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

Hydrology Report
Unit of Management 27

Final Report

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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 27. 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 catchment.

UoM 27 is located almost entirely within County Clare, with only a very small part of the unit of management within Limerick and Galway.

This unit of management is dominated by three main river catchments, which are, from east to west, the Owenogarney (or Ratty) River, the Rine River, and the River Fergus, all of which discharge into the Shannon Estuary. The River Fergus is the largest of these catchments.

The influence of soil types and geology was considered in deriving flood estimates.
The eastern half of the unit of management consists of mostly well drained soils. This includes the central north and middle of the Fergus catchments. The western part of the unit of management lying along the Shannon Estuary and also partly also along the Atlantic coast consists of a mixture of well to poorly drained soils, with a tendency of more poorly drained soils in the far west. The eastern edge of the unit of management also shows a mixed picture of poorly to well drained soils, with some poorly drained soils in the south east on the edge of Limerick.

The geology is reflected in the aquifer groups present within UoM 27. The central Fergus catchment consists of very permeable karstified aquifers dominated by conduit flow. This type of geology is exemplified in the area in the north of UoM 27, which is the southern part of The Burren, with its characteristic karst limestone features, and the virtual absence of any surface water features. The karstic geology covers over 50% of the Fergus catchment. To the east and west of the central karstic aquifers are locally important aquifers which can be expected to have considerable permeability. In the east of the Fergus and Owenogarney catchments are areas with poor (unproductive) aquifers, suggesting a low permeability.

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.

Reviews of the stage-discharge ratings were undertaken for two gauging stations in this unit of management. For both stations hydraulic modelling was undertaken local to the station to produce a revised rating. The rating at Station 27001 (Inch Bridge on the Claureen) is subject to considerable uncertainty and more high flow check gaugings are needed to confirm the rating in flood conditions. Station 27011 (Owenogarney) is tidally influenced and should be used with caution.

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 Flood Study Update (FSU) techniques, supplemented and adjusted using

gauged flow datawhere 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 Flood Studies Update (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. 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 high flow check gaugings at most gauging stations, in particular at Station 27001 where there is significant uncertainty in the stage-discharge rating. Station 27011 is tidally influenced; moving it further upstream should be considered.

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

Glossary

AEP	Annual Exceedance Probability (%)
AFA	Area for Further Assessment
AMAX	Annual Maxima
AOD(M)	Above Ordnance Datum (Malin)
AOD(P)	Above Ordnance Datum (Poolbeg)
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.)
DRAIND	Drainage Density (catchment descriptor)
DMF	Daily Mean Flow
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: $(1+URBEXT/100)^{1.482}$
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 27 (September 2012). That report also describes the methodologies that were chosen for this catchment.

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 five 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, whereby it is noted that sub-models S01a, b and c have now been integrated into one model. Conclusions and recommendations are provided in Chapter 5. Chapter 6 gives the relevant references. The rating review summary sheets for reviews undertaken in UoM 27 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 hydrograph estimation process. It discusses briefly the rating reviews 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

Rating reviews were undertaken for two stations in this Unit of Management. The rating review gauging stations are shown on Figure 2.1 below and on the model extent maps in the respective sub-catchment sections in Appendix A. For both stations hydraulic modelling was undertaken local to the station to produce a revised rating. The table below lists the gauging stations that were included in the review. The results of the analysis are provided in the Rating Review Summary Sheets, which have been included in this report in Appendix C.

The quality of all 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
27001	Inch Bridge
27011	Owenogarney

Table 2.1 UoM 27 Gauging Station Rating Reviews

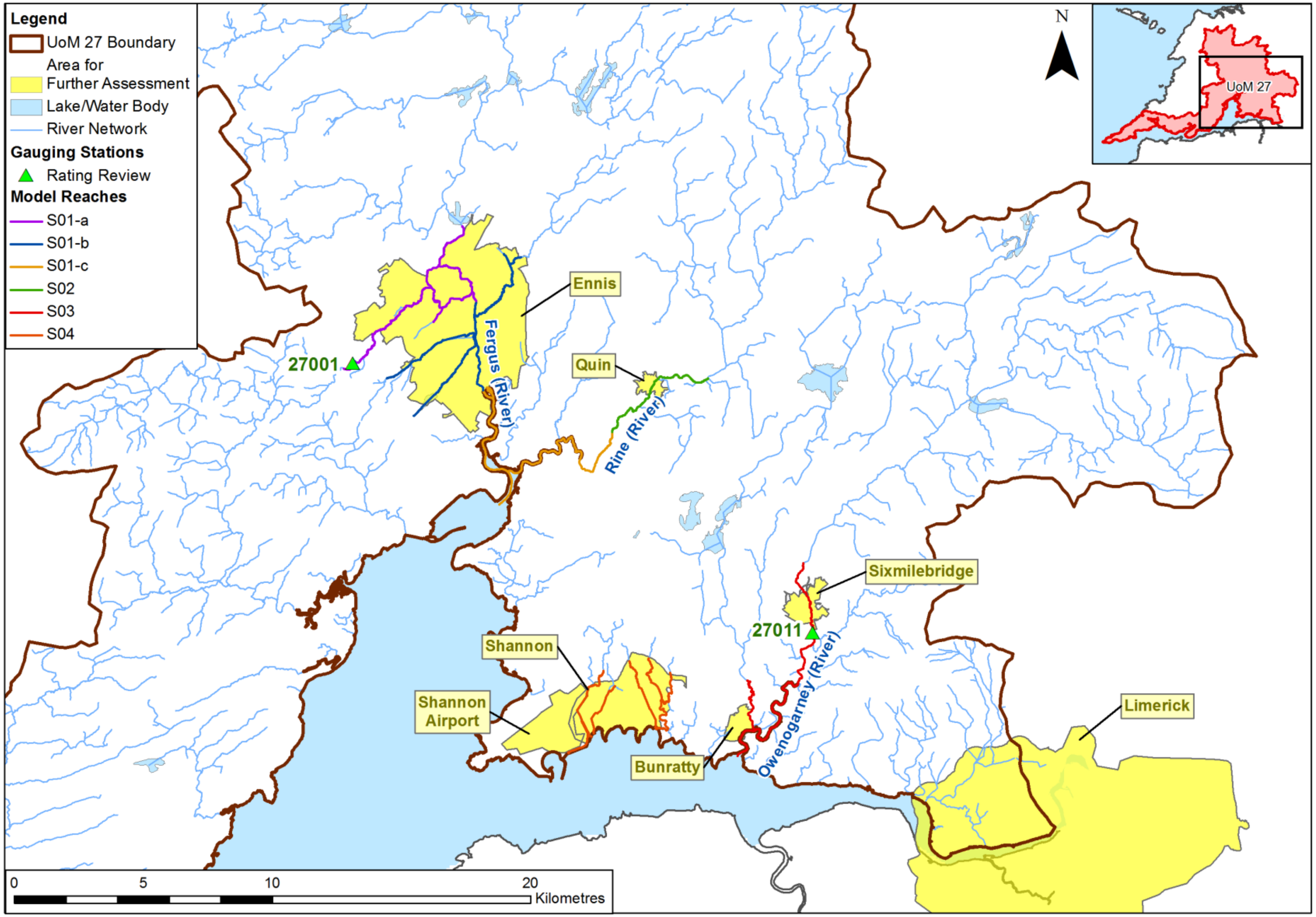

Figure 2.1 Rating Review Stations in UoM 27

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 (sub-daily) intervals.

Met Éireann operate two radars for rainfall detection. However, rainfall depths and intensities estimated indirectly from radar data are 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 Flood Study Update (FSU) techniques, supplemented by gauged flow data where 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) will be applied to, ***river reaches*** are 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 the catchment geometry, geology and an assessment of the availability and quality of data at the 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 need to be 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 calibration 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).

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^2, QMED x fse^2)

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

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.

The above method involving the hydrographs of real flood events was preferred over the use of the gauged n, Tr 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 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 Dij which is a function of the three catchment descriptors BFIsoil (geology), FARL (routing) and S1085 (slope). (Note that the FSU Dij parameter used for the hydrograph shape is different from the Dij used for peak flow estimation (Qmed and pooling) which is based on AREA, BFIsoil and SAAR.) 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, Tr 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).

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 pivotal site with 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, Tr, 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 FSU WP 3.1 method 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 is 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 detailed Calibration Strategy Sheets for the hydraulic calibration of each model extent are located 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 reworked to obtain a better match between modelled flows and anticipated flows based on the hydrological analysis. 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 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, two in-bank events and two out of bank events, were selected .The relevant hydrographs were obtained from the gauging station and applied 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 scaled according to the ratio of the peaks of the gauged calibration event 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, these hydrographs were applied 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 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^2 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^2) 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^2), or conglomerations of smaller river basins and their associated coastal areas.

There are five units of management (UoM) within the Shannon River Basin District (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 Shannon Estuary North Unit of Management (UoM 27) 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).

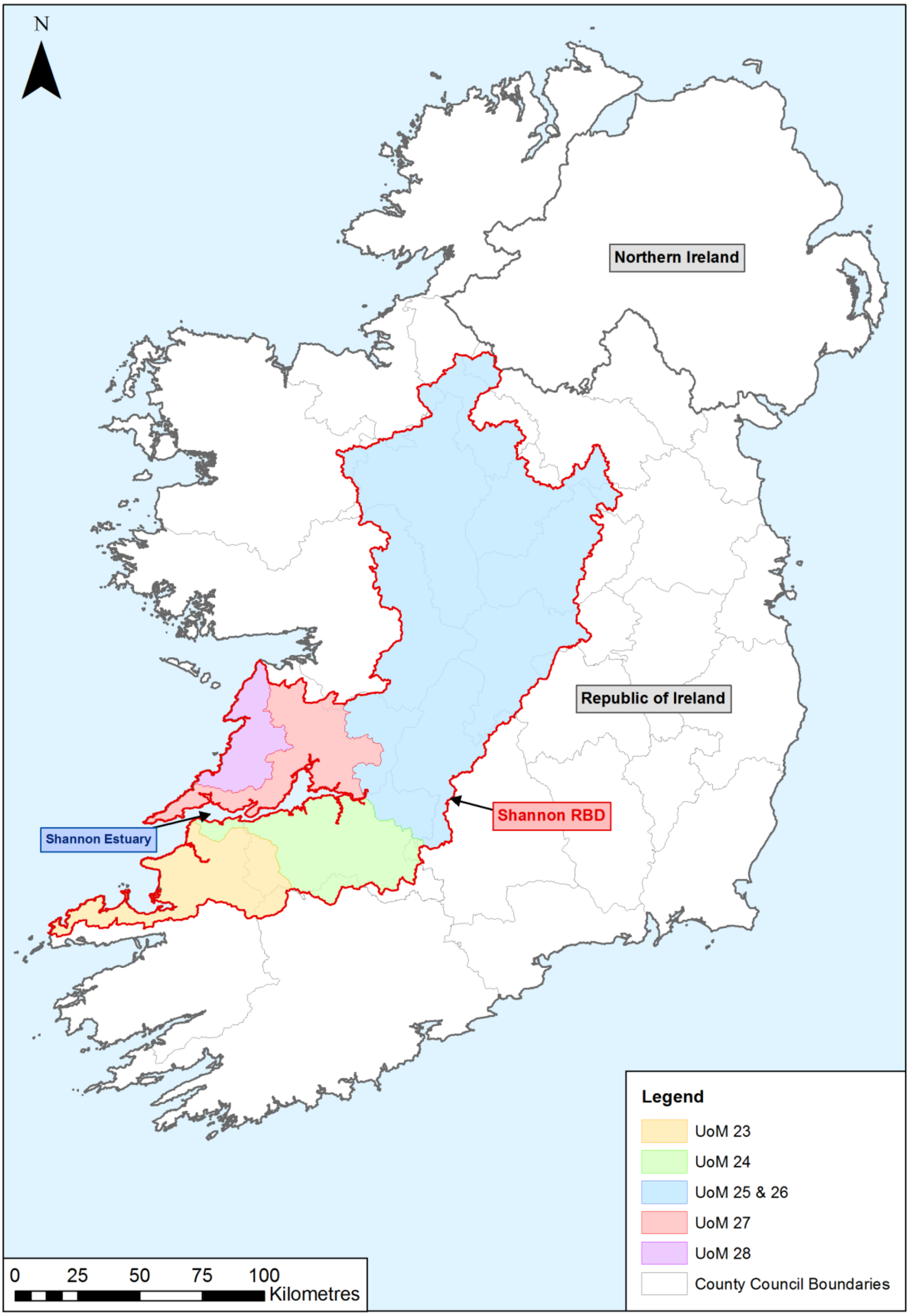

Figure 3.1 Shannon River Basin District and its Units of Management

3.4 Shannon Estuary North (Unit of Management 27)

The Shannon Estuary North (or UoM 27) is located almost entirely within County Clare, with only a very small part of the unit of management within Limerick and Galway (Figure 3.1). The total area of UoM 27 is approximately 1,650 km^2.

The unit of management is dominated by two main river catchments, which are, from east to west, the River Owenogarney (or Ratty) and the River Fergus, both of which discharge into the Shannon Estuary. The largest of these is the River Fergus. Further to the west, the rivers are much smaller, with several rivers draining generally southwards into the Shannon Estuary, such as the Crompaun. Although the latter river is in UoM 27, due to its vicinity to Limerick it has been considered with other rivers in and around Limerick in one model (N16), which has been reported on in the UoM 25/26 report.

The coastline extends along the Shannon Estuary from Limerick City in the east to where it meets the Atlantic Ocean at Loop Head in the far west of County Clare. From Loop Head the coastline extends northeast to Kilkee, along which the coastline is exposed to the Atlantic Ocean. UoM 27 is bounded to the east by the Lower Shannon Hydrometric Area (part of UoM 25/26), to the north by the Western RBD and to the west by UoM 28, separated from it by the upland area which creates the catchment divide.

The far north of UoM 27 includes the southern part of The Burren, with its characteristic karst limestone features, and the virtual absence of any surface water features. The southern part of UoM 27 is dominated by the tidal influence of the Shannon Estuary, which is reflected by the extensive flood defence assets (typically tidal embankments) located along the low-lying eastern part of the southern estuarine shoreline.

In the central part of UoM 27, the River Fergus dominates, rising northwest of Corrofin near Lough Fergus, flowing through Corrofin and then through the central part of UoM 27, where it is dominated by numerous groundwater-fed lakes, heavily influenced by the limestone geology. Just north of Ennis it flows through Ballyallia Lough before splitting into two channels in the northern part of Ennis. The main River Fergus channel flows through the northwestern part of the town and the town centre (where the River Claureen or Inch joins the Fergus from the west) while the smaller channel flows southeast through the northern part of the town. The two parts of the Fergus re-join on the eastern side of Ennis. South of Ennis, the river widens and there is a tidal barrage located at Clarecastle approximately 4 km south of the centre of Ennis. 3 km south of Clarecastle, the River Rine (or Ardsolus in its lower reaches) flows into the tidal River Fergus before entering the Shannon Estuary.

Towards the eastern boundary of UoM 27, the River Owenogarney (or Ratty) flows into the Shannon Estuary, draining the eastern part of the catchment, and separated from the Lower Shannon catchment (part of UoM 25/26) by the Slieve Bearnagh Mountains.

There are seven Areas for Further Assessment (AFAs) in Unit of Management 27:

Quin	Sixmilebridge	Bunratty	Shannon
Kilkee	Ennis	Kilrush	

There is one Individual Risk Receptors (IRRs) in UoM 27:

Shannon Airport

To assist with the hydrological analysis, the unit of management has been divided into sub-catchments. These are the Fergus, Owenogarney, Shannon, Kilrush and Kilkee. 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 A5.

3.5 Geology

The spatial distribution of geological features of UoM 27 including the hydrological groupings of the aquifers, soil drainage types and Karst geological features are presented in Figures 3.3, 3.4 and 3.5 respectively The classification of the aquifer groups are presented in Table 3.2. 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).

The influence of soil types and geology was considered in deriving flood estimates. The eastern half of the unit of management consists of mostly well drained soils. This includes the central north and middle of the Fergus catchments. The western part of the unit of management lying along the Shannon Estuary and also partly also along the Atlantic coast consists of a mixture of well to poorly drained soils, with a tendency of more poorly drained soils in the far west. The eastern edge of the unit of management also shows a mixed picture of poorly to well drained soils, with some poorly drained soils in the south east on the edge of Limerick.

The geology is reflected in the aquifer groups present within UoM 27. The central Fergus catchment consists of very permeable karstified aquifers dominated by conduit flow.

Where a limestone aquifer is exposed, karst features like springs, swallow holes (or sinkholes) and turloughs may be present on the surface. A turlough is a depression or lake from which water drains into the porous substrata. Springs, swallow holes and turloughs may be connected to underground drainage paths. These features can affect the local hydrological response to rainfall, as surface water may disappear into the ground and reappear elsewhere. For very large floods the effect of the karst features on flood flows may diminish as the capacity of the karst features and the underground pathways will not usually be sufficient to accommodate the largest floods.

The northern part of UoM 27 is an example of this type of geology, which is the southern end of The Burren, a limestone area known for its many karst features.

The karstic geology covers over 50% of the Fergus catchment. To the east and west of the central karstic aquifers are locally important aquifers which can be expected to have considerable permeability. In the east of the Fergus and Owenogarney catchments are areas with poor (unproductive) aquifers, suggesting a low permeability.

A detailed analysis of the hydrological response of individual karst features in the unit of management falls outside the scope of the CFRAM study. To best allow for the effects of karst features in a catchment, this study will rely on locally observed flow data where this is available. Therefore in a karst catchment it may be decided that locally gauged data is preferred over data transferred from pivotal sites. If a karst catchment has no reliable gauging station then a pivotal site from another

(similar) karst catchment is likely to be more appropriate than the use of pivotal sites that are hydrological similar only in terms of their catchment descriptors.

The locations of karst features and of geological strata that can exhibit karstic behaviour are shown on Figure 3.3. The Geological Survey of Ireland (GSI) has provided the base data for the information shown on this map. The karst features 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.

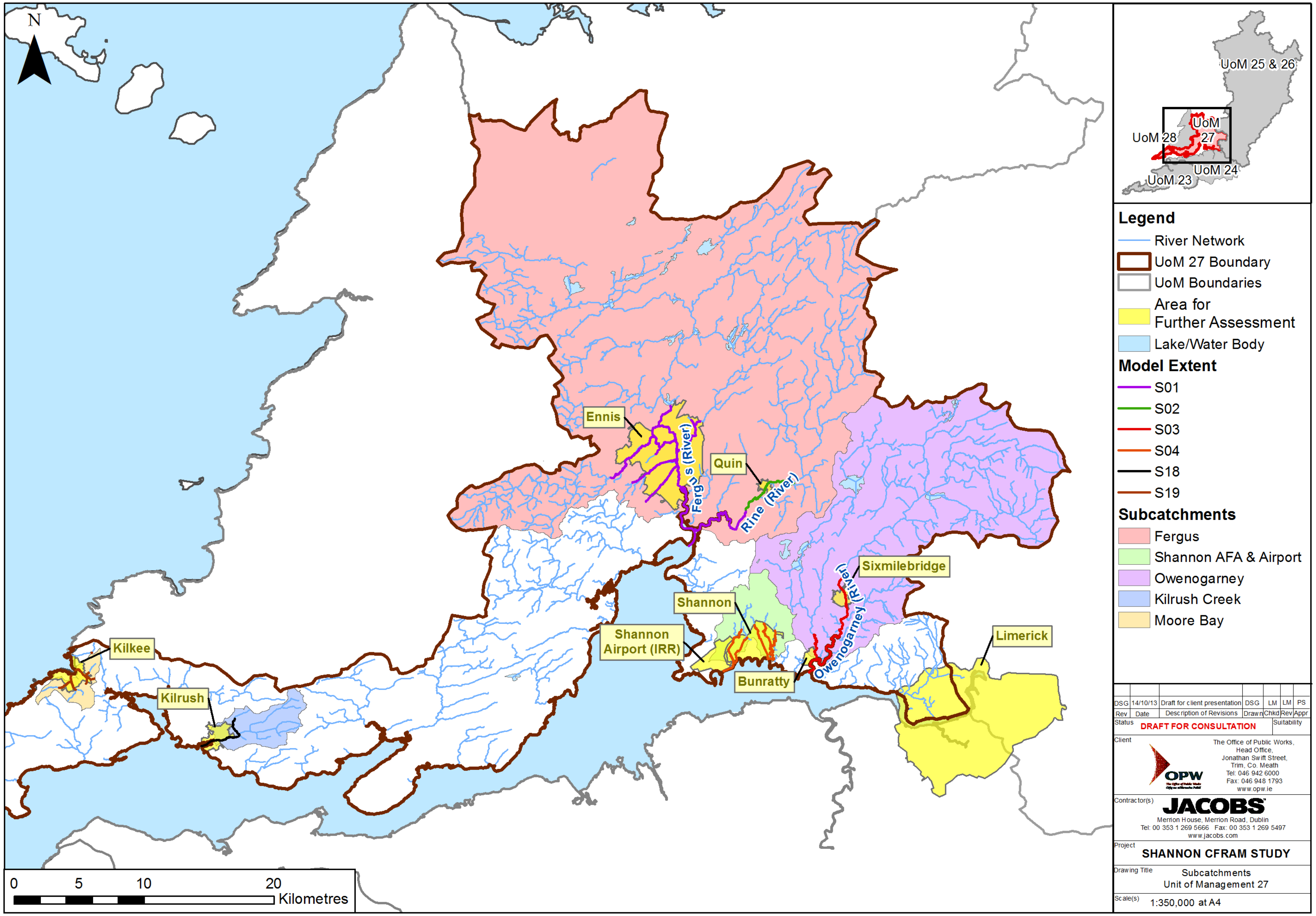

Figure 3.2 UoM 27 Sub-catchments

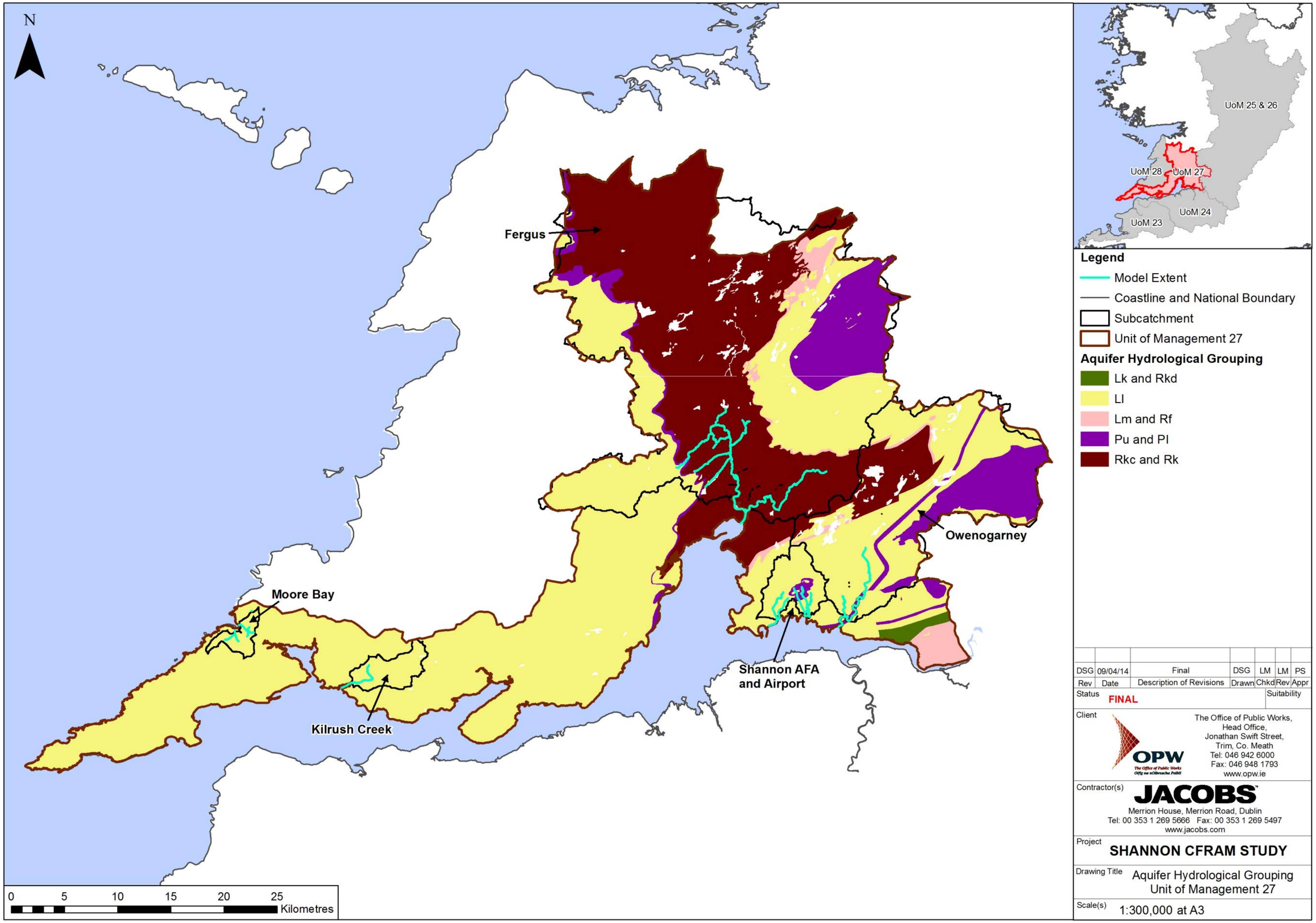

Figure 3.3 UoM 27 Aquifer Hydrological Grouping

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	Ll	Ll
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 Groupings (as shown on Figure 3.3)

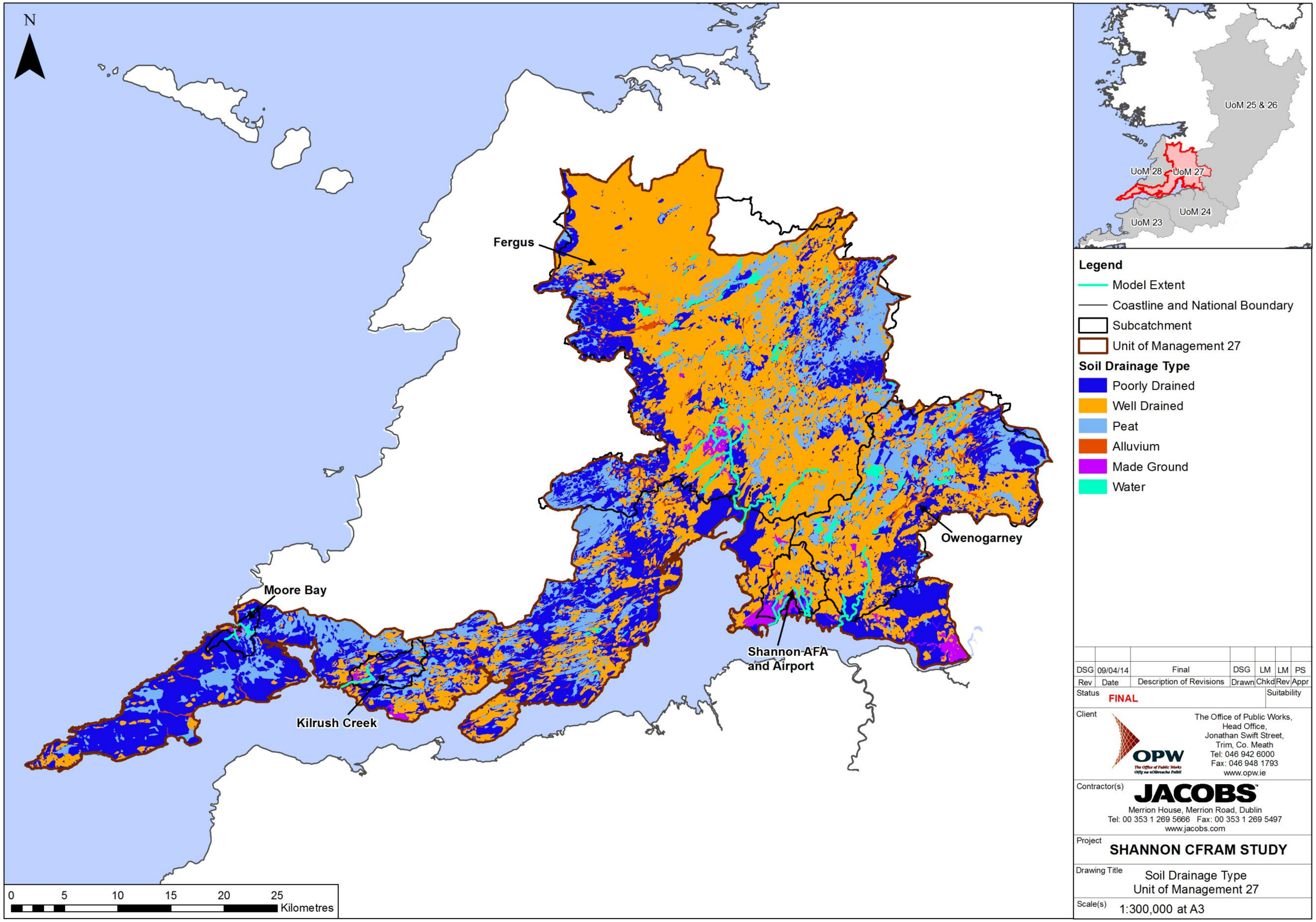

Figure 3.4 UoM27 Soil Drainage Type

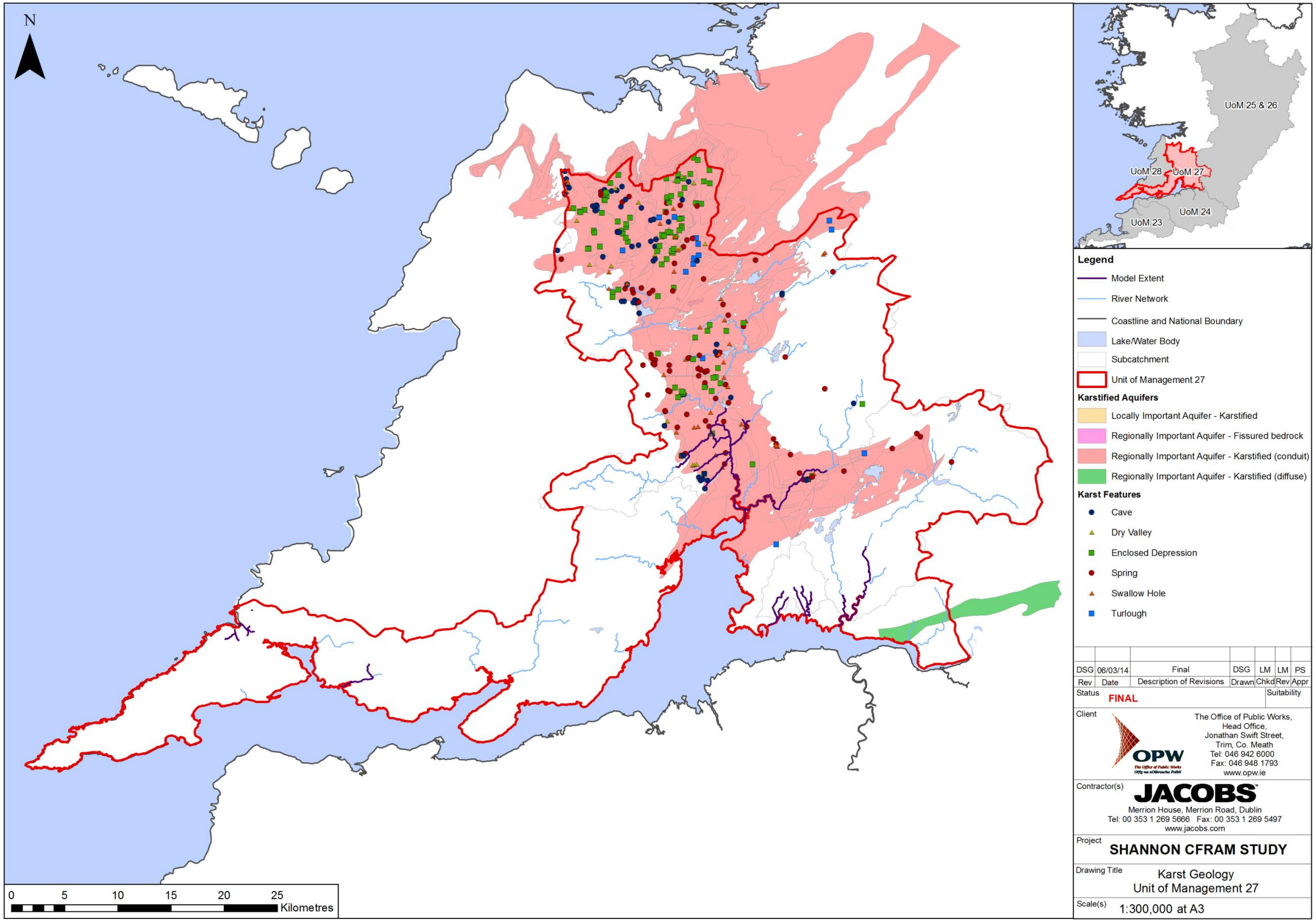

Figure 3.5 UoM 27 Karst Geological Features

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 27. 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 B6. Calibration strategy summary sheets are provided in Appendix F.

3.6.1 Fergus Catchment

Two AFAs, namely Ennis and Quin are located in the Fergus catchment. A brief review of the history of flooding in these two AFAs is presented below.

Ennis AFA

Several major flood events are known to have occurred in the Fergus catchment since 1947 that affected Ennis AFA. These flood events include the March 1947, December 1955, December 1959, January/February 1995, December 1999, February 2002 and November 2009. The information available at the National Flood Hazard mapping website www.floodmaps.ie indicates that high tides coincident with high fluvial discharges cause flooding at Ennis AFA. A tidal barrage was constructed in 1954 to protect Ennis from tidal flooding.

The November 2009 flood in Ennis town was considered to be due to the combination of prolonged intense rainfall over a period of several days coincident with high tides on the Fergus Estuary (the rainfall in November 2009 in Ennis was approximately five times the average rainfall). Approximately 112 houses in Ennis town and 12 properties in Ennis' environs were directly affected.

The February 2002 flood is reported as being caused by a combination of tidal and fluvial events, during which roads and two properties in Ennis were flooded.

The December 1999 flood event was caused by the coincidence of high river flow resulting from the extended heavy rainfall and the high tide on the Fergus Estuary. Subsequent to this flood event the Ennis Main Drainage and Flooding Study (June 2001) was carried out. As per the recommendation of the study a flood alleviation scheme was implemented in Ennis town.

The January/February 1995 flood event was also caused by a combination of prolonged intense rainfall coincident with the tidal peak on the Fergus Estuary. Similarly, the December 1959 flooding in Ennis occurred when exceptionally heavy rainfall, high tides and gale force south westerly winds coincided.

From the review of historic flood events it is observed that Ennis AFA is susceptible to flood risk from the River Fergus, which floods during prolonged extreme rainfall events coupled with high tides.

Quin AFA

Although no major historic flooding events have been reported at the Quin AFA, the local road and land adjacent to the River Rine (a tributary of the Fergus) in the vicinity of Quin are subject to recurrent flooding during extreme rainfall events.

3.6.2 Owenogarney (Ratty) Catchment

Two AFAs, namely Sixmilebridge and Bunratty are located in the Owenagarney catchment. A brief review of the history of flooding in these two AFAs of Owenogarney catchment is presented below.

Bunratty AFA

This AFA was affected by major historic flood events in January 2005, February 2002, February 1997 and January 1995. The main causes of flooding in Bunratty have been reported as high tides overtopping the flood defence embankments and the capacity of the surface water drainage systems in low lying areas being overwhelmed.

During the January 2005 historic flood event, the low lying area near Bunratty and some localised area of the L304 road adjacent to Bunratty Castle was flooded. The flooding was apparently caused by the surface water runoff from low lying land combined with high tide and high winds.

In February 2002 the land at Moyhill near Bunratty was flooded due to a high tide coupled with sluice failure. The sluice has subsequently been replaced.

During the February 1997 event a dwelling at Moyhill near Bunratty was threatened by the high tide, and a stretch of wall to the north of the premises was washed away.

During the January 1995 tidal flooding event lower levels in Bunratty castle were flooded due to overtopping of the flood protection embankment.

Sixmilebridge AFA

This AFA was affected by major historic flood events in November 2009, January 2005 and January 1995. The main cause of flooding is reported as the out of bank flows from the River Owenogarney after heavy rainfall; and backing up of water in a small tributary when the Owenogarney is flowing high.

During the November 2009 flooding event the R462 and R471 roads at this AFA were impassable and several commercial properties towards the northern end of the town were affected from the flooding in the River Owenogarney.

During the January 2005 flooding event several road sections at and in the vicinity of this AFA were flooded, mainly due to prolonged heavy rainfall and inadequate drainage capacity. The January 1995 flooding lasted for two weeks and caused substantial damage to 14 houses, threatened a number of other properties and inundated the sewerage treatment plant on the left bank of the Owenogarney. Subsequent to this flood event a study was carried out in December 1995 to investigate options for alleviating the flooding problem.

3.6.3 Shannon Catchment

Shannon AFA and Shannon Airport IRR are located in this catchment. The historic flood event of January 2005 affected both the AFA and IRR whereas the December 1999 event affected the IRR only. In addition, some recurring tidal flooding affected the local L7174 road around the year 2000.

The cause of flooding in Shannon (AFA) and at Shannon Airport IRR appears to be due to high tide backing up from the estuary and inadequacy of the surface water drainage system at Ballycally.

3.6.4 Kilrush Catchment

The Kilrush AFA located in this catchment is susceptible to the fluvial flooding from the River Kilrush and tidal/coastal flooding from the Shannon Estuary. Major historic flood events were recorded in Kilrush AFA in January 2005, August 1986, January 1969, December 1968, January 1965, October 1961, October 1949, December 1924 and October 1986. The only information available for the historic flood events are for the recurring flooding of the low lying land and cut away bog on both side of the R483 road as a result of 'poor drainage'.

3.6.5 Kilkee Catchment

The Kilkee AFA is susceptible to flooding from high tides and strong winds and from the out-of-bank flows from the Victoria Stream at Carrigaholt Road. Major historic flood events recorded in Kilkee AFA in February 1990, January 1965, October 1961, December 1954, October 1954, October 1949 and August 1946.

During the February 1990 event County Clare experienced serious tidal flooding with approximately 200 houses and many roads affected. Kilkee AFA was one of the most seriously affected areas. During the January 1965 flood event, caused by a high tide and strong winds, portions of the promenade wall were severely damaged and a house was affected. The October 1961 flood event was caused by torrential rainfall damaging buildings along the seafront in Kilkee. The December 1954 event resulted in flooding to large areas of land and low lying roads in Kilkee. The October 1954 flood event was due to heavy rainfall resulting in flooding to low lying roads and land in Kilkee AFA. In addition to the above major flood events some recurring flooding affects Church Street and Carrigaholt Road in front of St Patrick's Terrace and Well Road car park when the Victoria Stream just north of the R487 road overflows its banks. This can affect four to five houses. This is reported to happen approximately once a year and the flooding situation is said to be exacerbated by tides and wind.

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 five sub-catchments were defined, as shown on Figure 3.2. The analysis of each of the five sub-catchments is described in Appendix A, Chapters A1 to A5.

Subsequent to the sub-catchment analysis the hydrological analysis involves calibration of the six 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.

Tidal (water level) boundary information is provided in the hydraulic modelling reports for each model.

4.1 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 a-typical. 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:

68% confidence interval: (QMED/FSE , QMED x FSE)
95% confidence interval: (QMED/FSE^2 , QMED x FSE^2)

(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 geo-morphological 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 27 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 27 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 x FSE)
95% confidence interval: (QMED/FSE^2, QMED x 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.

4.2 Confidence Quantified

Tables 5.1 and 5.2 provide a list of HEPs within the AFAs in UoM 27, one HEP for each modelled watercourse. For each of the 19 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^3/s)		
				68% Lower Limit	Central Estimate	68% Upper Limit
Ennis	S01	27_1190_4	Gauged	32.7	34.6	36.6
Ennis	S01	27_1181_4	Statistical	0.44	0.60	0.82
Ennis	S01	27_1088_5	Statistical	2.26	3.10	4.25
Ennis	S01	27_1118_2	Statistical	3.00	3.50	5.00
Ennis	S01	27_1253_2	Gauged	35.0	47.9	65.6
Ennis	S01	27_1226_2	Statistical	0.30	0.36	0.50
Ennis	S01	27_1050_6	Statistical	1.53	2.10	2.88
Quin	S02	27_661_2	Statistical	15.3	21.0	28.8
Sixmilebridge	S03	27_634_8	Statistical	19.1	26.2	35.9
Bunratty	S03	27_1193_9	Statistical	1.90	2.60	3.56
Shannon	S04	27_805_2	Statistical	0.4	0.6	0.8
Shannon	S04	27_1160_5	Statistical	0.73	1.00	1.37
Shannon	S04	27_1134_3	Statistical	0.36	0.50	0.69
Shannon	S04	27_1164_2	Statistical	0	0.50	1
Shannon	S04	27_1147_3	Statistical	1	1.60	2
Shannon	S04	27_1147_5	Statistical	1.61	2.20	3.01
Kilrush	S18	27_968_4	Statistical	4.7	6.41	8.8
Kilkee	S19	27_1008_2	Statistical	0.8	1.10	1.5
Kilkee	S19	27_966_2	Statistical	1.7	2.30	3.2

Table 5.1 AFAs with 50% AEP Design Peak Flow Confidence Intervals (in m^3/s)

AFA	Model	HEP	QMED Estimation Method	1% AEP Design Peak Flow (m^3/s)		
				68% Lower Limit	Central Estimate	68% Upper Limit
Ennis	S01	27_1190_4	Gauged	64.1	67.9	71.9
Ennis	S01	27_1181_4	Statistical	0.88	1.20	1.64
Ennis	S01	27_1088_5	Statistical	4.74	6.50	8.91
Ennis	S01	27_1118_2	Statistical	5	6.50	9
Ennis	S01	27_1253_2	Gauged	70.15	96.10	131.66
Ennis	S01	27_1226_2	Statistical	0.5	0.75	1.0
Ennis	S01	27_1050_6	Statistical	3.21	4.40	6.03
Quin	S02	27_661_2	Statistical	28.39	38.90	53.29
Sixmilebridge	S03	27_634_8	Statistical	34.82	47.70	65.35
Bunratty	S03	27_1193_9	Statistical	3.50	4.80	6.58
Shannon	S04	27_805_2	Statistical	1.0	1.4	1.9
Shannon	S04	27_1160_5	Statistical	1.82	2.50	3.43
Shannon	S04	27_1134_3	Statistical	0.95	1.30	1.78
Shannon	S04	27_1164_2	Statistical	1	1.00	1
Shannon	S04	27_1147_3	Statistical	2	3.30	5
Shannon	S04	27_1147_5	Statistical	3.36	4.60	6.30
Kilrush	S18	27_968_4	Statistical	8.8	12.04	16.5
Kilkee	S19	27_1008_2	Statistical	1.5	2.10	2.9
Kilkee	S19	27_966_2	Statistical	3.1	4.2	5.8

Table 5.2 AFAs with 1% AEP Design Peak Flow Confidence Intervals (in m^3/s)

5 Future Environmental and Catchment Changes

5.1 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[1]	-0.5mm/year	-0.5mm/year
Urbanisation	Review case-by-case	Review case-by-case
Afforestation[2]	-1/6 Tp	-1/3 Tp +10% SPR[3]

[1] Applicable to southern part of the country only (Dublin-Galway and south of this)
[2] 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
[3] 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 27 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.

5.2 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 S01, S02, S03, S04, S18 and S19 respectively.

AFA	Model	HEP	URBEXT (%)	UAF
Ennis	S01	27_1181_4	35.9	1.58
Shannon	S04	27_1164_2	31.0	1.49
Shannon	S04	27_1134_3	27.9	1.44
Ennis	S01	27_1050_6	24.6	1.39
Ennis	S01	27_1226_2	16.6	1.26
Shannon	S04	27_1147_5	16.0	1.25
Shannon	S04	27_1160_5	11.6	1.18
Kilkee	S19	27_966_2	5.3	1.08
Shannon	S04	27_1147_3	5.3	1.08
Ennis	S01	27_1118_2	1.7	1.03
Bunratty	S03	27_1193_9	1.6	1.02
Ennis	S01	27_1190_4	1.3	1.02
Ennis	S01	27_1253_2	1.1	1.02
Kilrush	S18	27_968_4	1.1	1.02
Kilkee	S19	27_1008_2	1.0	1.02
Sixmilebridge	S03	27_634_8	0.3	1.00
Quin	S02	27_661_2	0.1	1.00
Shannon	S04	27_805_2	0.0	1.00
Ennis	S01	27_1088_5	0.0	1.00

Table 6.2 AFAs with Present Day URBEXT and Urban Adjustment Factor

There are nine locations in UoM 27 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 nine 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
Shannon (S04)	27_1160_5	1.00	1.40	1.70	1.90	2.20	2.50	2.70	3.30
Shannon (S04)	27_1134_3	0.50	0.70	0.90	1.00	1.20	1.30	1.40	1.70
Shannon (S04)	27_1164_2	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.30
Shannon (S04)	27_1147_3	1.60	2.00	2.40	2.60	3.00	3.30	3.60	4.30
Shannon (S04)	27_1147_5	2.20	2.80	3.20	3.60	4.20	4.60	5.00	5.90

AFA (and Model)	HEP	Annual Exceedance Probability (%)							
		50	20	10	5	2	1	0.5	0.1
Ennis (S01)	27_1181_4	0.60	0.80	0.90	1.00	1.10	1.20	1.40	1.60
Ennis (S01)	27_1226_2	0.36	0.46	0.53	0.60	0.68	0.75	0.81	0.96
Ennis (S01)	27_1050_6	2.10	2.70	3.10	3.50	4.00	4.40	4.80	5.60
Kilkee (S19)	27_966_2	2.30	2.80	3.20	3.50	3.90	4.20	4.50	5.10

Table 6.3 Present Day Design Flows

AFA (and Model)	HEP	Annual Exceedance Probability (%)							
		50	20	10	5	2	1	0.5	0.1
Shannon (S04)	27_1160_5	1.04	1.45	1.77	1.97	2.29	2.60	2.80	3.43
Shannon (S04)	27_1134_3	0.54	0.76	0.97	1.08	1.30	1.41	1.51	1.84
Shannon (S04)	27_1164_2	0.54	0.65	0.76	0.87	0.98	1.09	1.20	1.42
Shannon (S04)	27_1147_3	1.63	2.04	2.44	2.65	3.06	3.36	3.67	4.38
Shannon (S04)	27_1147_5	2.31	2.94	3.36	3.79	4.42	4.84	5.26	6.20
Ennis (S01)	27_1181_4	0.66	0.88	0.99	1.10	1.21	1.32	1.54	1.76
Ennis (S01)	27_1226_2	0.38	0.48	0.56	0.63	0.72	0.79	0.85	1.01
Ennis (S01)	27_1050_6	2.26	2.90	3.33	3.76	4.30	4.73	5.16	6.01
Kilkee (S19)	27_966_2	2.34	2.85	3.26	3.57	3.97	4.28	4.58	5.20

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
Shannon (S04)	27_1160_5	1.08	1.51	1.83	2.05	2.37	2.70	2.91	3.56
Shannon (S04)	27_1134_3	0.58	0.82	1.05	1.17	1.40	1.52	1.63	1.98
Shannon (S04)	27_1164_2	0.59	0.71	0.83	0.94	1.06	1.18	1.30	1.53
Shannon (S04)	27_1147_3	1.66	2.07	2.49	2.70	3.11	3.42	3.73	4.46
Shannon (S04)	27_1147_5	2.43	3.09	3.53	3.97	4.64	5.08	5.52	6.51
Ennis (S01)	27_1181_4	0.72	0.96	1.08	1.20	1.32	1.44	1.68	1.92
Ennis (S01)	27_1226_2	0.40	0.51	0.59	0.66	0.75	0.83	0.90	1.06
Ennis (S01)	27_1050_6	2.41	3.10	3.56	4.02	4.60	5.06	5.52	6.44
Kilkee (S19)	27_966_2	2.39	2.90	3.32	3.63	4.05	4.36	4.67	5.29

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[1]. 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 S01, S02, S03, S04, S18 and S19 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 two locations where the proportion of forest in the 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 (%)
Quin	S02	27_661_2	26.3
Ennis	S01	27_1226_2	25.1
Ennis	S01	27_1190_4	21.5
Sixmilebridge	S03	27_634_8	19.6
Ennis	S01	27_1181_4	15.4
Ennis	S01	27_1253_2	14.0
Kilrush	S18	27_968_4	13.8

[1] 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).

AFA	Model	HEP	FOREST (%)
Ennis	S01	27_1118_2	13.3
Ennis	S01	27_1088_5	12.7
Bunratty	S03	27_1193_9	5.3
Shannon	S04	27_1134_3	2.0
Shannon	S04	27_1164_2	1.7
Shannon	S04	27_1160_5	1.5
Shannon	S04	27_805_2	1.1
Shannon	S04	27_1147_5	0.1
Shannon	S04	27_1147_3	0.0
Kilkee	S19	27_1008_2	0.0
Kilkee	S19	27_966_2	0.0

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
Quin (S02)	27_661_2	21.0	25.8	29.0	32.0	36.0	38.9	41.9	48.7
Ennis (S01)	27_1226_2	0.36	0.46	0.53	0.60	0.68	0.75	0.81	0.96

Table 6.7 Present Day Design Flows

AFA (and Model)	HEP	Annual Exceedance Probability (%)							
		50	20	10	5	2	1	0.5	0.1
Quin (S02)	27_661_2	21.6	26.5	29.8	32.8	37.0	39.9	43.0	50.0
Ennis (S01)	27_1226_2	0.37	0.47	0.54	0.62	0.70	0.77	0.83	0.98

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
Quin (S02)	27_661_2	22.1	27.2	30.5	33.7	37.9	41.0	44.1	51.3
Ennis (S01)	27_1226_2	0.38	0.48	0.56	0.63	0.71	0.79	0.85	1.01

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

6 Conclusions and Recommendations

6.1 Conclusions

The upper catchment of the Fergus (the major river system in UoM 27) is found to be strongly influenced by karst features. This is reflected in the fact that Station 27002 (Ballycorey on the Fergus), with its catchment area of 511 km^2, has a Qmed value of 34 m^3/s whereas Station 27001 (Inch Bridge on the Claureen), with a catchment area of 47 km^2 (only 9% of 511 km^2) has a *higher* Qmed of 35 m^3/s.

The Fergus is prone to flooding from very long duration extreme rainfall events, such as those of November 2009; the annual exceedance probability (AEP) of which was approximately 0.5% (1 in 200) at Station 27002, whereas the AEP of the same event was only approximately 8% (1 in 12) at Station 27001.

A review of the stage-discharge rating at Gauging Station 27001 (Inch Bridge on the River Claureen) showed that there is considerable uncertainty in the rating for high flows. A rating review of Gauging Station 27011 (Owenogarney Bridge on the River Owenogarney) showed that although it has a good rating confirmed by high flows, the station is tidally influenced. Annual maximum (AMAX) flows reported for it may be affected by the tide, rendering the AMAX series potentially unreliable.

6.2 Recommendations

It is recommended that further high flow gaugings be completed to increase the confidence in the rating for Gauging Station 27001.

Station 27011 is tidally influenced. To obtain more reliable AMAX estimates moving it further upstream the Owenogarney should be considered.

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Appendix A Sub-catchment Hydrological Analysis

Table of Content

A1 Fergus Catchment

A1.1 Catchment Description

The Fergus Catchment, with a total drainage area of 775 km^2, is the largest of the sub-catchments within the Shannon Estuary North Unit of Management (UoM 27). The catchment is predominantly low lying with elevation rarely exceeding 100mAOD and largely flat with the exception of locally steep slopes in the north and west. The catchment is divided geologically with Carboniferous Limestone dominating the east, and Carboniferous Sandstone and Shale dominating the west of the catchment. Land cover within the upper and middle catchment is primarily pasture grassland (Corine Land Cover Map 2006). The lower catchment includes the urban land cover of Ennis town.

The tidal limit along the Fergus is situated in the town of Ennis. The tide does not intrude past the Mill Bridge weir and sluice gates (at GS 27024). Along the eastern branch of the Fergus bifurcation in Ennis the tidal limit is not well defined, but modelling suggests that the tide can affect water levels up to Gort Road Bridge. Along the Rine there is a variable tidal limit, but the tide does not normally go more than 200m beyond Blackweir Bridge. Despite the name there is no weir near this bridge.

The River Fergus rises near Lough Fergus, northwest of Corrofin. The river flows eastwards towards the low lying central part of UoM 27 before turning south where it is joined by the River Castle which (with its tributaries) drains the northern part of the catchment. The Fergus then continues in a broadly southerly direction through the central part of UoM 27, where it is dominated by numerous groundwater-fed lakes, heavily influenced by the limestone geology (refer to Figure A1.1 for an overview map).

The Fergus Catchment is covered by two hydraulic models, namely S01 and S02.
In addition to the main River Fergus, the other principal rivers in the catchment are the Claureen, Gaurus and downstream part of the Rine in Model S01 and the upstream reach of the Rine in Model S02. The model extents are shown in detail on Figures B1.1 and B2.1 in Appendices B1 (for Model S01) and B2 (for Model S02).

The two AFAs in the catchment are Ennis in Model S01 and Quin in Model S02. There are no IRRs in the catchment.

BFIsoil values within the catchment range from low index values in the north-west, to higher values in the eastern and southern part of the catchment. Along the main stem of the River Fergus, the BFIsoil values vary insignificantly from 0.67 at the upstream end of the model to 0.65 at the downstream near Clarecastle Bridge. Unlike the main stem of the River Fergus, its tributaries show greater diversity in BFIsoil values. For example, the River Claureen, which feeds into the Fergus from the west, has a very low BFIsoil value of 0.29 (at Station 27001). This contrasts with the values of 0.71 for the River Gaurus (at Station 27092) which drains from the eastern slopes, and 0.82 for an unnamed stream (Unnamed Inflow 3) which drains the western slopes near Clare Abbey in the south of the catchment. This prominent variation in BFIsoil values in the tributaries of the Fergus result from the distinctly different geology which essentially divides the catchment into less permeable

sandstone underlying the west, and more permeable limestone in the east and south of the catchment.

A number of karstic features are present within the Fergus catchment (refer to Section A1.2, and Figure 3.3 in Chapter 3 of the main UoM 27 report); these are mainly in the upper Fergus catchment and are known to have a significant impact on flood flows in the main River Fergus. The effect of the karst is reflected in the Qmed adjustment factor (ratio of the Qmed for observed data and the Qmed derived from catchment descriptors) of 0.83 (significantly less than unity) at Station 27002 (refer to Table A1.7).

The SAAR values throughout the Fergus Catchment also demonstrate an east/west divide with values greatest over the higher ground in the west of the catchment. The SAAR value on the River Claureen (at Station 27001) is 1477mm compared with 1117mm for the River Gaurus (at Station 27092). On the other hand, the SAAR values along the River Fergus main stem show a smaller variation, with 1341mm at the upstream model extent and 1332mm downstream near Clarecastle Bridge.

The variation in BFIsoil and SAAR in the Fergus Estuary Catchment suggests that the hydrological response of the north-western branches may be very different to those in the east and south of the catchment.

A1.2 Catchment Geology

An assessment of the geological and hydrogeological conditions anticipated within the River Fergus catchment area has been undertaken with reference to the following data sources (see full references in Chapter 6 of the main report):

- Geological Survey of Ireland GIS datasets public viewer
- Teagasc Soils and Subsoils Report
- County Clare Groundwater Protection Scheme, Geological Survey of Ireland, 2000

A large proportion of the River Fergus catchment has rock outcropping at or close to the surface with a thin subsoil cover of less than 3.0m depth. The predominant subsoil within the catchment is glacial till derived from the underlying limestone and sandstone bedrock. Peat deposits and minor alluvium, estuarine and lake sediments are also present.

Limestone tills occur throughout the catchment from Burren National Park in the north, down to the southern extents of the catchment around Ennis and Quin. The tills are predominantly derived from the underlying karstified limestone and calcareous shale of the Marine shelf facies and also from the limestone of the Waulsortian mudbank and Marine shelf and ramp facies (Courceyan limestone) in the area east of Ennis. The deposits north of Ennis up towards Burren are typically thin with much rock outcropping at surface. The GSI online National Groundwater Recharge map describes the limestone tills as moderately permeable subsoils and the General Soil Map of Ireland (1980) shows the tills to be overlain principally by well drained mineral and organic soils which are shallow in places.

Sandstone tills predominate in the west of the catchment derived from the underlying Namurian sandstone and shale. The GSI online National Groundwater Recharge map and the General Soil Map of Ireland (1980) show the tills to be of low

permeability, predominantly overlain by poorly drained gley soils, dominantly influenced by surface water impedance.

Sandstone tills also occur within limestone tills, rock outcrops and peat deposits to the east and northeast of Ennis where they are derived from the sandstone and siltstone of the Lower limestone shale and the Continental redbed facies (Old Red Sandstone or Up Dev–Lr Carb ORS) and described as low to moderate permeability.

The most extensive peat deposits occur over the poorly drained sandstone and shale in the upland areas east and northeast of Ennis and in the far west of the catchment over the poorly drained Namurian rocks. Isolated patches of peat occur over the limestone bedrock throughout the rest of the catchment and are typically associated with minor alluvial deposits along smaller rivers in the west of the catchment and more extensive estuarine deposits around the Fergus and Shannon estuaries, south of Ennis. The GSI online National Groundwater Recharge map describes the peat deposits as low to moderate permeability subsoils and the Peatland Map of Ireland (1978) indicates the peat to be typically between 1.2m and 2.5m in depth.

A large proportion of the Fergus catchment is underlain by the karstified Marine and shelf facies which is a regionally important bedrock aquifer with many karst features, notably Drumcliff Springs which are fed by the karstified bedrock and supply drinking water to Ennis. The shale limestone to the east and Namurian sandstone to the west of the catchment are designated locally important aquifers while the sandstone and siltstone bedrock to the far east of the catchment are designated poor aquifers.

A1.3 Hydrometric Stations in the Fergus Catchment

The gauging stations with a recorder in the catchment (on or near the model extents) are tabulated in Table A1.1. All gauging stations are shown on Figure A1.1.

In Table A1.1 the record data range refers to the range of AMAX data. HGF is the Highest Gauged Flow, i.e. the highest check gauging.

