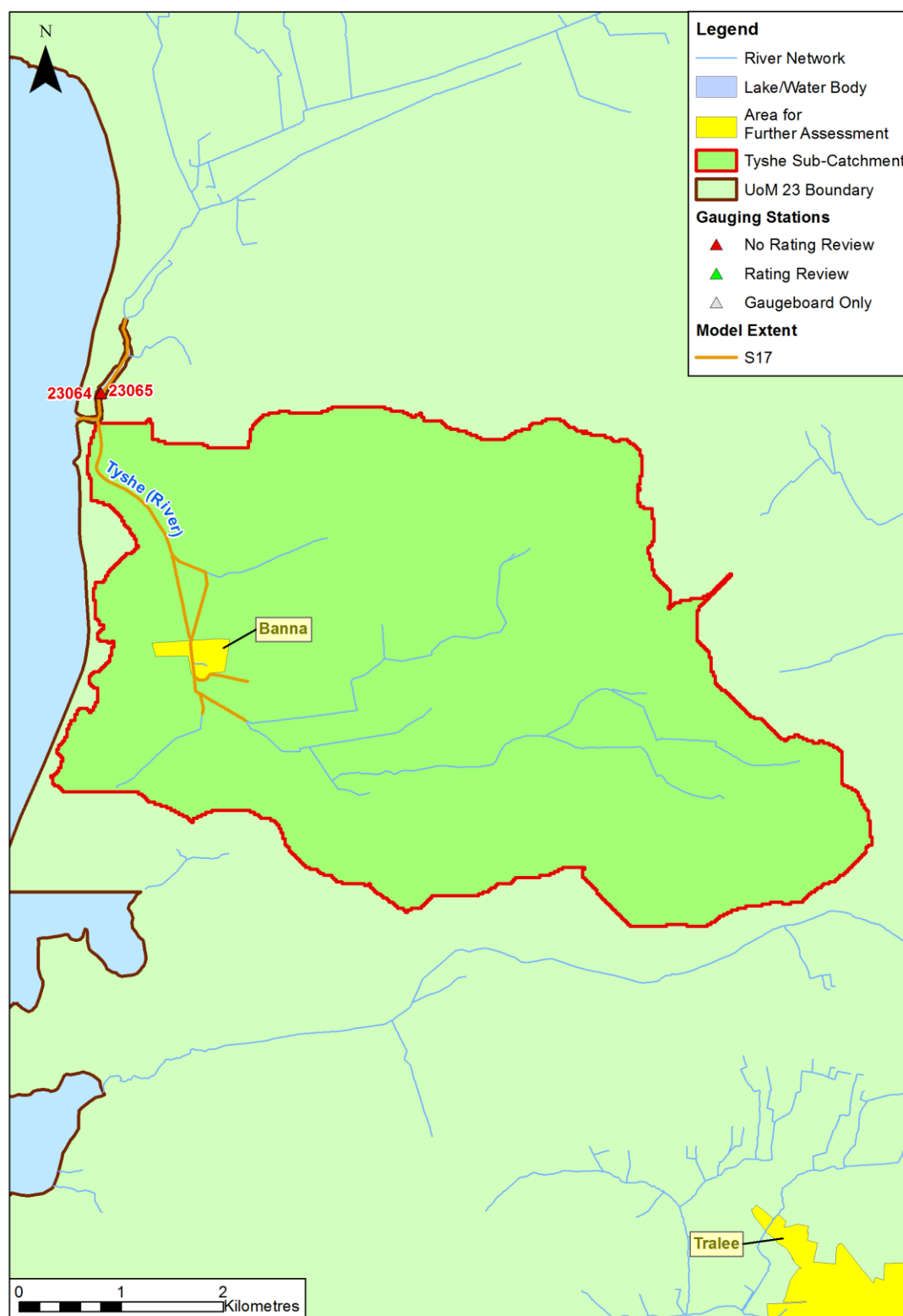
The general description of the Tyshe catchment (Figure A3.1) is given in Table A3.1.

\*\* Range of SAAR values taken from the FSU catchment

**Table A3.1 Tyshe Catchment description**

Attribute	Description
Unit of Management (UoM)	23
Main water courses	River Tyshe
Outflow point	Atlantic Ocean
Total catchment area	27.5 km <sup>2</sup> up to the mouth of its outfall to the Atlantic Ocean at Black Rock.
Areas for Further Assessment (AFAs)	Banna
Individual Risk Receptors (IRRs)	None
Model Extents*	S17
General topography	<p>Min altitude = 0 mAOD Max altitude = 82 mAOD</p> <p>A low-lying catchment that is topographically flat, with the exception of mildly sloping land around Rathkenny/Tubrid Beg in the southeast of the catchment, from where the River Tyshe rises.</p> <p>The tidal limit is shown on the flood extent maps for Model S16.</p>
Average annual rainfall**	1090mm to 1148mm.
Geology and soils	<p>Soils: Well drained soils predominate. Poorly drained soils associated only with areas of extensive peat deposits.</p> <p>Geology: Subsoils comprise predominantly low to moderate permeability glacial tills. Extensive peat and minor alluvial deposits occur along the course of the River Tyshe and windblown sand dunes occur along the coast. Limestone bedrock in the north of the catchment is a regionally important karstified bedrock aquifer and elsewhere is a locally important aquifer. Sandstone bedrock is limited to the far southeast of the catchment and is a locally important aquifer. Isolated surface outcrops of karstified limestone occur along the River Tyshe east of Ardfert and elsewhere within the glacial tills.</p> <p>Refer to Figures 3.3, 3.4 and 3.5 in the main report for details.</p>
Urban areas	The only significant urban areas within the catchment are the settlements of Ardfert and Banna, of which, only Banna is classified as being an AFA. The highest URBEXT value of 2.3% is found at the uppermost extent of the S17 model, thereafter, URBEXT values decrease with downstream extent.





**Figure A3.1 Tyshe Catchment with model extent and hydrometric stations**

## A3.2 Hydrometric Stations in the Feale Catchment

Details of the gauging stations in the Tyshe catchment are tabulated in Table A3.2. They are also shown on Figure A3.1.

Model	Gauging Station	Name	Record Data Range	AMAX Available	FSU Quality Class or HGF/QMED	CFRAMS Rating Review	Quality Comments
S17	23064	Akeragh Sluice D/S	1980 - 1983	Level Only	N/A	N/A	1
	23065	Akeragh Sluice U/S	1980 - 1983	Level Only	N/A	N/A	

**Table A3.2 Tyshe Catchment Gauging Stations**

### Table A3.2 Hydrometric Data Quality Comments:

1. Tidal gauge recording level data only. Limited data record. Not suitable for hydrological analysis and flood estimation.

### A3.3 Catchment River Reaches

River reaches are defined as sections of watercourse with similar hydrological characteristics, so that a single QMED adjustment factor and growth curve can be applied. Based on the catchment geometry, geology and an assessment of the availability and quality of data at the gauging stations listed in Table A3.2 above, the entire Tyshe catchment has been considered as a single reach as shown in Table A3.3 and on Figure A3.2. The variation in catchment descriptors for the reach is tabulated in Table A3.4 below.

Reach	Description	Model Extent
1	Entire S17 model extent from HEP 23_428_1 to the point of discharge into the Atlantic Ocean (refer to Appendix B6 for the HEP node numbering).	S17

**Table A3.3 River Reach in the Catchment**

Reach 1		
Catchment Descriptor	Lower Limit (HEP node)	Upper Limit (HEP node)
AREA (km <sup>2</sup> )	0.1 (23_524_4)	28 (23_2925_5)
BFIsoil	0.56 (23_224_1)	0.65 (23_2743_4)
SAAR (mm)	1090 (23_2743_4)	1148 (23_224_1)
FARL	1.0 (all)	1.0 (all)
DRAIND	0.1 (23_524_4)	7.3 (23_524_4)
S1085 (m/km)	0.7 (23_224_1)	3.2 (23_497_1)
ARTDRAIN2 (%)	0 (all)	0 (all)
URBEXT (%)	0.0 (23_224_1)	2.3 (23_428_1)

**Table A3.4 Reach 1 Catchment Descriptor Range**

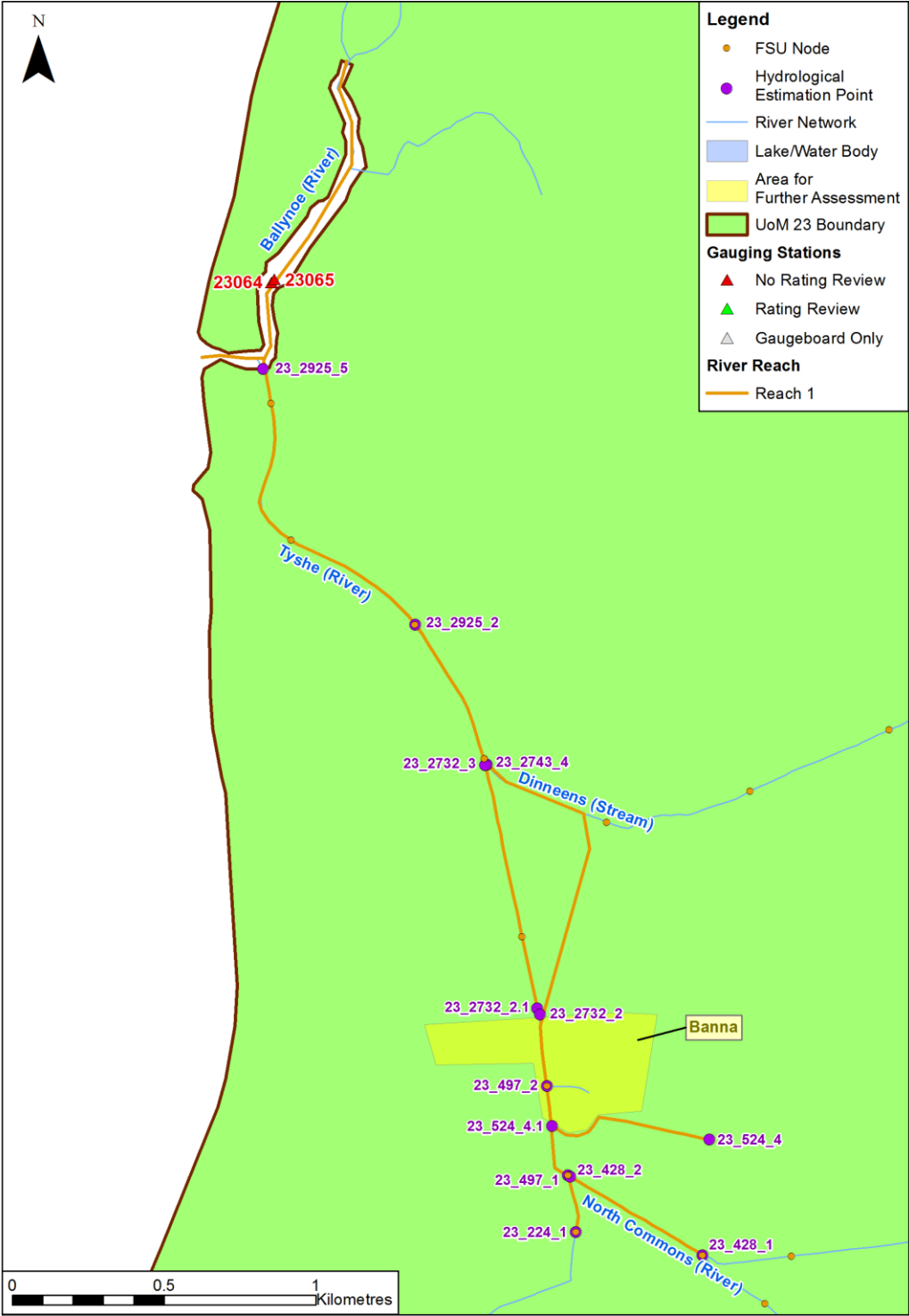


Figure A3.2 Tyshe Catchment River Reach

### A3.4 QMED Adjustment Factors

The QMED adjustment factor applied to the entire S17 Model extent was estimated using multiple pivotal sites in the absence of an adequate single pivotal site. The adjustment factor was estimated using a weighted geometric mean of the five hydrologically most similar gauged sites in the country (see Table A3.5). The Dij parameter summarises the hydrological similarity between the subject site and the pivotal site and is a function of the AREA, BFIsoil and SAAR catchment descriptors. The weight of a pivotal site is the inverse of Dij divided by the sum of the inverses for all five pivotal sites. The weights add up to 1. The geometric mean is the product of the site-specific adjustment factors to the power of the weight, for all five pivotal sites:

Final Adjustment Factor =  $\prod (\text{Adjustment Factor}^{\text{Weight}})$ . (where  $\prod$  is the product sign)

The adjustment factors for each station reflect the ratios of the gauged and statistical estimates and were provided by OPW as part of the FSU datasets.

Station Number	Station Name	Rank	Dij	Weight	Adjustment Factor
25040	ROSCREA	1	0.503	0.255	0.55
30020	BALLYHAUNIS	2	0.517	0.248	0.67
22009	DEENAGH ( LAUNE)	3	0.519	0.247	1.23
16051	ROSSESTOWN	4	1.004	0.128	0.73
6031	CURRALHIR	5	1.050	0.122	2.05
Final Adjustment Factor (Weighted Geometric Mean)					<b>0.86</b>

**Table A3.5 QMED Adjustment Factor for HEP 23\_497\_2**

Table A3.6 gives the final QMED adjustment factor applied to the reach with a justification for selection.

Reach	QMED adjustment factor	Station or HEP Node	Justification
1	0.86	23_497_2	No station suitable for flood estimation within the reach.  The adjustment factor calculated at 23_497_2 has been applied at all HEPs within Model S17

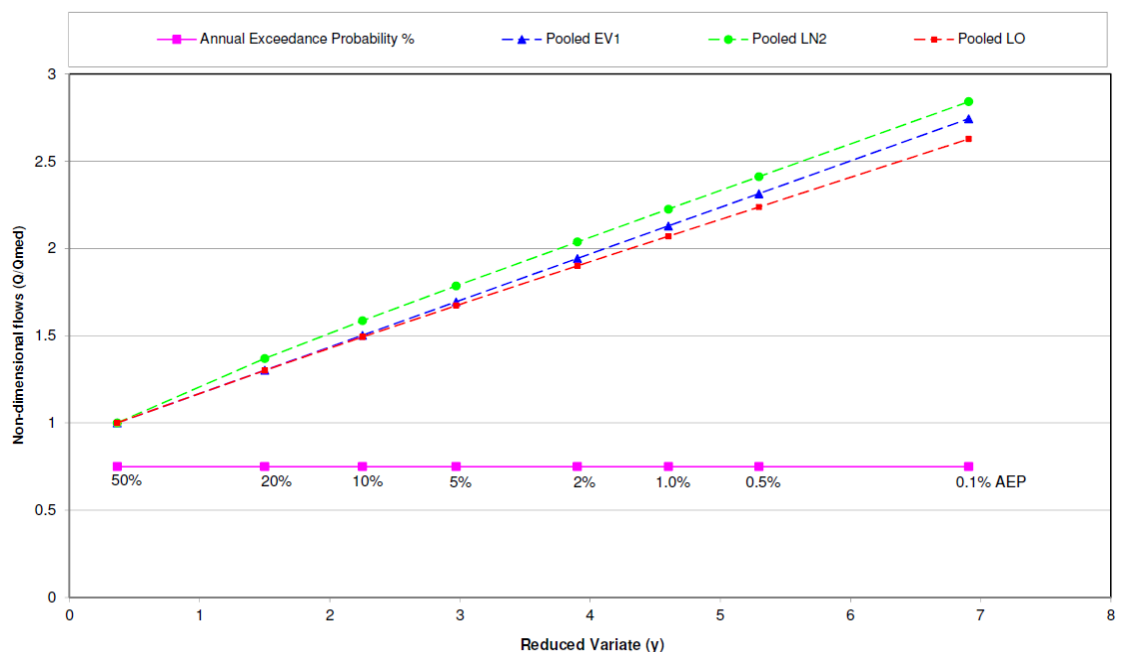
**Table A3.6 Final QMED Adjustment Factor Applied to the Reach**

## A3.5 Flood Frequency Curves

### Flood Frequency Curves

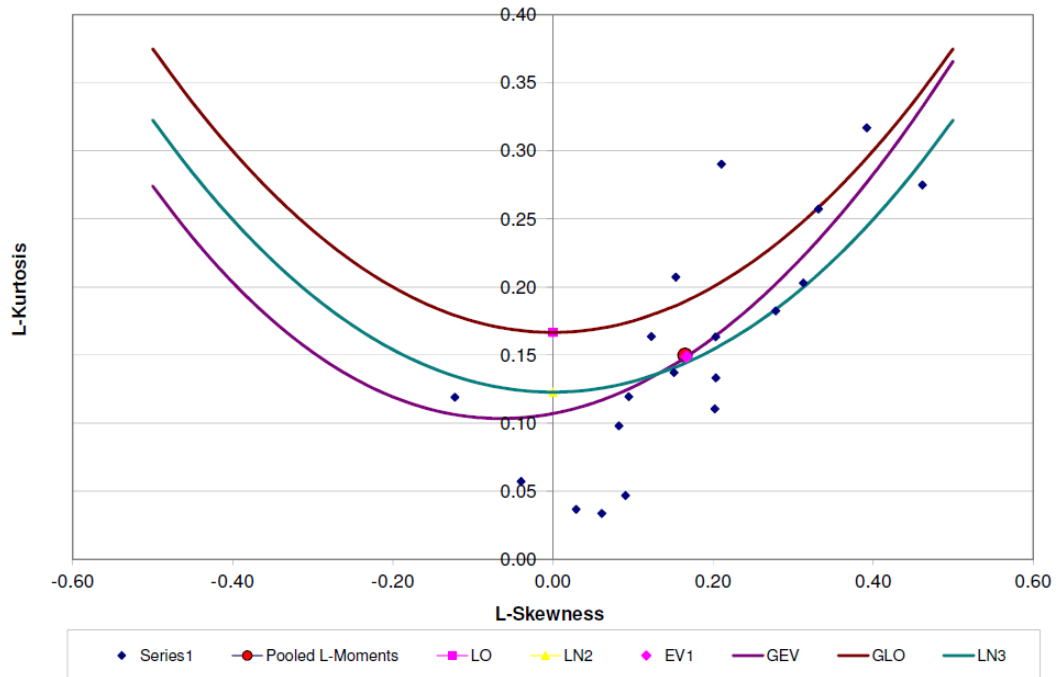
No station suitable for flood frequency analysis was identified in the catchment. The flood frequency curves (or growth curves) plotted in Figure A3.3 have been derived from a pooled analysis at HEP 23\_497\_2. The below figure shows three frequency curves plotted against a reduced variate (based on the Gringorten formula) and an AEP scale (fitted to a Gumbel extreme value distribution).

The pooled analysis is based on 505-years of station data. The final pooling group from which the growth curves in Figure A3.3 were derived, was deemed to be suitably homogenous, satisfying all criteria with the exception of catchment area as can be expected in small catchments (refer to Appendix G for details of the pooling group analysis).



**Figure A3.3 River Tyshe – Flood Frequency Curves (N=505)**

Selection of the most suitable distribution shown in Figure A3.3 has been based on interpretation of the L-Moment Ratio Diagram shown in Figure A3.4 below. It is observed from Figure A3.4 that an EV1 distribution gives the most appropriate fit to the data, as indicated by the closeness to the plotted pooled L-Moments for the whole pooling group (represented by the red dot).



**Figure A3.4 L-Moment Ratio Diagram**

### River Reach Flood Frequency

The growth curve distribution applied to the reach is shown in Table A3.7. Growth factors generated for a range of AEPs have been detailed in Table A3.8.

Reach	HEP Node	Single Site or Pooled	Selected distribution
1	23_497_2	Pooled	EV1

**Table A3.7 Final Growth Curves Selected**

Annual Exceedance Probability (%)	Growth Factors Reach 1
50%	1.00
20%	1.30
10%	1.50
5%	1.69
2%	1.94
1%	2.13
0.5%	2.31
0.1%	2.74

**Table A3.8 Final Growth Factors applied to the Tyshe Catchment**



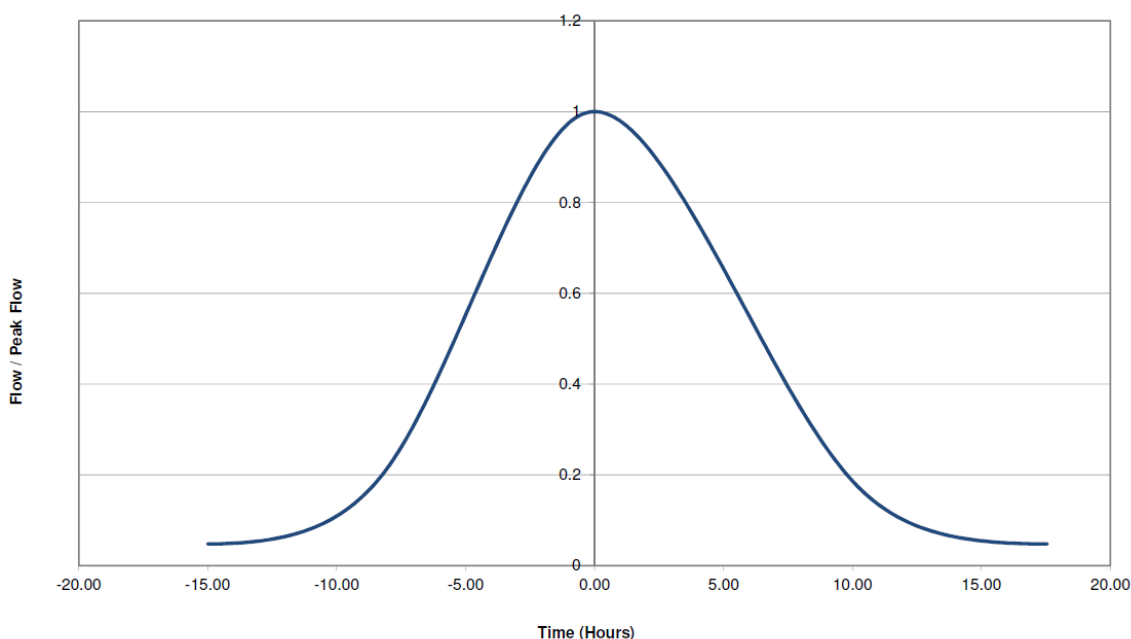
### A3.6 Hydrograph Shape

Section 2.6 of the main hydrology report describes the selection of the design hydrograph shape. The design flood hydrograph shape is preferably derived from flood events recorded at flow gauges.

Where the absence of hydrometric data prevents deriving actual event hydrographs, as is the case for the Tyshe catchment, a hydrograph shape generated for a pivotal station that is hydrologically similar to the target site is preferred.

The prescribed methodology of using pivotal station data fails to generate an appropriate hydrograph shape for the River Tyshe. Therefore, the FSSR boundary within ISIS has been utilised to generate a representative hydrograph shape.

Figure A3.5 shows the flood hydrograph chosen as being representative of flood events in the River Tyshe catchment. Figure A3.5 presents the chosen hydrograph in a non-dimensional manner by dividing flows by the flood peak.



**Figure A3.5** *Non-dimensional FSSR Generated Hydrograph*

### A3.7 Flows and Hydrological Estimation Points

The peak flow estimation process is described in Sections 2.3-2.5 and Section 2.7.2 of the main report. The resulting peak flows at individual HEPs for each model are detailed in Appendix B.

### A3.8 Calibration

The calibration and verification of hydraulic models is discussed in Section 2.7.3 of the main report. Model specific information is provided in Appendix B.

## Appendix B      Model Specific Hydrological Analysis

### Table of Content

B1	Model S14a
B2	Model S14b
B3	Model S14c
B4	Model S15
B5	Model S16
B6	Model S17

**B1****Model S14-a**

This appendix chapter summarises:

- i) the hydrology for the hydraulic model calibration; and
- ii) the target flows for the full range of modelled return periods and the inflow design hydrographs required to ensure that the river flows in the model agree with the target flows obtained from the hydrological techniques of the FSU (as described in Appendix A).

The model extent coverage is summarised in Table B1.1, and shown on Figure B1.1.

Model Attribute	Comment
Rivers included in model	River Feale, River Oolagh, River Allaghaun, and two minor unnamed tributaries.
Areas for Further Assessment (AFA)	Listowel, Abbeyfeale

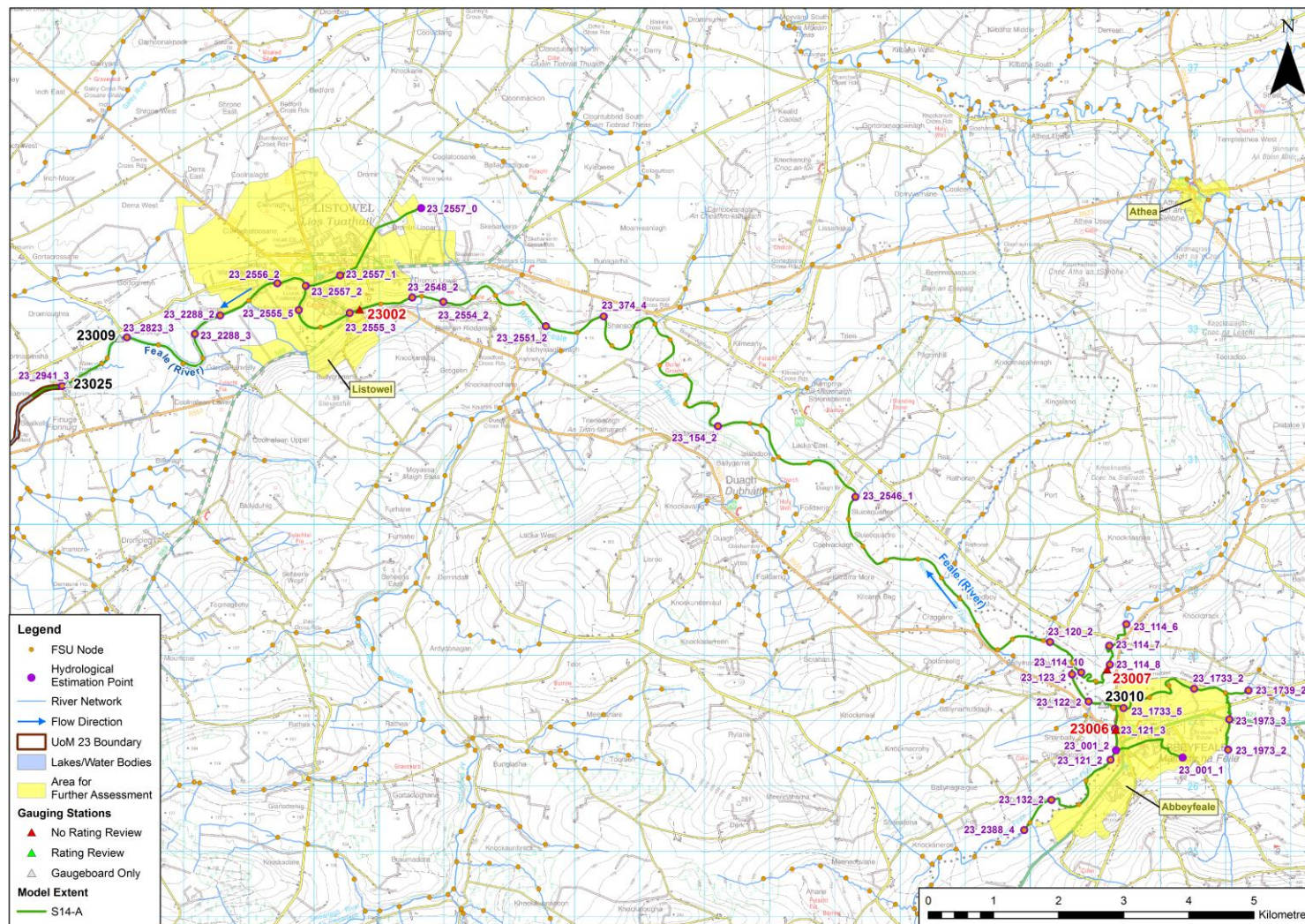
**Table B1.1** Model Extent coverage

### **B1.1 Hydrology for Hydraulic Model Calibration**

Although Model S14a cannot be calibrated/verified separately from Model S14b downstream, there is sufficient gauged data available to calibrate the lower reach of this model (downstream of Listowel GS) using the historic flood event hydrograph at this station and water levels in other gauging stations located in modelling extent S14-b.

A broad verification (sense check) of the upper reach of the modelled extents can be undertaken via comparison to the observed flood levels\ extents of the 7 January 2005 flood upstream of Abbeyfeale.

Refer to the calibration strategy in Appendix F and the hydraulic modelling report for S14-a for detail on the calibration/verification.



<sup>1</sup>Copyright Office of Public Works. All rights reserved. Includes Ordnance Survey Ireland data Reproduced under OSi License number EN0021011. Unauthorised reproduction infringes Ordnance Survey Ireland and Government of Ireland copyright, © Ordnance Survey Ireland, 2013.

## B1.2 Target Design Flows

The target flows are the peak flows required at the HEP nodes which have been derived using the design hydrology process detailed in Appendix A1. The target flows at the HEP nodes for model S14-a are shown in Tables B1.2 - B1.6.

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_2388_4	207.9	281.3	324.3	365.5	419.0	459.0	498.9	591.2
23_132_2 <sup>1</sup>	207.9	281.3	324.3	365.5	419.0	459.0	498.9	591.2
23_121_2	208.0	281.3	324.4	365.6	419.1	459.1	499.0	591.4
23_121_3	210.2	284.3	327.8	369.5	423.5	463.9	504.2	597.6
23_122_2	257.6	348.5	401.8	452.9	519.1	568.6	618.0	732.5
23_123_2	258.8	350.1	403.6	455.0	521.5	571.3	620.9	735.9
23_120_2	273.4	369.8	426.4	480.6	550.9	603.5	655.9	777.4
23_2546_1	287.4	388.8	448.2	505.3	579.1	634.4	689.5	817.2
23_154_2	295.0	398.9	460.0	518.5	594.3	651.0	707.6	838.6
23_374_4	297.7	402.6	464.2	523.3	599.8	657.1	714.1	846.4
23_2551_2 <sup>2</sup>	369.4	499.7	576.1	649.4	744.3	815.4	886.2	1050.3
23_2554_2 <sup>2</sup>	369.4	499.7	576.1	649.4	744.3	815.4	886.2	1050.3
23_2548_2 <sup>2</sup>	369.4	499.7	576.1	649.4	744.3	815.4	886.2	1050.3
23_2555_3 <sup>2,3</sup>	369.4	499.7	576.1	649.4	744.3	815.4	886.2	1050.3
23_2555_5 <sup>2</sup>	369.4	499.7	576.1	649.4	744.3	815.4	886.2	1050.3
23_2556_2 <sup>2</sup>	369.4	499.7	576.1	649.4	744.3	815.4	886.2	1050.3
23_2288_2 <sup>2</sup>	369.4	499.7	576.1	649.4	744.3	815.4	886.2	1050.3
23_2288_3 <sup>2</sup>	369.4	499.7	576.1	649.4	744.3	815.4	886.2	1050.3
23_2823_3 <sup>2</sup>	369.4	499.7	576.1	649.4	744.3	815.4	886.2	1050.3
23_2941_3 <sup>2</sup>	369.4	499.7	576.1	649.4	744.3	815.4	886.2	1050.3

**Table B1.2 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S14-a Model Extent (Main Stem).**

**Error! Not a valid link.**<sup>3</sup> This node is at Gauging Station 23002

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_1739_2	61.4	83.0	95.7	107.9	123.7	135.5	147.3	174.5



23_1733_2	64.5	87.2	100.6	113.4	129.9	142.4	154.7	183.4
23_1733_5	64.8	87.6	101.0	113.9	130.5	143.0	155.4	184.2
23_1973_2	2.5	3.4	4.0	4.5	5.1	5.6	6.1	7.2
23_1973_3	3.1	4.2	4.9	5.5	6.3	6.9	7.5	8.9

**Table B1.3 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S14-a Model Extent (River Allaghaun)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_114_6	23.4	31.6	36.5	41.1	47.1	51.6	56.1	66.5
23_114_7	23.5	31.8	36.7	41.3	47.4	51.9	56.4	66.9
23_114_8	23.6	31.9	36.8	41.5	47.5	52.1	56.6	67.1
23_114_10	23.6	32.0	36.9	41.6	47.6	52.2	56.7	67.2

**Table B1.4 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S14-a Model Extent (Oolagh River)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_2557_1	1.5	2.1	2.4	2.7	3.1	3.4	3.7	4.4
23_2557_2	2.0	2.7	3.1	3.4	4.0	4.3	4.7	5.6

**Table B1.5 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S14-a Model Extent (Listowel Tributary)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_001_2	2.4	3.2	3.7	4.2	4.8	5.2	5.7	6.8

**Table B1.6 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S14-a Model Extent (Abbeyfeale Tributary)**

### B1.3 Preliminary Design Inflows

To obtain the target flows at each HEP as shown in Tables B1.2 – B1.6, an initial set of inflow hydrographs was produced and run through the model.

Two separate runs were undertaken for each AEP: one run to mimic critical flows (in terms of the flood peaks and the flood duration) in the main stem and smaller tributaries, and a second run to mimic critical flows on the River Allaghaun. This river was modelled separately as running the critical peak flow for that watercourse as part of the main stem run would increase flows in the main stem by more than 5% above its target flow.

For modelling purposes the tributaries are defined as Tributary 1 – River Allaghaun (from HEP 23\_1739\_2 to 23\_1733\_5), Tributary 2 – River Oolagh (from HEP 23\_114\_6 to 23\_114\_10), Tributary 3 – Listowel Tributary (from HEP 23\_2557\_0 to 23\_2557\_2), and Tributary 4 – Abbeyfeale Tributary (from HEP 23\_001\_1 to 23\_001\_2).

The inflow hydrographs at the various HEPs were derived using the procedure outlined in Chapter 2 of the main hydrology report and using the adjustment factor, growth curves and hydrograph shape specified in Appendix A, Chapter A1. The QMED adjustment factor, growth curve and hydrograph shape are specified in Appendix A1. The HEPs are shown on Figure B1.1. Tables B1.7 – B1.11 present the peak values of the preliminary lateral inflows inserted into the model in the reach immediately upstream of the HEP in the hydraulic model for the main stem and tributary runs.

Preliminary design inflow hydrographs are shown in Figures B1.2 - B1.6 for the 1% AEP design runs.

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_2388_4	207.9	281.3	324.3	365.5	419.0	459.0	498.9	591.2
23_121_3	47.4	64.2	74.0	83.4	95.6	104.7	113.8	134.9
23_120_2	5.0	6.8	7.8	8.8	10.1	11.1	12.1	14.3
23_2546_1	7.5	10.2	11.7	13.2	15.2	16.6	18.1	21.4
23_374_4	78.4	106.1	122.3	137.9	158.0	173.1	188.2	223.0

**Table B1.7 Preliminary Design Hydrograph Peak Inflows ( $m^3/s$ ) at HEP Locations on the S14-a Model Extent (Main Stem)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_1739_2	61.7	83.4	96.2	108.4	124.3	136.1	148.0	175.4
23_1973_2	3.1	4.2	4.9	5.5	6.3	6.9	7.5	8.9

**Table B1.8 Preliminary Design Hydrograph Peak Inflows ( $m^3/s$ ) at HEP Locations on the S14-a Model Extent (River Allaghaun)**



HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_114_6	23.6	32.0	36.9	41.6	47.6	52.2	56.7	67.2

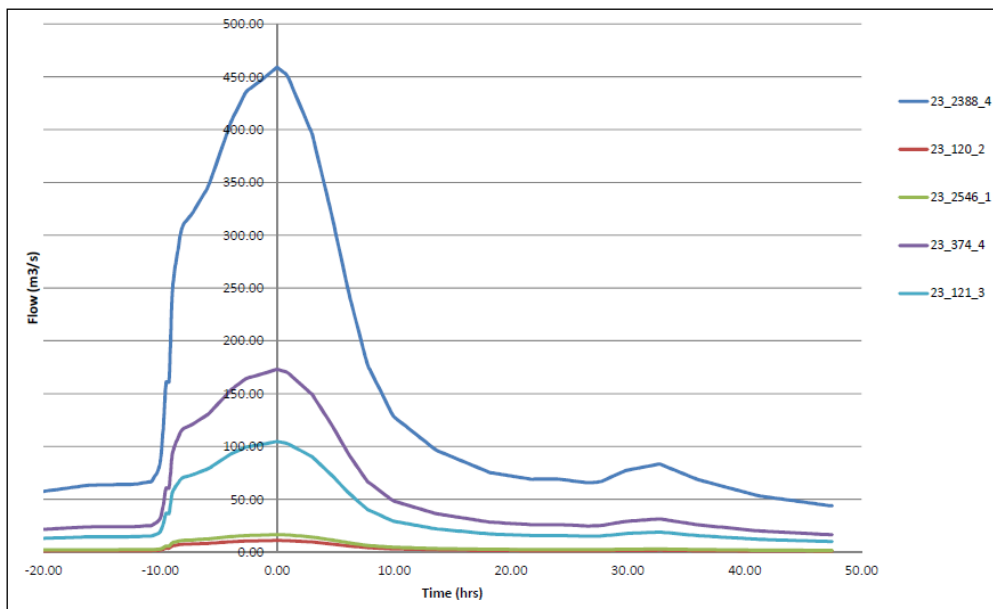
**Table B1.9 Preliminary Design Hydrograph Peak Inflows ( $m^3/s$ ) at HEP Locations on the S14-a Model Extent (River Oolagh)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_2557_0	1.5	2.1	2.4	2.7	3.1	3.4	3.7	4.4
23_2557_1	0.4	0.6	0.7	0.8	0.9	1.0	1.0	1.2

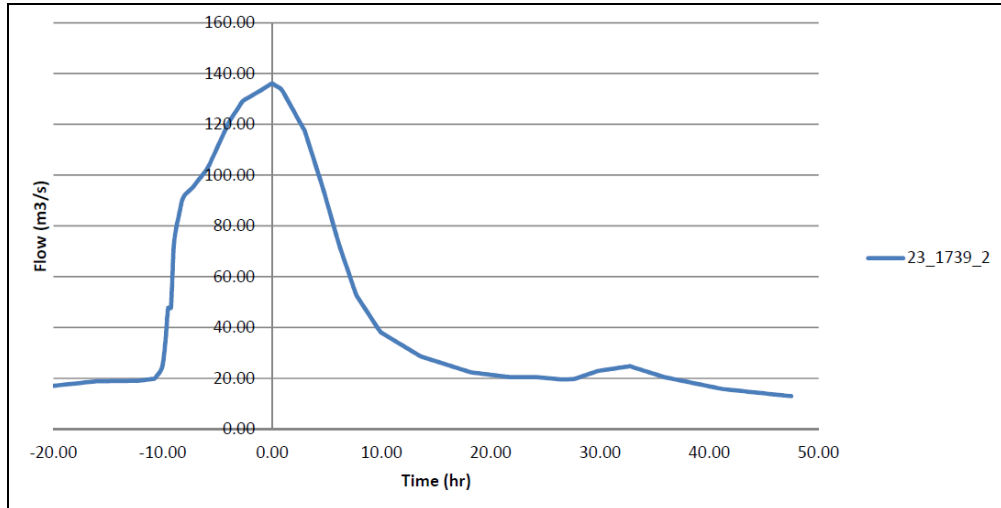
**Table B1.10 Preliminary Design Hydrograph Peak Inflows ( $m^3/s$ ) at HEP Locations on the S14-a Model Extent (Listowel Tributary)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_001_1	2.4	3.2	3.7	4.2	4.8	5.2	5.7	6.8

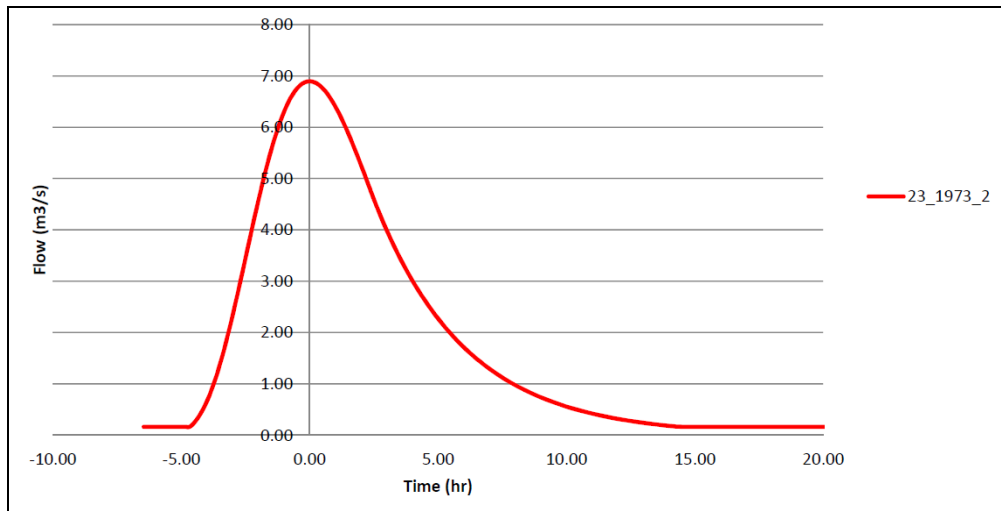
**Table B1.11 Preliminary Design Hydrograph Peak Inflows ( $m^3/s$ ) at HEP Locations on the S14-a Model Extent (Abbeyfeale Tributary)**



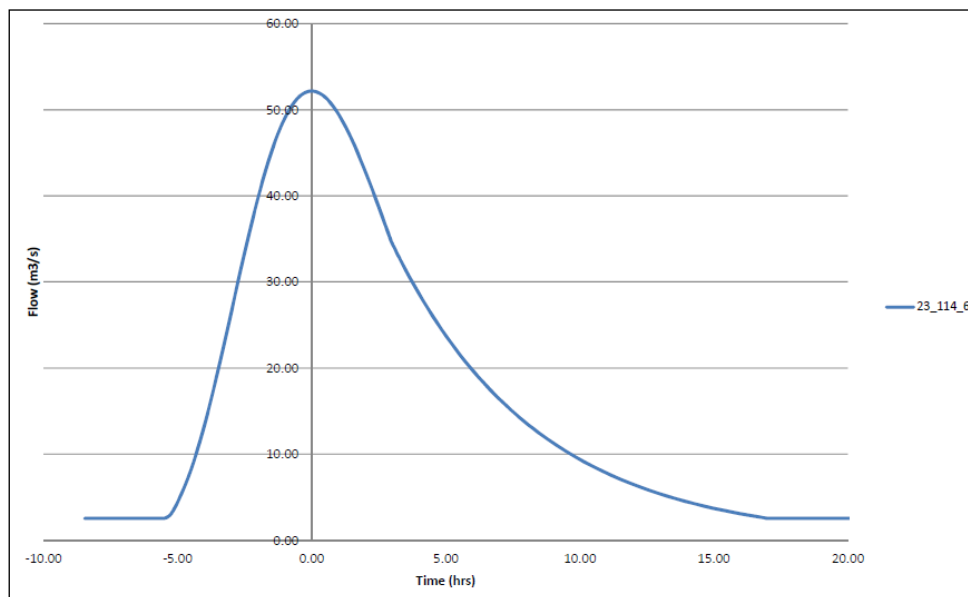
**Figure B1.2 S14-a Preliminary Design Inflow Hydrographs for 1% AEP (River Feale - Main Stem)**



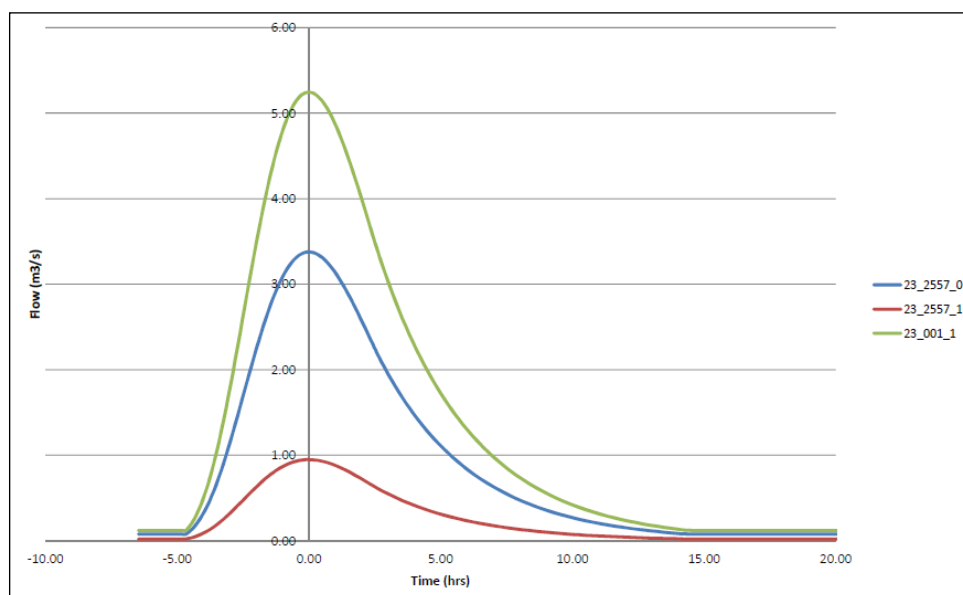
**Figure B1.3** S14-a Preliminary Design Inflow Hydrographs for 1% AEP (River Allaghaun – Tributary 1)



**Figure B1.4** S14-a Preliminary Design Inflow Hydrographs for 1% AEP (River Allaghaun – Tributary 1, Minor Branch)



**Figure B1.5** S14-a Preliminary Design Inflow Hydrographs for 1% AEP (River Oolagh – Tributary 2)



**Figure B1.6** S14-a Preliminary Design Inflow Hydrographs for 1% AEP (Tributaries 3 & 4)

## B1.4 Final Design Inflows

The hydraulic model uses the preliminary design inflows presented in Tables B1.7 – B1.11 for calibrating the model to the HEP target flows presented in Tables B1.2 – B1.6.

HEP calibration at each HEP was undertaken using the methodology described in Section 2.7.2 of the main hydrology report for UoM 23. Hydraulic modelling aspects of the HEP calibration including the results and final design peak flows are presented in the hydraulic modelling report for Model S14-a.

**B2****Model S14b**

This appendix chapter summarises:

- i) the hydrology for the hydraulic model calibration; and
- ii) the target flows for the full range of modelled return periods and the inflow design hydrographs required to ensure that the river flows in the model agree with the target flows obtained from the hydrological techniques of the FSU (as described in Appendix A).

The model extent coverage is summarised in Table B2.1, and shown on Figure B2.1

Model Attribute	Comment
Rivers included in model	River Brick* River Feale** River Galey*** River Cashen****
Areas for Further Assessment (AFA)	Moneycashen

\*From HEP node 23\_806\_2 to HEP node 23\_2945\_4.

\*\*From HEP node 23\_2941\_3 to the confluence with the River Cashen.

\*\*\*From HEP node 23\_2929\_5 to the confluence with the River Feale.

\*\*\*\*From the confluence of the River Brick and River Feale to the point of discharge into the Feale Estuary

**Table B2.1 Model Extent Coverage**

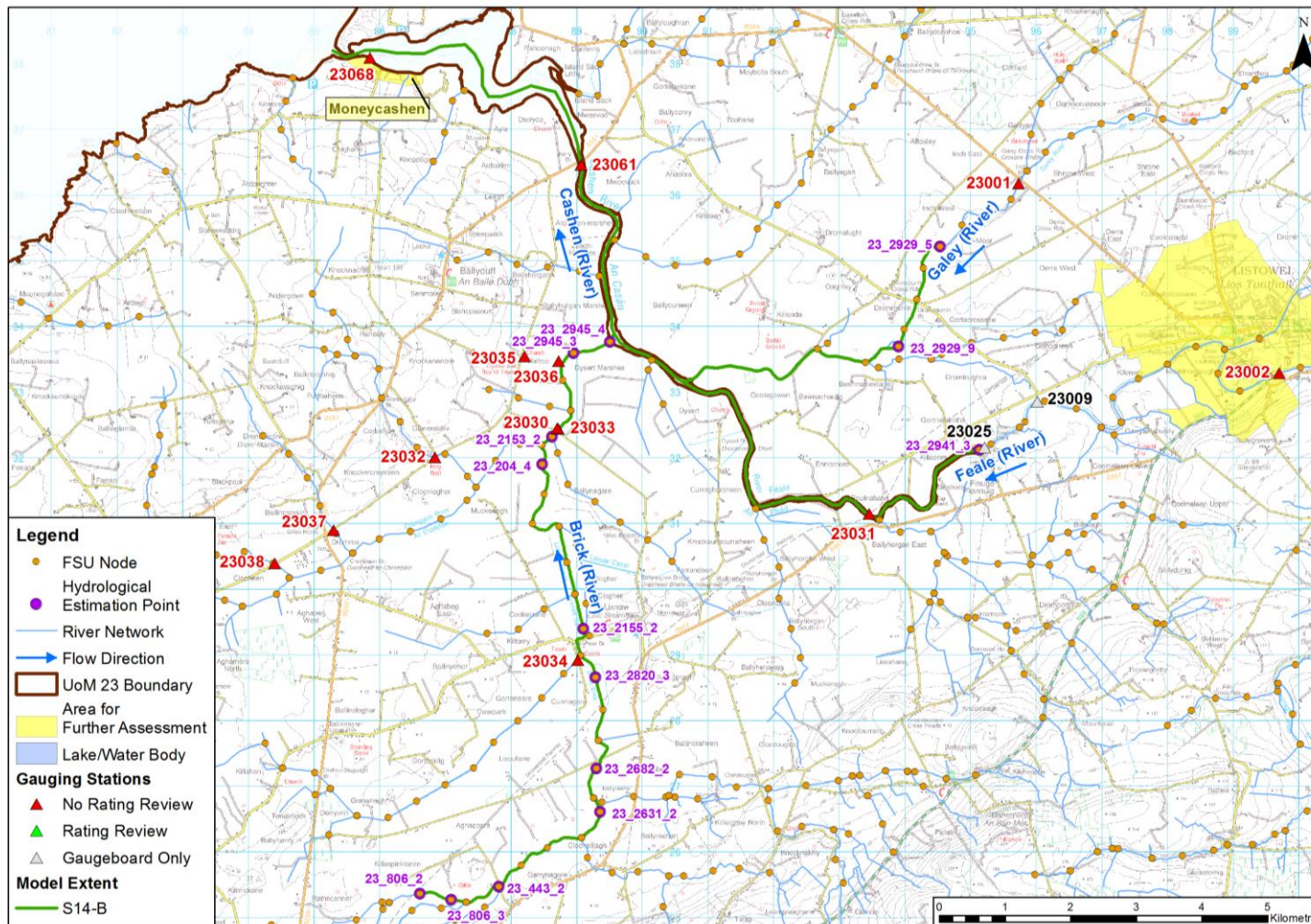


Figure B2.1 S14b Model Extent<sup>1</sup>

<sup>1</sup> Copyright Office of Public Works. All rights reserved. Includes Ordnance Survey Ireland data Reproduced under OSi License number EN0021011. Unauthorised reproduction infringes Ordnance Survey Ireland and Government of Ireland copyright, © Ordnance Survey Ireland, 2013.