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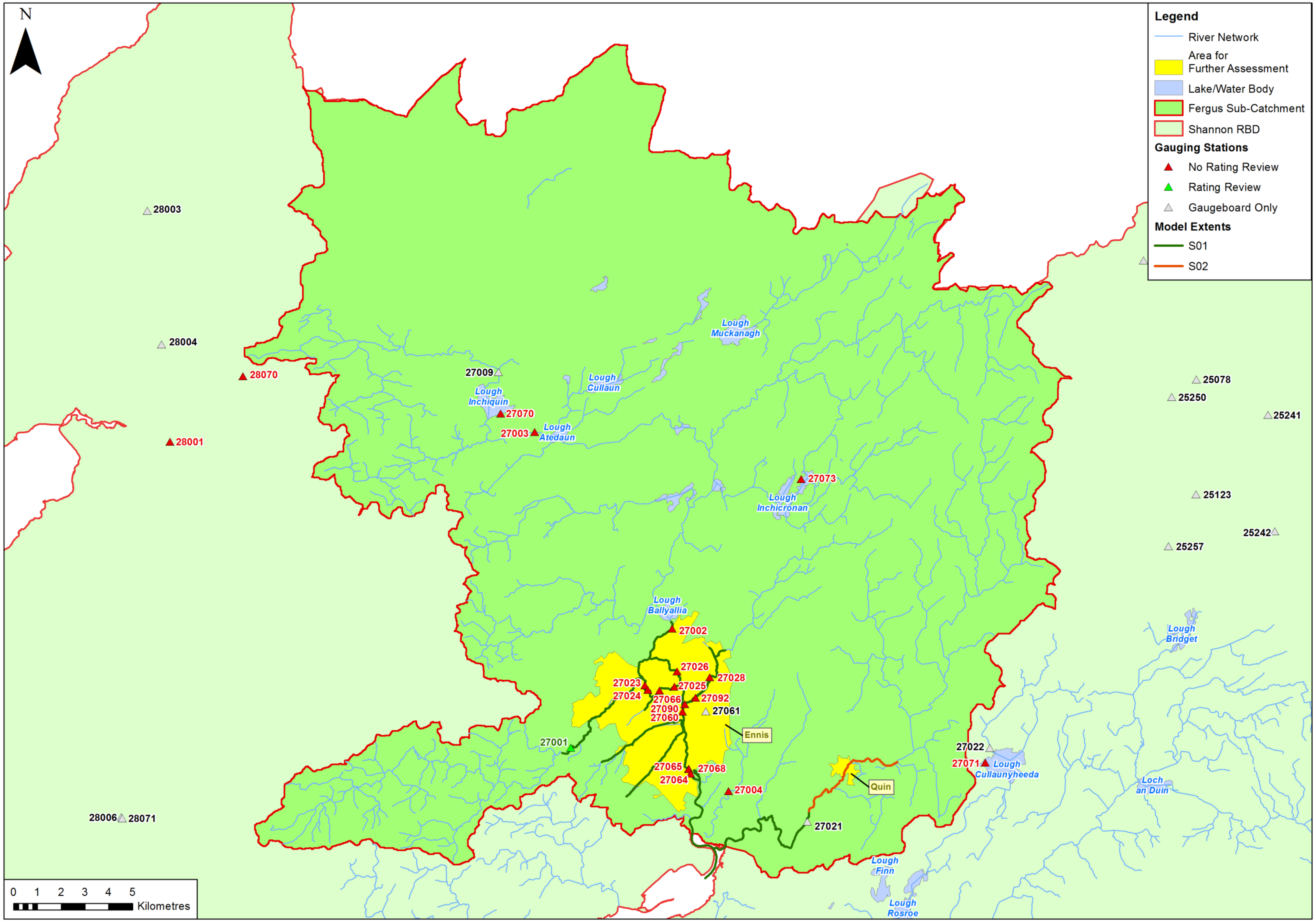


Figure A1.1 Fergus Catchment Model Extent

Model	Gauging station	Name	Record data range	AMAX available	FSU quality class or HGF/QMED	CFRAMS rating review	Quality Comments
S01	27001	Inch Bridge	1972 - 2009	Level and Flow	A2	Yes	1
	27002	Ballycorey	1954 - 2009	Level and Flow	A1	No	2
	27026	Tulla Road Bridge	2001 - 2009	Level Only	N/A	No	3
	27025	Knoxs Bridge	2001 - 2009	Level Only	N/A	No	3
	27066	Ennis Bridge	1980 - 2009	Level Only	N/A	No	3
	27024	Mill Bridge	N/A	Level Only	N/A	No	3
	27023	Victoria Bridge	N/A	Level Only	N/A	No	3
	27060	Doora Bridge	N/A	Level Only	N/A	No	3
	27064	Clarecastle U/S	1947 - 1990	Level Only	N/A	No	3
	27065	Clarecastle D/S	1950 - 1990	Level Only	N/A	No	3
	27090	Cappahard	N/A	No	N/A	No	4
	27092	Gaurus Landfill	N/A	Level Only	N/A	No	3,5
	27028	Gaurus Bridge	N/A	Level Only	N/A	No	3
	27068	Clarecastle Bridge	2002 - 2006	Level Only	N/A	No	3

Table A1.1 Fergus Catchment Gauging Stations

Table A1.1 Quality comments:

1. OPW has confirmed that the data prior to July 1993 was deemed to have a poor rating (See the rating review summary sheet for station 27001 for more details). A revised AMAX series from 1994 to present based on the revised rating equations has been adopted for estimating QMED and for flood frequency analysis.

2. Ballycorey has a reliable rating and AMAX series. The full AMAX series from 1954 – 2009 has been used. The initial AMAX series received has been revised following discussion with OPW.

3. Water level data only. Not used for flow analysis.

4. Cappahard station sited on the Gaurus floodplain is an inactive gauge, and no data was recorded by this station.

5. Gaurus Landfill is situated on a drain discharging into the Gaurus.

A1.4 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 A1.1 above. The river reaches are tabulated in Table A1.2 and shown on Figure A1.2 below. The variation in catchment descriptors for each reach is tabulated in Tables A1.3 to A1.6 below.

Reach	Description	Model Extent
1	River Fergus main stem from upstream model extent to Clarecastle Bridge (through Ennis AFA)	S01
2a	River Claureen	S01
2b	River Gaurus and several other smaller unnamed tributaries	S01
3	River Rine (through Quin AFA)	S01/S02

Table A1.2 River Reaches in the Catchment

Reach 1 (River Fergus)			
Catchment descriptor	Units	Lower limit (with HEP node)	Upper limit (with HEP node)
AREA	km^2	511.5 (27_1195_1)	625.6 (27_1122_5)
BFIsoil	-	0.65 (27_1254_2)	0.67 (27_1195_1)
SAAR	mm	1332 (27_1122_5)	1347 (27_1245_2)
FARL	-	0.82 (27_1195_1)	0.85 (27_1122_5)
DRAIND	-	0.58 (27_1195_1)	0.70 (27_1254_2)
S1085	m/km	1.11 (27_1195_2)	1.23 (27_1195_1)
ARTDRAIN2	%	0 (27_1195_1)	1.77 (27_1245_2)
URBEXT	%	0.09 (27_1195_1)	1.55 (27_1122_5)

Table A1.3 Reach 1 Catchment Descriptor Range

Reach 2a (River Claureen)			
Catchment descriptor	Units	Lower limit (with HEP node)	Upper limit (with HEP node)
AREA	km^2	46.5 (27_801_2)	55.3 (27_1190_4)
BFIsoil	-	0.28 (27_801_3)	0.41 (27_1190_4)
SAAR	mm	1443 (27_1190_4)	1478 (27_801_2)
FARL	-	0.987 (27_801_2)	0.989 (27_1190_4)
DRAIND	-	1.63 (27_1190_4)	1.78 (27_801_3)
S1085	m/km	4.16 (27_1190_4)	4.64 (27_840_2)
ARTDRAIN2	%	7.43 (27_1190_4)	8.10 (27_801_2)
URBEXT	%	0.00 (27_801_2)	1.29 (27_1190_4)

Table A1.4 Reach 2a Catchment Descriptor Range

Reach 2b (River Gaurus and other smaller tributaries)*			
Catchment descriptor	**Units**	**Lower limit (with HEP node)**	**Upper limit (with HEP node)**
AREA	km^2	1.1 (27_1181_1)	27.7 (27_1118_7)
BFIsoil	-	0.60 (27_1148_2)	0.71 (27_1118_7)
SAAR	mm	1113 (27_1088_5)	1264 (27_1148_1)
FARL	-	0.94 (27_1050_1)	1.0 (27_518_1)
DRAIND	-	0.31 (27_518_1)	1.76 (27_1068_2)
S1085	m/km	1.9 (27_518_1)	22.10 (27_1148_1)
ARTDRAIN2	%	0.0 (all)	0.0 (all)
URBEXT	%	0.0 (27_1148_1)	35.93 (27_1181_4)

**Catchment Descriptors of two short branches (27_1195_9 and 27_1226_2) are not included in the table).*

Table A1.5 Reach 2b Catchment Descriptor Range

Reach 3 (River Rine)			
Catchment descriptor	**Units**	**Lower limit (with HEP node)**	**Upper limit (with HEP node)**
AREA	km^2	93.5 (27_657_1)	112.4 (27_1275_4)
BFIsoil	-	0.571 (27_1275_4)	0.623 (27_661_4)
SAAR	mm	1086 (27_1275_4)	1088 (27_657_1)
FARL	-	0.984 (27_1275_2)	0.988 (27_660_3)
DRAIND	-	1.00 (27_1275_2)	1.06 (27_657_1)
S1085	m/km	8.66 (27_1275_2)	10.48 (27_657_1)
ARTDRAIN2	%	0 (all)	0 (all)
URBEXT	%	0.02 (27_657_1)	0.31 (27_661_4)

Table A1.6 Reach 3 Catchment Descriptor Range

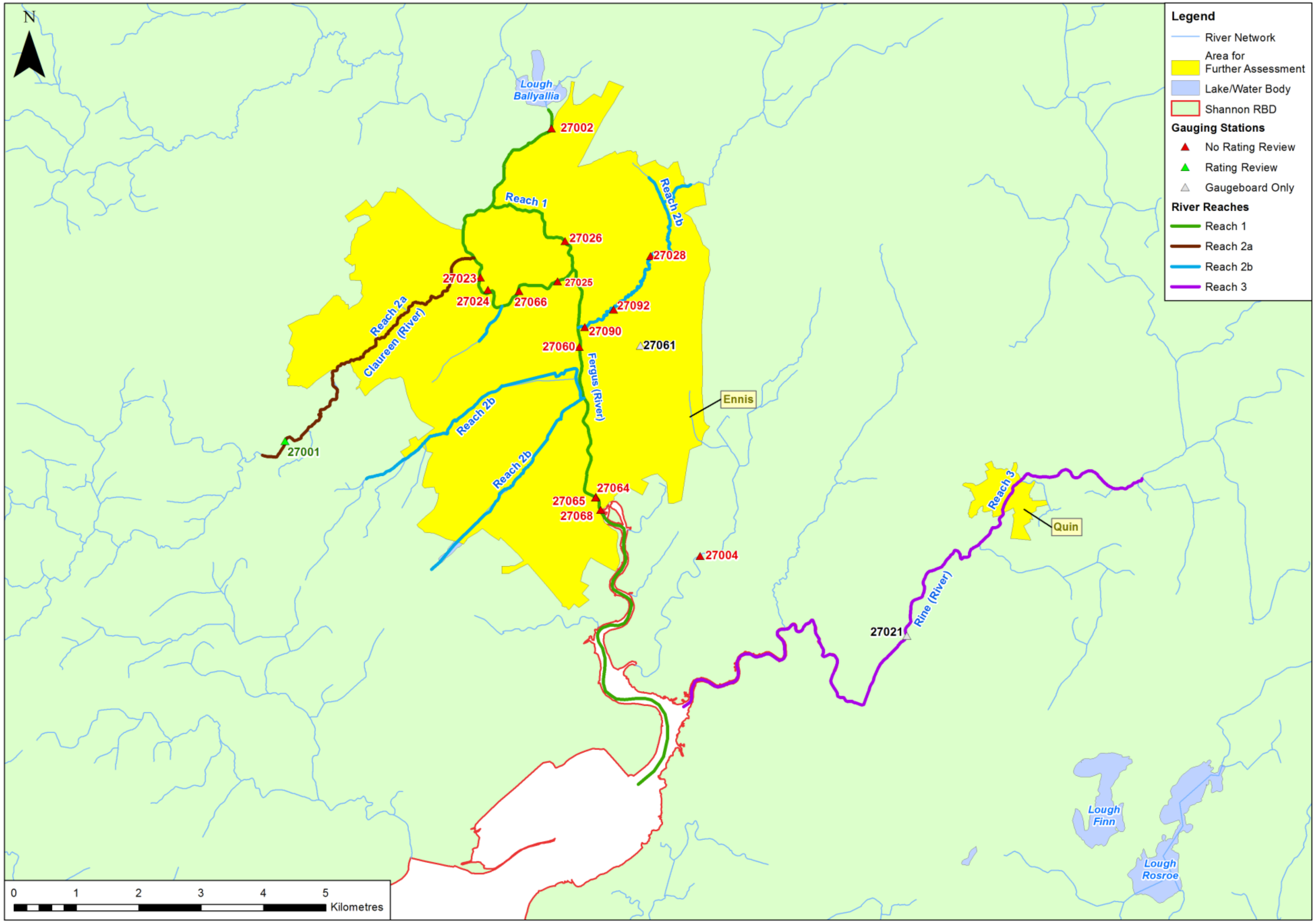


Figure A1.2 Fergus Catchment River Reaches

The selection of the QMED adjustment factors, growth curves and hydrograph shapes for these reaches is detailed in Sections A1.5 to A1.7 below.

A1.5 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. Notes on the adjustment factor estimates are provided below the table.

Reach	Gauging station number	QMED observed (m^3/s)[1]	QMED (urban) synthetic (m^3/s)	Adjustment Factor (-)	Model Extent	Note
1	27002	33.7	40.6	0.83	S01	1
2a	27001	34.6	32.0	1.08	S01	2
2b	27_1118_4	-	3.7	0.85	S01	3
3	27_661_2	-	21.0	1.03	S01/S02	4

Table A1.7 QMED Adjustment Factors

1. Station 27002 has 56-years of AMAX data (1954 - 2009). QMED is based on the full record of AMAX data. The OPW operated gauge has an A1 classification having a stable reliable rating up to approximately 57 m^3/s or 1.7 x QMED.

2. Station 27001 has 37 years of AMAX data from 1972 - 2009 (no data is available for 1993). QMED, from the supplied AMAX data, is estimated as 20.3 m^3/s. The gauge has an upper limit of reliable rating of 23.2 m^3/s for the start of the record up until 07/1993 and only 16.5 m^3/s beyond this. OPW has confirmed that the data prior to July 1993 was deemed to have a poor rating, which is supported by the wide scatter in older check gaugings and lack of high flow gaugings in the period 1972-1993. A revised AMAX series from 1994 to 2009 based on the Jacobs revised rating equations is adopted. This increases the estimate of QMED from 20.3 to 34.6 m^3/s.

3. No gauging station is present within Reach 2b. QMED adjustment at FSU node 27_1118_4 is based on the Top 5 hydrologically similar sites, see Table A1.8 below. The node location is shown on the model extent map in Appendix B, Section B1.

4. No gauging station is present within Reach 3. QMED adjustment at FSU node 27_661_2 is based on the Top 5 hydrologically similar sites, see Table A1.9 below. The node location is shown on the model extent map in Appendix B, Section B2.

The adjustment factors for Reach 2b and Reach 3 in the S01 and S02 model extents were estimated using a weighted geometric mean of the five hydrologically most similar gauged sites in the country (see Tables A1.8 – A1.9). The use of a single pivotal site was considered but no suitable station was found that was hydrologically similar and sufficiently near to the subject site. 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. Note that this FSU parameter is defined differently for peak flow estimation (as used here) then for hydrograph shape analysis. 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 adjustment factors to the power of the weight, for all five pivotal sites: $\prod$ (Adjustment Factor^{Weight}).

Station Number	Station Name	Rank	Dij	Weight	Adjustment Factor
30020	Ballyhaunis	1	0.359	0.346	0.67
25040	Roscrea	2	0.676	0.184	0.55
13002	Foulk's Mill	3	0.789	0.157	0.67
22009	Deenagh (Laune)	4	0.791	0.157	1.23
19046	Martin	5	0.793	0.157	2.18
Weighted Geometric Mean					**0.85**

Table A1.8 QMED Adjustment Factor for HEP 27_1118_4 (Reach 2b)

Station Number	Station Name	Rank	Dij	Weight	Adjustment Factor
26010	Cloone	1	0.164	0.292	1.12
29001	Raford	2	0.170	0.282	0.71
16006	Multeen	3	0.247	0.194	1.58
25044	Coole	4	0.384	0.125	1.16
19001	Owenboy	5	0.448	0.107	0.86
Weighted Geometric Mean					**1.03**

Table A1.9 QMED Adjustment Factor for HEP 27_661_2 (Reach 3)

Table A1.10 shows the QMED adjustment factor applied to each reach in the catchment, with a justification for the selection of the gauging station.

Reach	QMED adjustment factor	Station or HEP Node	Justification
1	0.83	27002	The OPW operated gauge has an A1 classification having a stable reliable rating up to 57 m³/s (1.7 x QMED). Relatively long (56 years) AMAX is available. The observed QMED flow may be affected by karst features which are abundant in the upper Fergus catchment.
2a	1.08	27001	This station has been subject to a rating review. The revised rating fits well to gaugings at medium flows and has been developed based on the current topography at the gauging station, the model rating is considered to be the best available high flow rating. Only post 1994-revised AMAX values were used for this estimate of QMED as the watercourse was subject to drainage works around 1993 and a reliable rating was not achievable for the pre-drainage condition, due to the modification of the channel geometry.
2b	0.85	27_1118_4	Ungauged. Based on geometric mean of adjustment factors at 5 pivotal sites.
3	1.03	27_661_2	Ungauged. Based on geometric mean of adjustment factors at 5 pivotal sites.

Table A1.10 QMED Adjustment Factors Applied to Each Reach

A1.6 Flood Frequency Curves

Two stations suitable for flood frequency analysis were identified in the catchment: stations 27001 (Inch Bridge) and 27002 (Ballycorey). The flood frequency curves (in the form of growth curves with non-dimensionalised flows) are plotted in Figures A1.3 and A1.4 below. The flood frequency curve plots for all relevant locations in Fergus catchment are included in Appendix E.

The figures show the at-site AMAX series (made dimensionless by dividing the flows by QMED), a distribution fitted to the AMAX data, and pooling group results plotted against the reduced variate (on a Gringorten plot).

Inch Bridge Gauging Station (27001 – on the River Claureen)

A rating review has been undertaken for gauging station 27001 (Inch Bridge), details of which are provided in Appendix C.

Inch Bridge has 37 years of AMAX data from 1972 to 2009 (no data is available for 1993). However, only the 16 years from 1994 were used as the river catchment underwent drainage works during 1993 and no reliable rating was available for the pre-1993 period as a result of the changed river channel geometry due to the drainage scheme.

The downstream part of the River Claureen is underlain by a karstified aquifer, with evidence of karst features, refer to Figure 3.5 in the main report. However, the gauging station is situated upstream of that aquifer and the catchment runoff to the station should therefore not be significantly affected by the karst features.

OPW report that local channel works which occurred at the gauge in July 1993, significantly altered the site. OPW report that channel works were undertaken around July 1993, which is also evident in a datum shift and change in the stage-discharge relationship in the check gaugings from that date. The model rating has therefore been compared only to check gaugings after local channel works occurred.

The modelled rating is found to fit well with gaugings at medium flows and is considered the best available high flow rating.

The Inch Bridge at-site and pooled growth curves are shown on Figure A1.3.

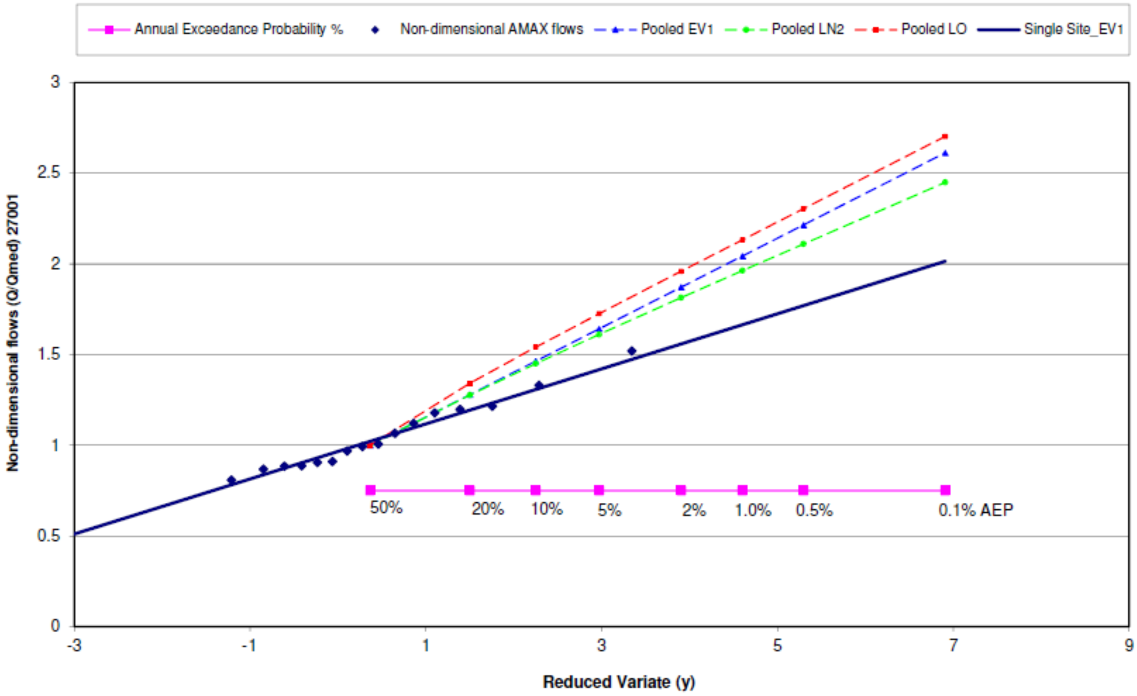


Figure A1.3 Station 27001 Inch Bridge – Flood Frequency Curves (N=16)

With 16 years of data the on-site data can be used directly to estimate growth factors for return periods up to approximately 8 years (1/2 N with N=16). For lower AEPs (higher return periods) it may be more appropriate to use pooled data.

At station 27001, growth factors derived from a pooled analysis of 18 representative stations with a total 505 years of data are found to be greater than those derived from an at-site analysis based on 16 hydrometric years of AMAX data. From the comparison with the at-site curve, the LN2 distribution based growth curve was selected.

The preference for adopting the pooled LN2 distribution based growth curve over those derived from the at-site data is for the following three reasons:

1. The revised AMAX series that can be used in flood frequency analysis has a short length (only 16 years data);
2. The at-site 1% AEP growth factor is only 1.66, which is much lower than that of most other Irish catchments and also much lower than the growth factor produced by pooling group analysis (which is 1.96);

3. An analysis of the November 2009 rainfall data suggests that for the Claureen the pooled LN2 event provides a much more reasonable assessment of flood rarity (or return period) than a growth curve based on the short at-site data record, as detailed below.

For the largest flood event in the AMAX series (52.6 m³/s on 19th November 2009), the at-site analysis based on 16 years of data suggests the event to have an AEP of approximately 3.3% or a return period of approximately 30 years. The pooled LN2 distribution based growth curve estimates this event to have an AEP of 8% or a return period of approximately 12 years. The rarity of the same event (November 2009) in the River Fergus (Station 27002) has been estimated in excess of 0.5% AEP (refer to Figure A1.4), with extensive flooding in the town of Ennis.

The difference in rarity of the November 2009 event in the River Fergus (Station 27002) and in the River Claureen (Station 27001) can be explained from the rarity of the rainfall event in the catchment. The nearest sub-daily rainfall station is Shannon Airport, which shows that the rarity of up to 24 hour duration rainfall was approximately 50% AEP only (refer to Table 6-J, page 50 of the Inception Report for UoM 27. On the other hand, the rarity of 1-day and 4-day duration rainfall events at Station 1218 (Tulla) was 26% and 1% respectively (refer to Table 6-G, page 48 of the Inception Report). It is observed from the hydrograph shape of the two rivers (Figures A1.5 and A1.6) that the time to peak (and hence the critical storm duration) for the River Claureen is less than 1 day whereas that of River Fergus, the time to peak is approximately 2 weeks. As a result the rarity of the November 2009 event in the River Fergus is much higher than the rarity of the same flood in the River Claureen.

Ballycorey Gauging Station (27002 – on the River Fergus)

Ballycorey is located on the River Fergus at the outer edge of the Ennis AFA. The gauge has an A1 FSU classification and upper limit of reliable rating of 1.7 x QMED. With 98% of daily flow data having the OPW quality code ‘good’, the Ballycorey gauge is the best quality gauge within the Fergus catchment.

The station has 56-years of AMAX data from 1954 to 2009. Although hydrometric year 2009 is incomplete and year 2001 has significant data gaps neither has been rejected due to the high flood flows recorded in both hydrometric years. The largest flow recorded at Station 27002 was in November 2009, during which Station 27001 also received the largest recorded flow.

The Fergus catchment upstream of the gauging station is largely underlain by a karstic aquifer and well-drained soils (see Figures 3.4 and 3.5 in the main report). The catchment response is therefore expected to be influenced by karstic features as described in Section 3.5 of the main report.

With 56 years of data the on-site data can be used directly to estimate growth factors for return periods up to approximately 28 years (1/2 N with N=56). For lower AEPs (higher return periods) it is most often more appropriate to use pooled data.

In the case of the Ballycorey gauge growth factors derived from the 56-years of at-site data are preferred to pooled analysis for the following reasons:

1. Due to the strongly karstic nature of the catchment more weight is given to observed data than pooled data, as the list of pooled stations includes many

stations that are not affected much by karst features (see Section 3.5 of the main report);

2. Had a pooled growth curve been selected then this would imply that the highest recorded flow (of November 2009) had an AEP smaller than 0.1% (i.e. a return period greater than 1000 years) which is considered very high, and it would also imply that the 56-years of date includes two extreme events with AEPs below 1% (return periods greater than 100 years). Although it is not impossible that one or more events with such low AEPs have occurred in that period, it lends weight to the argument in favour of adopting an at-site growth curve.

The Ballycorey at-site and pooled growth curves are shown on Figure A1.4 below.

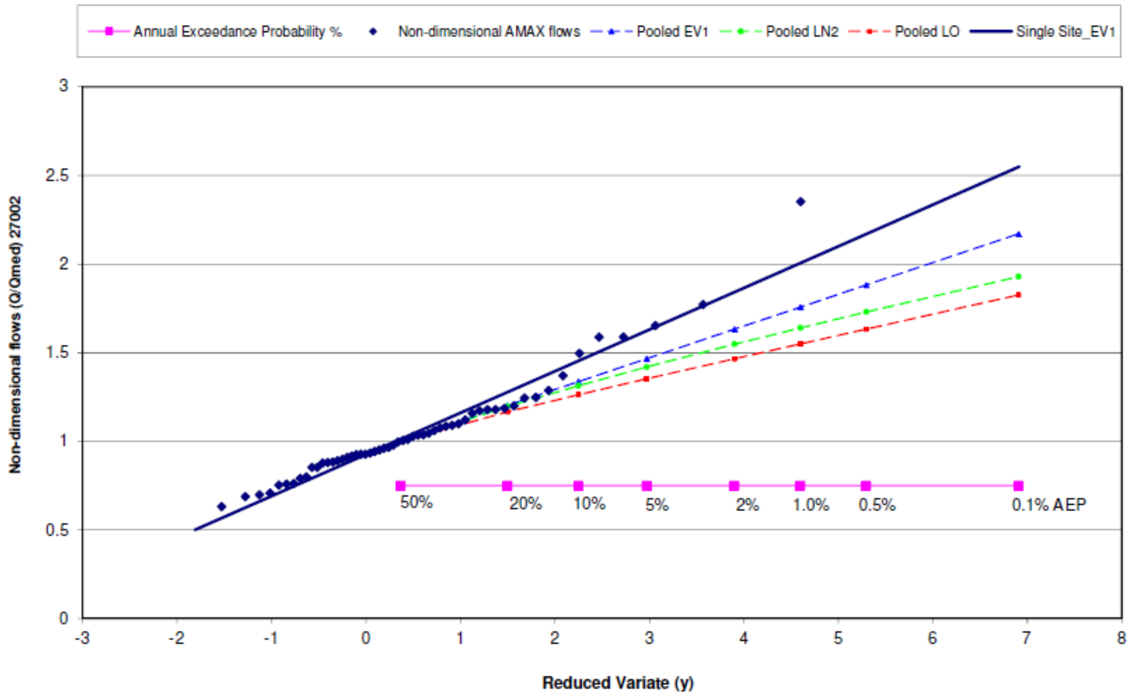


Figure A1.4 Station 27002 Ballycorey – Flood Frequency Curves (N=56)

River Reach Flood Frequency

(i) Flood Frequency Curve Reach 1

Station 27002 (Ballycorey) is the only reliable station for flood frequency analysis within the reach. Other stations along the main branch of the Fergus (See Table A1.1) were dismissed for flood frequency analysis either because they have no stage-discharge rating and/or the data recorded is subject to the influence of the tide.

Figure A1.4. shows the single site EV1 curve to provide a good fit with the recorded AMAX data and this has therefore been adopted for Reach 1.

(ii) Flood Frequency Curve Reach 2a

Station 27001 (Inch Bridge) on the River Claureen is the only other station within the Fergus sub-catchment suitable for flood frequency analysis. Growth curves derived from the at-site data and those from pooled analysis are shown in figure A1.3.

For Reach 2a, pooled group derived LN2 distribution based growth curve was selected for the reasons discussed above.

(iii) Flood Frequency Curve Reach 2b

No gauging station suitable for flood frequency analysis is present within Reach 2b. Instead, a representative growth curve was derived from a pooled analysis.

Pooling was undertaken at HEP node 27_1118_4 (see Figure B1.1 in Appendix B, Section B1). The resulting pooling group of 19 representative sites with a total of 514 years of data is considered suitably homogenous. The L-moment ratio diagram suggests that the EV1 distribution is appropriate for this pooling group.

(iv) Flood Frequency Curves Reach 3

No gauging station suitable for flood frequency analysis is present within Reach 3. Instead, a representative growth curve was derived from a pooled analysis.

Pooling was undertaken at HEP node 27_661_2 (within the Quin AFA, see Figure B2.1 in Appendix B, Section B2). The resulting pooling group of 16 representative sites with a total of 507 years of data is considered suitably homogenous. The L-moment ratio diagram suggests that the EV1 distribution is appropriate for this pooling group.

(v) Conclusion

The growth curve distributions applied to the relevant reaches are shown in Table A1.11. Growth factors generated for a range of AEPs have been detailed in Table A1.12.

Reach	Station	Single Site or Pooled	Selected distribution
1	27002 Ballycorey	Single Site	EV1
2a	27001 Inch Bridge	Pooled	LN2
2b	27_1118_4	Pooled	EV1
3	27_661_2	Pooled	EV1

Table A1.11 Final Growth Curves Selected

Annual Exceedance Probability (%)	Growth Factors Reach 1	Growth Factors Reach 2a	Growth Factors Reach 2b	Growth Factors Reach 3
50%	1.00	1.00	1.00	1.00
20%	1.28	1.28	1.29	1.23
10%	1.45	1.45	1.49	1.38
5%	1.62	1.61	1.67	1.53
2%	1.84	1.81	1.91	1.71
1%	2.01	1.96	2.09	1.85
0.5%	2.17	2.11	2.27	1.99
0.1%	2.55	2.45	2.69	2.32

Table A1.12 Final Growth Factors Applied to the Fergus Catchment

A1.7 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 no gauge is present within a river reach, design hydrograph shape has been derived from a hydrologically similar pivotal station.

Station 27002 at Ballycorey is the best choice for Reach 1 as the station is sited on the main branch of the river, located just outside the AFA and is the most reliable flow gauge in the Fergus Catchment.

Gauging stations present along the tributary branches within Reaches 2a and 2b are limited to stations 27028 (Gaurus Bridge) and 27092 (Gaurus Landfill) on the River Gaurus; and 27001 (Inch Bridge) on the River Claureen. Only station 27001 has both flow and level data to derive historic event hydrographs.

The hydrological behaviour of the River Claureen (Reach 2a) is considered significantly different to that of the River Fergus main stem (Reach 1) and those watercourses in Reach 2b, particularly in terms of catchment area, BFIsoil, and SAAR values. Based on the differences in hydrological parameters, data at pivotal station 13002 (Foulk's Mill) was used to produce a design hydrograph shape, to be adopted for all watercourses within Reach 2b.

As there are no flow gauging stations on Reach 3 (River Rine), pivotal station 16005 (Aughnagross) was used to produce a design hydrograph shape for Reach 3.

Table A1.13 lists the (pivotal) gauging stations used to produce a hydrograph shape for each reach.

Reach	Gauging Station
1	27002 – Ballycorey
2a	27001 – Inch Bridge
2b	Pivotal Station 13002
3	Pivotal Station 16005

Table A1.13 Hydrograph Shape Sub-Reaches – Gauging Stations

Tables A1.14 - 15 and Figures A1.5 and A1.6 show the highest flood events chosen for comparison at stations 27001 and 27002. Figures A1.5 and A1.6 present the hydrographs in a non-dimensional manner by dividing flows by their respective flood peaks. The hydrograph that best represents a typical or average storm duration has then been selected as the representative design hydrograph shape.

Date	Peak Flow (m^3/s)	Comments
19/11/2009	52.56	
23/08/2009	46.03	
07/01/2005	42.01	Selected Hydrograph
27/01/1995	41.15	

Table A1.14 Highest Flood Peaks for Gauging Station 27001

Date	Peak Flow (m^3/s)	Comments
24/11/2009	79.4	Selected Hydrograph (date of peak flow confirmed by OPW)
30/12/1959	59.6	
01/02/1995	53.8	
27/12/1999	53.6	

Table A1.15 Highest Flood Peaks for Gauging Station 27002

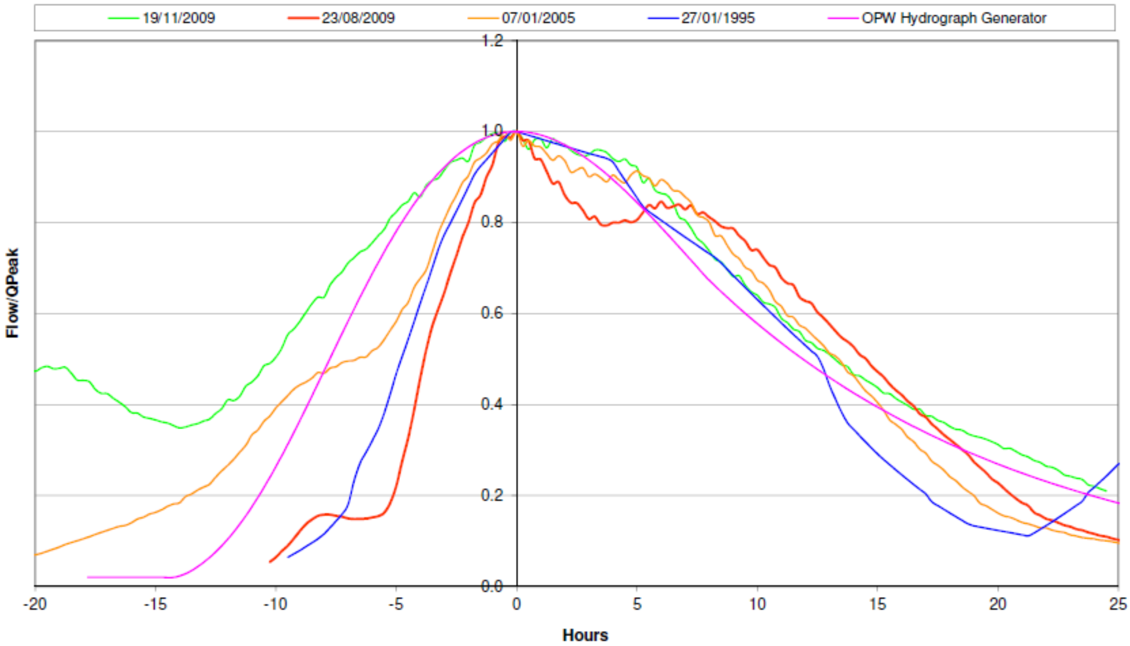


Figure A1.5 Non-dimensional Hydrographs for Gauging Station 27001

The 7/01/2005 historic flood hydrograph was selected at station 27001 as an appropriate hydrograph shape for Reach 2a as it is the best representation of all hydrograph shapes plotted in Figure A1.5.

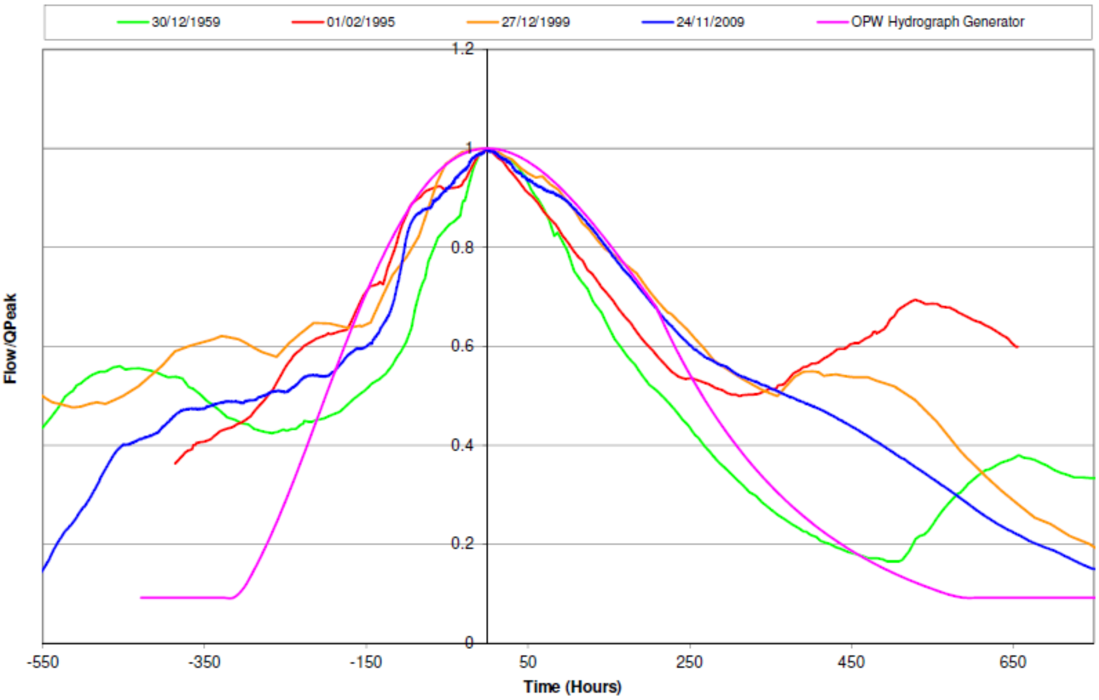


Figure A1.6 Non-dimensional Hydrographs for Gauging Station 27002

The 24/11/2009 historic flood hydrograph was selected at station 27002 as an appropriate hydrograph shape for the design hydrographs. Figure A1.6 shows that of the four highest events, the 2009 event has the approximate median duration and was therefore selected as the hydrograph shape at gauging station 27002.

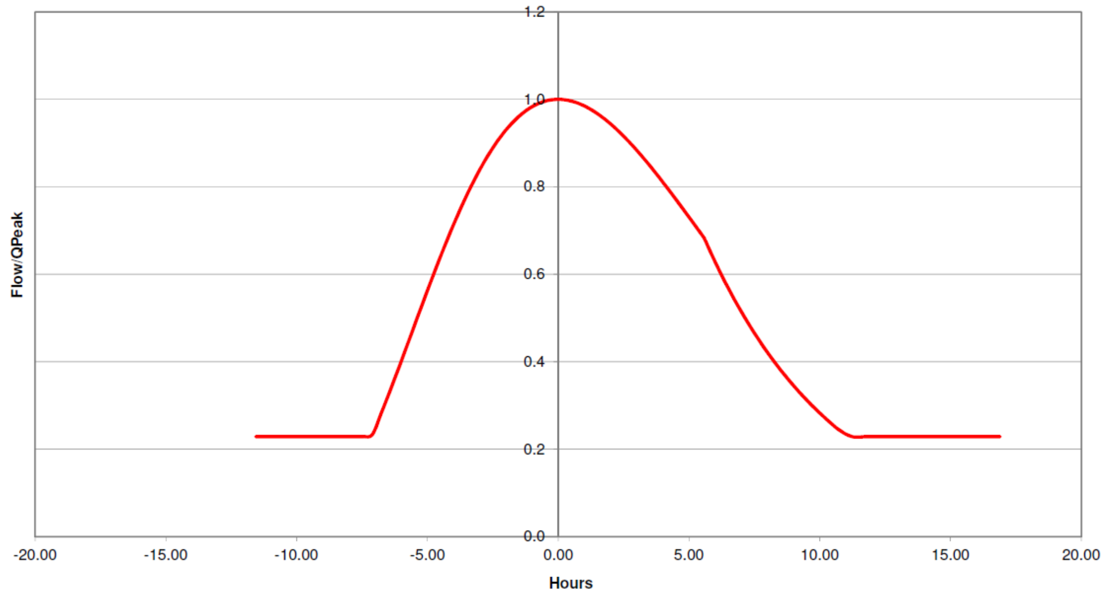


Figure A1.7 Non-dimensional Hydrograph for Reach 2b

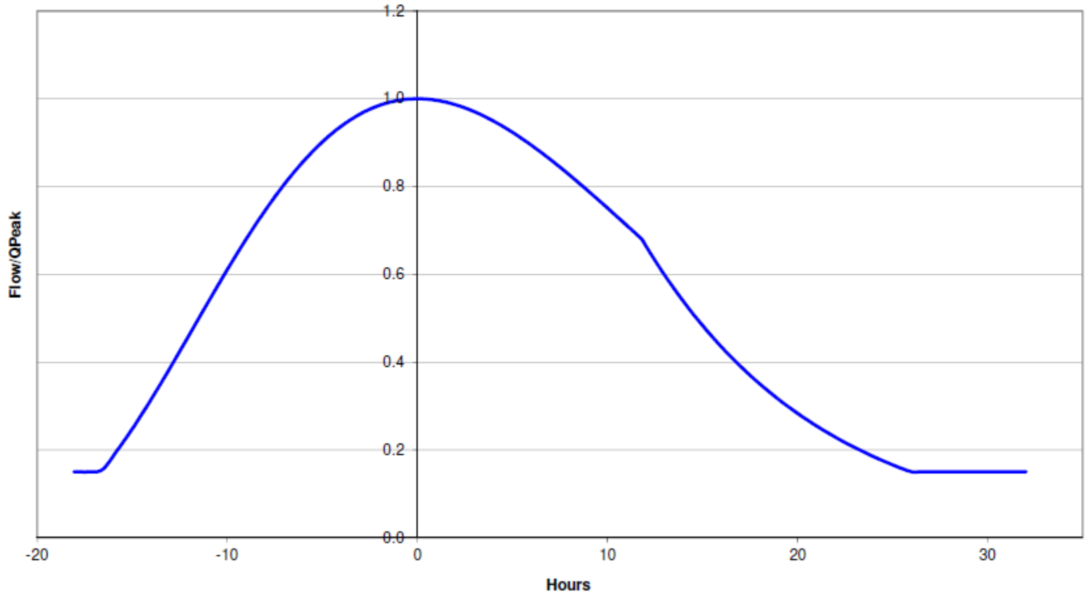


Figure A1.8 Non-dimensional Hydrograph for Reach 3

No suitable station exists within Reach 2b or Reach 3. Instead, the design hydrographs shown in Figures A1.7 and A1.8 were generated using data derived from hydrologically similar pivotal stations. Figure A1.7 shows the design hydrograph shape generated at Pivotal Station 13002 and adopted for all watercourses within Reach 2b. Figure A1.8 shows the hydrograph shape generated at Station 16005 which was selected as being representative of the Rine catchment (Reach 3) due to hydrological similarities including catchment area, BFIsoil, S1085 and URBEXT parameters.

A1.8 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.

A1.9 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 Owenogarney Catchment

A2.1 Catchment Description

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

Attribute	Description
Unit of Management (UoM)	27
Main water courses	Owenogarney River and an unnamed tributary at Bunratty
Outflow point	Shannon Estuary
Total catchment area	Owenogarney River: 186 km^2 to estuary (at FSU node 27_1261_2) Unnamed tributary at Bunratty: 73 km^2
Areas for Further Assessment (AFAs)	Sixmilebridge, Bunratty
Individual Risk Receptors (IRRs)	None
Model Extents*	S03
General topology	Min altitude = 0 mAOD Max altitude = 531 mAOD Catchment topography ranges from mountainous headwaters in the north-east to largely flat, low-lying land in the mid-reaches where lakes dominate. The headlands of the unnamed tributary (draining to Bunratty) are particularly lake-rich.particularly The tidal limit on the Owenogarney is immediately south of Sixmilebridge. The tidal limit of the Bunratty tributary is upstream of the model extent.
Average annual rainfall**	1053mm to 1248mm.
Soil and Geology	Soils: Well drained soils predominate with some poorly drained soils over the higher ground to the far north and east. Extensive peat deposits occur to the north and west of the catchment. Geology: Subsoils comprise primarily low to moderate permeability glacial tills over sandstone, mudstone and limestone bedrock with some alluvial deposits along watercourses, estuarine silts and clays around Bunratty and glacial sands and gravels around Broadford. Sandstone (locally important aquifer) and mudstone (poor aquifer) form the higher ground to the east where bedrock occurs at or close to surface. Limestone bedrock underlies the catchment to the west and frequently outcrops at surface. The limestone is predominantly a locally important bedrock aquifer but forms a regionally important karstified aquifer between Kilmurry and O'Callaghansmills.

Urban areas	The catchment is largely rural with Bunratty and Sixmilebridge being the only significant urbanised areas. The highest URBEXT value (1.62%) is found at the most downstream node on the tributary branch. In comparison, the highest URBEXT value found along the main stem of the Owenogarney is 0.51%.

* Specific hydrological details for the model is provided in Appendix B3
** Range of SAAR values taken from the FSU catchment descriptors covering the extent of modelling

Table A2.1 Owenogarney Catchment description

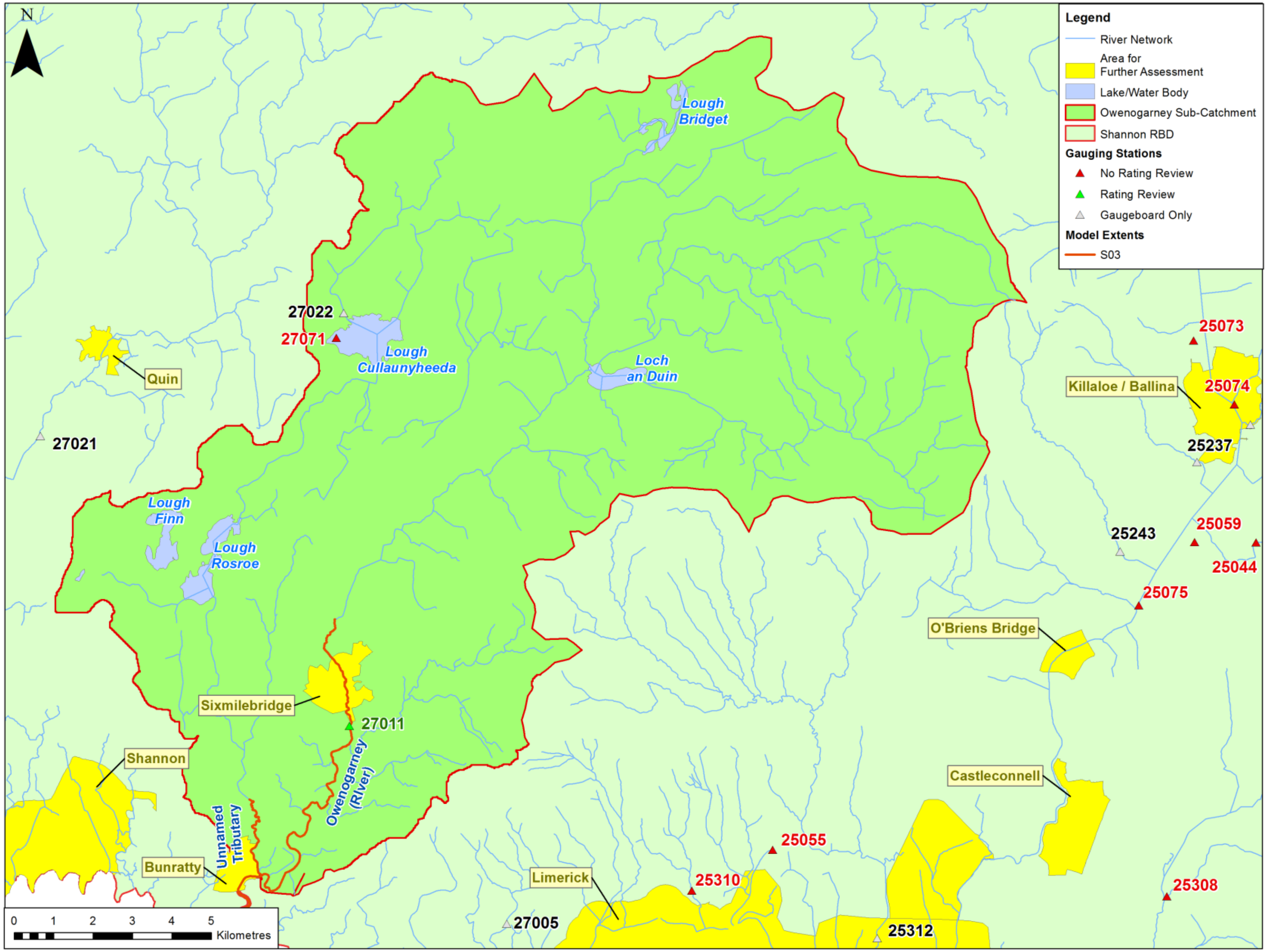


Figure A2.1 Owenogarney Catchment with model extents and hydrometric stations

A2.2 Hydrometric Stations in the Owenogarney Catchment

Details of the gauging stations in the Owenogarney 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
S03	27011	Owenogarney Rly Br.	1996 - 2009	levels & Flows	HGF / Qmed = 1.85	Yes	1

Table A2.2 Owenogarney Catchment Gauging Stations

Table A2.2 Hydrometric Data Quality Comments:

1. Station 27011 is the only station located within the S03 model extent. The station has just 14 years of AMAX data 1996 – 2009, of which, two years (1996 and 2000) are incomplete with data missing for the time intervals 24/02/2001 to 03/10/2001 (foot and mouth disease outbreak) and 11/01/2003 to 31/07/2007 (record not digitised). Qmed calculated over the entire record is 15.3m³/s and the reported upper limit of reliable rating is 28.3m³/s (1.85xQmed).

   A review of the station's rating suggests that the OPW rating is valid for the station. However, as the AMAX levels include tidal peaks and the station is located on a tidally influenced reach of the Owenogarney, the data is not used for Qmed adjustment or flood frequency analysis.

   Despite AMAX data being available for the period from 1996 to 2009 there are gaps in the record, 15-min data is available for the time intervals March 1997 to February 2001, October 2001 to January 2003 and July 2007 to present within the aforementioned time period.

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 Owenogarney catchment is covered by two 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 & A2.5 below.

Reach	Description	Model Extent
1	Owenogarney River (from HEP 27_634_4 to 27_1261_2)	S03
2	Unnamed tributary at Bunratty (from HEP 27_1193_4 to 27_1193_9)	S03

Table A2.3 River Reaches in the Catchment

Reach 1 (Owenogarney River)		
Catchment Descriptor	**Lower Limit (HEP node)**	**Upper Limit (HEP node)**
AREA (km^2)	154.9 (27_634_4)	186.1 (27_1261_2)
BFIsoil	0.64 (27_1274_1)	0.65 (27_634_11)
SAAR (mm)	1216 (27_1261_2)	1248 (27_634_4)
FARL	0.80 (27_634_4)	0.83 (27_1261_2)
DRAIND	1.11 (27_1274_1)	1.14 (27_634_4)
S1085 (m/km)	7.10 (27_1261_2)	8.88 (27_634_4)
ARTDRAIN2 (%)	0.0 (27_634_4)	1.99 (27_1261_2)
URBEXT (%)	0.11 (27_634_4)	0.51 (27_634_11)

Table A2.4 Reach 1 Catchment Descriptor Range

Reach 2 (Unnamed tributary at Bunratty)		
Catchment Descriptor	**Lower Limit (HEP node)**	**Upper Limit (HEP node)**
AREA (km^2)	70.3 (27_1193_4)	72.8 (27_1193_9)
BFIsoil	0.82 (all)	0.82 (all)
SAAR (mm)	1053 (27_1193_9)	1055 (27_1193_4)
FARL	0.65 (27_1193_4)	0.66 (27_1193_9)
DRAIND	0.80 (27_1193_4)	0.81 (27_1193_8)
S1085 (m/km)	1.24 (27_1193_4)	1.57 (27_1193_7)
ARTDRAIN2 (%)	0.72 (27_1193_4)	6.07 (27_1193_9)
URBEXT (%)	1.51 (27_1193_4)	1.62 (27_1193_9)

Table A2.5 Reach 2 Catchment Descriptor Range

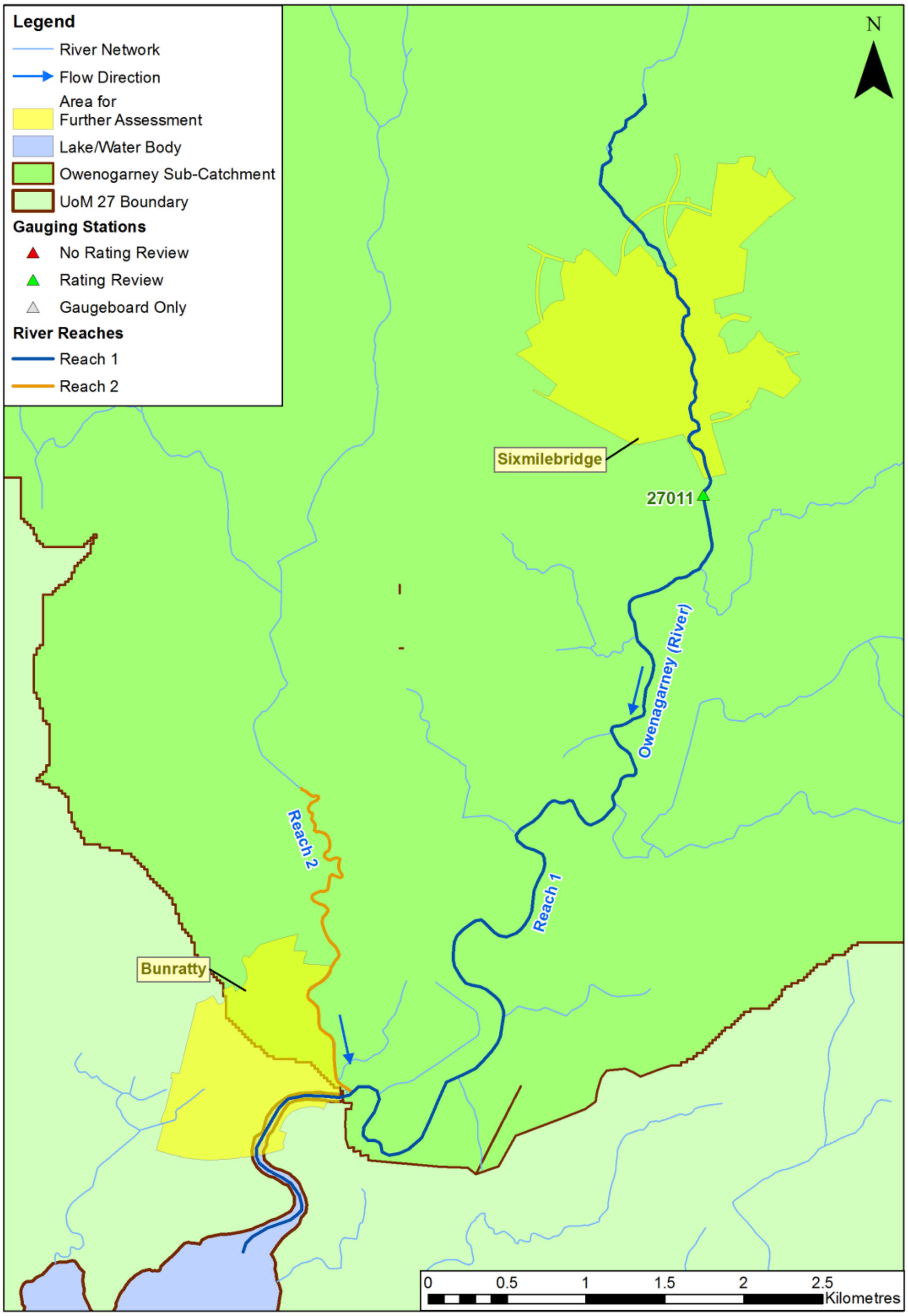


Figure A2.2 Owenogarney Catchment River Reaches

A2.4 QMED Adjustment Factors

As the only station on Owenogarney (27011) is located on the tidal reach and the AMAXs are tidal peaks, the data could not be used for calculating the Qmed Adjustment Factor. Thus the QMED adjustment factors applied to the S03 Model Extent were estimated using multiple pivotal sites. The adjustment factors were estimated using a weighted geometric mean of the five hydrologically most similar gauged sites in the country (see Tables A2.6 & A2.7). 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 adjustment factors to the power of the weight, for all five pivotal sites: Π (Adjustment $\text{Factor}^{\text{Weight}}$).

Station Number	Station Name	Rank	Dij	Weight	Adjustment Factor
25038	TYONE	1	0.347	0.230	1.14
19016	OVENS	2	0.360	0.221	1.36
19015	HEALY'S BR.	3	0.369	0.216	1.71
16012	TAR	4	0.419	0.190	0.89
19001	OWENBOY	5	0.437	0.143	0.86
Weighted Geometric Mean					**1.19**

Table A2.6 QMED Adjustment Factor for HEP 27_634_10 (Reach 1)

Station Number	Station Name	Rank	Dij	Weight	Adjustment Factor
26058	BALLINRINK BR.	1	0.457	0.285	0.63
13002	FOULK'S MILL	2	0.510	0.255	0.67
26018	OWENURE	3	0.717	0.181	1.39
6070	MUCKNO LAKE	4	0.846	0.154	0.95
19046	MARTIN	5	0.892	0.126	2.18
Weighted Geometric Mean					**0.86**

Table A2.7 QMED Adjustment Factor for HEP 27_1193_4 (Reach 2)

Table A2.8 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	1.19	27_634_10	No suitable hydrometric station to provide gauged data; the AMAX at Station 27011 are tidally influenced. Adjustment factors are based on top 5 most hydrologically similar stations.
2	0.86	27_1193_4	

Table A2.8 Final QMED Adjustment Factor Applied to Each Reach

A2.5 Flood Frequency Curves

The flood frequency curves (or growth curves) are plotted in Figures A2.3 and A2.4. The figures show the at-site AMAX series (made dimensionless by dividing the flows by QMED, and plotting positions based on the Gringorten formula), an EV1distribution 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.

One active gauging station (27011 - Owenogarney Railway Bridge) exists within the model extent of S03. The station's suitability for flood frequency analysis is discussed below.

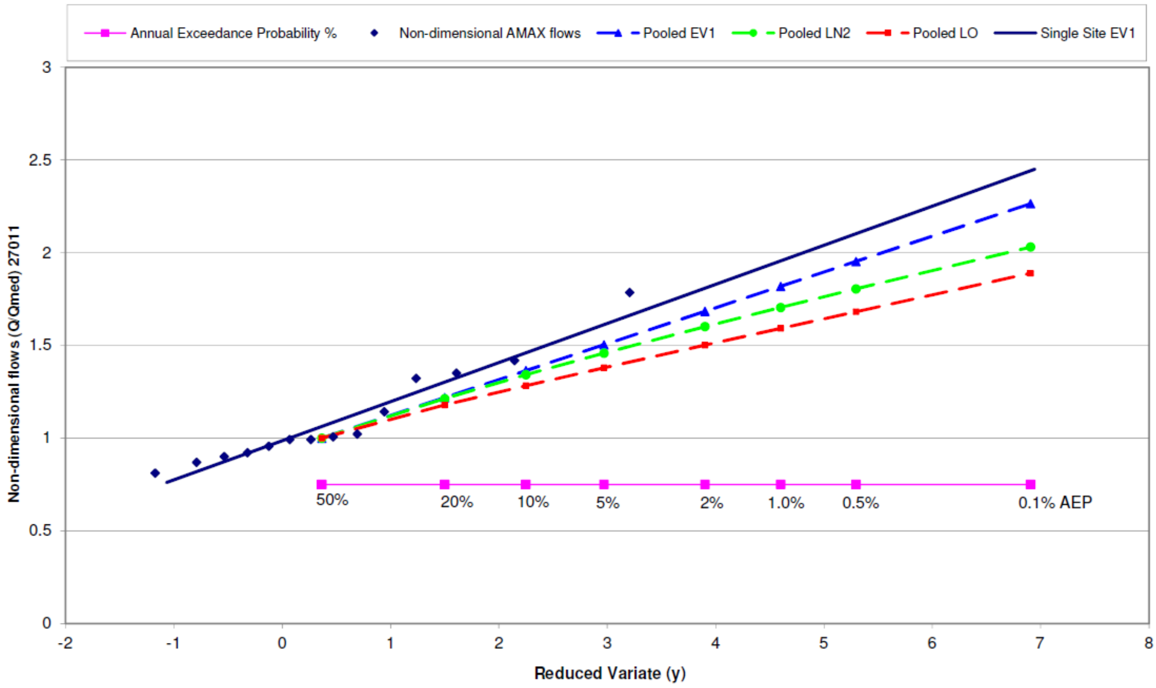
Owenogarney Railway Bridge Gauging Station

The Owenogarney gauge (Station 27011) is reported as having a reliable rating up to 1.85* QMED. A rating review for this station has been undertaken as part of the Shannon CFRAM Study. Revision of the station's rating suggests that the existing OPW rating is valid for the station. For full details, see Appendix C - Hydrometric Station Rating Review Summary Sheet for station 27011.

The semi-tidal nature of the station however, limits its usefulness for flood frequency analysis. Furthermore, there are only 14-years of annual maxima (AMAX) data at Station 27011, two of which are incomplete.

Although 14 years of good quality AMAX data can provide a reasonable estimate of Qmed, the data at this station could not be used as the AMAX levels and flows are tidally influenced. Similarly, the AMAX is not deemed appropriate for flood frequency analysis for the same reason.

Figure A2.3 shows the at-site growth curve alongside those derived from pooled analysis.