## B2.1 Hydrology for Hydraulic Model Calibration

There was insufficient gauged data available to calibrate the S14b model without using data from other models (cross-model calibration).

However tidal calibration across the model boundaries between S14a, S14b, S14c and S15 was possible for the 1<sup>st</sup> February 2002 tidal flood event using flow data from Stations 23001 and 23002 and water level data from gauges 23061 and 23068. As shown in Figure B2.1 gauge 23002 lies within the S14a model extent (upstream of the S14b model on the River Feale) and gauge 23001 lies within the S14c model extent (just upstream of S14b HEP node 23\_2929\_5 on the River Galey). Gauge 23068 is located at Moneycashen and gauge 23061 at Ferry Bridge.

Fluvial cross-model calibration/verification was also possible for the S14a and S14b models using flow data from Station 23002 and water level data from gauges 23031, 23061 and 23068 for the January 2005 event (calibration) and the November 2009 event (verification).

Fluvial cross-model calibration for the River Galey using flow data at Station 23001 in Model S14a was not possible as there are no level observations along the Galey near to or downstream of Station 23001.

Refer to the calibration strategy in Appendix F and the hydraulic modelling report for S14b for detail on the calibration/verification.

## B2.2 Target Design Flows

The target flows are the peak flows required at the HEP nodes which have been derived using the design hydrology process detailed in Appendix A1. The target flows at the HEP nodes for model S14b are shown in Tables B2.2, B2.3 and B2.4.

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_806_2	17.5	24.8	29.6	34.2	40.2	44.7	49.1	59.5
23_806_3	17.6	24.9	29.7	34.4	40.4	44.9	49.4	59.7
23_443_2	36.3	51.4	61.4	71.0	83.4	92.6	102	123
23_2631_2	41.0	57.9	69.2	80.0	94.0	104	115	139
23_2682_2	49.5	70.1	83.7	96.7	114	126	139	168
23_2820_3	53.1	75.2	89.8	104	122	136	149	180
23_2155_2	60.2	85.2	102	118	138	154	169	205
23_204_4	69.9	99.0	118	137	161	178	196	237
23_2153_2	74.8	106	126	146	172	191	210	254
23_2945_3	76.8	109	130	150	176	196	215	261
23_2945_4	76.8	109	130	150	176	196	215	261

**Table B2.2 Target Flows ( $m^3/s$ ) at HEP Locations on the S14b Model Extent (River Brick).**



HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_2941_3	366	495	571	644	738	808	878	1041

**Table B2.3 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S14b Model Extent (River Feale)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_2929_5	104	144	168	192	223	246	268	321
23_2929_9	108	148	174	198	230	253	277	331

**Table B2.4 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S14b Model Extent (RiverGaley)**

### B2.3 Preliminary Design Inflows

To obtain the target flows shown in Tables B2.2, B2.3 and B2.4, an initial set of inflow hydrographs was produced and run through the model.

The inflow hydrographs at the various HEPs were derived using the procedure outlined in Chapter 2 of the main hydrology report and using the QMED adjustment factor, growth curves and hydrograph shape specified in Appendix A, Sections A1.4 to A1.6. The HEPs are shown on Figure B2.1. Tables B2.5, B2.6 and B2.7 present the peak values of the preliminary lateral inflows inserted into the model in the reach immediately upstream of the HEP in the hydraulic model for the main stem runs.

Preliminary design inflow hydrographs are shown in Figures B2.2, B2.3 and B2.4 for the 1% AEP design runs.

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_806_2	17.6	24.9	29.7	34.4	40.4	44.9	49.4	59.7
23_806_3	18.7	26.5	31.7	36.6	43.0	47.8	52.5	63.6
23_443_2	4.6	6.5	7.8	9.0	10.6	11.8	13.0	15.7
23_2631_2	8.6	12.1	14.5	16.7	19.7	21.8	24.0	29.1
23_2682_2	3.6	5.1	6.1	7.1	8.3	9.2	10.2	12.3
23_2820_3	7.1	10.0	12.0	13.8	16.3	18.1	19.9	24.1
23_2155_2	9.7	13.8	16.4	19.0	22.3	24.8	27.3	33.0
23_204_4	4.8	6.8	8.2	9.4	11.1	12.3	13.6	16.4
23_2153_2	2.0	2.9	3.4	4.0	4.7	5.2	5.7	6.9

**Table B2.5 Preliminary Design Hydrograph Peak Inflows (m<sup>3</sup>/s) at HEP Locations on the S14b Model Extent (River Brick)**

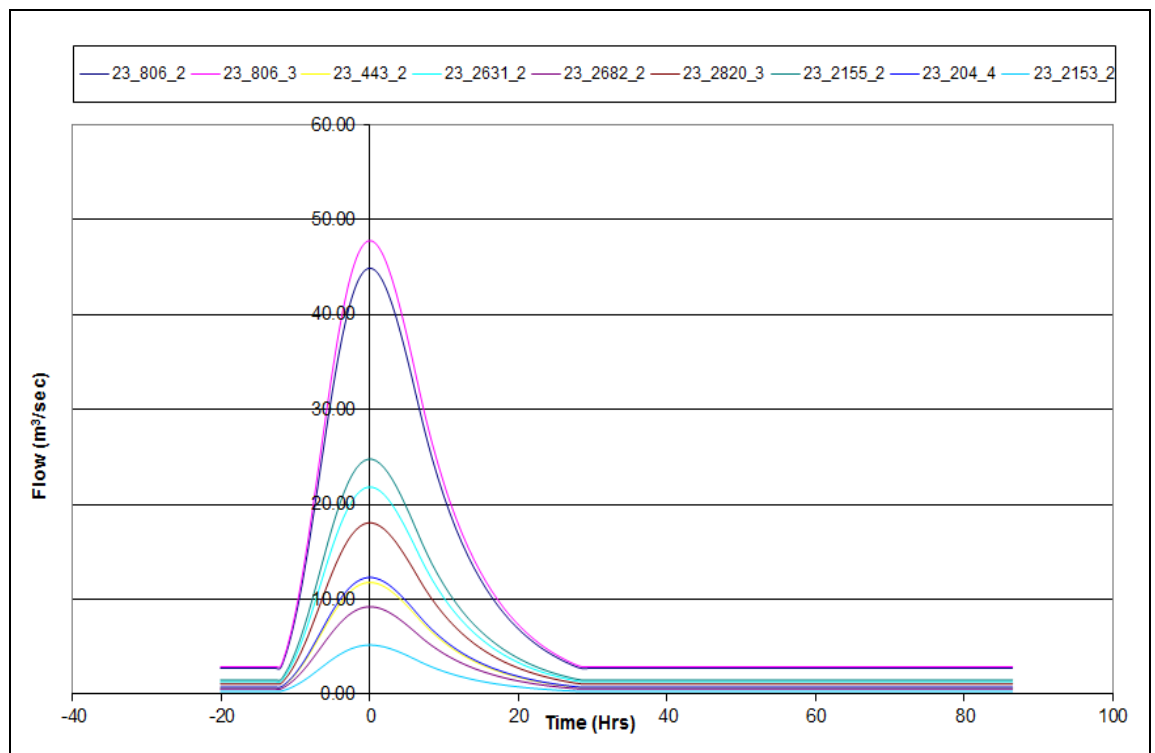


HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_2941_3	366	495	571	644	738	808	878	1041

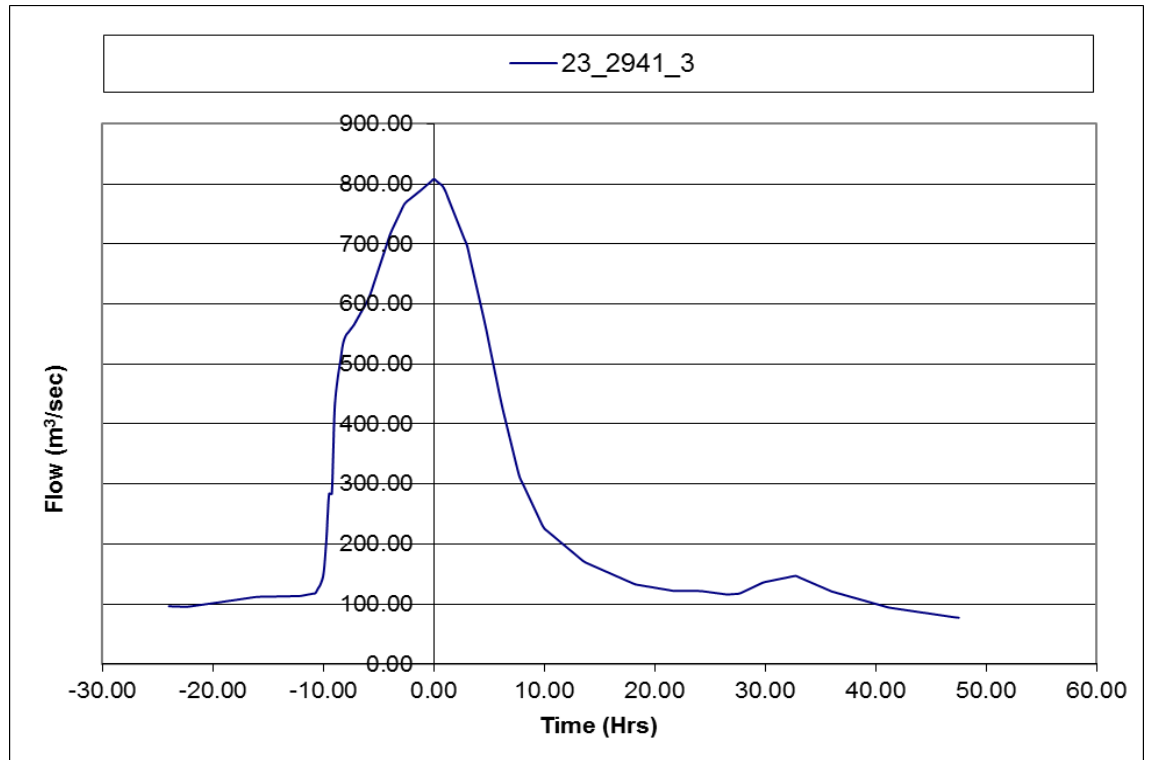
**Table B2.6** Preliminary Design Hydrograph Peak Inflows ( $m^3/s$ ) at HEP Locations on the S14b Model Extent (River Feale)

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_2929_5	108	148	174	198	230	253	277	331

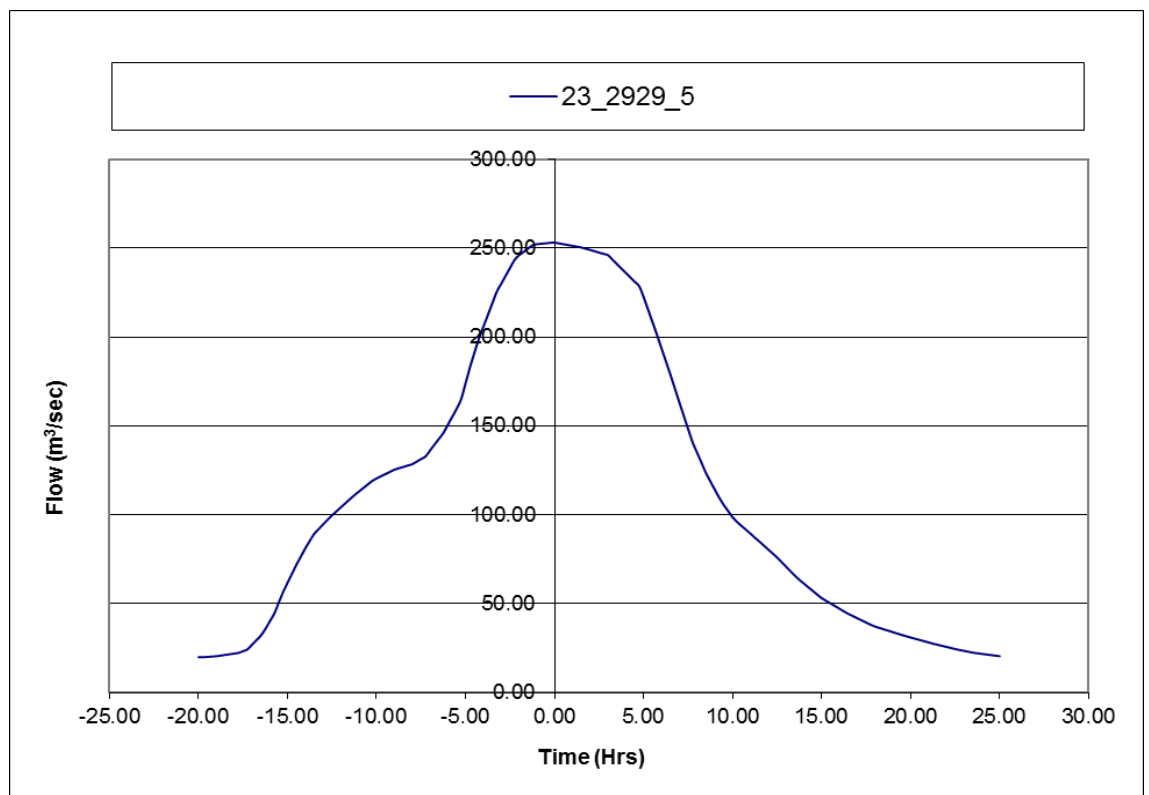
**Table B2.7** Preliminary Design Hydrograph Peak Inflows ( $m^3/s$ ) at HEP Locations on the S14b Model Extent (River Galey)



**Figure B2.2** S14b Preliminary Design Inflow Hydrographs for 1% AEP (River Brick)



**Figure B2.3** S14b Preliminary Design Inflow Hydrographs for 1% AEP (River Feale)



**Figure B2.4** S14b Preliminary Design Inflow Hydrographs for 1% AEP (River Galey)

## **B2.4 Final Design Inflows**

The hydraulic model uses the preliminary design inflows presented in Tables B2.5, B2.6 and B2.7 for calibrating the model to the HEP target flows presented in Tables B2.2, B2.3 and B2.4.

HEP calibration at each HEP was undertaken using the methodology described in Section 2.7.2 of the main hydrology report for UoM 23. Hydraulic modelling aspects of the HEP calibration including the results and final design peak flows are presented in the hydraulic modelling report for Model S14b.

**B3****Model S14c**

This appendix chapter summarises:

- i) the hydrology for the hydraulic model calibration; and
- ii) the target flows for the full range of modelled return periods and the inflow design hydrographs required to ensure that the river flows in the model agree with the target flows obtained from the hydrological techniques of the FSU (as described in Appendix A).

The model extent coverage is summarised in Table B3.1, and Figure B3.1.

Model Attribute	Comment
Rivers included in model	River Galey and an unnamed tributary branch which flows through Athea.
Areas for Further Assessment (AFA)	Athea

**Table B3.1** Model Extent coverage

### B3.1 Hydrology for Hydraulic Model Calibration

There was insufficient gauged data available to calibrate the S14c model. Only one gauging station with recorder (23001 Inch Bridge) and two gauge boards (23014 Athea; and 23004 Galey Bridge) are present within the Model Extent. The recorder station is in the lower reaches of the catchment. There are no other flow/level gauging stations near the Athea AFA to inform inflow for the calibration of Model S14c. Similarly, there are no other gauges on the Galey between Station 23001 and the Galey/Feale confluence (model extent S14B), and hence a cross-model fluvial calibration/verification is not possible.

The downstream model boundary is upstream of the tidal limit and therefore tidal calibration is not required.

A number of historic flood records are available in the Athea area including the events of August 2008 and September 2009 that could be used for a broad verification of the S14c Model.

Refer to the calibration strategy in Appendix F and the hydraulic modelling report for S14c for detail on the calibration/verification.

### B3.2 Target Design Flows

The target flows are the peak flows required at the HEP nodes which have been derived using the design hydrology process detailed in Appendix A1. The target flows at the HEP nodes for model S14c are shown in Tables B3.2 – B3.3.



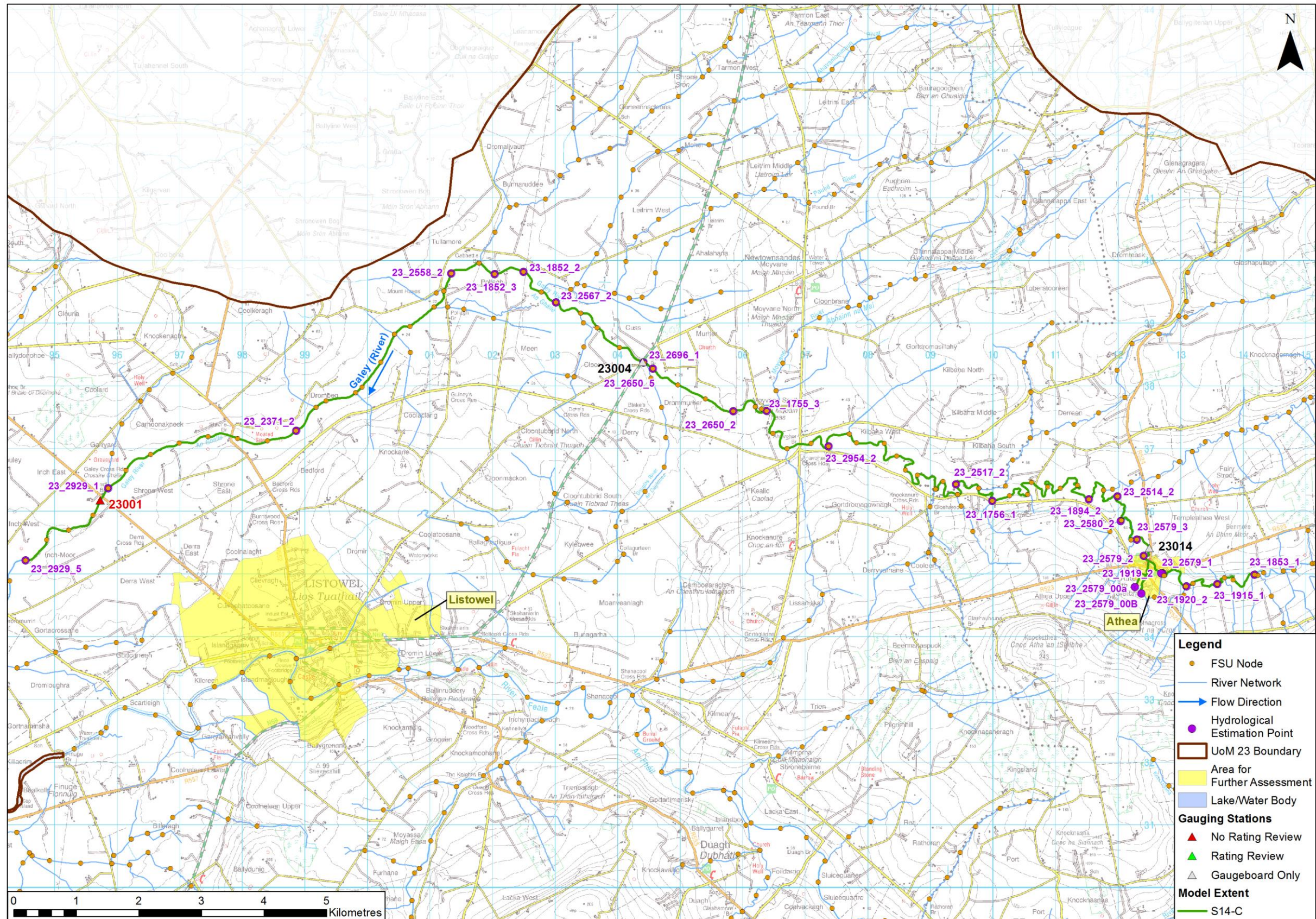


Figure B3.1 S14c Model Extent<sup>1</sup>

<sup>1</sup> Copyright Office of Public Works. All rights reserved. Includes Ordnance Survey Ireland data Reproduced under OSi License number EN0021011. Unauthorised reproduction infringes Ordnance Survey Ireland and Government of Ireland copyright, © Ordnance Survey Ireland, 2013.



HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_1853_1	26.4	36.3	42.5	48.5	56.2	62.0	67.8	81.1
23_1915_1	27.5	37.9	44.4	50.7	58.7	64.8	70.8	84.8
*23_1920_2	27.5	37.9	44.4	50.7	58.7	64.8	70.8	84.8
23_1919_2	30.0	41.3	48.3	55.1	63.9	70.5	77.0	92.2
*23_2579_1	30.0	41.3	48.3	55.1	63.9	70.5	77.0	92.2
*23_2579_2	30.0	41.3	48.3	55.1	63.9	70.5	77.0	92.2
*23_2579_3	30.0	41.3	48.3	55.1	63.9	70.5	77.0	92.2
23_2580_2	31.2	43.0	50.3	57.4	66.5	73.4	80.2	96.0
23_2514_2	32.2	44.3	51.9	59.2	68.6	75.7	82.7	99.0
23_1894_2	46.0	63.3	74.2	84.6	98.0	108	118	142
23_1756_1	46.1	63.5	74.3	84.8	98.3	108	119	142
23_2517_2	52.2	71.9	84.3	96.1	111	123	134	161
23_2954_2	55.7	76.7	89.8	102	119	131	143	171
23_1755_3	56.4	77.7	91.1	104	120	133	145	174
23_2650_2	63.9	88.0	103	118	136	150	164	197
23_2650_5	65.2	90.0	105	120	139	153	168	201
23_2696_1	73.0	101	118	134	156	172	188	225
23_2567_2	74.7	103	121	138	159	176	192	230
23_1852_2	90.0	124	145	166	192	212	231	277
*23_1852_3	90.0	124	145	166	192	212	231	277
23_2558_2	96.4	133	156	177	206	227	248	297
23_2371_2	102	140	164	187	217	239	261	313
23_2929_1	104	143	167	191	221	244	266	319

**Table B3.2 Target Flows ( $m^3/s$ ) at HEP Locations on the S14c Model Extent (Main Stem).**

*\*Target flows taken from upstream node as the estimate of the design peak flow based on the QMED regression equation, adjustment factor and growth factor at this node were less than those at the u/s node*

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_2579_00a	0.18	0.25	0.29	0.33	0.39	0.43	0.47	0.56
23_2579_00b	0.63	0.86	1.01	1.15	1.33	1.47	1.61	1.93

**Table B3.3 Target Flows ( $m^3/s$ ) at HEP Locations on the S14c Model Extent (Tributary Branch)**

### B3.3 Preliminary Design Inflows

To obtain the target flows at each HEP as shown in Tables B3.2 – B3.3, an initial set of inflow hydrographs was produced and run through the model.

The critical events in the main stem and for the tributary branch within the modelled extent were simulated in a single model run.

The inflow hydrographs at the various HEPs were derived using the procedure outlined in Chapter 2 of the main hydrology report and using the adjustment factor, growth curves and hydrograph shape specified in Appendix A, Chapter A1. The HEPs are shown on Figure B3.1. Tables B3.4 – B3.5 present the preliminary peak inflows at each HEP in the hydraulic model for the main stem and tributary run.

Preliminary design inflow hydrographs are shown in Figures B3.2 & B3.3 for the 1% AEP design run.

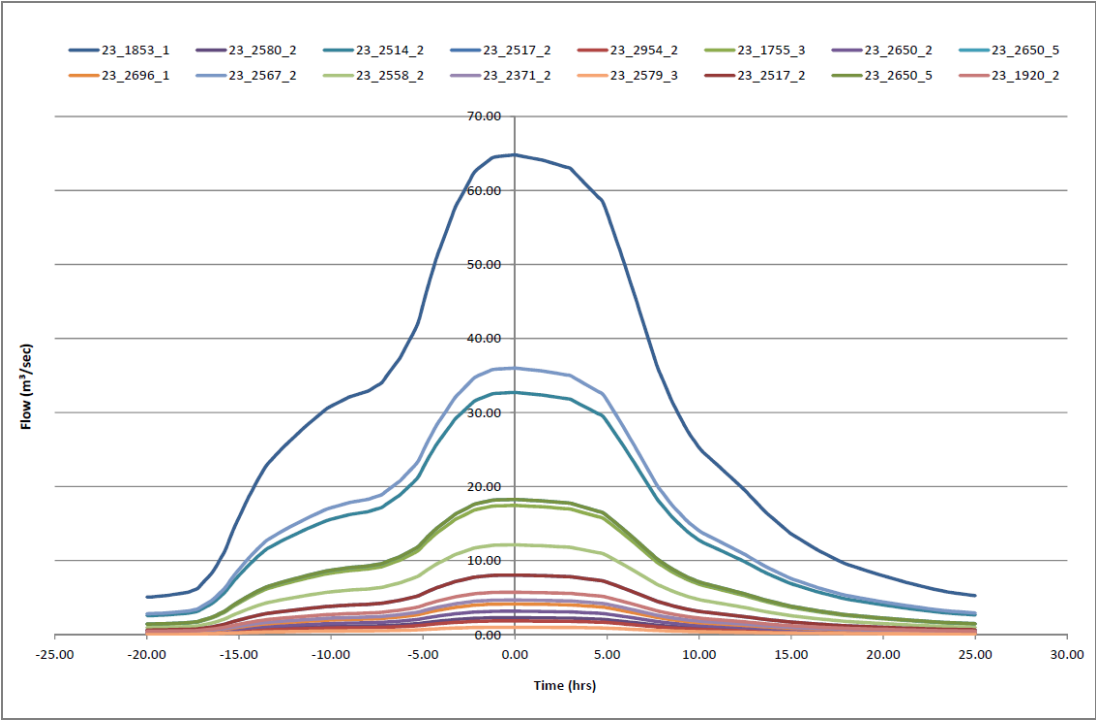


HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_1853_1	27.5	37.9	44.4	50.7	58.7	64.8	70.8	84.8
23_1920_2	2.4	3.4	3.9	4.5	5.2	5.7	6.3	7.5
23_2579_3	0.42	0.58	0.68	0.78	0.90	0.99	1.1	1.3
23_2580_2	0.97	1.3	1.6	1.8	2.1	2.3	2.5	3.0
23_2514_2	13.9	19.2	22.4	25.6	29.7	32.7	35.8	42.8
23_1756_1	6.2	8.5	9.9	11.3	13.1	14.5	15.8	19.0
23_2517_2	3.4	4.7	5.5	6.3	7.3	8.0	8.8	10.5
23_2954_2	0.78	1.1	1.3	1.4	1.7	1.8	2.0	2.4
23_1755_3	7.4	10.2	12.0	13.6	15.8	17.4	19.1	22.8
23_2650_2	1.3	1.8	2.2	2.5	2.9	3.2	3.4	4.1
23_2650_5	7.8	10.7	12.5	14.3	16.6	18.3	20.0	23.9
23_2696_1	1.8	2.4	2.8	3.2	3.7	4.1	4.5	5.4
23_2567_2	15.3	21.1	24.7	28.2	32.6	36.0	39.3	47.1
23_1852_3	6.4	8.8	10.3	11.7	13.6	15.0	16.4	19.6
23_2558_2	5.2	7.1	8.3	9.5	11.0	12.1	13.3	15.9
23_2371_2	2.0	2.7	3.2	3.7	4.2	4.7	5.1	6.1

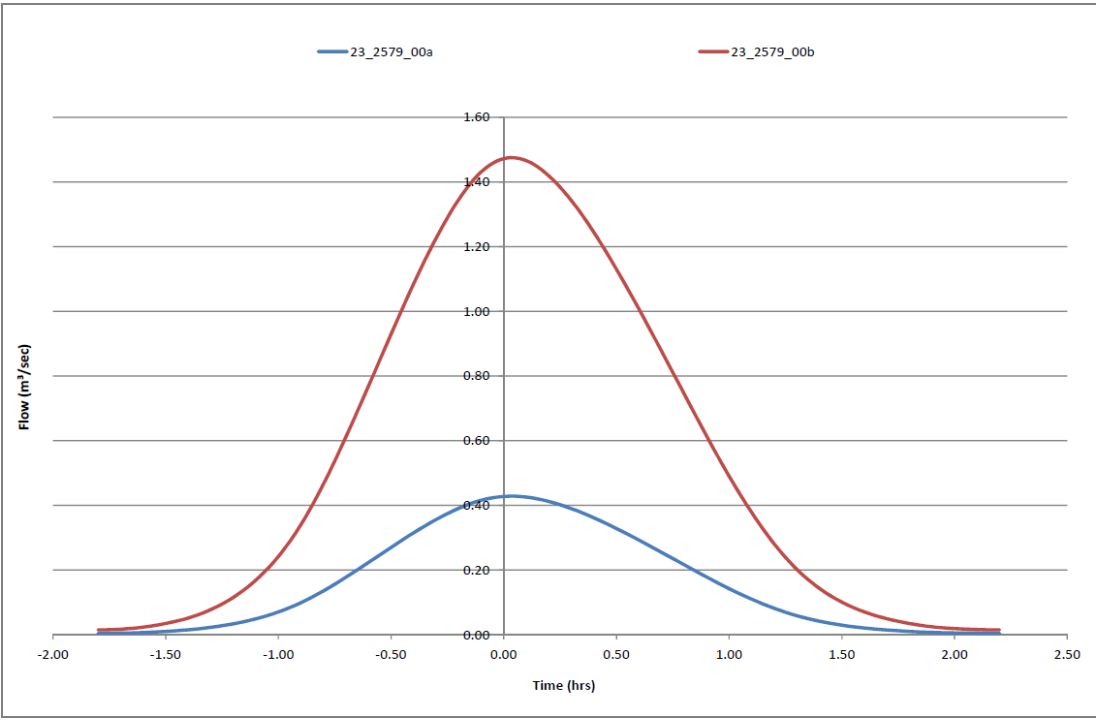
**Table B3.4 Preliminary Design Hydrograph Peak Inflows (m<sup>3</sup>/s) at HEP Locations on the S14c Model Extent (Main Stem)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_2579_00a	0.18	0.25	0.29	0.33	0.39	0.43	0.47	0.56
23_2579_00b	0.63	0.86	1.01	1.15	1.33	1.47	1.61	1.93

**Table B3.5 Preliminary Design Hydrograph Peak Inflows (m<sup>3</sup>/s) at HEP Locations on the S14c Model Extent (Tributary Branch)**



**Figure B3.2** S14c Preliminary Design Inflow Hydrographs for 1% AEP (River Galey - Main Stem)



**Figure B3.3** S14c Preliminary Design Inflow Hydrographs for 1% AEP (River Galey - Tributary Branch)

### **B3.4 HEP Calibration and Final Design Hydrographs**

The hydraulic model uses the preliminary design inflows presented in Tables B3.4 – B3.5 for calibrating the model to the HEP target flows presented in Tables B3.2 – B3.3.

HEP calibration at each HEP was undertaken using the methodology described in Section 2.7.2 of the main hydrology report for UoM 23. For the modelled peak flows to match the target flows the hydrograph ordinates were adjusted by linear scaling.

Hydraulic modelling aspects of the HEP calibration including the results and final design peak flows are presented in the hydraulic modelling report for Model S14c.

**B4****Model S15**

This appendix chapter summarises:

- i) the hydrology for the hydraulic model calibration; and
- ii) the target flows for the full range of modelled return periods and the inflow design hydrographs required to ensure that the river flows in the model agree with the target flows obtained from the hydrological techniques of the FSU (as described in Appendix A).

The model extent coverage is summarised in Table B4.1, and Figure B4.1

Model Attribute	Comment
Rivers included in model	River Brick and two unnamed tributaries
Areas for Further Assessment (AFA)	Abbeydorney

**Table B4.1** Model Extent coverage

### **B4.1 Hydrology for Hydraulic Model Calibration**

There was insufficient gauged data available to calibrate the S15 model. A number of 'water level only' gauges operate on the River Brick downstream of the S15 model, however, no hydrometric station is present within or upstream of the S15 modelling extent to provide reliable flows to calibrate the model.

In addition, no suitable past flood event information is available in the vicinity of the Abbeydorney AFA for calibration or even for a broad verification of Model S15. Therefore, the S15 model cannot be calibrated or verified using hydrometric data.

Refer to the calibration strategy in Appendix F and the hydraulic modelling report for S15 for detail on the calibration/verification.

### **B4.2 Target Design Flows**

The target flows are the peak flows required at the HEP nodes which have been derived using the design hydrology process detailed in Appendix A1. The target flows at the HEP nodes for model S15 are shown in Tables B4.2 - B4.4.

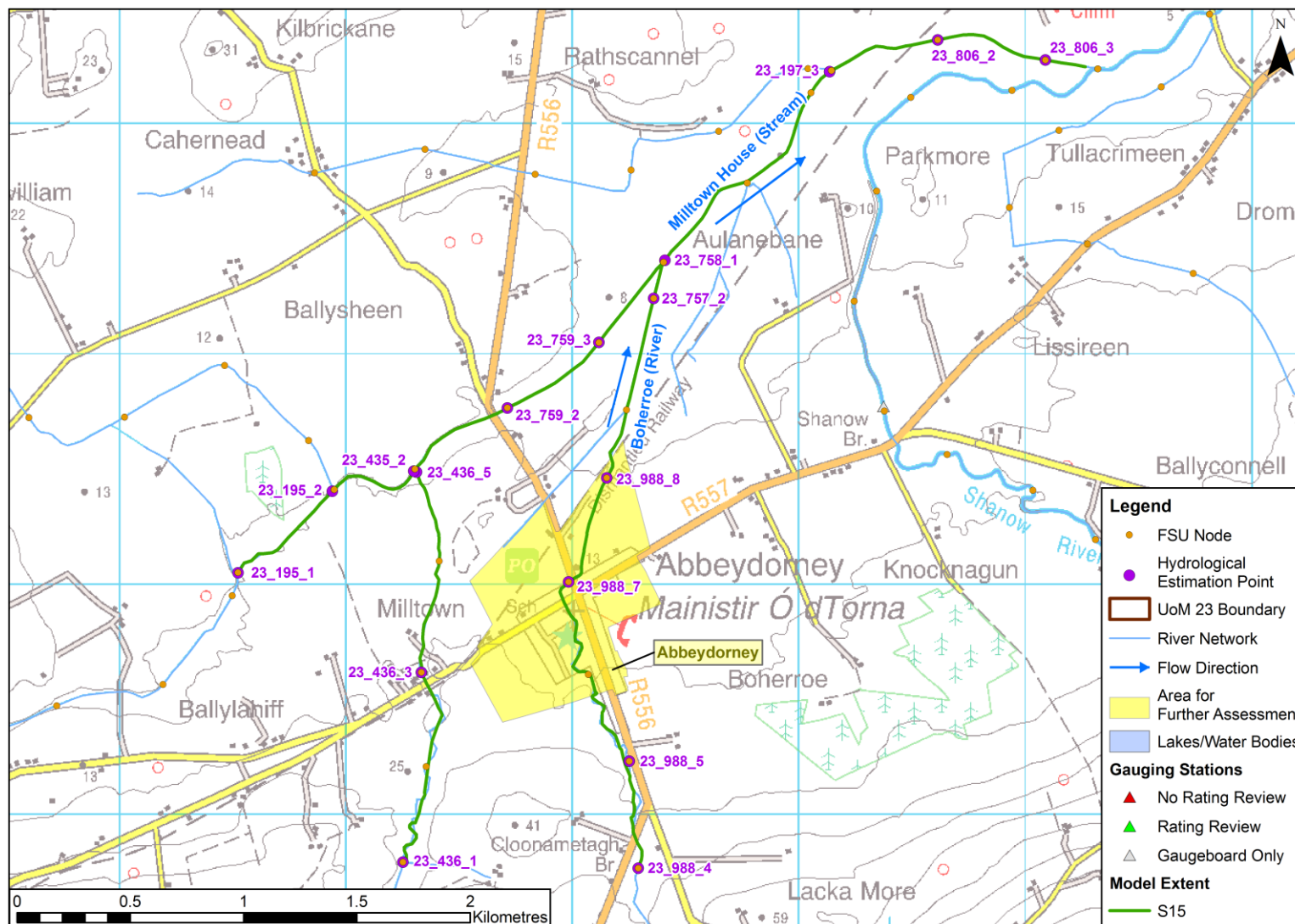


Figure B4.1 S15 Model Extent<sup>1</sup>

<sup>1</sup> Copyright Office of Public Works. All rights reserved. Includes Ordnance Survey Ireland data Reproduced under OSi License number EN0021011. Unauthorised reproduction infringes Ordnance Survey Ireland and Government of Ireland copyright, © Ordnance Survey Ireland, 2013.

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_436_1	4.8	6.8	8.2	9.4	11.1	12.3	13.5	16.4
23_436_3	5.2	7.3	8.8	10.1	11.9	13.2	14.6	17.6
23_436_5	5.6	7.9	9.4	10.9	12.8	14.2	15.6	18.9
23_759_2	8.2	11.6	13.8	16.0	18.8	20.9	22.9	27.8
23_759_3	8.5	12.0	14.4	16.6	19.5	21.7	23.9	28.9
23_758_1	14.4	20.4	24.4	28.2	33.1	36.8	40.4	49.0
23_197_3	15.8	22.4	26.7	30.9	36.3	40.3	44.4	53.7
23_806_2	17.5	24.8	29.6	34.2	40.2	44.7	49.1	59.5
23_806_3	17.6	24.9	29.7	34.4	40.4	44.9	49.4	59.7

**Table B4.2 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S15 Model Extent (Main Stem).**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_195_1	1.5	2.1	2.5	2.9	3.3	3.7	4.1	5.0
*23_195_2	1.5	2.1	2.5	2.9	3.3	3.7	4.1	5.0
23_435_2	3.8	5.4	6.5	7.5	8.8	9.7	10.7	13.0

**Table B4.3 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S15 Model Extent (Tributary 1)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_988_4	4.1	5.8	6.9	8.0	9.4	10.4	11.5	13.9
23_988_5	4.2	5.9	7.1	8.2	9.6	10.7	11.8	14.3
*23_988_7	4.2	5.9	7.1	8.2	9.6	10.7	11.8	14.3
23_988_8	4.4	6.2	7.4	8.6	10.1	11.2	12.3	14.9
23_757_2	5.1	7.2	8.6	10.0	11.7	13.0	14.3	17.4

**Table B4.4 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S15 Model Extent (Tributary 2)**

\*Target flows taken from upstream node as the estimate of the design peak flow based on the QMED regression equation, adjustment factor and growth factor at this node were less than those at the u/s node

### B4.3 Preliminary Design Inflows

To obtain the target flows at each HEP as shown in Tables B4.2 – B4.4, an initial set of inflow hydrographs was produced and run through the model.

Both the tributaries and the main stem were simulated in a single run, as the critical events on the tributaries and on the main stem were defined by a single run. For modelling purposes the tributaries are defined as Tributary 1 (from HEP 23\_195\_1 to 23\_435\_2) and Tributary 2 (from HEP 23\_988\_4 to 23\_757\_2).

The inflow hydrographs at the various HEPs were derived using the procedure outlined in Chapter 2 of the main hydrology report and using the adjustment factor, growth curves and hydrograph shape specified in Appendix A, Chapter A1. The QMED adjustment factor, growth curve and hydrograph shape are specified in Appendix A1. The HEPs are shown on Figure B4.1. Tables B4.5 - B4.7 present the peak values of the preliminary lateral inflows inserted into the model in the reach immediately upstream of the HEP in the hydraulic model for the main stem and tributary runs.

Preliminary design inflow hydrographs are shown in Figures B4.2 – B4.4 for the 1% AEP design runs.

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_436_1	5.2	7.3	8.8	10.1	11.9	13.2	14.6	17.6
23_436_3	0.4	0.5	0.6	0.7	0.9	1.0	1.1	1.3
23_758_1	1.4	2.0	2.4	2.7	3.2	3.6	3.9	4.8
23_197_3	1.7	2.4	2.9	3.3	3.9	4.3	4.8	5.8
23_806_2	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3

**Table B4.5 Preliminary Design Hydrograph Peak Inflows ( $m^3/s$ ) at HEP Locations on the S15 Model Extent (Main Stem)**

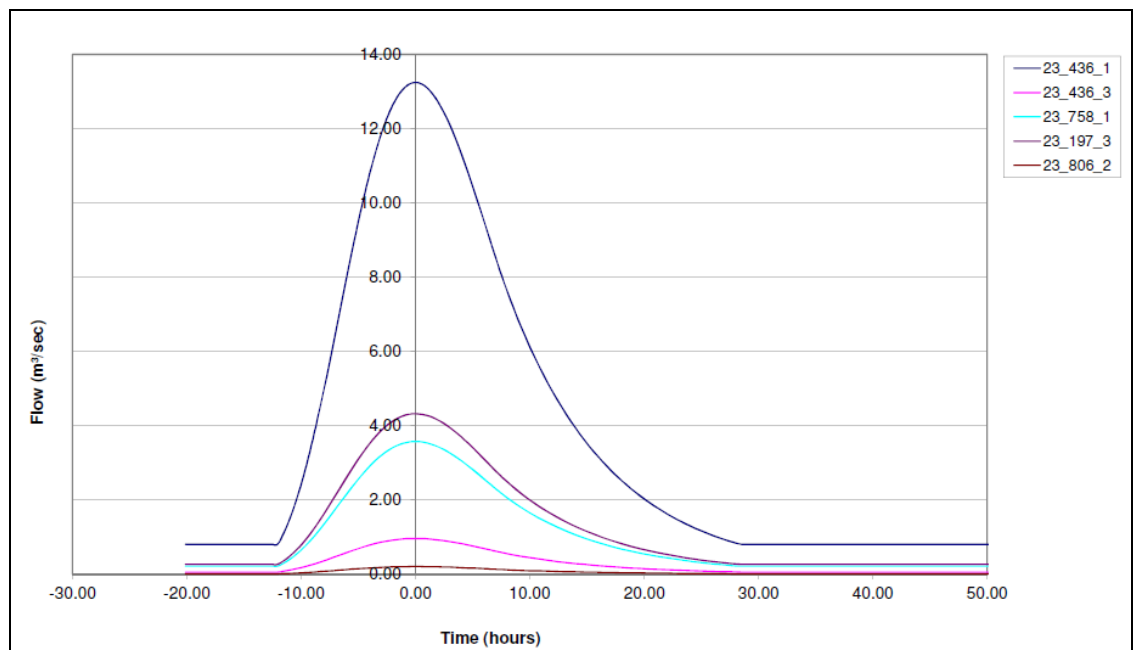
HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_195_1	1.5	2.1	2.5	2.9	3.3	3.7	4.1	5.0
23_435_2	2.4	3.3	4.0	4.6	5.4	6.0	6.6	8.0

**Table B4.6 Preliminary Design Hydrograph Peak Inflows ( $m^3/s$ ) at HEP Locations on the S15 Model Extent (Tributary 1)**

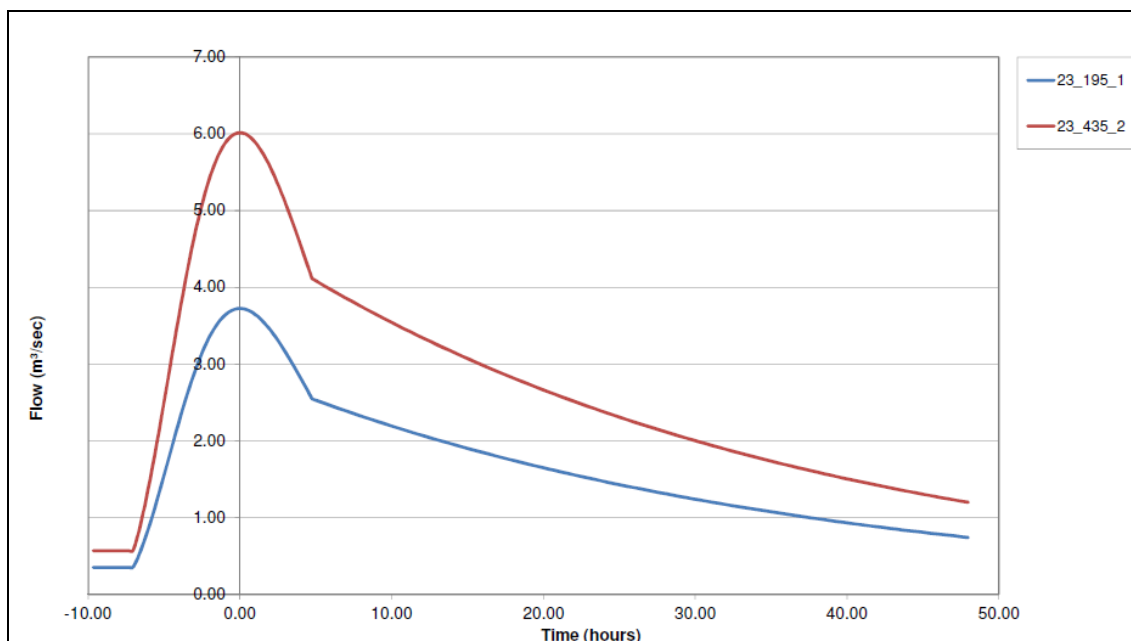


HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_988_4	4.2	5.9	7.1	8.2	9.6	10.7	11.8	14.3
23_988_5	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6
23_988_8	0.7	1.0	1.2	1.4	1.7	1.8	2.0	2.5

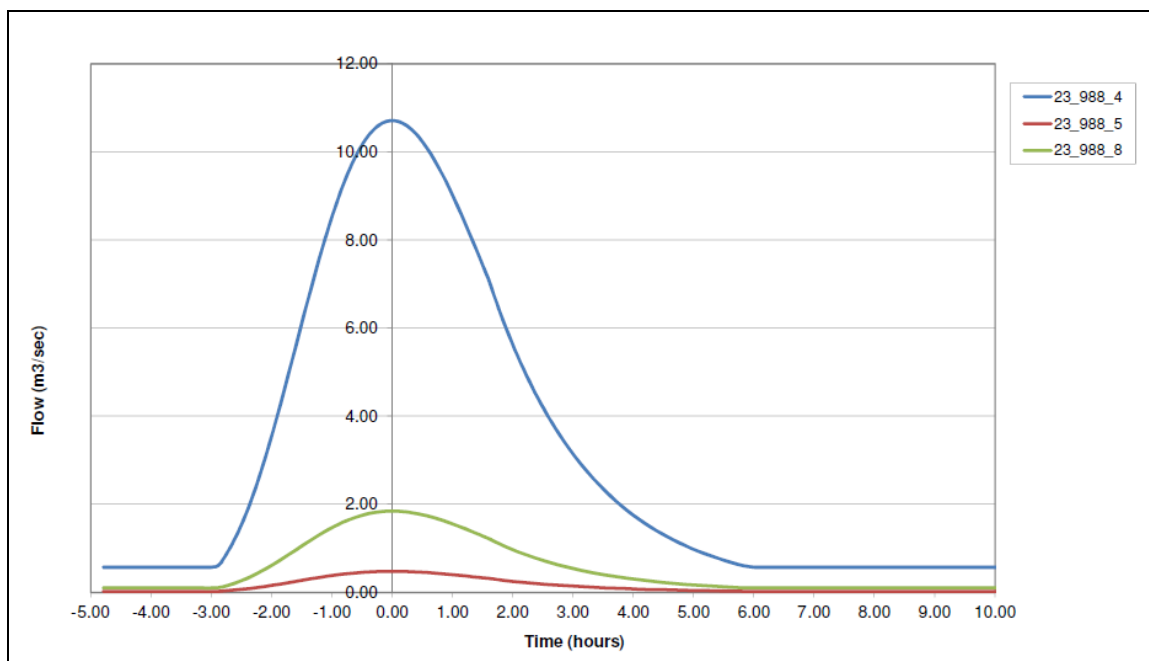
**Table B4.7** Preliminary Design Hydrograph Peak Inflows ( $\text{m}^3/\text{s}$ ) at HEP Locations on the S15 Model Extent (Tributary 2)



**Figure B4.2** S15 Preliminary Design Inflow Hydrographs for 1% AEP (River Brick - Main Stem)



**Figure B4.3** S15 Preliminary Design Inflow Hydrographs for 1% AEP (Tributary 1)



**Figure B4.4** S15 Preliminary Design Inflow Hydrographs for 1% AEP (Tributary 2)

#### **B4.4 HEP Calibration and Final Design Hydrographs**

The hydraulic model uses the preliminary design inflows presented in Tables B4.5 – B4.7 for calibrating the model to the HEP target flows presented in Tables B4.2 – B4.4

HEP calibration at each HEP was undertaken using the methodology described in Section 2.7.2 of the main hydrology report for UoM 23. Hydraulic modelling aspects of the HEP calibration including the results and final design peak flows are presented in the hydraulic modelling report for Model S15.

**B5****Model S16**

This appendix chapter summarises:

- i) the hydrology for the hydraulic model calibration; and
- ii) the target flows for the full range of modelled return periods, and the preliminary inflow design hydrographs used in the hydraulic modelling as the starting point in the process of ensuring that the river flows in the model agree with the target flows obtained from the hydrological techniques of the FSU (as described in Appendix A).

The model extent coverage is summarised in Table B5.1, and Figure B5.1

Model Attribute	Comment
Rivers included in model	River Lee and its four tributaries including River Big, in the vicinity of the Tralee AFA.
Areas for Further Assessment (AFA)	Tralee
Individual Risk Receptor (IRR)	None

**Table B5.1 Model Extent coverage**

### **B5.1 Hydrology for Hydraulic Model Calibration**

Although there are six gauging stations (23011, 23012, 23013, 23022, 23062 & 23063) in and around the S16 model there was insufficient gauged or historic event data available to calibrate the S16 model.

Station 23022 on the River Big and Station 23012 on the River Lee are the only gauges with flow data within the modelled extent. Station 23022 (Tralee Clonalour) is an EPA operated gauge which has a poor rating for flood frequency analysis (HGF is significantly less than QMED). At Station 23012, no rating has been developed post-1992 when flood relief works were undertaken in the catchment. While Station 23012 was included for rating review, this was abandoned because of the suspected tidal influence at this gauge. The two tidal stations 23062 and 23063 have not recorded 15-minute time series data for significant tidal events such as February 2002 and hence a tidal calibration was also not possible.

While numerous events are reported within the S16 model extent, the information contained is unsuitable for calibration and of little use for model verification. Flood alleviation measures which occurred in the catchment between 1992 -1996 prevents level data pre-1996 (where reported) from being applicable due to changes which may have occurred in channel geometry and/or catchment area.

Refer to the calibration strategy in Appendix F and the hydraulic modelling report for S16 for detail on the calibration/verification.

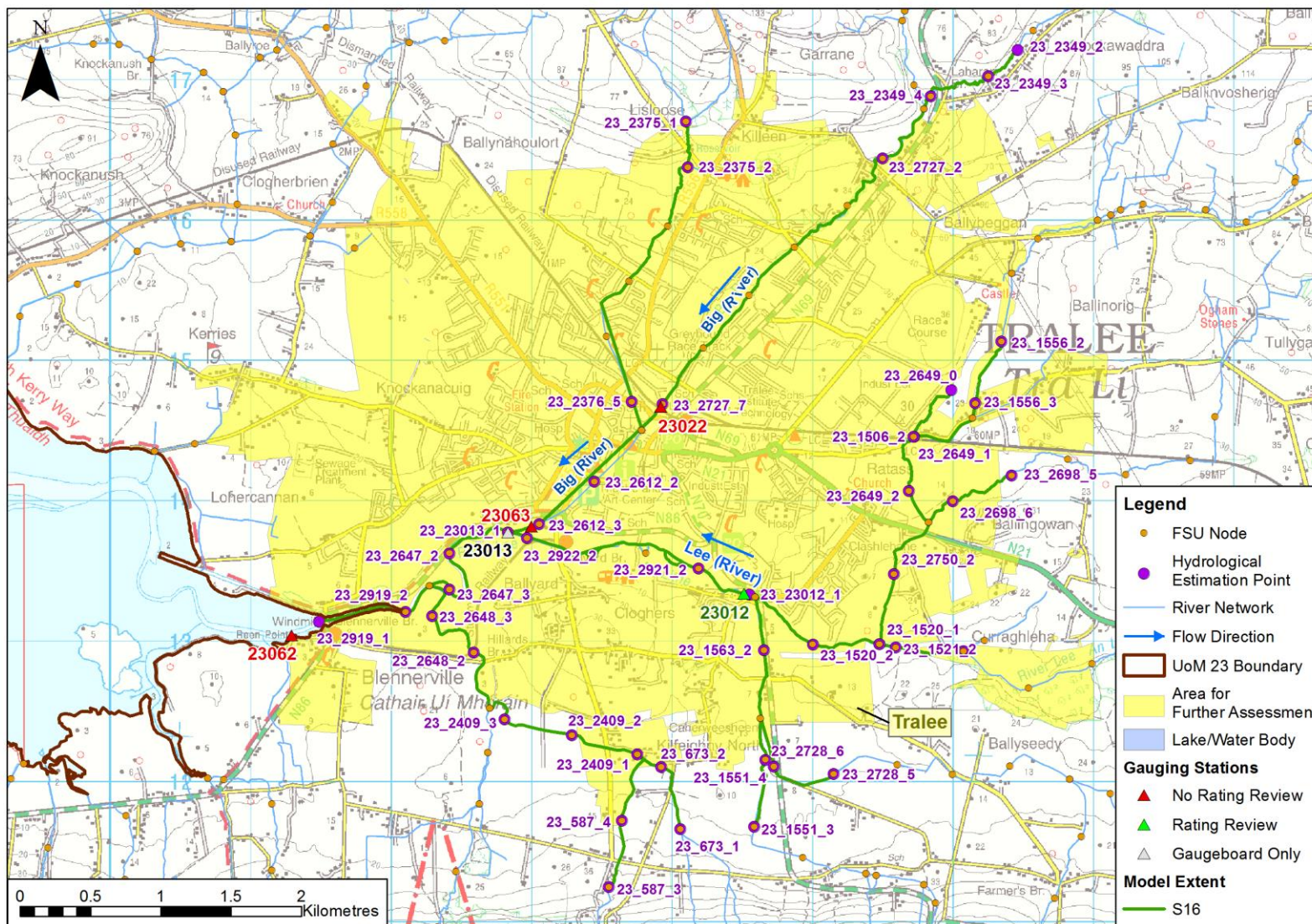


Figure B5.1 S16 Model Extent<sup>1</sup>

<sup>1</sup> Copyright Office of Public Works. All rights reserved. Includes Ordnance Survey Ireland data Reproduced under OSi License number EN0021011. Unauthorised reproduction infringes Ordnance Survey Ireland and Government of Ireland copyright, © Ordnance Survey Ireland, 2013.



## B5.2 Target Design Flows

The target flows are the peak flows required at the HEP nodes which have been derived using the design hydrology process detailed in Appendix A2. The target flows at the HEP nodes for model S16 are shown in Tables B5.2 – B5.6.

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_1521_1	16.1	19.9	22.4	24.8	27.9	30.2	32.6	38.0
23_1521_2*	16.1	19.9	22.4	24.8	27.9	30.2	32.6	38.0
23_1520_1	22.8	28.1	31.6	35.0	39.4	42.7	46.0	53.6
23_1520_2*	22.8	28.1	31.6	35.0	39.4	42.7	46.0	53.6
23_23012_1	28.8	35.5	40.0	44.3	49.9	54.0	58.2	67.8
23_2921_2*	28.8	35.5	40.0	44.3	49.9	54.0	58.2	67.8
23_2922_1	32.1	39.6	44.6	49.4	55.6	60.2	64.8	75.6
23_2922_2*	32.1	39.6	44.6	49.4	55.6	60.2	64.8	75.6
23_23013_1	45.0	55.5	62.5	69.3	77.9	84.5	91.0	106
23_2647_2*	45.0	55.5	62.5	69.3	77.9	84.5	91.0	106
23_2647_3*	45.0	55.5	62.5	69.3	77.9	84.5	91.0	106
23_2919_2	49.9	61.6	69.4	76.8	86.5	93.7	101	118

\*Target flows are less than respective upstream nodes. Flow from upstream carried forward downstream.

**Table B5.2 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S16 Model Extent (River Lee Main Stem – Reach 1).**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_1556_2	5.9	7.3	8.3	9.2	10.4	11.3	12.2	14.2
23_1556_3	6.1	7.6	8.6	9.6	10.8	11.8	12.7	14.8
23_1506_2	6.6	8.2	9.2	10.3	11.6	12.6	13.6	15.8
23_2649_0	0.24	0.30	0.34	0.38	0.43	0.46	0.50	0.58
23_2649_1	6.8	8.5	9.6	10.6	12.0	13.0	14.1	16.4
23_2649_2	6.9	8.6	9.7	10.8	12.2	13.3	14.3	16.7
23_2698_5	3.0	3.8	4.3	4.7	5.3	5.8	6.3	7.3
23_2698_6	3.2	4.0	4.5	5.0	5.7	6.1	6.6	7.7
23_2750_2	10.2	12.8	14.4	16.0	18.1	19.6	21.2	24.7
23_2750_3	10.3	12.8	14.5	16.1	18.2	19.8	21.3	24.9

**Table B5.3 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S16 Model Extent (Right-bank tributary of River Lee – Reach 2).**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_2728_5	4.4	5.5	6.3	7.0	7.9	8.6	9.3	10.9
23_2728_6	4.5	5.7	6.5	7.2	8.2	8.9	9.6	11.2
23_1563_2	8.3	10.4	11.8	13.1	14.9	16.2	17.4	20.4
23_1551_3	6.0	7.5	8.5	9.5	10.7	11.7	12.6	14.8
23_1551_4	6.1	7.7	8.7	9.7	11.0	11.9	12.9	15.1

**Table B5.4 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S16 Model Extent (Left-bank tributary of River Lee - Reach 3).**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_2349_2	3.1	3.9	4.4	4.9	5.6	6.1	6.6	7.7
23_2349_3	3.3	4.2	4.8	5.3	6.0	6.6	7.1	8.3
23_2349_4	3.7	4.7	5.3	5.9	6.7	7.3	7.9	9.3
23_2727_2	8.4	10.6	12.0	13.4	15.1	16.5	17.8	20.9
23_2727_7	11.1	14.0	15.8	17.7	20.0	21.8	23.5	27.6
23_2612_2	14.4	18.1	20.5	22.9	25.9	28.2	30.5	35.8
23_2612_3	17.3	21.7	24.7	27.5	31.2	33.9	36.7	43.0
23_2375_1	1.1	1.4	1.6	1.8	2.1	2.2	2.4	2.8
23_2375_2	1.6	2.0	2.3	2.6	2.9	3.2	3.4	4.0
23_2376_5	3.6	4.5	5.2	5.7	6.5	7.1	7.7	9.0

**Table B5.5 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S16 Model Extent (River Big Main stem – Reach 4).**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_587_3	8.6	10.9	12.4	13.8	15.7	17.0	18.4	21.6
23_587_4	8.8	11.1	12.6	14.1	16.0	17.4	18.8	22.1
23_673_1	1.6	2.0	2.3	2.5	2.9	3.1	3.4	3.9
23_673_2	1.8	2.3	2.6	2.9	3.3	3.6	3.9	4.6
23_2409_1	10.5	13.3	15.1	16.9	19.2	20.9	22.6	26.5
23_2409_2	10.8	13.6	15.5	17.3	19.7	21.4	23.1	27.2
23_2409_3	11.1	14.0	15.9	17.8	20.2	22.0	23.8	27.9
23_2648_2	15.7	19.8	22.5	25.1	28.5	31.1	33.6	39.4
23_2648_3	15.7	19.8	22.6	25.2	28.6	31.1	33.6	39.5

**Table B5.6 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S16 Model Extent (Lower tributary of River Lee – Reach 5).**



### B5.3 Preliminary Design Inflows

To obtain the target flows at each HEP, as shown in Tables B5.2 – B5.6, an initial set of inflow hydrographs was produced and run through the model.

The watercourses that comprise Model S16 include the River Lee, River Big, and four unnamed tributaries which flow through the Tralee AFA.

For modelling purposes the watercourses are defined as River Lee (from HEP 23\_1521\_1 to 23\_2919\_1), River Big (from HEP 23\_2349\_2 to 23\_2612\_3), unnamed right-bank tributary of River Lee (from HEP 23\_1556\_2 to 23\_2750\_3), unnamed left-bank tributary of River Lee (from HEP 23\_2728\_5 to 23\_1563\_2), lower tributary of River Lee (from HEP 23\_587\_3 to 23\_2648\_3), and upper tributary of River Big (from HEP 23\_2375\_1 to 23\_2376\_5).

The inflow hydrographs at the various HEPs were derived using the procedure outlined in Chapter 2 of the main hydrology report and using the adjustment factor, growth curves and hydrograph shape specified in Appendix A, Chapter A2. The HEPs are shown in Figure B5.1. Tables B5.7 – B5.12 present the preliminary peak inflows that were used at each HEP in the hydraulic model.

Preliminary design inflow hydrographs are shown in Figures B5.2 - B5.7 for the 1% AEP design run.

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_1521_1	16.1	19.9	22.4	24.8	27.9	30.2	32.6	38.0
23_1521_2	6.7	8.2	9.3	10.3	11.6	12.5	13.5	15.7
23_1520_1	6.0	7.4	8.4	9.3	10.4	11.3	12.2	14.2
23_2922_1	3.2	4.0	4.5	4.9	5.6	6.0	6.5	7.6
23_2647_2	0.73	0.90	1.0	1.1	1.3	1.4	1.5	1.7

**Table B5.7 Preliminary Design Hydrograph Peak Inflows (m<sup>3</sup>/s) at HEP Locations on the S16 Model Extent (River Lee Main Stem – Reach 1)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_1556_2	6.1	7.6	8.6	9.6	10.8	11.8	12.7	14.8
23_1556_3	0.43	0.53	0.60	0.67	0.75	0.82	0.88	1.0
23_2649_1	0.12	0.15	0.16	0.18	0.21	0.22	0.24	0.28
23_2649_2	0.19	0.23	0.26	0.29	0.33	0.36	0.39	0.45
23_2649_0	0.24	0.30	0.34	0.38	0.43	0.46	0.50	0.58
23_2698_5	3.2	4.0	4.5	5.0	5.7	6.1	6.6	7.7

**Table B5.8 Preliminary Design Hydrograph Peak Inflows (m<sup>3</sup>/s) at HEP Locations on the S16 Model Extent (Right-bank tributary of River Lee – Reach 2)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_2728_5	4.5	5.7	6.5	7.2	8.2	8.9	9.6	11.2
23_2728_6	3.7	4.7	5.3	5.9	6.7	7.3	7.9	9.2
23_1551_3	6.1	7.7	8.7	9.7	11.0	11.9	12.9	15.1

**Table B5.9 Preliminary Design Hydrograph Peak Inflows ( $m^3/s$ ) at HEP Locations on the S16 Model Extent (Left-bank tributary of River Lee – Reach 3)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_2349_2	3.3	4.2	4.8	5.3	6.0	6.6	7.1	8.3
23_2349_3	0.38	0.48	0.54	0.60	0.68	0.74	0.80	0.94
23_2349_4	4.7	5.9	6.7	7.4	8.4	9.2	9.9	11.6
23_2727_2	2.7	3.4	3.9	4.3	4.9	5.3	5.7	6.7
23_2612_2	2.9	3.7	4.1	4.6	5.2	5.7	6.2	7.2

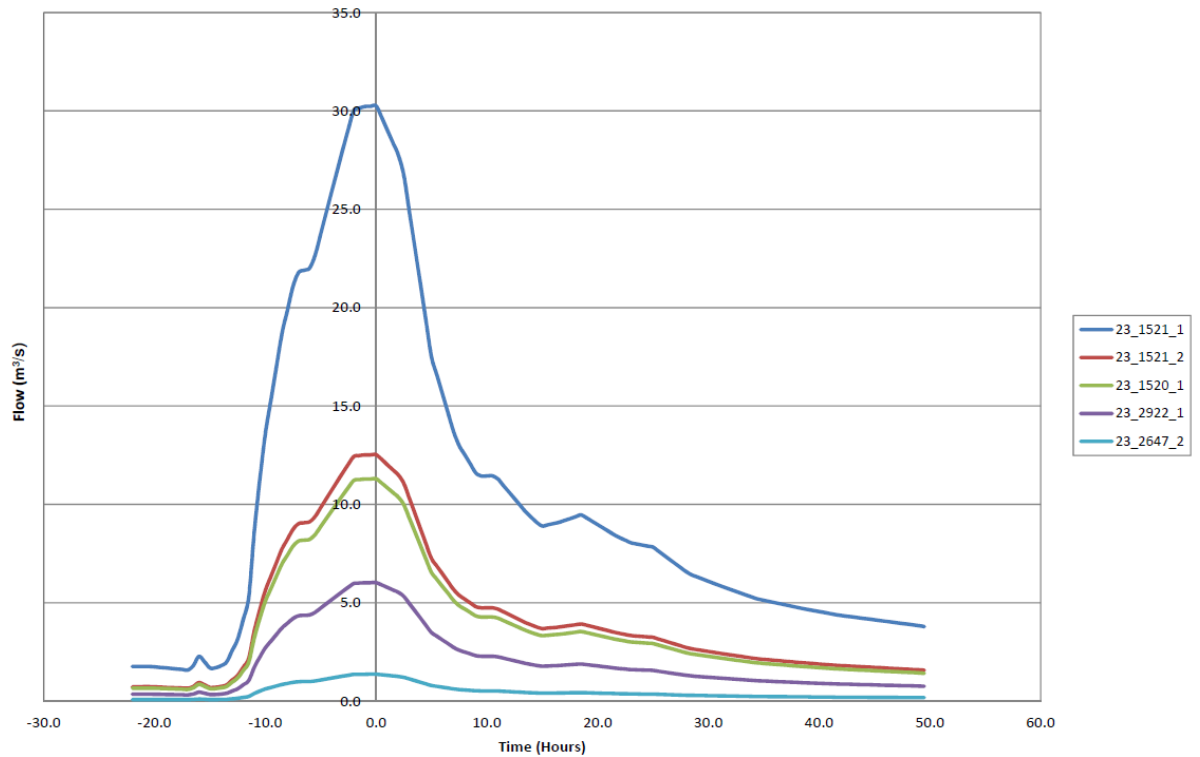
**Table B5.10 Preliminary Design Hydrograph Peak Inflows ( $m^3/s$ ) at HEP Locations on the S16 Model Extent (River Big Main Stem – Reach 4)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_2375_1	1.6	2.0	2.3	2.6	2.9	3.2	3.4	4.0
23_2375_2	2.0	2.5	2.8	3.2	3.6	3.9	4.2	5.0

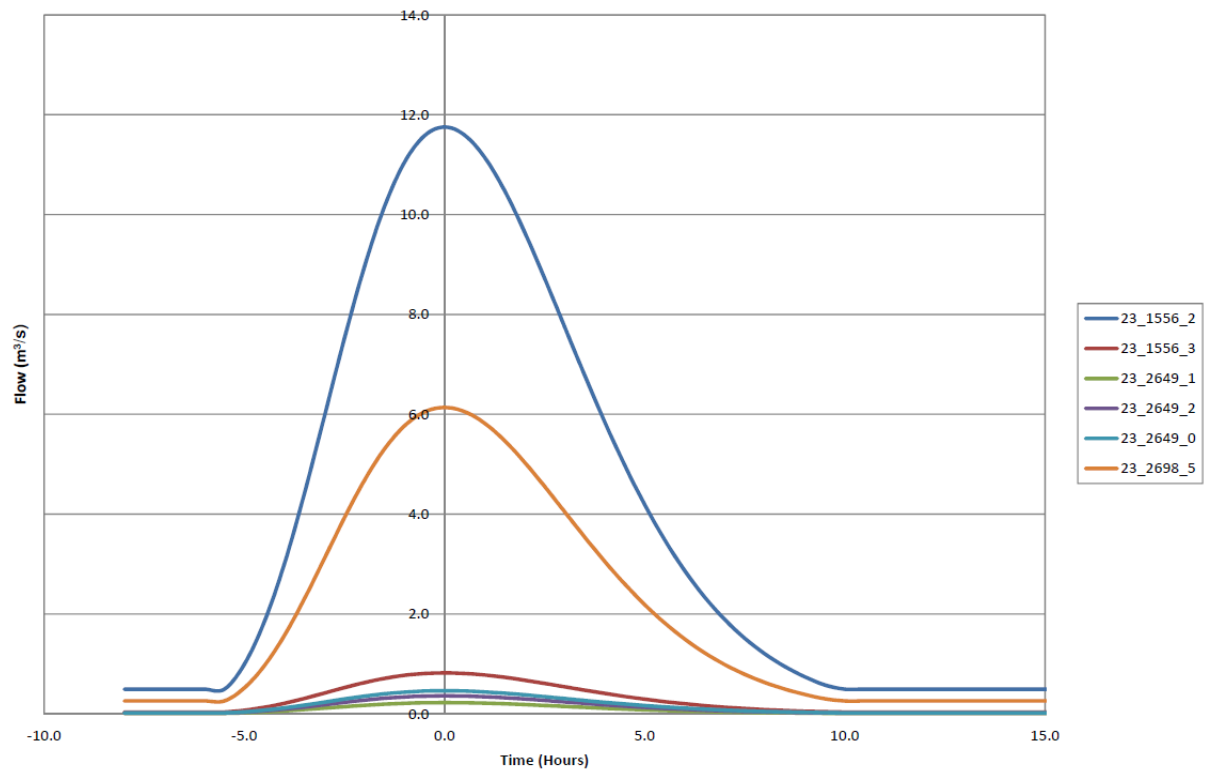
**Table B5.11 Preliminary Design Hydrograph Peak Inflows ( $m^3/s$ ) at HEP Locations on the S16 Model Extent (Upper tributary of River Big – Reach 4)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_673_1	1.8	2.3	2.6	2.9	3.3	3.6	3.9	4.6
23_587_3	8.8	11.1	12.6	14.1	16.0	17.4	18.8	22.1
23_2409_1	0.27	0.34	0.39	0.43	0.49	0.53	0.58	0.68
23_2409_2	0.29	0.37	0.42	0.46	0.53	0.57	0.62	0.73
23_2409_3	4.6	5.8	6.6	7.4	8.4	9.1	9.9	11.6

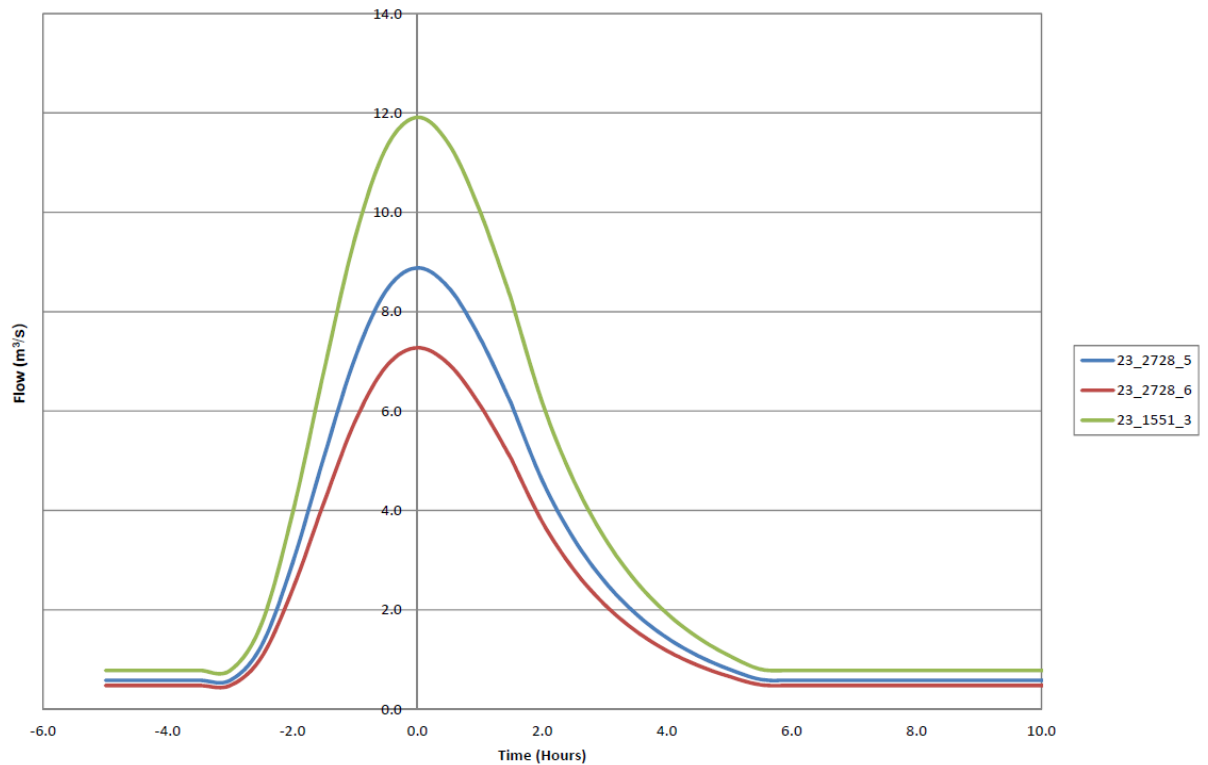
**Table B5.12 Preliminary Design Hydrograph Peak Inflows ( $m^3/s$ ) at HEP Locations on the S16 Model Extent (Lower tributary of River Lee – Reach 5)**



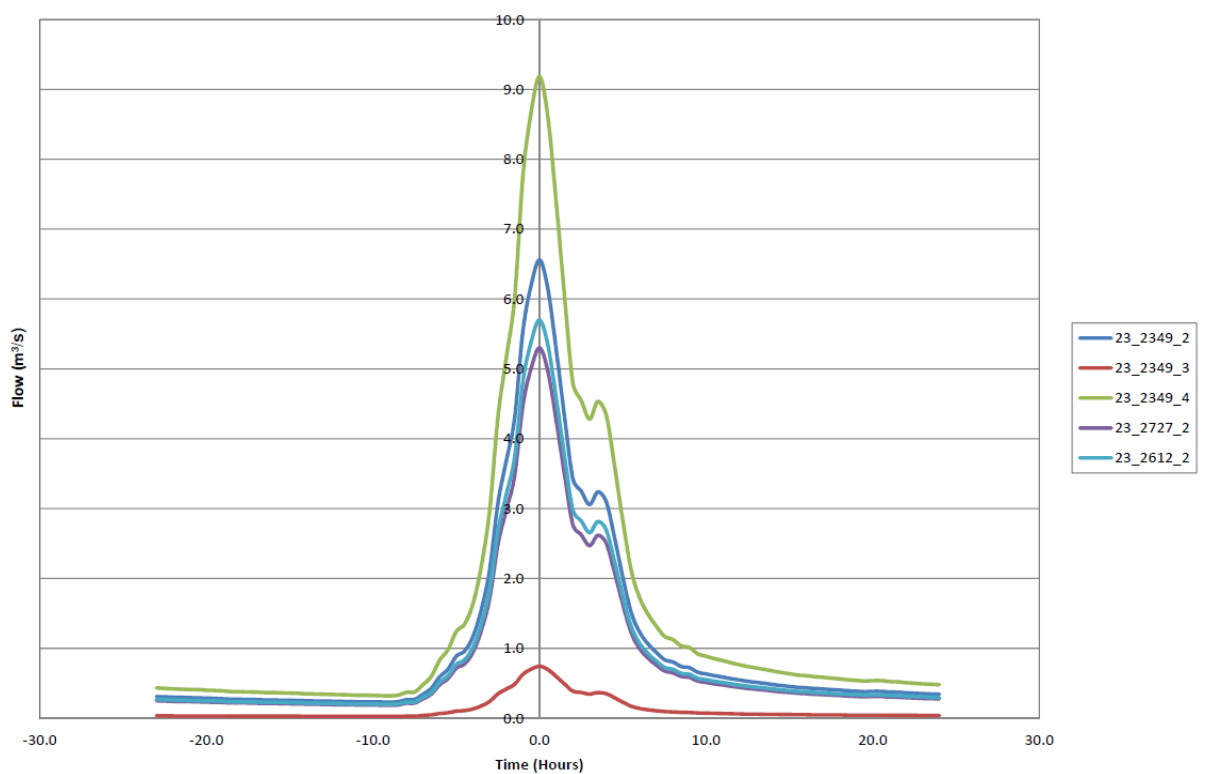
**Figure B5.2** S16 Preliminary Design Inflow Hydrographs for 1% AEP (River Lee Main Stem – Reach 1)



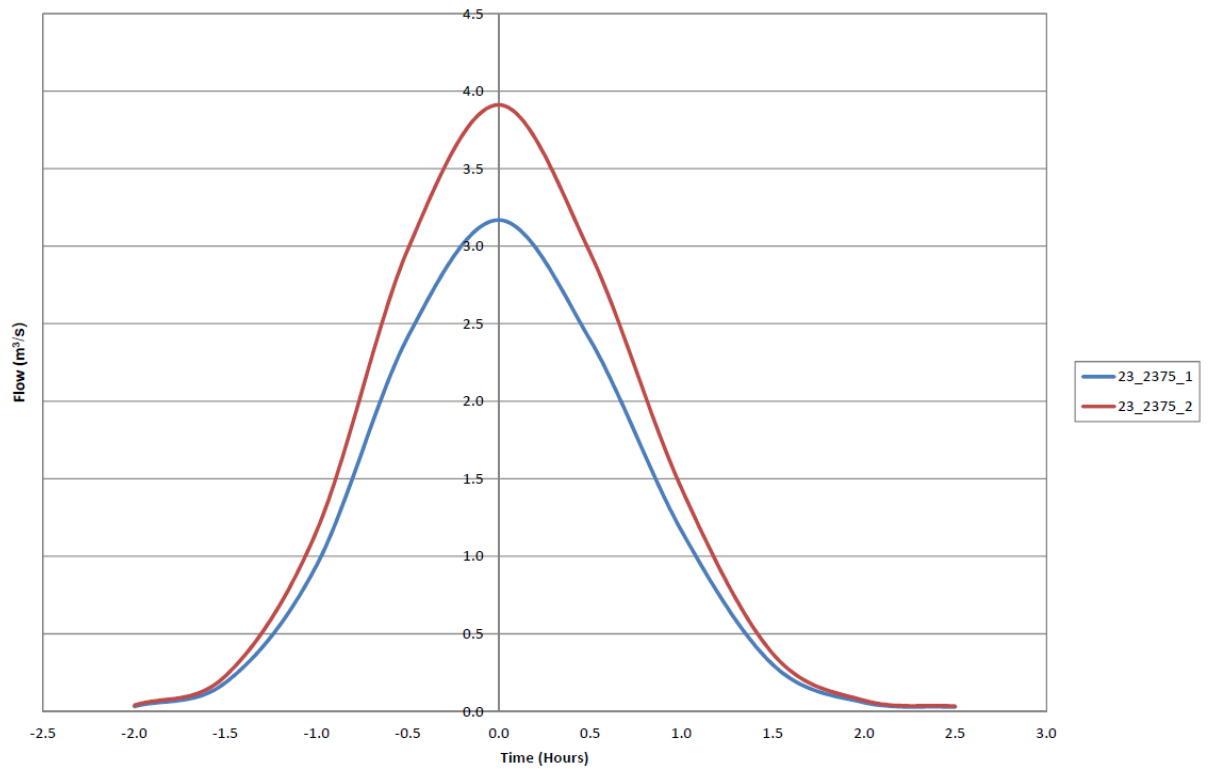
**Figure B5.3** S16 Preliminary Design Inflow Hydrographs for 1% AEP (Right-bank tributary of River Lee – Reach 2)



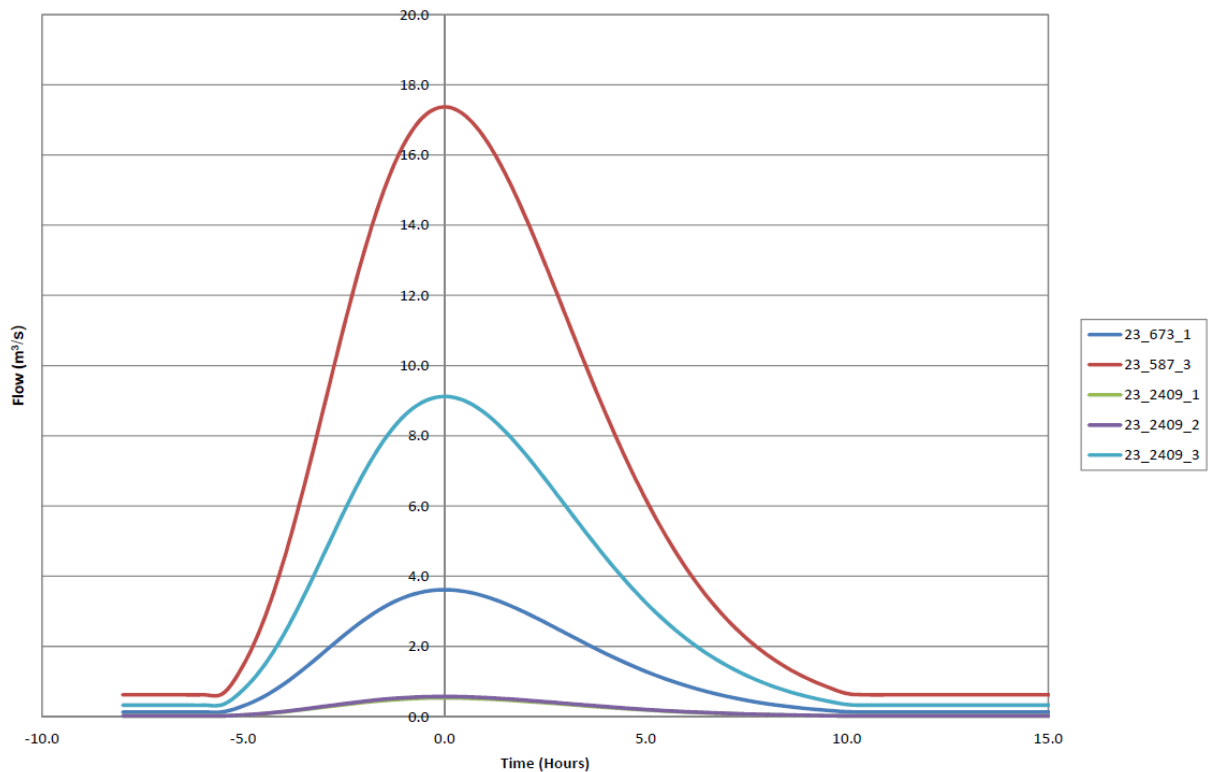
**Figure B5.4** S16 Preliminary Design Inflow Hydrographs for 1% AEP (Left-bank tributary of River Lee – Reaches 3a and 3b)



**Figure B5.5** S16 Preliminary Design Inflow Hydrographs for 1% AEP (River Big Main Stem – Reach 4)



**Figure B5.6** S16 Preliminary Design Inflow Hydrographs for 1% AEP (Upper tributary of River Big – Reach 4)



**Figure B5.7** S16 Preliminary Design Inflow Hydrographs for 1% AEP (Lower tributary of River Lee – Reach 5)

## **B5.4 HEP Calibration and Final Design Hydrographs**

The hydraulic model uses the preliminary design inflows presented in Tables B5.7 – B5.12 for calibrating the model to the HEP target flows presented in Tables B5.2 – B5.6.

HEP calibration at each HEP was undertaken using the methodology described in Section 2.7.2 of the main hydrology report for UoM 23. Hydraulic modelling aspects of the HEP calibration including the results and final design peak flows are presented in the hydraulic modelling report for Model S16.

**B6****Model S17**

This appendix chapter summarises:

- i) the hydrology for the hydraulic model calibration; and
- ii) the target flows for the full range of modelled return periods and the inflow design hydrographs required to ensure that the river flows in the model agree with the target flows obtained from the hydrological techniques of the FSU (as described in Appendix A).

The model extent coverage is summarised in Table B6.1, and Figure B6.1

Model Attribute	Comment
Rivers included in model	River Tyshe and its tributaries including River Ballynoe as well as minor tributary branches.
Areas for Further Assessment (AFA)	Banna

**Table B6.1** Model Extent coverage

### **B6.1 Hydrology for Hydraulic Model Calibration**

There was insufficient gauged data available to calibrate the S17 model. Two tidal gauges recording water level only, operate downstream of Akeragh Lough, away from the River Tyshe. No other hydrometric stations are present within or upstream of the S17 modelling extent to provide reliable flows to calibrate the model. In addition, there are no historic flood records available in the Banna area that could be used for model calibration

Refer to the calibration strategy in Appendix F and the hydraulic modelling report for S17 for detail on the calibration/verification.

### **B6.2 Target Design Flows**

The target flows are the peak flows required at the HEP nodes which have been derived using the design hydrology process detailed in Appendix A3. The target flows at the HEP nodes for model S17 are shown in Tables B6.2 – B6.5.



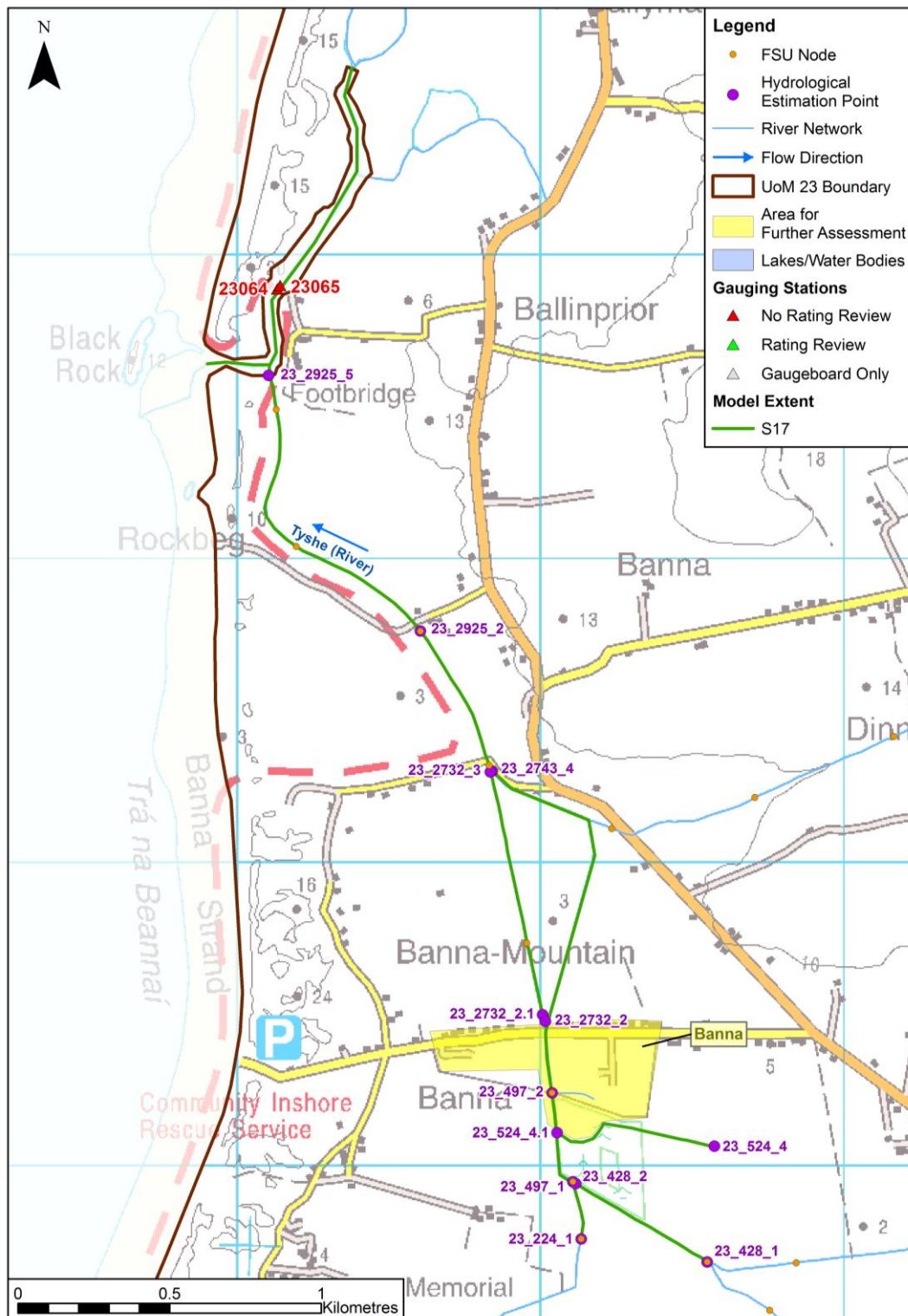


Figure B6.1 S17 Model Extent<sup>1</sup>

<sup>1</sup> Copyright Office of Public Works. All rights reserved. Includes Ordnance Survey Ireland data Reproduced under OSi License number EN0021011. Unauthorised reproduction infringes Ordnance Survey Ireland and Government of Ireland copyright, © Ordnance Survey Ireland, 2013.

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_428_1	2.8	3.6	4.2	4.7	5.4	5.9	6.5	7.7
23_428_2	3.0	3.9	4.5	5.0	5.8	6.3	6.9	8.2
23_497_1	3.2	4.1	4.8	5.4	6.2	6.8	7.3	8.7
*23_497_2	3.2	4.1	4.8	5.4	6.2	6.8	7.3	8.7
*23_2732_2	3.2	4.1	4.8	5.4	6.2	6.8	7.3	8.7
23_2732_3	3.4	4.5	5.2	5.8	6.7	7.3	8.0	9.4
23_2925_2	3.6	4.7	5.5	6.2	7.1	7.7	8.4	10.0
*23_2925_5	3.6	4.7	5.5	6.2	7.1	7.7	8.4	10.0

**Table B6.2 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S17 Model Extent (Main Stem).**

\*Target flows taken from upstream node as the estimate of the design peak flow based on the QMED regression equation, adjustment factor and growth factor at this node were less than those at the u/s node

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_224_1	0.18	0.24	0.28	0.31	0.36	0.39	0.43	0.51

**Table B6.3 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S17 Model Extent (Minor Branch)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_524_4.1	0.03	0.04	0.05	0.05	0.06	0.06	0.07	0.08

**Table B6.4 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S17 Model Extent (Right Bank Tributary)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_2743_4	0.12	0.15	0.18	0.20	0.23	0.25	0.27	0.32

**Table B6.5 Target Flows (m<sup>3</sup>/s) at HEP Locations on the S17 Model Extent (Field Drain)**

### B6.3 Preliminary Design Inflows

To obtain the target flows at each HEP as shown in Tables B6.2 – B6.5, an initial set of inflow hydrographs was produced and run through the model.

The hydrograph shapes and peaks for the inflows were determined using the standard procedure outlined in Section 2.6 of the main hydrology report for UoM 23. There are three minor tributaries, with one HEP each, having very small inflow contribution with respect to the main stem (refer to Tables B6.2 - B6.5). As the inflows from the tributaries were comparable with the difference in the target flow between upstream and downstream main stem nodes, the tributaries were run together with the main stem in a single run.

The inflow hydrographs at the various HEPs were derived using the procedure outlined in Chapter 2 of the main hydrology report and using the adjustment factor, growth curves and hydrograph shape specified in Appendix A, Chapter A3. The HEPs are shown on Figure B6.1. Tables B6.6 – B6.9 present the peak values of the preliminary lateral inflows inserted into the model in the reach immediately upstream of the HEP in the hydraulic model for the main stem and tributary run.

Preliminary design inflow hydrographs are shown in Figure B6.2 for the 1% AEP design run.

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_428_1	3.0	3.9	4.5	5.1	5.8	6.4	6.9	8.2
23_2732_2	0.23	0.35	0.40	0.45	0.52	0.57	0.62	0.73
23_2732_3	0.08	0.11	0.12	0.14	0.16	0.18	0.19	0.23

**Table B6.6 Preliminary Design Hydrograph Peak Inflows ( $m^3/s$ ) at HEP Locations on the S17 Model Extent (Main Stem)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_224_1	0.18	0.24	0.28	0.31	0.36	0.39	0.43	0.51

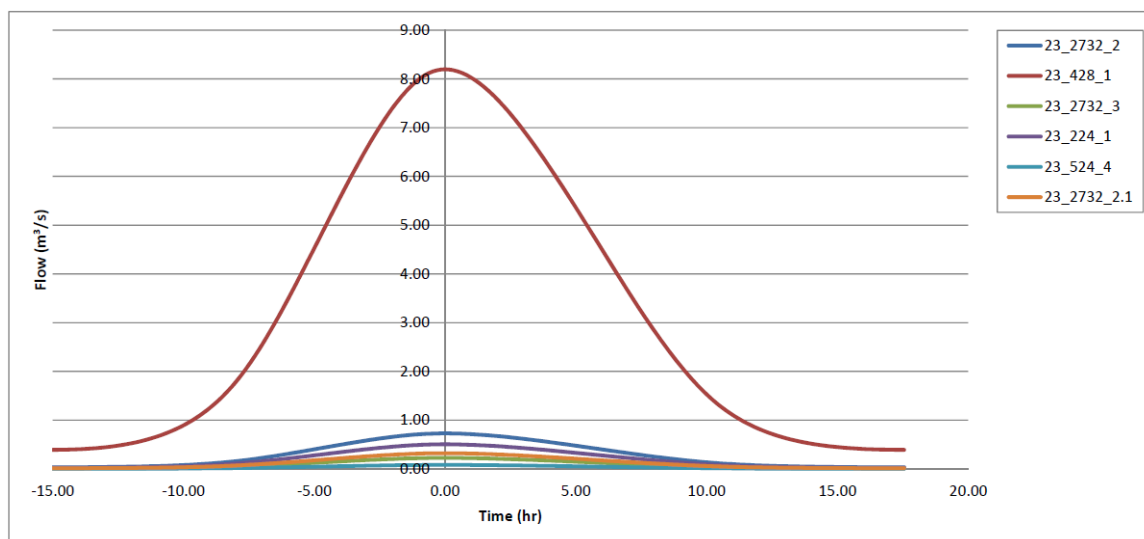
**Table B6.7 Preliminary Design Hydrograph Peak Inflows ( $m^3/s$ ) at HEP Locations on the S17 Model Extent (Minor Branch)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_524_4	0.03	0.04	0.05	0.05	0.06	0.06	0.07	0.08

**Table B6.8 Preliminary Design Hydrograph Peak Inflows ( $m^3/s$ ) at HEP Locations on the S17 Model Extent (Right Bank Tributary)**

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
23_2732_2.1	0.12	0.15	0.18	0.20	0.23	0.25	0.27	0.32

**Table B6.9** Preliminary Design Hydrograph Peak Inflows (m<sup>3</sup>/s) at HEP Locations on the S17 Model Extent (Field Drain)



**Figure B6.2** S17 Preliminary Design Inflow Hydrographs for 1% AEP (Main Stem & Tributary Branches)

## B6.4 HEP Calibration and Final Design Hydrographs

The hydraulic model uses the preliminary design inflows presented in Tables B6.6 – B6.9 for calibrating the model to the HEP target flows presented in Tables B6.2 – B6.5.

HEP calibration at each HEP was undertaken using the methodology described in Section 2.7.2 of the main hydrology report for UoM 23. Hydraulic modelling aspects of the HEP calibration including the results and final design peak flows are presented in the hydraulic modelling report for Model S17.

## Appendix C      Rating Review Summary Sheets

### Table of Content

23012 Ballymullen

The rating review summary sheets in this appendix refer to levels in metres above gauge zero (i.e. local datum), metres above the historic Poolbeg Ordnance Datum (mAOD(P)) and/or metres above the more recent Malin Ordnance Datum (mAOD(M)).

## 23012 – LEE AT BALLYMULLEN

Date of data collation: 05/01/2012

### Introduction:

High flow rating reviews have been undertaken for 44 selected hydrometric gauging stations within the Shannon River Basin District. A rating review summary sheet has been produced for each gauge to summarise the rating review process.

### Gauging Station Description:

Recorder and staff gauge in natural section immediately downstream of footbridge. Straight channel in urban area. Flood relief works took place in the period 1992-1996, which altered the rating. Jacobs site visit notes report that bypassing is considered unlikely. The OPW (FSU) RBD Shannon Data Summary spreadsheet reports some tidal influence at the gauge.

### Gauging Station Details:

Station Type	Recorder	Gauging Authority	OPW
Coordinates	84512, 113339	Period of Record	1974-2009 (AMAX levels), flows only derived for 1974–1991 (before works)
Existing Rating Curve	Yes	Validity / Upper Limit	W < 1.5 m (Q~16 m <sup>3</sup> /s; pre-works)

QMED synthetic	24.9 m <sup>3</sup> /s
QMED (AMAX, pre-rating review)	15.7 m <sup>3</sup> /s (18 years before works)

Gauge Zero (from operator)	3.49 mAOD(P)
Gauge Zero (from survey)	0.88 mAOD(M)

### Hydraulic Model Details and Calibration:

No hydraulic model was completed for this station. Refer to the Analysis and Results section for more details.

### Analysis and Results:

It is recommended that this station is not used for flood flow estimation for the following reasons:

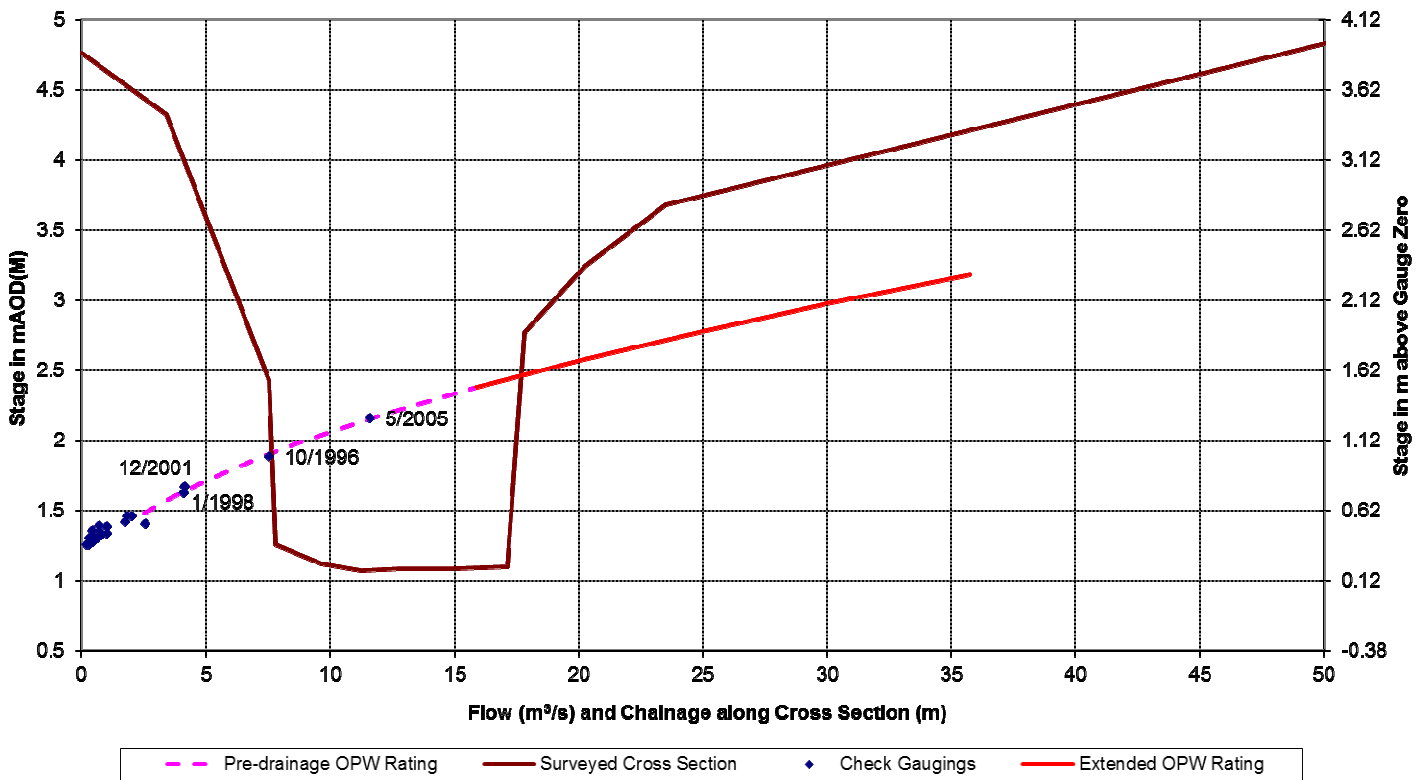
1. There are very few medium flow check gaugings and no high flow check gaugings since 1996 (when flood relief works were completed);
2. The high flow water levels recorded at this gauge can be affected by the tide; therefore AMAX levels may not represent a fluvial influence alone.

These reasons are explained in more detail below.

Flood relief works that took place between 1992 and 1996 make the check gaugings from before 1996 unsuitable for calibrating a rating post-1996. Since 1996 only very few mid-range check gaugings have been undertaken, with the highest 11.6 m<sup>3</sup>/s (1.28 m above local datum), lower than any of the AMAX flows and levels recorded to date. This makes any calibration of a hydraulic model unreliable.