A2.3 Reach 1 – Flood Frequency Curves (N=525)

It is observed that the pooling based growth curves are flatter than that derived from an at-site analysis. Figure A2.3 shows that the EV1 100-year growth factor derived from the pooling group method is 1.82 compared with 1.95 from an EV1 single site analysis.

Whilst the at-site analysis produces a steeper curve than those derived from the pooling group method; as discussed, the at-site growth curve is based on the tidally influenced AMAX and hence presented above for reference only. .

The above frequency curve suggests that with the pooled growth curves the largest AMAX event in the 14-year record (November 2009) has a return period of approximately 100 years. As the AMAX of November 2009 was tidal peak, the return period of November 2009 mentioned above is only for a reference.

Unnamed Tributary at Bunratty

The tributary's catchment characteristics differ to those of the main stem, particularly in terms of FARL and BFI. As such, independent growth factors have been derived. As no station exists on the tributary branch; the flood frequency curves plotted in Figure A2.4 have been derived from a pooled analysis at HEP 27_1193_4. Figure A2.4 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 Bunratty subject site is not ideal for pooled analysis due to a very high BFI value of 0.82 and a large degree of attenuation within the catchment (FARL of 0.67). Finding an appropriate pooling group has therefore proven problematic and a large number of sites were removed from the pooling group even after having relaxed criteria for station selection. The final pooling group gives just 394 years of station data (refer to Appendix G for details of the pooling group analysis).

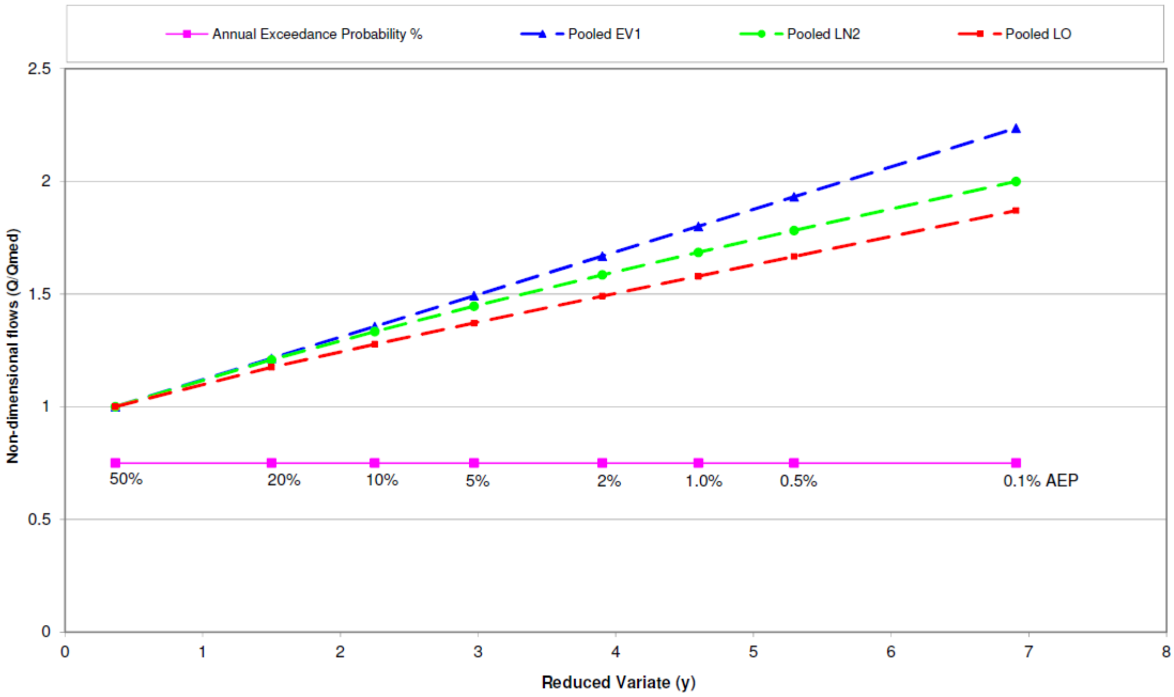


Figure A2.4 Reach 2 – Flood Frequency Curves (N=394)

Selection of the most suitable distribution shown in Figures A2.3 and A2.4 has been based on interpretation of the L-Moment Ratio Diagrams shown in Figures A2.5 & A2.6. It is observed that in both cases, 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.

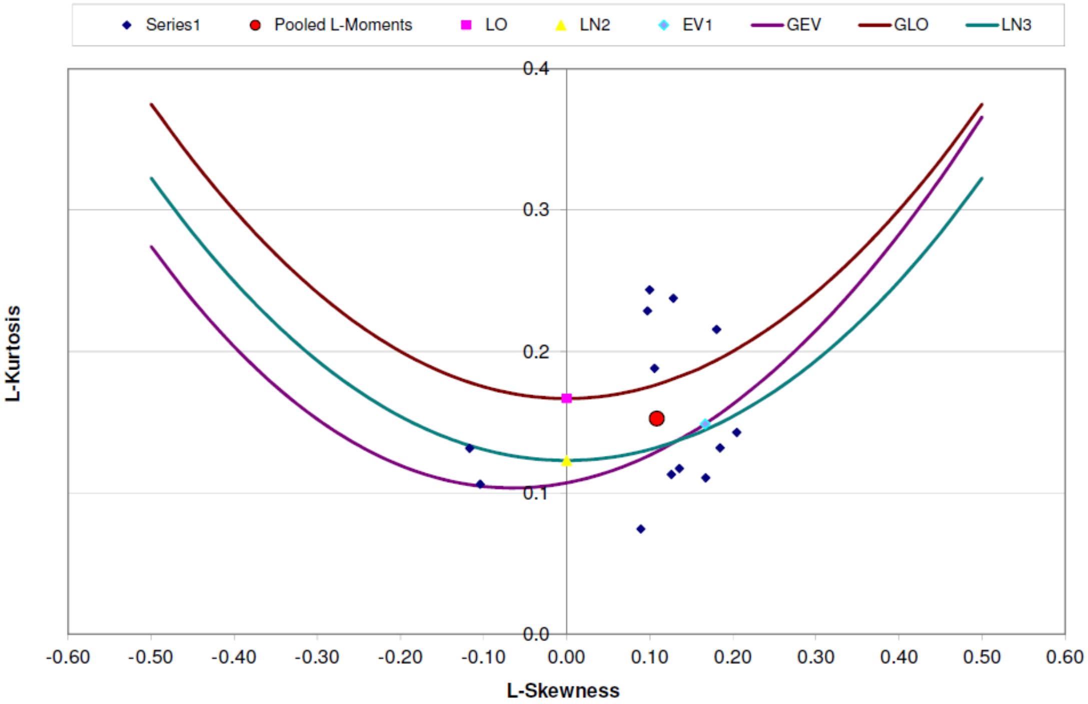


Figure A2.5 L-Moment Ratio Diagram (Reach 1)

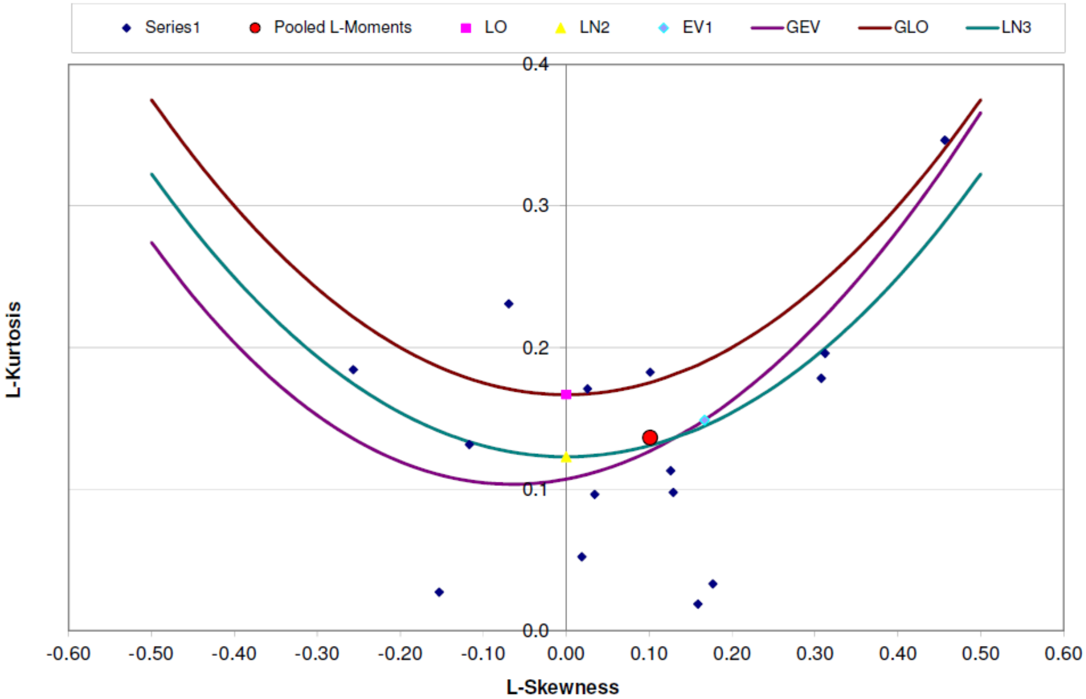


Figure A2.6 L-Moment Ratio Diagram (Reach 2)

River Reach Flood Frequency

The growth curve distribution applied to each reach is shown in Table A2.9. Growth factors generated for a range of AEPs have been detailed in Table A2.10.

Reach	Station	Single Site or Pooled	Selected distribution
1	27_634_10	Pooled	EV1
2	27_1193_4	Pooled	EV1

Table A2.9 Final Growth Curves Selected

Annual Exceedance Probability (%)	Growth Factors Reach 1	Growth Factors Reach 2
50%	1.00	1.00
20%	1.22	1.21
10%	1.36	1.36
5%	1.50	1.49
2%	1.68	1.67
1%	1.82	1.80
0.5%	1.95	1.93
0.1%	2.26	2.24

Table A2.10 Final Growth Factors Applied to the Owenogarney AFA 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 hydrograph shapes were obtained for the top five historic events, including that of November 2009 event at Station 27011 on the Owenogarney, the hydrograph shapes were found to be unrealistic (not usable for providing inflows to the hydraulic models) as the station is located on a tidally influenced reach of the river. Absence (or poor quality) of hydrometric data prevented deriving actual event hydrographs and hence a hydrograph shape was generated for a pivotal station that is hydrologically similar to the target site. Table A2.11 and Figure A2.7 show the highest flood events at station 27011 in the period where data is available namely March 1997 to February 2001, October 2001 to January 2003 and July 2007 to November 2009. The hydrographs are presented in a non-dimensional manner by dividing flows by their respective flood peaks.

Figure A2.8 identifies the hydrographs chosen to be representative of flood events in Reach 1 and Reach 2 of the Owenogarney catchment. Figure A2.8 presents the hydrographs in a non-dimensional manner by dividing flows by the flood peak.

Date	Peak Flow (m^3/s)	Comments
23/11/2009	43.56	Tidally influenced – GS27011 hydrograph shape not used
24/12/1999	20.60	
11/02/2002	15.43	
08/01/1998	14.97	
01/11/2000	14.35	

Table A2.11 Highest Flood Peaks for Gauging Station 27011

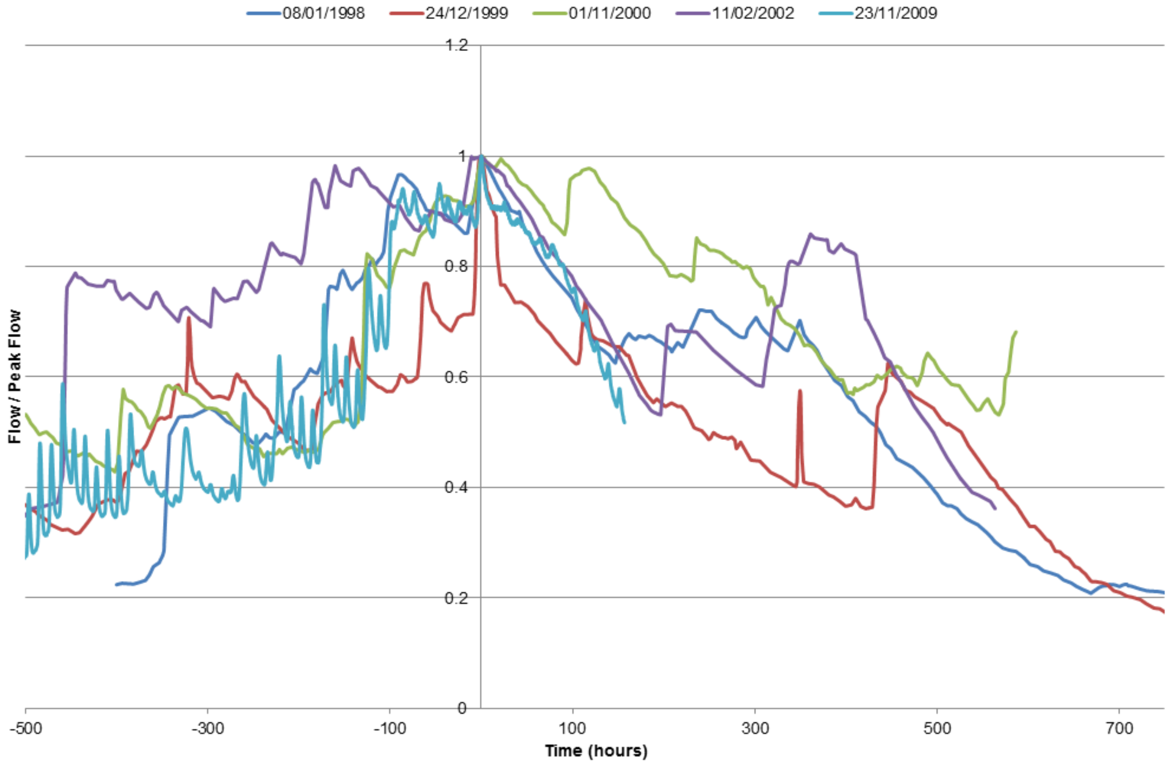


Figure A2.7 Non-dimensional Hydrographs for Gauging Station 27001

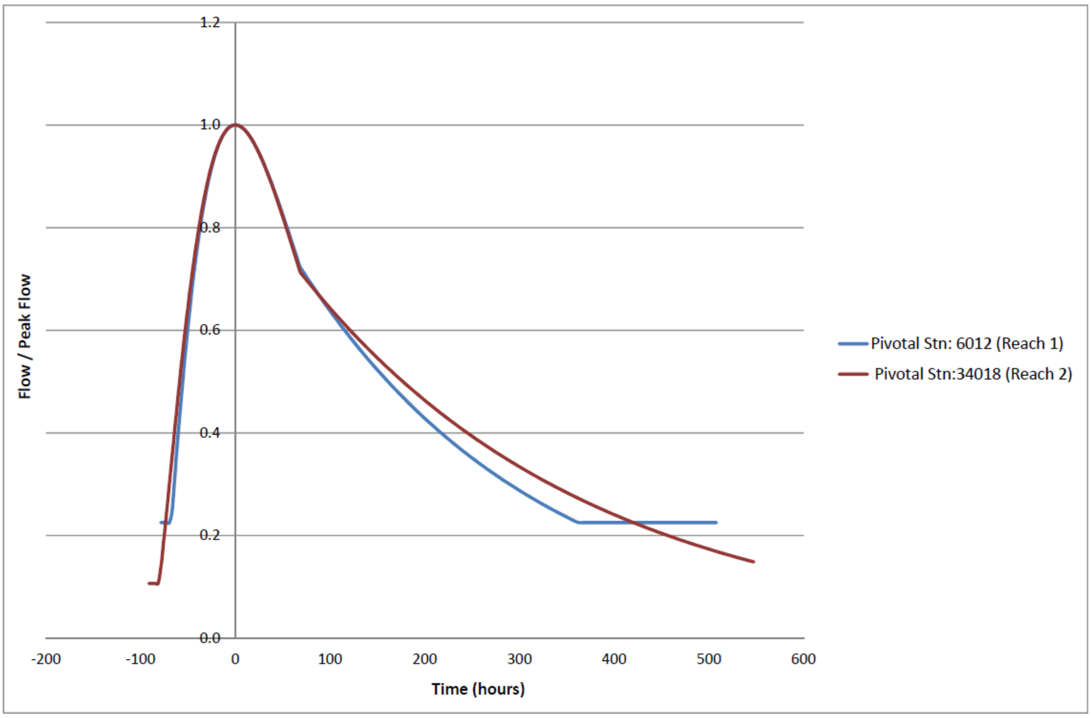


Figure A2.8 Non-dimensional Hydrographs Reach 1 (Pivotal Station 6012) & Reach 2 (Pivotal Station 34018)

The resulting design hydrographs for both reaches are very similar in width, although the catchment area for Reach 1 at Owenogarney AFA is about 2.2 times larger than the catchment area of Reach 2. It is noted however that the catchment to Reach 2 is more permeable (BFIsoil=0.82 instead of 0.64 for Owenogarney on Reach 1) and more affected by the presence of lakes (FARL=0.65 instead of 0.80 at Owenogarney on Reach 1). Both high permeability and the presence of lakes generally lead to longer hydrograph width, which suggests that the similarity in hydrograph width between the two reaches is not unreasonable.

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 Shannon AFA Catchment

A3.1 Catchment Description

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

Attribute	Description
Unit of Management (UoM)	27
Main water courses	Ballycasey Creek, Drumgeely Creek
Outflow point	Shannon Estuary
Total catchment area	28 km^2 up to the point of discharge to the Shannon Estuary
Areas for Further Assessment (AFAs)	Shannon Town
Individual Risk Receptors (IRRs)	Shannon Airport
Model Extents*	S04
General topology	Min altitude = 0 mAOD Max altitude = 53 mAOD The catchment is low-lying and flat. Some low-rising, undulating hills exist around Drumline and Leamaneigh
Average annual rainfall**	961mm to 1024mm.
Soil and Geology	Soils: Well-drained soils predominate with limited poorly drained soils and peat. Shannon (town) and Shannon Airport in the south are dominated by made ground. Geology: Subsoils comprise predominantly low to moderate permeability glacial tills over limestone bedrock. Low permeability estuarine deposits and made ground occur in the far south of the catchment to the east of Shannon and around Shannon Airport. The underlying limestone bedrock occurs at or close to surface throughout much of the catchment and is predominantly a locally important aquifer. Refer to Figures 3.3, 3.4 and 3.5 in the Main Report for details.
Urban areas	The lower reaches of the catchment are heavily urbanised, being dominated by Shannon Town and Shannon Airport. The highest URBEXT values of 54.9% and 48.15% are found at the downstream node of the two unnamed watercourses which discharge to the estuary alongside Drumgeely Creek and Ballycasey Creek respectively.

* Specific hydrological details for the model is provided in Appendix B4
** Range of SAAR values taken from the FSU catchment descriptors covering the extent of modelling

Table A3.1 Shannon AFA Catchment description

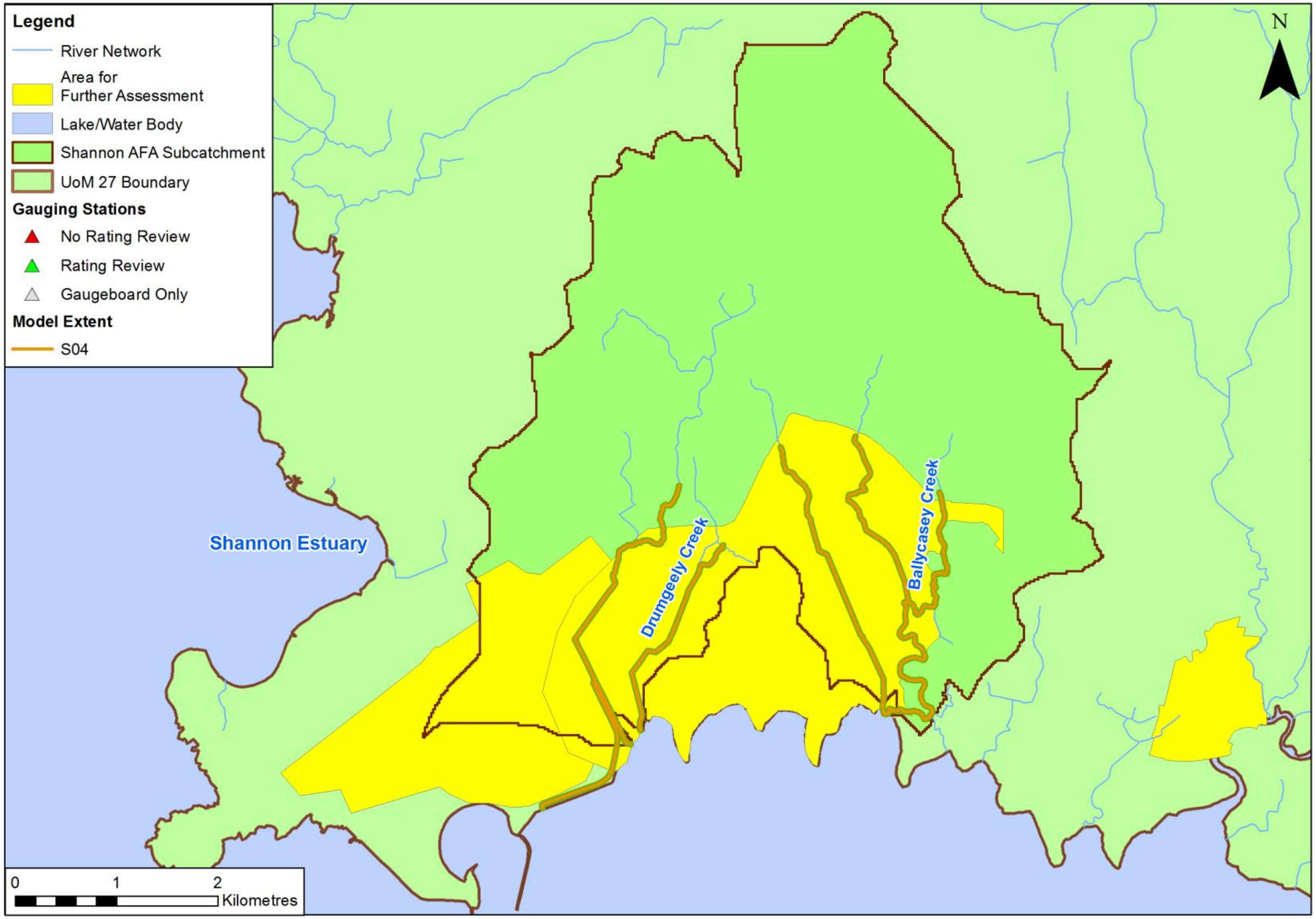


Figure A3.1 Shannon AFA Catchment with both model extents and hydrometric stations indicated

A3.2 Hydrometric Stations in the Shannon AFA Catchment

No gauging station is present within the Shannon (AFA) Catchment.

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. 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 Shannon (AFA) catchment is covered by two reaches, as tabulated in Table A3.2 and shown on Figure A3.2. The variation in catchment descriptors for each river reach is tabulated in Tables A3.3 & A3.4 below.

Reach	Description	Model Extent
1	Ballycasey Creek (from HEP node 27_ 1160_2 to 27_1161_5; and from HEP node 27_1134_1 to 27_1134_6).	S04
2	Drumgeely Creek (from HEP node 27_369_4 to 27_1147_5; and from HEP node 27_1164_0 to 27_1164_4).	S04

Table A3.2 River Reaches in the Catchment

Reach 1		
Catchment Descriptor	**Lower Limit (HEP node)**	**Upper Limit (HEP node)**
AREA (km^2)	1.0 (27_1134_1)	10.5 (27_1161_5)
BFIsoil	0.62 (27_1161_2)	0.71 (27_1160_2)
SAAR (mm)	961 (27_1134_6)	1007 (27_1160_2)
FARL	1.0 (all)	1.0 (all)
DRAIND	0.22 (27_805_1)	1.32 (27_1134_3)
S1085 (m/km)	3.1 (27_1161_5)	8.1 (27_805_2)
ARTDRAIN2 (%)	0.0 (all)	0.0 (all)
URBEXT (%)	0 (27_1160_2)	48 (27_1134_6)*

**High URBEXT value at most downstream node, URBEXT at all other nodes being relatively less*

Table A3.3 Reach 1 Catchment Descriptor Range

Reach 2		
Catchment Descriptor	Lower Limit (HEP node)	Upper Limit (HEP node)
AREA (km^2)	1.0 (27_1164_1)	12 (27_1147_5)
BFIsoil	0.60 (27_1164_2)	0.71 (27_1147_5)
SAAR (mm)	970 (27_1164_1)	1024 (27_369_4)
FARL	1.0 (all)	1.0 (all)
DRAIND	0.69 (27_369_4)	1.94 (27_1164_1)
S1085 (m/km)	3.0 (27_1164_4)	5.1 (27_1164_1)
ARTDRAIN2 (%)	0.0 (all)	0.0 (all)
URBEXT (%)	0.0 (27_369_4)	54.9 (27_1164_4)*

**High URBEXT value at most downstream node, URBEXT at all other nodes being relatively less.*

Table A3.4 Reach 2 Catchment Descriptor Range

The well-drained soils and permeable nature of the limestone geology are reflected in relatively high values of BFIsoil (0.60 – 0.71). It is noted however that there are significant amounts of low to moderate permeability glacial tills in the sub-soils that may limit the permeability of the overall catchment.

The effect of the urbanisation of Shannon and the airport are noticeable only in the most downstream HEPs, where the values of URBEX increase to 48% in Reach 1 and 55% in Reach 2.

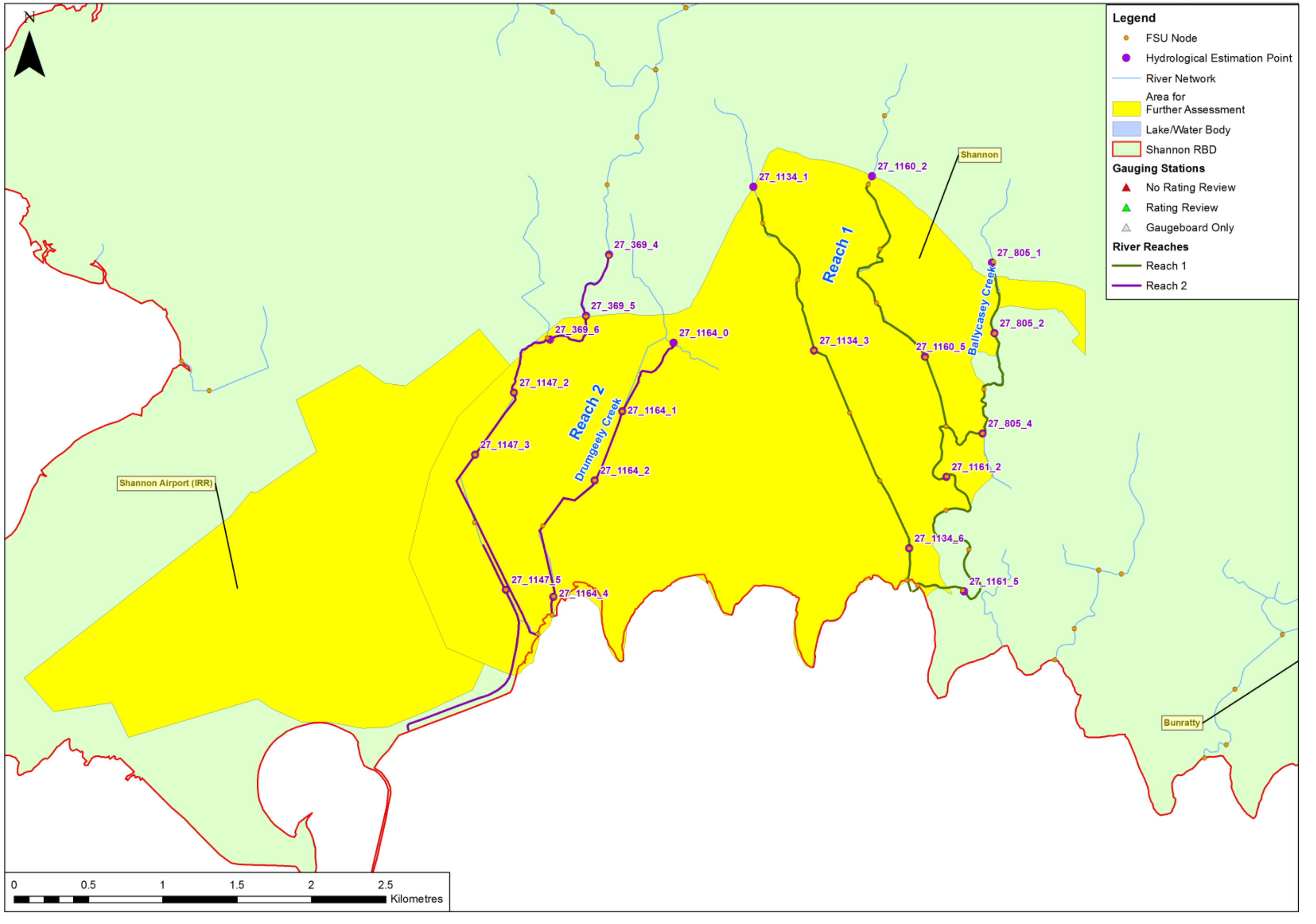


Figure A3.2 Shannon AFA Catchment River Reaches

A3.4 QMED Adjustment Factors

The QMED adjustment factors applied to the S04 Model Extent were estimated using multiple pivotal sites in the absence of an adequate single pivotal site. The adjustment factors were estimated using a weighted geometric mean of the five hydrologically most similar gauged sites in the country (see Tables A3.5 and A3.6). 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 adjustment factors to the power of the weight, for all five pivotal sites: Π (Adjustment Factor^{Weight}).

Station Number	Station Name	Rank	Dij	Weight	Adjustment Factor
25034	ROCHFORT	1	0.872	0.287	1.23
10022	CARRICKMINES	2	1.251	0.200	1.62
9011	SLANG	3	1.311	0.191	1.94
30020	BALLYHAUNIS	4	1.451	0.173	0.67
25040	ROSCREA	5	1.467	0.149	0.55
Weighted Geometric Mean					**1.18**

Table A3.5 QMED Adjustment Factor for HEP 27_1160_5 (Reach 1)

Station Number	Station Name	Rank	Dij	Weight	Adjustment Factor
25034	ROCHFORT	1	0.436	0.393	1.23
30020	BALLYHAUNIS	2	0.989	0.173	0.67
25040	ROSCREA	3	1.023	0.168	0.55
10022	CARRICKMINES	4	1.164	0.147	1.62
16051	ROSSESTOWN	5	1.242	0.119	0.73
Weighted Geometric Mean					**1.01**

Table A3.6 QMED Adjustment Factor for HEP 27_1147_3 (Reach 2)

Table A3.7 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	1.18	27_1160_5	No hydrometric station to provide gauged data; adjustment based on top 5 most hydrologically similar stations.
2	1.01	27_1147_3	

Table A3.7 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 Shannon AFA catchment. Instead, the flood frequency curves (or growth curves) plotted in Figures A3.3 & A3.4 have been derived from a pooled analysis. The below figures show 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 growth curves derived for Ballycasey and Drumgeely are based on 492 and 508-years of station data respectively. Due to the nature of the catchments (in particular catchment area and high URBEXT values) it has been necessary to relax the criteria for station selection (refer to Appendix G). For the pooled analysis undertaken on Ballycasey Creek it would have been possible to utilise more than 492 years of station data, but this would have been at the expense of relaxing parameter thresholds far more than is recommended.

In undertaking the pooling analysis the most hydrologically similar sites were selected, ensuring that the BFIsoil values were similar to those at the subject sites.

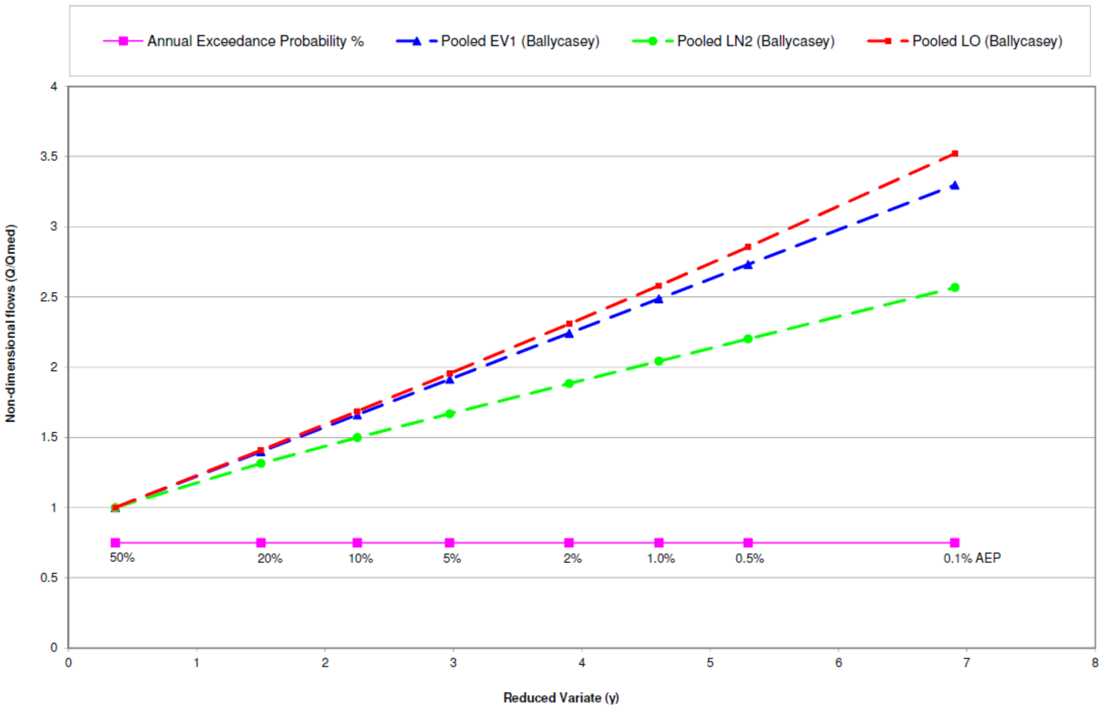


Figure A3.3 Reach 1 – Flood Frequency Curves (N=492)

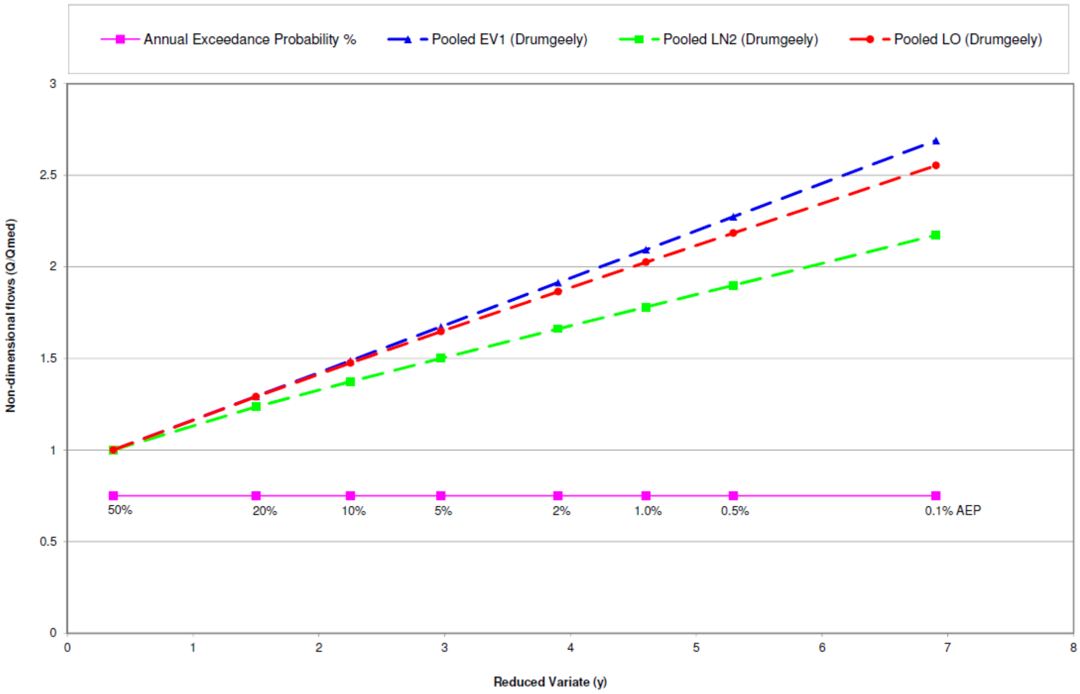


Figure A3.4 Reach 2 – Flood Frequency Curves (N=508)

Selection of the most suitable distribution shown in Figures A3.3 & A3.4 has been based on interpretation of the L-Moment Ratio Diagrams shown in Figures A3.5 & A3.6. It is observed that in both cases, 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).

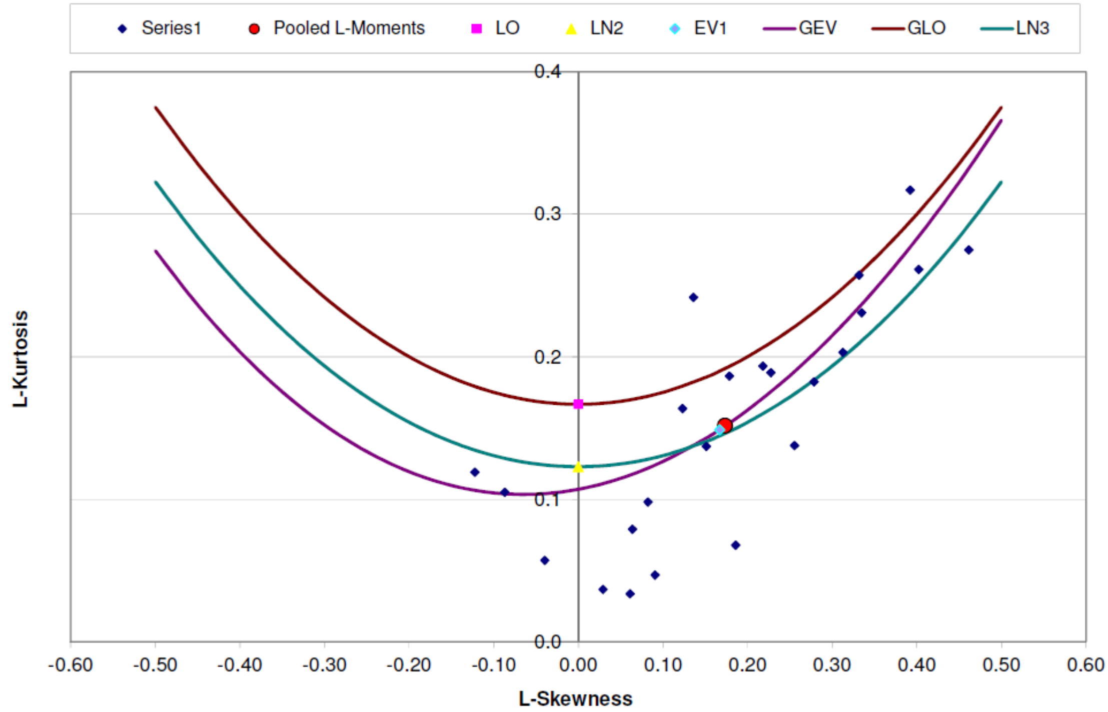


Figure A3.5 L-Moment Ratio Diagram (Reach 1)

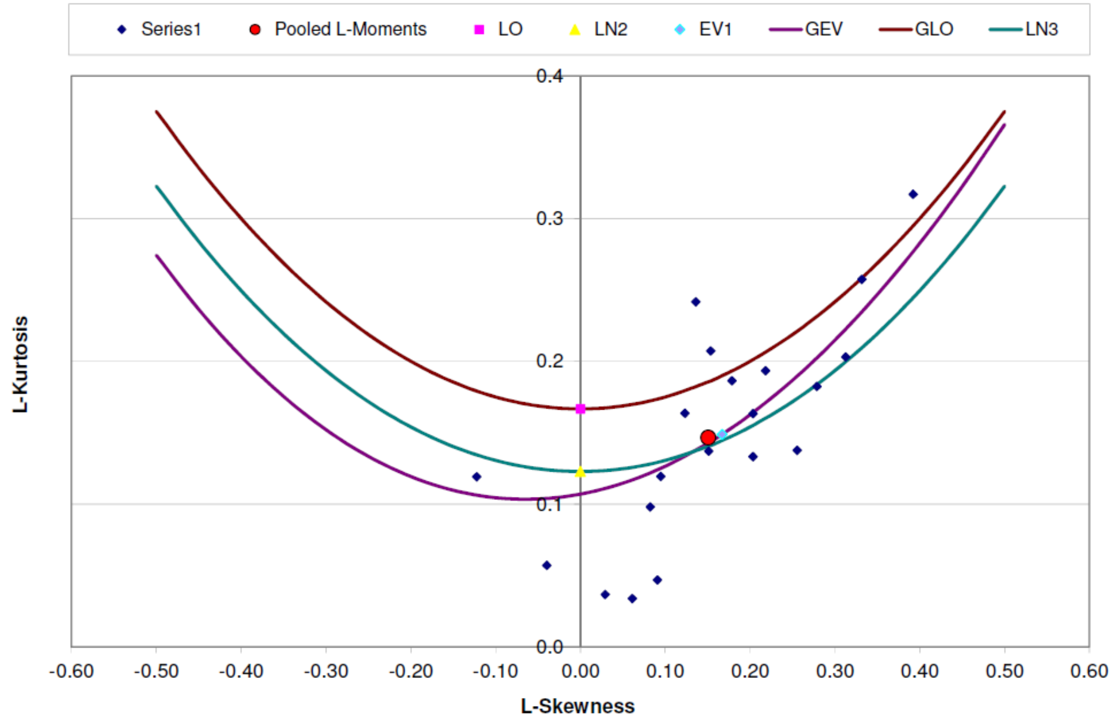


Figure A3.6 L-Moment Ratio Diagram (Reach 2)

River Reach Flood Frequency

The growth curve distribution applied to each reach is shown in Table A3.8. Growth factors generated for a range of AEPs have been detailed in Table A3.9.

Reach	Station	Single Site or Pooled	Selected distribution
1	27_1160_5	Pooled	EV1
2	27_1147_3	Pooled	EV1

Table A3.8 Final Growth Curves Selected

Annual Exceedance Probability (%)	Growth Factors Reach 1	Growth Factors Reach 2
50%	1.00	1.00
20%	1.40	1.29
10%	1.66	1.49
5%	1.91	1.67
2%	2.24	1.91
1%	2.49	2.09
0.5%	2.73	2.27
0.1%	3.30	2.69

Table A3.9 Final Growth Factors Applied to the Shannon AFA 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 in the Shannon AFA catchment, a hydrograph shape generated for a pivotal station that is hydrologically similar to the target site is preferred.

Figure A3.7 identifies the hydrographs chosen to be representative of flood events in the Shannon AFA catchment. Figure A3.7 presents the chosen hydrograph in a non-dimensional manner by dividing flows by the flood peak.

The selected pivotal sites are hydrologically similar to the subject sites, expressed in the similarity measure Dij for hydrographs shapes, which is a function of BFIsoil (baseflow index), S1085 (catchment slope) and FARL (effect of lakes). (A similar parameter Dij for flood frequency analysis is based on different catchment descriptors). Particular attention was given to the selection of a station that had a similar BFIsoil. Station 19020 has a BFIsoil of 0.66 and Station 13002 has a BFIsoil of 0.73.

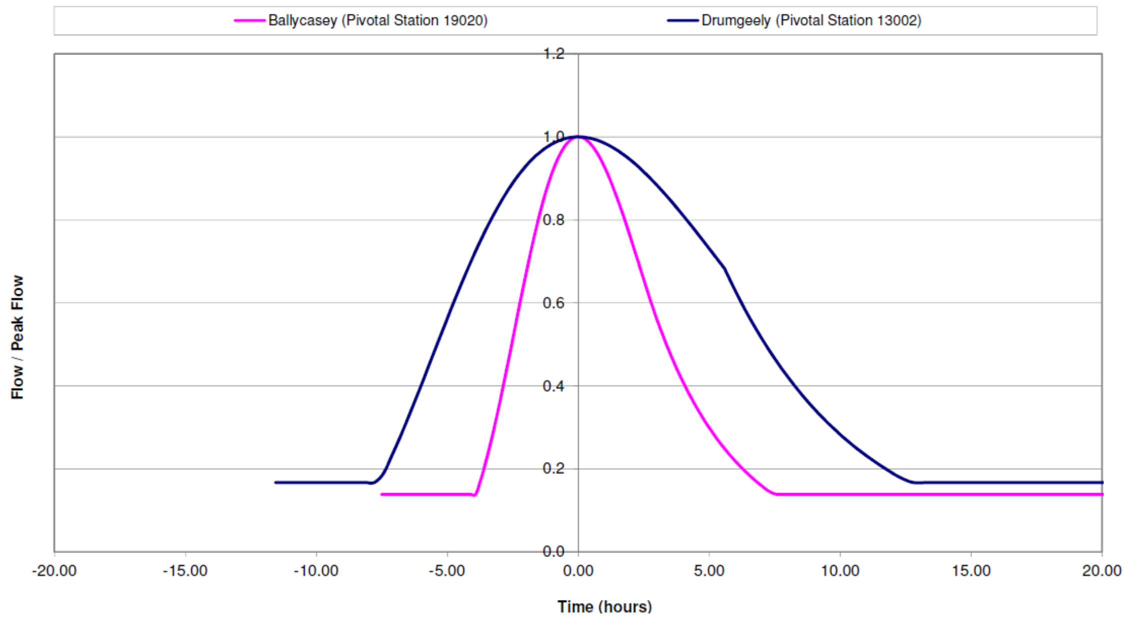


Figure A3.7 Non-dimensional Hydrographs Reach 1 & Reach 2

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.

A4 S19 Catchment

A4.1 Catchment Description

The general description of the Kilkee catchment (Figure A4.1) is given in Table A4.1.

Attribute	Description
Unit of Management (UoM)	27
Main water courses	Victoria Stream Unnamed watercourse
Outflow point	Moore Bay
Total catchment area	9.3 km^2
Areas for Further Assessment (AFAs)	Kilkee
Individual Risk Receptors (IRRs)	None
Model Extents*	S19
General topology	Min altitude = 0 m AOD Max altitude = <50 m AOD Gentle rolling hills (< 50 mAOD) surround the horseshoe bay.
Average annual rainfall**	1102 mm to 1110 mm
Soils and geology	Subsoils comprise predominantly low permeability peat and glacial till deposits with made ground limited to the area around Moore Bay and Kilkee. The underlying shale, sandstone and silt bedrock is a locally important bedrock aquifer and occurs at or near surface close to the coast and in the far south of the catchment. Refer to Figure 3.3 in the Main Report for the hydrogeological characteristics of the underlying rock formations. Soils are poorly drained with extensive peat deposits occurring across the centre of the catchment between Moore Bay and Termon. Refer to Figure 3.4 in the Main Report for the distribution of differing soil drainage classes.
Urban areas	This catchment is dominated by the town of Kilkee, through which the two watercourses drain before reaching Moore Bay. The upstream model nodes reflect rural catchments with URBEXT values of 0%, rising to 13% at downstream nodes.

* Specific hydrological details for the models are provided in Appendix B6
** range of SAAR values taken from the FSU catchment descriptors covering the extent of modelling. It excludes the erroneous SAAR value of node 27_298_1 of 527 mm.

Table A4.1 Kilkee Catchment description

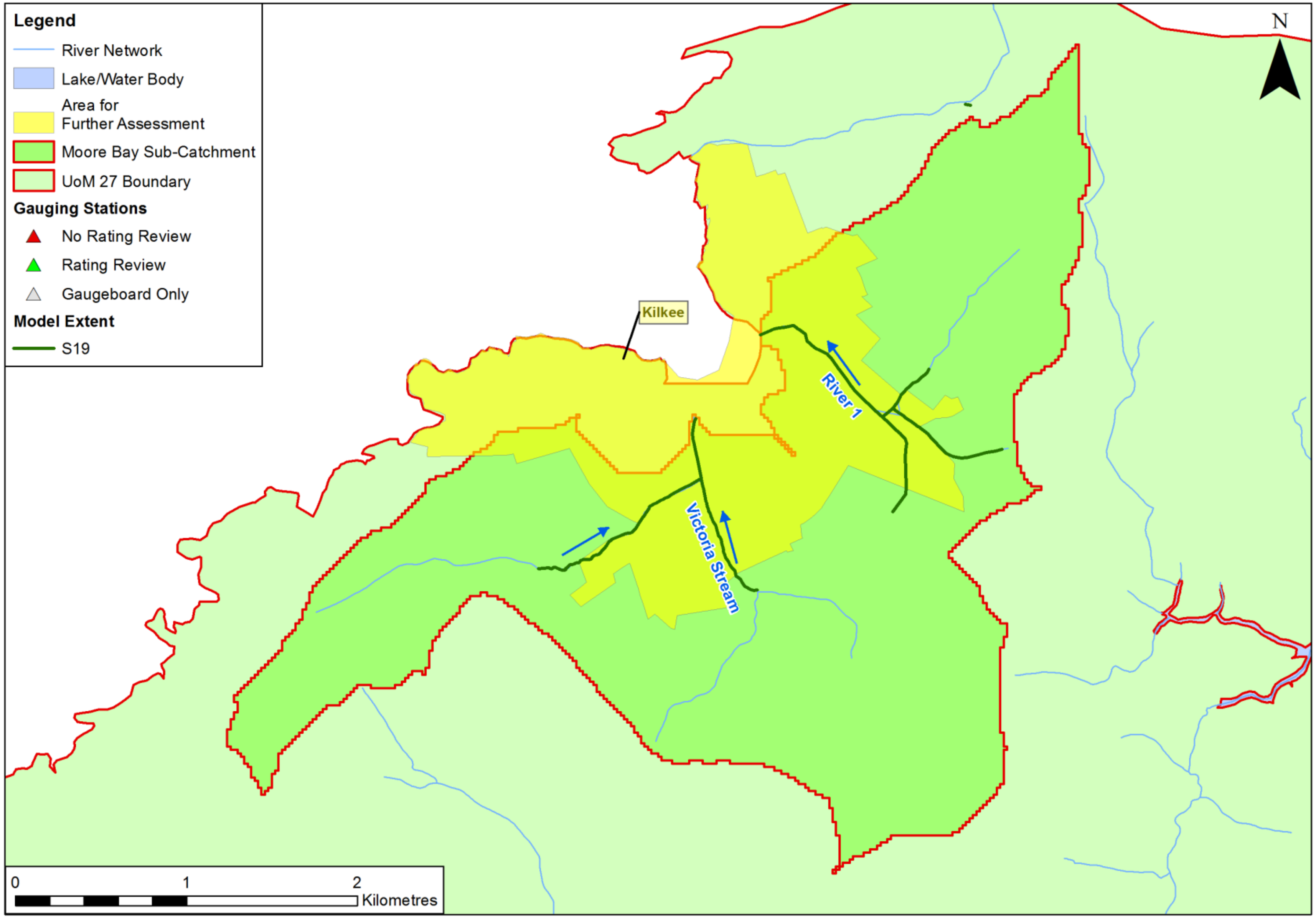


Figure A4.1 Kilkee Catchment with both model extents and hydrometric stations indicated

A4.2 Hydrometric Stations in the Kilkee Catchment

The Kilkee catchment is ungauged, therefore there are no hydrometric stations located within the Kilkee catchment.

A4.3 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 and geology and an assessment of the availability and quality of data at any gauging stations. The river reaches are tabulated in Table A4.2 and shown on Figure A3.2. The variation in catchment descriptors for each reach is tabulated in Tables A4.3 to A4.5 below.

Note: The SAAR value in node 27_298_1 of 527 mm is apparently erroneous when compared to the SAAR values for the remainder of the catchment (ranging between 1102 mm and 1110 mm). However, this error has not affected the design hydrology as the catchment descriptors for the upper inflow node are not used to derive flows (ref Main Report. Section 2.3) and the node has not been used in deriving the QMED adjustment factor.

Reach	Description	Model Extent
1	River 1 (u/s HEP node is 27_1006_2 and d/s HEP node is 27_966_3.)	S19
	Tributary 1 drains northwest into River 1 (u/s HEP node is 27_1007_1a and d/s HEP node is 27_1007_1b)	S19
	Tributary 2 drains northwest into River 1 (u/s HEP node is 27_965_1a and d/s HEP node is 27_965_1b)	S19
2	Victoria Stream (u/s HEP node is 27_298_1 and d/s HEP node is 27_232_2)	S19
3	Tributary 3 drains into Victoria Stream (u/s HEP node is 27_346_2 and d/s HEP node is 27_346_4)	S19

Table A4.2 River Reaches in the Catchment

Reach 1		
Catchment Descriptor	**Lower Limit (HEP node)**	**Upper Limit (HEP node)**
AREA (km^2)	1.2 (27_1006_2)	5.0 (27_966_3)
BFIsoil	0.33 (all)	0.33 (all)
SAAR (mm)	1104 (various)	1110 (various)
FARL	1.00 (all)	1.00 (all)
DRAIND	0.68 (27_966_2)	1.34 (27_966_1)
S1085 (m/km)	8.0 (27_966_3)	12.8 (27_1006_2)
ARTDRAIN2 (%)	0 (all)	0 (all)
URBEXT (%)	0 (various)	8.8 (27_966_3)

Table A4.3 Reach 1 Catchment Descriptor Range

Reach 2		
Catchment Descriptor	**Lower Limit (HEP node)**	**Upper Limit (HEP node)**
AREA (km^2)	1.2 (27_298_1)	4.4 (27_232_2)
BFIsoil	0.33 (all)	0.33 (all)
SAAR (mm)	527 (27_298_1)*	1102 (various)
FARL	1.00 (all)	1.00 (all)
DRAIND	1.31 (27_232_2)	1.68 (27_298_2)
S1085 (m/km)	15.1 (27_298_3)	21.3 (27_298_1)
ARTDRAIN2 (%)	0 (all)	0 (all)
URBEXT (%)	0.6 (27_298_1)	13 (27_232_2)

**** See note above***

Table A4.4 Reach 2 Catchment Descriptor Range

Reach 3		
Catchment Descriptor	**Lower Limit (HEP node)**	**Upper Limit (HEP node)**
AREA (km^2)	1.2 (27_346_2)	1.8 (various)
BFIsoil	0.32 (various)	0.33 (27_346_2)
SAAR (mm)	1103 (various)	1104 (27_346_2)
FARL	1.00 (all)	1.00 (all)
DRAIND	1.22 (27_346_2)	1.39 (27_346_5)
S1085 (m/km)	17.4 (27_346_2)	23.7 (27_346_4)
ARTDRAIN2 (%)	0 (all)	0 (all)
URBEXT (%)	0 (27_346_2)	13 (27_346_5)

Table A4.5 Reach 3 Catchment Descriptor Range

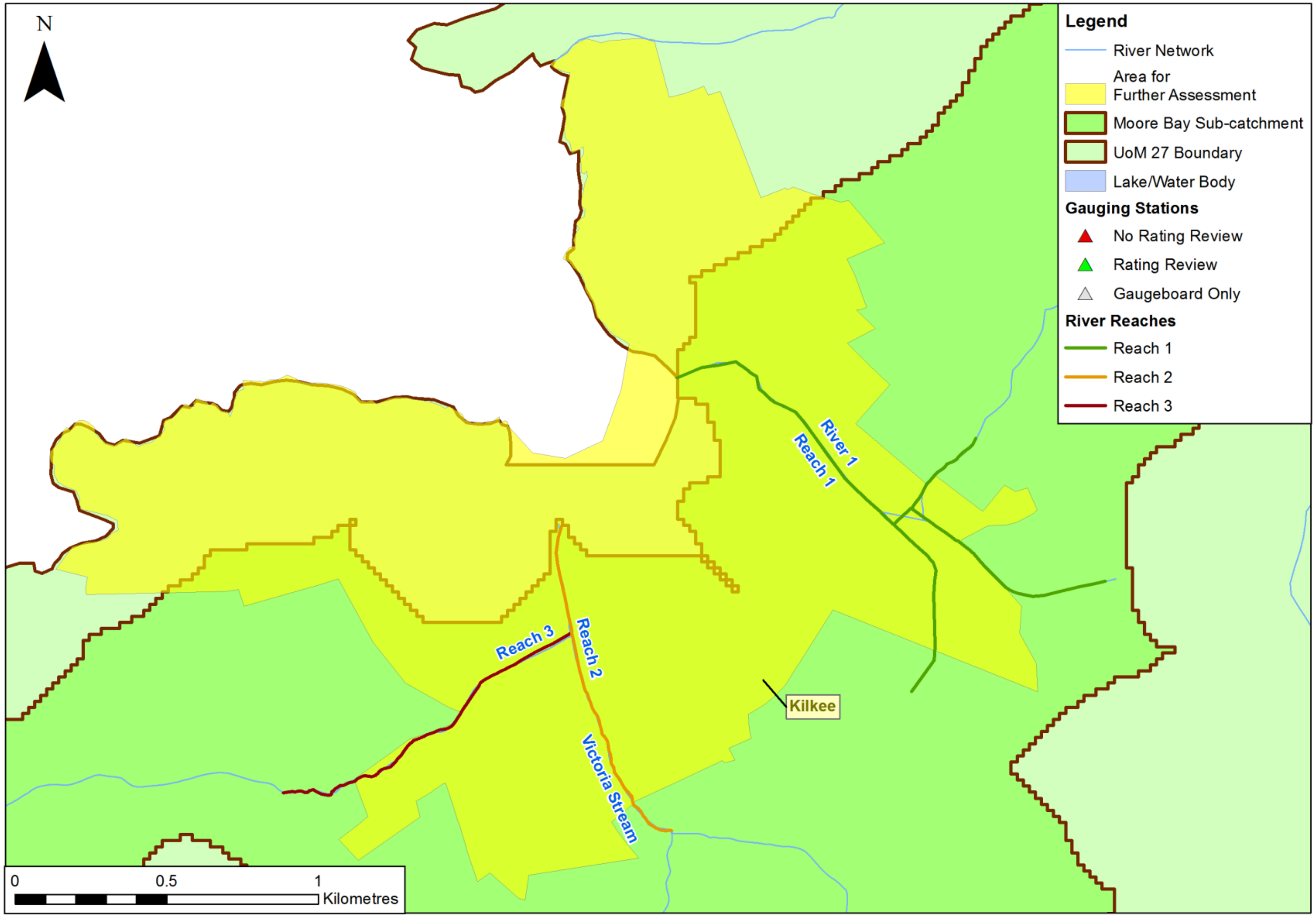


Figure A4.2 Kilkee Catchment River Reaches

A4.4 QMED Adjustment Factors

The Kilkee catchment is ungauged. For ungauged reaches (or reaches with inadequate high flow monitoring), the QMED adjustment factor was estimated using multiple pivotal sites in the absence of an adequate single pivotal site. The adjustment factors were estimated using a weighted geometric mean of the five hydrologically most similar gauged sites in the country (see Tables A4.6 to A4.8). The use of a single pivotal site was considered but no suitable station was found that was hydrologically similar and sufficiently near to the subject site. 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 adjustment factors to the power of the weight, for all five pivotal sites: Π (Adjustment Factor^{Weight}).

Station Number	Station Name	Rank	Dij	Weight	Adjustment Factor
6030	BIG	1	1.460	0.279	2.32
36021	KILTYBARDAN	2	1.985	0.205	1.22
8007	ASHBOURNE	3	2.199	0.185	1.02
27001	INCH BR.	4	2.331	0.175	0.66
23012	BALLYMULLEN	5	2.620	0.156	0.58
Weighted Geometric Mean					**1.13**

Table A4.6 QMED Adjustment Factor for Reach 1 based on multiple pivotal sites (Target location = HEP 27_966_3)

Station Number	Station Name	Rank	Dij	Weight	Adjustment Factor
6030	BIG	1	1.976	0.265	2.32
36021	KILTYBARDAN	2	2.630	0.199	1.22
9011	FRANKFORT (Post 21/08/19	3	2.883	0.182	1.94
8007	ASHBOURNE	4	2.898	0.181	1.02
8005	SLUICE	5	3.031	0.173	2.28
Weighted Geometric Mean					**1.70**

Table A4.7 QMED Adjustment Factor for Reach 2 based on multiple pivotal sites (Target location = HEP 27_298_3)

Station Number	Station Name	Rank	Dij	Weight	Adjustment Factor
6030	BIG	1	2.027	0.259	2.32
36021	KILTYBARDAN	2	2.565	0.205	1.22
8007	ASHBOURNE	3	2.878	0.183	1.02
27001	INCH BR.	4	2.959	0.178	0.66
9011	FRANKFORT (Post 21/08/19	5	2.989	0.176	1.94
Weighted Geometric Mean					**1.36**

Table A4.8 QMED Adjustment Factor for Reach 3 based on multiple pivotal sites (Target location = HEP 27_346_5)

Table A4.9 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	1.13	27_966_3	Adjustment factor estimated using multiple pivotal sites.
2	1.70	27_298_3	Adjustment factor estimated using multiple pivotal sites.
3	1.36	27_346_5	Adjustment factor estimated using multiple pivotal sites.

Table A4.9 Final QMED Adjustment Factors Applied to Each Reach

A4.5 Flood Frequency Curves

The catchment is ungauged therefore there were no gauging stations suitable for flood frequency analysis identified in the catchment. Instead a pooling group was developed based on FSU catchment descriptors at node 27_1006_2 and a chosen distribution of LN2 and applied to the entire catchment. Growth factors generated for a range of AEPs have been detailed in Table A4.10. Refer to Appendix G for further detail.

Annual Exceedance Probability (%)	Growth Factors Reaches 1, 2, 3
50%	1.00
20%	1.24
10%	1.40
5%	1.53
2%	1.71
1%	1.83
0.5%	1.96
0.1%	2.24

Table A4.10 Final Growth Factors Applied to the Kilkee Catchment

A4.6 Hydrograph Shape

Section 2.6 of the main hydrology report describes the selection of the design hydrograph shape. As the catchment is ungauged, the design flood hydrograph shape is derived from the OPW Hydrograph Shape Generator.

Table A4.11 summarises the gauging stations used to produce the typical flood hydrograph shapes for the catchment reaches, presented in Figures A4.3 and A4.4.

Reach	Gauging Station / HEP Node
1	27_1006_2 – pivotal station 39001 used from hydrograph generator)
2	27_298_2 – pivotal station 39001 used from hydrograph generator)
3	27_346_2 – pivotal station 39001 used from hydrograph generator)

Table A4.11 Gauging Stations used to Derive the Typical Hydrograph Shape in each Reach

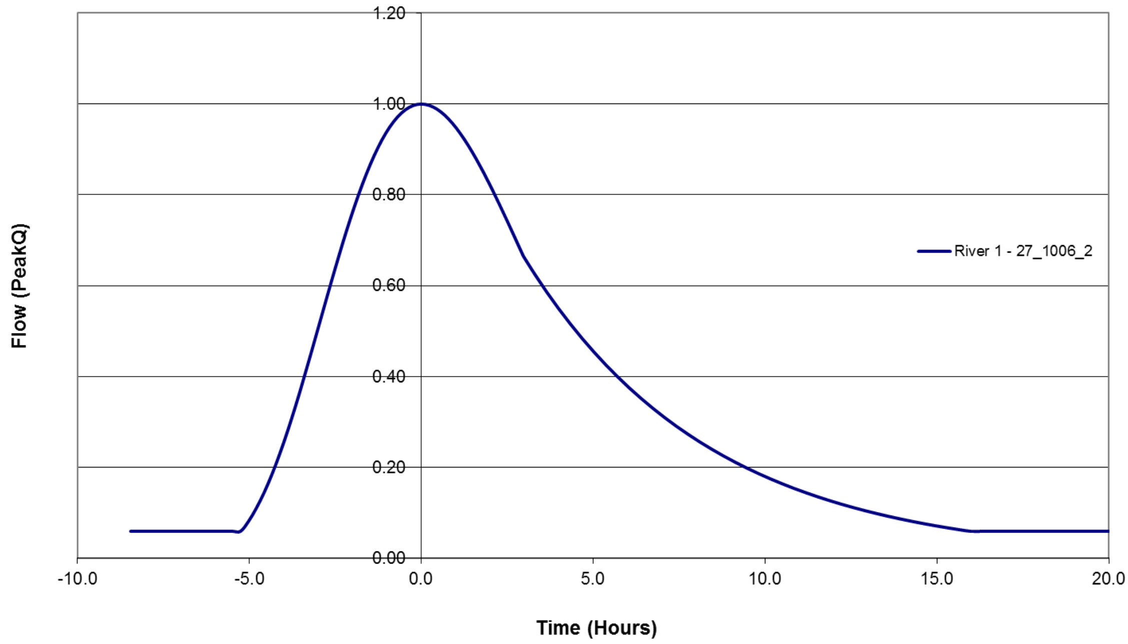


Figure A4.3 Non-dimensional Hydrograph for Ungauged Sites (Reach 1)

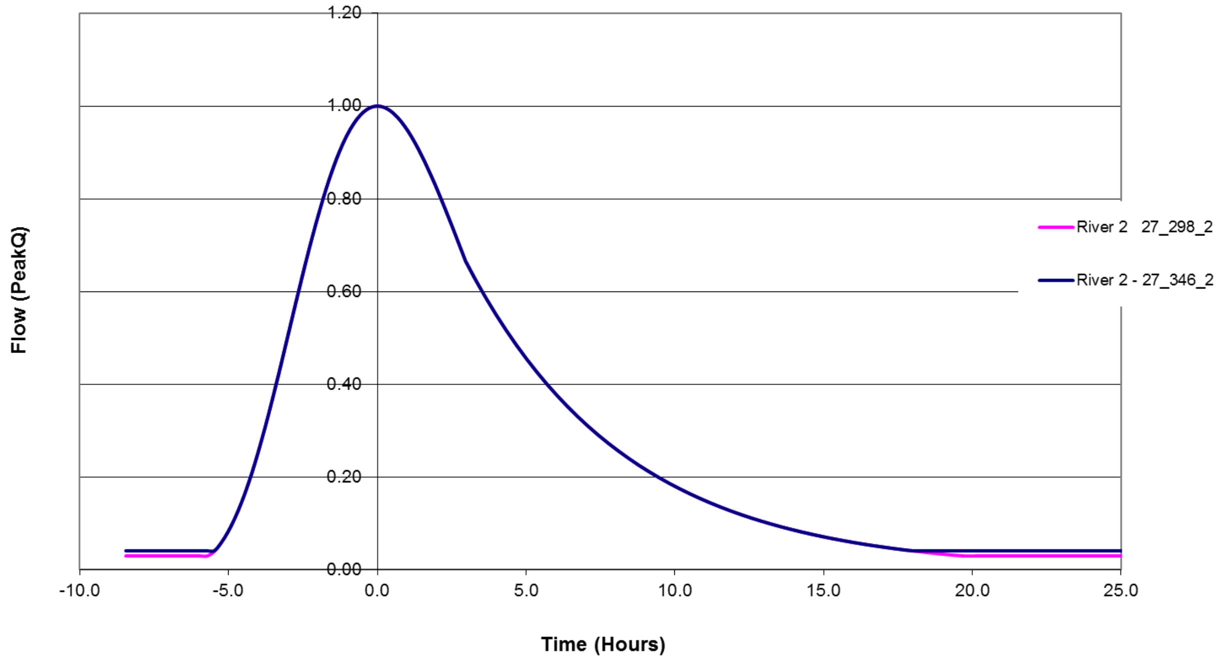


Figure A4.4 Non-dimensional Hydrographs for Ungauged Sites (Reaches 2 and 3)

A4.7 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.

A4.8 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.

A5 Kilrush Creek Catchment

A5.1 Catchment Description

The general description of the Kilrush Creek catchment (Figure A5.1) is given in Table A5.1.

Attribute	Description
Unit of Management (UoM)	27
Main water courses	River Wood and Kilrush Creek
Outflow point	Shannon Estuary
Total catchment area	19 km^2
Areas for Further Assessment (AFAs)	Kilrush
Individual Risk Receptors (IRRs)	None
Model Extents*	S18
General topography	Min altitude = 0 m AOD Max altitude = 45 mAOD Generally flat lowland. Sloping from the north east towards south west into the Shannon Estuary. The tidal extent is not well defined but is situated around the upstream boundary of the model.
Average annual rainfall**	1059 mm to 1068 mm
Soils and geology	Geology: Subsoil comprises predominantly of peat and low permeability glacial tills derived from the underlying sandstone, shale and siltstone bedrock. Minor glacial sands and gravels of moderate permeability occur in the northeast along the route of the R483 and minor alluvial deposits occur along watercourses to the south and east of Kilrush. Made ground of low to moderate permeability dominates the around Kilrush. The catchment is entirely underlain by sandstone, shale and siltstone bedrock which outcrops at surface within the glacial tills throughout the catchment. Refer to Figure 3.3 in the Main Report for the hydrogeological characteristics of the underlying rock formations. Soils: Well drained soils occur in the areas immediately north, south and east of Kilrush while further east from Kilrush poorly drained soils predominate, associated with areas of extensive peat deposits. Refer to Figure 3.4 in the Main Report for the distribution of differing soil drainage classes.
Urban areas	The URBEXT values ranges between 0% at the upstream end to 5% downstream of the Kilrush AFA.

* Specific hydrological details for the models are provided in Chapter B5 in Appendix B.
** Range of SAAR values taken from the FSU catchment descriptors covering the extent of modelling

Table A5.1 Kilrush Creek Catchment Description

A5.2 Hydrometric Stations in the Kilrush Catchment

Details of the gauging stations in the Kilrush catchment are tabulated in Table A5.2. They are also shown on Figure A5.1.

Model	Gauging Station	Name	Record Data Range	AMAX Available	FSU Quality Class or HGF/QMED	CFRAMS Rating Review	Quality Comments
S18	27013	Kilrush	N/A	staff gauge only	N/A	No	1

[1] *Gauging station 27013 is the only station in the catchment and is a staff gauge only.*

Table A5.2 Kilrush Creek Catchment Gauging Stations

A5.3 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 A5.2 above. The river reaches are tabulated in Table A5.3 and shown on Figure A5.1. The variation in catchment descriptors for each reach is tabulated in Table A5.4 below.

Reach	Description	Model Extent
1	Entire model extent	S18

Table A5.3 River Reach in the Catchment

Reach 1		
Catchment Descriptor	**Lower Limit (HEP node)**	**Upper Limit (HEP node)**
AREA (km^2)	1.0 (27_967_1)	18.8 (27_968_6)
BFIsoil	0.40 (27_968_2)	0.62 (27_967_3)
SAAR (mm)	1059 (27_967_1)	1069 (27_968_1)
FARL	0.98 (27_968_1)	1.00 (27_967_1)
DRAIND	1.09 (27_967_3)	1.45 (27_967_1)
S1085 (m/km)	6.0 (27_968_1)	11.9 (27_967_1)
ARTDRAIN2 (%)	0.0 (all)	0.0 (all)
URBEXT (%)	0.0 (27_967_1)	4.6 (27_968_6)

Table A5.4 Reach 1 Catchment Descriptor Range

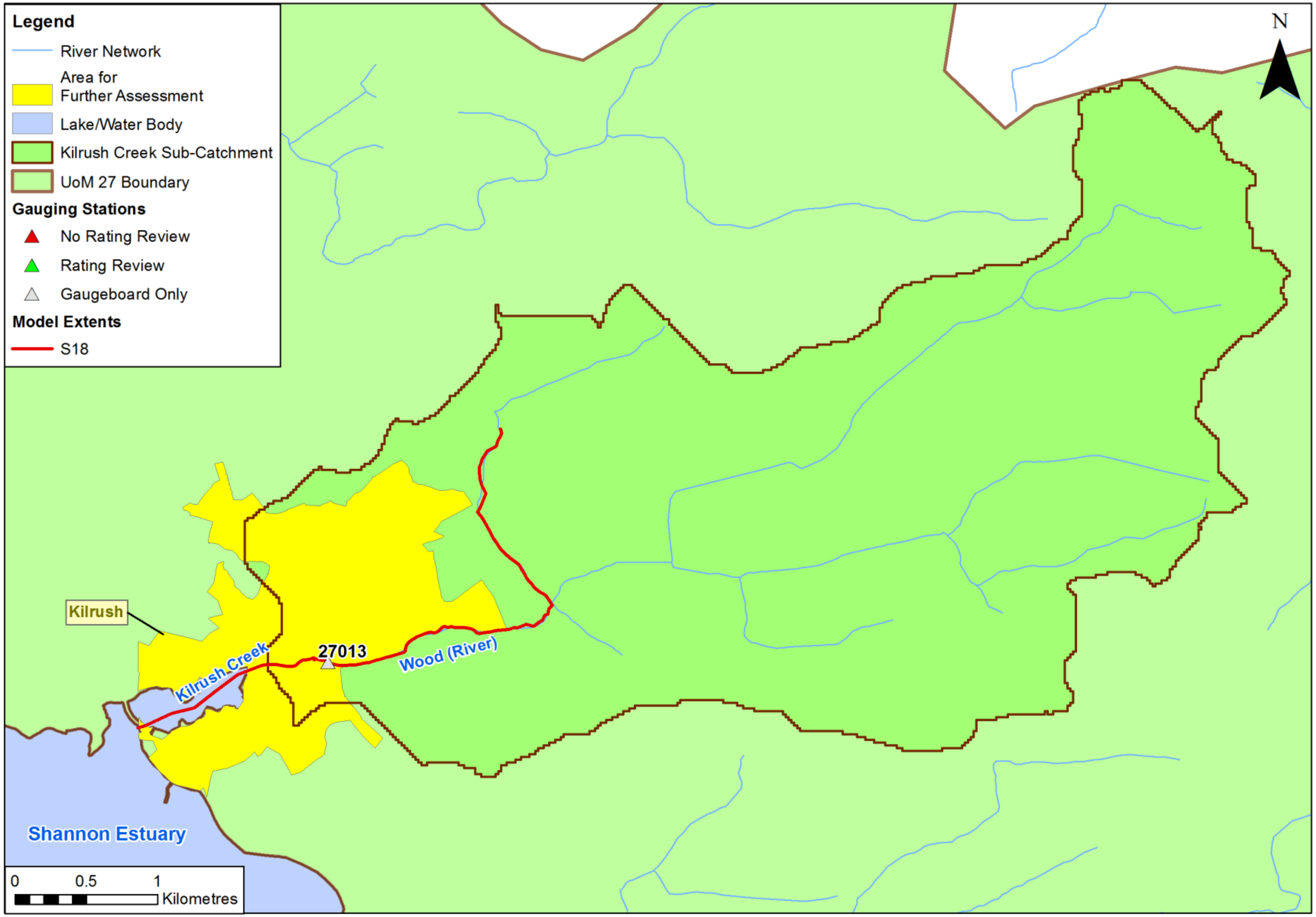


Figure A5.1 Kilrush Creek Catchment

A5.4 QMED Adjustment Factors

The QMED adjustment factors for the ungauged reaches (or reaches with inadequate high flow monitoring) in the catchment were estimated using multiple pivotal sites in the absence of an adequate single pivotal site. The adjustment factors were estimated using a weighted geometric mean of the five hydrologically most similar gauged sites in the country (see Table A5.5). The use of a single pivotal site was considered but no suitable station was found that was hydrologically similar and sufficiently near to the subject site. 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 adjustment factors to the power of the weight, for all five pivotal sites: Π (Adjustment Factor$^{\text{Weight}}$).

Station Number	Station Name	Rank	Dij	Weight	Adjustment Factor
6030	BIG	1	0.76	0.308	2.32
8007	ASHBOURNE	2	1.17	0.201	1.02
14033	OWENASS	3	1.39	0.169	1.17
23012	BALLYMULLEN	4	1.42	0.165	0.58
36031	CAVAN	5	1.49	0.157	0.62
Weighted Geometric Mean					**1.13**

Table A5.5 QMED Adjustment Factor based on Multiple Pivotal Sites (Target location HEP 27_968_4)

Table A5.6 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	1.13	27_968_4	Qmed calculator used to derive adjustment factor. This has been applied to the entire model extent.

Table A5.6 Final QMED Adjustment Factors Applied to Each Reach

A5.5 Flood Frequency Curves

Gauging Station Flood Frequency Curves

There is no gauging station with recorder in the catchment. The catchment was analysed as ungauged.

Ungauged Reach

The growth factors for the ungauged reach in the model extent were estimated using pooling analysis. The process and results are shown in Appendix G. L-Moment plots identified that the LN2 distribution was the best fit for the pooling group.

River Reach Flood Frequency

The growth curve distributions applied to the relevant reaches are shown in Table A5.7. The growth factors generated for a range of AEPs have been detailed in Table A5.8.

Reach	Station / HEP Node	Single Site or Pooled	Selected distribution
1	24_968_4	Pooled	LN2

Table A5.7 Final Growth Curves Selected

Annual Exceedance Probability (%)	Growth Factors Reach 1
50%	1.00
20%	1.26
10%	1.42
5%	1.56
2%	1.75
1%	1.88
0.5%	2.02
0.1%	2.32

Table A5.8 Final Growth Factors Applied to the Kilrush Catchment

A5.6 Hydrograph Shape

Section 2.6 of the main hydrology report describes the selection of the design hydrograph shape. For ungauged reaches the design hydrograph was generated from data of a suitable pivotal station where available. The hydrograph shape generated was selected on the basis of the subject and pivotal catchments having hydrological similarities. The resulting hydrograph is shown on Figure A5.2. Table A5.9 below summarises the pivotal station used to produce the typical flood hydrograph shapes for the catchment reach.

Reach	Gauging Station/HEP Node
1	23001 – Inch Bridge (pivotal site hydrograph shape used)

Table A5.9 Gauging Stations used to derive the Design Hydrograph Shape in Reach 1

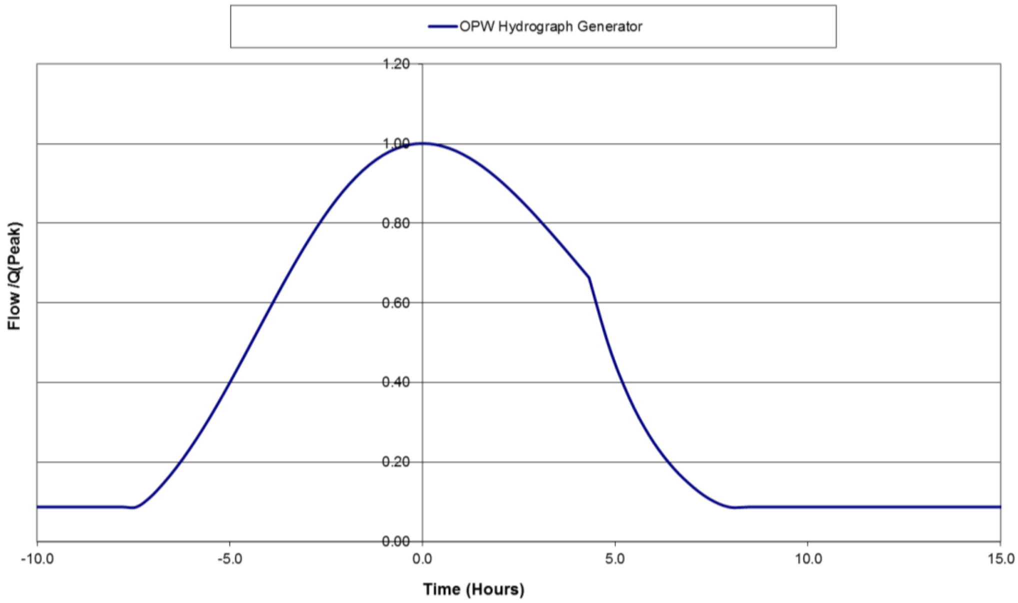


Figure A5.2 Non-dimensional Hydrograph for Ungauged Reach 1

A5.7 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.

A5.8 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 S01

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 Figure B1.1

Model Attribute	Comment
Rivers included in model	River Fergus and its tributaries - River Claureen, River Gaurus, River Rine* (lower reach) and a number of smaller tributaries.
Areas for Further Assessment (AFA)	Ennis
Individual Risk Receptor (IRR)	None

**The upper reach of River Rine is a separate model (S02)*

Table B1.1 Model Extent coverage

B1.1 Hydrology for Hydraulic Model Calibration

There was sufficient hydrometric data coupled with sufficient flood level/extent information to allow calibration and verification of the S01 model against a number of fluvial and tidal flood events.

Fluvial calibration/verification is based on inflows at gauging stations 27001 (Inch Bridge) and 27002 (Ballycorey) for each of two identified events (Dec 2006 and Nov 2009); and water levels at locations reported to have experienced flooding and at the downstream gauges. Fluvial floods before 2002 could not be used as it was found that during historic fluvial floods the tidal boundary condition significantly affected the water levels in Ennis, and tidal water levels are available from 2002 only.

Tidal calibration/verification is based on the availability of 15-minute time series data for significant tidal events at a minimum of two stations, of which at least one being a tide level recording station. Tidal data was only available from 2002. Accordingly, adequate data for tidal calibration was available for two events, one for calibration and another for verification.

Refer to the calibration strategy in Appendix F and the hydraulic modelling report for S01 for detail on the calibration/verification.

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 S01 are shown in Tables B1.2 – B1.5.

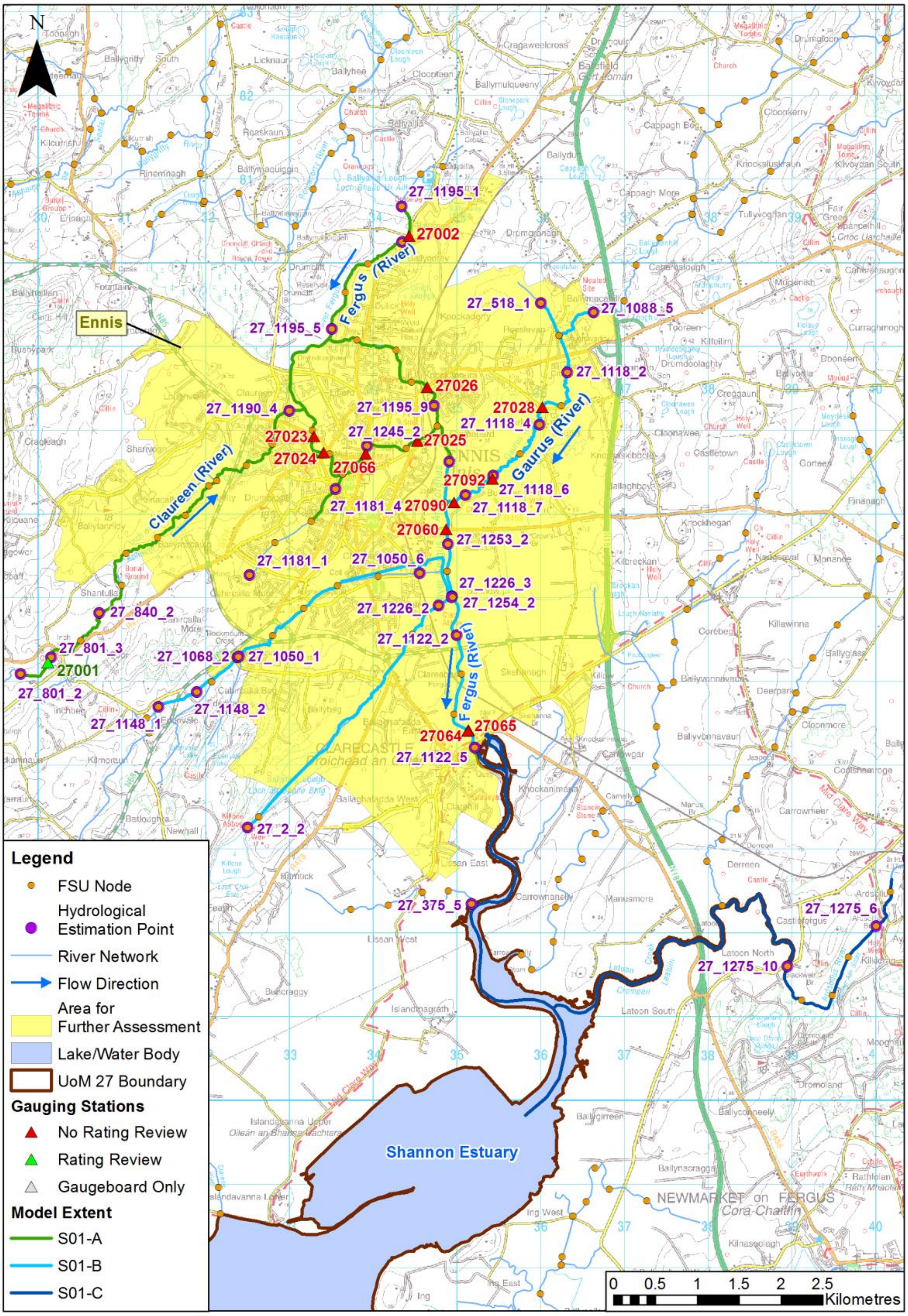


Figure B1.1 S01Model Extent [1]

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[1]

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_1195_1	33.7	43.1	49.1	54.8	62.2	67.7	73.2	86.0
27_1195_2	33.7	43.1	49.1	54.8	62.2	67.7	73.2	86.0
27_1195_5	34.6	44.2	50.3	56.1	63.7	69.4	75.0	88.1
27_1245_2	44.2	56.5	64.3	71.8	81.5	88.7	95.9	112.7
27_207_2	44.8	57.3	65.2	72.8	82.6	89.9	97.2	114.2
27_1253_2	47.9	61.2	69.7	77.8	88.3	96.1	104.0	122.1
27_1254_2	49.3	63.0	71.7	80.0	90.8	98.9	107.0	125.6
27_1122_2	49.7	63.6	72.3	80.7	91.6	99.8	107.9	126.7
*27_1122_5	49.7	63.6	72.3	80.7	91.6	99.8	107.9	126.7

Table B1.2 Target Flows (m^3/s) at HEP Locations on the S01 Model Extent (Reach 1 - River Fergus Main Stem).

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_801_2	34.2	43.7	49.6	55.2	62.1	67.2	72.2	83.9
27_801_3	34.6	44.1	50.1	55.7	62.7	67.9	73.0	84.7
*27_840_2	34.6	44.1	50.1	55.7	62.7	67.9	73.0	84.7
*27_1190_4	34.6	44.1	50.1	55.7	62.7	67.9	73.0	84.7

Table B1.3 Target Flows (m^3/s) at HEP Locations on the S01 Model Extent (Reach 2a – River Claureen).

**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%
27_1088_5	3.1	4.0	4.6	5.2	5.9	6.5	7.0	8.3
27_1118_2	3.5	4.5	5.1	5.8	6.6	7.2	7.9	9.3
27_1118_4	3.7	4.8	5.5	6.2	7.1	7.8	8.5	10.0
27_1118_6	4.0	5.1	5.9	6.6	7.6	8.3	9.0	10.7
27_1118_7	4.0	5.2	6.0	6.7	7.7	8.4	9.1	10.8
27_518_1	0.16	0.20	0.24	0.26	0.30	0.33	0.36	0.43
27_1181_1	0.24	0.30	0.35	0.39	0.45	0.49	0.53	0.63
27_1181_4	0.6	0.8	0.9	1.0	1.1	1.2	1.4	1.6
27_1148_1	0.7	1.0	1.1	1.2	1.4	1.6	1.7	2.0
27_1148_2	0.8	1.1	1.2	1.4	1.6	1.7	1.9	2.2
27_1068_2	1.1	1.4	1.6	1.8	2.0	2.2	2.4	2.9
27_1050_1	1.1	1.4	1.6	1.8	2.1	2.3	2.5	2.9
27_1050_6	2.1	2.7	3.1	3.5	4.0	4.4	4.8	5.6
27_2_2	0.07	0.09	0.10	0.11	0.13	0.14	0.16	0.18
27_1226_2	0.36	0.46	0.53	0.60	0.68	0.75	0.81	0.96
27_1226_3	2.8	3.6	4.2	4.7	5.4	5.9	6.4	7.6
27_1195_9	1.9	2.4	2.8	3.1	3.6	3.9	4.2	5.0

Table B1.4 Target Flows (m^3/s) at HEP Locations on the S01 Model Extent (Reach 2b – River Gaurus and unnamed tributaries)s).

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_1275_6	24.0	29.5	33.1	36.6	41.1	44.5	47.9	55.6
27_1275_10	25.1	30.8	34.6	38.2	42.9	46.5	50.0	58.1

Table B1.5 Target Flows (m^3/s) at HEP Locations on the S01 Model Extent (Reach 3 – River Rine lower reach).

B1.3 Preliminary Design Inflows

To obtain the target flows at each HEP, as shown in Tables B1.2 – B1.5, an initial set of inflow hydrographs was produced and run through the model.

The watercourses that comprise Model S01, are components of the wider Fergus system and discharge to the Shannon Estuary either directly (as in the case of the River Fergus itself), or indirectly (as for all tributary branches).

The critical events in the S01 Model Extent were simulated by three model runs. Run 1 includes the main stem of the Fergus, the River Gaurus and a number of smaller tributary branches; Run 2, includes only the River Claureen (the more significant of the tributary inflows to the Fergus). In addition, for the section of the S01 Model which covers the lower reach of the River Rine; the critical events were modelled in an independent model run (Run 1a).

For modelling purposes the watercourses included in Run 1 are defined as: River Fergus main stem (from HEP 27_1195_1 to 27_1122_5); River Claureen (from HEP (27_801_2 to 27_1190_4); River Gaurus (from HEP 27_1088_5 to 27_1118_7); Unnamed Tributary 1 (from HEP 27_1181_1 to 27_1181_4); Unnamed Tributary 2 (from HEP 27_1148_1 to 27_1050_6); Unnamed Tributary 3 (from HEP 27_2_2 to 27_1226_3); and Flood Relief Channel (HEP 27_1195_9).

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 B1.1. Tables B1.6 – B1.9 present the preliminary peak inflows at each HEP in the hydraulic model.

Preliminary design inflow hydrographs are shown in Figures B1.2 – B1.5 for the 1% AEP design run.

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_1195_1	33.7	43.1	49.1	54.8	62.2	67.7	73.2	86.0
27_1195_2	0.84	1.1	1.2	1.4	1.5	1.7	1.8	2.1
27_1195_5	9.0	11.6	13.1	14.7	16.7	18.1	19.6	23.0

Table B1.6 Preliminary Design Hydrograph Peak Inflows (m^3/s) at HEP Locations on the S01 Model Extent (Reach 1 – River Fergus Main Stem).

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_801_2	34.6	44.1	50.1	55.7	62.7	67.9	73.0	84.7

Table B1.7 Preliminary Design Hydrograph Peak Inflows (m^3/s) at HEP Locations on the S01 Model Extent (Reach 2a – River Claureen).

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_1181_1	0.6	0.8	0.9	1.0	1.1	1.3	1.4	1.6
27_1195_9	1.9	2.4	2.8	3.1	3.6	3.9	4.2	5.0
27_1088_5	3.3	4.3	4.9	5.5	6.3	6.9	7.5	8. 9
27_1118_2	0.27	0.35	0.40	0.46	0.52	0.57	0.62	0.73
27_1118_4	0.29	0.37	0.42	0.48	0.55	0.60	0.65	0.77
27_518_1	0.16	0.20	0.24	0.26	0.30	0.33	0.36	0.43
27_1148_1	0.8	1.1	1.2	1.4	1.6	1.7	1.9	2.2
27_1148_2	0.25	0.32	0.37	0.42	0.48	0.52	0.57	0.67
27_1050_1	1.0	1.3	1.5	1.7	2.0	2.1	2.3	2.7
27_1056_6	0.36	0.47	0.54	0.61	0.69	0.76	0.83	0.98
27_2_2	0.36	0.46	0.53	0.60	0.68	0.75	0.81	0.96

Table B1.8 Preliminary Design Hydrograph Peak Inflows (m^3/s) at HEP Locations on the S01 Model Extent (Reach 2b – River Gaurus and unnamed tributaries).

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_1275_6	25.1	30.8	34.6	38.2	42.9	46.5	50.0	58.1

Table B1.9 Preliminary Design Hydrograph Peak Inflows (m^3/s) at HEP Locations on the S01 Model Extent (Reach 3– River Rine lower reach).

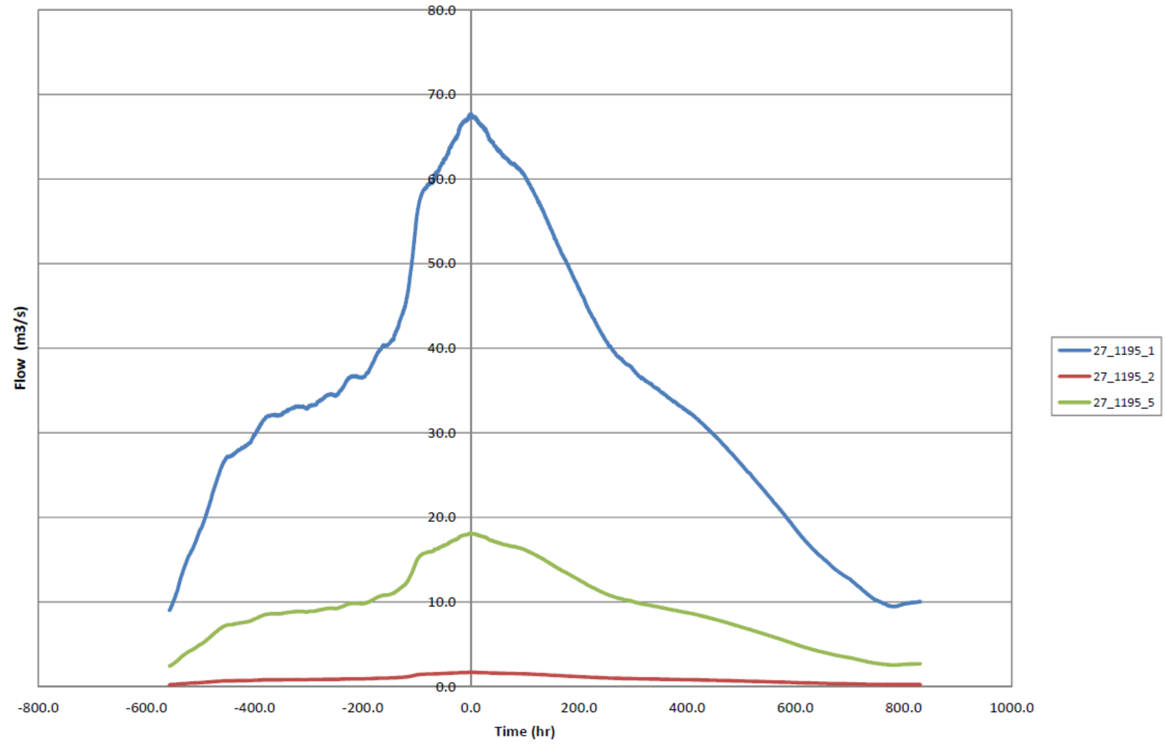

Figure B1.2 S01 Preliminary Design Inflow Hydrographs for 1% AEP (Reach 1 – River Fergus Main Stem)

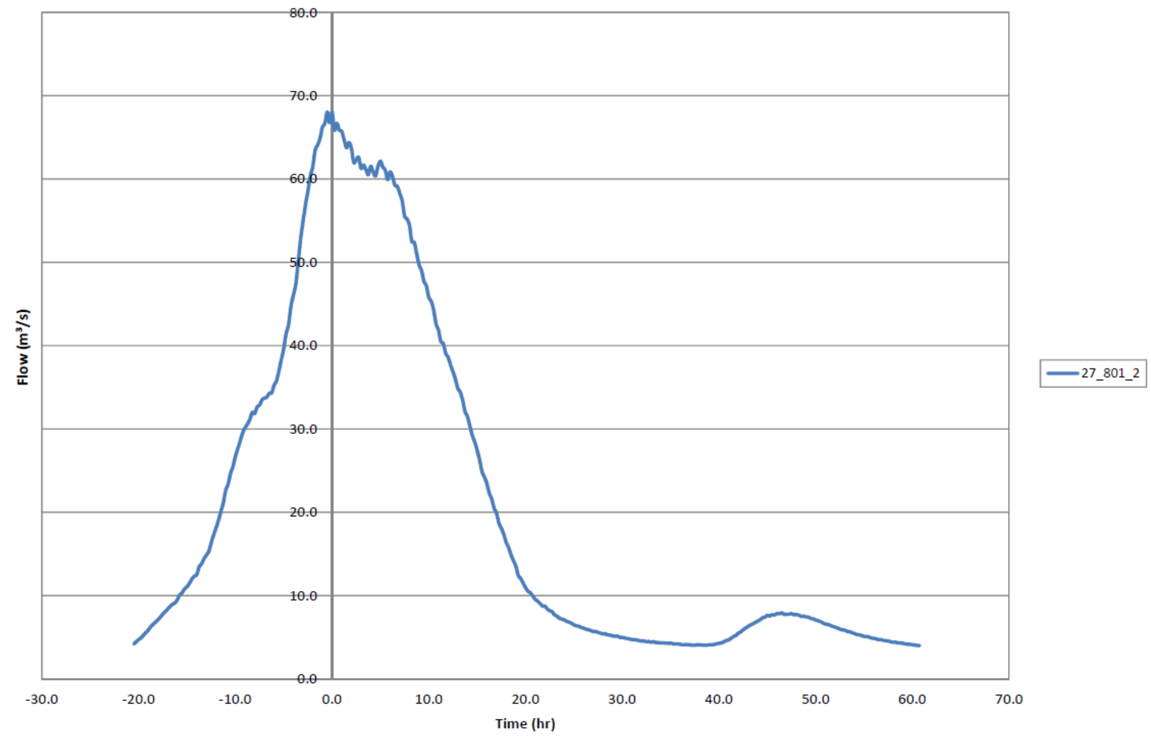

Figure B1.3 S01 Preliminary Design Inflow Hydrographs for 1% AEP (Reach 2a – River Claureen)

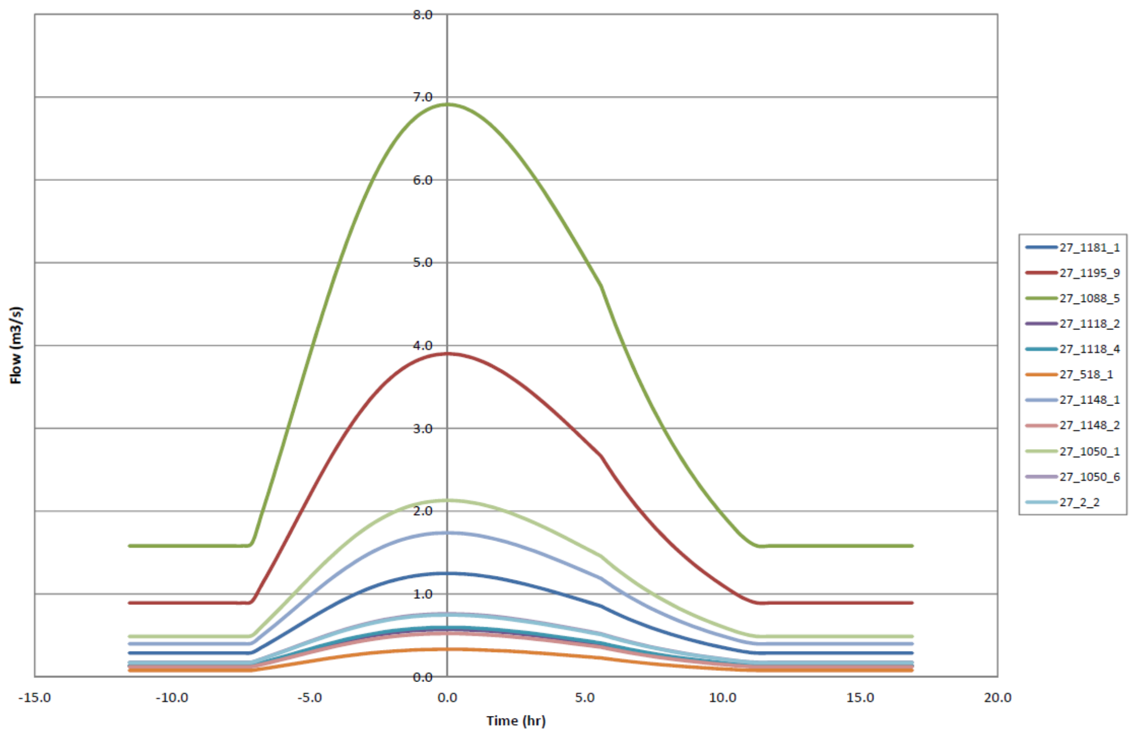

Figure B1.4 S01 Preliminary Design Inflow Hydrographs for 1% AEP (Reach 2b – River Gaurus and unnamed tributaries).

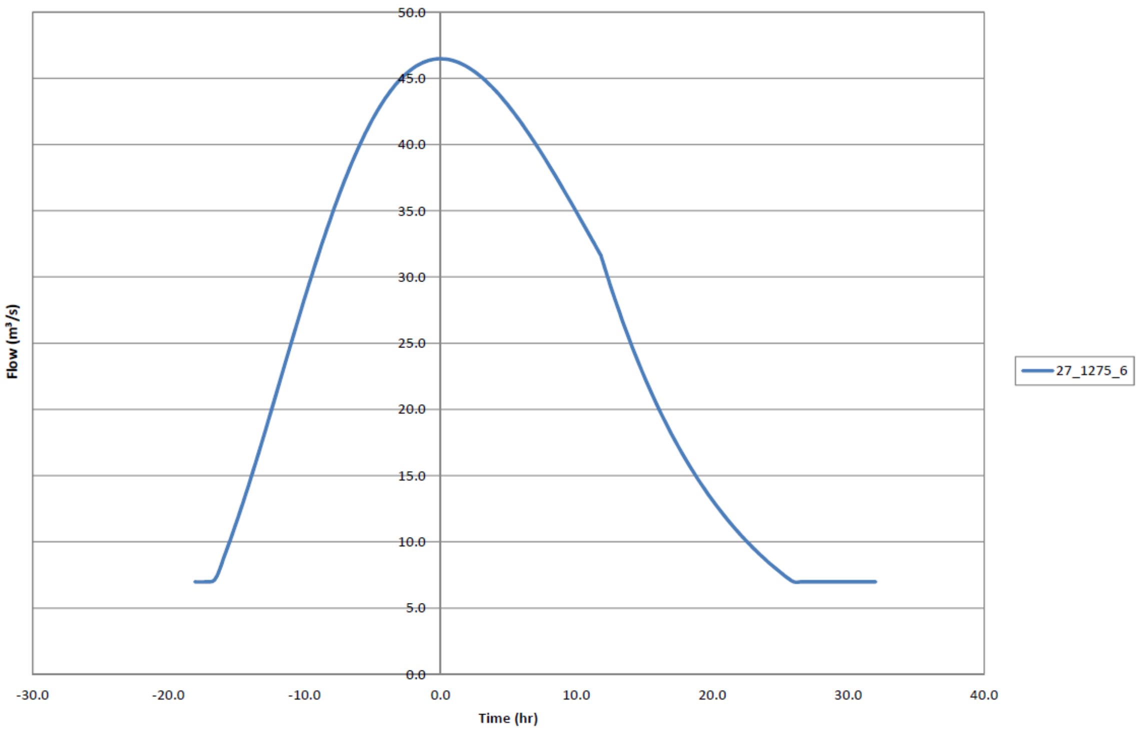

Figure B1.5 S01 Preliminary Design Inflow Hydrographs for 1% AEP (Reach 3 – River Rine).

B1.4 HEP Calibration and Final Design Hydrographs

The hydraulic model uses the preliminary design inflows presented in Tables B1.6 – B1.9 for calibrating the model to the HEP target flows presented in Tables B1.2 – B1.5.

HEP calibration at each HEP was undertaken using the methodology described in Section 2.7.2 of the main hydrology report for UoM 27. Hydraulic modelling aspects of the HEP calibration including the results and final design peak flows are presented in the hydraulic modelling report for Model S01.

B2 Model S02

Model S02 covers a part of the River Rine, which is a tributary of the River Fergus. One AFA (Quin) is located within the model extent. Both the River Rine and the River Fergus are tidally influenced at the confluence. The model extent of S02 is shown in Figure B2.1 overleaf.

The S02 Model covers the upstream part of Reach 3 (river reaches are described in Appendix A, Section A1.4.). The estimated QMED adjustment factors, growth curve and hydrograph shapes for this reach are documented in Appendix A, Section A1. The model calibration and design inflow hydrographs are summarised below.

B2.1 Calibration

Due to the absence of hydrometric data to inform historic flood flow, calibration of model S02 is not possible. Station 27021 (Ardsolus) is the only gauging station present on the River Rine, but is a staff gauge without level recorder. In addition, no historic observational information of sufficient detail was available within the model extent. Refer to the Calibration Strategy in Appendix F for more detail.

Table B2.1 summarises the flow and level gauging stations considered for the calibration/verification process.

Station	Data Length	Type	Comment
27021 Ardsolus	Not Available	Staff gauge	

Table B2.1 Gauging Stations considered for Calibration/Verification

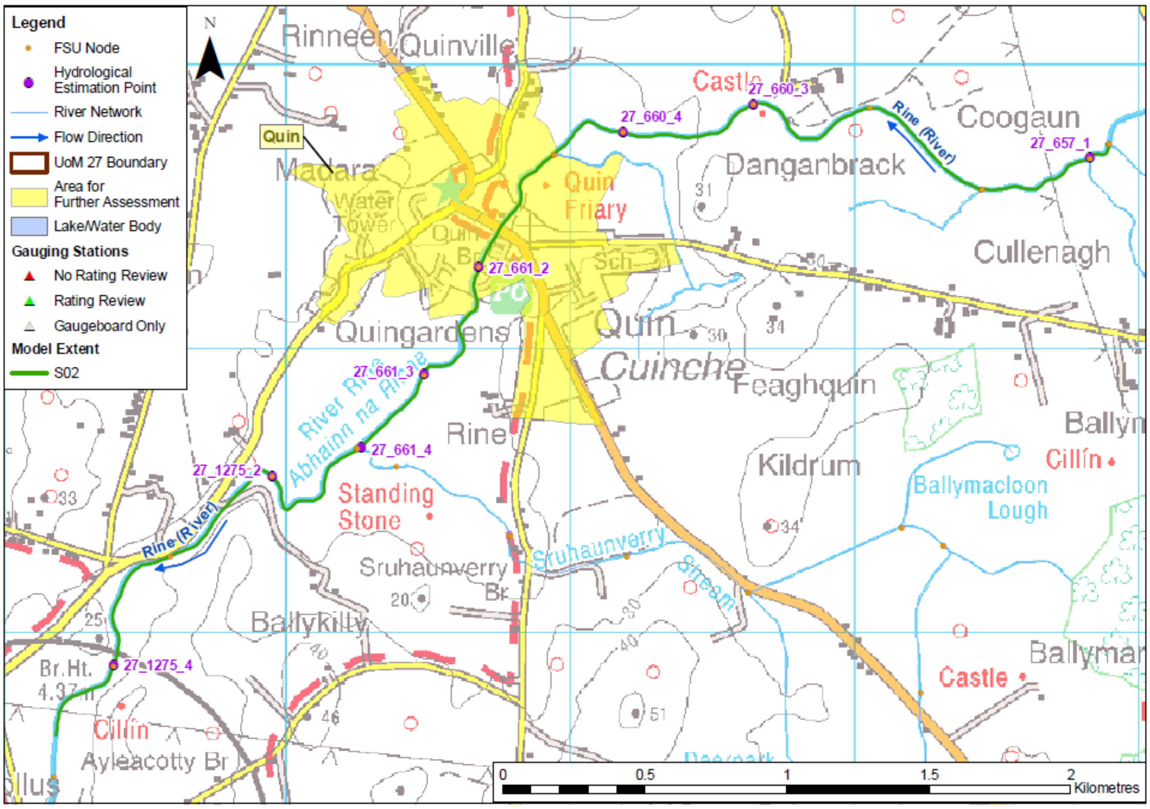

Figure B2.1 S02 Model Extent [1]

B2.2 Target Flows

The target flows are the total flows required at the HEP nodes which have been derived using the design hydrology process detailed in Appendix A, Chapter 1. The target flows at the HEP nodes for model S02 are shown in Table B2.2 below.

HEP reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_657_1	20.3	25.0	28.0	31.0	34.8	37.7	40.5	47.1
27_660_3	20.7	25.4	28.6	31.6	35.5	38.4	41.3	48.0
27_660_4	20.8	25.5	28.7	31.7	35.6	38.5	41.4	48.2
27_661_2	21.0	25.8	29.0	32.0	36.0	38.9	41.9	48.7
27_661_3	21.1	25.9	29.1	32.1	36.1	39.1	42.0	48.9
27_661_4*	21.1	25.9	29.1	32.1	36.1	39.1	42.0	48.9
27_1275_2	23.6	29.0	32.6	36.0	40.4	43.7	47.1	54.7
27_1275_4	23.9	29.3	32.9	36.4	40.9	44.3	47.6	55.4

**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*

Table B2.2 Target Flows at HEP Locations on the S02 Model Extent

B2.3 Preliminary Design Flows

To obtain the target flows at each HEP as shown in Table B2.2, an initial set of inflow hydrographs was produced and run through the model. As the S02 model does not include any tributary in its modelled extent a single model run was sufficient to achieve the target flows at all HEPs.

The inflow hydrographs shown in Figures B2.2 to B2.4 were derived using the procedure outlined in Chapter 2 and the adjustment factor, growth curves and hydrograph shape specified in Appendix A1. Table B2.3 overleaf summarises the preliminary peak inflows at each HEP. The HEPs used are shown on Figure B2.1.

Preliminary design inflow hydrographs are shown in Figures B2.2 to B2.4 for the 10%, 1% and 0.1% AEP flows.

HEP reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_657_1	20.70	25.4	28.6	31.6	35.5	38.4	41.3	48.0
27_660_3	0.06	0.08	0.09	0.10	0.11	0.12	0.13	0.15
27_660_4	0.23	0.28	0.32	0.35	0.39	0.42	0.46	0.53
27_661_2	0.07	0.09	0.10	0.11	0.13	0.14	0.15	0.17
27_661_4	3.19	3.92	4.40	4.86	5.46	5.91	6.35	7.39
27_1275_2	0.27	0.33	0.38	0.42	0.47	0.50	0.54	0.63

Table B2.3 Preliminary Design Hydrograph Peak Inflows (m^3/s) at HEP Locations on the S02 Model Extent

The inflows for the most upstream (HEP) node in Table B2.3 are equal to the target flows for the next node downstream of it. This is because we typically assign an inflow (as the difference between the target flows at a node and its downstream neighbour) at the upstream node. As a consequence the additional (lateral) inflow between the very first node along the model extent and the second node is included in the upstream inflow.

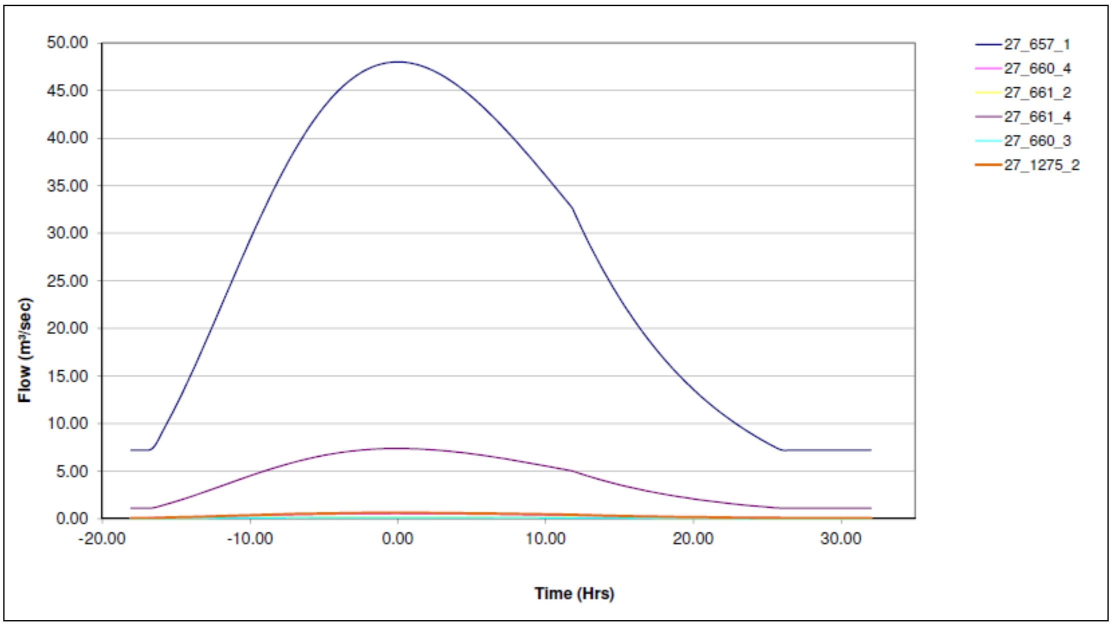

Figure B2.2 S02 Preliminary Design Inflow Hydrographs for 0.1% AEP

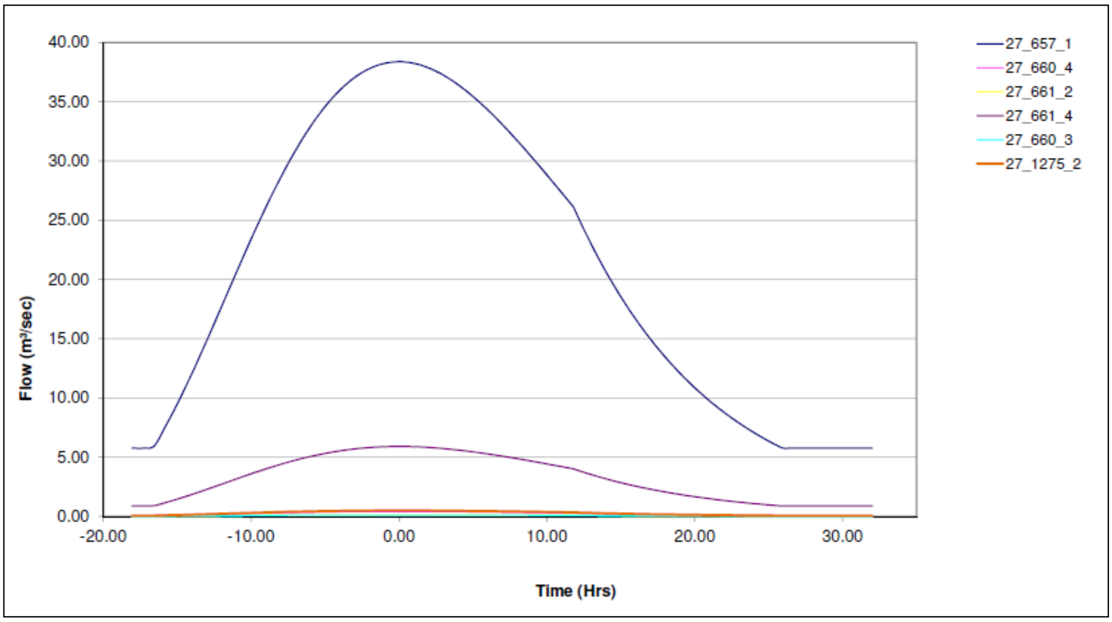

Figure B2.3 S02 Preliminary Design Inflow Hydrographs for 1% AEP

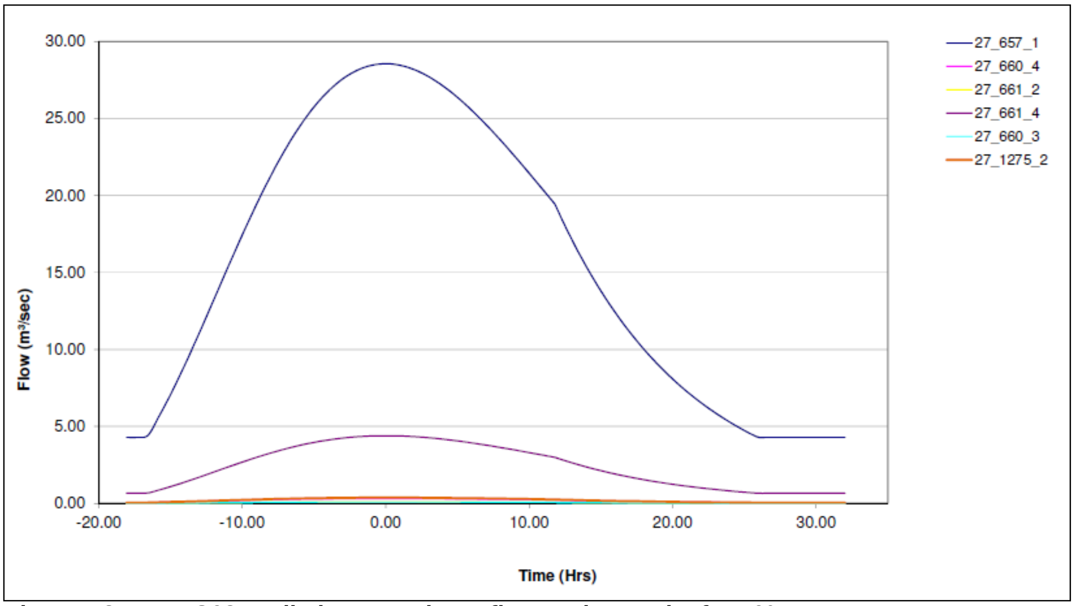

Figure B2.4 S02 Preliminary Design Inflow Hydrographs for 10% AEP

B2.4 HEP Calibration and Final Design Hydrographs

The hydraulic model uses the preliminary design inflows presented in Table B2.3 for calibrating the model to the HEP target flows presented in Table B2.2.

HEP calibration at each HEP was undertaken using the methodology described in Section 2.7.2 of the main hydrology report for UoM 27. Hydraulic modelling aspects of the HEP calibration including the results and final design peak flows are presented in the hydraulic modelling report for Model S02.

B3 Model S03

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	Owenogarney River and an unnamed right bank tributary (*Owenogarney Tributary).
Areas for Further Assessment (AFA)	Sixmilebridge, Bunratty
Individual Risk Receptor (IRR)	None

**Unnamed tributary named as as 'Owenogarney Tributary' for the purpose of reporting.*

Table B3.1 Model Extent coverage

B3.1 Hydrology for Hydraulic Model Calibration

There was insufficient gauged data available to calibrate the S03 model. Only one gauging station (27011 – Owenogarney Railway Br.) is present along the S03 model length and no station exists nearby to allow an independent comparison between flows and water levels.

Three historic events were identified for each AFA (Bunratty and Sixmilebridge); none have detailed information such as flood water levels that can be used for the calibration/verification of S03 model. Similarly, a tidal calibration/verification is also not possible for S03 model due to lack of suitable tidal event data.

Refer to the calibration strategy in Appendix F and the hydraulic modelling report for S03 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 A2. The target flows at the HEP nodes for model S03 are shown in Tables B3.2 – B3.3.

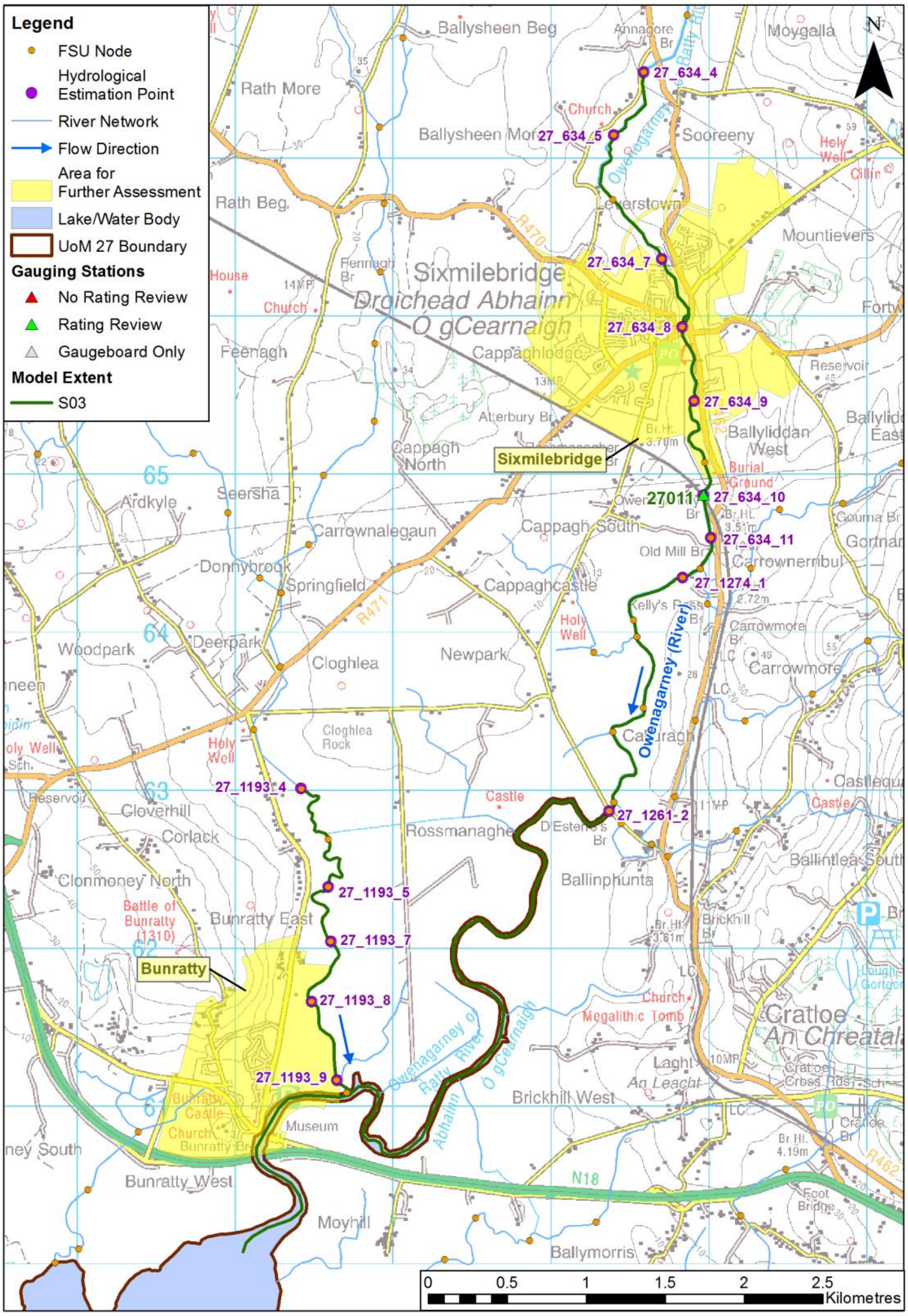

Figure B3.1 S03Model Extent [1]

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HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_634_4	26.1	31.8	35.5	39.2	43.9	47.4	50.9	59.0
27_634_5	26.1	31.8	35.6	39.3	44.0	47.5	51.0	59.1
27_634_7	26.2	31.9	35.7	39.4	44.1	47.6	51.2	59.3
27_634_8	26.2	32.0	35.8	39.4	44.2	47.7	51.2	59.4
*27_634_9	26.2	32.0	35.8	39.4	44.2	47.7	51.2	59.4
27_634_10	26.6	32.4	36.3	40.0	44.8	48.3	51.9	60.2
27_634_11	26.6	32.5	36.3	40.0	44.8	48.4	52.0	60.3
27_1274_1	30.2	36.8	41.1	45.3	50.8	54.8	58.9	68.3
27_1261_2	31.4	38.3	42.8	47.2	52.8	57.1	61.3	71.1

Table B3.2 Target Flows (m^3/s) at HEP Locations on the S03 Model Extent (Owenogarney – Main Stem).