To assess the influence of tidal water levels, data from the estuary level gauge at station 23062 near Tralee were extracted. The AMAX water levels at this tidal gauge (2004 to 2010) vary from 2.7 to 3.0 mAOD(M). AMAX water levels at station 23012 (Ballymullen) vary from 2.8 to 3.9 mAOD(M) over the period 1996-2010, thereby indicating that there is potential for AMAX levels in the past and in the future to be affected by spring tides.

The river bed at the Ballymullen gauge is at about 1.0 mAOD(M), therefore it can be expected that the gauged section is influenced by tidal levels and flows during most tidal cycles. Apart from having a direct effect on recorded water levels and flows, the tide may also cause variations in the local geomorphology.



#### Conclusions:

It is recommended that this station is not used for flood flow estimation for the following reasons:

1. There are very few medium flow check gaugings and no high flow check gaugings since 1996 (when flood relief works were completed);
2. The high flow water levels recorded at this gauge can be affected by the tide; therefore AMAX levels may not represent a fluvial influence alone.

No hydraulic model was completed for this station and no attempt was made to derive a set of rating equations following a request from OPW that work relating to this gauging station cease.



## Appendix D Gauging Station Information Sheets

### Table of Content

23001 Inch Bridge

23002 Listowel

The Gauging Station Information Sheets in this appendix show the original AMAX series as provided by OPW (if available) and the revised AMAX series as adopted for the at-site flood frequency analysis. If for a gauging station subject to a rating review the revised AMAX series is different from the original series then further information can be found on the Rating Review Summary Sheet for that station in Appendix C.

## 23001 – GALEY AT INCH BRIDGE

### Annual Maxima Series

Hydrological Year	Existing Flow (m <sup>3</sup> /s)	Revised Flow (m <sup>3</sup> /s)	Date
1946			
1947			
1948			
1949			
1950			
1951			
1952			
1953			
1954			
1955			
1956			
1957			
1958			
1959			
1960	169.56		25/01/1961
1961	115.58		06/10/1961
1962	215.13		08/12/1962
1963	85.65		20/06/1964
1964	178.09		12/12/1964
1965	159.52		09/12/1965
1966	113.91		23/02/1967
1967	197.40		07/10/1967
1968	204.35		24/12/1968
1969	103.71		19/12/1969
1970	78.57		18/11/1970
1971	86.56		18/10/1971
1972	103.27		12/11/1972
1973	210.07		01/12/1973
1974	98.22		22/01/1975
1975	99.05		01/12/1975
1976	38.04		30/12/1976
1977	64.92		09/11/1977
1978	71.19		10/05/1979
1979	76.26		26/12/1979
1980	104.13		02/11/1980
1981	71.91		18/06/1982
1982	90.07		31/01/1983
1983	105.84		09/12/1983
1984	74.07		14/08/1985
1985	120.08		25/08/1986
1986	79.24		18/11/1986
1987	84.57		18/03/1988
1988	111.08		11/10/1988
1989	124.70		28/10/1989
1990	99.89		24/02/1991
1991	135.17		12/09/1992
1992	43.20		13/01/1993
1993	104.98		07/01/1994
1994	164.72		22/02/1995
1995	72.63		26/10/1995
1996	94.10		29/11/1996
1997	127.52		06/03/1998
1998	89.28		15/01/1999
1999	102.42		28/11/1999
2000	122.84		26/10/2000
2001	104.13		23/01/2002
2002	73.35		21/10/2002
2003	74.80		14/11/2003
2004	159.42		08/01/2005
2005	101.58		02/12/2005
2006	91.27		07/10/2006
2007	138.29		01/08/2008
2008	132.27		12/12/2008
2009	158.37		19/11/2009

**Gauging Authority:** Office of Public Works

**Easting:** 95729

**Northing:** 136181

**Catchment:** Galey

**Telemetry:** Yes

**Station Type:** Recorder

**Catchment Area:** 192 km<sup>2</sup>

**QMED (gauged):** 103.5 m<sup>3</sup>/s

**AREA:** 192 km<sup>2</sup>

**QMED (synthetic urban):** 66.50 m<sup>3</sup>/s

**SAAR:** 1084 mm

**QMED (CFRAM revised):**

**FARL:** 1.0

**BFIsoils:** 0.32

**S1085:** 3.3 m/km

**URBEXT:** 0.3 %

**ARTDRAIN2:** 19.0%

**DRAIND:** 1.39

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

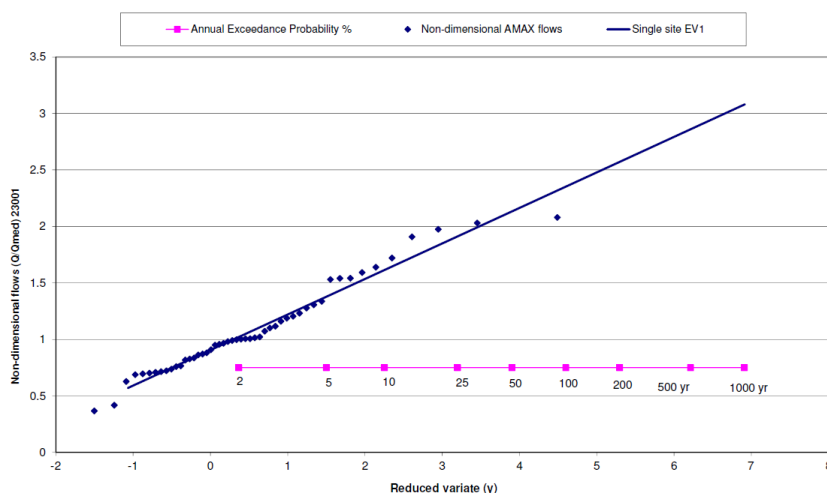
*Catchment descriptors from FSU.*

**Nearby AFAs:** N/A

**Jacobs Rating Review:** No

**FSU Station Classification:** A2

### Flood Frequency (EV1 with Gringorten plotting positions)



**Length of AMAX series:** 50 years

**CFRAM Revised:** years

No CFRAM rating review for this station. Original rating and AMAX series retained. The full AMAX series from 1960 was used for flood estimation purposes.

## 23002 – FEALE AT LISTOWEL

### Annual Maxima Series

Hydrological Year	Existing Flow (m <sup>3</sup> /s)	Revised Flow (m <sup>3</sup> /s)	Date
1946	246.1		28/06/1947
1947	439.5		04/01/1948
1948	517.9		05/12/1948
1949	420.6		25/10/1949
1950	340.4		10/01/1951
1951	594.6		05/11/1951
1952	383.6		29/08/1953
1953	340.4		24/01/1954
1954	353.0		05/06/1955
1955	243.9		11/12/1955
1956	360.5		31/12/1956
1957	386.2		24/01/1958
1958	284.9		04/11/1958
1959	275.6		09/12/1959
1960	407.2		24/01/1961
1961	330.5		08/10/1961
1962	368.2		08/12/1962
1963	241.7		31/10/1963
1964	330.5		12/12/1964
1965	428.6		03/12/1965
1966	330.5		22/02/1967
1967	368.2		06/10/1967
1968	428.6		10/01/1969
1969	325.6		21/04/1970
1970	180.7		20/02/1971
1971	271.0		03/07/1972
1972	286.1		12/11/1972
1973	765.4		01/12/1973
1974	353.6		27/09/1975
1975	353.6		01/12/1975
1976	240.5		12/10/1976
1977	357.0		20/04/1978
1978	323.9		07/12/1978
1979	381.1		24/10/1979
1980	762.3		02/11/1980
1981	320.7		28/09/1982
1982	454.7		31/01/1983
1983	428.1		16/01/1984
1984	323.9		14/08/1985
1985	767.3		06/08/1986
1986	360.4		18/11/1986
1987	343.6		01/02/1988
1988	447.0		14/10/1988
1989	502.2		28/10/1989
1990	357.0		01/01/1991
1991	330.4		12/11/1991
1992	292.6		18/05/1993
1993	370.7		15/01/1994
1994	600.2		22/02/1995
1995	320.7		09/02/1996
1996	381.1		31/08/1997
1997	424.4		06/03/1998
1998	431.9		30/12/1998
1999	454.7		28/11/1999
2000	613.7		27/10/2000
2001	417.0		23/01/2002
2002	271.7		21/10/2002
2003	420.7		14/11/2003
2004	669.2		08/01/2005
2005	402.4		01/12/2005
2006	595.7		03/12/2006
2007	541.5		13/08/2008
2008	428.1		05/10/2008
2009	670.1		19/11/2009

**Gauging Authority:** Office of Public Works

**Easting:** 99704

**Northing:** 133329

**Catchment:** Feale

**Telemetry:** Yes

**Station Type:** Recorder

**Catchment Area:** 647 km<sup>2</sup>

**QMED (gauged):** 369.4 m<sup>3</sup>/s

**AREA:** 647 km<sup>2</sup>

**QMED (synthetic urban):** 259.8 m<sup>3</sup>/s

**SAAR:** 1345 mm

**QMED (CFRAM revised):**

**FARL:** 1.0

**BFIsoils:** 0.31

**S1085:** 4.3 m/km

**URBEXT:** 0.4 %

**ARTDRAIN2:** 0.2%

**DRAIND:** 1.11

#### Comments:

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

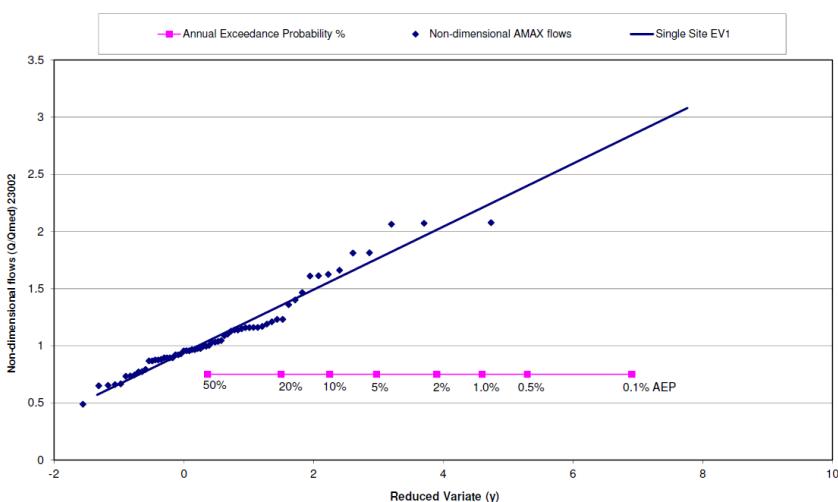
*Catchment descriptors from FSU.*

**Nearby AFAs:** Listowel

**Jacobs Rating Review:** No

**FSU Station Classification:** A1

#### Flood Frequency (EV1 with Gringorten plotting positions)



**Length of AMAX series:** 64 years

**CFRAM Revised:** N/A

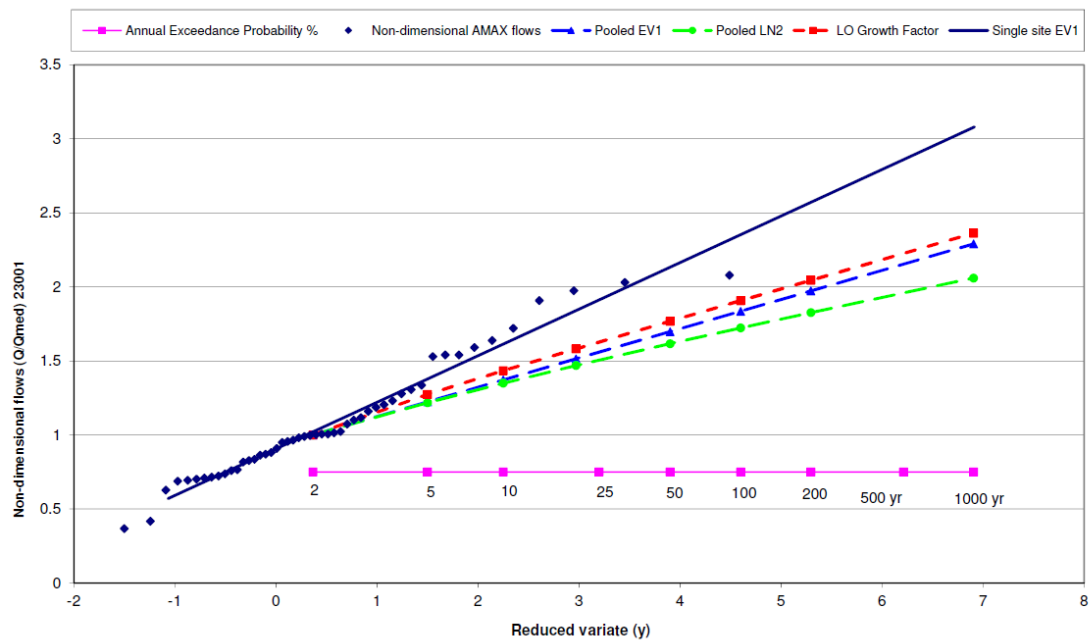
No CFRAM rating review for this station. Original rating and AMAX series retained. The full AMAX series from 1946 was used for flood estimation purposes.

## Appendix E      Flood Frequency Curves

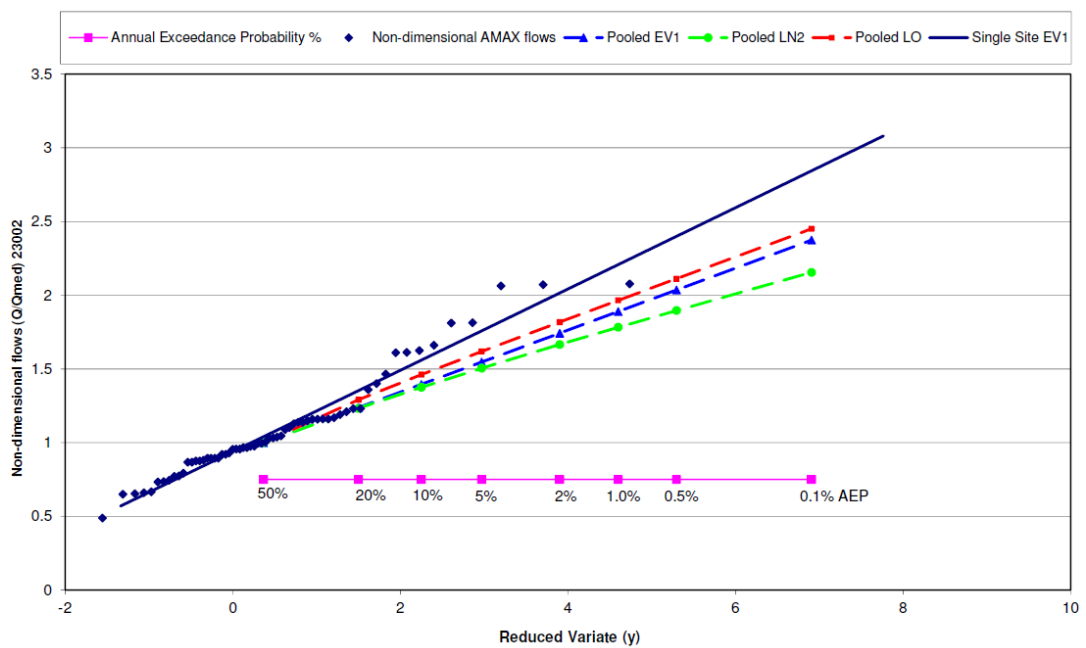
### Table of Content

23001 Inch Bridge

23002 Listowel



**Figure E.1** *Inch Bridge (23001) Flood Frequency Curves*



**Figure E.2** *Listowel (23002) Flood Frequency Curves*

## Appendix F      Calibration Strategy Sheets

### Table of Content

F1	Model S14a (Feale)
F2	Model S14b (Feale Estuary)
F3	Model S14c (Galey)
F4	Model S15 (Brick)
F5	Model S16 (Lee)
F6	Model S17 (Tyshe)

<b>Phase 1</b>				
Shannon CFRAM Study Calibration Information				
Refer to technical note TD041				
<b>Model No.</b>	<b>S14a</b>	<b>Length</b>	38.5km	
<b>Unit of Management</b>		23		
<b>AFA</b>		Listowel, Abbeyfeale		
<b>IRRs</b>		none		
<b>River / Catchment / Sub-catchment</b>		River Feale / Feale / Shannon		
<b>Type of Flooding / Flood Risk</b>		Fluvial non-tidal <input checked="" type="checkbox"/> Fluvial tidal <input checked="" type="checkbox"/> Coastal <input type="checkbox"/>		
<b>Comments</b>		<p>Model S14a contains two AFAs - Listowel and Abbeyfeale - and has limited number of suitable gauges along the model's extent.</p> <p>Model sections which pass through the AFAs, are classified as being HPW, while for the stretch of river which flows between the two areas; the model reach is designated a MPW.</p>		
<b>Completed by</b>	Kenny Samson	<b>Check:</b> Keshav Bhattarai	<b>Review:</b> K Bhattarai	
<b>Date</b>	22/10/2013	13/11/2013		
<b>Potential flood events to consider for calibration</b>				
<b>No</b>	<b>Description*</b>	<b>Category **(TD041)</b>	<b>Score (TD041)</b>	<b>Calibration or verification</b>
1	<u>Listowel</u> : On 12/08/2003, Land flooded at Coilbee (LIS 03/0419) (**FQC 4). No significant flood was recorded @ GS 23002 on 12/08/03.	1	0+0+0+0+1=1	Not suitable
2	<u>Listowel</u> : On 28/11/2002, House flooded at Curraghatoosane (LIS 02/1022) (FQC 4). No significant flood recorded @ GS 23002 on 28/11/02).	1	0+0+0+0+1=1	Not suitable
3	<u>Listowel</u> : On 11/11/2002. Septic tank flooded at Gortnaminch (LIS 02/0988) (FQC 4). No significant flood recorded @ GS 23002 on 11/11/02).	1	0+0+0+0+1=1	Not suitable
4	<u>Listowel</u> : On 22/02/2001. Field flooded near small Feale/Galey tributary at Shrone West (C3R C1/18/10) (FQC 4). No significant flooding was recorded @ GS 23002 on 22/02/01.	1	0+0+0+0+1=1	Not suitable
5	<u>Abbeyfeale</u> : On 07/01/2005. Flooding occurs at local road twice a year on Allaughan River (Feale tributary) near Abbeyfeale (Flood ID 1389). Peak flow @ GS 23002 = 669.2m <sup>3</sup> /s & WL = 19.69mOD Poolbeg on 08/01/2005.	1	0+0+0+0+1=1	Verification
6	01/02/2002. Tidal flooding. Document lists areas prone to flooding and indicates source / cause of flooding, damages and estimated recurrence of events. (**FQC 4)	2	0+2+1+0+0=3	Verification



7	Gauge Data Only - In-bank event – Qmed	1	To be identified in Phase 2	Calibration/verification	
8	Gauge Data Only - Out of bank event – Highest recorded flow	1	To be identified in Phase 2	Calibration/verification	
<div>* See Appendix B for Event Details of events 1-5, ** See Appendix C for Quality Category and Quality Score (Scoring - 0 (Not suitable for calibration) to 15 (Suitable for calibration)) ***FQC = Flood Quality Code (Refer to Appendix E)</div>					
Gauging Station Information within Model Extent (or close to)					
Station	Data Length	Type (flow, stage, both)	Gaugeboard Datum )	FSU Classification*	Comment
23002 Listowel	1946 - present	Water levels & Flows	16.665 (mAOD Poolbeg)	A1	No rating review required; pre-1972 rating verified (05/12/48) up to 1.3XQmed.  Post-1974 rating verified (14/03/1989) up to 1.03XQmed.
23009 Listowel weir	1975 - 1977	Staff gauge only	N/A	Not – FSU Classified	Inactive
23025 Listowel SW	1990 - 1997	Staff gauge only	N/A	Not – FSU Classified	Inactive
23006 Neodata	1976 - present	Water levels & Flows	49.166 (mAOD Malin) (EPA website)	Not – FSU Classified	No rating review required, tributary station not used in design hydrology.
23007 Oolagh Rly. Bridge	1976 - present	Water levels & Flows	64.313 (mAOD Malin) (EPA website)	Not – FSU Classified	No rating review required, tributary station not used in design hydrology.
23010 Abbeyfeale	1975 - 1981	Staff gauge only	N/A	Not – FSU Classified	Inactive
23031 Poulnahaha	1998-2009	Water Levels Only	2.060mOD (P)	N/A	Water Level Only, on Model Extent S14b
23061 Ferry Bridge	01/10/1946 - Present	Water Level Only	1.649mOD (P)	Not FSU Classified	Tidal, water level only, on Model Extent S14b
23068 Moneycashen	01/10/1980 to Present	Water Level Only	2.078mOD (P)	Not FSU Classified	Tidal, water level only, at the mouth of the estuary
* See Appendix D for Key to FSU Station Classification A1 (Good) to C (Poor))					
Control structures					
Reference	Type	Description			

## Conclusions from Phase 1

Phase 1 suggested:

- Two AFAs - Abbeyfeale and Listowel - are located within the S14a model extent. Model sections which pass through the AFAs, are classified as being HPW, while for the section of model between the two areas; the model reach is designated a MPW. Flood events reported as having occurred within the settlements (Source: Floodmaps.ie) are summarised in Phase 1 and presented alongside additional sources of flood information in Appendix B.
- Flood events 1, 2 and 4 are in the vicinity of Listowel AFA. ). The corresponding flows recorded at Station 23002 during these events are not significant.
- Event 1: This event is reported at Coilbee, but it is not clear from mapping which areas are considered to be part of Coilbee. It appears to be too far from the River Feale to be affected by it for most design floods (1400 metres). Given the lack of a flood response (see bullet point above) at the local flow gauge and the large distance to the River Feale, the flooding reported is likely to be from surface water runoff or from smaller drains not included in the model extent. This flood is therefore not suitable for calibration or verification.
- Event 2: The house location has not been documented and it is not known what distance it is from the River Feale.
- Event 3 is reported as septic tank flooding, therefore this has not been investigated further.
- Event 4: Shrone West is located adjacent to the River Galea and is 2600 metres away from the River Feale. The flooding reported is likely to be from surface water runoff or from the River Galea. This flood is therefore not suitable for calibration or verification.
- The one flood event in the vicinity of Abbeyfeale (Event No. 5) cannot be used in calibration. However, this flood event might be usable in verification of the model, as the flooding reported on 7 January 2005 coincides with the annual maxima of 8<sup>th</sup> January 2005. The local road in the vicinity of the Allaughan River (upstream of Abbeyfeale) is inundated by flooding occurring with greater frequency than Qmed flood (twice per year).
- Station 23002 has a reliable high flow rating up to 1.03\*Qmed (post-1974) and is an A2 FSU classified gauge.
- Station 23010 (WL only) is located upstream of Station 23002 and can not be used for calibration. Stations 23009 (WL only) has very short data (1975 – 1977) and no useful data available for calibration.
- Station 23025 (WL only) has approximately 7 years of data, between 1990 and 1997. The water level for this station can be used for calibration along with Station 23002. There was only one significant event during that period, namely, 22 February 1995. However, no hydrometric data is available at this station and a request has been sent to the OPW for providing available data.
- Stations 23006 and 23007 (upstream tributary gauges) are EPA stations, which are primarily for the recording of low/medium flows and for water quality. Station 23006 located on the western edge of upstream AFA Abbeyfeale, although reported as having both level and flow data; no rating information or flow data is present within the received data. Furthermore, no suitable station exists upstream to infer reliable inflows.
- It is considered that none of the 5 fluvial flood events in Listowel AFA – as described in Phase 1 - offer information useful for calibration purposes. However, event 5 at Abbeyfeale AFA could be used for the verification of the S14a model. The hydrometric data at Station 23002 could be used along with water level recording gauges downstream (in model S14b) for a cross model calibration or verification, i.e. calibration using more than one model (refer to calibration strategy for model S14b for details).
- Tidal flooding, which occurred during February 2002 (Event 6), allows further opportunity to verify modelled flood levels at downstream gauges (namely 23031, 23061, 23068) within model extent S14b

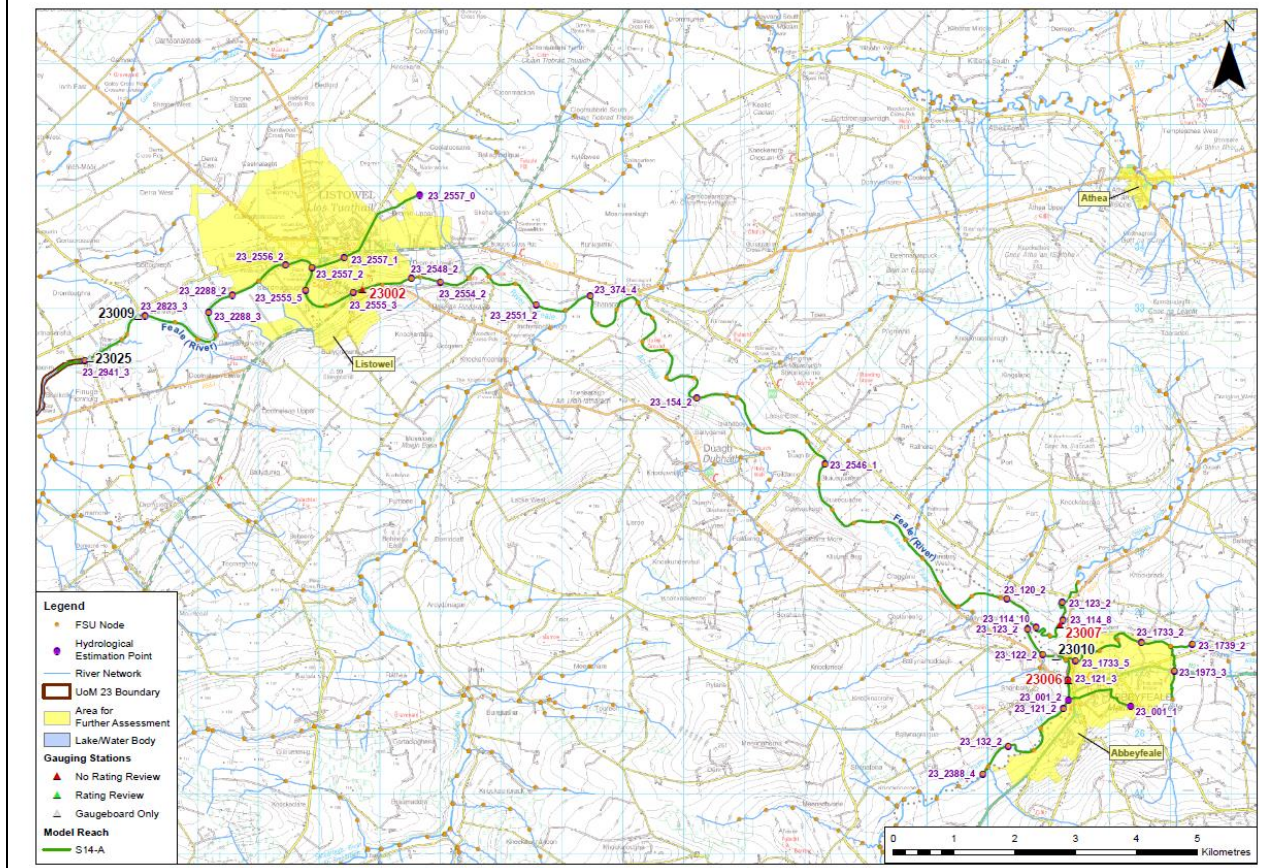
<b>Phase 2</b>					
<b>Gauging Station Information Used – Out of Bank* - Not possible as no other station for comparison.</b>					
<b>Gauging Station Information Used – In Bank* - Not possible as no other station for comparison.</b>					
Flood Event	5	AMAX			
GS Number	23002	23002			
Station Name	Listowel	Listowel			
Recorded Start of peak level	07/01/2005 06:00	26/10/2000 19:00			
Recorded Finish of peak level	08/01/2005 23:45	28/10/2000 11:00			
Peak level** (mAOD Malin)	19.71 (3.04 m)	19.57 (2.9 m)			
Peak flow (m <sup>3</sup> /sec)	679.6	620.2			
Other gauging stations for same event	Poulnahaha (23031) S14B Model	Poulnahaha (23031) S14B Model			
Flood Event	AMAX	6			
GS Number	23002	23002			
Station Name	Listowel	Listowel			
Approximate Start of peak level	19/11/2009 04:30	01/02/2002 04:15			
Approximate Finish of peak level	20/11/2009 10:30	01/02/2002 00:00			
Peak level** (mAOD Malin)	19.69 (3.02 m)	18.90(P) (2.23m)			
Peak flow (m <sup>3</sup> /sec)	670.1	349.56			
Other gauging stations for same event	23061, 23068	23031, 23061, 23068			
<p>*Calibration events may include more than one gauging station but the table above indicates the details for the most upstream gauging station which will provide the level and flow data for the calibration/verification.</p> <p>**Stage plus datum (see Phase 1) from topographical survey (Stage in brackets).</p>					
<p><b>Discussion and Strategy</b></p> <p>The only opportunity for calibrating the model using gauging stations that are within the extent of the S14A model; is between stations 23002 (level and flow) and 23006 (15-min levels). However, the stations are not on the same watercourse but rather one is on the main stem whilst the other on a tributary branch, reducing the usefulness for initial calibration of the model.</p>					
<p><b>Discussion</b></p> <ul style="list-style-type: none"> <li>Two AFAs - Abbeyfeale and Listowel - are located within the S14a model extent. Model sections which pass through the AFAs, are classified as being HPW, while for the section of model between the two areas; the model reach is designated a MPW.</li> </ul>					

- As discussed in the concluding remarks from Phase 1, no past flood event occurring in either Listowel or Abbeyfeale is suitable for calibration purposes. However, the fifth event upstream of Abbeyfeale could be used for verification of the model.
- Additionally, there could be an opportunity for a cross calibration of the River Feale models (S14a, S14b, S14c).

#### **Calibration/Verification Strategy**

- Over the entire S14a model reach, 23002 is the only reliable station. Other stations located upstream and downstream of 23002 have insufficient data or unreported ratings. Calibration of S14a model is not possible separately.
- Using the indicative flooding information upstream of Abbeyfeale for the January 2005 event and the hydrograph at GS 23002) a broad verification of the S14a model may be possible.
- A calibration of the S14a model together with S14b and S14c could be possible using the inflows at GS 23002 (Model S14a), 23001 (Model S14c) and the water levels at 23031, 23061 and 23068 (Model S14b). Flow data for Stations 23001 and 23002 is provided without any allowance for inflows downstream of these stations as from the QMED regression equation these inflows are thought to be very small.

# Appendix A - Plan of model S14a - DRAFT





Appendix B - Details Flood Event Records			
Flood Event	Material type	Data location	Contains
	GIS shapefile	B-0006	SERTIT: Water bodies mapped from RADARSAT-2 data acquired the 5th of December 2009 and SPOT 5 data acquired the 15th of May 2005.  *Coverage: <input type="checkbox"/> *No Coverage: <input checked="" type="checkbox"/>
	GIS Layer	B-0020	Digitisation of 1954 flood event.  *Coverage: <input type="checkbox"/> *No Coverage: <input checked="" type="checkbox"/>
	GIS Layer	B-0054	Jacobs digitisation of 2009 flood event.  *Coverage: <input type="checkbox"/> *No Coverage: <input checked="" type="checkbox"/>
	floodmaps.ie GIS layer	A-0171	Revised GIS layers showing the areas of Benefiting lands. AFA Listowel is shown to have large tracts of surrounding land classed as 'benefiting lands' for flood risk management as indicated on the National Flood Hazard Mapping tool.  *Coverage: <input checked="" type="checkbox"/> *No Coverage: <input type="checkbox"/>
1	.pdf report	B-0063	39-b. Flooding History from Files Data Base: Land flooded at Coilbee (LIS 03/0419).
2	.pdf report	B-0063	39-1a. OPW note. Reported flooding at Curraghatoosane, Listowel Co Kerry (Report includes: No. of Properties Damaged (1))  39-b. Flooding History from Files Data Base: gives peak level for the annual maxima (which does not coincide with the historic flood event day).
3	.pdf report	B-0063	39-b. Flooding History from Files Data Base:  Septic tank flooding at Gortnaminch (LIS 02/0988) on 02/11/2002.
4	.pdf Study	B-0063	39-b. Flooding History from Files Data Base  Field flooded C3R C1/18/19 Feale Galey Trib at Shrone West (C3R C1/18/19) on 22/02/2001.
5	.pdf report	B-0063	Flooding History from Minutes of Meeting. Document No. 0000001675  Ballagh, Abbeyfeale. Flood ID 1389 On the Allaughan River near Abbeyfeale. The Allaughan is a tributary of the River Feale. Local road rendered impassable. Flooding occurs roughly twice a year. One house is under threat of flooding. Last incident on January 07 <sup>th</sup> 2005.
6	.pdf report	B-0063	02-5d. Minutes of meeting identifying areas subject to flooding in Kerry / Listowel Area. Document includes: source and cause of flooding, damages / temporary losses of infrastructure and estimated recurrence of events.
All	.msg & .xls	OPW_Data\ HA23	Flow data for Station 23002 Listowel on the River Feale.  Note: No suitable station upstream or downstream of 23003 for calibration / verification of events.
All/ General Verification	Flood Risk Review	A-0100	Listowel (CAR 39) - Photographs and videos taken during UoM 23 Site Visit 26/05/2011
<p>*The information is deemed relevant if land adjacent to the model extent is indicated as having flooded during the event in question.</p> <p>**The information is deemed relevant if land adjacent to the model extent is indicated as at risk of flooding / could benefit from a flood defence scheme. The Office of Public Works has provided a map of lands that have benefited or would benefit from a flood relief scheme or drainage works. The designation of "benefiting lands" does not necessarily indicate that the respective sites are liable to flooding.</p>			

Appendix C – Event Category and Scoring								
1		2	3	4	5	6	7	8
Location description		Likely accuracy of Flow estimate	Likely accuracy of Gauged Level estimate	Known hydraulic conditions <sup>(1)</sup>	Supplementary known, useful flood levels <sup>(2)</sup>	Reliable flood history (levels, locations, dates) <sup>(3)</sup>	Indicative calibration score (sum of columns 2-6)	Calibration comment (with event number)
Category 1	Large gauged river within an AFA (HPW)	1(0) 2(0) 3(0) 4(0) 5(0) 6(0)	1(0) 2(0) 3(0) 4(0) 5(0) 6(2)	1(1) 2(1) 3(1) 4(1) 5(1) 6(1)	1(0) 2(0) 3(0) 4(0) 5(0) 6(0)	1(0) 2(0) 3(0) 4(0) 5(0) 6(0)	1(1) 2(1) 3(1) 4(1) 5(1) 6(3)	No event appropriate for use as calibration events. Reasons: 1- Reported flood levels not geographically specific 2- Reported flood levels not geographically specific. 3- Reported flood levels not geographically specific. 4- Reported flood levels not geographically specific. 5- Reported flood levels not geographically specific. 6- Report lacks event specific details.
	Small gauged river within an AFA (HPW)							
Category 3	Large ungauged river within an AFA (HPW)							
	Small ungauged river within an AFA (HPW)							
Category 2	Gauged MPW							
Category 4	Ungauged MPW							

Key: 1(2) = Flood Event 1 (score = 2)

**Table C.1 Event Category and Scoring**

Scores for columns 2 to 6: 0 = Not available; 1 = Poor / Unlikely; 2 = Fair / Possible; 3 = Good / Likely.

Total score in column 7 provides an overall guide as to how good the calibration may be, based on the data quality for columns 2 to 6.

**Notes:**

- (1) Hydraulic conditions relates to hydraulic controls influencing water level during a flood e.g. level of blockage at a bridge, culvert trashscreen blockage; any new works since flood event. It is a statement regarding whether the conditions in the flood can be accurately reflected in the hydraulic model.
- (2) Flood levels – these are levels during a known flood NOT at the gauged location that represent the true flood level at that location e.g. they must not be due to a very localised hydraulic issue such as flow around a building.
- (3) Flood history – for this information to be useful it must include a date, precise location and level as per note (2)



## Appendix D – FSU Classification (Abstract from Inception Report)

### 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 (Table B.1).

FSU Classification		Definition
A	Both	Suitable for flood frequency analysis. These were sites where the highest gauged flow (HGF) was significantly higher than the mean annual flood ( $Q_{med}$ ) [ $HGF > 1.3 \times Q_{med}$ ] 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 $1.3 \times Q_{med}$ and/or with a good confidence of extrapolation up to $2 \times Q_{med}$ , bankfull or, using suitable survey data, including flows across the flood plain.
	A2	Rating confirmed to measure $Q_{med}$ and up to around $1.3 \times Q_{med}$ . 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 D.1 - FSU Gauging station classification (from Hydro-Logic 2006)

### Appendix E – Quality Codes as assigned to data in floodmaps (OPW)

Quality codes have been assigned to define the reliability of the source of information. 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 the 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 E.1 – Quality Codes assigned to data in floodmaps (Table 8-A of Inception Report, UOM 23)

<b>Phase 1</b>					
Shannon CFRAM Study Calibration Information					
Refer to technical note TD041					
<b>Model No.</b>	<b>S14b</b>	<b>Length</b>	52.4km		
<b>Unit of Management</b>		23			
<b>AFA</b>		Moneycashen			
<b>IRRs</b>		none			
<b>River / Catchment / Sub-catchment</b>		Rivers Feale, Galey, Brick, Cashen / Cashen / Shannon			
<b>Type of Flooding / Flood Risk</b>		Fluvial non-tidal <input checked="" type="checkbox"/> Fluvial tidal <input checked="" type="checkbox"/> Coastal <input checked="" type="checkbox"/>			
<b>Comments</b>		<p>Model S14b covers an extensive area and includes the Cashen and Upper Feale Estuary as well as the lower reaches of the Rivers Feale, Galey and Brick.</p> <p>The entire modelled reach is categorised as a MPW with the only AFA being Moneycashen located at the mouth of the River Cashen.</p>			
<b>Completed by</b>	Kenny Samson	Kenny Samson	Keshav Bhattarai		
<b>Date</b>	20/08/2013	28/10/2013	20/11/2013		
<b>Potential flood events to consider for calibration</b>					
<b>No</b>	<b>Description*</b>	<b>Category **(TD041)</b>	<b>Score (TD041)</b>	<b>Calibration or verification</b>	
1	01/02/2002. Tidal flooding at in or near Moneycashen, Limerick, Clare, Kerry, Listowel. Flood depth and an eye-witness account of event rarity given. Three houses flooded. 4 sources of information, see Appendix B [02-5a to 5d] with FQC 3 / 4***)	2	0+2+1+0+0=3	Verification	
2	Gauge Data Only - In-bank event – Qmed	2	To be identified in Phase 2	Calibration/verification	
3	Gauge Data Only - Out of bank event – Highest recorded flow	2	To be identified in Phase 2	Calibration/verification	
<p>* See Appendix B for Event Details of events 1-4,</p> <p>** See Appendix C for Quality Category and Quality Score (Scoring - 0 (Not suitable for calibration) to 15 (Suitable for calibration))</p> <p>*** Flood Quality Code (See Appendix E)</p>					
<b>Gauging Station Information within Model Extent (or close to)</b>					
<b>Station</b>	<b>Data Length</b>	<b>Type (flow, stage, both)</b>	<b>Gaugeboard Datum (mAOD Malin)</b>	<b>FSU Classification*</b>	<b>Comment</b>
23009	1995 - 1997	Water Levels	Not Available	N/A	Very short data
23025 Listowel SW	1990 - 1997	Water Levels	Not Provided	N/A	Data request sent to the OPW

23030 Sleveen Main Channel	1998 - present	Water Levels	1.78(P?)	N/A	Water Level Only
23031 Poulinahaha	2000-2009	Water Levels	2.06(P?)	N/A	Water Level Only
23033 Sleveen Back Channel	1998 - 2005	Water Levels	Not Available	N/A	Water Level Only
23034 Lixnaw	1998 - 2005	Water Levels	Not Available	N/A	Water Level Only
23036 Ratoobank	2002 - 2005	Water Levels	2.11(P?)	N/A	Water Level Only
23068 Moneycashen	1997 - present	Water Levels	2.078(P?)	N/A	Tidal
23061 Ferry Br.	1997 - present	Water Levels	1.649(P?)	N/A	Tidal

\* See Appendix D for Key to FSU Station Classification A1 (Good) to C (Poor)  
P = Poolbeg datum

#### Control structures

Reference	Type	Description
none		

#### Conclusions from Phase 1

Phase 1 suggested:

Model S14b includes one AFA, Moneycashen and the tidal reach of the Feale, Galey and Brick rivers. All the major historic events are tidal events, as described below:

- Flood event 1 is related to the tidal flooding of 1 February 2002. No detailed information is provided to allow determination of levels at geographically specific locations along the extent of the model. Therefore, the available historic flood data cannot be used for calibration of the S14b river hydraulic model. However, the available tidal data at the two tidal stations, 23068 and 23061 can be used for the tidal calibration of the model.
- Water levels from the level gauges in model S14b can be used for fluvial cross calibration of model S14a/S14b. For this purpose, flow data from Listowel (Station 23002) and water level data from station 23031 were requested for the following events  
08 January 2005 & 19 November 2009 @ Station 23031, 23061 and 23068  
22/02/1995 @ Station 23025 (data not available, requested from OPW)

Phase 2a: Cross model calibration: S14a and S14b				
Flood Event	AMAX			
GS Number	23002			
Station Name	Listowel			
Recorded Start of peak level	07/01/2005 06:00			
Recorded Finish of peak level	08/01/2005 23:45			
Peak level** (mAOD Malin)	19.71 (P?) (3.04 m)			
Peak flow (m <sup>3</sup> /sec)	679.6			
Other gauging stations for same event	Poulnahaha (23031) 6.759 mAOD(P) (08/01/05 03:00); Ferry Bridge (23061) 5.43mAOD (P) Moneycashen 5.136 mAOD (P)			
Phase 2b: Cross model validation S14a and S14b				
Flood Event	AMAX	AMAX		
GS Number	23002	23002		
Station Name	Listowel	Listowel		
Approximate Start of peak level	19/11/2009 04:30	22/02/1995 00:00		
Approximate Finish of peak level	20/11/2009 10:30	23/02/1995 12:15		
Peak level** (mAOD Malin)	19.69 (P?) (3.02m)	19.52 (P) (2.8 m)		
Peak flow (m <sup>3</sup> /sec)	670.1	569.45		
Other gauging stations for same event	23061 (5.209 m AOD(P) @ 19:15), 23068 (5.109 mOAD (P) @ 19:00)	Listowel SW (23025) S14b Model Water level was not available (Awaiting data from OPW).		
Phase 2c: Tidal calibration (February 2002 Tidal Flood Event)				
Flood Event	AMAX	AMAX		
GS Number	23001	23002		
Station Name	Inch Bridge	Listowel Bridge		
Approximate Start of peak level	01/02/2002 02:45	01/02/2002 04:15		
Approximate Finish of peak level	02/02/2002 00:00	01/02/2002 00:00		
Peak level**	11.90(P)	18.90(P)		

(mAOD Malin)	(2.06m)	(2.23m)		
Peak flow (m <sup>3</sup> /sec)	80.44	349.56		
Other gauging stations for same event	23031 (6.01mAOD (P); 23061 (5.77mAOD (P); 23068 (5.79mAOD (P)			

\*Calibration events may include more than one gauging station but the table above indicates the details for the most upstream gauging station which will provide the level and flow data for the calibration/verification.

\*\*Stage plus datum (see Phase 1) from topographical survey (Stage in brackets).

#### Discussion and Strategy – Tidal calibration/verification

##### Discussion

- The only settlement along the S14b model reach is Moneycashen at the mouth of the River Cashen. The entire modelled reach is categorised as a MPW.

##### Calibration / Verification Strategy:

- As discussed in the **concluding remarks from Phase 1**, no past flood event occurring along the modelled reach or within Moneycashen is suitable for fluvial calibration of the S14b model due to a lack of event specific details. However, the water level data of 1 February 2002 tidal flood event at stations 23068 (Moneycashen) and 23061 (Ferry Bridge), together with the flow data from Station 23001 and 23002 could be used for tidal calibration of the S14b model. For these events the flow data from Stations 23001 and 23002 has not been adjusted to allow for inflows downstream of the gauges, as the FSU QMED regression equation suggests that these inflows are very small, refer to the target flow tables in Appendix B for the respective models.

#### Discussion and Strategy – Cross-model fluvial calibration of S14a and S14b

##### Discussion

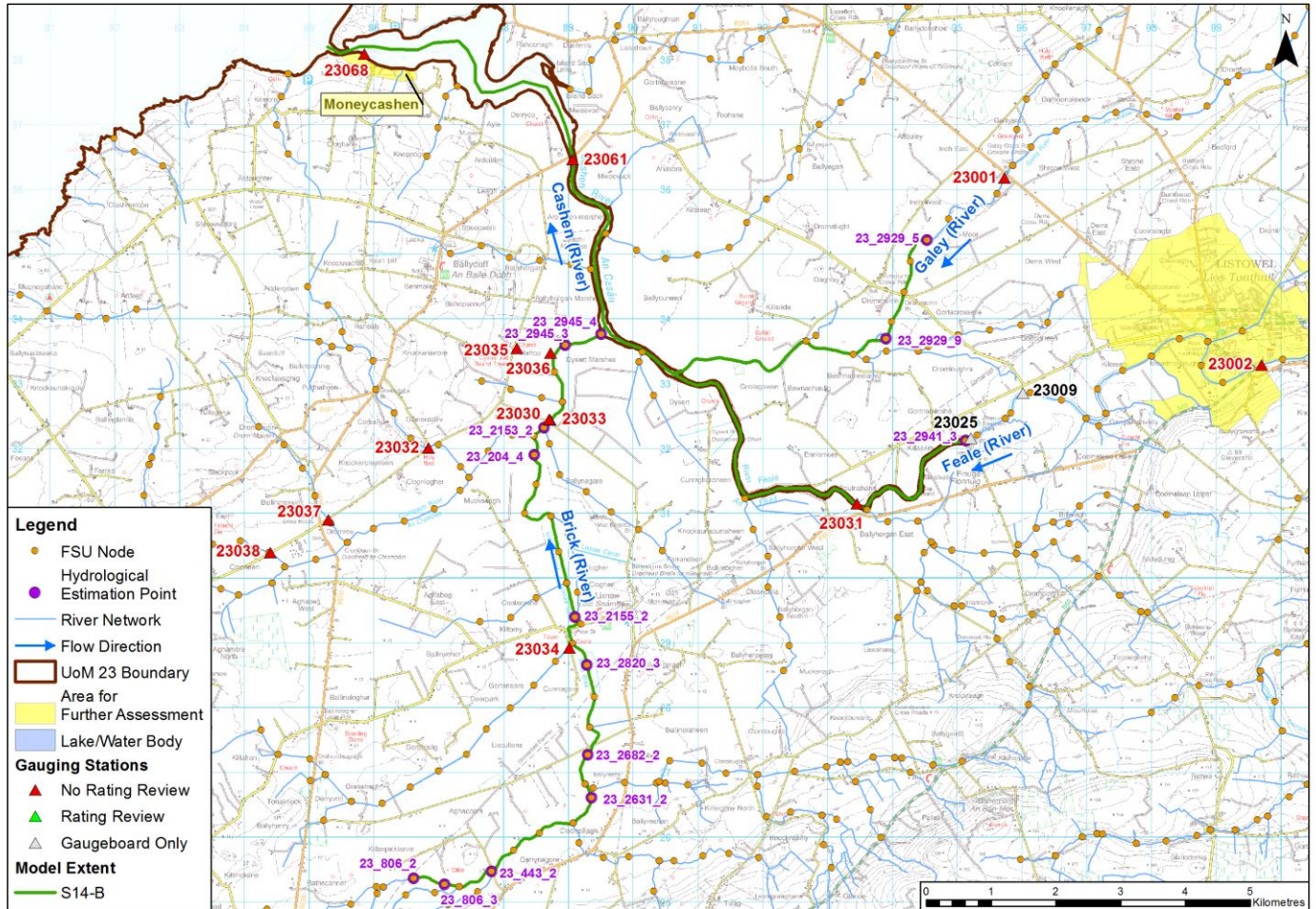
- The S14b model is located downstream of models S14a, S14c and S15. There is one level stations (23031) on the Feale downstream of the S14a model, upstream of where the Galey and Brick rivers join the Feale; and two stations (23061 and 23068) further downstream downstream of the Galey/Brick confluences.
- The event hydrograph from Station 23002 and the water levels at the downstream gauges can be used for fluvial cross model calibration of S14a/S14b models.

##### Calibration / Verification Strategy:

- The January 2005 event will be used for the cross-model fluvial calibration of S14a/S14b.
- Similarly, November 2009 and February 1995 events can be used for verification.



Appendix A - Plan of model S14b



Appendix B - Details Flood Event Records			
Flood Event	Material type	Data location	Contains
	GIS shapefile	B-0006	SERTIT: Water bodies mapped from RADARSAT-2 data acquired the 5th of December 2009 and SPOT 5 data acquired the 15th of May 2005.  *Coverage: <input type="checkbox"/> *No Coverage: <input checked="" type="checkbox"/>
	GIS Layer	B-0020	Digitisation of 1954 flood event.  *Coverage: <input type="checkbox"/> *No Coverage: <input checked="" type="checkbox"/>
	GIS Layer	B-0054	Jacobs digitisation of 2009 flood event.  *Coverage: <input type="checkbox"/> *No Coverage: <input checked="" type="checkbox"/>
	floodmaps.ie GIS layer	A-0171	Revised GIS layers showing the areas of Benefiting lands. (unable to view layer, however large tracts of land classed as benefiting lands for flood risk management are identified upstream and surrounding Moneycashen (as indicated on the National Flood Hazard Mapping tool).  *Coverage: <input checked="" type="checkbox"/> *No Coverage: <input type="checkbox"/>
1	.pdf memo	B-0063	02-5a. 01/02/2002. OPW memo describing flooding at Cashen Sea Wall (Report includes: flood depth, source, number of properties damaged and an eye witness indication of event rarity).
1	.pdf memo	B-0063	02-5b. OPW memo listing a number of locations (that from memory) have flooded in Limerick and Clare. One incidence of flooding in Moneycashen mentioned (Report includes: the cause of flooding, approximate floodwater depth, estimated event rarity and approximate dates)
1	.pdf memo	B-0063	02-5c. OPW memo listing locations with incidences of past flooding. Information is not likely to aid calibration or verification.
1	.pdf report	B-0063	02-5d. Minutes of meeting identifying areas subject to flooding in Kerry / Listowel Area. Document includes: source and cause of flooding, damages / temporary losses of infrastructure and estimated recurrence of events.
All	.msg & .xls	OPW_Data\HA23	Water level data at a number of stations (23068, 23061, 23031, 23033, 23034, 23036). Note: No suitable stations with reliable rating on model reach to allow for calibration / verification of events.
All/ General Verification	Flood Risk Review	A-0102	Moneycashen - Photographs and videos taken during UoM 23 Site Visit 13/05/2011
<p>*The information is deemed relevant if land adjacent to the model extent is indicated as having flooded during the event in question.</p> <p>**The information is deemed relevant if land adjacent to the model extent is indicated as at risk of flooding / could benefit from a flood defence scheme. The Office of Public Works has provided a map of lands that have benefited or would benefit from a flood relief scheme or drainage works. The designation of "benefiting lands" does not necessarily indicate that the respective sites are liable to flooding.</p>			



Key: 1(2) = Flood Event 1 (score = 2)

### Table C.1 Event Category and Scoring

Total score in column 7 provides an overall guide as to how good the calibration may be, based on the data quality for columns 2 to 6.