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_1193_4	2.3	2.8	3.2	3.5	3.9	4.2	4.5	5.2
27_1193_5	2.4	2.9	3.3	3.6	4.0	4.3	4.7	5.4
27_1193_7	2.6	3.1	3.5	3.8	4.3	4.6	5.0	5.7
27_1193_8	2.6	3.2	3.5	3.9	4.3	4.7	5.0	5.8
27_1193_9	2.6	3.2	3.6	3.9	4.4	4.8	5.1	5.9

Table B3.3 Target Flows (m^3/s) at HEP Locations on the S03 Model Extent (Owenogarney Tributary)

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 watercourses that comprise Model S03 include the main stem of the Owenogarney River and an unnamed tributary that flows by the Bunratty AFA before joining the Owenogarney in its lower tidal-reach. The modelled watercourses are treated as independent branches with the critical events in each simulated by independent model runs..

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 on Figure B3.1. Tables B3.4 – B3.5 present the preliminary peak inflows at each HEP in the hydraulic model.

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

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_634_4	26.2	32.0	35.8	39.4	44.2	47.7	51.2	59.4
27_634_8	0.36	0.44	0.49	0.54	0.61	0.65	0.70	0.81
27_634_11	3.6	4.4	4.9	5.4	6.0	6.5	7.0	8.1
27_1274_1	1.2	1.5	1.7	1.9	2.1	2.2	2.4	2.8

Table B3.4 Preliminary Design Hydrograph Peak Inflows (m^3/s) at HEP Locations on the S03 Model Extent (Owenogarney – Main Stem)

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_1193_4	2.4	2.9	3.3	3.6	4.0	4.3	4.7	5.4
27_1193_5	0.15	0.19	0.21	0.23	0.26	0.28	0.30	0.34
27_1193_7	0.03	0.04	0.04	0.04	0.05	0.05	0.06	0.07
27_1193_8	0.05	0.06	0.06	0.07	0.08	0.08	0.09	0.10

Table B3.5 Preliminary Design Hydrograph Peak Inflows (m^3/s) at HEP Locations on the S03 Model Extent (Unnamed Tributary at Bunratty)

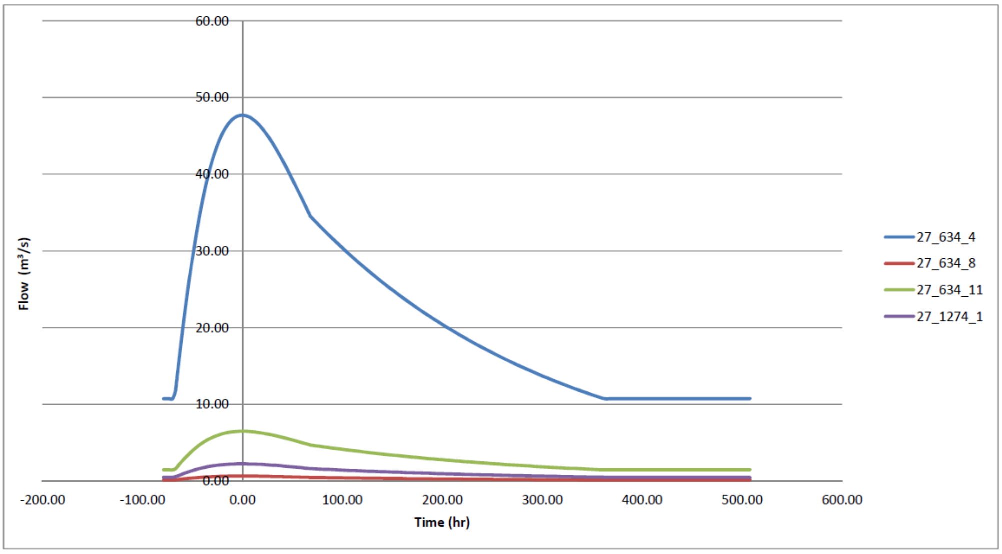

Figure B3.2 S03 Preliminary Design Inflow Hydrographs for 1% AEP (Owenogarney – Main Stem)

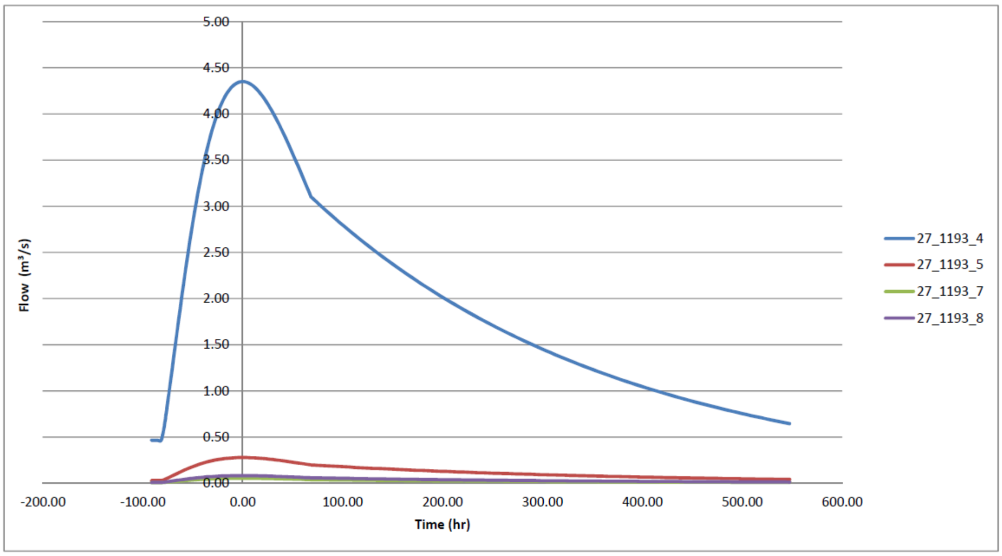

Figure B3.3 S03 Preliminary Design Inflow Hydrographs for 1% AEP (Owenogarney Tributary)

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 27. Hydraulic modelling aspects of the HEP calibration including the results and final design peak flows are presented in the hydraulic modelling report for Model S03.

B4 Model S04

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	Drumgeely Creek, Ballycasey Creek and two other minor tributaries.
Areas for Further Assessment (AFA)	Shannon Town
Individual Risk Receptor (IRR)	Shannon Airport

Table B4.1 Model Extent coverage

B4.1 Hydrology for Hydraulic Model Calibration

There was insufficient gauged data available to calibrate the S04 model. No hydrometric station is present within or upstream of the S04 modelling extent to provide reliable flows to calibrate the model.

Three past events were identified, of which, none provide observed water levels or a specific location or date and thus, are unlikely to be useful for model calibration or verification for both fluvial and tidal events.

Refer to the calibration strategy in Appendix F and the hydraulic modelling report for S04 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 A3. The target flows at the HEP nodes for Model S04 are shown in Tables B4.2 – B4.6.

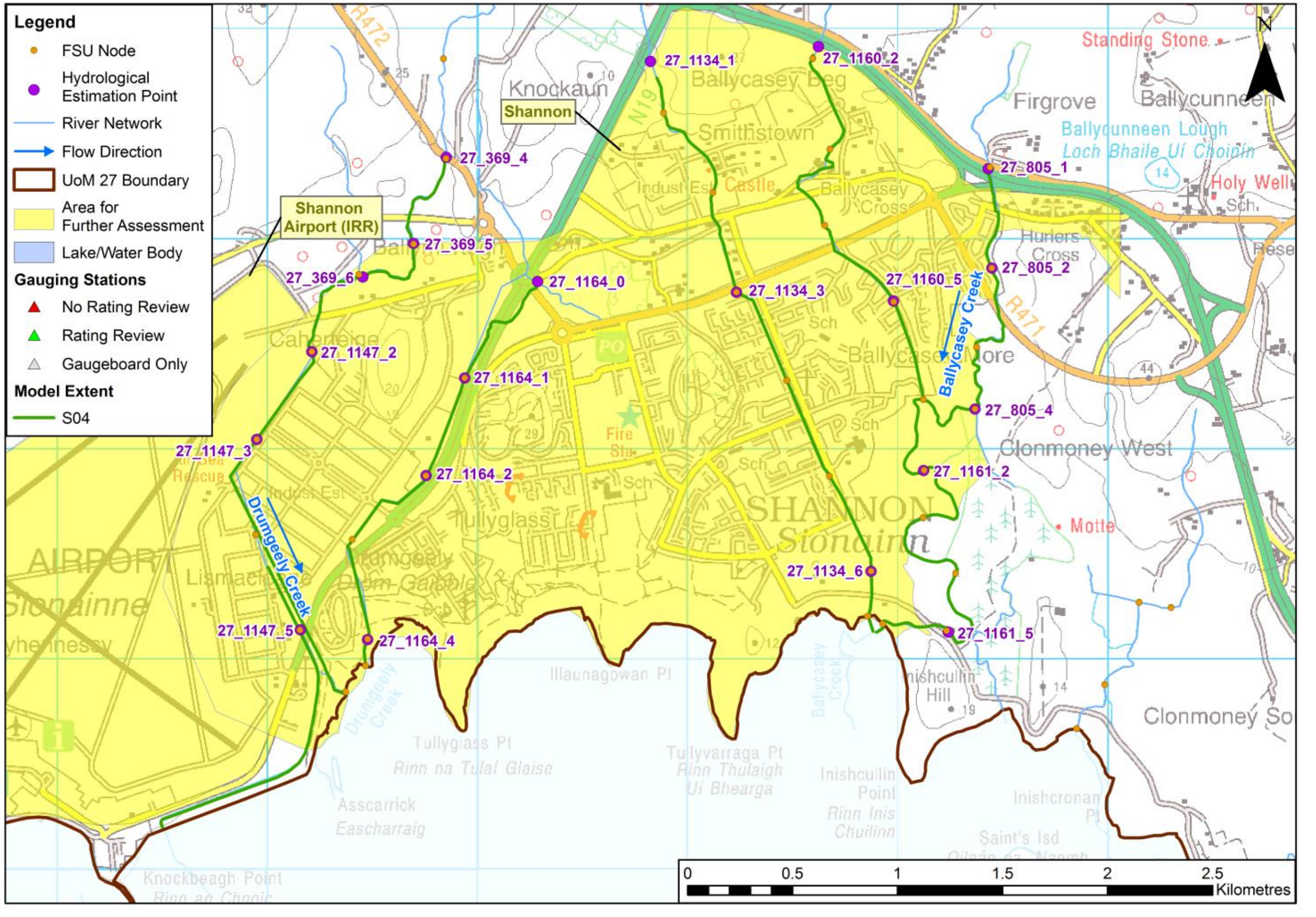

Figure B4.1 S04 Model Extent [1]

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_1160_2	0.5	0.7	0.8	0.9	1.0	1.2	1.3	1.5
27_1160_5	1.0	1.4	1.7	1.9	2.2	2.5	2.7	3.3
27_1161_2	2.0	2.7	3.2	3.7	4.4	4.9	5.3	6.4
27_1161_5	2.0	2.8	3.3	3.8	4.4	4.9	5.4	6.5

Table B4.2 Target Flows (m^3/s) at HEP Locations on the S04 Model Extent (Ballycasey – Primary Branch).

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_805_1	0.4	0.6	0.7	0.8	0.9	1.0	1.1	1.3
27_805_2	0.6	0.8	1.0	1.1	1.3	1.4	1.6	1.9
27_805_4	0.8	1.1	1.3	1.5	1.8	2.0	2.2	2.6

Table B4.3 Target Flows (m^3/s) at HEP Locations on the S04 Model Extent (Ballycasey – Tributary of Primary Branch)

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_1134_1	0.23	0.32	0.38	0.43	0.51	0.56	0.62	0.75
27_1134_3	0.5	0.7	0.9	1.0	1.2	1.3	1.4	1.7
27_1134_6	1.2	1.6	1.9	2.2	2.6	2.9	3.2	3.9

Table B4.4 Target Flows (m^3/s) at HEP Locations on the S04 Model Extent (Ballycasey – Secondary Branch)

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_369_4	1.0	1.3	1.5	1.7	1.9	2.1	2.3	2.7
27_369_5	1.1	1.4	1.6	1.8	2.1	2.3	2.4	2.9
27_369_6	1.2	1.6	1.8	2.0	2.3	2.5	2.8	3.3
27_1147_2	1.4	1.9	2.2	2.4	2.8	3.0	3.3	3.9
27_1147_3	1.6	2.0	2.4	2.6	3.0	3.3	3.6	4.3
27_1147_5	2.2	2.8	3.2	3.6	4.2	4.6	5.0	5.9

Table B4.5 Target Flows (m^3/s) at HEP Locations on the S04 Model Extent (Drumgeely – Primary Branch)

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_1164_1	0.30	0.39	0.45	0.50	0.58	0.63	0.69	0.81
27_1164_2	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.3
27_1164_4	0.9	1.1	1.3	1.4	1.6	1.8	1.9	2.3

Table B4.6 Target Flows (m^3/s) at HEP Locations on the S04 Model Extent (Drumgeely – Secondary Branch)

B4.3 Preliminary Design Inflows

To obtain the target flows at each HEP, as shown in Tables B4.2 – B4.6, an initial set of inflow hydrographs were produced and run through the model.

The watercourses that comprise Model S04 discharge independently to the Shannon Estuary; as such, the model has been treated as four independent branches. The critical events in each of the watercourses (including both primary and secondary branches) were simulated by independent model runs. For modelling purposes the watercourses are defined as Ballcasey primary branch (from HEP 27_1160_2 to 27_1161_5), Ballycasey secondary branch (from HEP 27_1134_1 to 27_1134_6), Drumgeely primary branch (from HEP 27_369_4 to 27_1147_5) and Drumgeely secondary branch (from HEP 27_1164_0 to 27_1164_4).

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 B4.1. Tables B4.7 – B4.11 present the preliminary peak inflows at each HEP in the hydraulic model.

Preliminary design inflow hydrographs are shown in Figures B4.2 – B4.3 for the 1% AEP design run.

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_1160_2	1.0	1.4	1.7	1.9	2.2	2.5	2.7	3.3
27_1160_5	0.16	0.22	0.27	0.31	0.36	0.40	0.44	0.53
27_1161_2	0.03	0.04	0.04	0.05	0.06	0.07	0.07	0.09

Table B4.7 Preliminary Design Hydrograph Peak Inflows (m^3/s) at HEP Locations on the S04 Model Extent (Ballycasey – Primary Branch)

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_805_1	0.6	0.8	1.0	1.1	1.3	1.4	1.6	1.9
27_805_2	0.22	0.31	0.36	0.42	0.49	0.54	0.60	0.72

Table B4.8 Preliminary Design Hydrograph Peak Inflows (m^3/s) at HEP Locations on the S04 Model Extent (Ballycasey – Tributary of Primary Branch)

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_1134_1	0.5	0.7	0.9	1.0	1.2	1.3	1.4	1.7
27_1134_3	0.7	0.9	1.1	1.3	1.5	1.6	1.8	2. 2

Table B4.9 Preliminary Design Hydrograph Peak Inflows (m^3/s) at HEP Locations on the S04 Model Extent (Ballycasey – Secondary Branch)

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_369_4	1.1	1.4	1.6	1.8	2.1	2.3	2.4	2.9
27_369_5	0.14	0.18	0.21	0.23	0.27	0.29	0.32	0.38
27_369_6	0.23	0.30	0.34	0.39	0.44	0.48	0.52	0.62
27_1147_2	0.14	0.18	0.20	0.23	0.26	0.28	0.31	0.36
27_1147_3	0.6	0.8	0.9	1.0	1.1	1.2	1.4	1.6

Table B4.10 Preliminary Design Hydrograph Peak Inflows (m^3/s) at HEP Locations on the S04 Model Extent (Drumgeely – Primary Branch)

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_1164_0	0.30	0.39	0.45	0.50	0.58	0.63	0.69	0.81
27_1164_1	0.18	0.23	0.26	0.30	0.34	0.37	0.40	0.48
27_1164_2	0.37	0.48	0.55	0.62	0.70	0.77	0.84	0.99

Table B4.11 Preliminary Design Hydrograph Peak Inflows (m^3/s) at HEP Locations on the S04 Model Extent (Drumgeely – Secondary Branch)

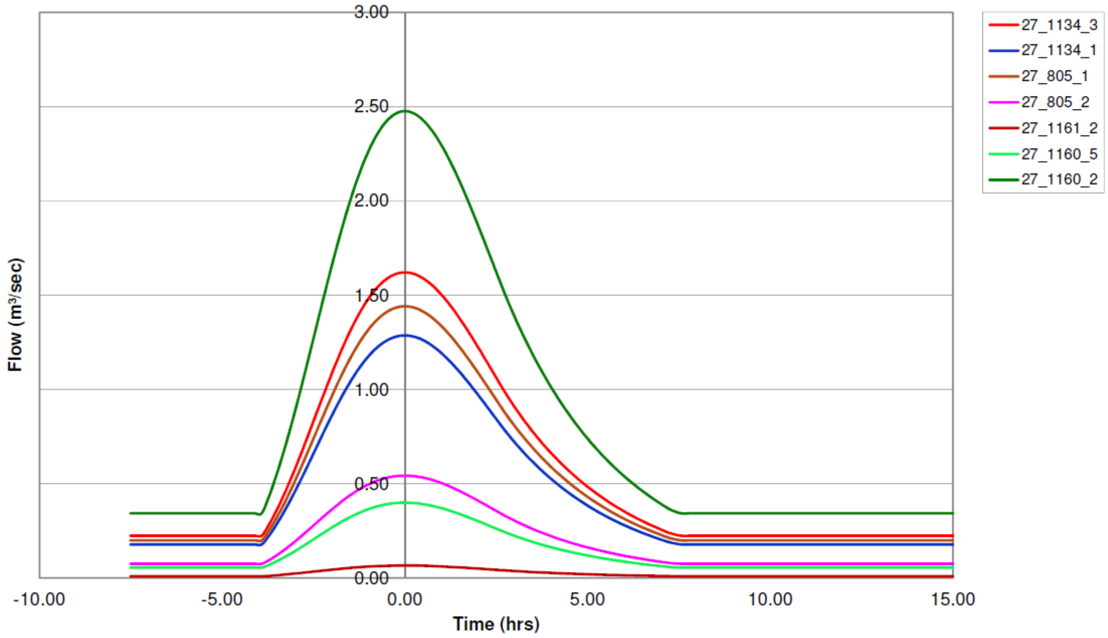

Figure B4.2 S04 Preliminary Design Inflow Hydrographs for 1% AEP (Ballycasey – Primary & Secondary Branches)

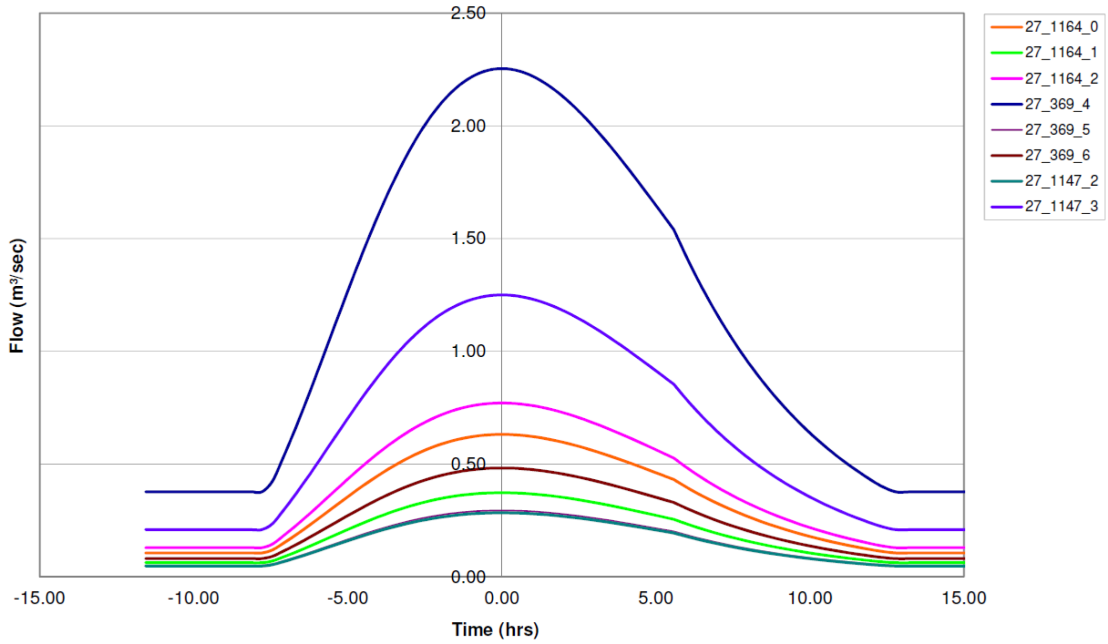

Figure B4.3 S04 Preliminary Design Inflow Hydrographs for 1% AEP (Drumgeely – Primary & Secondary Branches)

B4.4 HEP Calibration and Final Design Hydrographs

The hydraulic model uses the preliminary design inflows presented in Tables B4.7 – B4.11 for calibrating the model to the HEP target flows presented in Tables B4.2 – B4.6.

HEP calibration at each HEP was undertaken using the methodology described in Section 2.7.2 of the main hydrology report for UoM 27. Hydraulic modelling aspects of the HEP calibration including the results and final design peak flows are presented in the hydraulic modelling report for Model S04.

B5 Model S18

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 B5.1, and shown on Figure B5.1

Model Attribute	Comment
Rivers included in model	River Wood and Kilrush Creek
Areas for Further Assessment (AFA)	Kilrush

Table B5.1 Model Extent Coverage

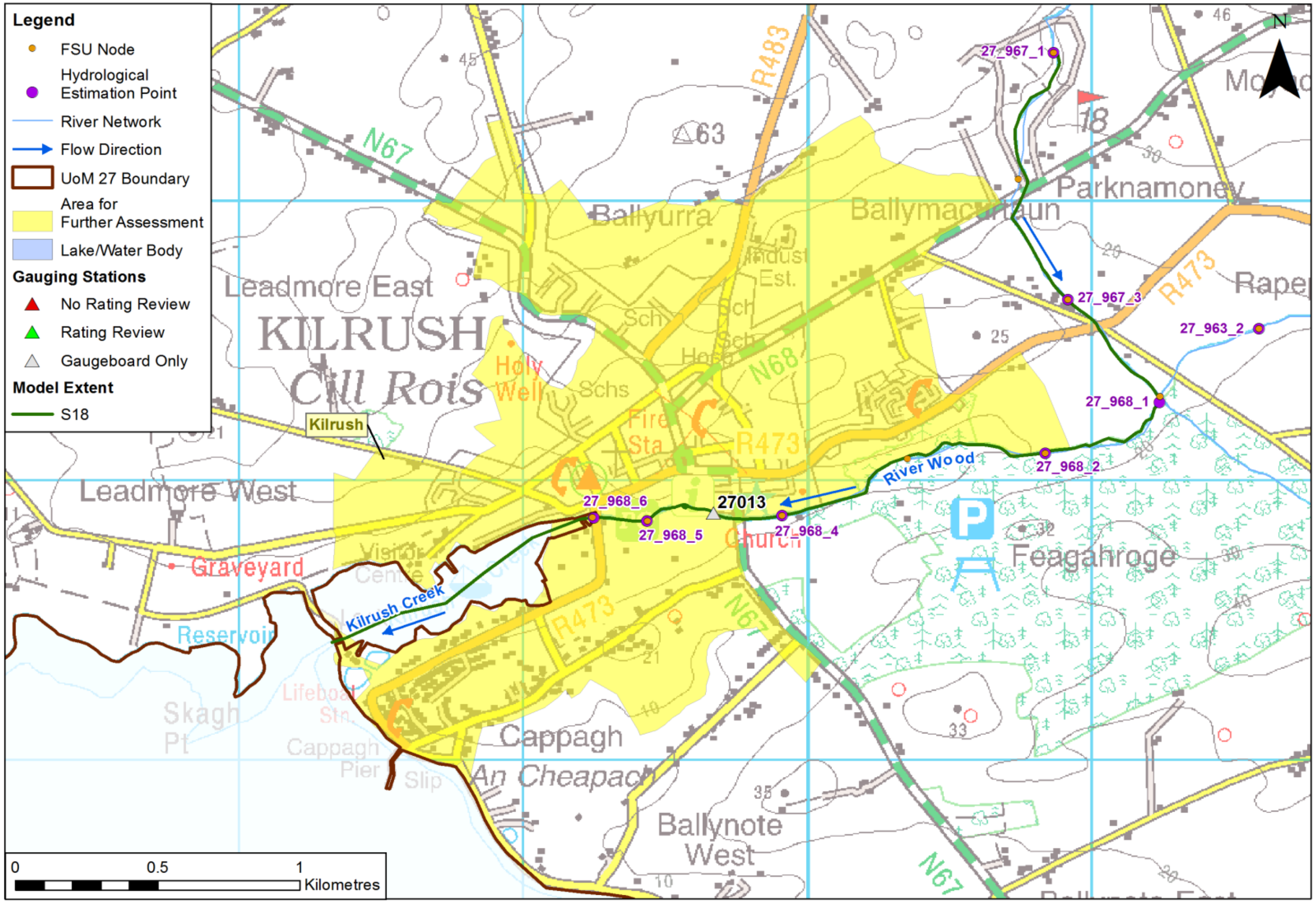

Figure B5.1 S18 Model Extent [1]

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B5.1 Hydrology for Hydraulic Model Calibration

There was insufficient gauged data available to calibrate the S18 model. A broad verification (sense check) of the modelled design extents was undertaken via comparison to the observed flood extents of the January 2005 flood event. Refer to the calibration strategy in Appendix F and the hydraulic modelling report for S18 for details on the verification.

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 A5. The target flows at the HEP nodes for model S18 are shown in Table B5.2.

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_967_1	0.68	0.86	0.96	1.06	1.19	1.28	1.37	1.58
27_967_3	0.68	0.86	0.96	1.06	1.19	1.28	1.37	1.58
27_968_1	5.58	7.03	7.92	8.71	9.77	10.49	11.27	12.95
27_968_2	5.93	7.47	8.42	9.25	10.38	11.15	11.98	13.76
27_968_4	6.41	8.07	9.10	9.99	11.21	12.04	12.94	14.86
27_968_5	6.50	8.19	9.23	10.14	11.37	12.22	13.13	15.08
27_968_6	6.90	8.70	9.80	10.77	12.08	12.98	13.95	16.02

Table B5.2 Target Flows (m^3/s) at HEP Locations on the S18 Model Extent

B5.3 Preliminary Design Inflows

To obtain the target flows shown in Table B5.2, an initial set of inflow hydrographs was produced and run through the model. One run on the main stem was required for this 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, Chapter A5.

The HEPs are shown on Figure B5.1. Table B5.3 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 run.

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

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_967_1	0.68	0.86	0.96	1.06	1.19	1.28	1.37	1.58
27_967_3	4.90	6.17	6.96	7.64	8.58	9.21	9.90	11.37
27_968_1	0.35	0.44	0.50	0.55	0.61	0.66	0.71	0.81
27_968_2	0.46	0.60	0.68	0.74	0.83	0.89	0.96	1.10
27_968_4	0.09	0.12	0.13	0.15	0.16	0.18	0.19	0.22
27_968_5	0.40	0.51	0.57	0.63	0.71	0.76	0.82	0.94

Table B5.3 Preliminary Design Hydrograph Peak Inflows (m^3/s) at HEP Locations on the S18 Model Extent

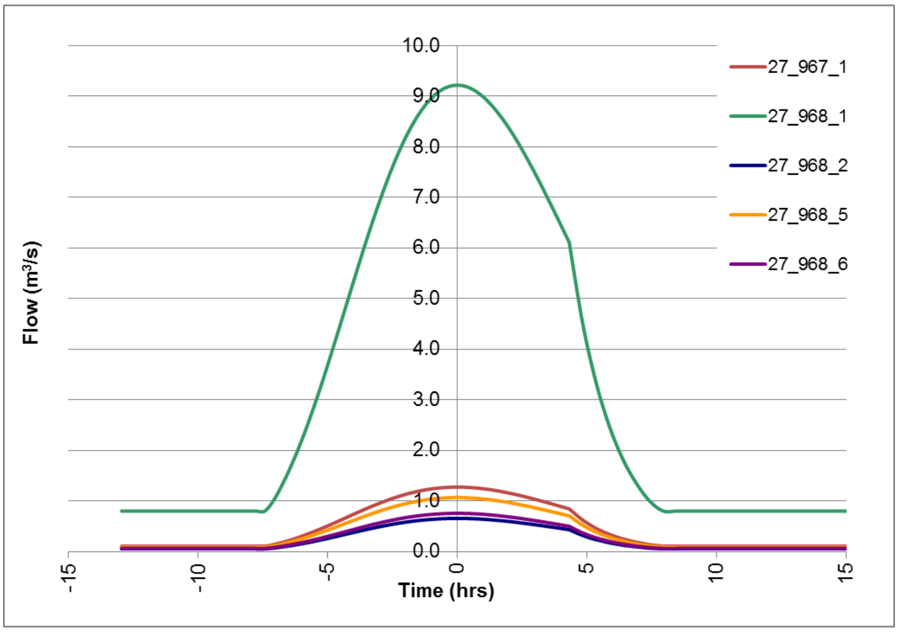

Figure B5.2 S18 Preliminary Design Inflow Hydrographs for 1% AEP

B5.4 Final Design Inflows

The hydraulic model uses the preliminary design inflows presented in Table B5.3 for calibrating the model to the HEP target flows presented in Table B5.2.

HEP calibration at each HEP was undertaken using the methodology described in Section 2.7.2 of the main hydrology report for UoM 27.

Hydraulic modelling aspects of the HEP calibration including the results and final design peak flows are presented in the hydraulic modelling report for Model S18. The hydraulic modelling report also provides details on the tidal water level boundaries applied to the model.

B6 Model S19

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 shown on Figure B6.1

Model Attribute	Comment
Rivers included in model	Victoria Stream Unnamed watercourse (referred to in this report as 'River 1')
Areas for Further Assessment (AFA)	Kilkee

Table B6.1 Model Extent coverage

B4.1 Hydrology for Hydraulic Model Calibration

There was insufficient gauged data available to calibrate or verify the S19 model.

(Refer to the calibration strategy in Appendix F and the hydraulic modelling report for S19 for detail on the calibration/verification).

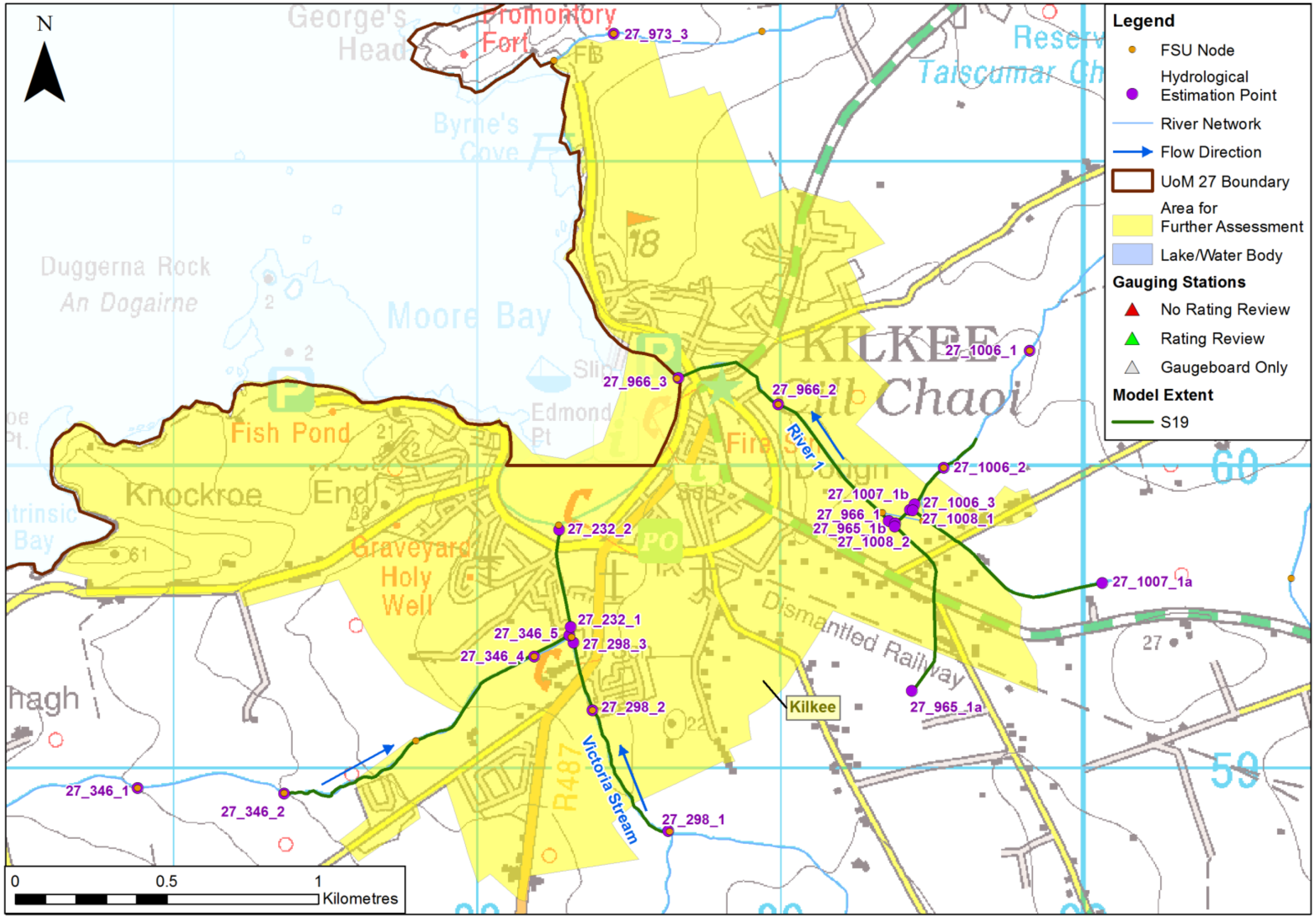

Figure B6.1 S19 Model Extent [1]

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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 A4. The target flows at the HEP nodes for model S19 are shown in Tables B6.2 to B6.5.

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
24_1006_2	0.71	0.88	1.0	1.1	1.2	1.3	1.4	1.6
27_1006_3	0.71	0.88	1.0	1.1	1.2	1.3	1.4	1.6
27_1008_1	1.1	1.3	1.5	1.6	1.8	1.9	2.1	2.4
27_1008_2	1.1	1.4	1.6	1.8	2.0	2.1	2.2	2.6
27_966_1	1.2	1.5	1.7	1.9	2.1	2.3	2.4	2.8
27_966_2	2.3	2.8	3.2	3.5	3.9	4.2	4.5	5.1
27_966_3	2.5	3.0	3.4	3.8	4.2	4.5	4.8	5.5

Table B6.2 Target Flows (m^3/s) at HEP Locations on the S19 Model Extent (Main stem- River 1).

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_298_1	1.7	2.1	2.4	2.6	2.9	3.1	3.3	3.8
27_298_2	1.7	2.1	2.4	2.6	2.9	3.1	3.3	3.8
27_298_3	5.0	6.2	7.0	7.7	8.6	9.2	9.9	11.3
27_232_1	5.0	6.2	7.0	7.7	8.6	9.2	9.9	11.3
27_232_2	5.0	6.2	7.0	7.7	8.6	9.2	9.9	11.3

Table B6.3 Target Flows (m^3/s) at HEP Locations on the S19 Model Extent (Main stem- Victoria Stream).

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_1007_1a	0.10	0.12	0.14	0.15	0.17	0.18	0.19	0.22
27_1007_1b	0.10	0.12	0.14	0.15	0.17	0.18	0.19	0.22
27_965_1a	0.34	0.42	0.48	0.52	0.58	0.62	0.67	0.76
27_965_1b	0.34	0.42	0.48	0.52	0.58	0.62	0.67	0.76

Table B6.4 Target Flows (m^3/s) at HEP Locations on the S19 Model Extent (Tributaries to River 1)

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_346_2	1.9	2.3	2.6	2.8	3.2	3.4	3.4	4.2

27_346_4	1.9	2.3	2.6	2.8	3.2	3.4	3.4	4.2
27_346_5	1.9	2.4	2.7	2.9	3.3	3.5	3.4	4.3

Table B6.5 Target Flows (m^3/s) at HEP Locations on the S19 Model Extent (Tributary to Victoria Stream)

B4.3 Preliminary Design Inflows

To obtain the target flows shown in Tables B6.2 to B6.5, an initial set of inflow hydrographs was produced and run through the model. To be able to model the critical events on the tributaries independently from the critical events on the main stem, two separate runs were undertaken for each AEP, one run to match the target flows in the main stem, and a separate independent run to obtain the target flows on the tributaries. For modelling purposes the tributaries are defined as the unnamed tributary to the Victoria Stream down to node 27_346_5 and the unnamed tributary draining to River 1 down to 27_965_1b.

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 A4. The QMED adjustment factor, growth curve and hydrograph shape are specified in Appendix A4. The HEPs are shown on Figure B6.1. Tables B6.6 to 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 runs.

Preliminary design inflow hydrographs are shown in Figures B6.2 and B6.3 for the 1% AEP design runs.

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_1006_2	0.71	0.88	1.0	1.1	1.2	1.3	1.4	1.6
27_1006_3	0.34	0.42	0.48	0.52	0.58	0.62	0.67	0.76
27_1007_1a	0.09	0.11	0.13	0.14	0.15	0.16	0.18	0.20
27_1008_2	0.10	0.12	0.14	0.15	0.17	0.18	0.19	0.22
27_966_1	1.0	1.3	1.5	1.6	1.8	1.9	2.3	2.3
27_966_2	0.18	0.22	0.25	0.28	0.31	0.33	0.36	0.41

Table B6.6 Preliminary Design Hydrograph Peak Inflows (m^3/s) at HEP Locations on the S19 Model Extent (Main Stem- River 1, Reach 1)

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_298_1	1.7	2.1	2.4	2.6	2.9	3.1	3.3	3.8
27_298_2	0.25	0.31	0.35	0.39	0.43	0.46	0.49	0.57
27_298_3	3.1	3.8	4.3	4.7	5.3	5.7	6.1	6.9

Table B6.7 Preliminary Design Hydrograph Peak Inflows (m^3/s) at HEP Locations on the S19 Model Extent (Main Stem – Victoria Stream – Reach 2)

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_965_1a	0.34	0.42	0.48	0.52	0.58	0.62	0.67	0.76

Table B6.8 Preliminary Design Hydrograph Peak Inflows (m^3/s) at HEP Locations on the S19 Model Extent (Tributary–River 1 – Reach 1)

HEP Reference	Annual Exceedance Probability							
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
27_346_4	0.05	0.06	0.07	0.08	0.09	0.10	0.10	0.12

Table B6.9 Preliminary Design Hydrograph Peak Inflows (m^3/s) at HEP Locations on the S19 Model Extent (Tributary – Victoria Stream – Reach 3)

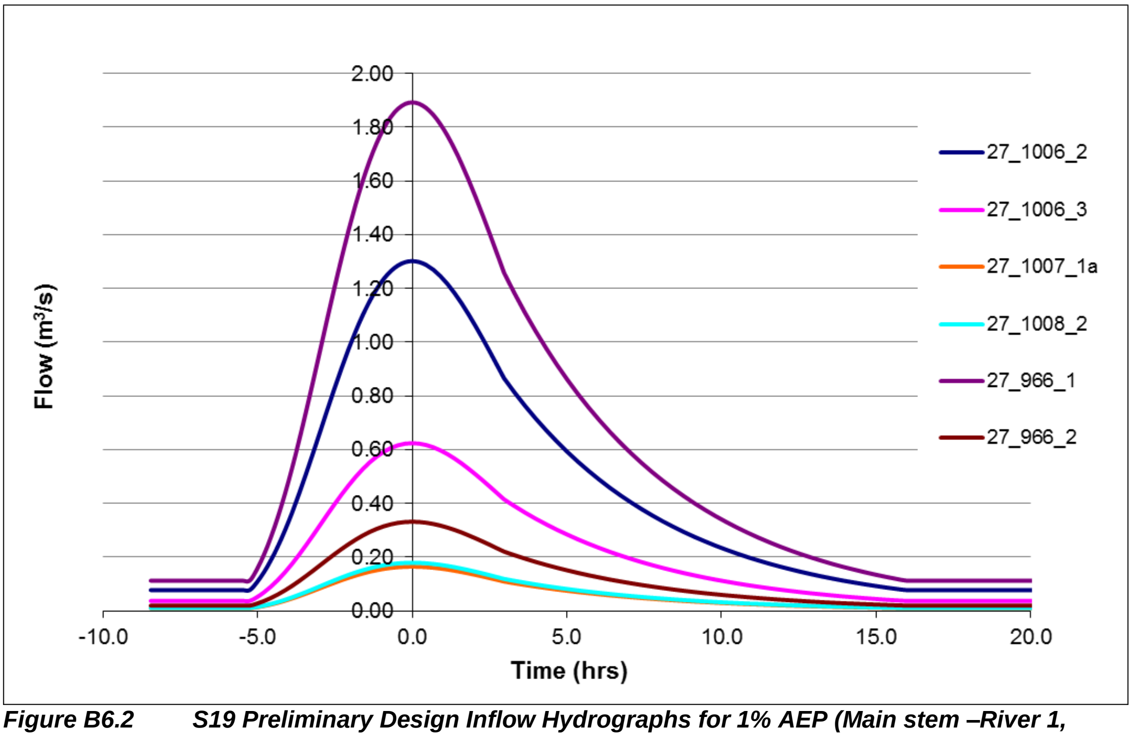


Figure B6.2 S19 Preliminary Design Inflow Hydrographs for 1% AEP (Main stem –River 1, Reach 1)

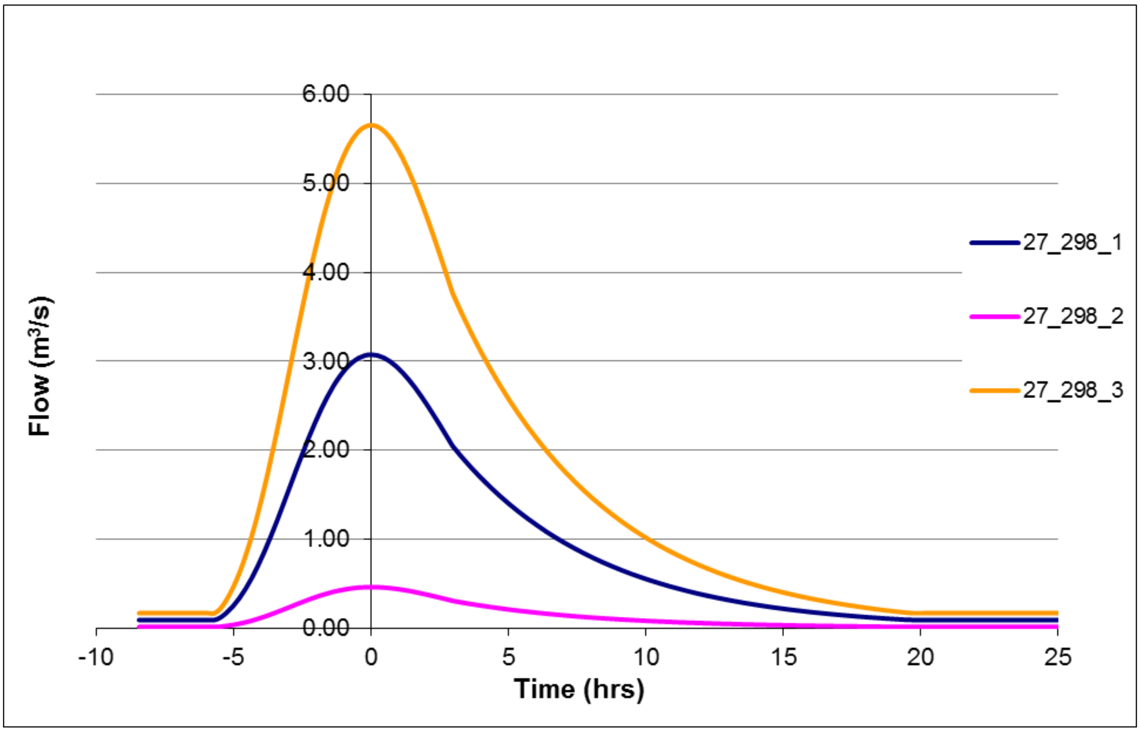


Figure B6.3 S19 Preliminary Design Inflow Hydrographs for 1% AEP (Main Stem – Victoria Stream, Reach 2)

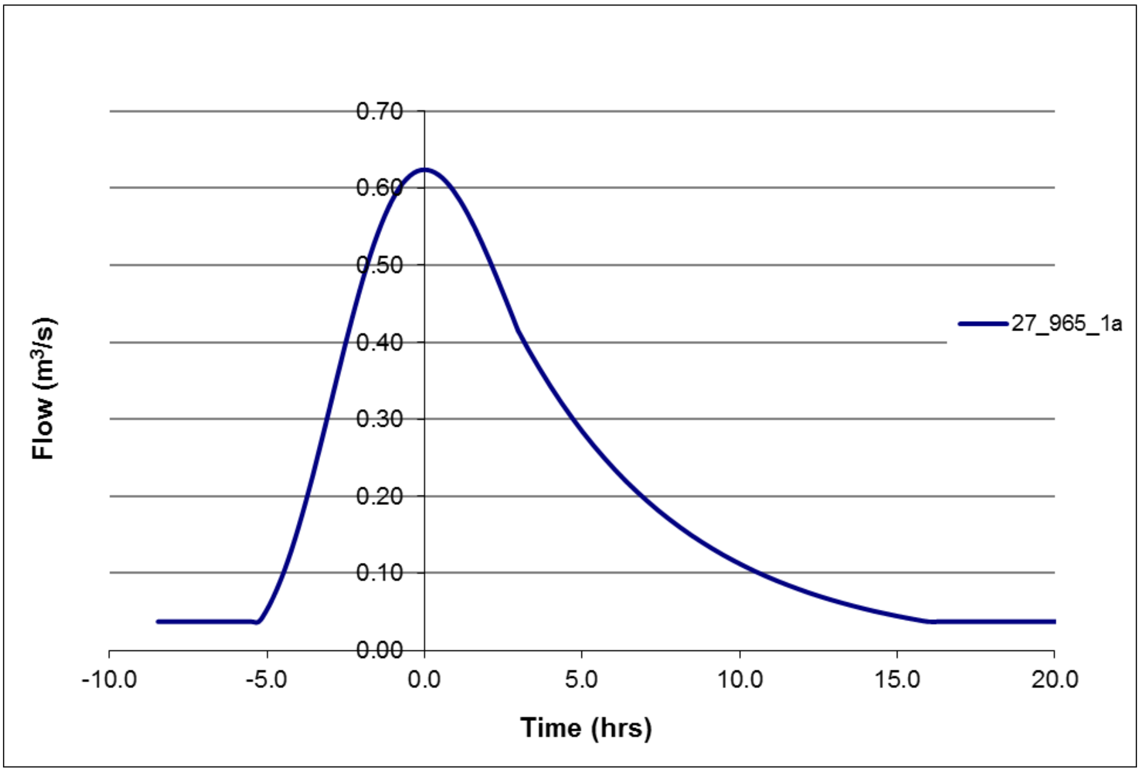


Figure B6.4 S19 Preliminary Design Inflow Hydrographs for 1% AEP (Tributary – River 1, Reach 1)

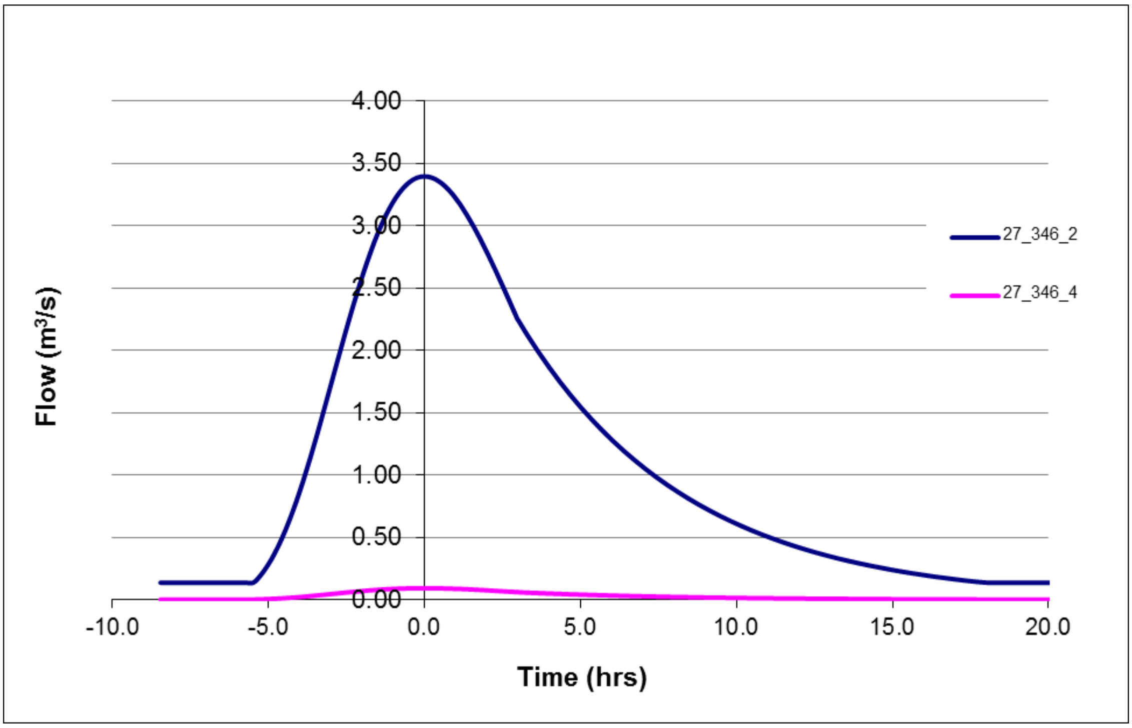


Figure B6.5 S19 Preliminary Design Inflow Hydrographs for 1% AEP (Tributary – Victoria Stream, Reach 3)

B4.4 Final Design Inflows

The hydraulic model uses the preliminary design inflows presented in Tables B6.6 to B6.9 for calibrating the model to the HEP target flows presented in Tables B6.2 to 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 27. Hydraulic modelling aspects of the HEP calibration including the results and final design peak flows are presented in the hydraulic modelling report for Model S19.

Appendix C Rating Review Summary Sheets

Table of Content

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

27001 – CLAUREEN AT INCH BRIDGE

Date of data collation: 09/01/2012, completed 04/10/2013

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 gauging station to summarise the rating review process.

Gauging Station Description:

A velocity-area station was installed in 1939 and automated in 1957. The station has a natural channel control with an unstable gravel bed. The gauging station is located on the left bank on the upstream face of a bridge. Upstream and downstream channel widths are fairly constant, with weed growth in the river channel. Downstream floodplain is restricted on the right bank by the road, around 20-30m from the river. Jacobs' site visit notes report that bypassing is unlikely due to the height of the bridge.

Gauging Station Details:

Station Type	Recorder	**Gauging Authority**	OPW
Coordinates	130159, 175321	**Period of Record**	1957 - 2009 (AMAX)*
Existing Rating Curve	Yes	**Validity / Upper Limit**	W < 1.35 m (~16.5 m^3/s; pre-rating review)

**AMAX data only available from 1972 as data prior to this not yet digitised.*

QMED synthetic	32.0 m^3/s
QMED (AMAX, pre-rating review)	20.3 m^3/s (36 years)

Gauge Zero (from operator)	12.26 mAOD (P)
Gauge Zero (from survey)	None provided ** (estimated to be 9.56mAOD(M))

***Gauge Zero was estimated to be 9.56 mAOD (M), calculated by taking 2.7 m from Poolbeg level (the difference between the two Ordnance Datums). This level was confirmed by comparing surveyed water level with recorded water level on day of survey.*

Revised Rating Equation:

$Q = 12.744 (W+0)^{1.7901}$ for the range: $0.40<W<0.76$m (above Gauge Zero)
$Q = 14.153 (W+0)^{2.0235}$ for the range: $0.76 \le W<1.74$m (above Gauge Zero)
$Q = 13.566 (W+0)^{2.1188}$ for the range: $1.74 \le W<2.11$m (above Gauge Zero)
$Q = 17.004 (W+0)^{1.7931}$ for the range: $2.11 \le W<2.70$m (above Gauge Zero)

Hydraulic Model Details:

Model Name: 27001_InchBridge_C1_GS3.DAT.

A one-dimensional hydraulic model of the River Claureen at Inch Bridge gauging station was built using river survey data collected by CCS Surveying in October 2011 (survey drawings P606-003, P606-004, P606-005-LS and P606-Inch 001-XS, P606-Inch 002-XS) and ISIS modelling software.

The gauging station is situated upstream of the bridge structure, with the gauge board located on the upstream face (at chainage CLAU_0312u in the ISIS model). The hydraulic model extends from 202m upstream of Inch Bridge (NGR: 130111, 175205) on the River Claureen to 312m downstream of the structure (NGR: 130446, 175430).

Inch Bridge was the only hydraulic structure included in the model and was schematised using an ISIS Arch bridge unit, at chainage CLAU_0312 and a spill unit to allow for bridge overtopping.

Hydraulic roughness (Manning's n) values used in the model were originally estimated using site visit and survey information. The river bed consist mainly of silt and gravel (n=0.035). Bank side and floodplain roughness values range from pasture with high grass (0.04) to dense vegetation (0.08). The roughness values were then modified at calibration stage within acceptable limits to best fit the available gaugings.

Floodplain areas were represented in the model using extended cross sections as deemed appropriate.

A normal depth boundary unit was used as the downstream boundary condition. This is considered appropriate as no backwater effect are expected on the downstream model boundary, and the model extends far enough downstream of the gauge to be insensitive to this boundary condition.

Hydraulic Model Calibration:

Calibration of the hydraulic model has been carried out using the available check gaugings provided by OPW. Gaugings prior to July 1993 have been disregarded as channel works were undertaken at this point in time, and there is a clear shift in the stage-discharge relationship following the works. The bed roughness coefficient has been gradually varied to achieve a best fit to the check gaugings. The bridge calibration coefficient was also varied; however no particular effect was noted. Channel roughness value of 0.050 and a bridge head loss coefficient of 1 have been adopted as the final coefficients. It was not considered appropriate to increase the in-bank channel roughness further as it was considered that the value used is the upper end of the valid range for this site.

There is a reasonable fit between the modelled rating and check gaugings up to a flow of 10m^3/s, where the gaugings lie up to 0.05 m above the model rating.
Following the calibration, the hydraulic model has been run with flows ranging from 0.5 to 127m^3/s using the unsteady state solver in ISIS and a triangular shape hydrograph. A rating curve (Q-H) was then extracted from the model results at the gauging station location (ISIS node CLAU_0312u).

Analysis and Results:

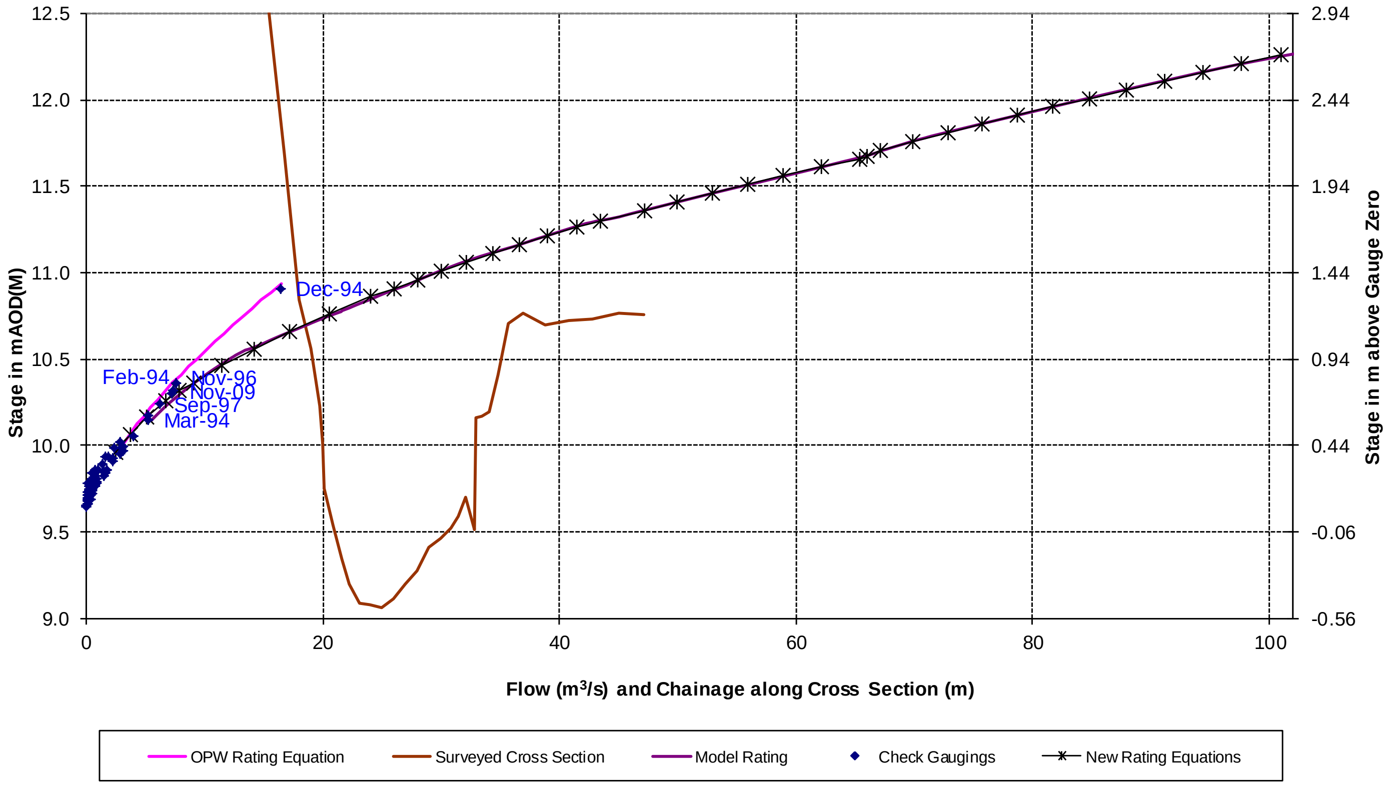
The model rating has only been compared to check gaugings since the local channel works occurred at the gauge in July 1993, as OPW stated that they were significant works that changed the site. It is clear from plotting all the gaugings at the site that there is a clear datum shift and change in stage-discharge relationship after July 1993.

OPW has confirmed that the data prior to July 1993 was deemed to have a poor rating, which is supported by the wide scatter in older check gaugings and lack of high flow gaugings in the period 1972-1993. It is recommended that the AMAX flow series before 1994 is not used for estimating QMED or for flood frequency analysis.

The model rating curve deviates from the existing OPW rating curve significantly at flows above 8 m^3/s. The upper part of the existing OPW rating is based on one high flow gauging (December 1994). This gauging was undertaken by EPA who could not provide any commentary on the accuracy of this measurement.

With the Jacobs model rating deviating from the December 1994 check gauging there is some doubt about the model rating. Hydraulic modelling of design events undertaken as part of the CFRAM flood mapping study using the Jacobs model rating suggests that the model rating results in overestimated flood depths and flood extents in the Claureen model extent, whilst the OPW rating results in more realistic flood depths and extents. It is therefore recommended that the OPW rating be retained. The OPW rating was adopted for the CFRAM flood mapping.

As the high flow rating is only based on one gauging in 1994, it is strongly recommended that further high flow gaugings are collected for this station.



Summary, Conclusions and Recommendations:

A stable model was created, calibrated to observed check gaugings and run to provide the flow-level relationship (rating) at the gauge board. A set of rating equations were established which result in a good fit with the model rating in the stage interval 0.40<W<2.70m. However, the model rating failed to fit to the highest recorded check gauging therefore raising doubt about the accuracy of the model rating. Therefore, the OPW AMAX series has been retained and can be used for QMED estimation.

It is recommended that the AMAX data before 1994 is not used for flood estimation purposes.

It is recommended that with only one high flow gauging completed at this site, further check gaugings be conducted to confirm the high flow rating.

27011 – OWENOGARNEY AT OWENOGARNEY BRIDGE

Date of data collation: 09/01/2012, completed 21/03/2014.

Introduction:

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

Gauging Station Description:

Owenogarney gauging station is located at a railway bridge at the southern edge of Sixmilebridge. The gauging station is located on the left bank, with access to the site via a field immediately south of the cemetery in Sixmilebridge. The gauging station has a natural channel control with a stable section and vertical concrete walls up to around 0.8m above bed level.

Gauging Station Details:

Station Type	Recorder	**Gauging Authority**	OPW
Coordinates	147964, 164870	**Period of Record**	1996-2009 (AMAX)
Existing Rating Curve	Yes	**Validity / Upper Limit**	W < 2.6m (~28.3m^3/s; pre-rating review)

QMED synthetic	22.2 m^3/s
QMED (AMAX, pre rating review)	15 m^3/s (14 years)

Gauge Zero (from operator)	4.49 mAOD (Poolbeg)
Gauge Zero (from survey)	1.79 mAOD (Malin)

The rating equations at Owenograney have not been revised as the OPW rating equations appear to be a better representation of the site.

Hydraulic Model Details:

Hydraulic Model Name: 27011_Owenogarney_GS_cal18.DAT

A one dimensional hydraulic model of the River Owenogarney near Owenogarney Railway Bridge was built using river survey data collected by CCS Surveying in November 2011 (P606-OG-XS-001, P606-OG-XS-002, P606-OG-XS-003, P606-OG-XS-004, P606-OG-XS-005, P606-OG-XS-006, P606-OG-XS-007, P606-OG-XS-008 and P606-OG-XS-009) and the ISIS hydraulic modelling software.

The hydraulic model extends for approximately 600m, from 200m upstream of the railway bridge to 400m downstream of the road bridge. The gauging station is located at ISIS node OWEN_3438u in the hydraulic model, which corresponds to the upstream face of the railway bridge. A road bridge is also represented in the model at ISIS node OWEN_3109. The railway bridge is schematised using an USPBR Bridge and the road bridge at OWEN_3109 is schematised using an Arch Bridge and a spill unit to allow for bridge overtopping.

Hydraulic roughness (Manning's n) values used in the model were originally estimated using site visit and survey information. The river bed consists mainly of silt and gravels (n=0.035), while bank side and floodplain roughness values range from n=0.035 to 0.060. A Manning's n of 0.020 has been assigned for roads in the floodplain.

Floodplain areas were represented in the model using extended cross sections as deemed appropriate.

A normal depth boundary unit was used as the downstream boundary condition.

Hydraulic Model Calibration:

Calibration of the hydraulic model has been carried out using the check gauging data provided by OPW. The gauging station has a natural channel control. The railway bridge does not act as a control, therefore the bed roughness coefficient was the only coefficient adjusted during the calibration. The bed roughness coefficient was gradually varied from 0.035 to 0.042, where a good agreement was found between the modelled water level at the gauging station and the check gauging levels at medium flows. However, it should be noted that at high flows the modelled water level are underestimating the check gauging water levels. A better fit could not be established within realistic ranges of the roughness coefficient.

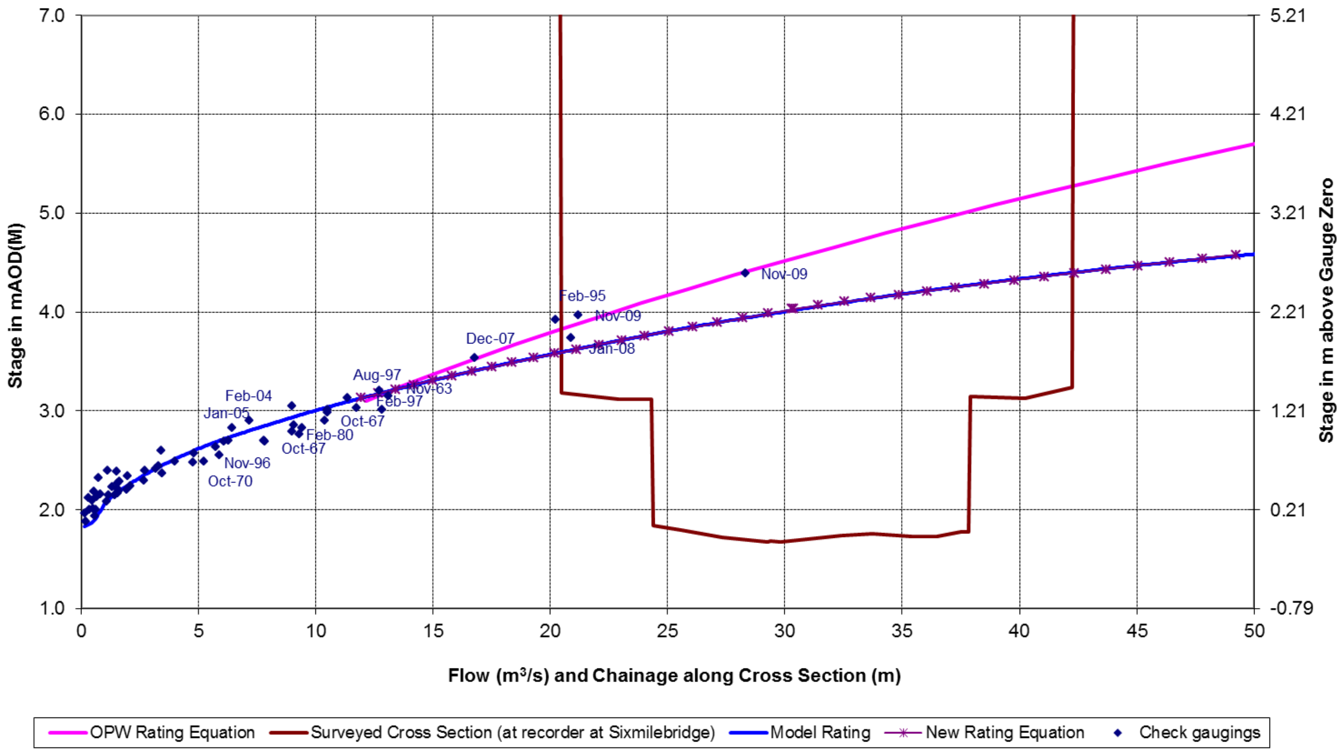
Once calibrated, the hydraulic model has been run with flows ranging from 0.8 to 87 m^3/s using the unsteady state solver in ISIS and a triangular shape hydrograph. The model showed no particular instabilities and a flow-level relationship (rating) has been extracted from the model results at the rating section (chainage 3438m).

Analysis and Results:

The model rating seems to correlate well with all the sites check gaugings up to QMED (15 m^3/s). However, for flows greater than QMED the model rating diverges away from the check gaugings. The OPW rating fits well to the majority of high flow gaugings and is confirmed by these gaugings up to 1.8xQMED. As the highest check gaugings were taken recently (November 2009), it is recommended that the rating at this site is not revised for high flows and the most recent OPW rating should continue to be used.

It is noted that OPW's Hydro-Data web-database reports that the AMAX series from 2005 to 2012 are tidal peaks. The AMAX data received from OPW came with the comment that '*fluvial peaks are estimated from semi-tidal hydrographs*'. Therefore the AMAX series should be treated with caution if it is used at all. The lack of scatter in the check gaugings suggests that these were collected during periods of low tide, and the original rating is therefore believed to be representative during low tides. The estimate of QMED excluding the data from 2005 to 2012 is similar to the estimate including that data (both 15 m^3/s).

The station only has level and flow AMAX data from 1996 when drainage works were completed local to the station. Given the fact that OPW have reported that the AMAX flows may be affected by the tide it is recommended that this data is not used for QMED estimation or flood frequency analysis.



Summary, Conclusions and Recommendations:

A stable model was created and calibrated to observed check gaugings. The model fitted well with check gauging up to QMED, but deviated significantly for flows above QMED. Based on the fact that the existing OPW rating has check gaugings to verify the rating up to 1.8xQMED, including two completed in 2009, the OPW rating should continue to be used at this station.

Given the fact that OPW have reported that the AMAX flows may be affected by the tide it is recommended that the AMAX data at this station is not used for QMED estimation or flood frequency analysis.

Appendix D Gauging Station Information Sheets

Table of Content

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.

27001 – CLAUREEN AT INCH BR.

Annual Maxima Series

Hydrological Year	Existing Flow (m^3/s)	Revised Flow (m^3/s)	Date
1946			
1947			
1948			
1949			
1950			
1951			
1952			
1953			
1954			
1955			
1956			
1957			
1958			
1959			
1960			
1961			
1962			
1963			
1964			
1965			
1966			
1967			
1968			
1969			
1970			
1971			
1972	21.2		12/11/1972
1973	26.7		29/11/1973
1974	19.9		22/01/1975
1975	21.4		09/01/1976
1976	15.8		12/10/1976
1977	21.4		21/04/1978
1978	23.2		15/11/1978
1979	21.8		04/09/1980
1980	18.5		14/11/1980
1981	22.6		18/06/1982
1982	20.3		14/12/1982
1983	20.2		09/12/1983
1984	24.7		14/08/1985
1985	31.4		06/08/1986
1986	21.3		18/11/1986
1987	18.1		14/08/1988
1988	19.2		11/04/1989
1989	19.5		23/01/1990
1990	14.6		24/02/1991
1991	31.7		05/01/1992
1992	14.8		21/11/1992
1993	N/A		N/A
1994	23.3	41.4	27/01/1995
1995	21.1	36.9	26/10/1995
1996	20.0	33.5	04/08/1997
1997	18.5	31.3	06/03/1998
1998	18.2	30.6	21/10/1998
1999	19.8	34.4	24/12/1999
2000	18.5	31.5	26/10/2000
2001	17.0	28.0	19/02/2002
2002	17.9	30.0	29/10/2002
2003	18.1	30.6	15/01/2004
2004	23.0	42.0	07/01/2005
2005	22.4	40.7	21/09/2006
2006	21.6	38.7	26/10/2006
2007	20.0	34.8	06/12/2007
2008	24.4	46.0	23/08/2009
2009	26.8	52.6	19/11/2009

Gauging Authority: Office of Public Works	
Easting: 130159	**Northing:** 175321
Catchment: Fergus	**Telemetry:** Yes
Station Type: Recorder	**Catchment Area:** 46.70 km^2

QMED (gauged): 20.30 m^3/s	**AREA:** 46.70 km^2
QMED (synthetic urban): 32.00 m^3/s	**SAAR:** 1477 mm
QMED (CFRAM revised): 34.58 m^3/s (1994 to 2009)	**FARL:** 0.99
BFIsoils: 0.33	**S1085:** 4.45 m/km
URBEXT: 0 %	**ARTDRAIN2:** 8.0 %
DRAIND: 1.79	

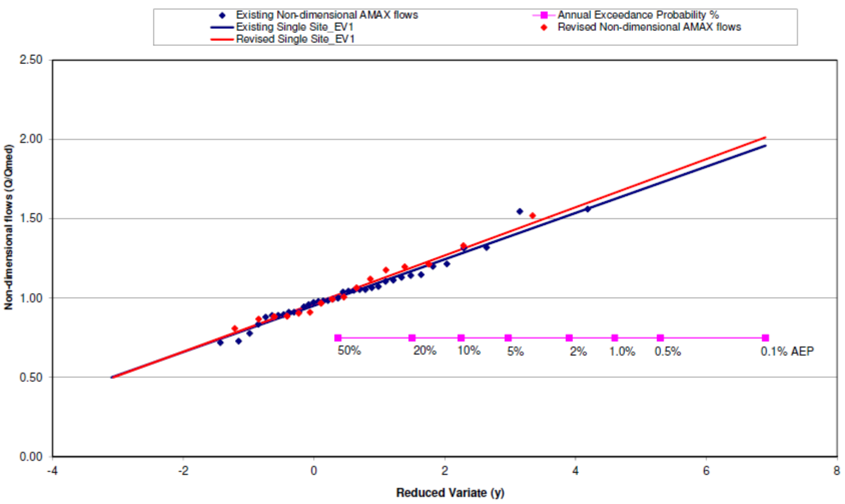
Comments:
Automated velocity-area station installed in 1939 and automated in 1957. Unstable gravel bed. Natural channel control. Channel works undertaken in July 1993.

Catchment descriptors from FSU.

Nearby AFAs: Ennis

Jacobs Rating Review: Yes	**FSU Station Classification:** A2

Flood Frequency (EV1 with Gringorten plotting positions)



Length of AMAX series: 37 years
CFRAM Revised: 16 years

OPW has confirmed that the data prior to channel works undertaken in July 1993 was deemed to have a poor rating. A revised AMAX series from 1994 to present based on the revised rating equations is used for estimating QMED. Further information can be found on the CFRAM Rating Review Summary Sheet for this station.

Gauging Hut

Picture not available

Channel looking upstream

Picture not available

Channel looking downstream

Picture not available

Structure Details	
Type of Structure:	N/A
Condition of structure	N/A

Gauging Station location description	At Inch Bridge on the R474, 2km SW of Ennis. Gauging station is located on the left bank on the upstream side of the bridge. Data logger and cabinet are located on downstream side of bridge.
Describe potential for flow bypassing gauging station	No bypassing on either bank. All flow channelled through bridge due to high ground on left bank, and slightly raised road level, with adjacent wall, on right bank.
Describe **left** bank **upstream** condition	Left bank has tree cover and rises sharply away from the river. No flood plain.
Describe **right** bank **upstream** condition	Grassed flood plain on right bank around 1.5m to 2m above estimated river bed level.
Describe **left** bank **downstream** condition	Grassed flood plain on left bank, elevated approximately 2m above river bed level. River bank has some trees.
Describe **right** bank **downstream** condition	Flood plain restricted on right bank, bound by the road around 20-30m from the river. There is also a wall at the edge of the road restricting the floodplain. River bank and land between river and road has some trees.

27002 – FERGUS AT BALLYCOREY

Annual Maxima Series

Hydrological Year	Existing Flow (m^3/s)	Revised Flow (m^3/s)	Date
1946			
1947			
1948			
1949			
1950			
1951			
1952			
1953			
1954	39.60		12/12/1954
1955	23.60		30/01/1956
1956	33.60		05/01/1957
1957	31.80		04/11/1957
1958	21.30		07/01/1959
1959	59.80		30/12/1959
1960	39.10		08/02/1961
1961	32.40		13/12/1961
1962	23.90		16/12/1962
1963	31.30		28/11/1963
1964	40.00		16/12/1964
1965	32.10		18/12/1965
1966	28.80		01/03/1967
1967	33.00		24/10/1967
1968	40.50		27/12/1968
1969	30.70		25/12/1969
1970	29.60		19/11/1970
1971	25.60		28/01/1972
1972	34.10		14/12/1972
1973	34.90		15/09/1974
1974	42.10		29/01/1975
1975	31.30		06/12/1975
1976	25.40		11/02/1977
1977	35.00		14/11/1977
1978	27.00		17/12/1978
1979	36.80		18/12/1979
1980	30.30		22/12/1980
1981	29.80		17/03/1982
1982	34.70		21/12/1982
1983	37.80		09/02/1984
1984	26.70		20/08/1985
1985	29.70		26/01/1986
1986	35.30		20/12/1986
1987	33.90		06/02/1988
1988	25.70		25/03/1989
1989	43.40		12/02/1990
1990	39.80		05/01/1991
1991	32.60		11/01/1992
1992	31.50		08/12/1992
1993	46.20		23/12/1993
1994	53.60		01/02/1995
1995	23.20		31/10/1995
1996	30.90		26/02/1997
1997	37.10		09/01/1998
1998	36.60		05/01/1999
1999	53.60		27/12/1999
2000	35.80		02/11/2000
2001	42.00		11/02/2002
2002	31.20		14/11/2002
2003	28.80		17/01/2004
2004	36.30		13/01/2005
2005	30.00		27/09/2006
2006	50.50		22/12/2006
2007	55.80		23/01/2008
2008	39.80		26/01/2009
2009	79.40		24/11/2009

Gauging Authority: Office of Public Works	
Easting: 134431	**Northing:** 180323
Catchment: Fergus	**Telemetry:** Yes
Station Type: Recorder	**Catchment Area:** 511.50 km^2

QMED (gauged): 33.75 m^3/s	**AREA:** 511.50 km^2
QMED (synthetic urban): 40.56 m^3/s	**SAAR:** 1341 mm
QMED (CFRAM revised):	**FARL:** 0.82
BFIsoils: 0.67	**S1085:** 1.05 m/km
URBEXT: 0.09 %	**ARTDRAIN2:** 0%
DRAIND: 0.59	

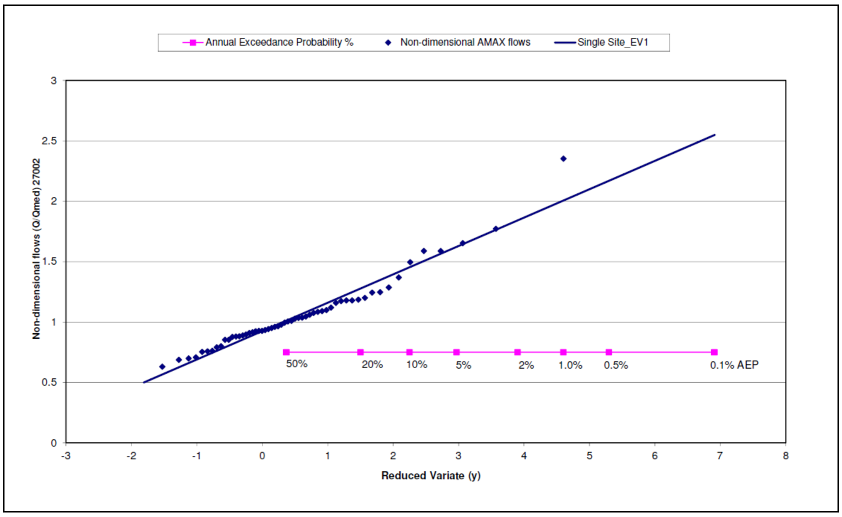
Comments:
Velocity-area station installed in 1940 and automated in 1954. Flat V crump weir acts as control. Stable bed, negligible weed growth

Catchment descriptors from FSU.

Nearby AFAs: Ennis

Jacobs Rating Review: No | **FSU Station Classification:** A1

Flood Frequency (EV1 with Gringorten plotting positions)



Length of AMAX series: 56 years
CFRAM Revised: years

The original rating is not revised at this station. Therefore, the original AMAX is not revised.

Gauging Hut

Picture not available

Channel looking upstream

Picture not available

Channel looking downstream

Picture not available

Structure Details	
Type of Structure:	N/A
Condition of structure	N/A

Gauging Station location description	N/A
Describe potential for flow bypassing gauging station	N/A
Describe **left** bank **upstream** condition	N/A
Describe **right** bank **upstream** condition	N/A
Describe **left** bank **downstream** condition	N/A
Describe **right** bank **downstream** condition	N/A

27011 – OWENOGARNEY AT OWENOGARNEY (RLY) BR.

Annual Maxima Series

Hydrological Year	Existing Flow (m^3/s)	Revised Flow (m^3/s)	Date
1946			
1947			
1948			
1949			
1950			
1951			
1952			
1953			
1954			
1955			
1956			
1957			
1958			
1959			
1960			
1961			
1962			
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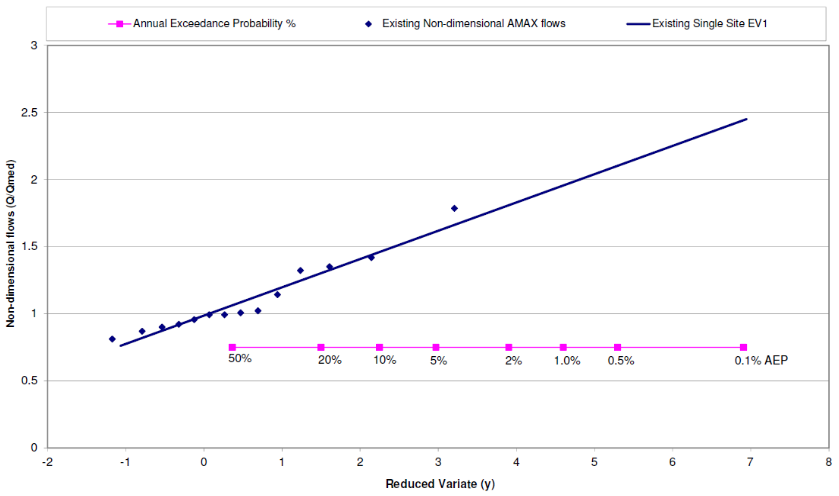
1981			
1982			
1983			
1984			
1985			
1986			
1987			
1988			
1989			
1990			
1991			
1992			
1993			
1994			
1995			
1996	14.12		05/08/1997
1997	15.21		08/01/1998
1998	13.32		15/01/1999
1999	21.73		09/12/1999
2000	15.21		06/11/2000
2001	15.66		18/01/2002
2002	12.44		10/11/2002
2003	13.79		15/01/2004
2004	20.70		08/01/2005
2005	14.66		13/01/2006
2006	15.43		12/10/2006
2007	20.26		23/01/2008
2008	17.51		25/10/2008
2009	27.35		23/11/2009

Gauging Authority: Office of Public Works	
Easting: 147964	**Northing:** 164870
Catchment: Owenogarney	**Telemetry:** Yes
Station Type: Recorder	**Catchment Area:** 161.80 km^2

QMED (gauged): 15.32 m^3/s	**AREA:** 161.80 km^2
QMED (synthetic urban): 22.27 m^3/s	**SAAR:** 1240 mm
QMED (CFRAM revised): N/A	**FARL:** 0.80
BFIsoils: 0.65	**S1085:** 7.63 m/km
URBEXT: 0.485 %	**ARTDRAIN2:** 0.8 %
DRAIND: 1.11	
Comments:	
Nearby AFAs: Sixmilebridge, Bunratty	
Jacobs Rating Review: Yes	**FSU Station Classification:** N/A

Flood Frequency (EV1 with Gringorten plotting positions)



Length of AMAX series: 14 years
CFRAM Revised: N/A

The rating equations at Owenogarney have not been revised as the OPW rating equations have been confirmed by check gaugings for design flows up to 1.8xQmed.

Gauging Hut

Picture not available

Channel looking upstream

Picture not available

Channel looking downstream

Picture not available

Structure Details	
Type of Structure:	Natural channel section. Section is stable, and has vertical concrete walls up to around 0.8m above bed level.
Condition of structure	Bridge condition not required

Gauging Station location description	Owenogarney gauging station is located at a railway bridge at the southern edge of Sixmilebridge. The gauging station is located on the left bank, with access to the site via a field immediately south of the cemetery in Sixmilebridge.
Describe potential for flow bypassing gauging station	No bypassing on either bank. All flow channelled through Railway Bridge due to railway embankments crossing floodplain leading to the railway bridge.
Describe **left** bank **upstream** condition	Embankment in place 1-1.5m above surrounding ground level. Surrounding areas is flood plain, but cut-off by railway embankment at the GS section. Grassed floodplain (with some marsh vegetation).
Describe **right** bank **upstream** condition	No embankment on right bank. Floodplain assumed to be similar in general to left bank, although it is obscured by trees along much of its length in this area.
Describe **left** bank **downstream** condition	Not visible downstream of railway bridge (difficult to access).
Describe **right** bank **downstream** condition	Flood plain grassed, and slightly higher than upstream floodplain.

Appendix E Flood Frequency Curves

Table of Content

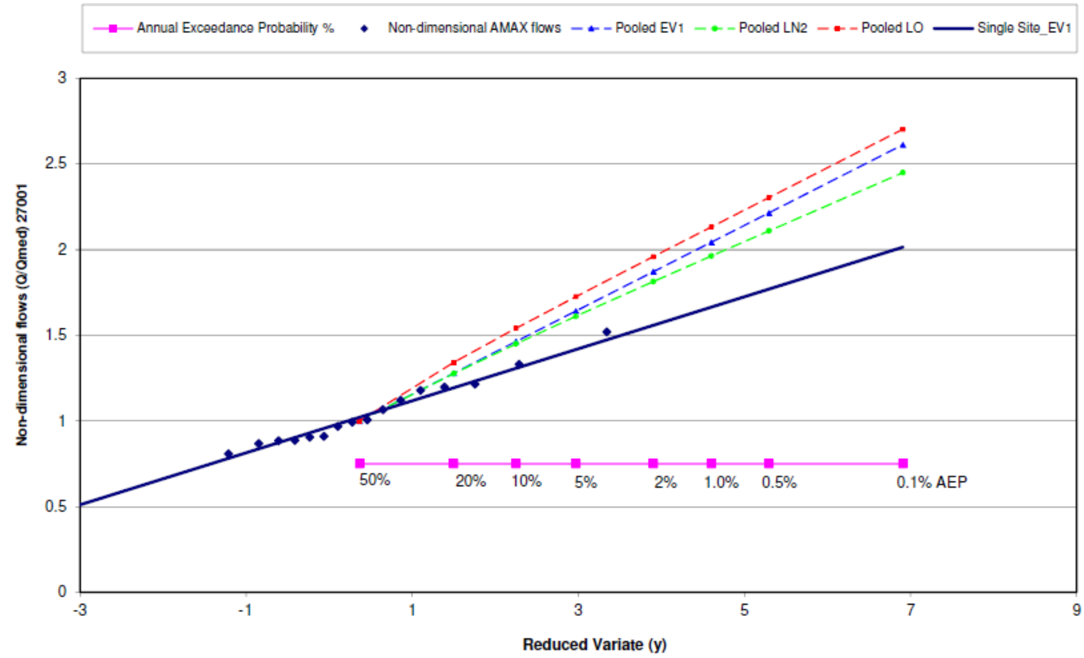


Figure E.1 Inch Bridge (27001) Flood Frequency Curves

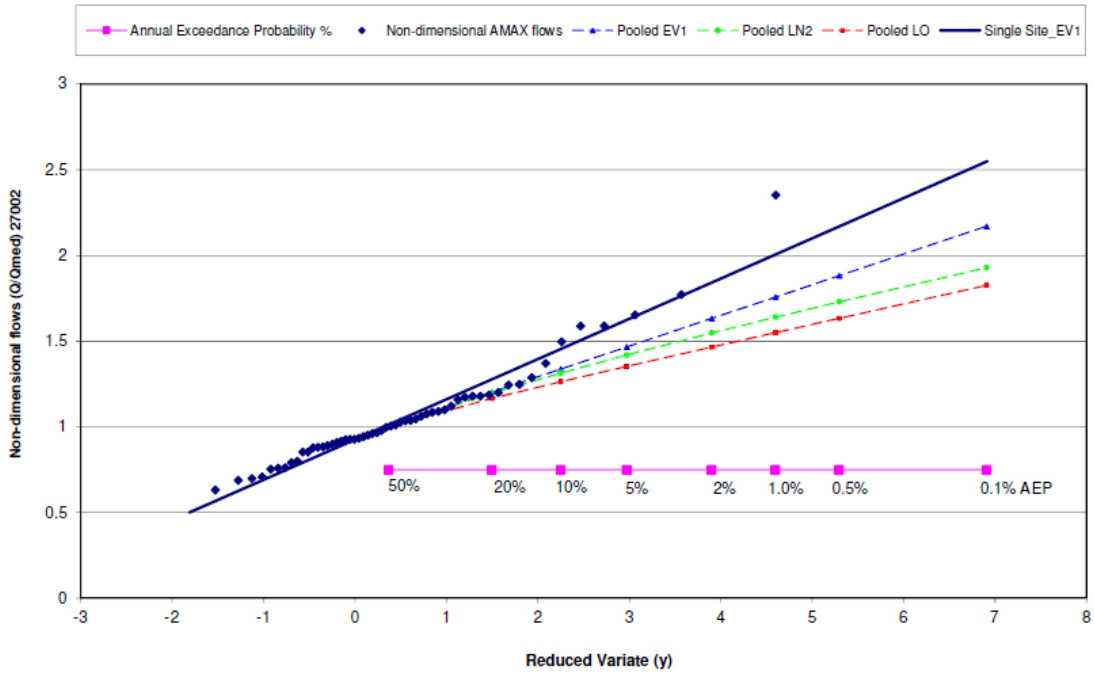


Figure E.2 Ballycorey (27002) Flood Frequency Curves

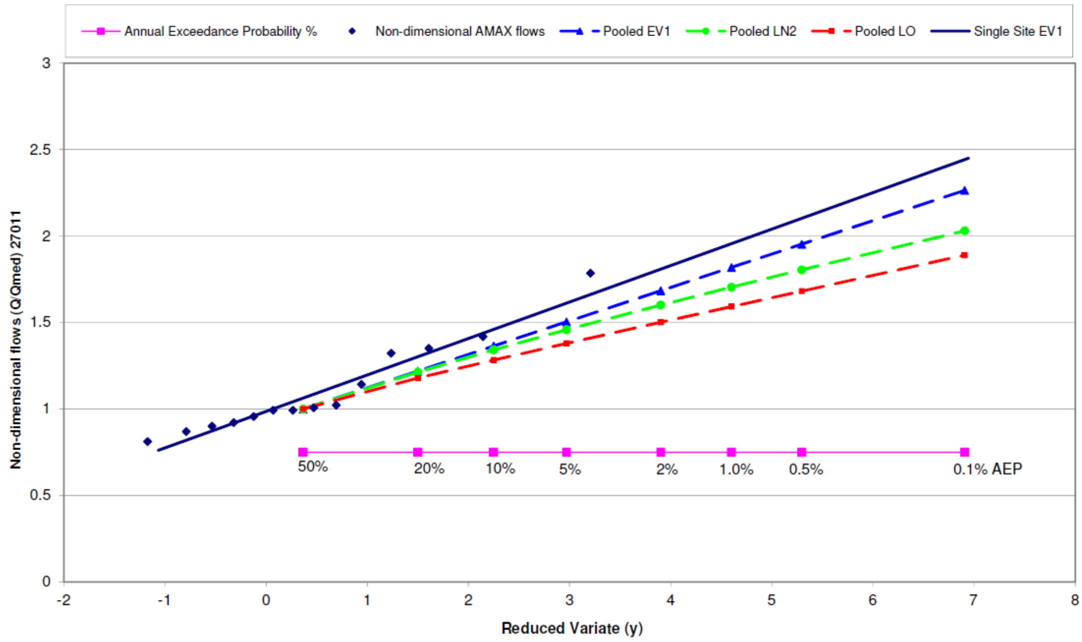


Figure E.3 Owenogarney (27011) Flood Frequency Curves (for reference only)

Appendix F Calibration Strategy Sheets

Table of Content

Phase 1			
Shannon CFRAM Study Calibration Information Refer to technical note TD041			
Model No.	**S01 (a,b,c)**	Length	57.3km
Unit of Management		27	
AFA	Ennis		
IRRs	none		
River / Catchment / Sub-catchment	River Fergus, Claureen and Gaurus / Fergus Estuary / Shannon		
Type of Flooding / Flood Risk	Fluvial non-tidal ☒ Fluvial tidal ☒ Coastal ☐		
Comments	Model reach S01(a, b, c) includes the River Fergus and its tributaries - River Claureen, River Gaurus - and a number of smaller tributaries. All three named watercourses flow through Ennis before discharging to the Fergus Estuary south of the AFA. The entire modelled reach, other than a small estuarine section within section S01c, is categorised as a HPW.		
Completed by	Kenny Samson		
Date	09/09/2013		

Potential flood events to consider for fluvial calibration or verification

No	Description*	Category **(TD041)	Score (TD041)	Calibration or verification
F.1	19th to 21st November 2009 Ennis Flooding. 112 houses affected in Ennis. (***FQC = 3)	1	2+2+2+2+2=10	Calibration
F.2	December 1999 Ennis Flooding. Properties and roads flooded at various locations in Ennis. (***FQC = 1)	1	2+2+2+2+2=10	Verification
F.3	January/February 1995: Severe flooding in Ennis town centre and Fergus Park. Properties in Fergus park flooded. Levels given at Courthouse; Fergus Park; Western Garage; Harry's Lawnmowers. Time of recording not indicated. (***FQC = 2)	1	2+2+0+1+1=6	Verification
F.4	December 2006 Fergus, Ennis Flooding. (***FQC = 2)	1	2+2+0+1+1=6	Verification
F.5	Gauge Data Only - In-bank event – Qmed	1	To be identified in Phase 2	Calibration/verification
F.6	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))
***FQC = Flood Quality Code (Refer to Appendix E)

Potential flood events to consider for tidal calibration or verification

No	Description*	Category **(TD041)	Score (TD041)	Calibration or verification
T.1	20th November 2009 tidal flooding (1st largest AMAX @ Station 27066 – Ennis Bridge)	1		Calibration
T.2	25th December 1999 tidal flooding (2nd largest AMAX @ Station 27066 - Ennis Bridge)	1		Verification
T.3	31st January 1995 tidal flooding (3rd largest AMAX @ Station 27066 - Ennis Bridge)	1		Verification
T.4	11th February 2002 tidal flooding (4th largest AMAX @ Station 27066 - Ennis Bridge)	1		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))
***FQC = Flood Quality Code (Refer to Appendix E)

Gauging Station Information within Model Extent (or close to)

Station	Data Length	Type (flow, stage, both)	Gaugeboard Datum (mAOD Malin/Poolbeg)[2]	FSU Classification*	Comment
27001 Inch Bridge	1972 - Present	Level and Flow	12.261 (P)	A2	Requires Jacobs rating review. Recent rating reliable only to 0.81XQmed
27002 Ballycorey	1954 - present	Level and Flow	7.06 (P)	A1	Reliable high flow rating
27023 Victoria Bridge	2002 - Present	Level Only	2.99 (M)	Not FSU Classified	Water Level Data only
27024 Mill Bridge	2002 - Present	Level Only	Not found within the survey data	Not FSU Classified	Water Level Data only
27025 Knoxs Bridge	2002 - Present	Level Only	Not found within the survey data	Not FSU Classified	Water Level Data only
27026 Tulla Road Bridge	2002 - present	Level Only	0.97 (M?)	Not FSU Classified	Water Level Data only
27028 Gaurus Bridge	2002 - Present	Level Only	2.04 (M?)	Not FSU Classified	Water Level Data only
27060 Doora Bridge	2002 - Present	Level Only	-1.04	Not FSU Classified	Water Level Data only
27064 CLARECASTLE U/S	1947 – 1990[1]	Level Only	Gauge 1 = 0.90	Not FSU Classified	Water Level Data only
27065 Clarecastle D/S[1]	1950 – 1990[1]	Level Only	Gauge 2 = 0.99	Not FSU Classified	Water Level Data only

27066 Ennis Bridge	1980 - Present	Level Only	3.68 (P)	Not FSU Classified	Water Level Data only
27068 Clarecastle Bridge	2002 - Present	Level Only	Gauge 2 = 0.99	Not FSU Classified	Water Level Data only
27092 Gaurus Landfill	2002 – Present	Level Only	Gauge 2 = 0.99	Not FSU Classified	Water Level Data only

* See Appendix D for Key to FSU Station Classification A1 (Good) to C (Poor)
[1] Although the EPA hydrometric stations table suggests that recording at these stations ended in 1990, Jacobs was provided with level records for these stations from 2002 to present.
[2] (M) and (P) refer to Malin and Poolbeg datums. In some instances the source information did not include the datum (M or P), shown in the table as (M?), in which case the modeller is asked to confirm the datum.

Control structures

Reference	Type	Description

Conclusions from Phase 1

Phase 1 suggested – fluvial calibration:

For the fluvial calibration, records of historic floods in the study catchment were searched at various sources including the National Hazard Mapping website www.floodmaps.ie .

Due to flood relief works within the River Fergus catchment in 1993 only events since 1993 are considered.

Events F.1 – F.4 appear to have sufficient flood level observations available for fluvial calibration or verification.

The calibration/verification strategy will be based on the inflows for each of the calibration/verification events from the two gauging stations, namely, Inch Bridge (Station 27001) and Ballycorey (Station 27002). The water levels at the flooding locations and at the downstream gauges can be compared for the calibration and verification of the model. As tidal water levels may affect water levels in Ennis for some or all events it may be important to have accurate level data for the downstream model extent.

Tidal water levels at the downstream end of the model are only available from 2002.

If tidal water levels affect flood levels at the level gauges in Ennis and downstream of Ennis, then event based calibration/verification can only be undertaken for events from 2002 onwards (Events F.1-Nov 2009 and F.4-Dec 2006)

Only two stations (27001 & 27002) have both flow and / level data, the remaining stations recording levels only. Corresponding flood levels/water levels at the downstream locations/gauges were compared with the model predicted levels for the corresponding events.

Phase 1 suggested – Tidal calibration:

For the tidal calibration/verification, four largest tidal AMAX from the top five events available at a tidal gauge in the modelling extent were identified. It is observed from above tidal event that the three largest tidal events are the same as the three largest fluvial events. The fourth largest tidal event was that of February 2002. Gauged level data in the Shannon Estuary are only available from summer 2002.

Based on the availability of 15-min time series, the following events were finally selected for tidal calibration and verification:

Calibration: November 2009 event for which data available at 27060, 27064, 27065, 27066 and 27068

Verification: December 2006 event for which data available at 27060, 27064, 27065 & 27068.

Phase 2

Gauging Station Information Used – for fluvial calibration

**Location	Upper model reach.			
Type	Calibration (1)	Calibration (1)	Verification (2)	Verification (2)
Flood Event	24/11/2009	24/11/2009	27/12/1999	27/12/1999
GS Number	27001	27002	27001	27002
Station Name	Inch Bridge	Ballycorey	Inch Bridge	Ballycorey
Approximate Start of peak level	17/11/2009 @ 20:00	16/10/2009	24/12/1999	21/11/1999
Approximate Finish of peak level	21/11/200 @ 00:00	26/12/2009	26/12/1999	28/01/2000
Peak level*** (mAOD Malin)	10.75 (M)	7.085(M)	11.11(M)	9.35 (P?)
Peak flow (m^3/sec)	13.30 (23/11/2009 @ 13:30)	80.6 (24/11/2009 @ 05:45)	19.74 (25/12/1999 @ 00:45)	53.63
Other gauging stations for same event	Victoria Bridge (GS 27023) = 5.531mOD (M), Ennis Bridge (GS 27066) = 6.39mOD (P), 20/11/2009 09:00		Doora Bridge (GS 27060) = 2.85mOD (M); Gaurus Floodplain (27092) = 2.7mOD (M); Parnell Street = 3.85mOD (M); Victoria Bridge (27023) = 5.2mOD (M); Auburn Lodge = 5.7mOD (M); Ennis Bridge (27066) = 6.13 (P)	
**Location				
Type	Verification (3)	Verification (3))	Verification (4)	Verification (4)
Flood Event	01/02/1995	01/02/1995	22/12/2006	22/12/2006
GS Number	27001	27002	27001	27002
Station Name	Inch Bridge	Ballycorey	Inch Bridge	Ballycorey
Approximate Start of peak level	30/01/1995	15/01/1995	14/12/2006 @ 00:00	15/11/2006
Approximate Finish of peak level	01/02/1995	15/02/1995	15/12/2006 @ 23:45	31/12/2006
Peak level*** (mAOD Malin)	11.06(M) 31/01/1995 @ 09:00	6.64 (M) 01/02/1995 @ 15:30	10.477 (M) 14/12/2006 @ 17:30	6.39 (M) 12/12/2006 @ 08:30
Peak flow (m^3/sec)	19.34	53.81	8.95	50.55
Other gauging stations for same event	Ennis Bridge (27066) = 6.02 (P) on 31/01/1995		Victoria Bridge = Max of 5.2(M) Mill Bridge = Max of 3.70 (M?)	

*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 (Fluvial Calibration / Verification)

Discussion

- Ennis is the only AFA within the extent of model S01 and (other than a small estuarine section along the lower Rine) is categorised a HPW.
- Due to the nature of the catchment, the River Fergus (as gauged at station 27002) has a longer response time than the River Claureen (as gauged at 27001). Based on the events for which gauged data is available for both rivers, typically the flood peak at the Fergus arrives approximately 5 days after the flood peak on the Claureen.
- From the thirteen stations identified in Phase 1; two stations (27064 & 27065) are inactive and only four stations (27001 / 27002 / 27023 / 27024) are reported as being unaffected by tidal influences (see report 28-2b).
- Due to drainage works events of before 1993 have not been considered.
- It has been confirmed in Phase 2 that tidal water levels affect the flood levels in Ennis. It will therefore only be possible to calibrate/verify the model to events for which downstream boundary tidal water levels are available. This data is only available for events from 2002 onwards.

Calibration/Verification Strategy

- Events 1 (Nov 2009) and 4 (Dec 2006) can be used for fluvial calibration/verification. These events were combined fluvial/tidal events.
- Apart from gauged data to calibrate the model, extensive aerial and ground-based photography for the Nov 2009 event can be used to verify the model. This information is less suitable for calibration as the accuracy of level estimates based on photographs is generally too low.
- It is proposed that stations 27001, 27002, 27023 and 27066 are used for calibration of the S01 model using the November 2009 event, and verification using the December 2006 event. The tidal boundary data can be obtained from the Carrigaholt tidal level gauge.

Discussion and Strategy (Tidal Calibration / Verification)

Discussion

A number of stations (27060, 27064, 27065, 27066, 27068) recording tidal water levels exist within the S01 model extent. With the exception of station 27066, all stations successfully recorded data during the flood events of November 2009 and December 2006, identified suitable for calibration/verification.

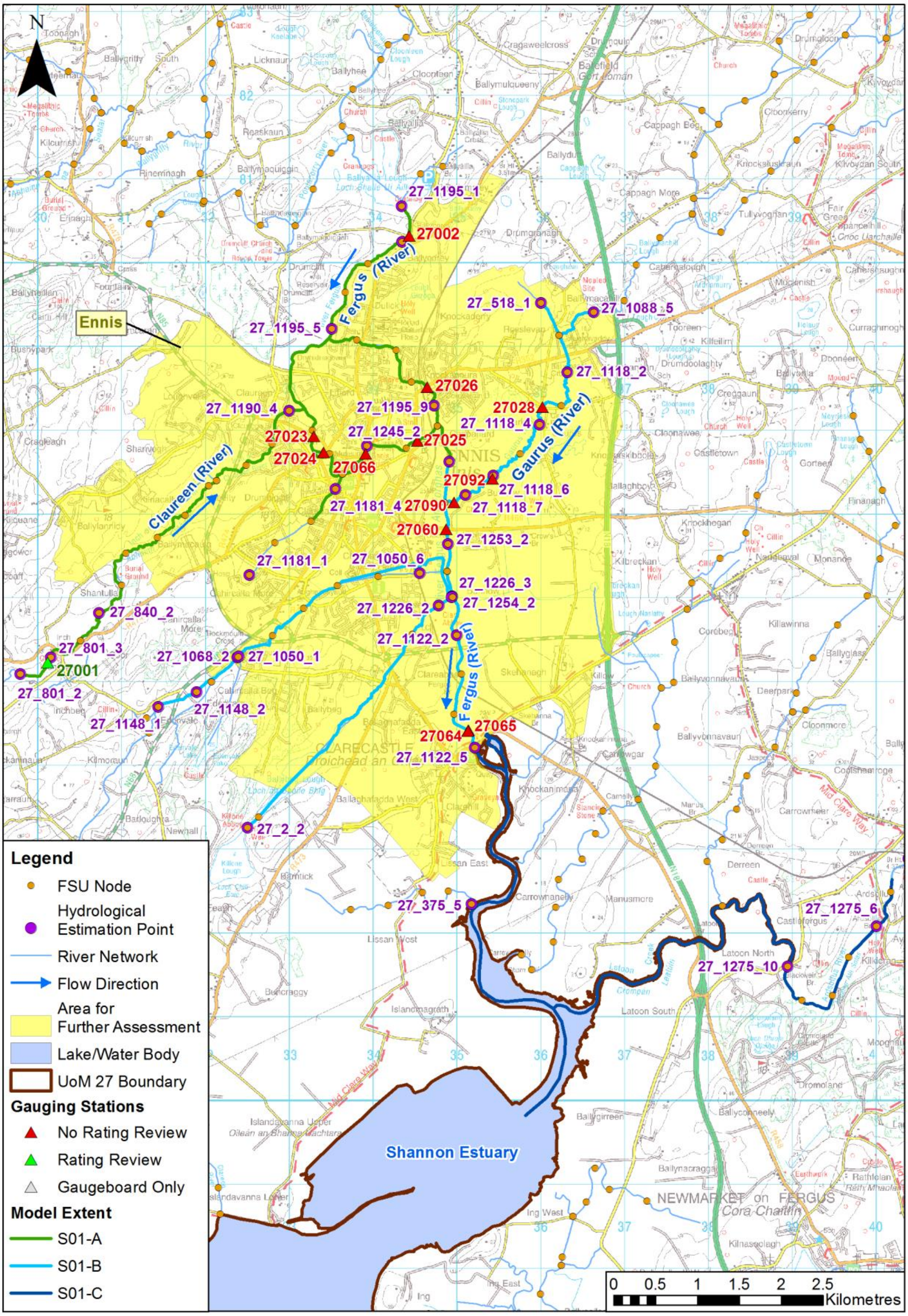
Calibration/Verification Strategy

Calibration: November 2009 event for which data available at 27060, 27064, 27065, 27066 and 27068

Verification: December 2006 event for which data available at 27060, 27064, 27065 & 27068.

The tidal boundary data can be obtained from the Carrigaholt tidal level gauge.

Appendix A - Plan of model S01a/b/c



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: ☐ *No Coverage: ☒ Flooding indicated at Ballyalia Lough upstream of station 27002 – outwith model extent.
	GIS Layer	B-0020	Digitisation of 1954 flood event. *Coverage: ☐ *No Coverage: ☒
	GIS Layer	B-0054	Jacobs digitisation of 2009 flood event. *Coverage: ☒ *No Coverage: ☐
	floodmaps.ie GIS layer	A-0171	Revised GIS layers showing the areas of Benefiting lands. (Unable to view layer, however the National Flood Hazard Mapping tool indicates that land classed as benefiting lands for flood risk management exist around the area of Clarecastle in the lower estuarine reach of the). *Coverage: ☒ *No Coverage: ☐
F.1 / T.1	.pdf report	B-0063	28-1a. Report describes detailed chronology of flooding events and response by various Public Bodies. Describes detailed information on number of properties flooded and roads affected. (Report includes: Source, Cause)
F.2 / T.2	.pdf report	B-0063	28-2a, 4a, 5a, 9a, 10a (duplicates). PDF report by J.B. Barry and Partners. Reports water levels and estimated peak flow during Dec.1995 & '99 flood events. Levels are given as: 2.85mOD Malin (@Doora bridge), 2.7mOD (@Gaurus floodplain), 4.02mOD (@ Mill Bridge), 3.75mOD (@ Clarecastle), 2.48mOD (lands at Knocknoura & Cappaghard), 3.85mOD (@ Parnell St), 5.7mOD (in the vicinity of Auburn Lodge), 5.2mOD (@ Victoria Bridge (Cusack Rd)), 5.9 to 6.1mOD (@ Clogleagh). An estimated flow of 73 m^3/s was reported on the 25/12/99
F.3 / T.3	.pdf report	B-0063	28-2c. Map with copy of level survey book. Level data based on flood debris marks and information from local people. Ennis Feb 1995 (Includes: Flood Level)

F.4 / T.4	Aerial Photographs.	B-0063	28-11b / 28-11c. Aerial photographs taken on 16/12/2006. Shows extent of flood waters.
All	.msg & .xls	OPW_Data\HA27	15-min Flow / level data and AMAX series for stations 27001 & 27002. 15-min level data at station 27060; 27023; 27024; 27025; 27026; 27028; 27066; 27068
All/ General Verification		A-0160	Photographs and videos taken during UoM 27 site visit. (June 2011).
All/ General Verification	-	B-0038	Photographs of 2009 flood event;
*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 [(1)]**	**Supplementary known, useful flood levels[(2)]**	**Reliable flood history (levels, locations, dates) [(3)]**	**Indicative calibration score (sum of columns 2-6)**	**Calibration comment (with event number)**
Category 1	Large gauged river within an AFA (HPW)	**1(2) 2(2) 3(2) 4(2)**	**1(2) 2(2) 3(2) 4(2)**	**1(2) 2(2) 3(0) 4(0)**	**1(2) 2(2) 3(1) 4(1)**	**1(2) 2(2) 3(1) 4(1)**	**1(10) 2(10) 3(6) 4(6)**	**The suitability of events for calibration are: 1-Source provides chronology and event specific details such as water levels at a number of locations. 2- Detailed report which discusses flooding mechanisms, provides levels at various locations and estimated flows. 3- Source lacks event specific details (i.e. timing, specific location. 4- Source provides aerial photography of flood extent. No flows or levels at specific locations.**
	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.

Table C.1 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 x Q_{med}] and it was felt by the OPW that the ratings provided a reasonable representation of extreme flood events
	A1	Confirmed ratings for flood flows well above Q_{med} with the HGF > than 1.3 x Q_{med} and/or with a good confidence of extrapolation up to 2 x Q_{med}, bankfull or, using suitable survey data, including flows across the flood plain.
	A2	Rating confirmed to measure Q_{med} and up to around 1.3 x Q_{med}. At least one gauging for confirmation and good confidence in the extrapolation.
B		Flows can be estimated up to Q_{med} with confidence. Some high flow gaugings must be around the Q_{med} value.
C		Sites within the classification have the potential to be upgraded to B sites but require more extensive gauging and/or survey information to make it possible to rate the flows to at least Q_{med}.

Table 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 27)

Phase 1				
Shannon CFRAM Study Calibration Information Refer to technical note TD041				
Model No.	**S02**	Length	6.0 km	
Unit of Management	27			
AFA	Quin			
IRRs	none			
River / Catchment	River Rine / Fergus Estuary			
Type of Flooding / Flood Risk	Fluvial non-tidal ☒ Fluvial tidal ☒ Coastal ☐			
Comments	Model S02 extends along the River Rine which flows through the Quin AFA before flowing into the Fergus and then entering the Shannon Estuary. The lower reach of the model is classified as a MPW whilst the upper section is classified as a HPW.			
Completed by	Kenny Samson			
Date	18/11/2013			

Potential flood events to consider for calibration

No	Description*	Category **(TD041)	Score (TD041)	Calibration or verification
1	On 09 March 2006: Boolyree and Rine Rivers at Dangan Bridge/ Brook Lodge - The L8180 floods over a length of 1 km on average twice per year, maximum depth of flooding varies between 450mm to 600mm. Cause is rainfall/ runoff which exceeds the channel capacity of the Quin river causing it to overflow. Land is flooded south of this area and right down to south of Quin.***Flood Quality Code: 4	1	0+0+2+2+1=5	Locations specified are upstream of the model extents and thus not suitable for calibration and verification.
2	Gauge Data Only - In-bank event – Qmed	1	To be identified in Phase 2	Calibration/verification
3	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 18(Suitable for calibration))
***Flood Quality Code (refer to Appendix E)

Gauging Station Information within Model Extent (or close to)

Station	Data Length	Type (flow, stage, both)	Gaugeboard Datum (mAOD Malin)	FSU Classification*	Comment
27021 Ardsolus	Not given	Staff gauge	Not given	No FSU Classification	station located d/s of S02 modelling extent.

* 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 findings:

- Only one station (27021) is present just downstream of the S02 modelling extent, which could not be used for calibrating this model as it is a staff gauge only.
- Only one (recurring) flood event is reported on *floodmaps.ie* however this is located upstream of the model extent.

The event information is outside the model domain, and there is no flow or level gauge near it.

Phase 2

Gauging Station Information Used – Out of Bank* - Not possible as no hydrometric data received.

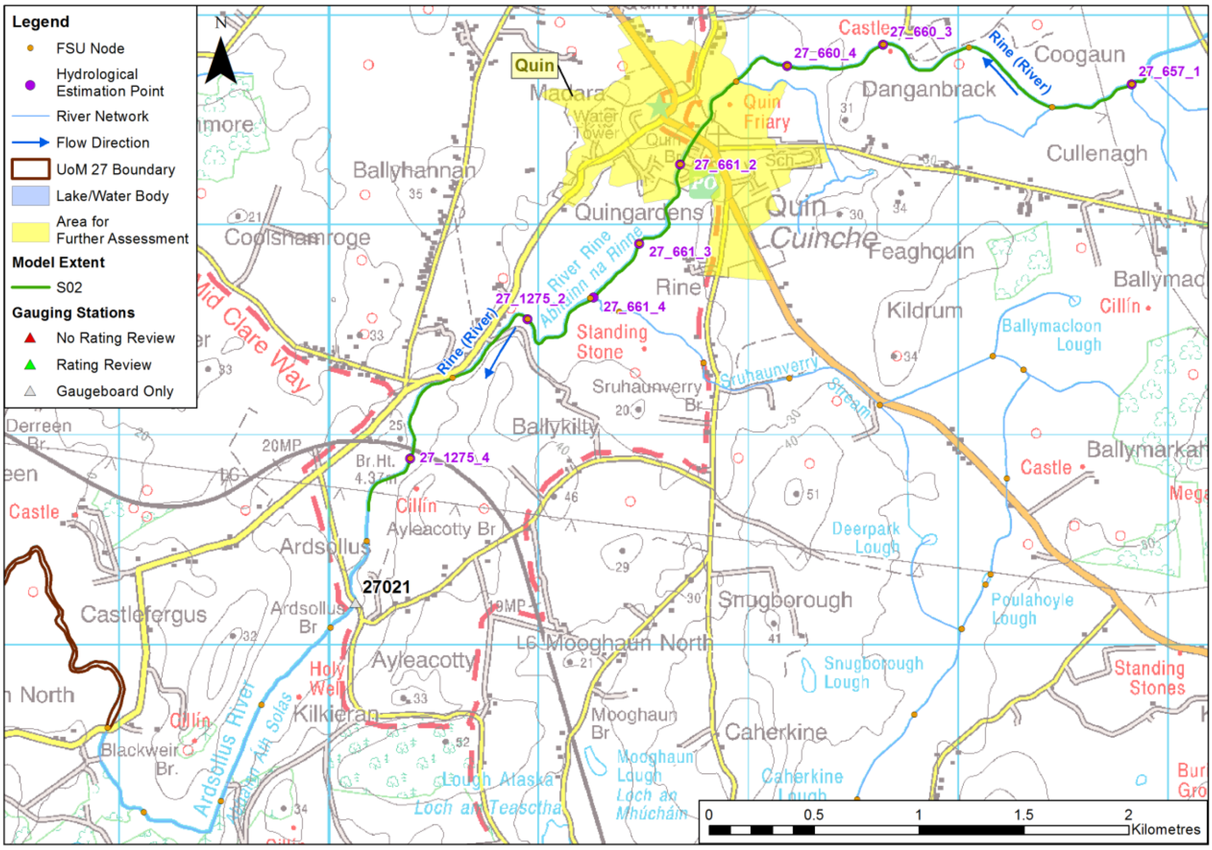
Gauging Station Information Used – In Bank* - Not possible as no hydrometric data received.

Discussion and Strategy

Discussion

It is not possible to calibrate or verify Model S02 due to an absence of a recorder gauge. Also, the only flood event observations in the area are upstream of the model extent and can therefore not be used.

Appendix A - Plan of model S02



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: ☐ *No Coverage: ☒
	GIS Layer	B-0020	Digitisation of 1954 flood event. *Coverage: ☐ *No Coverage: ☒
	GIS Layer	B-0054	Jacobs digitisation of 2009 flood event. *Coverage: ☐ *No Coverage: ☒
	floodmaps.ie GIS layer	A-0171	Revised GIS layers showing the areas of Benefiting lands. (Unable to view layer, however the National Flood Hazard Mapping tool indicates that land classed as benefiting lands for flood risk management exist around the upper and lower stretches of the River Rine. *Coverage: ☒ *No Coverage: ☐
1	.pdf report	B-0063	10-1A. Minutes of 2006 meeting identifying locations subject to recurring flooding - Co Clare - Ennis area (Report includes: Flood Depth, Frequency, Source, Cause).
2	-	-	N/A
3	-	-	N/A
4	-	-	N/A
All	-	-	N/A
All/ General Verification		A-0164	Photographs and videos taken during UoM 27 site visit. (June 2011).
All/ General Verification	-	B-0038	Photographs of 2009 flood event;
*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 (1)**	**Supplementary known, useful flood levels(2)**	**Reliable flood history (levels, locations, dates) (3)**	**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)	**1(0)**	**1(0)**	**1(2)**	**1(2)**	**1(1)**	**1(5)**	**Only one event is identified:** **1-Locations of recurring flooding within County Clare. Flood depths given for Dangan Bridge (outside model extent)**
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 x Q_{med}] and it was felt by the OPW that the ratings provided a reasonable representation of extreme flood events
	A1	Confirmed ratings for flood flows well above Q_{med} with the HGF > than 1.3 x Q_{med} and/or with a good confidence of extrapolation up to 2 x Q_{med}, bankfull or, using suitable survey data, including flows across the flood plain.
	A2	Rating confirmed to measure Q_{med} and up to around 1.3 x Q_{med}. At least one gauging for confirmation and good confidence in the extrapolation.
B		Flows can be estimated up to Q_{med} with confidence. Some high flow gaugings must be around the Q_{med} value.
C		Sites within the classification have the potential to be upgraded to B sites but require more extensive gauging and/or survey information to make it possible to rate the flows to at least Q_{med}.

Table 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 27)

Phase 1			
Shannon CFRAM Study Calibration Information Refer to technical note TD041			
Model No.	**S03**	Length	21.8km
Unit of Management		27	

AFA	Bunratty and Sixmilebridge
IRRs	None
River / Catchment / Sub-catchment	Owenogarney (Ratty) River / Owenogarney / Shannon
Type of Flooding / Flood Risk	Fluvial non-tidal ☒ Fluvial tidal ☒ Coastal ☒
Comments	Model S03 includes two AFAs – Sixmilebridge and Bunratty. The modelled extent includes the Owenogarney River and an unnamed right bank tributary which flows along the outskirts of the Bunratty AFA.

Completed by	Kenny Samson		
Date	18/11/2013		

***Site A: Bunratty AFA* - Potential flood events to consider for fluvial calibration or verification**

No	Description*	Category **(TD041)	Score (TD041)	Calibration or verification
F.1a	January 2005: L3040 to Bunratty (Grid Ref: 145246, 161280). Surface runoff from land at either side of road. Max depth of 400mm rendering it impassable. Frequency 1-in-5/10 years. ***FQC = 4	3	0+0+1+1+1=3	Potential for verification

***Site A: Bunratty AFA* - Potential flood events to consider for tidal calibration or verification**

No	Description*	Category **(TD041)	Score (TD041)	Calibration or verification
T.1a	16 – 17 January 1995: Bunratty. Widespread overtopping of embankments, especially those to the north of Shannon Estuary. Gives embankment height on Owenogarney (crest level circa 6.6 mOD (P)). No levels given for locations within model extent. Overtopping lasted for a very short duration. ***FQC = 3	3	0+0+1+1+1=3	Of limited use for verification – no actual levels given within modelled extent
T.2a	01/02/2002: Bunratty - List of areas significantly affected during tidal flooding. Provides flood data including depth, source, frequency.	3	0+0+1+0+1=2	Of limited use for verification .