(1) Hydraulic conditions relates to hydraulic controls influencing water level during a flood e.g. level of blockage at a bridge, culvert trashscreen blockage; any new works since flood event. It is a statement regarding whether the conditions in the flood can be accurately reflected in the hydraulic model.

(3) Flood history – for this information to be useful it must include a date, precise location and level as per note (2)

## Appendix D – FSU Classification (Abstract from Inception Report)

### 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 (Table B.1).

FSU Classification		Definition
A	Both	Suitable for flood frequency analysis. These were sites where the highest gauged flow (HGF) was significantly higher than the mean annual flood ( $Q_{med}$ ) [ $HGF > 1.3 \times Q_{med}$ ] 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 $1.3 \times Q_{med}$ and/or with a good confidence of extrapolation up to $2 \times Q_{med}$ , bankfull or, using suitable survey data, including flows across the flood plain.
	A2	Rating confirmed to measure $Q_{med}$ and up to around $1.3 \times Q_{med}$ . 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 D.1 - FSU Gauging station classification (from Hydro-Logic 2006)

## Appendix E – Quality Codes as assigned to data in floodmaps (OPW)

Quality codes have been assigned to define the reliability of the source of information. 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 the 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 E.1 – Quality Codes assigned to data in floodmaps (Table 8-A of Inception Report, UOM 23)

<b>Phase 1</b>				
Shannon CFRAM Study Calibration Information Refer to technical note TD041				
<b>Model No.</b>	<b>S14c</b>	<b>Length</b>	38km	
<b>Unit of Management</b>		23		
AFA		Athea		
IRRs		None		
River / Catchment / Sub-catchment		River Galey/Feale Catchment		
Type of Flooding / Flood Risk		Fluvial non-tidal <input checked="" type="checkbox"/> Fluvial tidal <input type="checkbox"/> Coastal <input type="checkbox"/>		
Comments		<p>The Galey catchment has one flow gauging station with recorder (23001) and two gauge boards. The recorder station is in the lower reaches of the catchment.</p> <p>There is some observed flood event data available for the town of Athea (See Appendix B), but there are no flow/level gauging stations near the town to inform the inflow for S14c model calibration. Similarly, there are no other stations on the Galey between Station 23001 and the Gally/Feale confluence.</p> <p>The model extent is upstream of the tidal limit.</p>		
Completed by	Kieran Daly	Alice Wiggins	Kenny/Keshav	
Date	28/03/2013	31/05/2013	28/04/2014	
<b>Potential flood events to consider for fluvial calibration / verification</b>				
No	Description*	Category **(TD041)	Score (TD041)	Calibration or verification
1	Athea: On 02/09/2009- Culvert overwhelmed by floodwaters resulting in overland flows along the small avenue & down to Con Colbert (main street). Four properties affected (FQC 3***).	1	0+0+0+1+1=2	Verification
2	Athea: On 31/07 and 06/08/2008: Localised flooding due to persistent rainfall (85.9mm in 6 hours; rarity 1 in 650-year RP) with saturated catchment, affecting at least 12 properties including R523 and WWTP. Water level 300mm below soffit of central arch of Athea Bridge (Refer to the JBA report prepared for Limerick Co Co.) (FQC 3).	1	0+0+0+1+2=3	Verification
3	Gauge Data Only - Out of bank event – Highest recorded flow	1	To be identified in Phase 2	Possibly Calibration
4	Gauge Data Only - In-bank event - Qmed	1	To be identified in Phase 2	Possibly Calibration
<b>Gauging Station Information within Model Extent (or close to)</b>				

Station	Data Length	Type (flow, stage both)	Gaugeboard Datum (mAOD Malin)	FSU Classification*	Comment
23001 Inch Bridge	01/03/1947-Present	Water Level and Stage	9.75 (up to 1973) and 9.84 (from 1974) mOD Poolbeg	A2	No Rating Review, Rating reliable up to Qmed, Highest Gauged flow at Qmed
23061 Ferry Bridge	01/10/1946 - Present	Water Level Only	None found in survey	Not FSU Classified	Tidal, water level only, on Model Extent S14b
23068 Moneycashen	01/10/1980 to Present	Water Level Only	None found in survey	Not FSU Classified	Tidal, water level only, at the mouth of the estuary
23004 Galey Bridge	N/A	-	Not available	N/A	Staff Gauge Only
23014 Athea	N/A	Level and flow (spot gaugings)	64.29	N/A	Staff Gauge Only

\* See Appendix D for Key to FSU Station Classification A1 (Good) to C (Poor))

#### Control structures

Reference	Type	Description
River Galey	Bridge	Triple Arch Bridge
Confluence of two unnamed watercourses	Culvert	Two unnamed tributaries meet within a culverted section

#### Conclusions from Phase 1

Phase 1 suggested:

- One AFA - Athea - is located within the S14c model extent. The section of the S14c Model which passes through the AFA is classified as a HPW, whilst the rest of the model is designated as a MPW.
- Observed data available for events 1 and 2 cannot be used for calibration due to the lack of gauging station information to provide inflow for model calibration.
- Observed data available for event 1 contains some photos of the flooding, aftermath and a crude map indicating sources of flooding, which could be used for broad *design event* verification purposes (not for specific event calibration runs as there are no gauged flows available).
- Similarly data for event 2, which includes photographs and approximate flood level at Athea Bridge (300 mm from bridge soffit), can be used for a broad *design event* verification of the model.
- There are no gauging stations with recorder near Athea (AFA) so the model at Athea cannot be calibrated.
- Station 23001 is an OPW operated A2 quality station.
- Two other stations, namely, 23004 and 23014 located downstream of Athea, are both staff gauges without recorder.
- The downstream model boundary is upstream of the tidal limit and therefore tidal calibration is not required.

\* Cross model calibration refers to the calibration of adjacent models on the same river system.

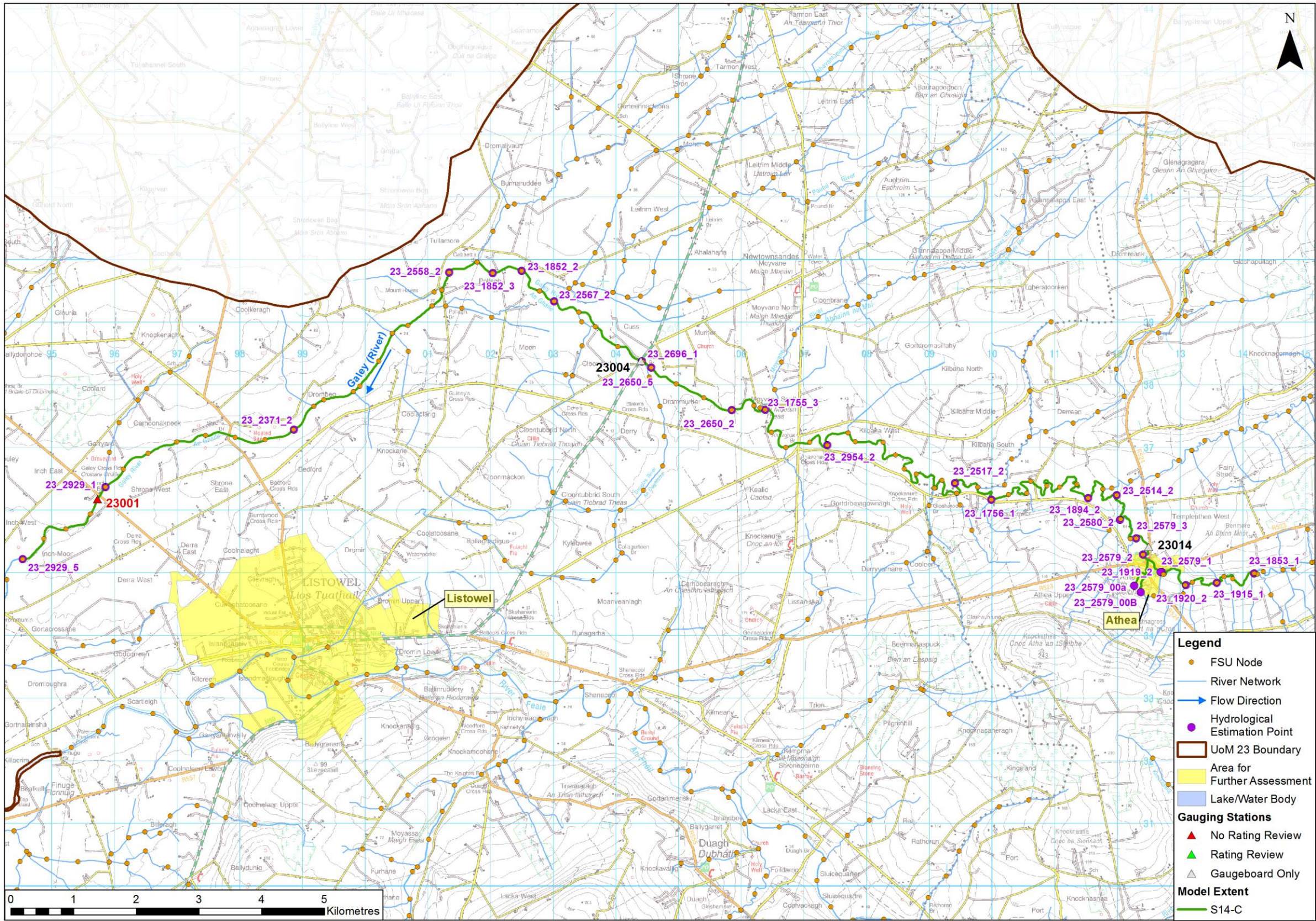
<b>Phase 2</b>					
<b>Gauging Station Information Used – Out of Bank*</b>					
Flood Event	5a	5b			
GS Number	23001	23001			
Station Name	Inch Bridge	Inch Bridge			
Recorded Start of peak level	17/11/2009 12:00	07/01/2005 03:30			
Recorded Finish of peak level	21/11/2009 07:15	09/01/2005 17:45			
Peak level** (mAOD Malin)	X (2.92m)	X (2.93m)			
Peak flow (m <sup>3</sup> /sec)	158.5	159.5			
Other gauging stations for same event	N/A	N/A			
<b>Gauging Station Information Used – In Bank*</b>					
Flood Event	6a (23/01/2002)	6b (01/12/2005)			
GS Number	23001	23001			
Station Name	Inch Bridge	Inch Bridge			
Approximate Start of peak level	22/01/2002 00:45	28/11/2005 08:15			
Approximate Finish of peak level	25/01/2002 03:45	06/12/2005 06:45			
Peak level** (mAOD Malin)	X (2.358m)	X (2.326m)			
Peak flow (m <sup>3</sup> /sec)	104.812	102.083			
Other gauging stations for same event	N/A	N/A			
<p>*Calibration events may include more than one gauging station but the table above indicates the details for the most upstream gauging station which will provide the level and flow data for the calibration/verification.</p> <p>**Stage plus datum (see Phase 1) from topographical survey (Stage in brackets). There is currently no gauge datum found in the survey for Inch Bridge. It will require requesting if calibration is decided along this reach.</p> <p>X – data not available</p>					
<b>Discussion and Strategy (Fluvial Calibration / Verification)</b>					
<p>Discussion:</p> <ul style="list-style-type: none"> <li>There is insufficient gauged and observed event data to complete calibration of the S14c model or for the entire Galey. Verification of the model(s) for specific events is not possible for the same reason.</li> <li>Events 1 &amp; 2 may be used to broadly verify the model design event outlines.</li> </ul> <p>Calibration/Verification Strategy:</p> <ul style="list-style-type: none"> <li>No event-specific calibration or verification is possible</li> </ul> <p>Post-Design Event Modelling Verification Strategy:</p> <ul style="list-style-type: none"> <li>Very high level verification will be undertaken using observational flood data by comparing the modelled</li> </ul>					

flood outlines to the September 2009 observed event data in the form of photos at known locations (Data Location B-0063), to verify that the model results seem consistent with the observed data. It is not possible to estimate the return period of the September 2009 event as there is no flow data available for this period, the AMAX value for 2009 is in November and there are no reports suggesting a possible return period.

- Similarly, very high level verification may be possible using the predicted flood outlines of the 200 year and 1000 year RP event in the Athea area, as it was reportedly flooded from a 6-hour rainfall event of 650year RP, on 31 July and 6 August 2008 (Data Location B-0063).



Appendix A - Plan of model S14c





Appendix B - Details Flood Event Records			
Flood Event	Material type	Data location	Contains
F.1	Photographs	B-0063	<p>05-1a</p> <p>Crude map indicates source of flooding in Athea and maps the flood route with arrows.</p> <p>Photographs highlight aftermath of flooding in village and show damage to houses and garden walls.</p> <p>Circa 4 properties, the Avenue and Con Colbert St (main street) flooded.</p>
F.2	Consultants report	B-0063	<p>05-2a</p> <p>Eye witness reports of flood route.</p> <p>Analysis of flood event which damaged 14 properties and resulted in a land slide upstream.</p> <p>Water level 300mm below soffit of central arch of Athea Bridge.</p> <p>Flood depths approximated for certain locations, Bridge House 0.6 m, Dance hall 0.3m and over- topped a structural glass wall flood defence. School on R523, petrol station, offices at Scanlon Construction &amp; ESB substation not flooded.</p>
T.1	.pdf memo	B-0063	<p>02-5a. 01/02/2002. OPW memo describing flooding at Cashen Sea Wall (Report includes: flood depth, source, number of properties damaged and an eye witness indication of event rarity).</p>
T.2	.pdf report	B-0063	<p>02-5d. Minutes of meeting identifying areas subject to flooding in Kerry / Listowel Area. Document includes: source and cause of flooding, damages / temporary losses of infrastructure and estimated recurrence of events.</p>
All/ General Verification	OSi Map	B-0063	<p>05-3a County Council map showing areas where heavy rain has caused recurring flooding and storm/ tidal flooding within County Limerick.</p>
	GIS shapefile	B-0006	<p>SERTIT: Water bodies mapped from RADARSAT-2 data acquired the 5<sup>th</sup> of December 2009</p> <p>*Coverage: <input type="checkbox"/> *No coverage: <input checked="" type="checkbox"/></p>
	GIS Layer	B-0020	<p>Digitisation of 1954 flood event.</p> <p>*Coverage: <input type="checkbox"/> *No coverage: <input checked="" type="checkbox"/></p>
	GIS Layer	B-0054	<p>Jacobs digitisation of 2009 flood event.</p> <p>*Coverage: <input type="checkbox"/> *No coverage: <input checked="" type="checkbox"/></p>
All/ General Verification	GIS layer	A-0171	<p>Revised GIS layers showing the areas of Benefiting lands.</p> <p>**Coverage: <input checked="" type="checkbox"/> **No coverage: <input type="checkbox"/></p>
All/ General Verification	FRR site visit	A-0095	<p>Athea - Notes marked up plans, photographs and videos during UoM 23 Site Visit.</p>

\*The information is deemed relevant if land adjacent to the model extent is indicated as having flooded during the event in question.

\*\*The information is deemed relevant if land adjacent to the model extent is indicated as at risk of flooding / could benefit from a flood defence scheme. The Office of Public Works has provided a map of lands that have benefited or would benefit from a flood relief scheme or drainage works. The designation of "benefiting lands" does not necessarily indicate that the respective sites are liable to flooding.

Appendix C – Event Category and Scoring								
1		2	3	4	5	6	7	8
Location description		Likely accuracy of Flow estimate	Likely accuracy of Gauged Level estimate	Known hydraulic conditions <sup>(1)</sup>	Supplement ary known, useful flood levels <sup>(2)</sup>	Reliable flood history (levels, locations, dates) <sup>(3)</sup>	Indicative calibration score (sum of columns 2-6)	Calibration comment (with event number)
Category 1	Large gauged river within an AFA (HPW)	1(0) 2(0)	1(0) 2(0)	1(0) 2(0)	1(1) 2(1)	1(1) 2(2)	1(2) 2(3)	All storms do not seem appropriate for use as calibration events. Reasons: 1- No specific information on date, location or hydraulic conditions (e.g. blockages) (Note: this may be used for broad-brush design flood verification). 2- No specific information on date or hydraulic conditions (e.g. blockages) but details on location (Note: this may be used for broad-brush design flood verification).
	Small gauged river within an AFA (HPW)							
Category 3	Large ungauged river within an AFA (HPW)							
	Small ungauged river within an AFA (HPW)							
Category 2	Gauged MPW							
Category 4	Ungauged MPW							

Key: 1(2) = Flood Event 1 (score = 2)

**Table C.1 Event Category and Scoring**

Scores for columns 2 to 6: 0 = Not available; 1 = Poor / Unlikely; 2 = Fair / Possible; 3 = Good / Likely.

Total score in column 7 provides an overall guide as to how good the calibration may be, based on the data quality for columns 2 to 6.

**Notes:**

- (1) Hydraulic conditions relates to hydraulic controls influencing water level during a flood e.g. level of blockage at a bridge, culvert trashscreen blockage; any new works since flood event. It is a statement regarding whether the conditions in the flood can be accurately reflected in the hydraulic model.
- (2) Flood levels – these are levels during a known flood NOT at the gauged location that represent the true flood level at that location e.g. they must not be due to a very localised hydraulic issue such as flow around a building.
- (3) Flood history – for this information to be useful it must include a date, precise location and level as per note (2)

## Appendix D – FSU Classification (Abstract from Inception Report)

### 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 (Table B.1).

FSU Classification		Definition
A	Both	Suitable for flood frequency analysis. These were sites where the highest gauged flow (HGF) was significantly higher than the mean annual flood ( $Q_{med}$ ) [ $HGF > 1.3 \times Q_{med}$ ] 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 $1.3 \times Q_{med}$ and/or with a good confidence of extrapolation up to $2 \times Q_{med}$ , bankfull or, using suitable survey data, including flows across the flood plain.
	A2	Rating confirmed to measure $Q_{med}$ and up to around $1.3 \times Q_{med}$ . 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 D.1 - FSU Gauging station classification (from hydrologic 2006)

## Appendix E – Quality Codes as assigned to data in floodmaps (OPW)

Quality codes have been assigned to define the reliability of the source of information. 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 the 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 E.1 – Quality Codes assigned to data in floodmaps (Table 8-A of Inception Report, UOM 23)

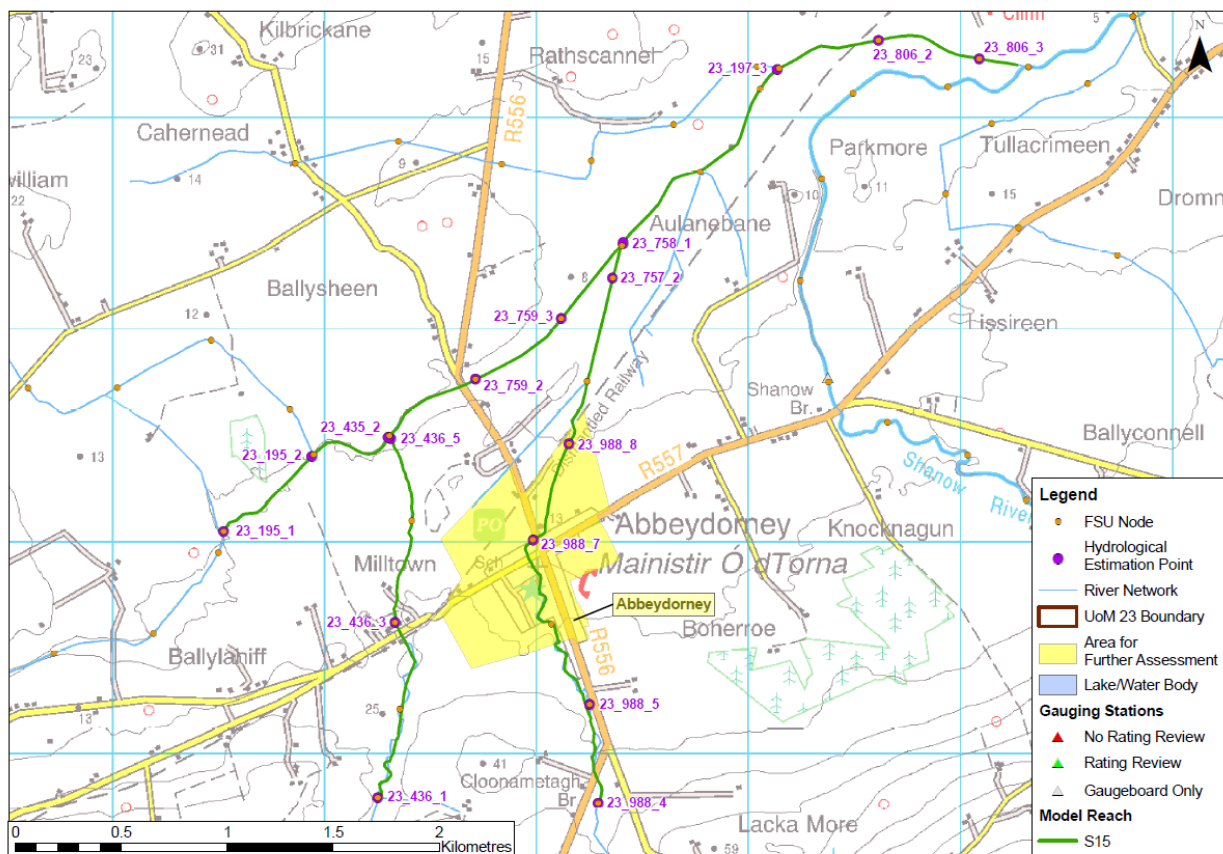
<b>Phase 1</b>				
Shannon CFRAM Study Calibration Information Refer to technical note TD041				
<b>Model No.</b>	<b>S15</b>	<b>Length</b>	8.5 km	
<b>Unit of Management</b>		23		
<b>AFA</b>		Abbeydorney		
<b>IRRs</b>		none		
<b>River / Catchment / Sub-catchment</b>		River Brick / Brick / Shannon		
<b>Type of Flooding / Flood Risk</b>		Fluvial non-tidal <input checked="" type="checkbox"/> Fluvial tidal <input type="checkbox"/> Coastal <input type="checkbox"/>		
<b>Comments</b>		Model S15 extends from Abbeydorney in the upper reaches of the River Brick catchment to the point of the Brick's confluence with the Shannon River. A significant unnamed tributary, categorised as a HPW, flows through the AFA Abbeydorney.		
<b>Completed by</b>	Kenny Samson	<b>Check/Review:</b>	K Bhattarai	
<b>Date</b>	23/10/2013			
<b>Potential flood events to consider for calibration</b>				
<b>No</b>	<b>Description*</b>	<b>Category **(TD041)</b>	<b>Score (TD041)</b>	<b>Calibration or verification</b>
1	On 21/10/1994: OPW memo referring to recurring flooding at Abbeydorney village. The memo is accompanied by a map indicating location of recurring flooding however it does not give any details of cause / extent of flooding. (**FQC 4)	3	0+0+0+0+0=0	Not suitable
2	On 07/11/1994: OPW memo referring to recurring flooding at Abbeydorney village. The memo is accompanied by a map indicating location of recurring flooding; however it gives no details of cause / extent of flooding. (**FQC 4)	3	0+0+0+0+0=0	Not suitable
3	No further events		N/A	N/A
4	No further events		N/A	N/A
5	Gauge Data Only - In-bank event – Qmed	3	To be identified in Phase 2	Calibration/verification
6	Gauge Data Only - Out of bank event – Highest recorded flow	3	To be identified in Phase 2	Calibration/verification
<p>* See Appendix B for Event Details of events 1-4,  ** See Appendix C for Quality Category and Quality Score  (Scoring - 0 (Not suitable for calibration) to 15(Suitable for calibration))  ***FQC = Flood Quality Code (Refer to Appendix E)</p>				

Gauging Station Information within Model Extent (or close to)					
Station	Data Length	Type (flow, stage, both)	Gaugeboard Datum (mAOD Malin)	FSU Classification*	Comment
N/A No station on model extent	N/A	N/A	N/A	N/A	N/A
* See Appendix D for Key to FSU Station Classification A1 (Good) to C (Poor))					
Control structures					
Reference	Type	Description			
Conclusions from Phase 1					
Phase 1 suggested:					
<ul style="list-style-type: none"><li>It has not been possible to find suitable past events occurring within the Abbeydorney AFA for calibration or verification of Model S15. The only reported event (Source: Floodmaps.ie) is described in Phase 1, however, no information in terms of location of the flooding or indication of water levels / flow is suggested in the report.</li><li>No hydrometric station is present within the revised S15 model extent. A number of ‘water level’ only gauges operate on the River Brick downstream of S15 model, namely, Stations 23030, 23033, 23034 and 23036, of which the latter three stations are now inactive. Only Station 23030 (located approximately 10.7 km d/s of the S15 model extent) is active.</li><li>However, no hydrometric station is present upstream to provide reliable inflow to allow for calibration.</li></ul>					

<b>Phase 2</b>
<b>Gauging Station Information Used – Out of Bank* - Not possible as no other station for comparison.</b>
<b>Gauging Station Information Used – In Bank* - Not possible as no other station for comparison.</b>
<b>Discussion and Strategy</b>
<p>Discussion</p> <ul style="list-style-type: none"> <li>The Abbeydorney AFA is located in the River Brick upper catchment. Two significant tributaries, categorised as HPW, feed into the River Brick system with one tributary flowing north-east through the settlement.</li> <li>As discussed in the concluding remarks from Phase 1, no past flood event occurring in Abbeydorney has been reported in sufficient detail to allow for use in calibration / verification of the model.</li> </ul> <p>Additionally, no hydrometric station is present along the entire extent of the S15 model following the revision of the model's boundary. Although four 'water level only' stations namely, 23030, 23033, 23034 and 23036 are present downstream of the model extent; these are of little use due to the absence of any station upstream to provide quality inflow data. Calibration and verification between stations on the S15 model is therefore not possible.</p>



Appendix A - Plan of model S15 - DRAFT



Appendix B - Details Flood Event Records			
Flood Event	Material type	Data location	Contains
	GIS shapefile	B-0006	SERTIT: Water bodies mapped from RADARSAT-2 data acquired the 5th of December 2009 and SPOT 5 data acquired the 15th of May 2005.  *Coverage: <input type="checkbox"/> *No Coverage: <input checked="" type="checkbox"/>
	GIS Layer	B-0020	Digitisation of 1954 flood event.  *Coverage: <input type="checkbox"/> *No Coverage: <input checked="" type="checkbox"/>
	GIS Layer	B-0054	Jacobs digitisation of 2009 flood event.  *Coverage: <input type="checkbox"/> *No Coverage: <input checked="" type="checkbox"/>
	floodmaps.ie GIS layer	A-0171	Revised GIS layers showing the areas of Benefiting lands. (Unable to view layer, however tracts of land classed as 'benefiting lands' for flood risk management along both major tributaries feeding into the River Brick (as indicated on the National Flood Hazard Mapping tool).  *Coverage: <input checked="" type="checkbox"/> *No Coverage: <input type="checkbox"/>
1	.pdf report	B-0063	01-01a. OPW memo with accompanying map indicating location and termination of OPW drain. Produced by regional engineer and refers to flooding in Abbeydorney. However, no event specific data given.
All/ General Verification			
<p>*The information is deemed relevant if land adjacent to the model extent is indicated as having flooded during the event in question.</p> <p>**The information is deemed relevant if land adjacent to the model extent is indicated as at risk of flooding / could benefit from a flood defence scheme. The Office of Public Works has provided a map of lands that have benefited or would benefit from a flood relief scheme or drainage works. The designation of "benefiting lands" does not necessarily indicate that the respective sites are liable to flooding.</p>			

Appendix C – Event Category and Scoring								
1		2	3	4	5	6	7	8
Location description		Likely accuracy of Flow estimate	Likely accuracy of Gauged Level estimate	Known hydraulic conditions <sup>(1)</sup>	Supplement ary known, useful flood levels <sup>(2)</sup>	Reliable flood history (levels, locations, dates) <sup>(3)</sup>	Indicative calibration score (sum of columns 2-6)	Calibration comment (with event number)
Category 1	Large gauged river within an AFA (HPW)							
	Small gauged river within an AFA (HPW)							
Category 3	Large ungauged river within an AFA (HPW)							
	Small ungauged river within an AFA (HPW)	1(0) 2(0)	1(0) 2(0)	1(0) 2(0)	1(0) 2(0)	1(0) 2(0)	1(0) 2(0)	No event is suitable for use as calibration events. Reasons: 1- No specific information of flood event, 2- No specific information of flood event,
Category 2	Gauged MPW							
Category 4	Ungauged MPW							

Key: 1(2) = Flood Event 1 (score = 2)

**Table C.1 Event Category and Scoring**

Scores for columns 2 to 6: 0 = Not available; 1 = Poor / Unlikely; 2 = Fair / Possible; 3 = Good / Likely.

Total score in column 7 provides an overall guide as to how good the calibration may be, based on the data quality for columns 2 to 6.

**Notes:**

- (1) Hydraulic conditions relates to hydraulic controls influencing water level during a flood e.g. level of blockage at a bridge, culvert trashscreen blockage; any new works since flood event. It is a statement regarding whether the conditions in the flood can be accurately reflected in the hydraulic model.
- (2) Flood levels – these are levels during a known flood NOT at the gauged location that represent the true flood level at that location e.g. they must not be due to a very localised hydraulic issue such as flow around a building.
- (3) Flood history – for this information to be useful it must include a date, precise location and level as per note (2)

## Appendix D – FSU Classification (Abstract from Inception Report)

### 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 (Table B.1).

FSU Classification		Definition
A	Both	Suitable for flood frequency analysis. These were sites where the highest gauged flow (HGF) was significantly higher than the mean annual flood ( $Q_{med}$ ) [ $HGF > 1.3 \times Q_{med}$ ] 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 $1.3 \times Q_{med}$ and/or with a good confidence of extrapolation up to $2 \times Q_{med}$ , bankfull or, using suitable survey data, including flows across the flood plain.
	A2	Rating confirmed to measure $Q_{med}$ and up to around $1.3 \times Q_{med}$ . 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 D.1 - FSU Gauging station classification (from Hydro-Logic 2006)

## Appendix E – Quality Codes as assigned to data in floodmaps (OPW)

Quality codes have been assigned to define the reliability of the source of information. 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 the 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 E.1 – Quality Codes assigned to data in floodmaps (Table 8-A of Inception Report, UOM 23)

<b>Phase 1</b>				
Shannon CFRAM Study Calibration Information Refer to technical note TD041				
<b>Model No.</b>	<b>S16</b>	<b>Length</b>	28km	
<b>Unit of Management</b>		23		
<b>AFA</b>		Tralee		
<b>IRRs</b>		none		
<b>River / Catchment / Sub-catchment</b>		River Lee / Tyshe-Big-Coastal / Shannon		
<b>Type of Flooding / Flood Risk</b>		Fluvial non-tidal <input checked="" type="checkbox"/> Fluvial tidal <input checked="" type="checkbox"/> Coastal <input checked="" type="checkbox"/>		
<b>Comments</b>		Model S16 includes the River Lee (Kerry) and its tributaries including Big River and the Lee Estuary. The Lee, the Big and all the modelled tributaries pass through the Tralee AFA. The entire S16 model is categorised as a HPW. There are five gauging stations within the model extent; 23012, 23013, 23022, 23062, and 23063. Stations 23062 and 23063 are tidal gauges. Stations 23012 and 23013 are also suspected to be tidally influenced; only Station 23022 is unaffected by tides.		
<b>Completed by</b>	Kenny Samson	<b>Rev.2</b>	Rev 3	
<b>Date</b>	23/08/2013	24/10/2013	22/05/2014	
<b>Potential flood events (tidal/fluviat) to consider for calibration</b>				
<b>No</b>	<b>Description*</b>	<b>Category **(TD041)</b>	<b>Score (TD041)</b>	<b>Calibration or verification</b>
F.1	<p><u>19/11/2009</u>. Heavy rain (50 mm in 24-hr) coupled with high tides rendered combined sewers unable to discharge surface waters into the River Lee. Flooding occurred at the N70 from Army Barracks to Ballymullen Roundabout; 6 residential properties, 1 commercial property and roads impacted. FQC = 3</p> <p><u>19/11/2009</u>. Flooding at Curragraigue, Blennerville (IGC: 81674 112753), flood level 3.3m OD (Malin). Local GAA Clubhouse flooded to depth of 0.3m. Flooding reported as pluvial, occurring periodically at this location. Road access to Blennerville village flooded. ***FQC = 3</p>	1	0+0+1+0+1=2	Not suitable for fluvial calibration / verification as it is a pluvial flooding event.
F.2	<p><u>13/08/2008</u>. Flooding at Caherweesheen, Ballyard (IGC: 84008 112123), flood level 6.3m OD (Malin). Flooding caused by surface run-off / overflowing of river banks during heavy rainfall. Periodic flooding reported at this location. One house, farm buildings, agricultural land and the L6516 road were flooded. ***FQC = 3</p>	3	0+0+0+3+3=6	Not suitable for calibration / potential use for broad model verification.

F.3	05/08/1986. Extensive flooding on the River Lee, the Big River and Tralee city centre. Severe flooding noted in the Ballymullen and Castlecountess areas along the main River Lee. Flood levels are available at the gauges. ***FQC = 3	1	0+2+0+2+2=6	Not suitable for calibration / verification (pre dates flood works).	
F.4	29/11/2011. Heavy rainfall resulted in a storm sewer becoming overwhelmed once the outfall flaps were closed resulting in flooding in the River Lee catchment. Flooding is reported to occur frequently at this location. The main street of Ballymullen was flooded. ***FQC = 4	1	0+0+2+0+1=3	Not suitable for calibration / potential use for a broad verification.	
T.1	18/02/2011. Flooding at Kearney's Road, Blennerville (****IGC 81812 112984), 200m of road (L6513) and adjacent farm land flooded. Reported maximum flood level 2.9 mOD (Malin), maximum flood depth 0.9m. Flooding reported as tidal from Lee Estuary, occurring 4/5 times per year at this location. ***FQC = 3	1	0+0+0+3+3=6	Not suitable for calibration / potential use for broad model verification.	
5-8	See Appendix B: 5 – pre-dates channel works 6 – outside model extent 7 – outside model extent 8 – pre-dates channel works			Not suitable for calibration or verification	
9	Gauge Data Only - In-bank event – Qmed	1	To be identified in Phase 2	Calibration/verification	
10	Gauge Data Only - Out of bank event – Highest recorded flow	1	To be identified in Phase 2	Calibration/verification	
* See Appendix B for Event Details of events 1-4, ** See Appendix C for Quality Category and Quality Score (Scoring - 0 (Not suitable for calibration) to 15 (Suitable for calibration)) *** Flood Quality Code (See Appendix E) ****Irish Grid Co-ordinates					
Gauging Station Information within Model Extent (or close to)					
Station	Data Length	Type (flow, stage, both)	Gaugeboard Datum (mAOD Malin)	FSU Classification*	Comment
23022 Tralee Clonalour	1985 - 2012	Flow and Levels	6.92	Station reported as suspended. Last reading 16/01/2012.	Rating based on 123 gaugings with a maximum flow of 3.82 m <sup>3</sup> /s which is significantly less than the station QMED of 28.2 m <sup>3</sup> /s (0.14xQMED).
23062 Blennerville	1960 – 2010	Water Level only	Not available	N/A	Tidal level station. Moved in 2003 from the quay to d/s face of bridge
23063 Ballyard	1974 – 2010	Water Level only	Not available	N/A	Tidal level station. Relocated in 1994 from Ballyard Rail Bridge to Ballyard/O'Hara Road Bridge after major channel alterations including re-routing and excavation of new channel.
23013 Oakview	Not given	Inactive	Not available	staff gauge only	Station inactive. No data received. Tidally influenced.

23012	1974 – 2009	Water levels & flow	3.49 (Poolbeg)	A2	Since 1996 only mid-flow check gaugings undertaken. Likely to be tidally influenced. No rating developed for post-1992-96 flood relief scheme.  Jacobs rating review abandoned due to suspected tidal influence.
* See Appendix D for Key to FSU Station Classification A1 (Good) to C (Poor))					
Control structures					
Reference	Type	Description			
Conclusions from Phase 1					
Five hydrometric stations exist within the S16 model extent, see table above. Only two of those have a flow rating.  In order to allow fluvial calibration of the model, reliable flow data is required at (at least) one station and independent reliable flood levels are required sufficiently near to the flow gauging station. Both flow gauges in the model domain are unsuitable for calibration for the following reasons:  <div><div>1.</div><div>Station 23022 on the Big cannot be relied upon as its high flow rating is unconfirmed.</div></div> <div><div>2.</div><div>Station 23012 on the Lee is affected by tidal water levels. When a high fluvial flood coincides with high tidal levels the flow may deviate from the rating.</div></div> Numerous fluvial and mixed source events are reported within the S16 model extent; however, the information provided for these events gives limited useable data for verification. Some of the reported flood events pre-date the implementation of flood alleviation measures which occurred in the catchment between 1992 and 1996. As such, level data pre-1996 (where reported) may no longer be relevant due to changes which may have occurred in channel geometry.  <div><div>-</div><div>Events F.3, 5 and 8 pre-date the channel works and are unsuitable for calibration or verification</div></div> <div><div>-</div><div>Events 6 and 7 observations are outside the model extent and are therefore also not considered</div></div> <div><div>-</div><div>F.1 is reported as a pluvial flood event and is therefore dismissed</div></div> <div><div>-</div><div>F.2 (August 2008) can be considered for broad verification, see Phase 2</div></div> <div><div>-</div><div>F.4 (November 2011) ditto</div></div> Tidal calibration/verification: Long-term 15-minute level data is available at two gauges (23062 and 23063) which are affected by tidal as well as fluvial sources. However, any observed or gauged water levels that could be used for the calibration of the model would be affected by fluvial flows as well as the tide, and it is not possible to reliably estimate the fluvial flows.					



<b>Phase 2</b>					
<b>Gauging Station Information Used – Out of Bank* - Not possible</b>					
<b>Gauging Station Information Used – In Bank* - Not possible</b>					
**Location					
Type					
Flood Event					
GS Number					
Station Name					
Approximate Start of peak level					
Approximate Finish of peak level					
Peak level*** (mAOD Malin)					
Peak flow (m <sup>3</sup> /sec)					
Other gauging stations for same event					
<p>*Calibration events may include more than one gauging station. The table above indicates the details of the only two gauging station for which calibration may be possible.</p> <p>** Calibration is only possible between stations if concurrent flow/data is available</p> <p>***Stage plus datum (see Phase 1) from topographical survey (Stage in brackets).</p>					
<b>Discussion and Strategy (Fluvial Calibration / Verification)</b>					
<b>Discussion</b>					
<ul style="list-style-type: none"> <li>Fluvial calibration of the S16 model is not possible for any of the observed flood events due to a lack of reliable event specific data (i.e. flow data) within the modelled reach.</li> <li>The 2008, 2009 and 2011 flood events could potentially be used for a broad verification of the model using the observed flood extents and assessing whether these historically flooded locations are simulated to flood during higher return period flood simulations. Further verification using gauging station data is not possible for these events as only level/flow data is available for gauge 23022 for the 2011 event. For the 2008 event the cable at gauge 23022 is reported as being 'off the pull' and therefore the peak level / flow data at gauge 23022 has not been recorded. Rating curve is not developed at 23012 for the post 1992 period.</li> </ul>					
<b>Calibration/Verification Strategy</b>					
<p>Broad verification of the model will be attempted using flood information from the 2008, 2009 and 2011 flood events as discussed below:</p> <ul style="list-style-type: none"> <li>For the 2008 event at Caherweesheen, Ballyard (grid ref 84008,112123) which lies eastwards of HEP node 23_673_2 flood water depth is reported as being 0.6m and is indicated as inundating the road (L6516) as well as adjacent farmland, farm buildings and a house as a result of flooding from the River Lee tributary and surface water runoff. Broad verification could be carried out to see if this floods for higher return period events simulations (i.e. for 2% / 1% AEP events).</li> <li>The February 2011 flood event reports reoccurring flooding at Kearney's Road, Blennerville (IGC: 81812 112984). (4/5 times per year on average). 200m of road (L6513) and adjacent farm land reported to be flooded at high tide during the recorded event. Given this location is reported to be</li> </ul>					

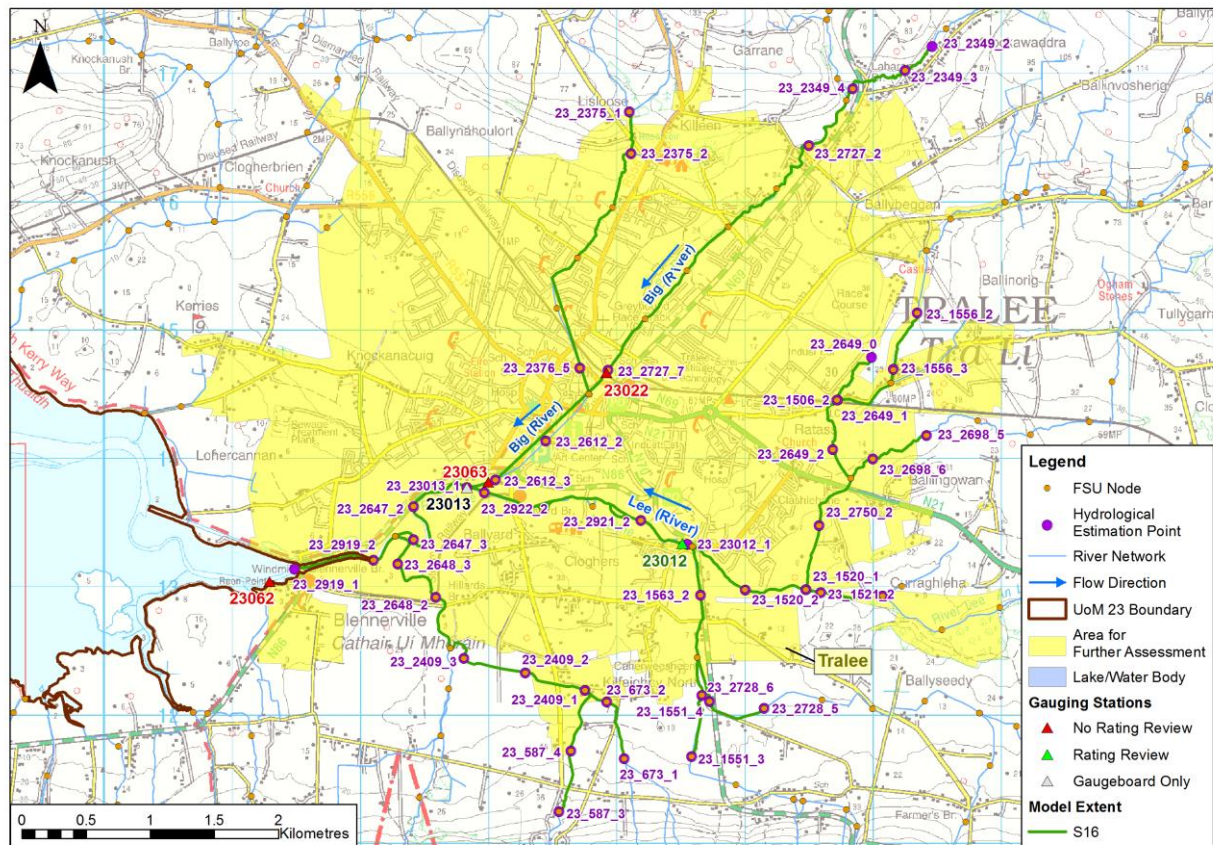
flooded on a number of occasions every year, a broad verification will include testing to see if the 2-year event results in flooding at this location. However an ambiguous description of the event leaves some suggestion that the flooding could be caused by local surface runoff instead of fluvial flows.

- For higher return period events (e.g. 2% / 1% AEP events) the areas identified as flooding during the 2009 event will be assessed to see if these areas flood.

#### **Discussion and Strategy (Tidal Calibration / Verification)**

The two water level gauges 23062 and 23063 as well as any observed flooding depths are affected by a combination of tidal levels and fluvial flows. Without reliable event fluvial flows historic flooding events cannot be accurately modelled.

Appendix A - Plan of model S16



Appendix B - Details Flood Event Records			
Flood Event	Material type	Data location	Contains
	GIS shapefile	B-0006	SERTIT: Water bodies mapped from RADARSAT-2 data acquired the 5th of December 2009 and SPOT 5 data acquired the 15th of May 2005.  *Coverage: <input type="checkbox"/> *No Coverage: <input checked="" type="checkbox"/>
	GIS Layer	B-0020	Digitisation of 1954 flood event.  *Coverage: <input type="checkbox"/> *No Coverage: <input checked="" type="checkbox"/>
	GIS Layer	B-0054	Jacobs digitisation of 2009 flood event.  *Coverage: <input type="checkbox"/> *No Coverage: <input checked="" type="checkbox"/>
	floodmaps.ie GIS layer	A-0171	Revised GIS layers showing areas of Benefiting lands. (Unable to view layer, however the S16b model is shown to have land classed as benefiting lands for flood risk management along the lower reaches of the River Lee (as indicated on the National Flood Hazard Mapping tool).  *Coverage: <input checked="" type="checkbox"/> *No Coverage: <input type="checkbox"/>
F.1	.pdf report	B-0063	56_kry2. OPW Flood Event Report. <b>19/11/2009</b> . Flooding at Curragraigue, Blennerville (Irish Grid Co-ordinates – 81,674 112,753). Reported flood level 3.3 meters OD (Malin) and reported flood depth of 1.0 metre. Local GAA Clubhouse flooded to depth of 300mm. Flooding reported as pluvial and flooding noted as occurring periodically at this location. Road access to Blennerville village flooded.
F.1	.pdf report	B-0063	kry_re_MN. OPW Flood Event Report: <b>19/11/2009</b> Heavy rain (50mm in 24-hr) rendered combined sewers unable to discharge surface waters into the River Lee. This was coupled with high tides and the River Lee in flood. Flooding occurred at Ballymullen N70 from Army Barracks to Ballymullen Roundabout. No flood data provided. 6 residential properties, 1 commercial property and transport infrastructure impacted.
F.2	.pdf report	B-0063	56_kry3. OPW Flood Event Report. <b>13/08/2008</b> . Flooding at Caherweesheen, Ballyard (Irish Grid Co-ordinates – 84,008 112,123). Reported flood level 6.3 meters OD (Malin) and flood depth of 0.6 meters. Flooding was reported as being due to surface run-off and overflowing of river banks as a result of heavy rain. Flooding has been reported at this location periodically. One house was reported as being flooded along with farm buildings, agricultural land and the L6516 road.
F.3			05/08/1986 Extensive flooding on the Lee and Big Rivers and Tralee city centre. Severe flooding noted in the Ballymullen and

	.pdf report	B-0063	Castlecountess areas along the main River Lee. Flood levels have been estimated in the following document 56-2a oph_re_ab_0000000675 at 3.00m at Ballymullen (gauge 23012 – upstream of the S16-b model); 2.76m at Ballyard; 2.82m at 18:00hr and 3.0m at 06:00hr on 06/08/86 at Blennerville. It should be noted that the 1986 flood event pre-dates flood works being implemented in the catchment. Peak flow (31.74m <sup>3</sup> /s) and peak level (7.24mAOD) provided for the Ballymullen gauge during this event.
F.4	.pdf report		Floodmaps.ie. OPW Flood Event Report + photos <b>29/11/2011</b> . Heavy rainfall resulted in a storm sewer becoming overwhelmed once the outfall flaps were closed resulting in flooding in the River Lee catchment, on the River Lee. Flooding is reported to occur frequently at this location. The main street of Ballymullen was flooded. ***FQC = 4
T.1	.pdf report	B-0063	56 kry-1. OPW Flood Event Report. <b>18/02/2011</b> . Flooding at Kearney's Road, Blennerville (Irish Grid Co-ordinates – 81,812 112,984). 200m of road (L6513) and adjacent farm land flooded at high tide. Reported maximum flood level 2.9 meters OD (Malin) and maximum flood depth 0.9 meters. Flooding reported as tidal flooding from River Lee estuary. Flooding reported as occurring in this location 4/5 times per year on average.
5	.pdf report	B-0063	01/12/1973. Storm event which resulted from heavy rainfall. Heavy rainfall coincided with a high tide and resulted in widespread flooding of the entire business area of Tralee. The River Lee was reported to flood. It should be noted that the 1973 flood event pre-dates flood works being implemented in the catchment. A number of flood depths reported for a variety of areas in Tralee in report 56-1a.
6	.pdf report	B-0063	56 kry5. OPW Brief Flood Summary Resident Engineer. <b>31/08/1997</b> . Flooding occurred at Ardnabraher Ballinorig where 3 houses were reported to be flooded to a depth of 3 feet. Ballinorig is just east of a modelled section of tributary.
7	.pdf report	B-0063	kry_mm_th_0000002449. OPW Flood Event Report. <b>Reoccurring flooding</b> . Flooding reported as occurring at Caherleheen annually. The N70 – Tralee to Castlemaine road is reported to flood over a length of approximately 0.8 to 1.6km along with surrounding land. The maximum depth of the flood has been reported as 600mm on the road. The cause of the problem is

			reported as heavy rainfall over a long period of time resulting in the limestone subterranean caves / caverns overflowing. Caherleheen is upstream of one of the S16-a modal tributaries.
8	.pdf report	B-0063	53_4a. OPW Flood Report with map and photos. <b>02/11/1980.</b> Ballyseedy, Ballyard, Oakview and the railway yard near Ashe Street flooded. New Ring Road flooded due to surface water. Ballymullen areas – Killerisk, terrace houses opposite Army Barracks and land near Castlemaine Road flooded. Peak flow (16.94m <sup>3</sup> /s) and peak level (6.71mAOD) provided for the Ballymullen gauge during this event. It should be noted that the 1980 flood event pre-dates flood works being implemented in the catchment.
All	.msg & .xls	OPW_Data\HA23	Flow / level data and AMAX series for station 23022 (1985 – 2012) and level data downstream at 23062 (1960 – present) and 23063 (1974 – present).
All/ General Verification	Flood Risk Review	A-0127 / A-0129	Photographs and videos taken during UoM 23 Site Visit (June 2011).
<p>*The information is deemed relevant if land adjacent to the model extent is indicated as having flooded during the event in question.</p> <p>**The information is deemed relevant if land adjacent to the model extent is indicated as at risk of flooding / could benefit from a flood defence scheme. The Office of Public Works has provided a map of lands that have benefited or would benefit from a flood relief scheme or drainage works. The designation of “benefiting lands” does not necessarily indicate that the respective sites are liable to flooding.</p>			



Appendix C – Event Category and Scoring								
1		2	3	4	5	6	7	8
Location description		Likely accuracy of Flow estimate	Likely accuracy of Gauged Level estimate	Known hydraulic conditions <sup>(1)</sup>	Supplement ary known, useful flood levels <sup>(2)</sup>	Reliable flood history (levels, locations, dates) <sup>(3)</sup>	Indicative calibration score (sum of columns 2-6)	Calibration comment (with event number)
Category 1	Large gauged river within an AFA (HPW)	F.1(0) F.3(0) F.4(0) T.1(0)	F.1(0) F.3(2) F.4(0) T.1(0)	F.1(1) F.3(0) F.4(2) T.1(0)	F.1(0) F.3(2) F.4(0) T.1(3)	F.1(1) F.3(2) F.4(1) T.1(3)	F.1(2) F.3(6) F.4(3) T.1(6)	<p>Suitability of Identified events in Phase 1. for calibration:</p> <p>F.1- Reported flooding occurred at a distance from the River Lee channel / modelled reach. The source of the flooding is reported as pluvial.</p> <p>F.3 – Widespread flooding in Tralee City Centre. However, the event occurred prior to flood relief works being implemented within the catchment.</p> <p>F.4 Flood location given along with photos showing some of the flooding extent. No details on flood depths/flows.</p> <p>T.1- Tidal flooding in River Lee estuary.</p>
	Small gauged river within an AFA (HPW)							
Category 3	Large ungauged river within an AFA (HPW)							
	Small ungauged river within an AFA (HPW)	F.2(0)	F.2(0)	F.2(0)	F.2(3)	F.2(3)	F.2(6)	F.2- Broad model verification possible using this event. Fluvial flooding from one of the River Lee tributaries.
Category 2	Gauged MPW							
Category 4	Ungauged MPW							

Key: 1(2) = Flood Event 1 (score = 2)



# Table C.1 Event Category and Scoring

Scores for columns 2 to 6: 0 = Not available; 1 = Poor / Unlikely; 2 = Fair / Possible; 3 = Good / Likely.

Total score in column 7 provides an overall guide as to how good the calibration may be, based on the data quality for columns 2 to 6.

## Notes:

- (1) Hydraulic conditions relates to hydraulic controls influencing water level during a flood e.g. level of blockage at a bridge, culvert trashscreen blockage; any new works since flood event. It is a statement regarding whether the conditions in the flood can be accurately reflected in the hydraulic model.
- (2) Flood levels – these are levels during a known flood NOT at the gauged location that represent the true flood level at that location e.g. they must not be due to a very localised hydraulic issue such as flow around a building.
- (3) Flood history – for this information to be useful it must include a date, precise location and level as per note (

## Appendix D – FSU Classification (Abstract from Inception Report)

### 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 (Table B.1).

FSU Classification		Definition
A	Both	Suitable for flood frequency analysis. These were sites where the highest gauged flow (HGF) was significantly higher than the mean annual flood ( $Q_{med}$ ) [ $HGF > 1.3 \times Q_{med}$ ] 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 $1.3 \times Q_{med}$ and/or with a good confidence of extrapolation up to $2 \times Q_{med}$ , bankfull or, using suitable survey data, including flows across the flood plain.
	A2	Rating confirmed to measure $Q_{med}$ and up to around $1.3 \times Q_{med}$ . 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 D.1 - FSU Gauging station classification (from Hydro-Logic 2006)

## Appendix E – Quality Codes as assigned to data in floodmaps (OPW)

Quality codes have been assigned to define the reliability of the source of information. 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 the 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.

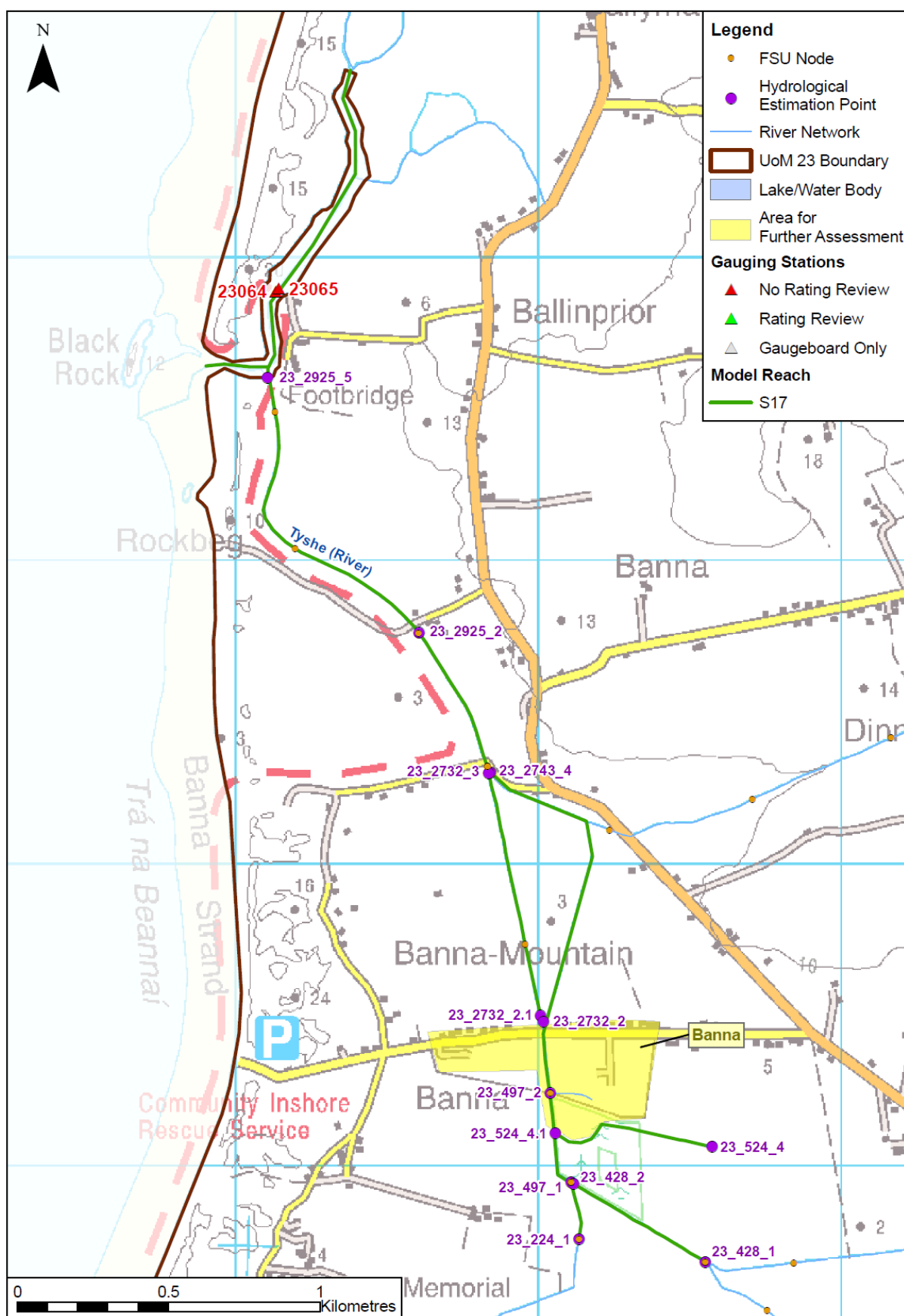
Table E.1 – Quality Codes assigned to data in floodmaps (Table 8-A of Inception Report, UOM 23)

<b>Phase 1</b>				
Shannon CFRAM Study Calibration Information Refer to technical note TD041				
<b>Model No.</b>	<b>S17</b>	<b>Length</b>	6.7km	
<b>Unit of Management</b>		23		
<b>AFA</b>		Banna		
<b>IRRs</b>		None		
<b>River / Catchment / Sub-catchment</b>		Tyshe River / North Kerry Tralee Bay Catchment / Shannon		
<b>Type of Flooding / Flood Risk</b>		Fluvial non-tidal <input checked="" type="checkbox"/> Fluvial tidal <input checked="" type="checkbox"/> Coastal <input checked="" type="checkbox"/>		
<b>Comments</b>		<p>Model S17 extends through the settlement of Banna which is classified as an AFA. The model includes a section of the Tyshe River and a tidally influenced short reach at the downstream model extent. Two gauges, namely, 23064 and 23065 are located within the S17 modelling extent, however, these are tidally influenced, inactive, water level only gauges with short records of data making them of limited use.</p> <p>The downstream section of the S17 model is categorised a MPW with the remaining model sections (including the Banna AFA) being categorised as a HPW.</p>		
<b>Completed by</b>		Kenny Samson		
<b>Date</b>		04/11/2013		
<b>Potential flood events to consider for fluvial calibration or verification</b>				
<b>No</b>	<b>Description*</b>	<b>Category **(TD041)</b>	<b>Score (TD041)</b>	<b>Calibration or verification</b>
1	02/11/1980. Flood levels on the 03/11/1980 were recorded as 1.26m at Ballymaquinn Bridge, and 1.20m at Banna House. Flood levels were also recorded at Ballynoe Bridge on the 02/11/1980 as being at 0.90m. The main Ballyheigue – Ardfer Road was also reported as being flooded to approximately 0.15m depth in three places at Ballymaquinn Bridge.	3	0+1+0+2+2=5	Not suitable for calibration / potentially could be used for verification
2	Recurring annual flooding. Minutes report regular (3/4 times per year) flooding on the R551 running through the village of Ardfer. 10 houses are affected. Cause of the problem is heavy rainfall and consequent surface water runoff. Ardfer is located approximately 2km upstream of the start of the S17 model.	3	0+0+0+0+0=0	Not suitable
3	Gauge Data Only - In-bank event – Qmed	3	To be identified in Phase 2	Calibration/verification
4	Gauge Data Only - Out of bank event – Highest recorded flow	3	To be identified in Phase 2	Calibration/verification

Potential flood events to consider for tidal calibration or verification					
No	Description*	Category **(TD041)	Score (TD041)	Calibration or verification	
N/A	N/A	N/A	N/A	N/A	
* See Appendix B for Event Details of events 1-2, ** See Appendix C for Quality Category and Quality Score (Scoring - 0 (Not suitable for calibration) to 15 (Suitable for calibration))					
Gauging Station Information within Model Extent (or close to)					
Station	Data Length	Type (flow, stage, both)	Gaugeboard Datum (mAOD Malin)	FSU Classification*	Comment
Akeragh Sluice D/S (23064)	1980 - 1983	Water Level Only	N/A	N/A	Inactive Tidal Gauge
Akeragh Sluice U/S (23065)	1980 - 1983	Water Level Only	N/A	N/A	Inactive Tidal Gauge
* See Appendix D for Key to FSU Station Classification A1 (Good) to C (Poor))					
Control structures					
Reference	Type	Description			
Conclusions from Phase 1					
Phase 1 suggested:					
Limited flood event data is available for the area covered by the S17 model. Two historic floods have been identified from data held on the National Flood Hazard Mapping website <a href="http://www.floodmaps.ie">www.floodmaps.ie</a> ; however, both are of limited use for calibration due to insufficient information on levels / flow, as discussed below.					
<ul style="list-style-type: none"><li>Event 1 (02/11/1980) reports flooding at Ballymaquinn and Ballyheigue – Ardfert Road, both north of the S17 model extent; at Banna House, approximately 313m east of the Tyshe channel; and at Ballynoe Bridge. At Banna house (approximately 4.59mOD Poolbeg), and along the Ballyheigue – Ardfert Road, flood water was recorded to a depth of approximately 0.15m.</li><li>Event 2 (recurring flooding) meeting minutes describes regular flooding (3/4 times per year) attributed to heavy rainfall and subsequent surface runoff at Ardfert. The R551 road running through the village of Ardfert is reported to flood with 10 houses noted as being affected. Ardfert is located approximately 2km upstream of the upper extent of the S17 Model.</li></ul>					
No further events are reported on Floodmaps.ie.					
Hydrometric stations within the S17 model extent are limited to two inactive tidal stations (23064 and 23065) which have limited data records (1980 – 1983).					

<b>Phase 2</b>
<b>Gauging Station Information Used – Out of Bank*</b> - Not possible as no active station on modelled reach.
<b>Gauging Station Information Used – In Bank*</b> - Not possible as no active station on modelled reach.
<b>Discussion and Strategy (Fluvial Calibration / Verification)</b>
<p>Discussion</p> <ul style="list-style-type: none"> <li>Flood events 1 &amp; 2 cannot be used for calibration due to insufficient event details and / or reported flooding occurring too far from the modelled channel / floodplain (see Phase 1).</li> <li>Flood event 1 could be used to broadly verify the model using the known flood location at Banna House to test to see if this location floods for higher return period events.</li> <li>Two hydrometric stations, each with 3-years of data (1980-83) are reported, although both stations are inactive, located at the downstream end of the model extent and are in an estuarine stretch of the river.</li> </ul> <p>Calibration/Verification Strategy</p> <p>Calibration of model S17 is not possible due to an absence of suitable hydrometric data and event specific records. As noted above, broad verification of the model may be possible using the known flood location within the model extent (Banna House) to broadly assess whether flooding is simulated at this location for higher return period events.</p>
<b>Discussion and Strategy (Tidal Calibration / Verification)</b>
<p>Discussion</p> <ul style="list-style-type: none"> <li>No past tidal event, reported in sufficient detail, has been identified within the Banna AFA.</li> </ul> <p>Calibration/Verification Strategy</p> <p>Calibration of model S17 is not possible due to an absence of suitable hydrometric data and event specific records.</p>

Appendix A - Plan of model S17



Appendix B - Details Flood Event Records			
Flood Event	Material type	Data location	Contains
	GIS shapefile	B-0006	SERTIT: Water bodies mapped from RADARSAT-2 data acquired the 5th of December 2009 and SPOT 5 data acquired the 15th of May 2005.  *Coverage: <input type="checkbox"/> *No Coverage: <input checked="" type="checkbox"/>
	GIS Layer	B-0020	Digitisation of 1954 flood event.  *Coverage: <input type="checkbox"/> *No Coverage: <input checked="" type="checkbox"/>
	GIS Layer	B-0054	Jacobs digitisation of 2009 flood event.  *Coverage: <input type="checkbox"/> *No Coverage: <input checked="" type="checkbox"/>
	floodmaps.ie GIS layer	N/A	Revised GIS layers showing areas of Benefiting lands. The S17 model is not shown to have benefiting lands for flood risk management (as indicated on the National Flood Hazard Mapping tool).  *Coverage: <input type="checkbox"/> *No Coverage: <input checked="" type="checkbox"/>
1	.pdf report	B-0063	53-4a. OPW Flood Event Report. 02/11/1980 Flood levels on the 3 <sup>rd</sup> November at Ballymaquinn Bridge were recorded as 1.26m (tide reported as nearly fully in) and Banna House as 1.20m. Flood levels were also recorded at Ballynoe Bridge on the 2 <sup>nd</sup> November as being a 0.90m (bypassing also noted to be occurring on the right bank). The main Ballyheigue – Ardfert Road was also reported as being flooded to approximately 0.15m in three places at Ballymaquinn Bridge.
2	.pdf report	B-0063	Kry_mm_th. OPW Flood Event Report. 01/12/2005. Provides details of regular (3/4 times per year) flooding on the R551 running through the village of Ardfert. 10 houses reported as affected. Cause of the problem is heavy rainfall and consequent surface water runoff. Ardfert is located approximately 2km upstream of the start of the S17 model.
All	.msg & .xls	N/A	N/A
All/ General Verification	Flood Risk Review	A-0119	Photographs and videos taken during UoM 23 Site Visit (June 2011).
<p>*The information is deemed relevant if land adjacent to the model extent is indicated as having flooded during the event in question.</p> <p>**The information is deemed relevant if land adjacent to the model extent is indicated as at risk of flooding / could benefit from a flood defence scheme. The Office of Public Works has provided a map of lands that have benefited or would benefit from a flood relief scheme or drainage works. The designation of “benefiting lands” does not necessarily indicate that the respective sites are liable to flooding.</p>			



Appendix C – Event Category and Scoring								
1		2	3	4	5	6	7	8
Location description		Likely accuracy of Flow estimate	Likely accuracy of Gauged Level estimate	Known hydraulic conditions <sup>(1)</sup>	Supplementary known, useful flood levels <sup>(2)</sup>	Reliable flood history (levels, locations, dates) <sup>(3)</sup>	Indicative calibration score (sum of columns 2-6)	Calibration comment (with event number)
Category 1	Large gauged river within an AFA (HPW)							
	Small gauged river within an AFA (HPW)							
Category 3	Large ungauged river within an AFA (HPW)							
	Small ungauged river within an AFA (HPW)	1(0) 2(0)	1(1) 2(0)	1(0) 2(0)	1(2) 2(0)	1(2) 2(0)	1(5) 2(0)	<b>Suitability of Identified events in Phase 1. for calibration:</b>  <b>1- Flooding either too far outside extent of model or insufficient event details.</b>  <b>2- Flooding too far outside extent of model. Insufficient event details.</b>
Category 2	Gauged MPW							
Category 4	Ungauged MPW							

Key: 1(2) = Flood Event 1 (score = 2)

**Table C.1 Event Category and Scoring**

Scores for columns 2 to 6: 0 = Not available; 1 = Poor / Unlikely; 2 = Fair / Possible; 3 = Good / Likely.

Total score in column 7 provides an overall guide as to how good the calibration may be, based on the data quality for columns 2 to 6.

**Notes:**

- (1) Hydraulic conditions relates to hydraulic controls influencing water level during a flood e.g. level of blockage at a bridge, culvert trashscreen blockage; any new works since flood event. It is a statement regarding whether the conditions in the flood can be accurately reflected in the hydraulic model.
- (2) Flood levels – these are levels during a known flood NOT at the gauged location that represent the true flood level at that location e.g. they must not be due to a very localised hydraulic issue such as flow around a building.
- (3) Flood history – for this information to be useful it must include a date, precise location and level as per note (2)

## Appendix D – FSU Classification (Abstract from Inception Report)

### 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 (Table B.1).

FSU Classification		Definition
A	Both	Suitable for flood frequency analysis. These were sites where the highest gauged flow (HGF) was significantly higher than the mean annual flood ( $Q_{med}$ ) [ $HGF > 1.3 \times Q_{med}$ ] 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 $1.3 \times Q_{med}$ and/or with a good confidence of extrapolation up to $2 \times Q_{med}$ , bankfull or, using suitable survey data, including flows across the flood plain.
	A2	Rating confirmed to measure $Q_{med}$ and up to around $1.3 \times Q_{med}$ . 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 D.1 - FSU Gauging station classification (from Hydro-Logic 2006)

## Appendix E — Quality Codes as assigned to data in floodmaps (OPW)

Quality codes have been assigned to define the reliability of the source of information. 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 the 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 E.1 – Quality Codes assigned to data in floodmaps (Table 8-A of Inception Report, UOM 23)

## Appendix G      Pooling Group Audit Trail

### Table of Content

#### Gauging Stations

23001 Inch Bridge

23002 Listowel

23012 Ballymullen

23022 Big

#### FSU Nodes

23\_757\_2      Model S15

23\_1563\_2      Model S16A

23\_2750\_2      Model S16A

23\_2648\_3      Model S16B

23\_497\_2      Model S17

Shannon RBD Design Hydrology

## CALCULATION AUDIT TRAIL

### PART A4.A2 - Pooled analysis site A

Site name:

Gauging station No:

Table A4.1 Pooled analysis file location

Description	File path
Pooled analysis	\\Europe.jacobs.com\reading\Projects\32103000 - Shannon CFRAMS Study\Hydrological Assessment\A) Modelling\UoM 23\Feale catchment model\S14-c\120912 - Pooled FloodFrequency Analysis -V4_23001

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	23_2929_1
Area	192.20
BFI	0.32
SAAR	1084.00
FARL	1.00
URBEXT	0.30
FLATWET	0.62

Number of pooled years required: 500 years

STEP 1 Use OPW pooled flood frequency spreadsheet to generate pooled group with (many) more years than required. Give initial number of years:

Is subject site in pooled group? ☒ Yes ☐ No at ranked position

Give reason if not at position 1:

STEP 2 Remove sites with record lengths of 8 years or less.

Table A4.2 Stations removed due to short record

Station No	No of years of data
34029	7

STEP 3 Remove sites with high discordancy Di  
Discordancy limit used:

Table A4.3 Stations removed due to discordancy

Station No	Discordancy

**STEP 4** Remove sites with outlying AREA, BFIsoil, FARL, URBEXT or FLATWET (to ensure homogeneity of the pooling group)

AREA	between 0.25 and 4 times the area of the subject site
BFIsoil	+/- 25% of subject site
SAAR	+/- 25% of subject site
FARL	+/- 10% of subject site
URBEXT	+/- 2.5
FLATWET	(FORMWET) +/- 0.10 (half of total range)

These criteria can be relaxed in some circumstances if agreed with reviewer.  
Add reviewer initials to the table below for deviations from the criteria above.

Table A4.4 Stations with outlying catchment descriptors

Station	Removed or kept with explanation + Reviewer initials if kept
9001	Outlier URBEXT value
3051	Outlier URBEXT value
22003	Outlier URBEXT value
23012	Outlier URBEXT value
24012	Outlier URBEXT value
24013	Outlier URBEXT value
27001	AREA less than 0.25 times that of subject site
36021	AREA less than 0.25 times that of subject site
39009	Outlier FARL value of 0.816

**STEP 5** Revisit STEPS 1 to 4

The pooling group may need to be revised several times until a pooling group has been developed that is suitably homogeneous.

Copy the tables from steps 1-4 to below Step 5 to record removed sites in additional iterations of the process.

Note that the nature of the subject site may mean that the pooling group will always be heterogeneous in which case the use of pooled analysis will need to be reconsidered in agreement with the reviewer.

insert additional iterations of Steps 1-4 here

**Final pooling group**

Table A4.5 Final pooling group summary

Station No	Years of data	Discordancy	Area (km2)
23001	33	0.048	192
28001	17	1.760	169
1041	32	0.077	116
18050	24	0.161	249
18016	20	0.223	117
23002	31	0.279	647
24030	25	0.234	259
33001	25	0.049	76
34007	53	0.052	152
34010	12	0.082	484
14033	9	0.948	79
34009	33	0.029	117
32011	25	0.093	70
26006	53	0.919	185
38001	33	0.085	111
24011	33	0.474	281
35004	14	0.350	117
39001	31	0.137	51

Pooled distributions for further consideration if different from EV1 and LN2:


### Final pooled growth factors

insert growth factor table from pooled analysis spreadsheet here  
for the following RPs

RP	GF (EV1)	GF (LN2)	GF (LO)
2	1.00	1.00	1.00
5	1.22	1.22	1.27
10	1.37	1.35	1.43
20	1.51	1.47	1.58
50	1.70	1.62	1.77
100	1.84	1.72	1.91
200*	1.97	1.83	2.04
1000*	2.29	2.06	2.36

### Comments:

The FSU recommends a pooling-group size that is five times the target return period (the 5T rule). In this instance the pooling group is based on 500-years of AMAX event data, corresponding to a 100-year target return period. Growth curves have been extended to include estimates for the 200-year and 1000-year return periods, but due to the number of AMAX events being less than 5T the estimates will be less certain and should be treated with caution.

Shannon RBD Design Hydrology

## CALCULATION AUDIT TRAIL

### PART A4.A2 - Pooled analysis site A

Site name:

Gauging station No:

Table A4.1 Pooled analysis file location

Description	File path
Pooled analysis	\\Europe.jacobs.com\reading\Projects\32103000 - Shannon CFRAMS Study\Hydrological Assessment\A) Modelling\UoM 23\Feale catchment model\S14-a\130813_Simialr BFI_ Pooled FloodFrequency Analysis_MAT

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	23_2555_3
Area	647.04
BFI	0.31
SAAR	1345
FARL	1.00
URBEXT	0.36
FLATWET	0.63

Target number of pooled years: 500 years

STEP 1 Use OPW pooled flood frequency spreadsheet to generate pooled group with (many) more years than required. Give initial number of years:

Is subject site in pooled group? ☒ Yes ☐ No at ranked position:

Give reason if not at position 1:

**Then move the subject gauging station to number 1 by setting distance measure Dij to 0.**

STEP 2 Remove sites with record lengths of 8 years or less.

Table A4.2 Stations removed due to short record

Station No	No of years of data
34029	7



STEP 3 Remove sites with outlying AREA, BFIsoil, FARL, URBEXT or FLATWET (to ensure homogeneity of the pooling group)

AREA	between 0.25 and 4 times the area of the subject site
BFIsoil	+/- 25% of subject site
SAAR	+/- 25% of subject site
FARL	+/- 10% of subject site
URBEXT	+/- 2.5
FLATWET	(FORMWET) +/- 0.10 (half of total range)

These criteria can be relaxed in some circumstances if agreed with reviewer.  
Add reviewer initials to the table below for deviations from the criteria above.

Table A4.4 Stations with outlying catchment descriptors

Station	Removed or kept with explanation + Reviewer initials if kept
39009	Removed FARL 0.816 / BFI outwith limits
34007	Kept as similar BFI (area outwith limit)
18016	Kept as similar BFI (area outwith limit)
1041	Kept as similar BFI (area outwith limit)
33001	Kept as similar BFI (area outwith limit)
38001	Kept as similar BFI (area / SAAR outwith limit)
32011	Kept as similar BFI (area outwith limit)
27001	Kept as similar BFI (area outwith limit)
39001	Kept as similar BFI (area / SAAR outwith limit)
36021	Kept as similar BFI (area outwith limit)
34010	Removed BFI outwith limit
34029	Removed BFI outwith limit
22006	Removed BFI / SAAR / FLATWET outside limit
18006	Removed BFI outwith limit
18003	Removed BFI outwith limit
18048	Removed BFI outwith limit
24030	Removed BFI / URBEXT outwith limit
22003	Removed BFI outwith limit
34009	Removed URBEXT / BFI / FLATWET outwith limit
24013	Removed BFI outwith limit
24012	Removed BFI outwith limit
30001	Removed Area / FLATWET / BFI / SAAR outwith limit
23012	Removed BFI / area outwith limits
14033	Removed area outwith limit
24011	Removed BFI outwith limit
25001	Removed BFI outwith limit
3051	Removed BFI / Area / URBEXT outwith limit
26006	Removed BFI outwith limit
19014	Removed BFI / SAAR / FARL outwith limit
10002	Removed BFI outwith limit
39008	Removed BFI / SAAR / FARL / Area outwith limit
35004	Removed BFI / Area outwith limit
16012	Removed BFI outwith limit
25158	Removed BFI / Area outwith limit

STEP 4 Remove sites with high discordancy Di  
Discordancy limit used:

Table A4.3 Stations removed due to discordancy

Station No	Discordancy

**STEP 5** Revisit STEPS 1 to 4

The pooling group may need to be revised several times until a pooling group has been developed that is suitably homogeneous.

Copy the tables from steps 1-4 to below Step 5 to record removed sites in additional iterations of the process.

Note that the nature of the subject site may mean that the pooling group will always be heterogeneous in which case the use of pooled analysis will need to be reconsidered in agreement with the reviewer.

insert additional iterations of Steps 1-4 here
------------------------------------------------

**Final pooling group**

Table A4.5 Final pooling group summary

Station No	Years of data	Discordancy	Area (km <sup>2</sup> )
23002	31	0.381	647
18050	24	0.220	249
28001	17	2.401	169
23001	33	0.066	192
34007	53	0.070	152
18016	20	0.304	117
1041	32	0.105	116
33001	25	0.066	76
38001	33	0.116	111
32011	25	0.127	70
27001	9	0.190	47
39001	31	0.187	51
36021	27	0.101	23
Total Years	360		

Pooled distributions for further consideration if different from EV1 and LN2:


**Final pooled growth factors**

Insert growth factor table from pooled analysis spreadsheet here for the following RPs

RP	GF (EV1)	GF (LN2)	GF (LO)
2	1.00	1.00	1.00
5	1.24	1.23	1.29
10	1.40	1.37	1.46
20	1.55	1.50	1.62
50	1.74	1.67	1.82
100	1.89	1.78	1.97
200	2.04	1.90	2.11
1000	2.37	2.15	2.45

**Comments:**

The FSU recommends a pooling-group size that is five times the target return period (the 5T rule). In this instance the pooling group is based on only 360-years of AMAX event data, corresponding to a 70-year target return period. As the initial pooling group did not prove sufficiently homogenous, it was necessary to remove a large number of sites that had parameter values outwith the prescribed range shown in Step 3. This resulted in a limited numbers of years of data being available for the pooling analysis.

Shannon RBD Design Hydrology

## CALCULATION AUDIT TRAIL

### PART A4.A2 - Pooled analysis site A

Site name:

Gauging station No:

Table A4.1 Pooled analysis file location

Description	File path
Pooled analysis	\\Europe.jacobs.com\reading\Projects\32103000 - Shannon CFRAMS Study\Hydrological Assessment\A) Modelling\UoM 23\Feale catchment model\S16-a\Revised Design Hydrology_2014\S16-a Pooled Flood Frequency Analysis_23012 REMOVED_Corrected 7th March

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	23012
Area	61.6
BFI	0.43
SAAR	1264
FARL	1.0
URBEXT	2.43
FLATWET	0.64

Number of pooled years required: 500 years

STEP 1 Use OPW pooled flood frequency spreadsheet to generate pooled group with (many) more years than required. Give initial number of years:

Is subject site in pooled group? ☐ Yes ☒ No at ranked position:

Give reason if not at position 1:

**Then move the subject gauging station to number 1 by setting distance measure Dij to 0.**

STEP 2 Remove sites with record lengths of 8 years or less.

Table A4.2 Stations removed due to short record

Station No	No of years of data
34029	7-year

STEP 3 Remove sites with outlying AREA, BFIsoil, FARL, URBEXT or FLATWET (to ensure homogeneity of the pooling group)

AREA	between 0.25 and 4 times the area of the subject site
BFIsoil	+/- 25% of subject site
SAAR	+/- 25% of subject site
FARL	+/- 10% of subject site
URBEXT	+/- 2.5
FLATWET	(FORMWET) +/- 0.10 (half of total range)

These criteria can be relaxed in some circumstances if agreed with reviewer.  
Add reviewer initials to the table below for deviations from the criteria above.

Table A4.4 Stations with outlying catchment descriptors

Station	Removed or kept with explanation	+ Reviewer initials if kept
1041	Removed - Low BFI relative to other stations in pooling group	
7033	Removed - FARL outside prescribed threshold	
9010	Removed - URBEXT outside prescribed threshold	
10004	Removed - SAAR outside prescribed threshold	
22003	Removed - Area outside prescribed threshold	
16006	Removed - BFI outside prescribed threshold	
22009	Removed - URBEXT outside prescribed threshold	
23012	Removed - Station 23012 (Ballymullen) was removed because the rating review (Appendix C) found that water levels recorded here can be affected by the tide	
24012	Removed - Area outside prescribed threshold	
25038	Removed - BFI outside prescribed threshold	
29001	Removed - BFI outside prescribed threshold	
29071	Removed - FARL outside prescribed threshold	
30001	Removed - SAAR outside prescribed threshold	
31002	Removed - FARL outside prescribed threshold	
32011	Removed - SAAR / FARL outside prescribed threshold	
33070	Removed - FARL outside prescribed threshold	
34010	Removed - Area outside prescribed threshold	
34011	Removed - FARL outside prescribed threshold	
34029	Removed - short station record	
36031	Removed - SAAR / URBEXT outside prescribed threshold	
39008	Removed - FARL outside prescribed threshold	
39009	Removed - FARL outside prescribed threshold	

STEP 4 Remove sites with high discordancy Di  
Discordancy limit used:

3.0

Table A4.3 Stations removed due to discordancy

Station No	Discordancy

**STEP 5** Revisit STEPS 1 to 4

The pooling group may need to be revised several times until a pooling group has been developed that is suitably homogeneous.

Copy the tables from steps 1-4 to below Step 5 to record removed sites in additional iterations of the process.

Note that the nature of the subject site may mean that the pooling group will always be heterogeneous in which case the use of pooled analysis will need to be reconsidered in agreement with the reviewer.

insert additional iterations of Steps 1-4 here
------------------------------------------------

**Final pooling group**

Table A4.5 Final pooling group summary

Station No	Years of data	Discordancy	Area (km2)
14033	9	0.772	78.9
34009	33	0.024	117
35002	34	0.105	88.8
25158	18	0.332	109.5
35004	14	0.285	117
34024	28	0.195	127
16005	30	0.067	84.0
3051	15	1.947	143
16013	33	0.096	93.6
26006	53	0.748	185
25044	40	0.028	92.5
30021	26	0.130	104
26009	35	0.083	98.2
16012	28	0.041	230
25002	51	0.436	222
26010	35	0.043	94.5

Pooled distributions for further consideration if different from EV1 and LN2:


**Final pooled growth factors**

insert growth factor table from pooled analysis spreadsheet here for the following RPs

RP	GF (EV1)	GF (LN2)	GF (LO)
2	1.00	1.00	1.00
5	1.24	1.23	1.29
10	1.39	1.37	1.46
20	1.54	1.50	1.61
50	1.73	1.66	1.81
100	1.88	1.77	1.95
200	2.02	1.88	2.10
1000	2.36	2.14	2.43

Shannon RBD Design Hydrology

## CALCULATION AUDIT TRAIL

### PART A4.A2 - Pooled analysis site A

Site name:

Gauging station No:

Table A4.1 Pooled analysis file location

Description	File path
Pooled analysis	<a href="\\Europe.jacobs.com\reading\Projects\32103000 - Shannon CFRAMS Study\Hydrological Assessment\A) Modelling\UoM 23\Feale catchment model\S16-b\Revised Design Hydrology\S16-b (23022) Pooled Flood Frequency Analysis_MAT check_Opt1_Rev1_corrected 7th march">\\Europe.jacobs.com\reading\Projects\32103000 - Shannon CFRAMS Study\Hydrological Assessment\A) Modelling\UoM 23\Feale catchment model\S16-b\Revised Design Hydrology\S16-b (23022) Pooled Flood Frequency Analysis_MAT check_Opt1_Rev1_corrected 7th march</a>

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	23022
Area	10.9
BFI	0.34
SAAR	1127
FARL	1.0
URBEXT	16.2
FLATWET	0.64

Number of pooled years required: 500 years

STEP 1 Use OPW pooled flood frequency spreadsheet to generate pooled group with (many) more years than required. Give initial number of years:

Is subject site in pooled group? ☐ Yes ☒ No at ranked position:

Give reason if not at position 1:

**Then move the subject gauging station to number 1 by setting distance measure Dij to 0.**

STEP 2 Remove sites with record lengths of 8 years or less.

Table A4.2 Stations removed due to short record

Station No	No of years of data
34029	8

STEP 3 Remove sites with outlying AREA, BFIsoil, FARL, URBEXT or FLATWET (to ensure homogeneity of the pooling group)

AREA	between 0.25 and 4 times the area of the subject site
BFIsoil	+/- 25% of subject site
SAAR	+/- 25% of subject site
FARL	+/- 10% of subject site
URBEXT	+/- 2.5
FLATWET	(FORMWET) +/- 0.10 (half of total range)

These criteria can be relaxed in some circumstances if agreed with reviewer.  
Add reviewer initials to the table below for deviations from the criteria above.

Table A4.4 Stations with outlying catchment descriptors

Station	Removed or kept with explanation + Reviewer initials if kept
14033 / 8012 / 8007 / 34009 / 36031 / 35004 / 3051 / 31002 / 25040 / 22009 / 6031 / 39008 / 10004 / 8003 / 16005 / 35002 / 9010 / 25158 / 26006 / 9011 / 34024 / 33070 / 8008 / 26009 / 7033 / 30020 / 25040 / 6033 / 16013 / 6030 / 16051 / 1055 / 9001 / 22003 / 16006 / 8002 / 26010 / 8009 / 30021 / 24011 / 26020 / 29071 / 24012 / 26022 / 24022 / 29001 / 24004 / 34011 / 16012 / 24013 / 25002 / 9035 / 20006 / 25038 / 8011 / 10002 / 30037 / 30005 / 9002 / 14009 / 25022 / 10022 / 36071 / 36015 / 25027 / 13002 / 25005 / 11001 / 10021 / 25034	Removed - BFI values (and other parameters) outside limit. *see concluding comments
39009 / 19014	Removed - FARL outwith limit.
23012	Removed - Tidally influenced

STEP 4 Remove sites with high discordancy Di  
Discordancy limit used:

3.0

Table A4.3 Stations removed due to discordancy

Station No	Discordancy

STEP 5 Revisit STEPS 1 to 4

The pooling group may need to be revised several times until a pooling group has been developed that is suitably homogeneous.

Copy the tables from steps 1-4 to below Step 5 to record removed sites in additional iterations of the process.

Note that the nature of the subject site may mean that the pooling group will always be heterogeneous in which case the use of pooled analysis will need to be reconsidered in agreement with the reviewer.



insert additional iterations of Steps 1-4 here

### Final pooling group

Table A4.5 Final pooling group summary

Station No	Years of data	Discordancy	Area (km2)
36021	27	0.080	23.4
27001	9	0.150	46.7
33001	25	0.053	76.1
1041	32	0.083	116
32011	25	0.100	70.1
18016	20	0.241	117
39001	31	0.148	50.7
23001	33	0.052	192
28001	17	1.902	169
34007	53	0.056	152
38001	33	0.092	111
18050	24	0.174	249
34029	7	1.775	227
34010	12	0.089	484
23002	31	0.302	647
22006	51	0.036	329

Pooled distributions for further consideration if different from EV1 and LN2:


### Final pooled growth factors

insert growth factor table from pooled analysis spreadsheet here  
for the following RPs

RP	GF (EV1)	GF (LN2)	GF (LO)
2	1.00	1.00	1.00
5	1.26	1.25	1.32
10	1.43	1.41	1.50
20	1.59	1.55	1.67
50	1.80	1.74	1.89
100	1.96	1.87	2.05
200	2.12	2.00	2.20
1000	2.49	2.29	2.57

### Comments:

Achieving an appropriately homogenous pooling group has proven difficult due to low BFI and large URBEXT parameters (relative to stations in pooling bank) criteria for station selection has been relaxed entirely with the exception of FARL and BFIHOST.

## CALCULATION AUDIT TRAIL

### PART A4.A2 - Pooled analysis site A

Site name:

Gauging station No:

Table A4.1 Pooled analysis file location

Description	File path
Pooled analysis	\\Europe.jacobs.com\reading\Projects\32103000 - Shannon CFRAMS Study\Hydrological Assessment\A) Modelling\UoM 23\Feale catchment model\S15\S15_Abbeydorney_Pooled FloodFrequency Analysis_Corrected 7th March

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	23_757_2
Area	8.9
BFI	0.47
SAAR	1042
FARL	1.0
URBEXT	2.4
FLATWET	0.64

Number of pooled years required: 500 years

STEP 1 Use OPW pooled flood frequency spreadsheet to generate pooled group with (many) more years than required. Give initial number of years:

Is subject site in pooled group? ☐ Yes ☒ No at ranked position:

Give reason if not at position 1:

STEP 2 Remove sites with record lengths of 8 years or less.

Table A4.2 Stations removed due to short record

Station No	No of years of data

STEP 3 Remove sites with outlying AREA, BFIsoil, FARL, URBEXT or FLATWET  
(to ensure homogeneity of the pooling group)

AREA	between 0.25 and 4 times the area of the subject site
BFIsoil	+/- 25% of subject site
SAAR	+/- 25% of subject site
FARL	+/- 10% of subject site
URBEXT	+/- 2.5
FLATWET	(FORMWET) +/- 0.10 (half of total range)

These criteria can be relaxed in some circumstances if agreed with reviewer.  
Add reviewer initials to the table below for deviations from the criteria above.

Table A4.4 Stations with outlying catchment descriptors

Station	Removed or kept with explanation + Reviewer initials if kept
25040	Kept - URBEXT just outside limit
8007	Kept - URBEXT and Area just outside limit
6030	Kept - BFI just outside limit
22009	Kept - URBEXT just outside limit
30020	Kept - BFI just outside limit
6031	Kept - Area just outside limit
36031	Kept - URBEXT and Area just outside limit
16051	Kept - BFI just outside limit
23012	Kept - Area just outside limit
14033	Kept - Area just outside limit
6033	Kept - Area just outside limit
24022	Kept - Area and BFI just outside limit
16005	Kept - Area just outside limit
26022	Kept - Area and BFI just outside limit
8003	Kept - Area just outside limit
16006	Kept - Area and BFI just outside limit
8009	Kept - URBEXT, Area and SAAR just outside limit
9002	Kept - BFI and SAAR just outside limit
10021	Kept - BFI just outside limit
8005	Kept - BFI and SAAR just outside limit
35002	Kept - Area and SAAR just outside limit
9011	Removed - URBEXT and SAAR outside prescribed threshold
10022	Removed - URBEXT and BFI outside prescribed threshold
25034	Removed - BFI outside prescribed threshold
9010	Removed - URBEXT and Area outside prescribed threshold
9035	Removed - URBEXT, Area and BFI outside prescribed threshold
35004	Removed - Area outside prescribed threshold
7033	Removed - FARL and Area outside prescribed threshold
26010	Removed - Area outside prescribed threshold
25044	Removed - Area outside prescribed threshold
34009	Removed - Area outside prescribed threshold
3051	Removed - Area outside prescribed threshold

STEP 4 Remove sites with high discordancy Di  
Discordancy limit used:

3.0

Table A4.3 Stations removed due to discordancy

Station No	Discordancy

## STEP 5 Revisit STEPS 1 to 4

The pooling group may need to be revised several times until a pooling group has been developed that is suitably homogeneous.

Copy the tables from steps 1-4 to below Step 5 to record removed sites in additional iterations of the process.

Note that the nature of the subject site may mean that the pooling group will always be heterogeneous in which case the use of pooled analysis will need to be reconsidered in agreement with the reviewer.

insert additional iterations of Steps 1-4 here
------------------------------------------------

### Final pooling group

Table A4.5 Final pooling group summary

Station No	Years of data	Discordancy	Area (km2)
8012	19	0.282	26.0
25040	19	0.040	28.0
8007	15	0.201	37.9
6030	27	0.248	10.4
22009	24	0.030	35.4
30020	16	0.024	21.4
6031	18	0.396	46.2
36031	30	0.413	63.8
16051	13	0.204	34.2
23012	18	0.354	61.6
14033	9	0.513	78.9
8002	21	0.080	33.4
6033	25	0.715	55.2
24022	20	0.024	41.2
16005	30	0.045	84.0
26022	33	0.060	61.9
8003	18	0.544	83.6
16006	33	0.099	75.8
8009	15	2.446	61.6
9002	25	0.578	35.0
10021	24	0.071	32.5
8005	18	0.231	9.2
35002	34	0.069	88.8

Pooled distributions for further consideration if different from EV1 and LN2:

### Final pooled growth factors

insert growth factor table from pooled analysis spreadsheet here for the following RPs

RP	GF (EV1)	GF (LN2)	GF (LO)
2	1.00	1.00	1.00
5	1.42	1.43	1.51
10	1.69	1.72	1.80
20	1.95	2.01	2.08
50	2.29	2.39	2.42
100	2.55	2.68	2.68
200	2.80	2.98	2.94
1000	3.39	3.71	3.53

Shannon RBD Design Hydrology

## CALCULATION AUDIT TRAIL

### PART A4.A2 - Pooled analysis site A

Site name:

Gauging station No:

Table A4.1 Pooled analysis file location

Description	File path
Pooled analysis	\\Europe.jacobs.com\reading\Projects\32103000 - Shannon CFRAMS Study\Hydrological Assessment\A) Modelling\UoM 23\Feale catchment model\S16-a\Revised Design Hydrology_2014\S16-a Left Bank Trib. Pooled Flood Frequency Analysis_corrected March 7th

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	23_1563_2
Area	13.46
BFI	0.455
SAAR	1346
FARL	1
URBEXT	1.13
FLATWET	0.65

Number of pooled years required: 500 years

STEP 1 Use OPW pooled flood frequency spreadsheet to generate pooled group with (many) more years than required. Give initial number of years:

Is subject site in pooled group? ☐ Yes ☒ No at ranked position:

Give reason if not at position 1:

**Then move the subject gauging station to number 1 by setting distance measure Dij to 0.**

STEP 2 Remove sites with record lengths of 8 years or less.

Table A4.2 Stations removed due to short record

Station No	No of years of data

## STEP 3

Remove sites with outlying AREA, BFIsoil, FARL, URBEXT or FLATWET  
(to ensure homogeneity of the pooling group)

AREA	between 0.25 and 4 times the area of the subject site
BFIsoil	+/- 25% of subject site
SAAR	+/- 25% of subject site
FARL	+/- 10% of subject site
URBEXT	+/- 2.5
FLATWET	(FORMWET) +/- 0.10 (half of total range)

These criteria can be relaxed in some circumstances if agreed with reviewer.  
Add reviewer initials to the table below for deviations from the criteria above.

Table A4.4 Stations with outlying catchment descriptors

Station	Removed or kept with explanation + Reviewer initials if kept
22009	Removed - URBEXT outwith revised limit.
31002	Removed - FARL outwith revised limit.
30020	Removed - BFI outwith revised limit.
33070	Removed - FARL outwith revised limit.
6030	Removed - BFI outwith revised limit.
1055	Removed - FARL / SAAR outwith revised limits.
25040	Removed - URBEXT outwith revised limit.
39008	Removed - FARL / SAAR outwith revised limits.
36031	Removed - URBEXT / SAAR outwith revised limits.
3051	Removed - Area outwith revised limit.
8007	Removed - SAAR / URBEXT outwith revised limits.
29071	Removed - FARL outwith revised limit.
30001	Removed - SAAR outwith revised limit.
6031	Removed - SAAR outwith revised limit.
36071	Removed - FARL / BFI outwith revised limit.
23012	Removed as gauge tidally influenced.
10004	Kept - FLATWET / SAAR within revised limits.
20006	Kept - BFI within revised limit.
36021	Kept - BFI within revised limit.
27001	Kept - BFI within revised limit.
16006	Kept - BFI within revised limit.
30021	Kept - BFI within revised limit.
32011	Kept - BFI within revised limit.
25044	Kept - BFI within revised limit.
26010	Kept - BFI within revised limit.
25158	Kept - Area within revised limit.
35002	Kept - Area within revised limit.
34024	Kept - Area within revised limit.
34009	Kept - Area within revised limit.
35004	Kept - Area within revised limit.
1041	Kept - Area within revised limit.

## STEP 4

Remove sites with high discordancy Di  
Discordancy limit used:

3.0

Table A4.3 Stations removed due to discordancy

Station No	Discordancy

**STEP 5**      Revisit STEPS 1 to 4  
 The pooling group may need to be revised several times until a pooling group has been developed that is suitably homogeneous.

Copy the tables from steps 1-4 to below Step 5 to record removed sites in additional iterations of the process.

Note that the nature of the subject site may mean that the pooling group will always be heterogeneous in which case the use of pooled analysis will need to be reconsidered in agreement with the reviewer.

insert additional iterations of Steps 1-4 here
------------------------------------------------

### Final pooling group

Table A4.5 Final pooling group summary

Station No	Years of data	Discordancy	Area (km2)
10004	14	1.857	30.6
14033	9	1.252	78.9
35002	34	0.169	88.8
36021	27	0.098	23.4
34009	33	0.039	117
16013	33	0.155	93.6
25158	18	0.539	110
16005	30	0.109	84.0
27001	9	0.184	46.7
1041	32	0.101	116
35004	14	0.462	117
20006	25	0.227	77.6
25044	40	0.045	92.5
34024	28	0.317	127
16006	33	0.241	75.8
30021	26	0.210	104
32011	25	0.123	70.1
26009	35	0.135	98.2
26010	35	0.070	94.5


### Final pooled growth factors

insert growth factor table from pooled analysis spreadsheet here for the following RPs

RP	GF (EV1)	GF (LN2)	GF (LO)
2	1.00	1.00	1.00
5	1.26	1.25	1.31
10	1.42	1.41	1.50
20	1.59	1.55	1.66
50	1.80	1.73	1.88
100	1.95	1.86	2.04
200	2.11	1.98	2.19
1000	2.47	2.27	2.56



**Comments:** Criteria for station selection has been relaxed to allow sites with:  
Catchment area up to a max. of 10x that of the subject site. Upper threshold relaxed to allow sites with BFI values  $\pm 32\%$  that of the target site.  
Upper threshold relaxed to allow sites with SAAR values  $\pm 30\%$  that of target site.  
FLATWET Relaxed to allow  $\pm 0.11$ .

Shannon RBD Design Hydrology

## CALCULATION AUDIT TRAIL

### PART A4.A2 - Pooled analysis site A

Site name:

Gauging station No:

Table A4.1 Pooled analysis file location

Description	File path
Pooled analysis	\\Europe.jacobs.com\reading\Projects\32103000 - Shannon CFRAMS Study\Hydrological Assessment\A) Modelling\UoM 23\Feale catchment model\S16-a\Revised Design Hydrology_2014\S16a Right Bank Trib. Pooled Flood Frequency Analysis_corrected 7th March

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	23_2750_2
Area	12.03
BFI	0.350
SAAR	1200
FARL	1
URBEXT	4.47
FLATWET	0.64

Number of pooled years required: 500 years

STEP 1 Use OPW pooled flood frequency spreadsheet to generate pooled group with (many) more years than required. Give initial number of years:

Is subject site in pooled group? ☐ Yes ☒ No at ranked position:

Give reason if not at position 1:

**Then move the subject gauging station to number 1 by setting distance measure Dij to 0.**

STEP 2 Remove sites with record lengths of 8 years or less.

Table A4.2 Stations removed due to short record

Station No	No of years of data

STEP 3

Remove sites with outlying AREA, BFIsoil, FARL, URBEXT or FLATWET  
(to ensure homogeneity of the pooling group)

AREA	between 0.25 and 4 times the area of the subject site
BFIsoil	+/- 25% of subject site
SAAR	+/- 25% of subject site
FARL	+/- 10% of subject site
URBEXT	+/- 2.5
FLATWET	(FORMWET) +/- 0.10 (half of total range)

These criteria can be relaxed in some circumstances if agreed with reviewer.  
Add reviewer initials to the table below for deviations from the criteria above.