***Site B: Sixmilebridge AFA* - Potential flood events to consider for fluvial calibration or verification**

No	Description*	Category **(TD041)	Score (TD041)	Calibration or verification
F.1b	January 2005 – Setright's Cross (Grid Ref: 148906, 160461) to Sixmilebridge Road (R462) flooded and impassable with up to 450mm of water on road close to railway line. Cause is prolonged heavy rainfall resulting in surface runoff off from land to east of road. Estimated frequency is once in 10 to 20 years. ***FQC = 4	1	0+0+1+1+1=3	Potential for verification

F.2b	January 1995: Fourteen homes were affected to varying degrees and the Sixmilebridge WWTP flooded, backing up sewer pipe and manhole system.	1	0+1+0+0+1=2	Potential for verification.(Photographs of January 1995 flooding available)
F.3b	19 – 22 Nov. 2009. Photographs of flooding on 22nd November 2009. Source and cause reported, however, no water levels. ***FQC = 4	1	3+0+0+0+1=4	Potential for a broad verification.
F.4b	Gauge Data Only - In-bank event – Qmed	1	To be identified in Phase 2	Calibration/verification
F.5b	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 (refer to Appendix E)

Gauging Station Information within Model Extent (or close to)

Station	Data Length	Type (flow, stage, both)	Gaugeboard Datum (mAOD Malin)	FSU Classification*	Comment
27011 Owenogarney (RLY Bridge)	1997 – Present	Flow and level	1.79	No FSU Classification	Upper limit of reliable rating = 28.3m^3/s (1.85xQmed).

* 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 (Fluvial Calibration):

Only hydrometric station (27011) is present along the S03 modelled reach. Water levels have been recorded at the station since 1994, but digitised data extends from 1997 only. There are long periods missing from the record, including data recorded between 11/01/03 – 31/07/07 which has not been digitised and from 24/02/2001 to 03/10/2001 due to the foot and mouth crisis. Despite the gauge reported as having a reliable upper limit of rating of 28.3m^3/s (1.85xQMED); 0% of the gauged record is flagged as good and 45% flagged as cautionary.

A review of the station's rating suggests that the OPW rating is valid for the station. However, the semi-tidal nature of the station limits the usefulness of this gauge for use in fluvial calibration. The recorded levels may be tidally affected, as indicated on the OPW Hydro website (www.opw.ie/hydro).

There are no other stations up or downstream of Station 27011 to provide inflows for fluvial calibration of the S03 model.

Three events are identified for each AFA (Bunratty and Sixmilebridge). The most useful of these are – F.1a, (Bunratty), F.1b, F.2b and F.3b (Sixmilebridge). Flood event F.2b is limited in its usefulness however as it pre-dates the start of the station's available record. As flood alleviation measures were implemented post-1995 and given that the station's record of data does not begin until 1997; flood data for the January 1995 events (F.2b) might not be useful for the verification of the model.

The indicative flood locations of 2009 (F.5b) could be used for a broad verification of the model.

Phase 1 (Tidal Calibration):

Tidal calibration is possible only when 15-min time series data is available at a minimum of two stations, of which one station being a tidal recording station. In the case of the S03 model, 15-minute data for significant tidal events was not available. Therefore, a tidal calibration of S03 model is not possible.

Phase 2

Gauging Station Information Used – Out of Bank* - No out of bank event identified.

Gauging Station Information Used – In Bank* - Not possible as no hydrometric data up/downstream

Discussion and Strategy - Fluvial

Discussion

- Only station 27011 - which appears to be located in the tidally influenced reach of the watercourse - is present along the S03 model length. The largest 3 events in the AMAX series, listed in order of magnitude, are 2009, 1995, and 2005. However, no 15-min hydrometric data is available for the 1995 and 2005 events (although an AMAX flow estimate was provided which is for the 2005 event).

- It is not possible to calibrate the S03 model due to an absence of gauged data to complement the gaugings at Station 27011.

Calibration/Verification Strategy

- For the November 2009 flood event, the post flood data shows that a local road and crossing on the Owenogarney, situated downstream of the GS, was flooded but passable. As the rarity of the November 2009 event was estimated in the range of around 1% AEP, this will be used for a broad verification of the model to see whether the local road crossing on the Owenogarney downstream of Station 27011 would be flooded or not at low probability floods such as the 1% AEP.

Discussion and Strategy – Tidal

Discussion

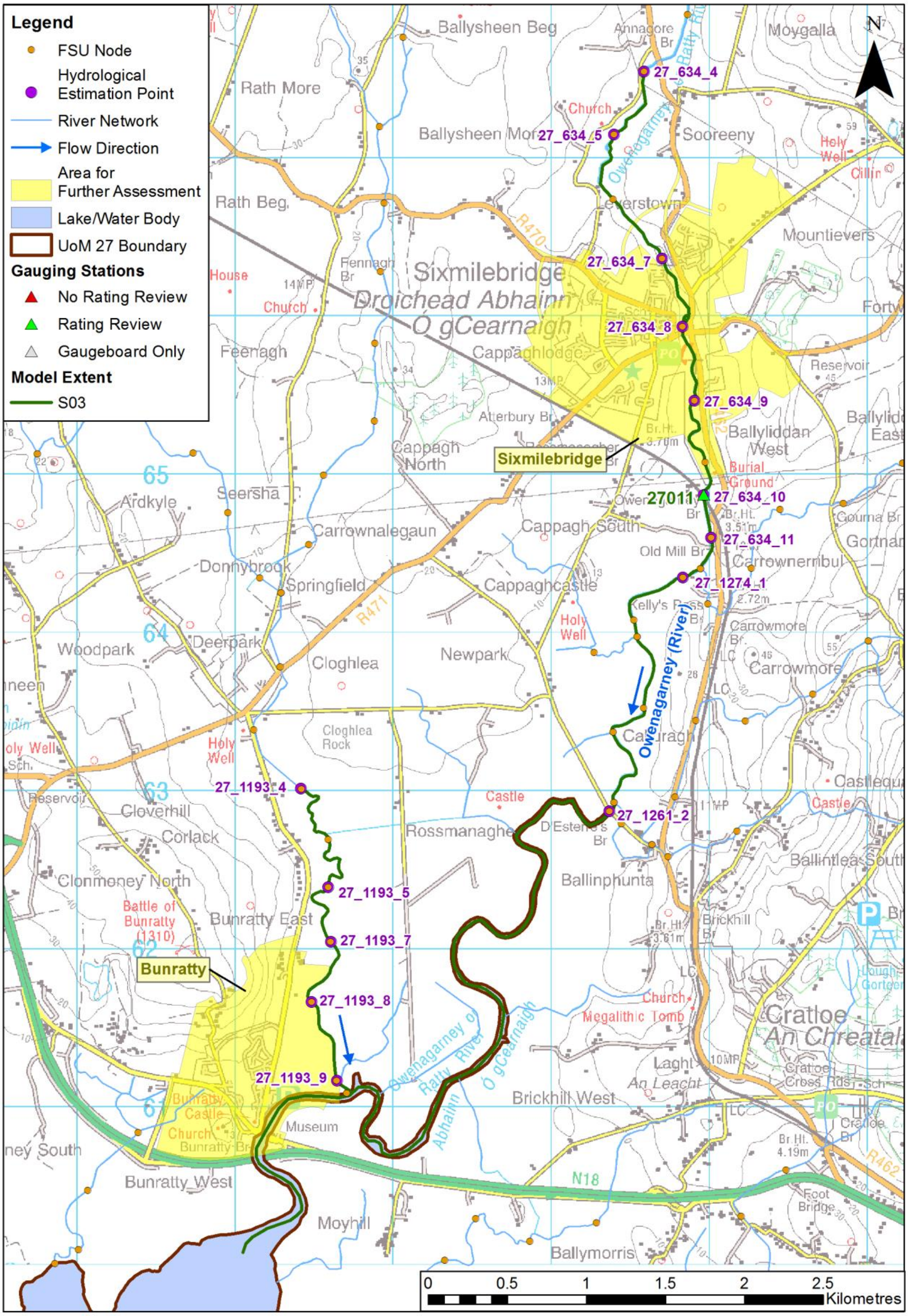
- No hydrometric station recording tidal levels is present in the lower reaches of the S03 Model.

- As discussed in Phase 1, at least two stations are required for model calibration.

Calibration/Verification Strategy

- Although model calibration is not possible with the available data; the tidal events of 16-17 January 1995 (T.1a) and 1st February 2002 (T.2a), which affected the Bunratty area, can potentially be used to broadly verify the model.

Appendix A - Plan of model – S03



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: ☐ *No Coverage: ☒
	GIS Layer	B-0020	Digitisation of 1954 flood event. *Coverage: ☐ *No Coverage: ☒
	GIS Layer	B-0054	Jacobs digitisation of 2009 flood event. *Coverage: ☐ *No Coverage: ☒
	floodmaps.ie GIS layer	A-0171	Revised GIS layers showing the areas of Benefiting lands. (Unable to view layer, however the National Flood Hazard Mapping tool indicates that land classed as benefiting lands for flood risk management exist around the Shannon Estuary and extending upstream to the settlement of Sixmilebridge. *Coverage: ☒ *No Coverage: ☐
F.1a; F.1b	.pdf report	B-0063	14-2a (14-4a; 14-5a; 14-6a Duplicates). Minutes of 2006 meeting identifying (15) areas subject to flooding. Co Clare - Shannon Area (Report includes: Flood Depth, Cause). Flood depth of nearby locations include on L3040 road and at Setright's Cross. FQC = 4
T.1a	.pdf report	B-0063	14-1a. OPW memo. Refers to tidal flooding at a number of locations in Co Limerick and Clare in January 1995. Tide level given. (Report includes: Properties Affected, Source, Cause). FQC = 3
T.2a	.pdf report		14-3a. Lists a number of locations around Co's Limerick, Kerry, and Clare which were affected by flooding on 01/02/2002. Source / cause / properties affected. FQC = ?
F.2b	.pdf map	B-0063	55-2a. OPW report. Detailed information on 1995 flooding in Sixmilebridge, Co Clare. (Includes: Flood Level, No. of Properties Damaged (14), Financial Damage Caused, Source, Cause). Maximum flood levels are given at Railway bridge and at upstream dwellings. FQC = 1
F.3b	.pdf report		(cla_re_OT_0000012309[1]) Map showing point locations of flooding on 22nd November 2009 (Includes: Source / Cause). FQC = 3
F.4b	.pdf report	B-0063	55-2d. Consultants Report. Environmental Impact Statement (EIS). Refers to (1995) flooding on the River Owenogarney, Sixmilebridge, Co. Clare (Report Includes: Source, Cause, number of properties affected). FQC = 3
All	.msg & .xls		Flow and level data from 1997 – 2009 at Station 27011 (Owenogarney Bridge).

All/ General Verification		A-0158 / A-0167	Photographs and videos taken at Bunratty and Sixmilebridge respectively, during UoM 27 site visit. (June 2011).
All/ General Verification	-	B-0063	Aerial Photographs of 27th Jan 1995.

*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** (1)	**Supplementary known, useful flood levels**(2)	**Reliable flood history (levels, locations, dates)** (3)	**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)	**F.1a(0) T.1a(0) T.2a(0) F.1b(0) F.2b(0) F.3b(3)**	**F.1a(0) T.1a(0) T.2a(0) F.1b(0) F.2b(1) F.3b(0)**	**F.1a(1) T.1a(1) T.2a(1) F.1b(1) F.2b(0) F.3b(0)**	**F.1a(1) T.1a(1) T.2a(0) F.1b(1) F.2b(0) F.3b(0)**	**F.1a(1) T.1a(1) T.2a(1) F.1b(1) F.2b(1) F.3b(1)**	**F.1a(3) T.1a(3) T.2a(2) F.1b(3) F.2b(2) F.3b(4)**	Three events are identified for each AFA (Bunratty / Sixmilebridge); none are of use for calibration however, may be of use for broad verification of the model: F.1(a&b)-Provides Max depth of flooding on nearby roads – no actual date, recurring event. T.1a- Provides tidal levels at a number of locations during January 1995 tidal flooding. Gives design crest height of Owenogarney embankment. No levels for locations within model extent. T.2a– Lists a number of locations around Co's Limerick, Kerry, and Clare which were affected by flooding on 01/02/2002. Not useable as no inflow hydrograph available. F.2b- Details flooding in Sixmilebridge. Maximum flood levels are given at Railway bridge (Stn: 27011) and at upstream dwellings. F.3b- Map showing flood locations around Sixmilebridge. No reported levels.
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 x Q_{med}] and it was felt by the OPW that the ratings provided a reasonable representation of extreme flood events
	A1	Confirmed ratings for flood flows well above Q_{med} with the HGF > than 1.3 x Q_{med} and/or with a good confidence of extrapolation up to 2 x Q_{med}, bankfull or, using suitable survey data, including flows across the flood plain.
	A2	Rating confirmed to measure Q_{med} and up to around 1.3 x Q_{med}. At least one gauging for confirmation and good confidence in the extrapolation.
B		Flows can be estimated up to Q_{med} with confidence. Some high flow gaugings must be around the Q_{med} value.
C		Sites within the classification have the potential to be upgraded to B sites but require more extensive gauging and/or survey information to make it possible to rate the flows to at least Q_{med}.

Table 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 27)

Phase 1

Shannon CFRAM Study Calibration Information

Refer to technical note TD041

Model No.	**S04**	Length	19.1km
Unit of Management		27	

AFA	Shannon
IRRs	Shannon Airport
River / Catchment / Sub-catchment	Ballycassey, Drumgeely / Shannon Estuary / Shannon AFA
Type of Flooding / Flood Risk	Fluvial non-tidal ☒ Fluvial tidal ☒ Coastal ☒
Comments	Model S04 includes the watercourses Ballycassey and Drumgeely. Both watercourses flow south-westward through the Shannon AFA. In addition to an AFA, the model includes one IRR – Shannon Airport.

Completed by	Kenny Samson		
Date	20/11/2013		

Potential flood events to consider for fluvial calibration / verification

No	Description*	Category **(TD041)	Score (TD041)	Calibration or verification
F1	January 2005: Surface water flooding of L3169 road from land to the south. Water 'flowed around' one property but was not flooded. Event reported as being rare. No water levels at geographically specific location indicated. ***FQC = 4	3	0+0+1+0+0=1	Not usable for calibration / verification.
F2	C2000: Carrygerry near Shannon; Surface water flooding of two properties located in a local shallow pocket. FQC = 3	3	0+0+1+0+0 = 1	Not usable for calibration / verification.
F3	Gauge Data Only - In-bank event – Qmed	3	To be identified in Phase 2	Calibration/verification.
F4	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 / verification

No	Description*	Category **(TD041)	Score (TD041)	Calibration or verification
T1	C 2000. L7174 road was flooded due to tidal backup from the estuary. Problem has not recurred since a flap valve was installed. No water levels at geographically specific location indicated. FQC = 4	3	0+0+1+1+0=2	Not usable for 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 in Appendix E)

Gauging Station Information within Model Extent (or close to)

No gauging station within (or close to) Model Extent

Control structures		
Reference	Type	Description

Conclusions from Phase 1

Phase 1 suggested:

No hydrometric station exists within the S04 model extent to provide flow data for calibration of the model.

Three past events have been identified from www.floodmaps.ie

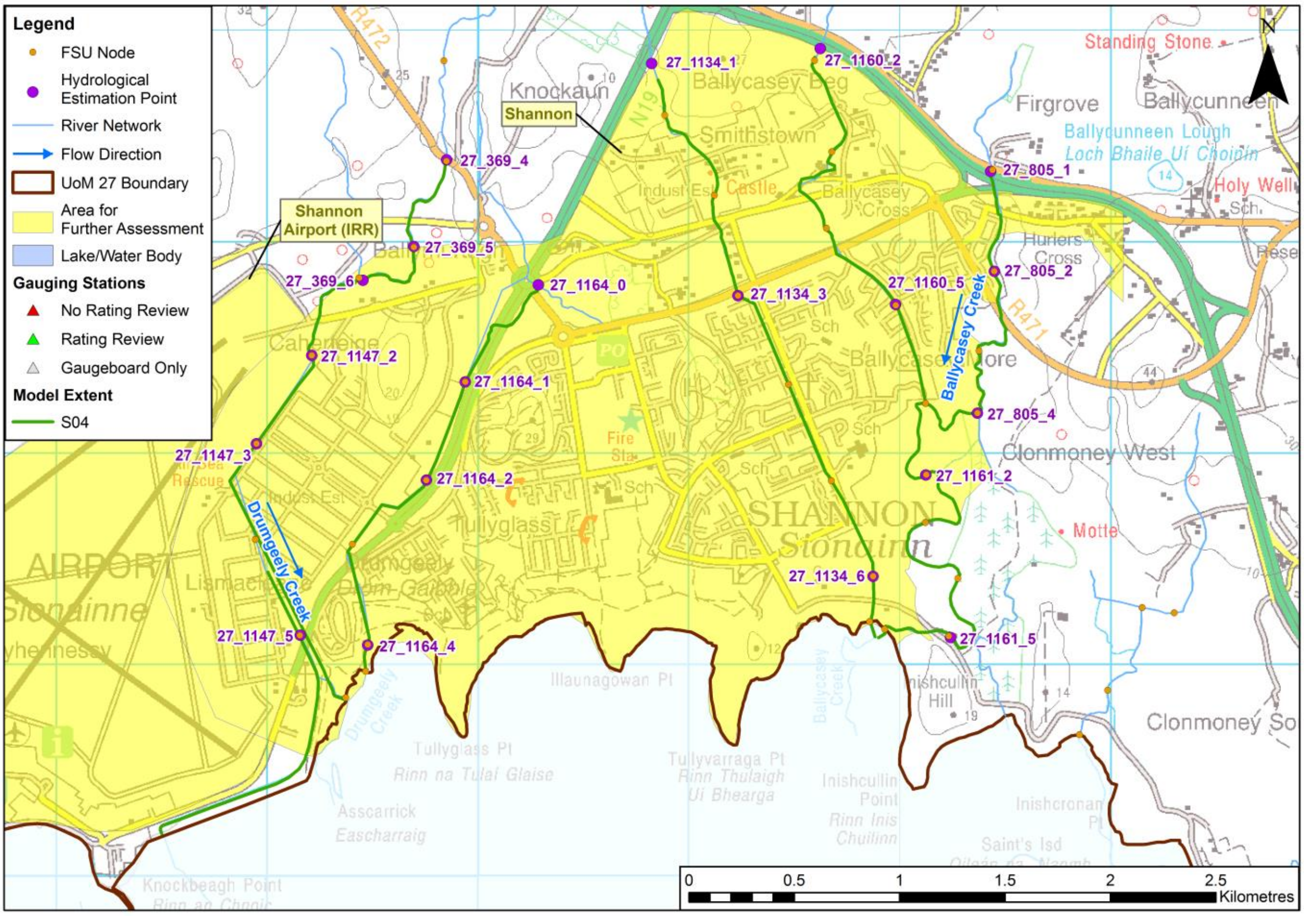
No event provides:

- Observed water levels
- Geographically specific locations
- Date of event

From the data available, it is not possible to calibrate or verify Model S04. Three events are reported, none of which provide observed water levels or a specific location or date and thus, are unlikely to be useful for model calibration or verification.

Phase 2
Gauging Station Information Used – Out of Bank* - No hydrometric data available.
Gauging Station Information Used – In Bank* - No hydrometric data available.
Discussion and Strategy
Discussion The entire S04 Model is categorised a HPW.   Within the Model Extent, one AFA – Shannon Town and one IRR, namely, Shannon Airport, are present. Calibration/Verification Strategy: • As discussed in the concluding remarks from Phase 1**,** it is not possible to calibrate model S04 due to an absence of gauged hydrometric data. • Information relating to historic flooding is limited to that reported for the two events identified from 'Floodmaps.ie'. • The usefulness of this information is limited by the reports failing to give specific dates / locations of flooding. With the data and information available, even a broad verification of the model is unlikely to be possible.

Appendix A - Plan of model – S04



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: ☐ *No Coverage: ☒
	GIS Layer	B-0020	Digitisation of 1954 flood event. *Coverage: ☐ *No Coverage: ☒
	GIS Layer	B-0054	Jacobs digitisation of 2009 flood event. *Coverage: ☐ *No Coverage: ☒
	floodmaps.ie GIS layer	A-0171	Revised GIS layers showing the areas of Benefiting lands. (Unable to view layer, however the National Flood Hazard Mapping tool indicates that land classed as benefiting lands for flood risk management exist over almost the entire area covered by the S04 model. *Coverage: ☒ *No Coverage: ☐
F1	.pdf report	B-0063	53-1a. January 2005. At Ballycally, surface water ran off onto road L3169. No levels reported, no properties flooded, event noted as being rare. FQC = 4.
T1	.pdf report	B-0063	53-1a. Tidal back up from estuary caused flooding on the L7174. However, a flap valve has been installed and since then the problem has not recurred. FQC = 4
F2	OPW memo	B-0063	06-2a. Report dated 18/09/00. Describes recurring flooding at Carrygerry. Most recent of which is reported as occurring on 25/12/99. FQC = 3
All/ General Verification	Photographs	B-0011	Aerial photographs from Dec. 2006 Shannon and Clare Flood Study.
All/ General Verification	Photographs / Videos	A-0166	Shannon. Photographs and videos taken during UoM 27 Site Visit: June 2011.
All/ General Verification	Photographs / Videos	A-0165	Shannon Airport. Photographs and videos taken during UoM 27 Site Visit: June 2011.
All/ General Verification	Combined shoreline wave and water level conditions and reference maps	A-0189	Outputs from the Irish Coastal Wave & Water Level Study (ICWWS) for the Shannon CFRAM area, including Shannon Airport.
All/ General Verification	Maps, tables & water levels shapefiles	A-0053	Irish Coastal Protection Strategy Study (ICPSS) - involved advanced numerical modelling of combined storm surges and tide levels to obtain extreme water levels along the south and east coast.
*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** (1)	**Supplementary known, useful flood levels**(2)	**Reliable flood history (levels, locations, dates)** (3)	**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)	**F1(0)** **F2(0)** **T1(0)**	**F1(0)** **F2(0)** **T1(0)**	**F1(1)** **F2(1)** **T1(1)**	**F1(0)** **F2(0)** **T1(1)**	**F1(0)** **F2(0)** **T1(0)**	**F1(1)** **F2(1)** **T1(2)**	**F1. No levels / specific location reported.** **F2. Recurring flooding, no levels reported.** **T1. Non-recurring tidal flood.**
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 x Q_{med}] and it was felt by the OPW that the ratings provided a reasonable representation of extreme flood events
	A1	Confirmed ratings for flood flows well above Q_{med} with the HGF > than 1.3 x Q_{med} and/or with a good confidence of extrapolation up to 2 x Q_{med}, bankfull or, using suitable survey data, including flows across the flood plain.
	A2	Rating confirmed to measure Q_{med} and up to around 1.3 x Q_{med}. At least one gauging for confirmation and good confidence in the extrapolation.
B		Flows can be estimated up to Q_{med} with confidence. Some high flow gaugings must be around the Q_{med} value.
C		Sites within the classification have the potential to be upgraded to B sites but require more extensive gauging and/or survey information to make it possible to rate the flows to at least Q_{med}.

Table 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 27)

Phase 1			
Shannon CFRAM Study Calibration Information Refer to technical note TD041			
Model No.	**S18**	Length	5km
Unit of Management		27	
AFAs	Kilrush		
IRRs	None		
River / Catchment / Sub-catchment	Wood River / Shannon Estuary North		
Type of Flooding / Flood Risk	Fluvial non-tidal ☐ Fluvial tidal ☒ Tidal ☐		
Comments	The model comprises of the River Wood that runs through the Kilrush AFA and discharges into the Kilrush Creek. The model has an inactive gauging station (27013 Kilrush). The model has a tidal boundary. The fluvial flood risk is considered to be non-tidal as the operation of the tidal lock now keeps a constant level in the marina.		
Completed by	Clodagh Fitzgerald	Agnes Adjei	
Date	13/03/13	22/11/2013	

Potential Flood Events to Consider for Calibration

Event No	Description*	Category **(TD041)	Score (TD041)	Calibration or verification
1	01/2005	3	0+0+0+2+0=2	Verification
2	(no date provided) - R473 at Cappagh Recurring of Tidal Origin.	3	0+0+0+1+0=1	Not suitable for calibration or verification
3	(no date provided) - Kilrush Recurring, is outside of the model extent	3	0+0+0+1+0=1	Not suitable for calibration or verification

*Appendix B for Event Details, **Appendix C for Quality Category and Quality Score (Score 0 (Poor) to 18(Good))

Gauging Station Information within Model Extent (or close to)

Station	Data Length	Type (flow, stage both)	Gaugeboard Datum (mAOD Malin)	FSU Classification*	Comment
27013 – Kilrush	28/06/1984–28/09/1995	Flow Measurements	N/A	Not FSU classified	Inactive

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

Control Structures

Reference	Type	Description
No Control Structures	N/A	N/A

Conclusions from Phase 1

Phase 1 Suggested:

- The model only has an inactive gauging station 27013 Kilrush.
- The River Wood flows through the Kilrush AFA.
- Event 1 consists of meeting minutes, reporting land and roads (R483) flooded to about 500mm depth on 25/01/2005. This event may be used for verification.
- Event 2 has a flood report mentioning flooding on Cappagh Road (R483) to a depth of 1.2m, but has not specific date. The source of flooding is tidal and therefore cannot be used for calibration or verification.
- Event 3 consists of meeting minutes reporting of flooding in Kilrush due to the River Cooraclare. The reports do not provide specific date of flooding and the event is outside of the model extent so cannot be used for calibration or verification.

Phase 2 – Gauging station event table omitted as the gauge data cannot be used for calibration within this model extent.

Discussion and Strategy

Discussion:

- There is insufficient hydrometric or event data for the calibration of this model.
- Event 1 contains meeting minutes which includes reports of land and roads (R483) which flooded to a depth of 500mm on 25/01/2005. Frequency of flooding is twice a year. It may be possible to use this information for post-design event verification in the local area, but not for calibration.
- Event 2 is a tidal event and due to the presence of the marina lock gates cannot be used for calibration or verification (see below).
- Event 3 is outside of the model extent and cannot be used for calibration or verification.

Calibration/Verification Strategy:

- No calibration or verification can be undertaken using hydrometric data.

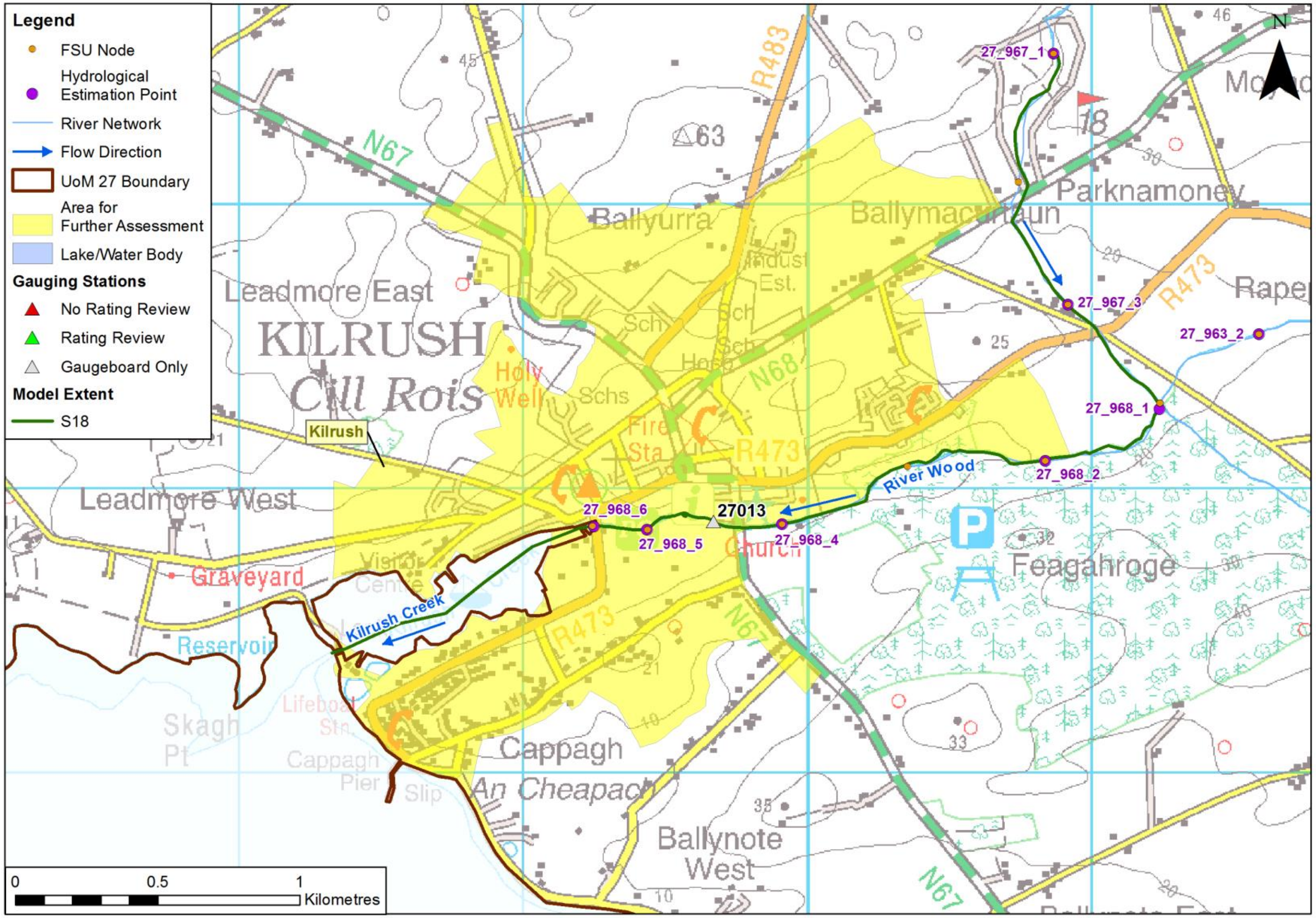
Post-Design Event Modelling Verification Strategy:

- Event 1 can be used for post-design event calibration. The modelled flood outline will be compared to the January 2005 event (i.e. Event 1) on the R483 road, to verify that the model results and frequency of flooding seem consistent with the observed data.

Tidal Calibration/Verification

- The effect of the tide is controlled by the marina lock gates and therefore tidal calibration or verification is not appropriate

Appendix A – Plan of model S18



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 *Coverage: ☐ *No coverage: ☒
	GIS layer	B-0020	Digitisation of 1954 flood event. *Coverage: ☐ *No coverage: ☒
	GIS layer	B-0054	Jacobs digitisation of 2009 flood event. In Bunratty only. All in-bank flooding. *Coverage: ☐ *No coverage: ☒
	GIS layer	A-0171	Revised GIS layers showing the areas of Benefiting lands. **Coverage: ☐ **No coverage: ☒
All/ General Verification	FRR site visit	A-0162	Kilrush – Notes, marked up plans, photographs and videos during UoM 27 Site Visit.
All/ General Verification	GIS layer	A-0157	Tidal Hazard Area data for the Shannon Open coastal area.
All/ General Verification	Maps, tables & water levels shapefiles	A-0053	Irish Coastal Protection Strategy Study (ICPSS) - involved advanced numerical modelling of combined storm surges and tide levels to obtain extreme water levels along the south and east coast.
All/ General Verification	Combined shoreline wave and water level conditions and reference maps	A-0189	Outputs from the Irish Coastal Wave & Water Level Study (ICWWS) for the Shannon CFRAM area, including Shannon Airport. These include combined shoreline wave and water level (joint probability) conditions for Coastal Areas Potentially Vulnerable to Wave Overtopping (CAPOs) within the Shannon CFRAM area.
1	Clare County Council Meeting Minutes	B-0063	36-1a Low lying land, cut away bog, at each side of road R483 with very poor drainage results in lands and road flooding. 500mm maximum depth on road on 07/01/2005. Frequency is twice per year.
2	Clare County Council Meeting Minutes	B-0063	36-1a Road is flooded on the Cappagh side of the Creek Lodge Hotel to a maximum depth of 1.2m. This occurs on average every 2/3 years. Road is impassable. Cause is tidal but may be exacerbated by the operation of Marina lock gates, which may have the affect of prolonging high water levels.
3	Clare County Council Meeting Minutes	B-0063	36-1a R483 on Kilrush Road from Cooraclare - Road is flooded on average once per year but passable. No houses affected. Cause appears to be back up of Cooraclare River. This is outside the study area.
**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 (1)**	**Supplementary known, useful flood levels(2)**	**Reliable flood history (levels, locations, dates) (3)**	**Indicative calibration score (sum of columns 2-6)**	**Calibration comment (with event number):**
Category 1	Large gauged river within an AFA (HPW)							
Category 1	Small gauged river within an AFA (HPW)							
Category 3	Large ungauged river within an AFA (HPW)							
Category 3	Small ungauged river within an AFA (HPW)	**1(0) 2(0) 3(0)**	**1(0) 2(0) 3(0)**	**1(0) 2(0) 3(0)**	**1(2) 2(1) 3(1)**	**1(0) 2(0) 3(0)**	**1(2) 2(1) 3(1)**	
Category 2	Gauged MPW							
Category 4	Ungauged MPW							

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

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 (See Table 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 x Q_{med}] and it was felt by the OPW that the ratings provided a reasonable representation of extreme flood events
	A1	Confirmed ratings for flood flows well above Q_{med} with the HGF > than 1.3 x Q_{med} and/or with a good confidence of extrapolation up to 2 x Q_{med}, bankfull or, using suitable survey data, including flows across the flood plain.
	A2	Rating confirmed to measure Q_{med} and up to around 1.3 x Q_{med}. At least one gauging for confirmation and good confidence in the extrapolation.
B		Flows can be estimated up to Q_{med} with confidence. Some high flow gaugings must be around the Q_{med} value.
C		Sites within the classification have the potential to be upgraded to B sites but require more extensive gauging and/or survey information to make it possible to rate the flows to at least Q_{med}.

Table 1: FSU Gauging station classification (from Hydro-Logic 2006)

Phase 1				
Shannon CFRAM Study Calibration Information Refer to technical note TD041				
Model No.	**S19**	Length	5km	
Unit of Management		27		
AFAs	Kilkee			
IRRs	None			
River / Sub-catchment / Catchment	Unnamed Watercourses within Shannon Estuary North			
Type of Flooding / Flood Risk	Fluvial non-tidal ☐ Fluvial tidal ☒ Tidal ☐			
Comments	The model has a number of small streams in the area but no significant rivers. Kilkee is the only AFA. The model is ungauged and has a tidal boundary.			
Completed by	Clodagh Fitzgerald	Agnes Adjei	Alison Janes	
Date	13/03/13	14/03/2014	20/03/2014	

Potential flood events to consider for Calibration

Event No	Description*	Category **(TD041)	Score (TD041)	Calibration or verification
1	02/1990 (depth of flooding not specified. Source of flooding is tidal)	3	0+0+0+0+0=0	Not suitable for calibration or verification
2	16/01/1965 (depth of flooding specified. Source of flooding is tidal)	3	0+0+0+1+0=1	Not suitable for calibration or verification
3	22/10/1961 (Source of flooding is tidal)	3	0+0+0+1+0=1	Not suitable for calibration or verification
4	Recurring event	3		

*Appendix B for Event Details, **Appendix C for Quality Category and Quality Score (Score 5 (Poor) to 18(Good))

Gauging Station Information within Model Extent (or close to)

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

Station	Data Length	Type (flow, stage both)	Gaugeboard Datum (mAOD Malin)	FSU Classification*	Comment
None					

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

Control structures

Reference	Type	Description
No Control Structures	N/A	N/A

Conclusions from Phase 1

Phase 1 Suggested:

- The model is ungauged and has a tidal boundary.
- All streams flow through the Kilkee AFA.
- Event 1 - Consists of newspaper reports of significant flooding in Clare County. Some of the areas worst affected includes Kilkee. About 200 properties were reported to be damaged. Information on the depth of flooding has not been indicated. The source of flooding is tidal and therefore cannot be used for calibration or verification.
- Event 2 - Newspaper reports of high tides, and with spray of up to 500ft over the cliff, with spray effects for a one mile distance. Portions of the promenade wall were damaged by a huge tide causing 2ft of flooding to the houses along the front of the wall. The source of flooding is tidal and therefore cannot be used for calibration or verification.
- Event 3 – newspaper reports of the golf pavilion being blown away and the windows of a number of properties on the seafront smashed due to high tides. Depth of flooding has not been indicated. The source of flooding is tidal and therefore cannot be used for calibration or verification.
- Event 4 – Clare CC meeting minutes regarding OPW flood hazard mapping. Victoria Stream overflows its banks over a length of 200-300m. Church Street and Well Road car park are flooded. Road is not passable and the car park is closed. 4 to 5 houses are affected. Frequency is about once per year. Reported cause is heavy rainfall/runoff exacerbated by tides/wind.

Phase 2 – Gauging station event table omitted as the gauge data cannot be used for calibration within this model extent.

Discussion and Strategy

Discussion:

- There is insufficient hydrometric or event data for the calibration or verification of this model.
- Events 1, 2 and 3 are tidal events and cannot be used for calibration or verification.

Calibration/Verification Strategy:

- No calibration or verification can be undertaken for Events 1, 2 or 3.

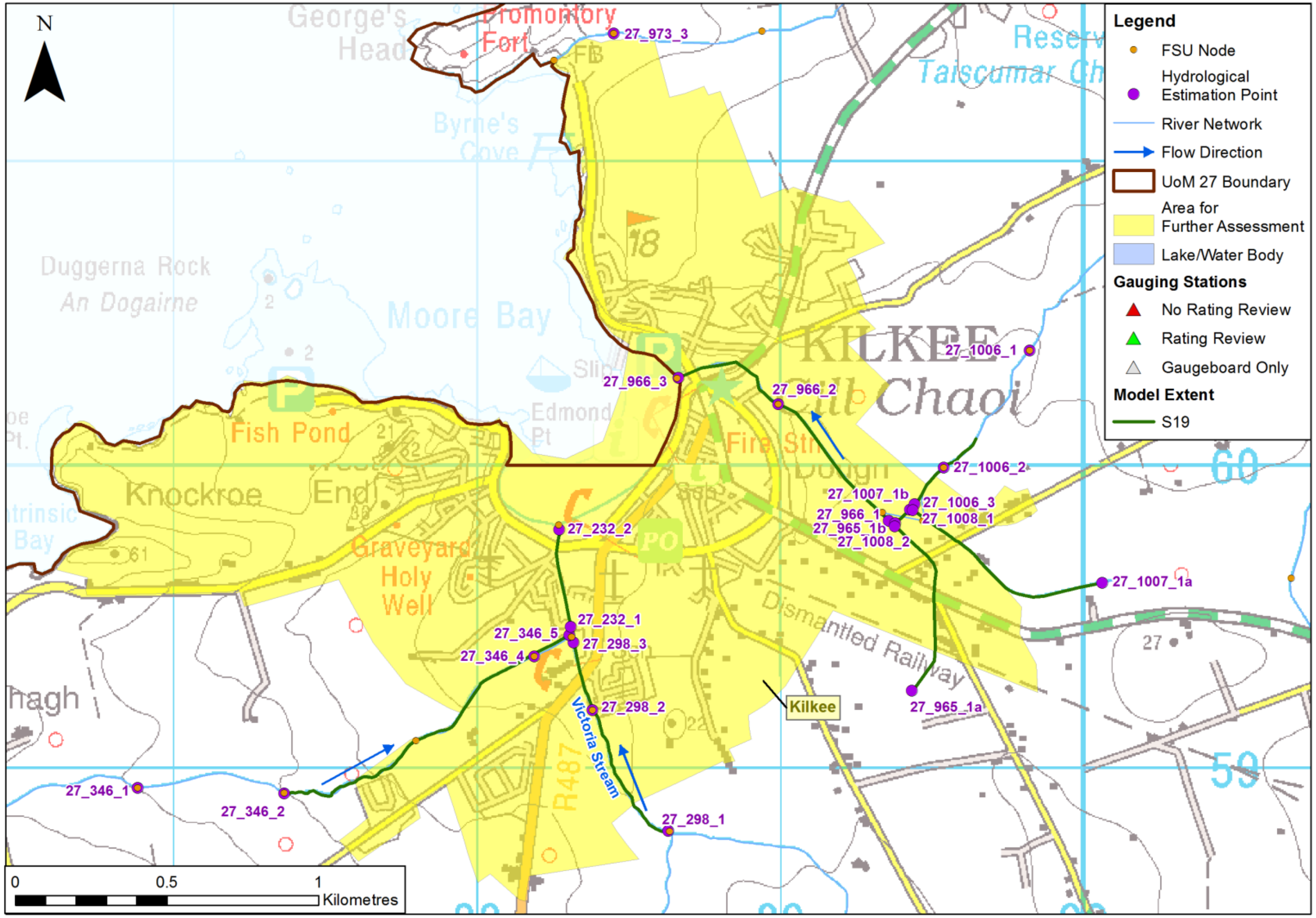
Post-Design Event Modelling Verification Strategy:

- Events 1, 2 and 3 can not be used for post design event verification.

Tidal Calibration/Verification

- The watercourse is not gauged and therefore there is no hydrometric information for tidal calibration.
- Although some tidal events have been identified for Kilkee (2002 and 1965) the only anecdotal evidence is in the form of newspaper reports. The level of detail or accuracy provided is not sufficient for the calibration or verification of the model.

Appendix A – Plan of model S19



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Flood Event	Material type	Data location	Contains
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	GIS layer	B-0054	Jacobs digitisation of 2009 flood event. In Bunratty only. All in-bank flooding. *Coverage: ☐ *No coverage: ☒
	GIS layer	A-0171	Revised GIS layers showing the areas of Benefiting lands. **Coverage: ☐ **No coverage: ☒
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All/ General Verification	GIS layer	A-0157	Tidal Hazard Area data for the Shannon Open coastal area.
All/ General Verification	Maps, tables & water levels shapefiles	A-0053	Irish Coastal Protection Strategy Study (ICPSS) - involved advanced numerical modelling of combined storm surges and tide levels to obtain extreme water levels along the south and east coast.
All/ General Verification	Combined shoreline wave and water level conditions and reference maps	A-0189	Outputs from the Irish Coastal Wave & Water Level Study (ICWWS) for the Shannon CFRAM area, including Shannon Airport. These include combined shoreline wave and water level (joint probability) conditions for Coastal Areas Potentially Vulnerable to Wave Overtopping (CAPOs) within the Shannon CFRAM area.
1	Newspaper	B-0063	33-1b, 33-1c Co Clare experienced serious flooding with about 200 houses & many roads affected. Kilkee was one of the most seriously affected areas. Roads also damaged in Co Clare - Galway Bay to Loop Head & on up to Carrigaholt in the Shannon Estuary.
2	Newspaper	B-0063	33-1o "Seas were breaking 500ft over the cliffs & sending spray inland for a distance of one mile". 2ft flooding to houses along the front of the wall.
3	Newspaper	B-0063	33-1e 10ft of water (@ mudflat near Moyasta). A golf pavilion was blown away in Kilkee. Windows on the seafront & a number of shop windows were smashed by flying slates.
4	Meeting minutes Clare CC for OPW Flood Hazard Mapping project		Kilkee – Church Street on Carrigaholt Road in front of St Patrick's Terrace: Victoria Stream flows in an easterly direction just north of the R487 and overflows its banks over a length of 200-300m. Church Street and Well Road car park are flooded. Road is not passable and

			the car park is closed. 4 to 5 houses are affected. Some reports have been written on this problem. Frequency is about once per year. Cause is heavy rainfall/runoff exacerbated by tides/wind.
*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.			

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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) 3(0) 4(0)**	**1(0) 2(0) 3(0) 4(0)**	**1(0) 2(0) 3(0) (1)**	**1(0) 2(1) 3(1) 4(2)**	**1(0) 2(0) 3(0) 4(2)**	**1(0) 2(1) 3(1) (5)**	Broad verification to be attempted
Category 2	Gauged MPW							
Category 4	Ungauged MPW							

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

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 flows 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 (See Table 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 x Q_{med}] and it was felt by the OPW that the ratings provided a reasonable representation of extreme flood events
	A1	Confirmed ratings for flood flows well above Q_{med} with the HGF > than 1.3 x Q_{med} and/or with a good confidence of extrapolation up to 2 x Q_{med}, bankfull or, using suitable survey data, including flows across the flood plain.
	A2	Rating confirmed to measure Q_{med} and up to around 1.3 x Q_{med}. At least one gauging for confirmation and good confidence in the extrapolation.
B		Flows can be estimated up to Q_{med} with confidence. Some high flow gaugings must be around the Q_{med} value.
C		Sites within the classification have the potential to be upgraded to B sites but require more extensive gauging and/or survey information to make it possible to rate the flows to at least Q_{med}.

Table 1: FSU Gauging station classification (from Hydro-Logic 2006)

Appendix G Pooling Group Audit Trail

Table of Content

CALCULATION AUDIT TRAIL

PART A4.A2 - Pooled analysis site A

Site name: Inch Bridge

Gauging station No: 27001

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 27\S01 - S04 Catchment Model {Glasgow}\S01-a,b,c\S01_Pooled Flood Frequency Analysis _27001 _Corrected_7th March

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	27001
Area	46.70
BFI	0.33
SAAR	1477
FARL	0.99
URBEXT	0.00
FLATWET	0.61

Number of pooled years required: 500 years

STEP 1 Use OPW pooled flood frequency spreadsheet to generate pooled group.

Is subject site in pooled group? (●) Yes ( ) No at ranked position: 1

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 A4.3 Stations with outlying catchment descriptors

Station	Removed or kept with explanation
39009	Removed - Low FARL
39008	Removed - Low FARL
31002	Removed - Low FARL
34010	Removed - Large difference in area
23002	Removed - Large difference in area
33070	Removed - Low FARL
3051	Removed - High reletive URBEXT
22003	Removed - BFI outwith prescribed thresholds
25158	Removed - BFI outwith prescribed thresholds
10004	Removed - BFI outwith prescribed thresholds
35002	Removed - BFI outwith prescribed thresholds
35004	Removed - BFI outwith prescribed thresholds
16013	Removed - BFI outwith prescribed thresholds
10002	Removed - BFI outwith prescribed thresholds
34024	Removed - BFI outwith prescribed thresholds
16008	Removed - BFI outwith prescribed thresholds
16012	Removed - BFI outwith prescribed thresholds
34029	Removed - less than 7 years of data.
33001	Kept - FLATWET value just outwith prescribed threshold
34007	Kept - FLATWET value just outwith prescribed threshold
18050	Kept - Area ~5.3* target site
23012	Kept - BFI less than 30% greater
23001	Kept - SAAR and Area only just outwith threshold
34029	Kept - Parameters only just outwith prescribed thresholds
34009	Kept - Parameters only just outwith prescribed thresholds
30001	Kept - BFI less than 30% greater
14033	Kept - BFI less than 30% greater
22006	Kept - BFI less than 30% greater
19014	Kept - BFI less than 30% greater

STEP 4 Remove sites with high discordancy Di
Discordancy limit used:

Table A4.4 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)
27001	9	0.15	46.7
32011	25	0.10	70.1
36021	27	0.08	23.4
33001	25	0.05	76.1
39001	31	0.15	50.7
18016	20	0.24	116.7
34007	53	0.06	151.7
38001	33	0.09	111.2
28001	17	1.93	169.4
1041	32	0.08	116.2
18050	24	0.18	248.8
23012	18	0.72	61.6
23001	33	0.05	191.7
34009	33	0.03	117.1
30001	18	0.72	121.0
14033	9	1.04	78.9
22006	51	0.04	328.8
19014	47	0.29	170.8

Total years of data	505

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	EV1	LO	LN2
2	1.00	1.00	1.00
5	1.28	1.34	1.28
10	1.46	1.54	1.45
20	1.64	1.73	1.61
50	1.87	1.96	1.81
100	2.04	2.13	1.96
200	2.21	2.30	2.11
1000	2.61	2.70	2.45

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.

Comments:

CALCULATION AUDIT TRAIL

PART A4.A2 - Pooled analysis site A

Site name: Ballycorey

Gauging station No: 27002

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 27\S01 - S04 Catchment Model {Glasgow}\S01-a,b,c\S01_Pooled Flood Frequency Analysis_27002_Corrected

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	27002
Area	511.5
BFI	0.67
SAAR	1341
FARL	0.82
URBEXT	0.09
FLATWET	0.62

Number of pooled years required: 500 years

STEP 1 Use OPW pooled flood frequency spreadsheet to generate pooled group.

Is subject site in pooled group? (●) Yes ( ) No at ranked position: 1

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 A4.3 Stations with outlying catchment descriptors

Station	Removed or kept with explanation
	Removed all stations with FARL <0.737 or > 0.901

STEP 4 Remove sites with high discordancy Di
Discordancy limit used:

Table A4.4 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)
27002	51	0.12	564.3
35005	55	0.15	639.7
35073	30	0.04	362.6
26012	14	0.54	519.9
26108	15	0.98	527.3
25030	48	0.12	280.0
34005	13	0.13	309.1
34003	29	0.17	1802.4
34001	31	0.20	1974.8
6011	48	0.19	229.2
7011	22	0.09	281.7
34011	30	0.12	143.0
7004	23	0.96	245.7
36016	14	0.49	506.9
26008	50	0.11	280.3
36011	49	0.91	320.5

Total years of data	522

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	EV1	LO	LN2
2	1.00	1.00	1.00
5	1.20	1.17	1.20
10	1.34	1.26	1.31
20	1.47	1.35	1.42
50	1.63	1.47	1.55
100	1.76	1.55	1.64
200	1.88	1.63	1.73
1000	2.17	1.83	1.93

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.

Comments:

CALCULATION AUDIT TRAIL

PART A4.A2 - Pooled analysis site A

Site name: River Gaurus

Gauging station No: 27028

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 27\S01 - S04 Catchment Model {Glasgow}\S01-a,b,c\River Gaurus_Pooled Flood Frequency Analysis

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	27_1118_4
Area	25.86
BFI	0.71
SAAR	1115.05
FARL	0.98
URBEXT	1.81
FLATWET	0.61

Number of pooled years required: 500 years

STEP 1 Use OPW pooled flood frequency spreadsheet to generate pooled group.

Is subject site in pooled group? ○ Yes ◉ No at ranked position:

Give reason if not at position 1: Station not listed

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 A4.3 Stations with outlying catchment descriptors

Station	Removed or kept with explanation
36071	REMOVED FARL < than threshold
26018	REMOVED FARL < than threshold
22009	REMOVED URBEXT > than threshold
25040	REMOVED URBEXT > than threshold
10022	REMOVED URBEXT > than threshold
10021	REMOVED URBEXT > than threshold
6070	REMOVED FARL < than threshold
6012	REMOVED FARL < than threshold
19016	REMOVED AREA > 4.5 x tagget area
29004	REMOVED AREA > 4.5 x tagget area
25027	REMOVED AREA > 4.5 x tagget area
9035	REMOVED URBEXT > than threshold
25014	REMOVED AREA > 4.5 x tagget area
30020	KEPT FORMWET slightly outwith threshold
25023	KEPT AREA < 4.5 x Target area
30021	KEPT AREA < 4.5 x Target area
29001	KEPT AREA < 4.5 x Target area
14009	KEPT SAAR only slightly outwith threshold

STEP 4 Remove sites with high discordancy Di
Discordancy limit used:

Table A4.4 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)
19046	9	0.43	63.2
30020	16	0.08	21.4
13002	19	0.05	63.0
26058	24	0.35	60.0
19020	28	0.32	74.0
25034	26	0.72	10.8
6030	27	0.80	10.4
24022	20	0.08	41.2
19001	48	0.08	103.3
16006	33	0.32	75.8
16051	13	0.66	34.2
26022	33	0.19	61.9
25023	34	0.39	113.9
26010	35	0.09	94.5
25044	40	0.06	92.5
6031	18	1.28	46.2
30021	26	0.28	103.6
29001	40	0.09	115.5
14009	25	0.07	68.4

Total years of data	514

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	EV1	LO	LN2
2	1.00	1.00	1.00
5	1.29	1.23	1.29
10	1.49	1.37	1.47
20	1.67	1.50	1.65
50	1.91	1.66	1.86
100	2.09	1.78	2.02
200	2.27	1.90	2.18
1000	2.69	2.17	2.55

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.

Comments:

CALCULATION AUDIT TRAIL

PART A4.A2 - Pooled analysis site A

Site name: Quin

Gauging station No: N/A

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 27\S01 - S04 Catchment Model\S02Pooled Flood Frequency Analysis_corrected.xls

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	27_661_2
Area	98.41
BFI	0.60
SAAR	1088.13
FARL	0.99
URBEXT	0.14
FLATWET	0.61

Number of pooled years required: 500 years

STEP 1 Use OPW pooled flood frequency spreadsheet to generate pooled group.

Is subject site in pooled group? ○ Yes ◉ No at ranked position:

Give reason if not at position 1: Ungauged location

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 A4.3 Stations with outlying catchment descriptors

Station	Removed or kept with explanation
26018	Removed - Low FARL relative to target site
29071	Removed - Low FARL relative to target site
30021	Kept - FLATWET only just outwith threshold
25005	Removed - High discordancy relative to overall pooling group
34011	Removed - Low FARL relative to pooling group

STEP 4 Remove sites with high discordancy Di

Discordancy limit used: 1.69

Table A4.4 Stations removed due to discordancy

Station No	Discordancy
25005	1.69

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)
29001	40	0.18	115.5
26010	35	0.18	94.5
16006	33	0.61	75.8
29004	32	0.29	121.4
30021	26	0.53	103.6
36015	33	1.35	153.1
25027	43	0.15	118.9
25044	40	0.11	92.5
26020	33	0.66	122.4
16005	30	0.28	84.0
26009	35	0.34	98.2
25022	22	0.24	161.3
13002	19	0.09	63.0
25038	17	0.12	136.1
25014	54	0.06	164.4
7033	25	0.13	124.9

Total years of data	517

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	EV1	LO	LN2
2	1.00	1.00	1.00
5	1.23	1.28	1.22
10	1.38	1.44	1.36
20	1.53	1.59	1.48
50	1.71	1.78	1.63
100	1.85	1.93	1.74
200	1.99	2.07	1.85
1000	2.32	2.39	2.09

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.

CALCULATION AUDIT TRAIL

PART A4.A2 - Pooled analysis site B

Site name: Bunratty Tributary

Gauging station No: N/A

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 27\S01 - S04 Catchment Model {Glasgow}\S03\Revised Hydrology_140403\S03 Trib Pooled Flood Frequency Analysis (Corrected)

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	27_1193_4
Area	70.30
BFI	0.82
SAAR	1055
FARL	0.65
URBEXT	1.51
FLATWET	0.60

Number of pooled years required: 500 years

STEP 1 Use OPW pooled flood frequency spreadsheet to generate pooled group.

Is subject site in pooled group? ○ Yes ◉ No at ranked position:

Give reason if not at position 1: Ungauged Site

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 A4.3 Stations with outlying catchment descriptors

Station	Removed or kept with explanation
26058	Removed FARL outwith threshold
25023	Removed FARL outwith threshold
6070	Removed FARL outwith threshold
19046	Removed FARL outwith threshold
6012	Removed FARL outwith threshold
19020	Removed FARL outwith threshold
7001	Removed FARL outwith threshold
19001	Removed FARL outwith threshold
13002	Removed FARL outwith threshold
25025	Removed FARL outwith threshold
6011	Removed FARL outwith threshold
14013	Removed FARL outwith threshold
19016	Removed FARL outwith threshold
25020	Removed FARL outwith threshold
19015	Removed FARL outwith threshold
29004	Removed FARL outwith threshold
7002	Removed FARL outwith threshold
25014	Removed FARL outwith threshold
25027	Removed FARL outwith threshold
7006	Removed FARL outwith threshold
29007	Removed FARL outwith threshold
18001	Removed FARL outwith threshold
36071	Removed FARL outwith threshold
24022	Removed FARL outwith threshold
36018	Removed FARL outwith threshold
25016	Removed FARL outwith threshold
6026	Removed FARL outwith threshold
12013	Removed FARL outwith threshold
16001	Removed FARL outwith threshold
16004	Removed FARL outwith threshold
36015	Removed FARL outwith threshold
26014	Removed FARL outwith threshold
16006	Removed FARL outwith threshold
14007	Removed FARL outwith threshold
10028	Removed FARL outwith threshold
14011	Removed FARL outwith threshold
26022	Removed FARL outwith threshold
6025	Removed FARL outwith threshold
26108	Removed FARL outwith threshold
35001	Removed FARL outwith threshold
15005	Removed FARL outwith threshold
34018	Removed URBEXT outwith threshold
26010	Removed FARL outwith threshold
14009	Removed FARL outwith threshold

7003	Removed FARL outwith threshold
29001	Removed FARL outwith threshold
11001	Removed FARL outwith threshold
25034	Removed FARL outwith threshold
10021	Removed FARL outwith threshold
6014	Removed FARL outwith threshold
25022	Removed FARL outwith threshold
25029	Removed FARL outwith threshold
36016	Removed FARL outwith threshold
25005	Removed FARL outwith threshold
26012	Removed FARL outwith threshold
25044	Removed FARL outwith threshold
25038	Removed FARL outwith threshold
30020	Removed FARL outwith threshold
29011	Removed FARL outwith threshold
16051	Removed FARL outwith threshold
18005	Removed FARL outwith threshold
30021	Removed FARL outwith threshold
26019	Removed FARL outwith threshold
18004	Removed FARL outwith threshold
22009	Removed FARL outwith threshold
25040	Removed FARL outwith threshold
16003	Removed FARL outwith threshold
16007	Removed FARL outwith threshold
26020	Removed FARL outwith threshold
9035	Removed FARL outwith threshold
7007	Removed FARL outwith threshold
35071	Removed FARL outwith threshold
6013	Removed FARL outwith threshold
26008	Removed FARL outwith threshold
29071	Removed FARL outwith threshold
34011	Removed FARL outwith threshold
24002	Removed FARL outwith threshold
25030	Removed FARL outwith threshold
36019	Removed Area outwith threshold
30031	Removed Area outwith threshold
30061	Removed Area outwith threshold
25124	Kept - FARL within relaxed threshold (19% greater than subject site)
36012	Kept - FARL within relaxed threshold (19% greater than subject site)
26018	Kept - FARL within relaxed threshold (19% greater than subject site)
7011	Kept - FARL within relaxed threshold (19% greater than subject site)
7004	Kept - FARL within relaxed threshold (19% greater than subject site)
36011	Kept - FARL and Area within boundaries of relaxed threshold
35073	Kept - FARL and Area within boundaries of relaxed threshold
36027	Kept - Area within relaxed boundary
22035	Kept - Area within relaxed boundary
22071	Kept - Area within relaxed boundary
33070	Kept - BFI within relaxed boundary
31002	Kept - BFI within relaxed boundary
21001	Kept - BFI within relaxed boundary
1055	Kept - BFI within relaxed boundary
31072	Kept - BFI within relaxed boundary

STEP 4

Remove sites with high discordancy Di

Discordancy limit used: 3.0

Table A4.4 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)
25124	18	0.29	215.5
26059	23	0.07	256.6
36012	47	0.09	262.0
26018	49	0.04	119.5
7004	23	0.42	245.7
34018	27	0.18	95.4
36027	15	1.07	333.8
33070	28	0.03	87.9
31002	26	0.27	71.4
22035	14	0.68	559.7
22071	31	0.18	557.7
21001	25	1.09	47.2
39008	33	0.04	77.4
1055	9	0.22	9.7
31072	26	0.30	111.8

Total years	394

Pooled distributions for further consideration if different from EV1 and LN2:

EV1

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	1.21	1.21	1.17
10	1.36	1.33	1.28
20	1.49	1.45	1.37
50	1.67	1.58	1.49
100	1.80	1.68	1.58
200	1.93	1.78	1.67
1000	2.24	2.00	1.87

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 just 394-years of AMAX data and therefore caution is advised when applying the growth factors produced.

The target site, Bunratty Tributary, is not an ideal pooling site as the tributary has a relatively high BFI value of 0.82 and relatively high attenuating affect within the catchment (FARL = 0.67). Finding an appropriate pooling group has therefore proven difficult and a large number of sites have been removed from the pooling group even after relaxing parameter thresholds.

Shannon RBD Design Hydrology

CALCULATION AUDIT TRAIL

PART A4.A2 - Pooled analysis site A

Site name: Owenogarney (Rly Br.)

Gauging station No: 27011

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 27\S01 - S04 Catchment Model {Glasgow}\S03\Revised Hydrology_140403\S03 MS Pooled Flood Frequency Analysis (Corrected)

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	27011
Area	161.80
BFI	0.65
SAAR	1240.46
FARL	0.80
URBEXT	0.49
FLATWET	0.60

Number of pooled years required: 500 years

STEP 1 Use OPW pooled flood frequency spreadsheet to generate pooled group.