Table A4.4 Stations with outlying catchment descriptors

Station	Removed or kept with explanation	+ Reviewer initials if kept
28001	Removed - Area outwith limit	
23001	Removed - Area outwith limit	
34007	Removed - Area outwith limit	
31002	Removed - FARL outwith limit	
39008	Removed - FARL outwith limit	
22009	Removed - BFI outwith limit	
18050	Removed - Area outwith limit	
39009	Removed - FARL and area outwith limit	
34029	Removed - Area outwith limit	
33070	Removed - FARL outwith limit	
25040	Removed - BFI outwith limit	
6031	Removed - BFI outwith limit	
24030	Removed - Area outwith limit	
26006	Removed - Area outwith limit.	
23012	Removed as gauge tidal influenced and suspect.	
36021	Kept - SAAR and URBEXT within revised limits.	
27001	Kept - URBEXT within revised limits.	
23012	Kept - Area within revised limits.	
32011	Kept - SAAR / AREA / URBEXT within revised limits.	
14033	Kept - BFI / AREA / URBEXT within revised limits.	
33001	Kept - AREA / URBEXT within revised limits.	
1041	Kept - AREA / URBEXT within revised limits.	
18016	Kept - AREA / URBEXT within revised limits.	
39001	Kept - SAAR / AREA / URBEXT within revised limits.	
34009	Kept - BFI / AREA / URBEXT within revised limits.	
8007	Kept - BFI / SAAR within revised limits.	
8012	Kept - URBEXT within revised limits.	
38001	Kept - SAAR / AREA / URBEXT within revised limits.	
36031	Kept - Area / BFI within revised limits.	
35004	Kept - BFI / AREA / URBEXT within revised limits.	
3051	Kept - Area / BFI within revised limits.	
10004	Kept - URBEXT / BFI / SAAR within revised limits.	
35002	Kept - BFI / AREA / URBEXT within revised limits.	
25158	Kept - BFI / AREA / URBEXT within revised limits.	
16005	Kept - BFI / AREA / URBEXT within revised limits.	
30001	Kept - SAAR / AREA / URBEXT within revised limits.	
34024	Kept - BFI / AREA / URBEXT within revised limits.	
16013	Kept - BFI / AREA / URBEXT within revised limits.	

STEP 4

Remove sites with high discordancy Di  
Discordancy limit used:

3.0

Table A4.3 Stations removed due to discordancy

Station No	Discordancy

**STEP 5**      Revisit STEPS 1 to 4  
 The pooling group may need to be revised several times until a pooling group has been developed that is suitably homogeneous.

Copy the tables from steps 1-4 to below Step 5 to record removed sites in additional iterations of the process.

Note that the nature of the subject site may mean that the pooling group will always be heterogeneous in which case the use of pooled analysis will need to be reconsidered in agreement with the reviewer.

insert additional iterations of Steps 1-4 here
------------------------------------------------

### Final pooling group

Table A4.5 Final pooling group summary

Station No	Years of data	Discordancy	Area (km2)
36021	27	0.057	23.4
27001	9	0.107	46.7
32011	25	0.072	70.1
14033	9	0.731	78.9
33001	25	0.037	76.1
1041	32	0.059	116
18016	20	0.172	117
39001	31	0.106	50.7
34009	33	0.023	117
8007	15	0.287	37.9
8012	19	0.402	26.0
38001	33	0.066	111
36031	30	0.588	63.8
35004	14	0.270	117
3051	15	1.844	143
10004	14	1.084	30.6
35002	34	0.099	88.8
25158	18	0.315	110
16005	30	0.064	84.0
30001	18	0.505	121
34024	28	0.185	127
16013	33	0.090	93.6

### Final pooled growth factors

Growth factor table from pooled analysis spreadsheet for the following RPs

RP	GF (EV1)	GF (LN2)	GF (LO)
2	1.00	1.00	1.00
5	1.25	1.24	1.30
10	1.41	1.39	1.48
20	1.56	1.52	1.64
50	1.77	1.69	1.84
100	1.92	1.81	1.99
200	2.07	1.93	2.15
1000	2.42	2.20	2.50

**Comments:** Criteria for station selection relaxed. Upper threshold for catchment area relaxed to allow sites with area up to a max. of x12 that of the target site. Upper threshold for BFI parameter relaxed to allow sites with BFI values up to 55% greater than target site. Upper and lower threshold for SAAR relaxed to allow values  $\pm 50\%$  than that of target site. Subject site has relatively low URBEX (4.47); lower threshold reduced to zero - no relaxation of upper threshold.

Shannon RBD Design Hydrology

## CALCULATION AUDIT TRAIL

### PART A4.A2 - Pooled analysis site A

Site name:

Gauging station No:

Table A4.1 Pooled analysis file location

Description	File path
Pooled analysis	\\Europe.jacobs.com\reading\Projects\32103000 - Shannon CFRAMS Study\Hydrological Assessment\A) Modelling\UoM 23\Feale catchment model\S16-b\Revised Design Hydrology\Downstream Trib Pooled Flood Frequency Analysis_Rev1_corrected march 7th

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	23_2648_3
Area	13.7
BFI	0.369
SAAR	1371
FARL	1.00
URBEXT	0.56
FLATWET	0.65

Number of pooled years required: 500 years

STEP 1 Use OPW pooled flood frequency spreadsheet to generate pooled group with (many) more years than required. Give initial number of years:

Is subject site in pooled group? ☐ Yes ☒ No at ranked position:

Give reason if not at position 1:

**Then move the subject gauging station to number 1 by setting distance measure Dij to 0.**

STEP 2 Remove sites with record lengths of 8 years or less.

Table A4.2 Stations removed due to short record

Station No	No of years of data
34029	7

STEP 3 Remove sites with outlying AREA, BFIsoil, FARL, URBEXT or FLATWET (to ensure homogeneity of the pooling group)

AREA	between 0.25 and 4 times the area of the subject site
BFIsoil	+/- 25% of subject site
SAAR	+/- 25% of subject site
FARL	+/- 10% of subject site
URBEXT	+/- 2.5
FLATWET	(FORMWET) +/- 0.10 (half of total range)

These criteria can be relaxed in some circumstances if agreed with reviewer. Add reviewer initials to the table below for deviations from the criteria above.

Table A4.4 Stations with outlying catchment descriptors

Station	Removed or kept with explanation + Reviewer initials if kept
10004	Removed - BFI outside limit
35002	Removed - BFI outside limit
25158	Removed - BFI outside limit
16013	Removed - BFI outside limit
35004	Removed - BFI outside limit
22009	Removed - BFI / URBEXT outside limit
16005	Removed - BFI outside limit
34024	Removed - BFI outside limit
36031	Removed - SAAR / URBEXT /BFI outside limit
30020	Removed - BFI outside limit
26006	Removed - Area / BFI outside limit
25040	Removed - BFI / URBEXT outside limit
6030	Removed - BFI outside limit
25044	Removed - BFI outside limit
26009	Removed - BFI outside limit
6031	Removed - SAAR / BFI outside limit
7033	Removed - FARL / BFI outside limit
20006	Removed - BFI outside limit
30021	Removed - BFI outside limit
29071	Removed - FARL / BFI outside limit
9010	Removed - SAAR / URBEXT /BFI outside limit
16006	Removed - BFI outside limit
10002	Removed - Area / BFI outside limit
39008	Removed - FARL / SAAR outside limit
31002	Removed - FARL / BFI outside limit
1055	Removed - FARL / SAAR / BFI outside limit
39009	Removed - FARL outside limit
33070	Removed - FARL / BFI outside limit
19014	Removed - FARL / SAAR outside limit
8007	Removed - SAAR / URBEXT
23012	Removed - Tidal influence
34029	Removed - Only 7 years of data



34007	Kept - Area within revised limit
28001	Kept - Area within revised limit
23001	Kept - Area within revised limit
18050	Kept - Area within revised limit
3051	Kept - Area within revised limit
22003	Kept - Area within revised limit
24030	Kept - Area within revised limit
22006	Kept - Area within revised limit

STEP 4 Remove sites with high discordancy  $D_i$

Discordancy limit used:

3.0

Table A4.3 Stations removed due to discordancy

Station No	Discordancy

STEP 5 Revisit STEPS 1 to 4

The pooling group may need to be revised several times until a pooling group has been developed that is suitably homogeneous.

Copy the tables from steps 1-4 to below Step 5 to record removed sites in additional iterations of the process.

Note that the nature of the subject site may mean that the pooling group will always be heterogeneous in which case the use of pooled analysis will need to be reconsidered in agreement with the reviewer.

insert additional iterations of Steps 1-4 here

### Final pooling group

Table A4.5 Final pooling group summary

Station No	Years of data	Discordancy	Area (km <sup>2</sup> )
36021	27	0.058	23.4
27001	9	0.110	46.7
32011	25	0.073	70.1
39001	31	0.108	50.7
1041	32	0.061	116
18016	20	0.176	117
33001	25	0.038	76.1
14033	9	0.749	78.9
34009	33	0.023	117
34007	53	0.041	152
28001	17	1.391	169
38001	33	0.067	111
30001	18	0.518	121
23001	33	0.038	192
18050	24	0.127	249
3051	15	1.889	143
8012	19	0.411	26.0
22003	10	0.576	271
24030	25	0.185	259
22006	51	0.026	329

Pooled distributions for further consideration if different from EV1 and LN2:


**Final pooled growth factors**

insert growth factor table from pooled analysis spreadsheet here  
for the following RPs

RP	GF (EV1)	GF (LN2)	GF (LO)
2	1.00	1.00	1.00
5	1.26	1.26	1.32
10	1.44	1.42	1.51
20	1.60	1.57	1.68
50	1.82	1.75	1.90
100	1.98	1.89	2.06
200	2.14	2.02	2.22
1000	2.51	2.32	2.60

**Comments:**

Shannon RBD Design Hydrology

## CALCULATION AUDIT TRAIL

### PART A4.A2 - Pooled analysis site A

Site name:

Gauging station No:

Table A4.1 Pooled analysis file location

Description	File path
Pooled analysis	\\Europe.jacobs.com\reading\Projects\32103000 - Shannon CFRAMS Study\Hydrological Assessment\A) Modelling\UoM 23\Feale catchment model\S17\S17 Pooled FloodFrequency Analysis_Corrected

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	23_497_2
Area	21.55
BFI	0.62
SAAR	1098
FARL	1.00
URBEXT	2.02
FLATWET	0.64

Number of pooled years required: 500 years

STEP 1 Use OPW pooled flood frequency spreadsheet to generate pooled group with (many) more years than required. Give initial number of years:

Is subject site in pooled group? ☐ Yes ☒ No at ranked position:

Give reason if not at position 1:

**Then move the subject gauging station to number 1 by setting distance measure Dij to 0.**

STEP 2 Remove sites with record lengths of 8 years or less.

Table A4.2 Stations removed due to short record

Station No	No of years of data

STEP 3 Remove sites with outlying AREA, BFIsoil, FARL, URBEXT or FLATWET (to ensure homogeneity of the pooling group)

AREA	between 0.25 and 4 times the area of the subject site
BFIsoil	+/- 25% of subject site
SAAR	+/- 25% of subject site
FARL	+/- 10% of subject site
URBEXT	+/- 2.5
FLATWET	(FORMWET) +/- 0.10 (half of total range)

These criteria can be relaxed in some circumstances if agreed with reviewer.  
Add reviewer initials to the table below for deviations from the criteria above.

Table A4.4 Stations with outlying catchment descriptors

Station	Removed or kept with explanation + Reviewer initials if kept
25040	Removed - URBEXT outwith prescribed threshold
22009	Removed - URBEXT outwith prescribed threshold
36071	Removed - FARL outwith prescribed threshold
26010	Kept - AREA = 4.4 x Target Area
25044	Kept - AREA = 4.3 x Target Area
10022	Removed - SAAR / URBEXT outwith threshold
30021	Kept - AREA = 4.8 x Target Area
19001	Kept - AREA = 4.8 x Target Area
10021	Removed - SAAR / URBEXT outwith threshold
29004	Removed - AREA outwith relaxed threshold
29001	Removed - AREA outwith relaxed threshold
26018	Removed - FARL / AREA outwith prescribed threshold
25027	Removed - AREA outwith relaxed threshold
9035	Removed - SAAR / URBEXT outwith threshold
26009	Kept - AREA = 4.6 x Target Area
8002	Removed - SAAR outwith prescribed threshold

STEP 4 Remove sites with high discordancy Di  
Discordancy limit used:

3.0

Table A4.3 Stations removed due to discordancy

Station No	Discordancy

STEP 5 Revisit STEPS 1 to 4

The pooling group may need to be revised several times until a pooling group has been developed that is suitably homogeneous.

Copy the tables from steps 1-4 to below Step 5 to record removed sites in additional iterations of the process.

Note that the nature of the subject site may mean that the pooling group will always be heterogeneous in which case the use of pooled analysis will need to be reconsidered in agreement with the reviewer.

insert additional iterations of Steps 1-4 here

## Final pooling group

Table A4.5 Final pooling group summary

Station No	Years of data	Discordancy	Area (km2)
30020	16	0.059	21.4
6030	27	0.603	10.4
24022	20	0.059	41.2
13002	19	0.035	63.0
25034	26	0.541	10.8
16051	13	0.495	34.2
16006	33	0.240	75.8
19046	9	0.326	63.2
26058	24	0.264	60.0
6031	18	0.962	46.2
19020	28	0.242	74.0
26022	33	0.146	61.9
26010	35	0.070	94.5
25044	40	0.045	92.5
16005	30	0.109	84.0
30021	26	0.210	103.6
19001	48	0.057	103.3
6033	25	1.738	55.2
26009	35	0.135	98.2

Pooled distributions for further consideration if different from EV1 and LN2:


## Final pooled growth factors

insert growth factor table from pooled analysis spreadsheet here for the following RPs

RP	GF (EV1)	GF (LN2)	GF (LO)
2	1.00	1.00	1.00
5	1.30	1.30	1.37
10	1.50	1.49	1.59
20	1.69	1.67	1.79
50	1.94	1.90	2.04
100	2.13	2.07	2.23
200	2.31	2.24	2.41
1000	2.74	2.63	2.84

**Comments:** The FSU recommends a pooling-group size that is five times the target return period (the 5T rule). In this instance the pooling group is based on 505-years of AMAX event data, corresponding to a 100-year target return period. Growth curves have been extended to include estimates for the 200-year and 1000-year return periods, but due to the number of AMAX events being less than 5T the estimates will be less certain and should be treated with caution.

## Appendix H      Geomorphology Assessment



# Shannon Catchment-based Flood Risk Assessment and Management Study

Office of Public Works

## Geomorphology Assessment

## Final Report





## Executive Summary

The Office of Public Works (OPW) has commissioned Jacobs to undertake a geomorphological assessment to help inform the Catchment Flood Risk and Management Strategy (CFRAMS) for the River Shannon in the Republic of Ireland. This requires information to be provided on both erosion and sedimentation risks in the catchment.

Given the uncertainties of working at a strategic level with limited data and information two complementary geomorphological approaches have been used independently to increase confidence in the observations made:

- Approach One: a 'top-down' approach founded largely on an existing British River typology; and,
- Approach Two: a 'bottom-up' approach using catchment level information.

The first approach (Approach One) classified the catchment by using variables including the altitude, historic channel activity and geology. Using this information a high level understanding of river channel types and associated potential risks of erosion and deposition has been developed. The key deliverables obtained through this approach are maps showing river channel type, risk of erosion and risk of deposition.

The second approach (Approach Two) used various data and information sources to obtain measurements of slope, stream power, sinuosity, land use, soil type, bedrock, historical change, structures and waterfall locations for the catchment, albeit at a strategic level. From this a series of scenarios has been created using the variables to create three outputs highlighting risks of erosion and deposition and a specific output focusing solely on stream power and soil type.

Both approaches identified key parts of the catchment that could potentially be at risk of erosion and/or deposition or more generally of morphological change. It should be noted that both approaches are strategic and that at this level the data/information is not focused on individual channels. No site work was undertaken to ground truth the strategic findings and the analyses drawn from this report need to be caveated accordingly.

The two approaches did lead to similar findings, suggesting some form of validity in the information/data used. In particular two key areas of the Shannon catchment have been highlighted to be at potential risk of deposition and/or erosion, namely the northern and south western areas. The two approaches have allowed the potential for geomorphological change to be assessed across the entire Shannon catchment and specifically for the management units used in the wider hydrological study. From this strategic study it has been found (overall) that the hydrological sites are located in areas of medium to high risk of either erosion and/or deposition. This would indicate a potential for future management intervention such as repeated dredging and/or bank reinforcement (dependent on the solutions adopted for tackling flood risk).

## Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Aims and Objectives	1
1.2	Study Area	1
1.3	What is Fluvial Geomorphology?	1
<b>2</b>	<b>Methodology</b>	<b>4</b>
2.1	Approach One	4
2.1.1	Classification	4
2.1.2	Mapping River Channel Types	4
2.2	Approach Two	7
2.2.1	Variables	7
2.2.2	Variables	8
2.3	Limitations and Assumptions	12
<b>3</b>	<b>Shannon Catchment Background Information</b>	<b>13</b>
3.1	Catchment Overview	13
3.2	Water Framework Directive	14
<b>4</b>	<b>Approach One – Data Representation and Analysis</b>	<b>16</b>
4.1	Overview	16
4.2	River Channel Typology Description and Risks	16
4.3	Locations of River Channel Types	17
<b>5</b>	<b>Approach Two – Data Representation and Analysis</b>	<b>23</b>
5.1	Overview	23
5.2	Areas at Risk of Erosion	23
5.3	Areas at Risk of Deposition	26
5.4	Stream Power and Soil Type	29
<b>6</b>	<b>Summary of Approach One and Approach Two</b>	<b>31</b>
<b>7</b>	<b>Analysis of Hydrological Sites</b>	<b>32</b>
7.1	Unit of Managemet 23	32
7.2	Unit of Management 24	32

7.3	Unit of Management 25 & 26	32
7.4	Unit of Management 27	32
<b>8</b>	<b>Summary, Recommendations and Next Steps</b>	<b>39</b>
<b>9</b>	<b>References</b>	<b>40</b>
	<b>Appendix A Gauging Station Information Sheets</b>	<b>1</b>

## 1 Introduction

As part of a hydrological study of the Shannon catchment, The Office of Public Works (OPW) in Ireland has commissioned Jacobs to carry out a high level geomorphological assessment to establish sites/areas susceptible to erosion/deposition risks and to determine the potential for morphological change more generally. This information should potentially help inform the types of flood risk management solution recommended for a site.

Given the uncertainties of working at a strategic level with limited data and information two complementary geomorphological approaches have been used independently to try to increase confidence in the observations made:

- Approach One: a 'top-down' approach founded largely on an existing British River typology; and,
- Approach Two: a 'bottom-up' approach using catchment level information.

### 1.1 Aims and Objectives

The primary aim of this geomorphological study is to identify sites/areas (management units) at risk of change through erosion and/or deposition. This additional data/information should help inform the suitability of particular flood risk management options proposed.

### 1.2 Study Area

This report focuses on the Shannon catchment, with a catchment area of over 18,000km<sup>2</sup> and consists of the River Shannon and a network of major and minor tributaries and sub-catchments. The River Shannon is approximately 360.5km in length. For the purposes of the hydrological assessment, which this geomorphological study feeds into, the Shannon catchment has been subdivided into units of management. Figure 1.1 shows the study area and the units of management adopted.

### 1.3 What is Fluvial Geomorphology?

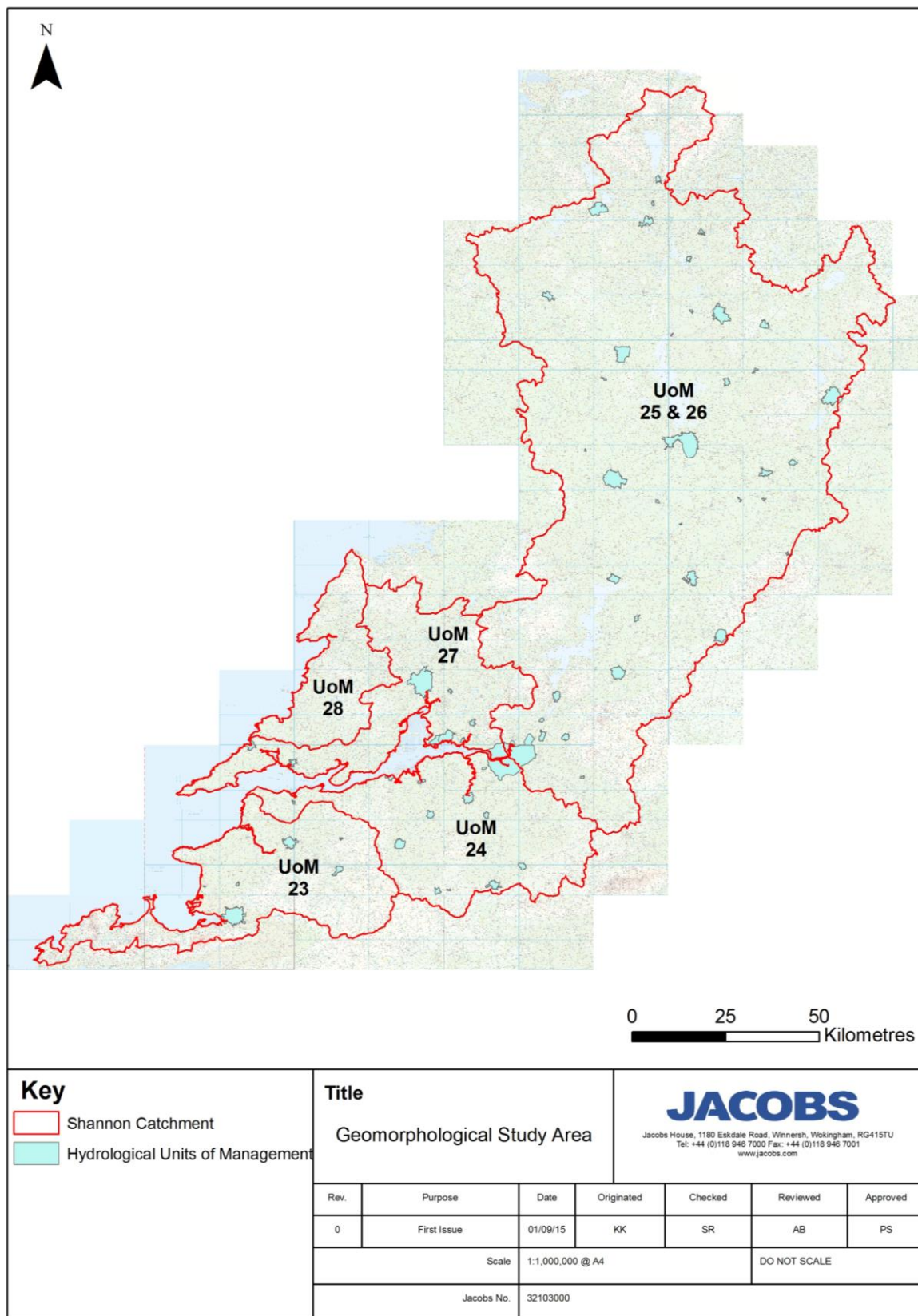
This study concerns fluvial geomorphology which is the study of landforms associated with river channels and the processes that form them. It considers the process of sediment transfer (erosion, transport and deposition) in river systems and also the relationship between channel forms and processes.

The geomorphological form of a river channel and valley floor is complex and influenced by many different factors and inter-related processes. Controls influencing the river system include external controls and internal controls. External controls include catchment geology, topography, soil type, climatic trends and land management practices. Internal controls may include bed and bank materials, vegetation characteristics, gradient, cross-sectional morphology and flow conditions. These controls interact to determine fluvial processes, such as flow and sediment transport, which in turn, influence channel form.

As a natural system, a river evolves in response to natural influences. However, rivers are often significantly affected by human activities. Artificial structures in the river, alterations to the channel dimensions and land management around it can have major implications for river forms and processes. Changes in one part of the

river catchment either through natural or human activity can result not only in geomorphological adjustment over time at that point, but also in changes upstream and downstream. An understanding of the controls on channel morphology is required before an action to enhance conditions or reduce and mitigate the impacts of current or future activities is decided upon.

Hydromorphology is a specific term coined by the Water Framework Directive (Directive 2000/60/EC). It refers to the relationship between hydrological processes and the morphological effects and encompasses key factors such as river width and depth, riparian zone, longitudinal profile, lateral profile, groundwater connectivity and bed substrate. Within this report hydromorphology and fluvial geomorphology are taken to be synonymous.



**Figure 1.1 Geomorphological assessment study area**

## 2 Methodology

To assess the risk of erosion and deposition, two distinct approaches have been followed. The first (Approach One) has used a ‘top-down’ method to create a crude typology of channels, using a combination of informed professional judgement and aerial photography. Approach Two has collected a database of information and data which has been variously combined to develop a score, providing an indication of potential risk for erosion and/or deposition (subsequently mapped at the catchment scale). Both approaches allow outputs to be displayed at a catchment scale, showing areas at potential risk of erosion and deposition. These outputs have then subsequently been compared to the hydrological units of management identified in the overarching hydrological study to establish any potential risk of geomorphological change.

### 2.1 Approach One

#### 2.1.1 Classification

Channels have been classified into five broad river typologies, outlined in Table 2.1. These correlate approximately to the channel types identified for British Rivers in general in Ferguson (1986). The humid-temperate climate and glaciated landscape of Britain is assumed in this study to translate across to the Shannon Catchment. This typology has been applied to the catchment using desk study information on geology and altitude, channel pattern and stream power, photographs previously gathered from the previous hydrological site visits to the Shannon and aerial photography, together with informed professional judgement. This has led to the broad typing of channels at a catchment scale.

#### 2.1.2 Mapping River Channel Types

River channel types have been assigned based on the specific altitudes of the catchment (see Table 2.1) and an overview assessment of historical channel change (using maps) indicating potential natural adjustment. The following briefly summarises the definition of each of the types:

- Type 1 river channels - below the 40m contour;
- Type 2 river channels - inactive channels between the 40m and 300m contours;
- Type 3 river channel - between the 40m and 60m contours and active;
- Type 4 river channels - between the 60m and 300m contours; and,
- Type 5 river channels - above the 300m contour.

A GIS platform was used to generate the different types



Channel Type	Description	Potential River Management Issues	Key Features	Comments
<b>Type 1</b>	<p>Lower catchment channels:</p> <ul style="list-style-type: none"> <li>Those having not perceptibly changed their courses (naturally);</li> <li>Low to very low energy;</li> <li>Predominantly sediment sinks;</li> <li>Likely to have regular to irregular sinuosity (note: straight channels extremely rare in nature);</li> <li>Tree-lined gravelly channels to clay bound channels;</li> <li>Sinuosity could have been inherited from early Holocene times; and,</li> <li>Includes clay channels found locally on glacio-lacustrine and glacio-marine sediments.</li> </ul>	<p>Maintenance of flood schemes (e.g. involving widening and/or deepening) probably concentrating on the need to remove accumulated finer sediments (from point and diffuse sources upstream).</p>	<ul style="list-style-type: none"> <li>Less than 40m contour; and,</li> <li>Alluvium as shown on drift geology map.</li> </ul>	None.
<b>Type 2</b>	<p>Inactive alluvial channels:</p> <ul style="list-style-type: none"> <li>Narrow valleys of the main stem of the Shannon and its tributaries;</li> <li>Little scope for meander development;</li> <li>Confined channel patterns;</li> <li>Likely to be a legacy from the Ice Age (i.e. palaeohydrological origin); river terraces could be present; and,</li> <li>Could be locally cut into rock sides.</li> </ul>	<p>Due to the confined flood risk could be low, obviating the need for flood risk management solutions such as intervention. However, if settlements located in the valley bottom then could be localised issues of migration of channels. Sedimentation of artificially enlarged channels likely to occur.</p>	<ul style="list-style-type: none"> <li>Areas between the 40m and 300m contours; and,</li> <li>Alluvium as shown on drift geology map.</li> </ul>	None.
<b>Type 3</b>	<p>Self-formed alluvial channels:</p> <ul style="list-style-type: none"> <li>Moderate energy;</li> <li>Predominantly a sediment exchange (transfer);</li> <li>Can be described as an active mobile gravel bed river;</li> <li>Presence of active meandering;</li> <li>Bedload likely to be a mix of coarse and fine gravels to coarse gravels carried from upstream; and,</li> <li>Well defined pools and riffles and bar features; mature floodplain with a fining upwards sequence of sediments.</li> </ul>	<p>Lower risk of erosion than Type 4 but probably a higher risk of sediment issues than Type 4.</p> <p>Generally a moderate to high risk of erosion of embankments. Local modifications to the channel morphology through flood works could cause a sediment sink (e.g. excavation through a town or an arterial drainage scheme). Over-deep and over-wide channels could attempt to adjust to a more natural cross-section through sediment deposition (in the absence of maintenance).</p> <p>Previously straightened channels could have partially recovered sinuosity.</p>	<ul style="list-style-type: none"> <li>Areas between the 40m and 60m contours;</li> <li>Alluvium as shown on drift geology map; and</li> <li>Historically active.</li> </ul>	Field drains in Piedmont alluvial floodplain not included. Tributaries on floodplain of main stem may exhibit some of the characteristics of Type 4 channels.

<b>Type 4</b>	<p>Self-formed alluvial channels: Piedmont</p> <ul style="list-style-type: none"> <li>• High energy;</li> <li>• Predominantly a sediment exchange (transfer);</li> <li>• Can be described as an active mobile gravel bed river;</li> <li>• Presence of active meandering;</li> <li>• Bedload likely to be coarse gravels carried down from Type 1 channels and deposited on less steep slopes;</li> <li>• Exposed point bars; and</li> <li>• Could be some fine silt from diffuse pollution sources such as agriculture.</li> </ul>	<p>Higher risk of erosion of embankments (i.e. would require embankments to be located outside of the meander belt to avoid erosion). Local modifications to the channel morphology through flood works could cause a sediment sink (e.g. excavation through a town or an arterial drainage scheme).</p> <p>Previously straightened channels could have partially or fully recovered their sinuosity.</p>	<ul style="list-style-type: none"> <li>• Areas between the 60m and 300m contours;</li> <li>• Alluvium as shown on drift geology map; and,</li> <li>• Historically active.</li> </ul>	<p>Field drains in Piedmont alluvial floodplain not included. Tributaries on floodplain of main stem could exhibit some of the characteristics of Type 4 channels.</p>
<b>Type 5</b>	<p>Bedrock channels:</p> <ul style="list-style-type: none"> <li>• High energy;</li> <li>• Inherently stable; and,</li> <li>• Predominantly sediment sources.</li> </ul>	<p>Assumed little need for flood risk management. Erosion and deposition not likely to be relevant management issue. Areas of low population in uplands; relatively stable bed and banks; predominantly erosion (sediment sources).</p>	<ul style="list-style-type: none"> <li>• Areas above the 300m contour.</li> </ul>	<p>Peat bogs/peat channels and local field drains could be present but not included at this scale.</p>

**Table 2.1**      **River channel typology**

## 2.2 Approach Two

A Geographic Information System (GIS) has been used to develop a database of information and desk based data, subsequently manipulated to inform this high level geomorphological assessment. The overall outputs are three key maps highlighting areas potentially at risk of erosion and deposition and another plan taking into account the two key variables, soil type and stream power. The following data sources were used:

- Contemporary OS maps (Magic, 2015);
- Aerial photography (Bing, 2015);
- Flood maps (OPW, 2015);
- Historic maps (OSI, 2015); and,
- Hydrology data (CEH, 2015).

### 2.2.1 Variables

To establish the potential for erosion and deposition at a catchment scale, the relationships between multiple variables were assessed, including both natural and anthropogenic factors. These included historical change, stream power, sinuosity, soils, land use and slope. The following provides a brief description of each variable.

#### Stream Power

Stream power ( $\Omega$ ) represents the potential energy loss rate per unit length of the channel. Stream power is the product of gravitational acceleration ( $g = 9.8\text{m/s}^2$ ), discharge ( $Q$ ,  $\text{m}^3/\text{s}$ ), water surface slope ( $S$ ), and the density of water ( $\rho = 1000\text{kg/m}^3$ ) (Eq. 1). As stream power increases, the risk of erosion increases, and (generally) the risk of long-term deposition decreases. The risk ratings for each output are shown in Tables 2.2, 2.3, and 2.4. Stream power has been classified into five categories:  $<10\text{Wm}^{-2}$ ;  $10\text{-}35\text{ Wm}^{-2}$ ;  $35\text{-}100\text{ Wm}^{-2}$ ;  $100\text{-}300\text{ Wm}^{-2}$ ; and over  $300\text{ Wm}^{-2}$ .

$$\Omega = \rho g Q S \quad (\text{Eq. 1})$$

#### Soil

Soil type can affect the rate at which the surrounding land is eroded and the likelihood of a specific area being susceptible to erosion. Soil type, derived from the Irish Soil Information System (EPA, 2015), has been mapped and put into five categories. These are bedrock at the surface; made ground; peat; glacial till and alluvium. The more resistant the soil type, the smaller the risk of erosion and deposition. Therefore, bedrock and made ground have been classed as low risk, peat has been judged to be medium risk, and glacial tills and alluvium have been classed as high risk.

#### Sinuosity

The channel planform is reflected by the sinuosity index ( $S_i$ ); this is the ratio between the actual length of the main channel and tributaries, and the straight length of the main channel and its tributaries. The more variable the channel planform, i.e. the more sinuous, it has been assumed that there is a higher the potential for erosion and/or deposition to occur. Sinuosity was used for both the assessment of the potential risk of erosion and deposition. Sinuosity has been mapped and classified into five categories: less than 1.05; 1.05-1.3; 1.3-1.6; 1.6-2;

and greater than 2. A sinuosity value less than 1.05 is typically indicative of an artificially straightened channel. As the sinuosity of the channel increases, the risk of erosion or deposition also increases. Therefore for this study a sinuosity greater than 1.3 has been taken as low risk, a sinuosity of 1.3-1.6 w taken as medium risk, and sinuosity of greater than 1.6 as high risk.

### **Land Use**

Land use potentially impacts sediment movement and therefore the extent of erosion and deposition mapped. Land use has been mapped and then put into eight categories. These are artificial land; plantation; arable land; woodland; pasture; open space; wetland; and shrubs and herbs. Different land uses potentially affect the hydrology of an area, impacting flashiness of flood events, runoff rates, infiltration rates and erosion rates.

### **Slope**

The slope of a channel affects sediment transport and the potential for erosion and deposition. Slope was mapped and then classed into five categories. These are  $s=0-0.2$ ;  $0.2-10$ ;  $10-100$ ;  $100-200$ ; and  $200+$ . As the slope of a river channel increases, so risk of erosion increases, risk of deposition decreases and stream power increases.

### **Historical Channel Change**

Some historical analysis of the Shannon catchment has been undertaken, and any evidence of historical change recorded. This variable has been divided into five categories: naturally migrating; realigned and sinuous; channelized; newly built field drains; and newly built canals. This data layer has only been used to assess the risk of erosion. The erosion risk of each category has been identified: naturally migrating channels potentially at high risk of erosion, realigned channels and channelized channels at medium risk of erosion, and any built channels at low risk of erosion.

### **Other Factors**

Various other factors have been mapped but not used in any of the reported output calculations. These have been deemed as potentially important and could have local risks associated with them. Structures have been mapped as they could impact on sediment regime. These included various types of weirs, sluices and embankments. Locations of waterfalls have also been mapped, as these could have indicated active migration if not within areas of bedrock.

#### **2.2.2 Variables**

All data layers have been converted from vector to raster, to a resolution of 1km. This resolution has been chosen as it suitably reflects the precision needed. For each of the three outputs, different weightings have been applied to each variable, as shown in Tables 2.2, 2.3 and 2.4. These weights have been used to combine the raster datasets in the weighted overlay process to create a corresponding output map. Once completed, the output raster dataset has been converted back into a vector dataset for ease of data handling.

Parameter	Ranking	Categories	Risk of Erosion	Notes
Historical change (evidence of change)	1	Canals (created)	Low	Low risk as likely reinforcement prevents erosion.
	2	Created field drains	Low	Low risk as low discharges and straight planforms indicate a relatively inactive channel with little erosion.
	3	Channelized	Medium	Medium risk as influenced by humans and possibly dynamic.
	4	Realigned (sinuous)	High	High risk as recovering back to a sinuous state, and therefore an active channel readily eroding.
	5	Naturally migrating	High	High risk as indication of an active channel, therefore readily eroding.
Stream power	1	<10	Low	Low risk due to low energy.
	2	10-35	Medium	Medium risk due to moderate energy
	3	35-100	Medium	Medium risk due to moderate energy
	4	100-300	High	High risk due to high energy.
	5	>300	High	High risk due to high energy.
Sinuosity	1	<1.05	Low	Low risk as a straight channel (evidenced over time) indicates reluctance to change and therefore less potential erosion.
	2	1.05-1.3	Low	Low risk as a relatively straight channel (evidenced over time) indicates reluctance to change and therefore less potential erosion.
	3	1.3-1.6	Medium	Medium risk as the channel can have a highly sinuous channel that formed in last glacial period and is not currently active.
	4	1.6-2	High	High risk as high sinuosity possibly indicates an active channel with erosion.
	5	>2	High	High risk as high sinuosity possibly indicates an active channel with erosion.
Soil type	1	Bedrock at the surface	Low	Low risk due to high resistance to erosion.
	2	Made ground	Low	Low risk due to high resistance to erosion.
	3	Peat	Medium	Medium risk due to moderate resistance to erosion.
	4	Glacial till	High	High risk due to low resistance to erosion if unconsolidated tills or sand. However, possible consolidation increases resistance.
	5	Alluvium	High	High risk due to lowest resistance to erosion.
Land Use	1	Artificial land	Low	Low risk due to high resistance to erosion.
	2	Plantation/ arable	Low	Low risk due to high resistance to erosion.
	3	Woodland/ pasture	Medium	Medium risk due to moderate resistance to erosion.
	4	Open space	High	High risk due to low resistance to erosion.
	5	Wetland/ shrub/ herb	High	High risk due to low resistance to erosion, and could act as sediment sources.

Slope	1	<0.2	Low	Low risk due to decreased stream power (i.e. lower slope) and lower potential for geomorphological work, including erosion.
	2	0.2-10	Low	Low risk due to decreased stream power (i.e. lower slope) and lower potential for geomorphological work, including erosion.
	3	10-100	Medium	Medium risk due to moderate stream power and moderate potential for geomorphological work, including erosion.
	4	100-200	High	High risk due to increased stream power and higher potential for geomorphological work, including erosion. Lateral adjustment could also be apparent.
	5	>200	High	High risk due to increased stream power and higher potential for geomorphological work, including erosion. Lateral adjustment could also be apparent.

**Table 2.2 Erosion ranking of variables**

Parameter	Ranking	Categories	Risk of Deposition	Notes
Stream Power	1	>300	Low	Low risk due to fast flowing water reducing potential deposition.
	2	100-300	Low	Low risk due to fast flowing water reducing potential deposition.
	3	35-100	Medium	Medium risk due to moderate potential for geomorphological work, including deposition.
	4	10-35	High	High risk due to high potential for geomorphological work, including deposition.
	5	<10	High	High risk due to high potential for geomorphological work, including deposition.
Sinuosity	1	<1.05	Low	Low risk as a straight channel indicates reluctance to change, and therefore less potential for deposition.
	2	1.05-1.3	Low	Low risk as a relatively straight channel indicates reluctance to change, and therefore less potential for deposition.
	3	1.3-1.6	Medium	Medium risk as the channel can have a highly sinuous channel that formed in last glacial period and not currently active.
	4	1.6-2	High	High risk as high sinuosity indicates an active channel with deposition.
	5	>2	High	High risk as high sinuosity indicates an active channel with deposition.
Soil Type	1	Bedrock at the surface	Low	Low risk due to high resistance to erosion, leading to small sediment yield within channels.
	2	Made ground	Low	Low risk due to high resistance to erosion, leading to small sediment yield within channels.
	3	Peat	Medium	Medium risk due to moderate resistance to erosion, leading to moderate sediment yield within channels.
	4	Glacial till	High	High risk due to low resistance to erosion of tills or sand, increasing sediment yield within channels. However, possible consolidation increases resistance.
	5	Alluvium	High	High risk due to lowest resistance to erosion, increasing sediment yield within channels.
Land Use	1	Woodland/ wetland	Low	Low risk due to high resistance to erosion, leading to small sediment yield within channels.
	2	Shrub/ herb veg	Low	Low risk due to high resistance to erosion, leading to small sediment yield within channels.

Slope	3	Open space/ artificial land	Medium	Medium risk due to moderate resistance to erosion, leading to moderate sediment yield within channels.
	4	Plantation/ pasture	High	High risk due to low resistance to erosion, leading to high sediment yield within channels.
	5	Arable	High	High risk due to low resistance to erosion and potential sediment sources, leading to high sediment yield within channels.
	1	>200	Low	Low risk due to decreased stream power, and lower potential for geomorphological work, including deposition.
	2	100-200	Low	Low risk due to decreased stream power, and lower potential for geomorphological work, including deposition.
	3	10-100	Medium	Medium risk due to moderate stream power, and moderate potential for geomorphological work, including deposition.
	4	0.2-10	High	High risk due to increased stream power, and higher potential for geomorphological work, including deposition. Lateral adjustment could also be apparent.
	5	<0.2	High	High risk due to increased stream power, and higher potential for geomorphological work, including deposition. Lateral adjustment could also be apparent.

**Table 2.3 Deposition ranking of variables**

Parameter	Ranking	Categories	Risk of Change	Notes
Stream Power	1	<10	Low	Low risk due to low energy and low potential for geomorphological work.
	2	10-50	Medium	Medium risk due to moderate energy and moderate potential for geomorphological work.
	3	50-150	High	High risk due to high energy and high potential for geomorphological work.
	4	150-300	High	High risk due to high energy and high potential for geomorphological work.
	5	>300	High	High risk due to high energy and high potential for geomorphological work.
Soil Type	1	Bedrock at the surface	Low	Low risk due to high resistance to erosion, leading to small sediment yield within channels.
	2	Made ground	Low	Low risk due to high resistance to erosion, leading to small sediment yield within channels.
	3	Peat	Low	Low risk due to high resistance to erosion, leading to small sediment yield within channels.
	4	Glacial till	Medium	Medium risk due to moderate resistance to erosion of tills or sand, leading to moderate sediment yield within channels. However, possible consolidation increases resistance.
	5	Alluvium	High	High risk due to low resistance to erosion, leading to large sediment yield within channels.

**Table 2.4 Stream power and soil type ranking**



## 2.3 Limitations and Assumptions

The two approaches to assessment have been undertaken using a combination of desk based information and informed professional judgement obtained by working on British Rivers in general. The approach is therefore necessarily strategic/high level and no field visits have been made from a geomorphological perspective to verify the conclusions drawn. It should be noted that the results do not identify specific areas of deposition or erosion, but instead provide potential areas that could be at risk of erosion or deposition.

The following are specific assumptions and limitations of the two approaches:

- Approach One has assumed that all rivers above the 300m contour are likely to be predominantly bedrock channels. For the purposes of this assessment it is also assumed that there are no bedrock channels present below the 300m contour. The limitation is that an arbitrary contour might not be a suitable surrogate for channel slope measured between two contours and seen as a key variable used in stream power calculation (which can be related to channel type);
- Approach One assumes that all channels below the 40m contour and above the 300m contour are stable. The limitation is again that an arbitrary contour might not be a suitable surrogate for channel slope measured between two contours and seen as a key variable used in stream power calculation (which can be related to channel type);
- Approach Two has assumed that the sinuosity index is reflective of the entire catchment or sub-catchment (i.e. tributaries and drains), even though it has been calculated using the main stem of a reach of river only;
- For Approach Two the values for slope and stream power have been taken from available point data sources and are assumed to be reflective of adjacent reaches/areas. The stream powers have been calculated using a high level/strategic assessment of the bankfull width of a river at a specific data point;
- Approach Two has used informed professional judgement of the authors (based substantially on experience of British rivers) to develop variables used to define each category, with the scoring using a non-weighted approach to define the risks of erosion and deposition; and,
- For both approaches it has been assumed that all areas of historical channel change have been identified using available historical mapping.

### 3 Shannon Catchment Background Information

#### 3.1 Catchment Overview

At 360.5km, the River Shannon is the longest river in Ireland, draining a relatively enormous area of over 18,000km<sup>2</sup>. The Shannon is flat, with the majority of the fall in altitude taking place on the 24km stretch between Killoe and Limerick. The Shannon flows southwards from Shannon Pot in County Cavan, before then flowing westwards to the 102.1km Shannon Estuary. Numerous tributaries contribute to the Shannon before discharging into Lough Allen. The river then flows through 11 Irish counties, incorporating the key tributaries of Boyle, Inny, Suck, Mulkear and Brosna, as well as several others, before reaching Limerick and the Shannon Estuary. Many artificial canals also connect to the River Shannon.

The Shannon is a traditional freshwater river for 45% of its total length, due to an extensive estuary. There are also 1,600 lakes in the Shannon catchment, with many located along the main channel.

Anthropogenic impacts are apparent throughout the catchment. Some of the watercourses have been heavily modified for uses such as navigation, water storage and public drinking water supply. These include Foynes Harbour, Limerick Dock, Doo Lough, Lough Derg and the River Fergus tidal barrage. A number of other watercourses are man-made, including the Grand Canal, Royal Canal and Shannon Erne waterway. These artificial channels provide important uses and benefits to society, with examples such as the Ardnacrusha hydroelectric power generation station which was built between Killaloe and Limerick, during the 1920s.

Limestone rocks dominate the geology of the Shannon District. The Burren in County Clare is well known for its seasonal lakes and disappearing rivers during prolonged dry spells. The most productive aquifers are located mainly in East Galway and Roscommon, contributing to approximately half of surface water.

There are a number of water dependent protected areas in the Shannon catchment, as summarised in Table 3.1.

Protected Areas	Legislation	Locations
Drinking Waters	The European Communities (Drinking Water (No. 2) Regulations 2007 (SI 278 of 2007)	Drumcliff, Ballinaguard
Shellfish Waters	European Communities (Quality of Shellfish Waters) Regulations 2006 (SI 268 of 2006) as amended in 2009	Inner Tralee Bay
Bathing Waters	Bathing Water Quality Regulations SI 79 of 2008	Kilkee, Lough Derg
Nutrient Sensitive Areas	Urban Waste Water Treatment Regulations 2001 (SI 254 of 2001) as amended in 2004 and 2010	The Brosna, the Upper Feale estuary
Special Areas of Conservation	European Communities (Natural Habitats) Regulations, SI 94 of 1997 as amended in 1998 and 2005. Environmental Objectives (Freshwater Pearl Mussel) Regulations (SI 296 of 2009)	River Shannon Callows, Lower Shannon Estuary, Clara Bog, Lough Ree
Special Protection Areas	European Communities (Natural Habitats) Regulations, SI 94 of 1997 as amended in 1998 and 2005	

**Table 3.1 Water dependent protected areas within the Shannon Catchment (EPA, 2010)**

### 3.2 Water Framework Directive

The Water Framework Directive (WFD) (Directive 2000/60/EC) is a significant piece of EU water legislation that came into force in 2000, with the overarching objective of enabling all water bodies in Europe to attain Good or High Ecological Status. In addition, any modification to a water body should not lead to deterioration in the status of a water body or any of the quality elements.

The surface water ecological status combines three factors: biological factors (including fish, aquatic invertebrates, diatoms, macrophytes, filamentous algae and phytoplankton), physico-chemical factors (including oxygen, nutrients, transparency, temperature, acidity, salinity and specific pollutants) and hydromorphological factors (including flow, lake level and tidal patterns). Reaches are classified into high, good, moderate, poor and bad status. Surface water ecological statuses for the Shannon Catchment are stated below in Table 3.2.

Waterbody	Satisfactory (high or good ecological status)	Unsatisfactory (moderate, poor or bad status)	Yet to be assigned
Rivers and Canals	42%	57%	1%
Lakes	43%	55%	2%
Estuaries	35%	35%	30%
Coastal Waters	27%	0%	73%

**Table 3.2 Surface water ecological status (EPA, 2010)**

There are 46 rivers, 16 lakes and one coastal water body classified by the Environmental Protection Agency (EPA) under the WFD as high status. These areas are affected negligibly by human activity, some at or near natural conditions and supporting naturally diverse aquatic wildlife. These areas are important for supporting species sensitive to enrichment or increased siltation, such as freshwater peal mussel and juvenile salmon. Presence of these areas increases overall species diversity and recolonization over the entire channel.

The Shannon River Basin Management Plan (RBMP) (Cycle 1) covers the period from 2009 and 2015, aiming to protect all waters within the Shannon catchment. This plan sets out to improve waters to reach at least good status by 2027. The four core objectives of the Shannon RBMP are to:

- Prevent deterioration;
- Restore good status;
- Reduce chemical pollution; and,
- Achieve water related protected areas objectives.

The EPA has highlighted a decline in high status waters over the past two decades. According to the 2009 EPA indicators report, the number of high quality river sites, nationally, has almost halved over the last 20 years and the Shannon catchment is one of the Districts with the greatest decline.

Some surface waters have been substantially changed in character or artificially constructed for uses such as navigation, water storage, public supply, flood defence, and land drainage. Twenty-one such waters have been designated as heavily modified waters or artificial waters in the Shannon International River Basin District. The objective for heavily modified waters and artificial waters is to achieve good ecological potential. This objective allows the important function of these waters to

be retained whilst ensuring that the ecology is protected or improved. The method used is based on a common approach, agreed between EU member states. The method requires a set of agreed mitigation measures to be implemented to improve the hydromorphological characteristics (water flow and physical conditions) as much as possible, without having significant adverse impacts on the function of these waters or the wider environment.

## 4 Approach One – Data Representation and Analysis

### 4.1 Overview

The analysis has been undertaken for the entire Shannon catchment. A channel typology has been developed using an existing British River typology, informed professional judgement, aerial photography and photographs taken from the overarching hydrological site visit. The risk of erosion and deposition for each river type has also been determined, as well as potential river management techniques. Five river channel types have been defined in this Report:

- Type 1: Lower catchment channels;
- Type 2: Inactive alluvial channels;
- Type 3: Self-formed alluvial channels;
- Type 4: Self-formed alluvial channels – Piedmont; and
- Type 5: Bedrock channels.

The following provides the outputs from the GIS maps and shows general areas of high and low risk of erosion and deposition.

### 4.2 River Channel Typology Description and Risks

Type 1 river channels are taken to be low energy alluvial channels located below the 40m contour in the Shannon Catchment. These channels are predominantly sediment sinks due to the low stream power. Therefore river management should focus mainly on restricting fine sediments input, especially from point and diffuse sources upstream.

Type 2 river channels are determined as stable alluvial channels, between the 40m and 300m contours, with little scope for meander development. These channels are predominantly sediment transfer zones due to their confined nature. Localised issues of channel migration could occur if settlements are located in the valley bottom. Sedimentation (requiring periodic maintenance) could occur within artificially enlarged channels.

Type 3 river channels are taken as moderate energy, between the 40m and 60m contours. These channels are predominantly sediment exchange zones with active meandering present. Type 3 channels have lower erosion risks than type 4 river channels, but greater potential sedimentation issues. Generic issues are listed as follows:

- Moderate to high risk of bank and embankment erosion;
- Over-deep and over-wide channels could attempt to adjust to a more natural cross-section through deposition;
- Local modifications to channel morphology through flood works could cause or enhance an existing sediment sink; and,
- Previously straightened channels could have partially recovered their sinuosity by active meandering processes.

Type 4 channels are determined to be high energy located between the 60m and 300m contours. These channels are predominantly sediment exchange zones with active meandering present. Type 4 river channels have higher erosion risks than

type 3 river channels, but lower sedimentation potential. Generic issues are listed below:

- High risk of bank and embankment erosion – bank protection could need to be positioned on the outside of meander bends preventing lateral erosion (and this could prove to be unsustainable and environmentally unacceptable);
- Local modifications to channel morphology through flood works could cause a sediment sink; and,
- Previously straightened channels could have partially recovered by regaining some of their former sinuosity.

Type 5 river channels are high energy bedrock channels above the 300m contour. These channels are predominantly sediment sources due to their steep gradient. Erosion and deposition are unlikely to be a management issue in these channels.

### 4.3 Locations of River Channel Types

The location of each river channel type has been discussed below and shown in Figure 4.1.

#### Type 1

Type 1 river channels are located within the lower catchment, below the 40m contour. Much of the main stem of the River Shannon is also classed as a type 1 river channel. Multiple lakes are found associated with this type, including Lough Ree and Lough Derg. The lowland rivers within County Clare and northern County Kerry are also classed as type 1.

This river channel type has been stated as having a low risk of erosion and a high risk of deposition.

#### Type 2

Type 2 river channels are inactive between the 40m and 300m contours. This river channel type covers the vast majority of channels within the catchment. Main areas where there are not as many type 2 river channels are around Limerick in County Limerick, Tralee in County Kerry, and within County Clare.

This river channel type has been stated as having a low to moderate risk of erosion and deposition.

#### Type 3

Type 3 river channels are located between the 40m and 60m contours and are active. There are few type 3 river channels throughout the catchment. These are mainly located in County Roscommon around Strokestown and Longford, in County Galway around Ballinasloe, in County Offaly around Birr, and small areas in County Limerick, Clare and Kerry.

This river channel type has been stated as having a moderate to high risk of erosion and deposition.

#### Type 4

Type 4 river channels are located between the 60m and 300m contours and determined to be likely to be active. There are few type 4 river channels throughout the catchment. These are mainly located in northern County Kerry around Tralee and Listowel, in central County Roscommon around Castlerea, and in County Westmeath around Castlepollard and Kilbeggan.

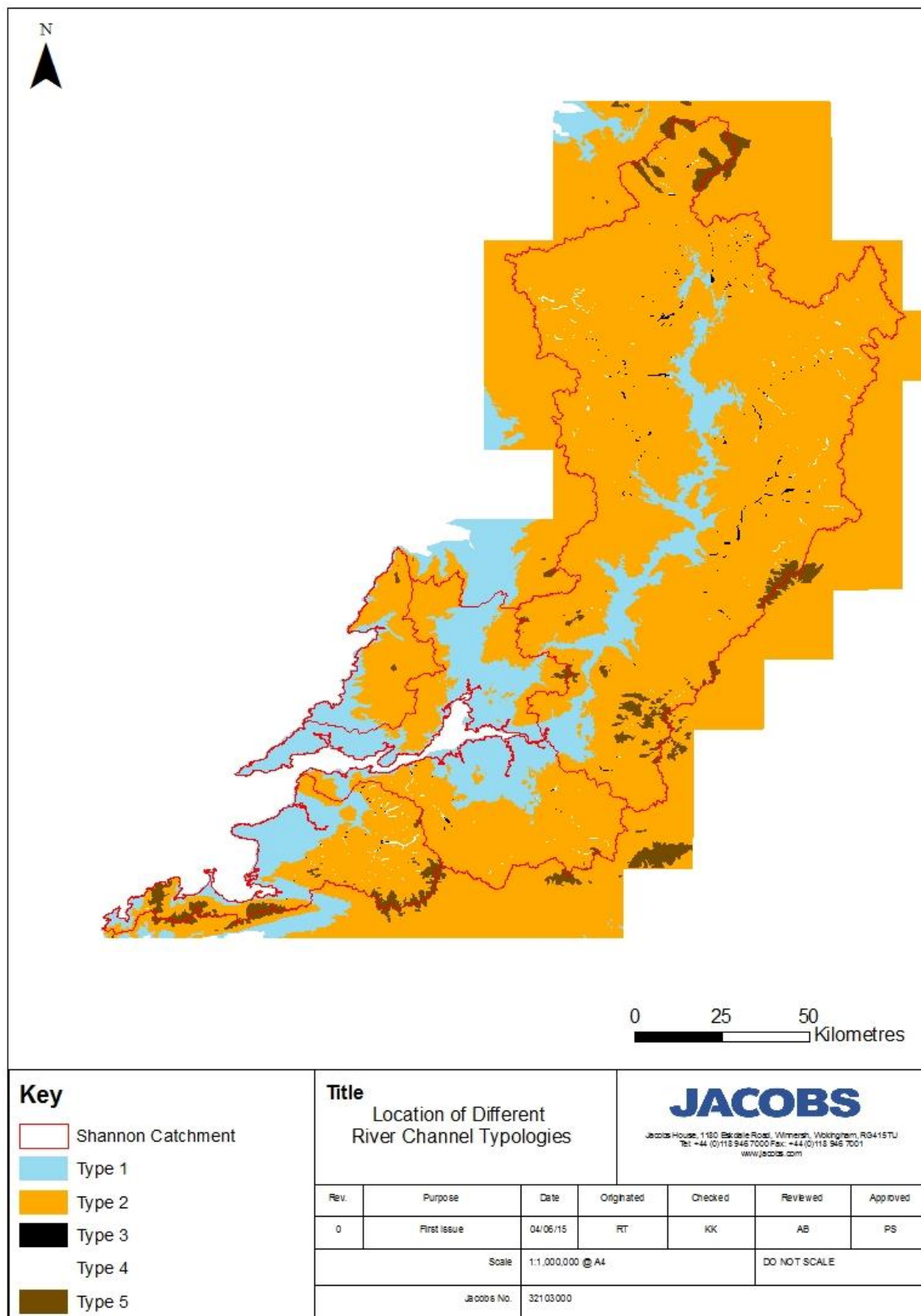
This river channel type has been stated as having a high risk of erosion and a moderate risk of deposition.

### **Type 5**

Type 5 river channels are located within the upper catchment, above the 300m contour. Apart from highlands to the east of Sligo, type 5 river channels are within the southern area of the catchment. Significant mountains where type 5 river channels are located include the Slieve Bloom Mountains, Slieve Felim Mountains, Silvermere Mountains, Mullaghreirk Mountains, Ballyhoura Mountains, Dartry Mountains, and Sieve Mish Mountians.

This river channel type has been determined in this study to have a very low risk of erosion and deposition.





**Figure 4.1 River channel types**

Different river channel types vary in degree of risk of erosion and deposition. Table 4.1 below summarises the risks to each type as well as potential river management techniques to mitigate risk.

River Channel Type	Significant Locations	Risk of Erosion	Risk of Deposition	Potential River Management Solutions
Type 1	<ul style="list-style-type: none"> <li>Main stem of the River Shannon;</li> <li>Lowland rivers in County Clare and County Kerry.</li> </ul>	Low	High	<ul style="list-style-type: none"> <li>Land management to prevent poaching of existing eroding banks and control of diffuse runoff from agricultural sources;</li> <li>Incorporate Sustainable Urban Drainage Systems (SuDS) and blue-green infrastructure into future developments, sustainably managing potential sources of sediment;</li> <li>Riparian corridor planting along eroding banks to minimise access to channel, addition of a buffer and removing some sediment sources; and,</li> <li>Dredging to remove fines directly from the channels (NB this could be unsustainable or environmentally undesirable).</li> </ul>
Type 2	<ul style="list-style-type: none"> <li>Throughout the catchment.</li> </ul>	Low to Moderate	Low to Moderate	<ul style="list-style-type: none"> <li>Incorporate Sustainable Urban Drainage Systems (SuDS) and blue-green infrastructure into future developments, sustainably managing potential sources of sediment;</li> <li>Land management to prevent poaching of existing eroding banks and control of diffuse agricultural sources; and,</li> <li>Riparian corridor planting along eroding banks to minimise access to channel, add a buffer and remove some sediment sources.</li> </ul>
Type 3	<ul style="list-style-type: none"> <li>River Brosna around Ferbane in County Offally;</li> <li>River Scramage around Strokestown in County Roscommon;</li> <li>Hind river around Roscommon in County Roscommon; and,</li> <li>The river network around Mohill in County Leitrim.</li> </ul>	Moderate to High	Moderate to High	<ul style="list-style-type: none"> <li>Land management to prevent poaching of existing eroding banks and agricultural diffuse runoff;</li> <li>Riparian corridor planting along eroding banks to minimise access to channel, add a buffer and remove some sediment sources;</li> <li>Incorporate Sustainable Urban Drainage Systems (SuDS) and blue-green infrastructure into future developments, sustainably managing potential sources of sediment;</li> <li>'Soft' bank reinforcement such as</li> </ul>

River Channel Type	Significant Locations	Risk of Erosion	Risk of Deposition	Potential River Management Solutions
				<p>vegetative techniques reducing erosion and increasing resilience of eroding banks;</p> <ul style="list-style-type: none"> <li>• 'Hard' bank reinforcement such as gabions and concrete bed/banks reducing erosion and increasing resilience of eroding banks (NB this may be unsustainable and environmentally unacceptable);</li> <li>• Flow deflectors to protect eroding banks, encouraging flow diversity and remove fine sediment; and,</li> <li>• Dredging to remove fines directly from the channels (although this may be unsustainable and environmentally unacceptable).</li> </ul>
Type 4	<ul style="list-style-type: none"> <li>• The river network around Tralee and Listowel in County Kerry;</li> <li>• River Suck around Castlerea in County Roscommon;</li> <li>• River Brosna around Kilbeggan in County Westmeath; and,</li> <li>• The river network around Castlepollard in County Westmeath.</li> </ul>	High	Moderate	<ul style="list-style-type: none"> <li>• Land management to prevent poaching of existing eroding banks and control diffuse pollution from agricultural sources;</li> <li>• Riparian corridor planting along eroding banks to minimise access to channel, addition of a buffer and removal of some sediment sources from discharging into the channel;</li> <li>• Incorporate Sustainable Urban Drainage Systems (SuDS) and blue-green infrastructure into future developments, sustainably managing potential sources of sediment;</li> <li>• 'Soft' bank reinforcement such as vegetative techniques reducing erosion and increasing resilience of eroding banks;</li> <li>• 'Hard' bank reinforcement such as gabions and concrete bed/banks reducing erosion and increasing resilience of eroding banks; and,</li> <li>• Flow deflectors to protect eroding banks, encourage flow diversity and locally induce deposition of fine sediment.</li> </ul>

River Channel Type	Significant Locations	Risk of Erosion	Risk of Deposition	Potential River Management Solutions
Type 5	<ul style="list-style-type: none"> <li>• Slieve Bloom Mountains;</li> <li>• Slieve Felim Mountains;</li> <li>• Silvermere Mountains;</li> <li>• Mullaghreirk Mountains;</li> <li>• Ballyhoura Mountains;</li> <li>• Dartry Mountains; and,</li> <li>• Sieve Mish Mountains.</li> </ul>	Very Low	Very Low	<ul style="list-style-type: none"> <li>• Do nothing</li> </ul>

**Table 4.1 Risk of erosion and deposition to different river types**

## 5 Approach Two – Data Representation and Analysis

### 5.1 Overview

Following the GIS analysis of the variables three outputs have been developed as follows:

- Sensitivity to erosion;
- Sensitivity to deposition; and,
- Comparison of stream power (including slope) and soil type.

Section 2 details the methodology for the assessment of each of the key variables. The following provides the outputs from the GIS models and details the areas potentially at risk.

### 5.2 Areas at Risk of Erosion

Figure 5.1 provides the output for erosion risk for the Shannon Catchment giving consideration to the following variables, further detailed in Section 2:

- Historical change;
- Stream power;
- Sinuosity;
- Soil type;
- Land use; and,
- Slope.

From initial analysis of the data, the key areas at risk of erosion are primarily located in the south west of the catchment and to the north of the catchment. This primarily includes the following rivers and locations:

- South West:
  - Along the Galey River;
  - River Feale (particularly by Abbeyfeale);
  - River Brick; and,
  - The river network by Tralee.
- North:
  - River Suck (particularly around Castlerea, Ballymoe and Athleague);
  - Arigna River;
  - Cloone River;
  - Eslin River (near Drumod);
  - River Eithne (near Ballinalack); and,
  - River Brosna (near Kilbeggan and Ballycumber).

The area of highest erosion risk in the south west of the catchment is located within an area of high slope where the river channels are sinuous or meandering. The stream powers have been calculated as ranging from 50-1000 Wm<sup>-2</sup> and the soil type dominated by tills, alluvium and peat. Each of these factors is likely to have contributed to the higher risk of erosion. The alluvium and tills are more likely to be

relatively easily eroded, with the steeper slopes and higher stream powers indicating a greater stream power (i.e. energy for erosion). The area of high erosion risk in the north of the catchment is located in areas of low to mid slope except for the very northern reach feeding into Loch Aillionn, which has a steep catchment. Lower slopes would typically be associated with areas of less erosion risk. The stream powers are also typically low from less than  $10\text{Wm}^{-2}$  to  $50\text{Wm}^{-2}$ , with only the very upper catchment areas having stream powers in excess of  $50\text{Wm}^{-2}$ . The substrate type is predominantly tills and alluvium with some areas of peat, which are more likely to be more susceptible to erosion, even with the lower stream powers. The River Suck channel to the west is classified as meandering, with the other rivers channels determined as sinuous (and some reaches with active meanders).

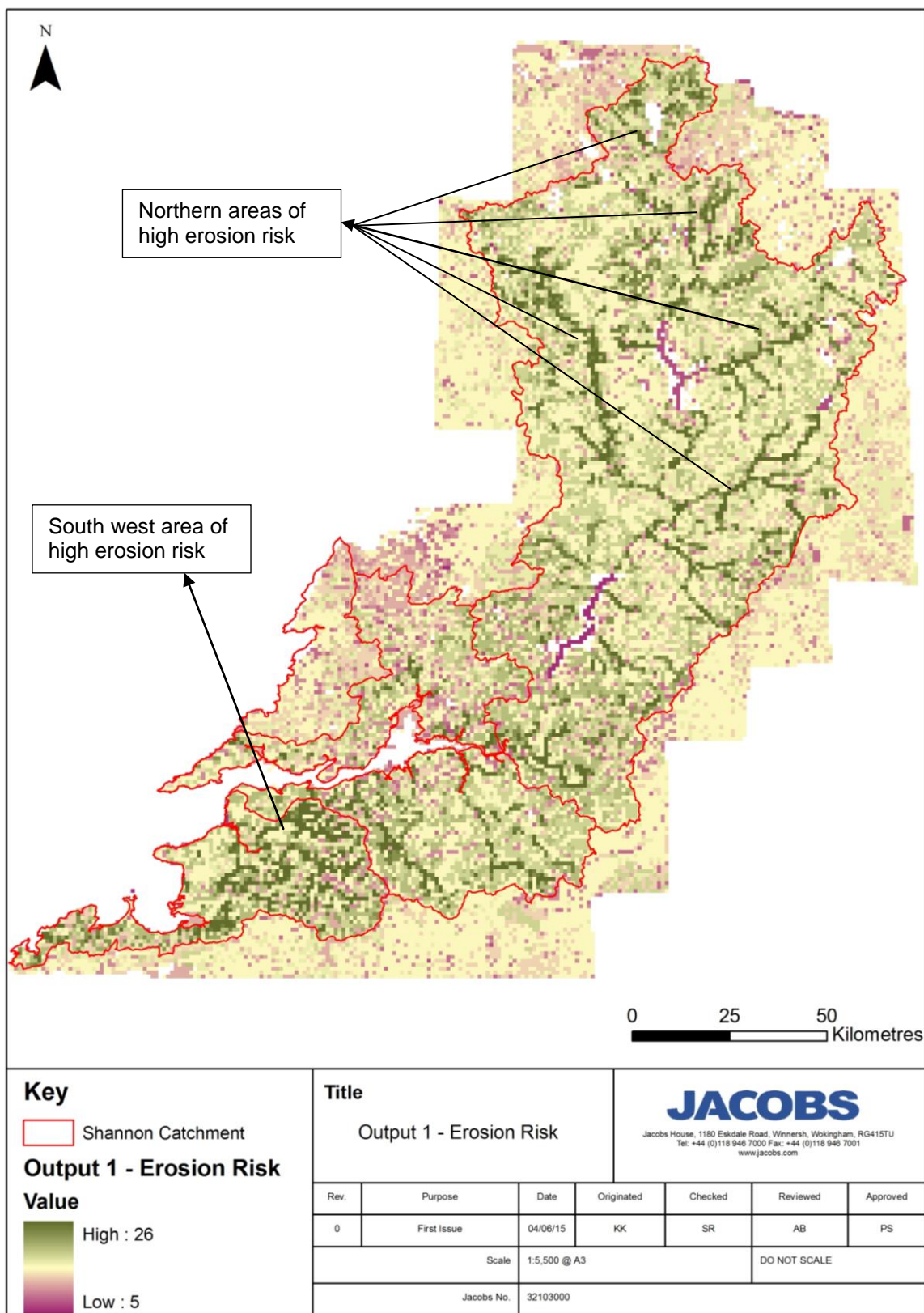
Some of the locations with embankments within the river corridor (particularly where some lengths of channel have been straightened) potentially have a greater risk of erosion than the upper sections where the river channel is more sinuous. This is particularly evident along the River Brick, Cashen River to the south west, the Clodiagh River to the west and the Ratty River to the east of the catchment. This is likely to be due to increased stream power as a result of direct channel modification and the embankment itself confining the higher flows from being dissipated on the floodplain.

The other areas within the catchment shown to have a decreased risk of erosion (Figure 5.1 – coloured yellow to pink) are typically located in the lowland areas around urban areas. The urban areas are typically assumed to be modified to some extent with altered geomorphological regimes. They are often sediment sinks due to traditional forms of flood control such as channel widening and channel deepening.

The confidence in flood estimation can be increased by having more high flow check gaugings at most gauging stations (in particular at stations 24008, 24011, 24012, 24015, 24029 and 24030). In addition, it is noted that stations 24003 (River Loobagh at Garroose) and 24006 (River Mague at Creggane) are affected by backwater effects from the Mague and Loobagh respectively, and both from the River Glen as well. It is therefore recommended that locations further upstream on the Loobagh and Garroose are considered for relocation of the gauges. The River Glen is currently not gauged, and a gauge on that watercourse would be beneficial for flood estimation along that watercourse, e.g. at Charleville.

It is recommended that the flood hydrology be reviewed every 5 to 10 years as more annual maxima and flood event data become available.





**Figure 5.1 Potential risk of erosion (output 1)**



### 5.3 Areas at Risk of Deposition

Figure 5.2 provides the output for the areas at risk of deposition. The study has given consideration to the following variables, further detailed in Section 2:

- Stream power;
- Sinuosity;
- Soil type;
- Land use; and,
- Slope.

From initial analysis of the data, the key areas at risk of erosion are primarily located to the south west, to the north and in the centre of the catchment. This primarily includes the following rivers and locations:

- South West:
  - River Brick (upstream of the Lixnew Canal confluence);
  - River Feale; and,
  - Galey River.
- North:
  - River Suck (particularly around Castlerea, Ballymoe and Athleague);
  - River Shannon (near Leitrim and Carrick-on-Shannon);
  - Camlin River;
  - Eslin River (near Drumod);
  - Rinn River (near Mohill);
  - River Eithne; and,
  - River Brosna
- Central:
  - River Shannon and tributaries near Limerick.

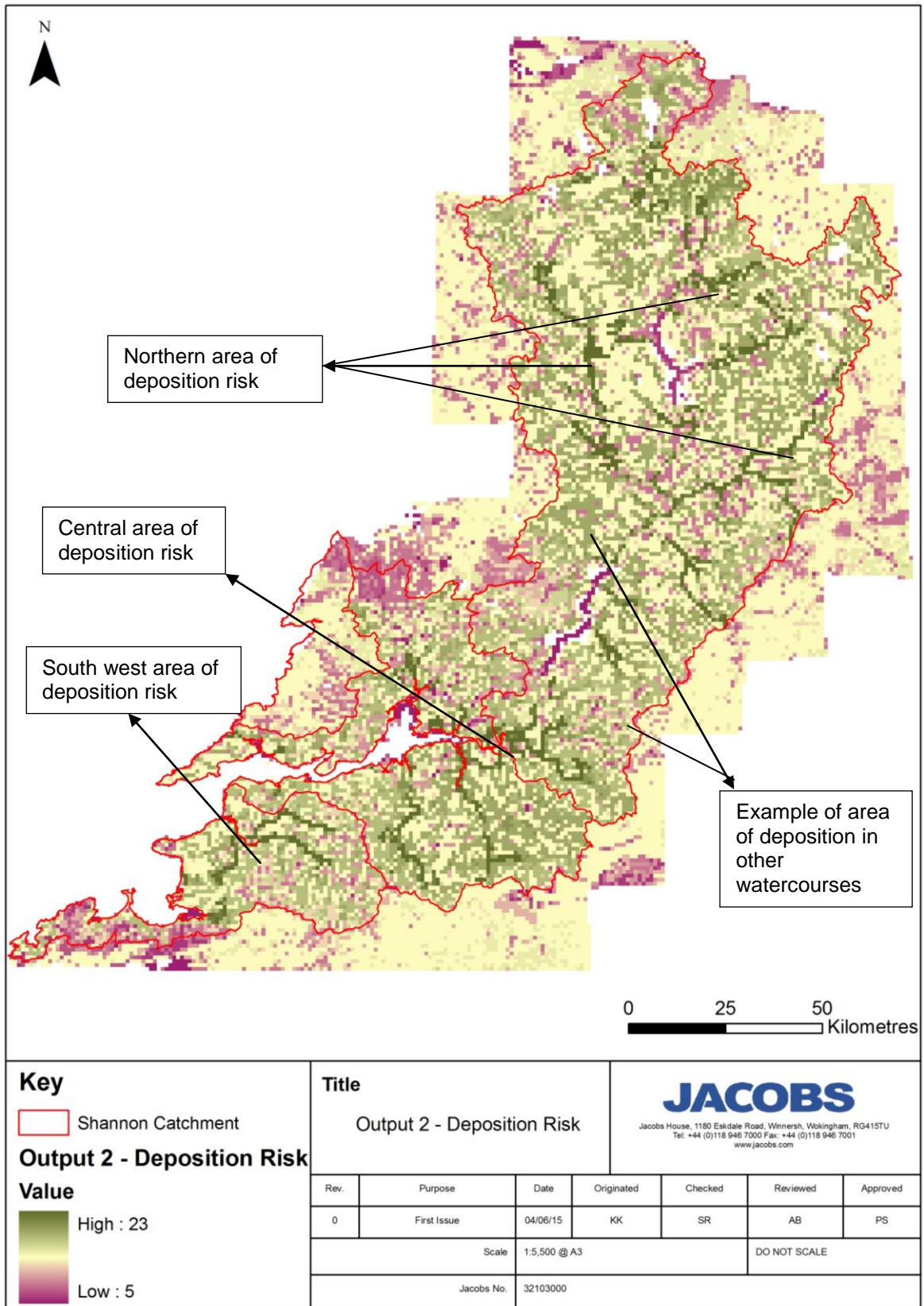
The area of high deposition risk in the south west of the catchment is primarily confined to the three rivers listed above. These typically have a mid to lower slope range and cut into alluvium and tills. The stream powers are typically within the range of 50-300Wm<sup>-2</sup> and the rivers sinuous with the Galey River channel categorised as meandering. These factors all suggest that the rivers have sufficient energy to adjust their morphology and as a result are likely to have depositional processes and forms present, particularly on the inside of meander bends. Historical channel change analysis supports this with a number of the areas noted to have naturally migrated through time.

The area of high deposition risk in the north of the catchment typically is shown to have lower slope and lower stream power (ranging from less than 10Wm<sup>-2</sup> to 50Wm<sup>-2</sup>) values. The river channels are all shown to have a sinuous planform. Although the slopes and stream powers are low, a sinuous planform suggests some form of channel adjustment could be occurring and likely to lead to deposition on the insides of meander bends. The lower stream powers suggest lower rates of energy within the river channel, likely to lead to deposition of sediments at specific locations. Following historical analysis a large portion of the northern catchment has been noted to have been realigned along a mix of short and long reaches, with some natural adjustment towards a more sinuous planform perhaps shown on the Rinn River and the River Eithne.

The River Suck channel to the north west is typed as meandering with a relatively low slope and lower range of stream powers. From aerial photographs this river channel can be seen to accommodate areas of erosion within a wide and deep channel. Deposition on the inside of meanders and in the form of shallower 'silty' areas can be observed at some locations.

The area of high deposition risk in the centre of the catchment is typically of a lower gradient (ranging from 0.2-10). The lower part of the catchment near the mouth of the Shannon exhibits lower predicted stream powers (less than  $10\text{Wm}^{-2}$ ) with the upper section indicating some areas of higher stream powers (ranging from  $50\text{--}300\text{Wm}^{-2}$ ). The section near to the mouth of the Shannon is also predominantly urban, but is still typed as sinuous or meandering. The lowest reach of channel near to the mouth is likely to be at risk of deposition due to the lower gradients and therefore lower stream powers. The upper reach of channel has a higher stream powers suggesting the river/tributary channels could have the energy to adjust their morphology. This is evidenced by some historic natural adjustment, which would include erosion and deposition particularly at meander bends.

Figure 5.2 highlights the risk of deposition throughout the Shannon Catchment (see medium risk colouring of light green). These reaches are typically the smaller channels with lower slopes and rivers with lower stream powers with the potential to deposit fine sediment.



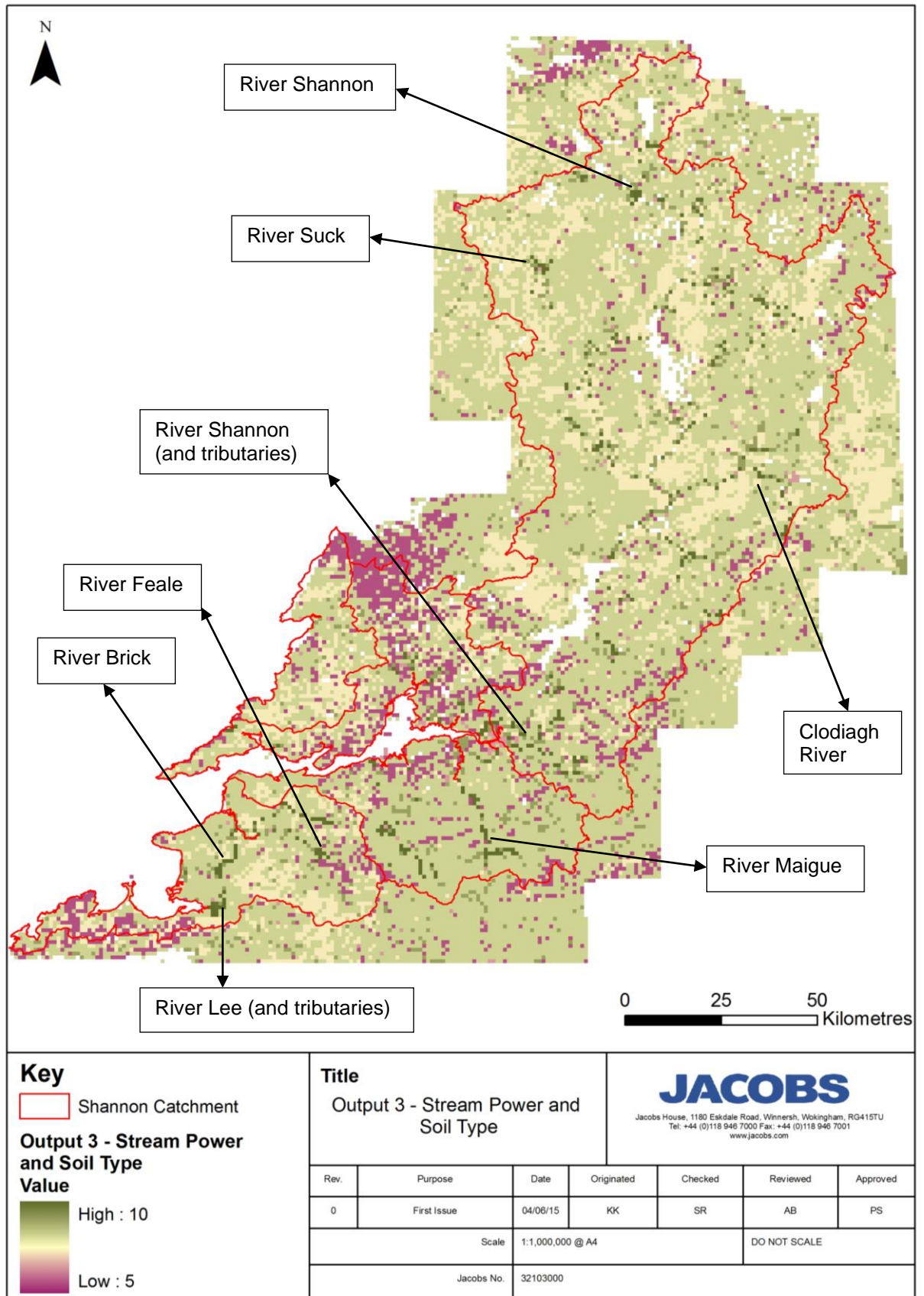
**Figure 5.2 Potential risk of deposition (output 2)**

## 5.4 Stream Power and Soil Type

Following analysis of the main erosion and deposition risk areas using the variables detailed in Section 5.2 and 5.3, a further assessment of stream power and soil type has been undertaken. The aim of this has been to identify key channels with higher stream powers, suggesting higher rates of energy with potential to erode the bed and banks, and reaches with a soil type particularly vulnerable to be eroded and undergo deposition.

Figure 5.3 shows the output of the analysis of stream power and soil type. Eight reaches of river channels have been highlighted in the figure as potentially having higher stream powers and soil types typically alluvium, tills or peat. The areas do coincide with those identified in Section 5.2 and 5.3 supporting the analysis made previously. These areas should be considered as at high risk for potential erosion and/or deposition.

Figure 5.3 also highlights channel reaches within the catchments at medium risk (light green). These are typically smaller channels within the main river catchments likely to either be steep with high stream powers and some erosion (and deposition risk) or channels with lower slopes more susceptible to deposition.



**Figure 5.3 Stream power and soil type analysis (output 3)**



## 6 Summary of Approach One and Approach Two

The first approach (Approach One) focused on river channel types. Analysis of these types has shown key areas of concern to be in the northern and south western areas of the Shannon Catchment. It should be noted that these river channel typologies are based on informed professional judgement and catchment information. Site visits have not been undertaken as part of this study.

The second (Approach Two) focused on multiple variables of hydrology, geology and adjacent land use. Analysis of the risk of erosion and deposition and the subsequent analysis of the key variables (stream power and soil type) have shown three key areas of risk in the northern, central and south western areas of the Shannon Catchment. It should be noted that these assessments are based on high level catchment information and a GIS analysis and further specific work could look to refine the outputs. Site visits have not been undertaken to ground truth the data collected as part of this initial study.

Various high risk areas were flagged up by both approaches, for both erosion and deposition. There has been most consistency in northern areas around the River Suck, Arigna River, Cloone River, Eslin River, River Eithne, Rinn River and River Brosna, as well as upper areas of the River Shannon itself. The River Feale and channels near the town of Tralee have been also flagged as at high risk areas using both approaches.

Active areas close to Limerick and within County Kerry have been identified only by Approach Two. This is probably because they are below the 40m contour and assumed to have been low energy river channels near to the mouth. However, these areas could be active due to development, structures and historic realignment, given the close proximity of the urban areas of Limerick and Listowel.

## 7 Analysis of Hydrological Sites

From the hydrological work that has been undertaken previously 66 priority sites have been defined for potential further work from the over-arching study. These priority sites are discussed in this section of the Report using the ‘top-down approach’ and ‘bottom-up approach’ assessments undertaken independently of each other. The sites have been grouped and discussed per catchment, and Table 7.1 provides a summary assessment for each proposed area.

### 7.1 Unit of Management 23

Seven sites have been identified in this catchment located to the south west of the catchment. The risk of erosion and deposition are primarily medium to high. One location has been identified as having a low risk, namely Moneycashen.

### 7.2 Unit of Management 24

Thirteen sites have been identified in this part of the catchment located to the south. The risk of erosion and deposition ranges from medium to high at most sites. Three sites have been identified with low risk including Tartbet (Power Station) with a low risk for erosion and deposition, Foynes with a low risk of deposition and Akeaton having a low risk of erosion.

### 7.3 Unit of Management 25 & 26

Thirty-seven sites have been identified in the north of this catchment. Typically the risk of potential erosion and deposition at these sites has been shown to range from medium to high. Some sites have been assessed as low risk of erosion (including Limerick, O'Brien Bridge and Portuma) but conversely all sites have been shown to have a medium to high risk of deposition.

### 7.4 Unit of Management 27

Eight sites have been identified to the west of this catchment. The Shannon Airport (IRR3) site has been shown to have a low risk of both deposition and erosion, with the site at Quin having a low risk of erosion. Otherwise all other sites in this management unit have been assessed to have a medium to high risk of erosion and deposition.



Site Name	Notes	Strategic Level Assessment			Overall
		Provisional Typology	Risk of Erosion	Risk of Deposition	Predicted Geomorphological Risk
Unit of Management 23					
Banna	Historically modified including realignment and channelisation. Scheme located in an area of made ground. Low slope and low stream power.	Type 1	High	High	High
Moneycashen	Sinuuous planform cut into glacial till.	Type 1	Low	Low	Low
Listowel	Located immediately upstream of a reach that has naturally migrated. Situated in an area of made ground. Low stream power with some locally straightened reaches through a predominantly sinuous length of valley.	Type 1 and Type 2	Medium	High	Medium
Abbeydorney	Located in area that has been historically realigned or canalised. Typically straightened with upstream reach noted as sinuous. Medium stream powers. Channels underlain by made ground, tills and alluvium.	Type 1	High	High	High
Tralee	The south eastern extent of the area exhibits evidence of active lateral migration and the channels are predominantly sinuous. Stream powers are medium to high. The remainder of the area consists of artificially straightened channels.	Type 1 and Type 2	Medium	Medium	Medium
Athea	Located in a reach recorded to have naturally migrated (based on historical mapping). Bed and bank material potentially consists of alluvium and tills with the eastern extent composed mainly of bedrock at the surface. Meandering channel planform with medium slope. High stream power assessed for the river.	Type 2 and Type 4	High	High	High
Abbeyfeale	Southern extent located in a low risk zone. The remainder of the area is comprised of channels that have exhibited some historical channel change. Stream powers assessed as typically medium to high.	Type 2, Type 3 and Type 4	High	High	High
Unit of Management 24					
Ballylongford	Sinuuous channel in an urban area.	Type 1	Medium	High	Medium
Tartbet (Power Station)	Some embankments recorded.	Type 1	Low	Low	Low
Foynes	Area predominantly consisting of sinuous channels with medium slope. River assessed to have medium stream power. Some reaches artificially straight.	Type 1	Medium	Low	Medium
Newcastle West	Sinuuous channels with medium slopes and rivers with mid-ranging stream powers. Locally channelization/realignment in the defined area as well as some natural migration through time. A few locations to the north of the area have been identified as lower risk.	Type 2, Type 3 and Type 4	High	High	High
Dromcolliher	Typically sinuous channels with medium slopes. Rivers with mid-ranging stream powers,	Type 2	High	High	Medium-High

Site Name	Notes	Strategic Level Assessment			Overall Predicted Geomorphological Risk
		Provisional Typology	Risk of Erosion	Risk of Deposition	
Millford	Predominantly sinuous channels with medium slopes. Rivers with high stream powers. Some historic channel change recorded upstream and downstream of the defined area.	Type 2	High	High	High
Charleville	Sinuous channels with low slopes. Rivers with low predicted stream powers. Area underlain by tills and with a large reach located in an urban area.	Type 2	Medium	High	Medium
Rathkeale	Meandering and sinuous channels with medium slopes. Rivers assessed as having high stream powers. South western extent of the area is typically at a greater risk than the remainder of the area.	Type 1	Medium	Medium	Medium
Askeaton	Sinuous and straightened channels with a low slope. Rivers with low stream powers. Predominantly underlain by made ground or exposed bed rock.	Type 1	Low	Medium	Low-Medium
Clarina	On the outskirts of Limerick City, southern part of area is more at risk than northern part.	Type 1	Medium	Medium	Medium
Adare	Consists of meandering and sinuous channels with low slopes and rivers with low stream powers.	Type 1	Medium	High	Medium
Croom	Sinuous channels with low slopes and occupied by rivers with low stream powers, except for the river channel to the north of the area with a river with stream powers ranging from 10-50Wm <sup>-2</sup> .	Type 1	High	High	High
Kilmallock	Typically sinuous channels, with one meandering tributary. Medium slopes and low-mid ranging stream powers.	Type 2 and Type 4	High	High	High
<b>Unit of Management 25 and 26</b>					
Limerick	The reaches to the north and far south of the area are those identified to be at greatest risk. Predominantly channels with a sinuous or meandering planform. Stream powers of the occupying rivers assessed to be low except for two steep channels to the north where the river is assessed to have locally higher energy.	Type 1	Low	Medium	Low
Springfield	Typically straightened channels with a low slope. Rivers assessed to have low stream power values.	Type 1	Medium	High	Medium
Cappamore	Medium slopes of channels, occupied by rivers with relatively high stream powers. Reaches both upstream and downstream of this area are embanked.	Type 2	High	High	High
Newport	Channels downstream of the area are embanked. The slope is typically medium with occupying rivers with high stream powers.	Type 2	High	High	High
Castleconnell	Primarily artificially straightened channels with a low slope and rivers with low stream power values. Some evidence of historic natural channel adjustment.	Type 1	Medium	High	Medium

Site Name	Notes	Strategic Level Assessment			Overall Predicted Geomorphological Risk
		Provisional Typology	Risk of Erosion	Risk of Deposition	
O'Briens Bridge	Primarily artificially straightened channels with a low slope and rivers with low stream power values. Predominantly canalised.	Type 1	Low	High	Medium
Killalow / Ballina	Primarily artificially straightened channels with low to medium slopes and occupying rivers with relatively low stream power values. Southern section of the area has been canalised.	Type 1 and Type 2	Medium	High	Low
Nenagh	Predominantly naturally sinuous channels with some evidence of artificial realignment to the east of the area. Medium slopes. Rivers with high stream powers to the east and low stream powers to the west.	Type 2 and Type 3	High	High	Medium
Roscrea	Sinuuous planform with medium slopes. Rivers with low stream powers. Main area of risk is located to the north and east.	Type 2	Medium	Medium	Medium
Borrisokane	Sinuuous channels with reaches channelized downstream of the defined area. Typically medium slopes with rivers of medium stream power (ranging from 10-50Wm <sup>-2</sup> ).	Type 2	Medium	Medium	Medium
Portuma	Channels with artificially straightened planform and medium slopes. Rivers with low stream powers. One reach with natural migration identified.	Type 1 and Type 2	Low	Medium	Low
Birr	Sinuuous channels with medium slopes and rivers assessed as medium to high stream powers. Some channelization of channels to the east of the defined area and natural adjustment of channels within the northern extent of the area.	Type 2	High	High	Medium
Clonaslee	Sinuuous channels with medium slopes and rivers with high stream powers. Embankments located along channels to the north of the defined area.	Type 2	High	High	High
Shannon Harbour	Artificially straightened channel with low slopes and rivers with low stream powers.	Type 1	High	Medium	Medium
Shannonbridge (Power Station)	Bordered to the west by two naturally sinuous channels with one small reach of artificially straightened channel. Slope predominantly low with rivers of low stream powers (<10Wm <sup>-2</sup> ).	Type 1 and Type 2	High	High	Medium
Pollagh	Sinuuous planforms with low gradients and rivers with relatively low stream powers.	Type 2 and Type 3	High	High	Medium
Rahan	Sinuuous planform of channel with a medium slope. Occupied by rivers with high stream powers. Some areas with artificially realigned channel.	Type 2 and Type 3	High	High	High
Clara	Sinuuous planforms with reaches of meandering channel. Low gradients and rivers of low stream powers. Some reaches with artificial realignment and channelization.	Type 2 and Type 3	High	High	High
Kilbeggan	Sinuuous planforms with low gradients and rivers with low stream powers. Some historic natural adjustment evident; however, some reaches of the channel embanked.	Type 2 and Type 4	High	High	Medium

Site Name	Notes	Strategic Level Assessment			Overall Predicted Geomorphological Risk
		Provisional Typology	Risk of Erosion	Risk of Deposition	
Ballinasloe	Meandering channels with low slopes and rivers with typically low stream powers. Some historic natural adjustment upstream and some artificial realignment to the west of the defined area.	Type 1 and Type 2	Medium	High	Medium
Ahascargh	Meandering channels with low slopes and occupied by rivers with typically low stream powers.	Type 2	High	High	High
Athlone	A combination of naturally sinuous and artificially straightened channel planforms. Low slope and rivers with low stream powers. Some reaches with of historic channel adjustment identified.	Type 1 and Type 2	Medium	Medium	Low
Mullingar	Sinuous planforms with low channel slope and rivers of low to medium stream power. Some artificial realignment within the defined area.	Type 2 and Type 3	Medium	High	Low
Abbeyshrule	Sinuous channel planforms with low slopes and occupied by rivers with low stream powers.	Type 2	High	High	Medium
Ballymahon	Sinuous channel planforms with low slopes and occupied by rivers with low stream powers. Some historic channel adjustment recorded and slightly higher stream powers present for the rivers upstream of the defined area.	Type 1 and Type 2	High	High	Medium
Athleague	Meandering channel planform with low slopes and occupied by rivers with low stream powers. Some historic channel adjustment noted in the defined area.	Type 2	High	High	Medium
Roscommon	Meandering channel planform with low slopes and rivers with low stream powers. The northern extent exhibits rivers with some higher stream powers. Some artificial channel realignment noted downstream of the defined area.	Type 2	Medium	High	Medium
Lanesboro (Power Station)	Artificially straightened planforms with low slopes and rivers with low stream powers.	Type 1	High	High	High
Edgeworthstown	Sinuous channel planforms with medium slopes. Rivers of medium stream powers. Predominantly underlain by tills, with made ground present in the central areas.	Type 2	Medium	High	Medium
Longford	Sinuous channel planforms with low slopes and occupied by rivers of low stream power. Marginal areas exhibit rivers with higher stream power values from 10-50Wm <sup>-2</sup> .	Type 2	Medium	High	Medium
Cloondara	Sinuous channel planforms with low slopes and occupied by rivers with low stream powers.	Type 1 and Type 2	Medium	Medium	Low
Castlerea	Meandering channel planforms with some historic natural channel adjustment noted. Channel slopes typically low and rivers with low stream powers. Southern extent of defined area exhibits rivers with slightly higher stream powers. Channels to the east have been historically realigned.	Type 2 and Type 4	High	High	High

Site Name	Notes	Strategic Level Assessment			Overall Predicted Geomorphological Risk
		Provisional Typology	Risk of Erosion	Risk of Deposition	
Dramod	Sinuuous channel planforms with low slopes but rivers with medium stream powers (ranging from 10-50Wm <sup>-2</sup> ). Reach has been historically realigned.	Type 2 and Type 3	High	High	High
Mohill	Sinuuous channel planform with low slopes but rivers with medium stream powers (ranging from 10-50Wm <sup>-2</sup> ).	Type 2 and Type 3	High	High	High
Carrick on Shannon	Low channel slopes with rivers of medium stream powers. Some channelization to the south of the defined area.	Type 2	Medium	High	High
Boyle	Eastern extent consists of low channel slopes with rivers of low stream power; some historic natural adjustment noted. Reach to the west has a medium channel slope and rivers with medium stream powers.	Type 2 and Type 3	High	High	Medium
Leitrim Village	Low channel slopes and rivers with low stream powers. Historic modification recorded in the form of channelization, with other reaches canalised.	Type 2	High	High	Medium
Drumshanbo	Medium channel slopes and rivers with high stream powers.	Type 2	Medium	High	High
<b>Unit of Management 27</b>					
Kilkee	Sinuuous and meandering channels, with some straighter reaches. Predominantly medium slope with rivers of high stream powers.	Type 1	High	High	High
Kilrush	Sinuuous channels in upstream section, which then become more artificially straight at the coastal area. Medium channel slopes with rivers of high stream powers.	Type 1	Medium	High	Medium
Shannon Airport (IRR3)	Located in an area bordered to the east by sinuuous channels and rivers with medium stream powers. Typically underlain by made ground – i.e. urban area.	Type 1	Low	Low	Low
Shannon	Typically underlain by made ground and some marine deposits and exposed bedrock. Sinuuous channels with low slopes and rivers with low stream powers. Embankments present along coastal area.	Type 1	Medium	High	Medium
Bunratty	Low channel slope and rivers with low stream powers with a predominantly embanked, artificially straightened channel.	Type 1 and Type 2	High	High	Low
Sixmilebridge	Sinuuous channel planform with medium slopes and rivers with high stream powers.	Type 1	High	High	High
Quin	Area with medium channel slopes and rivers of high stream powers.	Type 1	Low	Medium	Medium

Site Name	Notes	Strategic Level Assessment			Overall Predicted Geomorphological Risk
		Provisional Typology	Risk of Erosion	Risk of Deposition	
Ennis	Large area covering predominantly sinuous channels with some artificially straighter reaches. The channel slope is typically low to medium with rivers of medium to high stream powers. Downstream of the defined area the channels are embanked.	Type 1	High	High	Medium

**Table 7.1** *High level geomorphology risk for each of the 66 catchment areas (based on outputs from Approach One and Approach Two. NB: this is a high level strategic assessment)*

This report summarises a high level strategic assessment of the potential for geomorphological change (and specifically erosion and deposition processes) within the Shannon Catchment. Due to the uncertainties inherent at such a strategic level of study, two independent approaches were followed in an attempt to provide more certainty in the findings. Promisingly the two approaches have arrived at similar conclusions of geographical areas potentially at risk. The northern and south western extents of the catchment have been identified by both approaches as being at particular risk. Using the channel typology (developed in the first approach) these channels have been classed predominantly as Type 2, Type 3 and Type 4. The risk of erosion and deposition for these types ranges from Low to High. There are necessarily a series of limitations and assumptions made at this strategic level, not least that ground truthing through a site visit has not been possible.

This geomorphological assessment is intended to inform the CFRAMS hydrological study for the Shannon Catchment carried out in parallel. This hydrological study had previously identified a number of potential units of management (or areas) and most of the specific sites identified have been identified in this report as a Medium to High risk of either erosion or deposition. Before specific flood risk management solutions can be identified for individual rivers, tributaries or reaches then further geomorphological assessment would be required to more accurately inform options/decisions. Such work would need to involve desk based and field based elements and would allow a handle on the scale and extent of geomorphological change.

A detailed walkover survey (fluvial audit) might reveal that in a natural reach there could be a mix of sediment sources, transfers/exchanges and sinks operating. The fluvial audit approach (now a British industry-wide standard) was first developed by Sear, Newson and Brookes (1995). So the locating of a structure or channel works at a specific point along a river's long section could be variously influenced by these processes (and in turn influence them). This would potentially affect the need for and frequency of channel maintenance. Capital works and maintenance records were not available from OPW (or other readily available sources) for this study. In practice it is highly likely that previous channel works in the Shannon Catchment will have been extensive, particularly extensive arterial drainage schemes. These will have been implemented in the past hundred or so years to facilitate free fall drainage of adjacent fields primarily by lowering the channel bed. In effect these will have become sediment traps extended over a considerable distance of the main stem or tributaries. Again the consequence locally could have been to artificially trap and store the entire bed load of a river. In turn this could have had downstream consequences, locally initiating erosion (due to sediment starvation) or reducing the need for sediment management in a downstream flood scheme (for example).



## 9 References

Bing (2015). Bing Maps [online]. Available at: <https://www.bing.com/maps/> (accessed on 17/08/2015).

CEH Centre for Ecology and Hydrology (2015). 69006 – Bollin at Dunham Massey [online]. Available at: <http://nrfa.ceh.ac.uk/data/station/info/69006> (accessed on 17/08/2015).

Ferguson, R, I (1986) Channel form and channel changes., pp 90-125 in Lewin, J (ed) British Rivers., George Allen and Unwin.

Magic (2015). Magic Map [online]. Available at: <http://www.magic.gov.uk/MagicMap.aspx> (accessed on 17/08/2015).

OPW Office of Public Works (2015). Shannon CFRAM study catchment flood risk assessment and management [online]. Available at: <http://shannoncframstudy.ie/maps.aspx> (accessed on 01/09/2015).

OSI Ordinance Survey Ireland (2015). \*Unnamed [online]. Available at: <http://maps.osi.ie/publicviewer/#V2,633234,724290,0,10> (accessed on 01/09/2015).

EPA Environmental Protection Agency (2010). Shannon River Basin Management Plan (2009-2015) [online]. Available at: [http://www.shannonrbd.com/Final%20RBMP/Final\\_ShIRBD\\_RBMP\\_18Mar2010.pdf](http://www.shannonrbd.com/Final%20RBMP/Final_ShIRBD_RBMP_18Mar2010.pdf) (accessed on 01/08/2015).

EPA (2015) Irish Soil Information System, <http://gis.teagasc.ie/soils/index.php> (accessed on 04/08/2015)

Sear, D.A, Newson, M.D and Brookes, A (1995) Sediment-related river maintenance: the role of fluvial geomorphology, Earth, Surface Processes and Landforms, 20., 629-647.

## Appendix A Gauging Station Information Sheets