Is subject site in pooled group? ○ Yes ◉ No at ranked position:

Give reason if not at position 1: Station not listed

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 A4.3 Stations with outlying catchment descriptors

Station	Removed or kept with explanation
26014	Removed FARL outwith threshold
19016	Removed FARL outwith threshold
19015	Removed FARL outwith threshold
25038	Removed FARL outwith threshold
19001	Removed FARL outwith threshold
16007	Removed FARL outwith threshold
35071	Removed FARL outwith threshold
29004	Removed FARL outwith threshold
35001	Removed FARL outwith threshold
16003	Removed FARL outwith threshold
10028	Removed FARL outwith threshold
12013	Removed FARL outwith threshold
36015	Removed FARL outwith threshold
29007	Removed FARL outwith threshold
18005	Removed FARL outwith threshold
25029	Removed FARL outwith threshold
19020	Removed FARL outwith threshold
18001	Removed FARL outwith threshold
30037	Removed FARL outwith threshold
30021	Removed FARL outwith threshold
25044	Removed FARL outwith threshold
34005	Removed FARL outwith threshold
29001	Removed FARL outwith threshold
19046	Removed FARL outwith threshold
15007	Removed FARL outwith threshold
30005	Removed FARL outwith threshold
25020	Removed FARL outwith threshold
25014	Removed FARL outwith threshold
29011	Removed FARL outwith threshold
25027	Removed FARL outwith threshold
16006	Removed FARL outwith threshold
25002	Removed FARL outwith threshold
25005	Removed FARL outwith threshold
26010	Removed FARL outwith threshold
27003	Removed FARL outwith threshold
20006	Removed FARL outwith threshold
30007	Removed FARL outwith threshold
13002	Removed FARL outwith threshold

27070	Removed FARL outwith threshold
16005	Removed FARL outwith threshold
25022	Removed FARL outwith threshold
16012	Removed FARL outwith threshold
26019	Removed FARL outwith threshold
34024	Removed FARL outwith threshold
36027	Removed FARL outwith threshold
26012	Removed FLATWET outwith threshold
36071	Removed FARL outwith threshold
35005	Kept FARL (0.898) outwith upper threshold (0.88)
34011	Kept FLATWET slightly outwith threshold (0.72)

STEP 4 Remove sites with high discordancy Di

Discordancy limit used: 3.0

Table A4.4 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)
34011	30	0.176	143.0
25030	48	0.170	280.0
29071	26	0.018	123.8
26018	49	0.120	119.5
6070	27	0.081	162.0
6012	47	0.160	162.8
6011	48	0.276	229.2
7004	23	1.367	245.7
26008	50	0.162	280.3
7011	22	0.123	281.7
27002	51	0.170	564.3
36011	49	1.298	320.5
35005	55	0.213	639.7

Total years	525

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	1.21	1.18
10	1.36	1.34	1.28
20	1.50	1.46	1.38
50	1.68	1.60	1.50
100	1.82	1.70	1.59
200	1.95	1.80	1.68
1000	2.26	2.03	1.89

Comments:

CALCULATION AUDIT TRAIL

PART A4.A2 - Pooled analysis site A

Site name: Shannon (AFA) Drumgeely Creek

Gauging station No: N/A

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 27\S01 - S04 Catchment Model {Glasgow}\S04\S04_Pooled Flood Frequency Analysis_(27_1147_3)_Rev.2.1_Corrected 7th March

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	27_1147_3
Area	8.82
BFI	0.700
SAAR	1018
FARL	1.00
URBEXT	5.28
FLATWET	0.60

Number of pooled years required: 500 years

STEP 1 Use OPW pooled flood frequency spreadsheet to generate pooled group.

Is subject site in pooled group? ○ Yes ◉ No at ranked position:

Give reason if not at position 1: Ungauged Site

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
N/A	N/A

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
FLATWE	(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 A4.3 Stations with outlying catchment descriptors

Station	Removed or kept with explanation
	Removed all stations with area > 11.7 x target site
	Kept stations with URBEXT in the range of 0 - 6.18

Remove sites with high discordancy Di
STEP 4 Discordancy limit used: 3.0

Table A4.4 Stations removed due to discordancy

Station No	Discordancy
8009	3.65

Revisit STEPS 1 to 4
STEP 5 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)
25034	26	0.77	10.8
6030	27	0.86	10.4
30020	16	0.08	21.4
25040	19	0.14	28.0
24022	20	0.08	41.2
16051	13	0.71	34.2
26058	24	0.38	60.0
22009	24	0.10	35.4
13002	19	0.05	63.0
19046	9	0.47	63.2
8002	21	0.28	33.4
26022	33	0.21	61.9
6031	18	1.37	46.2
19020	28	0.34	74.0
16006	33	0.34	75.8
14009	25	0.08	68.4
19001	48	0.08	103.3
26010	35	0.10	94.5
25044	40	0.06	92.5
16005	30	0.15	84.0

Total Years	508

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)
2	1.00	1.00
5	1.29	1.29
10	1.49	1.48
20	1.67	1.65
50	1.91	1.86
100	2.09	2.03
200	2.27	2.18
1000	2.69	2.55

Comments:

For Area, the upper limit as prescribed in Step 3, has been relaxed to 11.7 x subject site. No change to lower limit.
URBEXT parameter also relaxed to allow sites with -5.28 (no relaxing of upper boundary as not necessary)

CALCULATION AUDIT TRAIL

PART A4.A2 - Pooled analysis site A

Site name: Shannon AFA (Ballycasey Creek)

Gauging station No: N/A

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 27\S01 - S04 Catchment Model {Glasgow}\S04\S04_Pooled Flood Frequency Analysis_Ballycassey_27_1160_5_corrected 7th Mar

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	27_1160_5
Area	4.7
BFI	0.669
SAAR	997
FARL	1.0
URBEXT	11.63
FLATWET	0.6

Number of pooled years required: 500 years

STEP 1 Use OPW pooled flood frequency spreadsheet to generate pooled group.

Is subject site in pooled group? ○ Yes ◉ No at ranked position:

Give reason if not at position 1: Ungauged Site

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
N/A	N/A

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 A4.3 Stations with outlying catchment descriptors

Station	Removed or kept with explanation
	Removed ALL stations with area > 16x target site
25034, 6030, 10022, 30020, 8005, 25040, 16051, 24022, 10021, 22009, 9035, 8002, 9002, 26058, 6031, 13002, 26022, 19046, 6033, 14009, 19020, 16006, 8012	Kept as within relaxed URBEXT / BFI / Area thresholds

STEP 4 Remove sites with high discordancy Di
Discordancy limit used: 3.0

Table A4.4 Stations removed due to discordancy

Station No	Discordancy
N/A	N/A

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.

STEP 5 | 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)
25034	26	0.42	10.8
6030	27	0.47	10.4
10022	17	0.13	12.9
30020	16	0.05	21.4
8005	18	0.44	9.2
25040	19	0.08	28.0
16051	13	0.38	34.2
24022	20	0.05	41.2
10021	24	0.13	32.5
22009	24	0.06	35.4
9035	9	0.58	37.1
8002	21	0.15	33.4
9002	25	1.09	35.0
26058	24	0.20	60.0
6031	18	0.75	46.2
13002	19	0.03	63.0
26022	33	0.11	61.9
19046	9	0.25	63.2
6033	25	1.35	55.2
14009	25	0.04	68.4
19020	28	0.19	74.0
16006	33	0.19	75.8
8012	19	0.53	26.0

Total Years	492

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)
2	1.00	1.00
5	1.40	1.41
10	1.66	1.69
20	1.91	1.95
50	2.24	2.31
100	2.49	2.58
200	2.73	2.86
1000	3.30	3.52

Comments:

The criteria for station selection has, by necessity, been relaxed. For catchment area, the upper limit as prescribed in Step 3, has been relaxed to allow sites with area ~16x that of the subject site. The lower threshold of the BFI parameter was relaxed to allow sites with values ~ < 30% and URBEXT threshold relaxed to allow sites with values -11.63 to +21.74

CALCULATION AUDIT TRAIL

PART A4.A2 - Pooled analysis site A

Site name: Kilrush

Gauging station No: Ungauged

Table A4.1 Pooled analysis file location

Description	File path
Pooled analysis	P:\32103000 - Shannon CFRAMS Study\Hydrological Assessment\A) Modelling\UoM 27\Kilrush_S18\Pooled FloodFrequency Analysis_S18.xls

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	27_968_4
Area	17.732
BFI	0.3954
SAAR	1067.26
FARL	0.982
URBEXT	1.06
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: 512

Is subject site in pooled group? ○ Yes ◉ No at ranked position:

Give reason if not at position 1: Site is ungauged

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
N/A	

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.

Using the recommended thresholds there is not a single suitable site for the pooling group based on Area. The upper limits of AREA has been increased to 140. Other thresholds has also been altered to improve the number of stations that fall outside the limits. The upper limit of BFIsoil value increased to 0.579, the lower limit of SAAR has been decreased to 790 and upper limit increased to 1480, the upper limit of FLATWET has been increased to 0.73.

AREA	between 0.25 and 7.8 times the area of the subject site.
BFIsoil	- 25% and +46.4% of subject site
SAAR	-74.02% and +38.7% of subject site
FARL	+/- 10% of subject site
URBEXT	+/- 2.5
FLATWET	(FORMWET) - 0.10 and +0.11 (half of total range)

Table A4.3 Stations with outlying catchment descriptors

Station	**Removed with explanation** + Reviewer initials if kept
8007	URBEXT value greater than 3.56.
36031	URBEXT value greater than 3.56.
36021	SAAR value greater than 138.7% of subject site.
3051	AREA larger than 7.8 times subject site.
25040	URBEXT value greater than 3.56.
22009	URBEXT value greater than 3.56.
8003	URBEXT value greater than 3.56.
9010	URBEXT value greater than 3.56.
8008	URBEXT value greater than 3.56.
23001	AREA larger than 7.8 times subject site.

STEP 4 Remove sites with high discordancy Di

Discordancy limit used: 3

Table A4.4 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

2nd iteration

Table A4.5 Stations with outlying catchment descriptors

Station	**Removed with explanation** + Reviewer initials if kept
26006	AREA larger than 7.8 times subject site.
30020	BFI value greater than 146.4% of subject site.
16051	BFI value greater than 146.4% of subject site.
32011	SAAR value greater than 138.7% of subject site
24030	AREA larger than 7.8 times subject site.
31002	SAAR value greater than 138.7% of subject site. FARL value less than 10% of subject site.

3rd iteration

Table A4.6 Stations with outlying catchment descriptors

Station	**Removed with explanation** + Reviewer initials if kept
33070	FARL value less than 10% of subject site.
33001	BFI value less than 25% of subject site.
9011	SAAR value less than 74.02% of subject site. URBEXT value greater than 3.56.
16006	BFI value greater than 146.4% of subject site.

4th iteration

Table A4.7 Stations with outlying catchment descriptors

Station	**Removed with explanation** + Reviewer initials if kept
6030	BFI value greater than 146.4% of subject site.
8009	URBEXT value greater than 3.56. SAAR value less than 74.02% of subject site.

Final pooling group

Table A4.5 Final pooling group summary

Station No	Years of data	Discordancy	Area (km2)
23012	18	0.695	61.631
14033	9	1.008	78.892
8012	19	0.553	25.953
34009	33	0.031	117.114
1041	32	0.082	116.180
27001	9	0.148	46.699
35004	14	0.372	116.957
6031	18	0.777	46.174
16005	30	0.088	84.000
26009	35	0.109	98.221
18016	20	0.237	116.728
7033	25	0.042	124.936
6033	25	1.405	55.227
34024	28	0.255	127.227
35002	34	0.136	88.820
25158	18	0.434	109.547
26010	35	0.057	94.527
8002	21	0.158	33.428
25044	40	0.037	92.546
26020	33	0.209	122.436
30021	26	0.169	103.630

Pooled distributions for further consideration if different from EV1 and LN2:

LO

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	1.21
10	1.43	1.42	1.34
20	1.60	1.56	1.45
50	1.82	1.75	1.59
100	1.98	1.88	1.70
200	2.14	2.02	1.81
1000	2.51	2.32	2.05

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.

Comments:

CALCULATION AUDIT TRAIL

PART A4.A2 - Pooled analysis site A

Site name: Kilkee (River 1)

Gauging station No: Ungauged

Table A4.1 Pooled analysis file location

Description	File path
Pooled analysis	P:\32103000 - \\reafil08\projects\32103000 - Shannon CFRAMS Study\Hydrological Assessment\A) Modelling\UoM 27\Kilkee_S19

FSU location details from pooled flood frequency analysis spreadsheet:

Site no.	27_1006_2
Area	1.194
BFI	0.334
SAAR	1110.31
FARL	1
URBEXT	0
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: 508

Is subject site in pooled group? ○ Yes ◉ No at ranked position:

Give reason if not at position 1: This site is ungauaged

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.

Using the recommended thesholds there is not a single suitable site for the pooling group based on Area. The upper limit value of the following descriptors i.e. AREA, BFIsoils, FORMWET and SAAR has therefore been increased to improve the number of stations that fall outside catchment descriptors limits. AREA has been increased from 5 to 120, BFIsoil value increased from 0.42 to 0.579, FORMWET from 0.72 to 0.73 and SAAR increased from 1387.9 to 2000.

AREA	between 0.25 and 100.5 times the area of the subject site
BFIsoil	- 25% and +73.4% of subject site
SAAR	- 25% and +80.1% of subject site
FARL	+/- 10% of subject site
URBEXT	+/- 2.5
FLATWET	(FORMWET) - 0.10 and +0.11 (half of total range)

Table A4.3 Stations with outlying catchment descriptors

Station	**Removed with explanation** + Reviewer initials if kept
9011	URBEXT is 2.5 points greater than subject site. SAAR less than 25% of subject site
8012	SAAR less than 25% of subject site.
8007	URBEXT is 2.5 points greater than subject site.
6030	BFIsoils value greater than 180.1% of subject site.
1055	FARL value less than 10% of subject site.
25040	URBEXT is 2.5 points greater than subject site.
30020	BFIsoils value greater than 180.1% of subject site.
22009	URBEXT is 2.5 points greater than subject site.
36031	URBEXT is 2.5 points greater than subject site.
16051	BFIsoils value greater than 180.1% of subject site.
8005	SAAR less than 25% of subject site. BFIsoils value greater than 180.1% of subject site. URBEXT is 2.5 points greater than subject site.
10022	SAAR less than 25% of subject site. BFIsoils value greater than 180.1% of subject site. URBEXT is 2.5 points greater than subject site.
8002	SAAR less than 25% of subject site.

STEP 4 Remove sites with high discordancy Di

Discordancy limit used: 3

Table A4.4 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

2nd iteration

Table A4.5 Stations with outlying catchment descriptors

Station	**Removed with explanation** + Reviewer initials if kept
25034	BFIsoil value greater than 180.1% of subject site.
31002	FARL value less than 10% of subject site.
23001	AREA value larger than 100.5 times of subject site.
28001	AREA value larger than 100.5 times of subject site.
6033	URBEXT is 2.5 points greater than subject site.
39008	FARL value less than 10% of subject site.

8003	URBEXT is 2.5 points greater than subject site. SAAR value less than 25% of subject site.

3rd iteration
Table A4.6 Stations with outlying catchment descriptors

Station	Removed with explanation + Reviewer initials if kept
9010	URBEXT is 2.5 points greater than subject site.
33070	FARL value less than 10% of subject site.
34007	AREA larger than 100.5 times of subject site.
3051	URBEXT is 2.5 points greater than subject site. AREA larger than 100.5 times of subject site.
24022	BFIsoils value greater than 180.1% of subject site.

4th iteration
Table A4.7 Stations with outlying catchment descriptors

Station	Removed with explanation + Reviewer initials if kept
8009	URBEXT is 2.5 points greater than subject site. SAAR value less than 25% of subject site.
8008	URBEXT is 2.5 points greater than subject site. SAAR value less than 25% of subject site.
9035	URBEXT is 2.5 points greater than subject site. SAAR value less than 25% of subject site. BFIsoils value greater than 180.1% of subject site.

5th iteration
Table A4.8 Stations with outlying catchment descriptors

Station	Removed with explanation + Reviewer initials if kept
9002	URBEXT is 2.5 points greater than subject site. SAAR value less than 25% of subject site. BFIsoils value greater than 180.1% of subject site.
26022	BFIsoils value greater than 180.1% of subject site.

6th iteration
Table A4.9 Stations with outlying catchment descriptors

Station	Removed with explanation + Reviewer initials if kept
34024	AREA larger than 100.5 times of subject site.
16006	BFIsoils value greater than 180.1% of subject site.

7th iteration
Table A4.10 Stations with outlying catchment descriptors

Station	Removed with explanation + Reviewer initials if kept
7033	FARL value less than 10% of subject site. AREA larger than 100.5 times of subject site.

8th iteration
Table A4.11 Stations with outlying catchment descriptors

Station	Removed with explanation + Reviewer initials if kept
30001	AREA larger than 100.5 times of subject site.

9th iteration
Table A4.12 Stations with outlying catchment descriptors

Station	Removed with explanation + Reviewer initials if kept
10021	URBEXT is 2.5 points greater than subject site. SAAR value less than 25% of subject site. BFIsoils value greater than 180.1% of subject site.

Final pooling group

Table A4.13 Final pooling group summary

Station No	Years of data	Discordancy	Area (km2)
36021	27	0.087	23.406
27001	9	0.164	46.699
23012	18	0.773	61.631
39001	31	0.162	50.710
33001	25	0.057	76.120
32011	25	0.110	70.102
14033	9	1.121	78.892
1041	32	0.091	116.180
10004	14	1.662	30.567
18016	20	0.263	116.728
6031	18	0.865	46.174
34009	33	0.035	117.114
38001	33	0.101	111.245
35004	14	0.414	116.957
16005	30	0.098	84.000
35002	34	0.152	88.820
26009	35	0.121	98.221
25158	18	0.483	109.547
16013	33	0.139	93.583
25044	40	0.041	92.546
26010	35	0.063	94.527

Pooled distributions for further consideration if different from EV1 and LN2:

LO

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	1.25	1.24	1.31
10	1.42	1.40	1.48
20	1.57	1.53	1.65
50	1.78	1.71	1.86
100	1.93	1.83	2.01
200	2.09	1.96	2.17
1000	2.44	2.24	2.52

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.

Comments:

35 of the selected catchments were removed as they were not deemed appropriate - this amounts to 16% of the dataset. These stations had to be removed because of the following reason(s); SAAR <25%, FLATWET>110%, URBEXT more than 2.5 points greater, FARL<10%, BFIsoil>180.1% and AREA>120. With so many stations removed the resultant pooling group will be less hydrologically similar to the study site.

Appendix H Geomorphology Assessment

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

SHANNON CFRAM STUDY
CATCHMENT FLOOD RISK ASSESSMENT AND MANAGEMENT

Shannon Catchment-based Flood Risk Assessment and Management Study

Office of Public Works

Geomorphology Assessment

Final Report

JACOBS

July 2016

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).

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OPW
The Office of Public Works
Oifig na nOibreacha Poiblí

Contents

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 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 18,000km2 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.

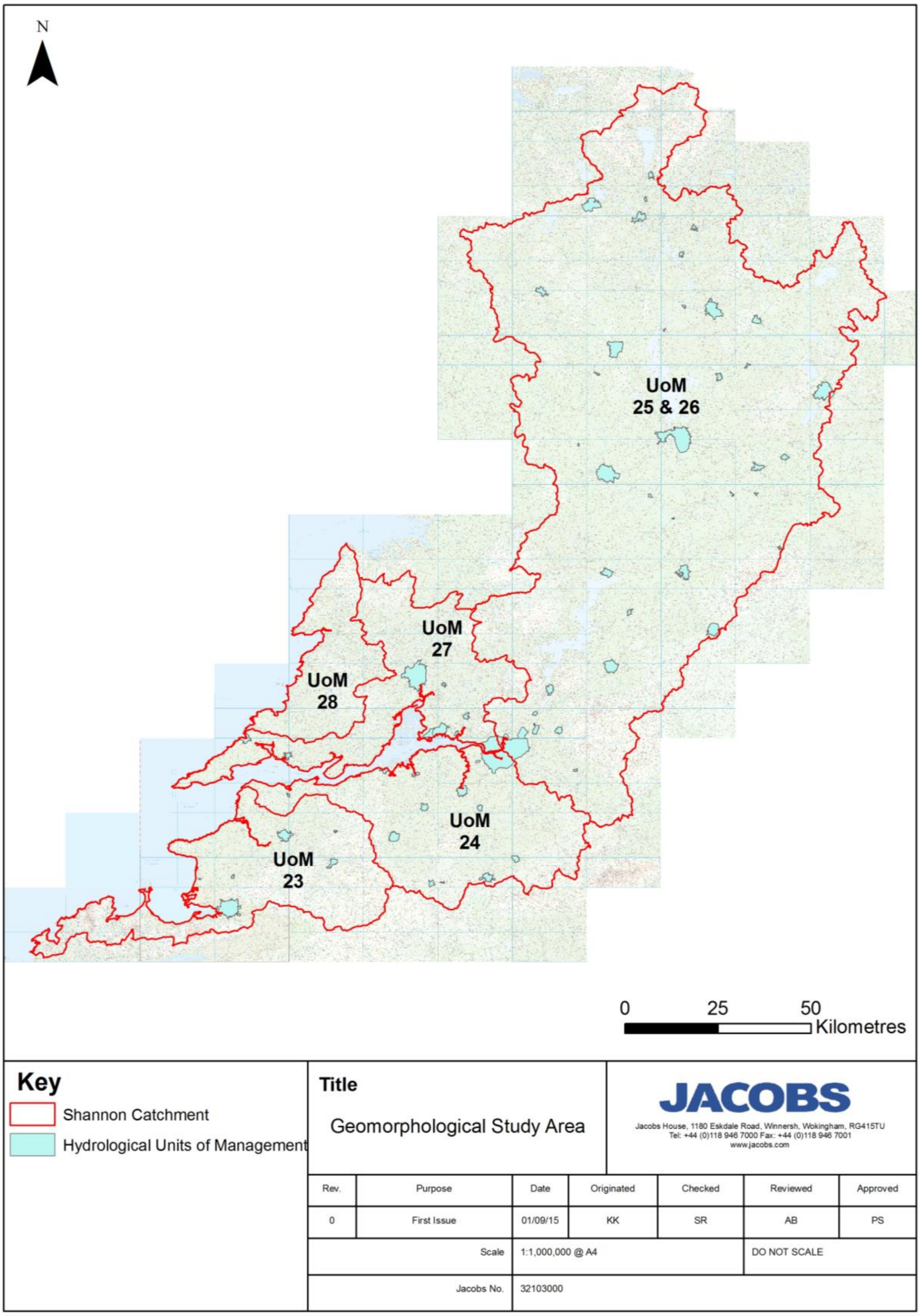

Figure 1.1 Geomorphological assessment study area

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
Type 1	Lower catchment channels: • Those having not perceptibly changed their courses (naturally); • Low to very low energy; • Predominantly sediment sinks; • Likely to have regular to irregular sinuosity (note: straight channels extremely rare in nature); • Tree-lined gravely channels to clay bound channels; • Sinuosity could have been inherited from early Holocene times; and, • Includes clay channels found locally on glacio-lacustrine and glacio-marine sediments.	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).	• Less than 40m contour; and, • Alluvium as shown on drift geology map.	None.
Type 2	Inactive alluvial channels: • Narrow valleys of the main stem of the Shannon and its tributaries; • Little scope for meander development; • Confined channel patterns; • Likely to be a legacy from the Ice Age (i.e. palaeohydrological origin); river terraces could be present; and, • Could be locally cut into rock sides.	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.	• Areas between the 40m and 300m contours; and, • Alluvium as shown on drift geology map.	None.
Type 3	Self-formed alluvial channels: • Moderate energy; • Predominantly a sediment exchange (transfer); • Can be described as an active mobile gravel bed river; • Presence of active meandering; • Bedload likely to be a mix of coarse and fine gravels to coarse gravels carried from upstream; and, • Well defined pools and riffles and bar features; mature floodplain with a fining upwards sequence of sediments.	Lower risk of erosion than Type 4 but probably a higher risk of sediment issues than Type 4. 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). Previously straightened channels could have partially recovered sinuosity.	• Areas between the 40m and 60m contours; • Alluvium as shown on drift geology map; and • Historically active.	Field drains in Piedmont alluvial floodplain not included. Tributaries on floodplain of main stem may exhibit some of the characteristics of Type 4 channels.

Type 4	Self-formed alluvial channels: Piedmont • High energy; • Predominantly a sediment exchange (transfer); • Can be described as an active mobile gravel bed river; • Presence of active meandering; • Bedload likely to be coarse gravels carried down from Type 1 channels and deposited on less steep slopes; • Exposed point bars; and • Could be some fine silt from diffuse pollution sources such as agriculture.	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). Previously straightened channels could have partially or fully recovered their sinuosity.	• Areas between the 60m and 300m contours; • Alluvium as shown on drift geology map; and, • Historically active.	Field drains in Piedmont alluvial floodplain not included. Tributaries on floodplain of main stem could exhibit some of the characteristics of Type 4 channels.
Type 5	Bedrock channels: • High energy; • Inherently stable; and, • Predominantly sediment sources.	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).	• Areas above the 300m contour.	Peat bogs/peat channels and local field drains could be present but not included at this scale.

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 (Ω) represents the potential energy loss rate per unit length of the channel. Stream power is the product of gravitational acceleration (g = 9.8m/s2), discharge (Q, m3/s), water surface slope (S), and the density of water (ρ =1000kg/m3) (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: <10Wm-2; 10-35 Wm-2; 35-100 Wm-2; 100-300 Wm-2; and over 300 Wm-2.

$$\Omega = \rho g Q S \qquad \text{(Eq. 1)}$$

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 (Si); 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.

	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.
Slope	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 bank full 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 18,000km2. The Shannon is flat, with the majority of the fall in altitude taking place on the 24km stretch between Killaloe 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 over-arching 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 Rosscommon 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.

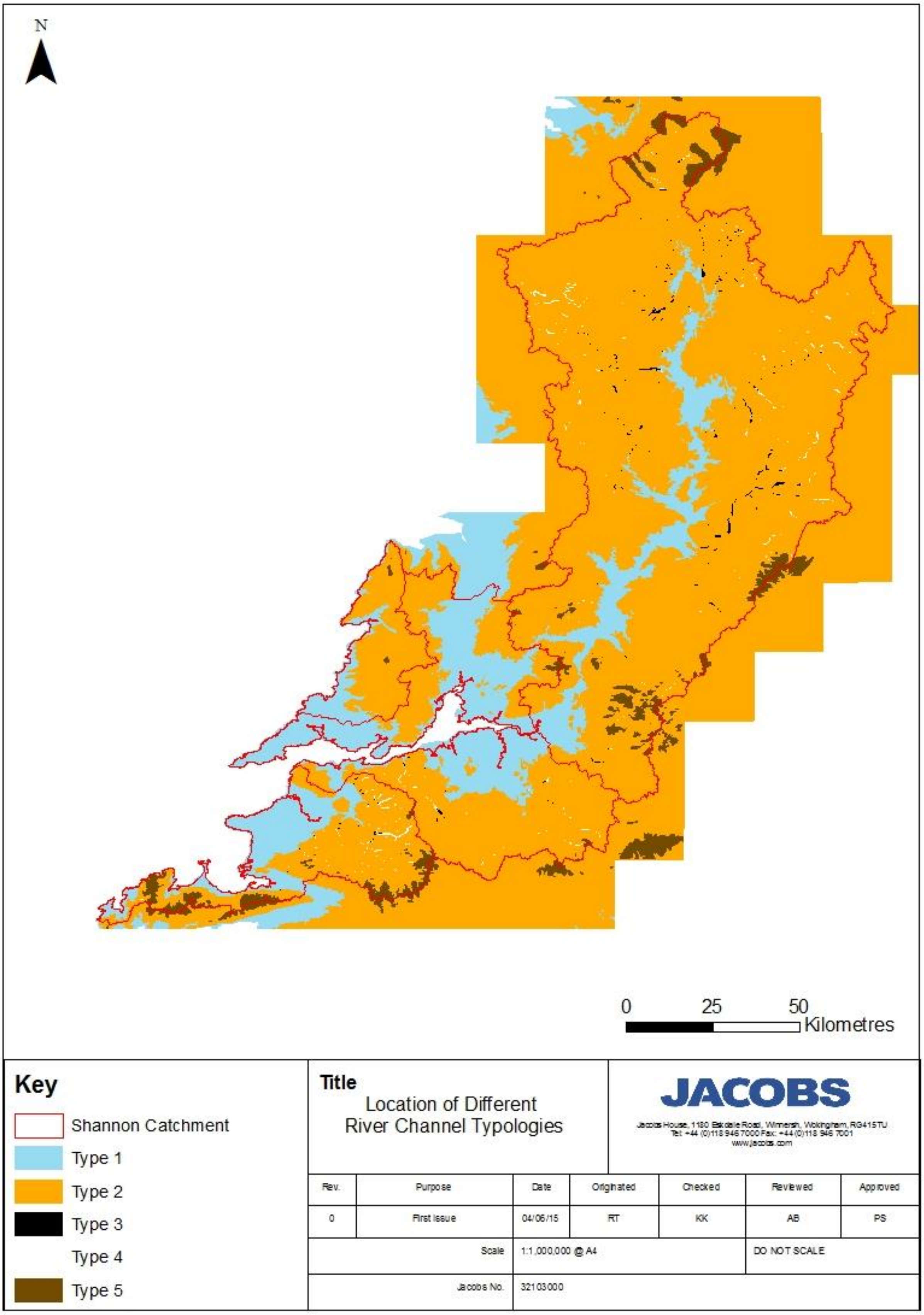

Figure 4.1 River channel types

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	• Main stem of the River Shannon; • Lowland rivers in County Clare and County Kerry.	Low	High	• Land management to prevent poaching of existing eroding banks and control of diffuse runoff from agricultural sources; • Incorporate Sustainable Urban Drainage Systems (SuDS) and blue-green infrastructure into future developments, sustainably managing potential sources of sediment; • Riparian corridor planting along eroding banks to minimise access to channel, addition of a buffer and removing some sediment sources; and, • Dredging to remove fines directly from the channels (NB this could be unsustainable or environmentally undesirable).
Type 2	• Throughout the catchment.	Low to Moderate	Low to Moderate	• Incorporate Sustainable Urban Drainage Systems (SuDS) and blue-green infrastructure into future developments, sustainably managing potential sources of sediment; • Land management to prevent poaching of existing eroding banks and control of diffuse agricultural sources; and, • Riparian corridor planting along eroding banks to minimise access to channel, add a buffer and remove some sediment sources.
Type 3	• River Brosna around Ferbane in County Offaly; • River Scramage around Strokestown in County Roscommon; • Hind river around Roscommon in County Roscommon; and, • The river network around Mohill in County Leitrim.	Moderate to High	Moderate to High	• Land management to prevent poaching of existing eroding banks and agricultural diffuse runoff; • Riparian corridor planting along eroding banks to minimise access to channel, add a buffer and remove some sediment sources; • Incorporate Sustainable Urban Drainage Systems (SuDS) and blue-green infrastructure into future developments, sustainably managing potential sources of sediment; • ‘Soft’ bank reinforcement such as

River Channel Type	Significant Locations	Risk of Erosion	Risk of Deposition	Potential River Management Solutions
				vegetative techniques reducing erosion and increasing resilience of eroding banks; • '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); • Flow deflectors to protect eroding banks, encouraging flow diversity and remove fine sediment; and, • Dredging to remove fines directly from the channels (although this may be unsustainable and environmentally unacceptable).
Type 4	• The river network around Tralee and Listowel in County Kerry; • River Suck around Castlerea in County Roscommon; • River Brosna around Kilbeggan in County Westmeath; and, • The river network around Castlepollard in County Westmeath.	High	Moderate	• Land management to prevent poaching of existing eroding banks and control diffuse pollution from agricultural sources; • 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; • Incorporate Sustainable Urban Drainage Systems (SuDS) and blue-green infrastructure into future developments, sustainably managing potential sources of sediment; • 'Soft' bank reinforcement such as vegetative techniques reducing erosion and increasing resilience of eroding banks; • 'Hard' bank reinforcement such as gabions and concrete bed/banks reducing erosion and increasing resilience of eroding banks; and, • Flow deflectors to protect eroding banks, encourage flow diversity and locally induce deposition of fine sediment.

River Channel Type	Significant Locations	Risk of Erosion	Risk of Deposition	Potential River Management Solutions
Type 5	• Slieve Bloom Mountains; • Slieve Felim Mountains; • Silvermere Mountains; • Mullaghreirk Mountains; • Ballyhoura Mountains; • Dartry Mountains; and, • Sieve Mish Mountains.	Very Low	Very Low	• Do nothing

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-2 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 10Wm-2 to 50Wm-2, with only the very upper catchment areas having stream powers in excess of 50Wm-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 Maigue at Creggane) are affected by backwater effects from the Maigue 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.

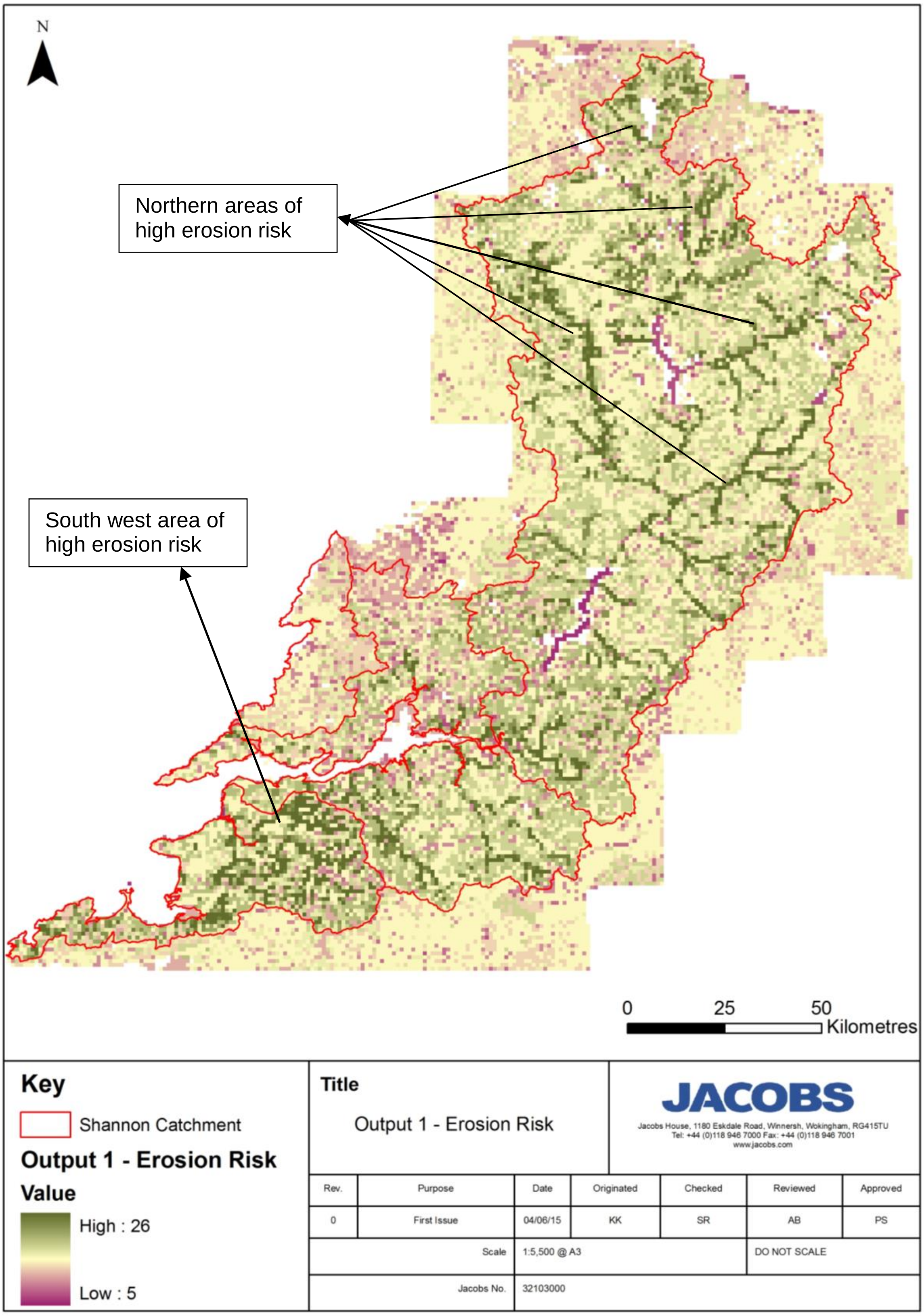

Figure 5.1 Potential risk of erosion (output 1)

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-2 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-2 to 50Wm-2) 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 10Wm-2) with the upper section indicating some areas of higher stream powers (ranging from 50-300Wm-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.

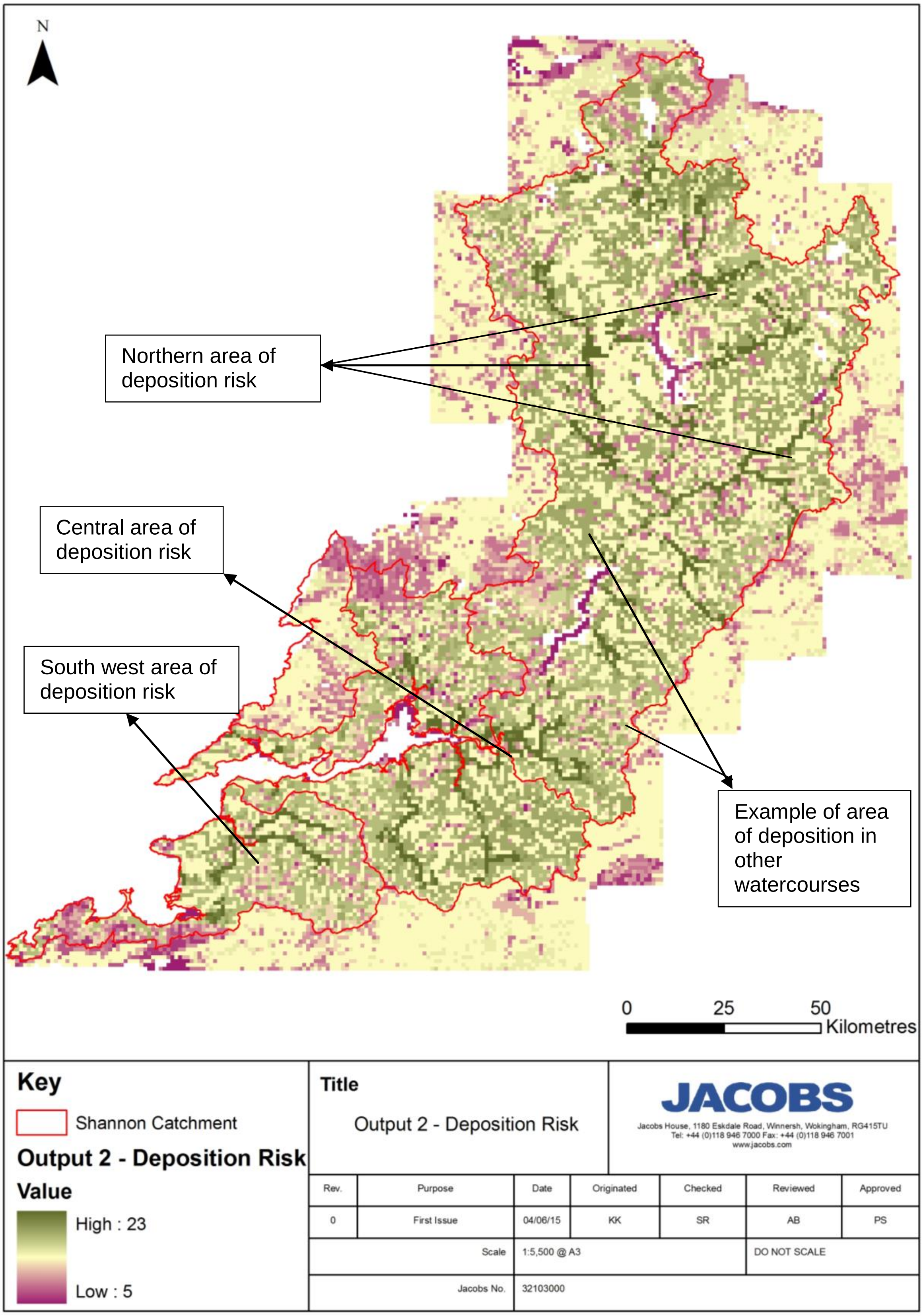

Figure 5.2 Potential risk of deposition (output 2)

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.

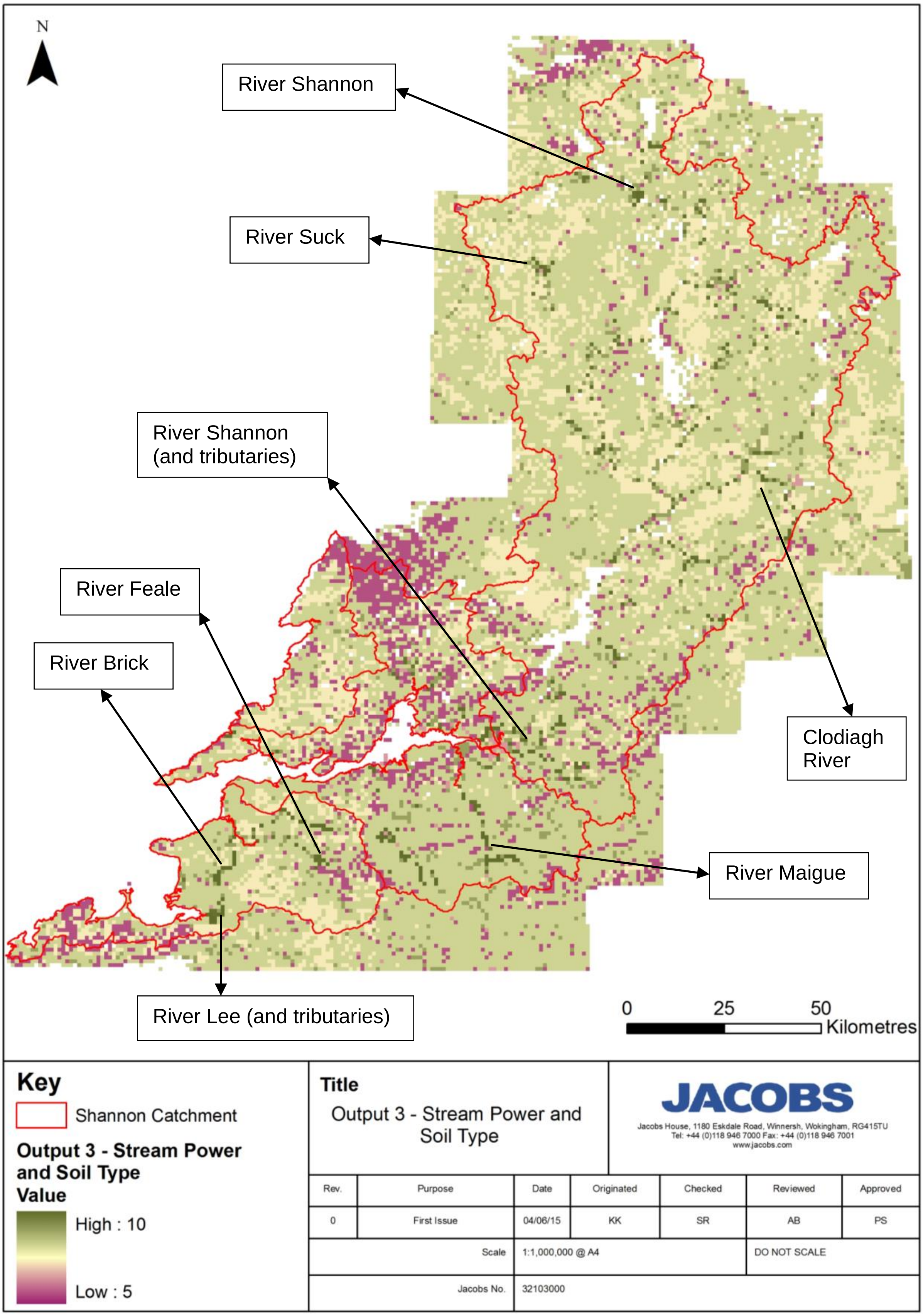

Figure 5.3 Stream power and soil type analysis (output 3)

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 Predicted Geomorphological Risk
		Provisional Typology	Risk of Erosion	Risk of Deposition	
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	Sinuous 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	Sinuous 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	Sinuous 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^{-2}.	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
Unit of Management 25 and 26					
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	Sinuous 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	Sinuous channels with reaches channelized downstream of the defined area. Typically medium slopes with rivers of medium stream power (ranging from 10-50Wm^{-2}).	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	Sinuous 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	Sinuous 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 powesr.	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^{-2}).	Type 1 and Type 2	High	High	Medium
Pollagh	Sinuous planforms with low gradients and rivers with relatively low stream powers.	Type 2 and Type 3	High	High	Medium
Rahan	Sinuous 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	Sinuous 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	Sinuous 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^{-2}.	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	Sinuous channel planforms with low slopes but rivers with medium stream powers (ranging from 10-50Wm^{-2}). Reach has been historically realigned.	Type 2 and Type 3	High	High	High
Mohill	Sinuous channel planform with low slopes but rivers with medium stream powers (ranging from 10-50Wm^{-2}).	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
Unit of Management 27					
Kilkee	Sinuous and meandering channels, with some straighter reaches. Predominantly medium slope with rivers of high stream powers.	Type 1	High	High	High
Kilrush	Sinuous 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 sinuous 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. Sinuous 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	Sinuous 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)

8 Summary, Recommendations and Next Steps

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).

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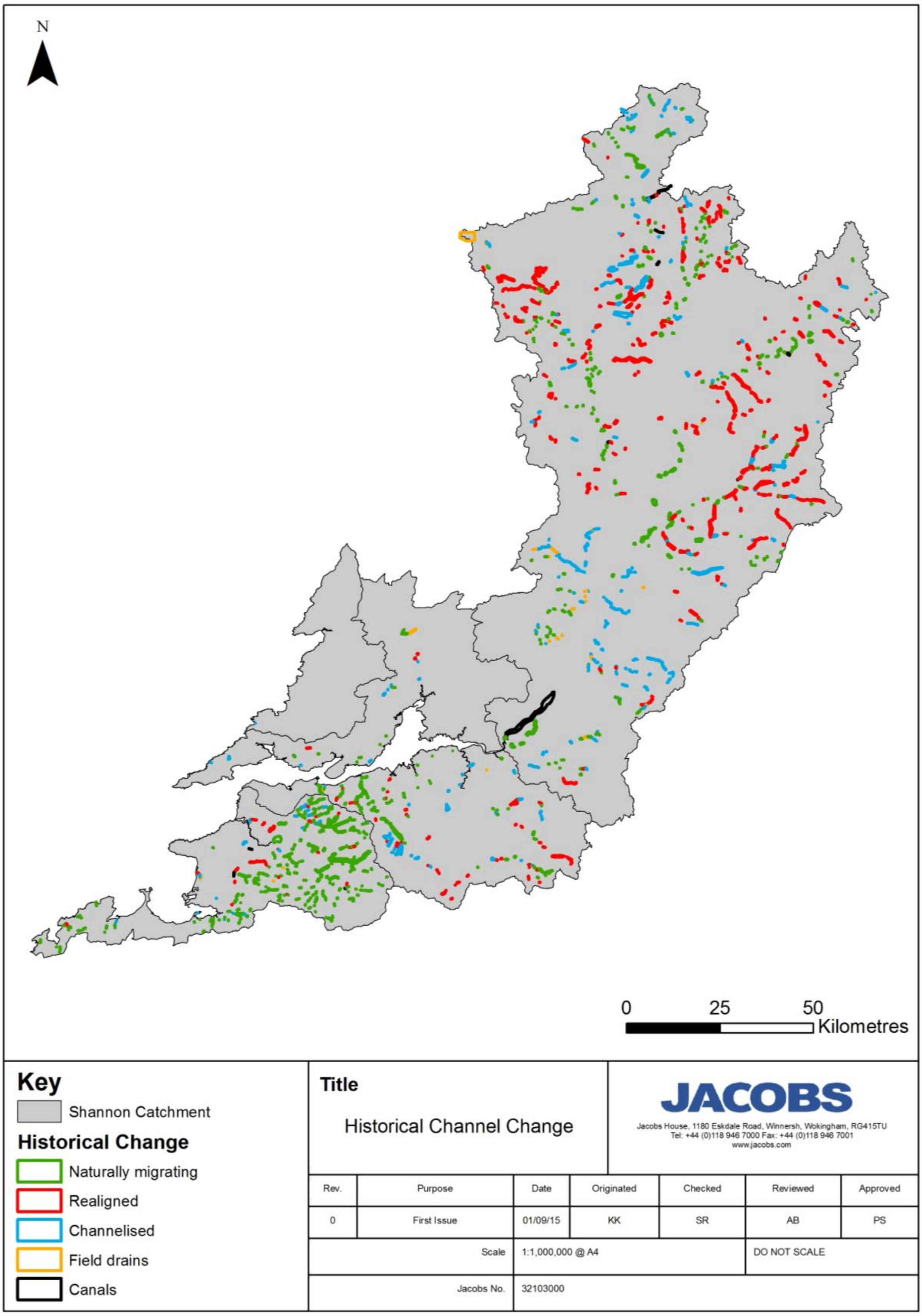
Appendix A Gauging Station Information Sheets



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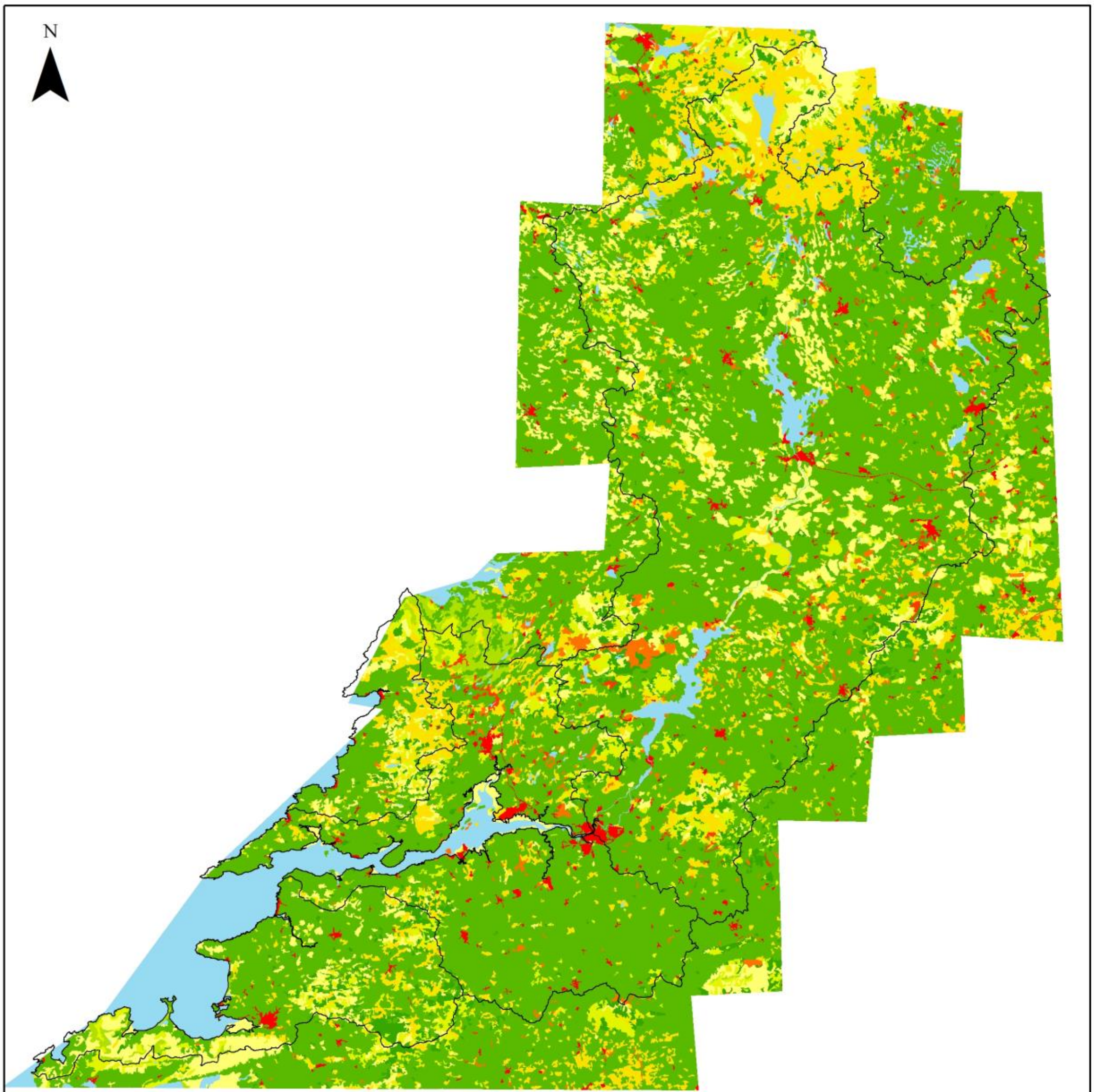

Shannon Catchment

Land Use

- Arable
- Artificial surface
- Coniferous/Plantation
- Forest
- Open space with little veg
- Pastures
- Shrub/herbaceous veg
- Water body
- Wetlands
- Woodland

0 25 50 Kilometres

Title

Land Use

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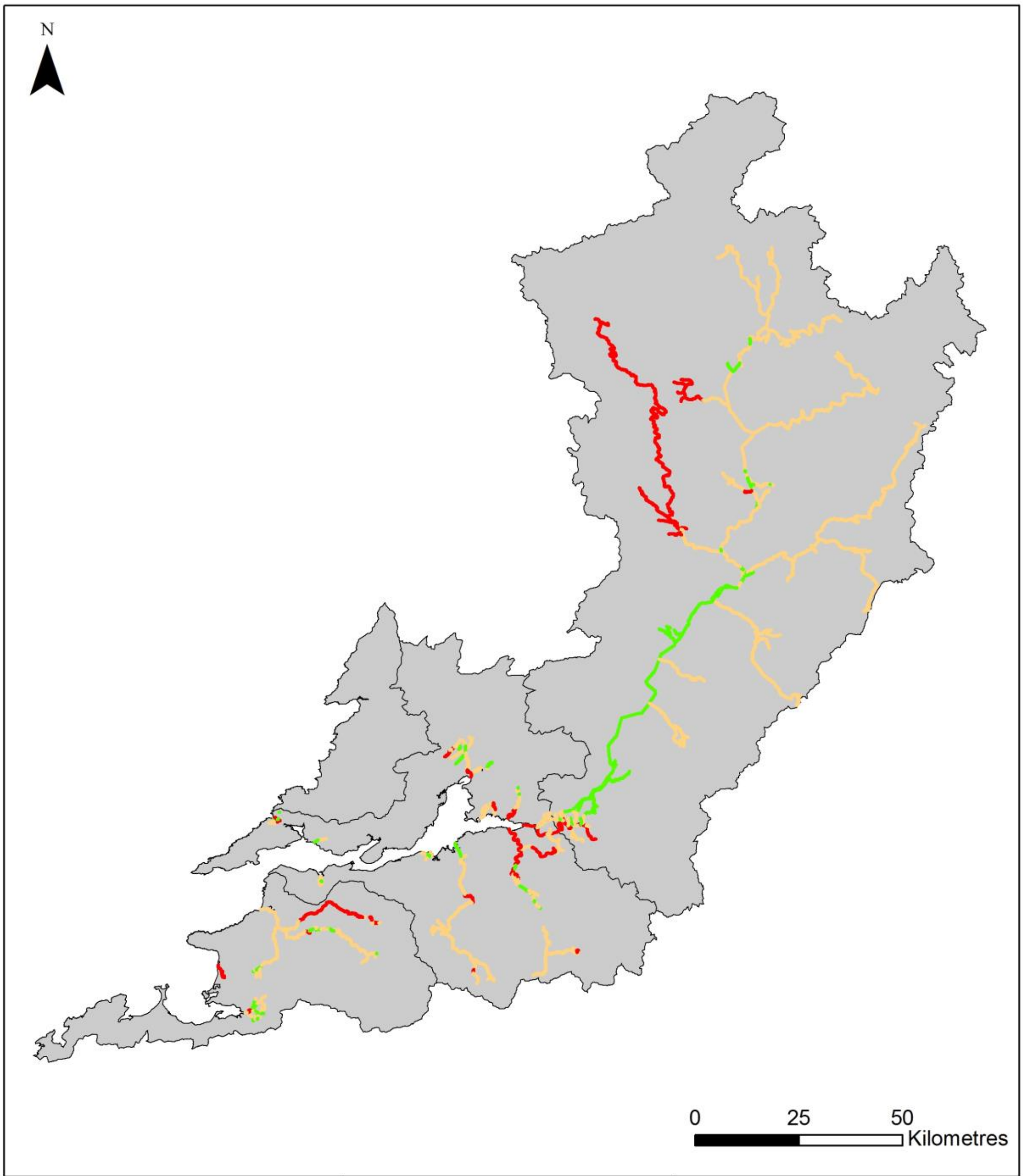

Key

Shannon Catchment

Sinuosity

Straight

Sinuous

Meandering

Title

Sinuousity Index

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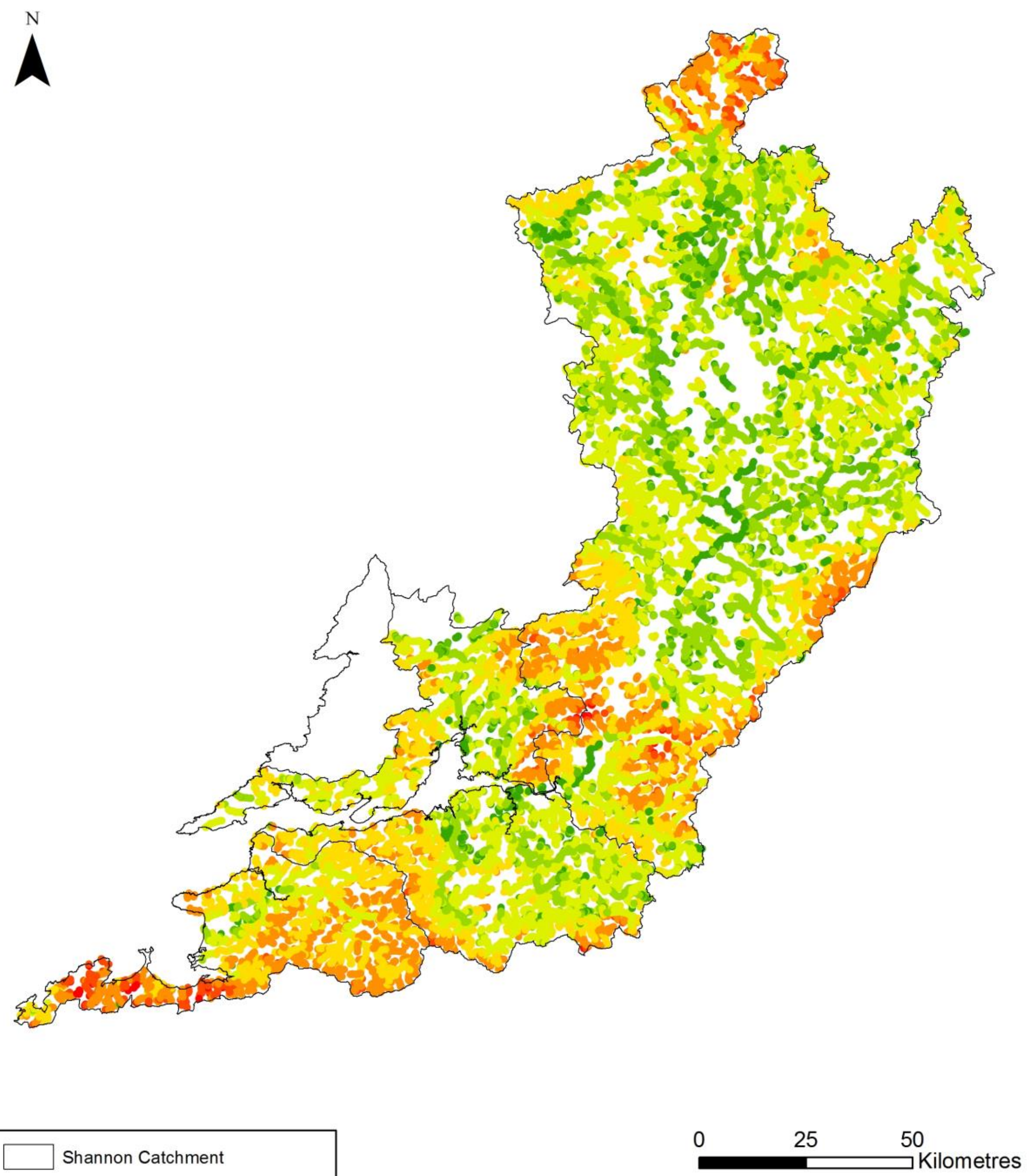

Shannon Catchment

Slope

- 0-0.2
- 0.3-1
- 1-3
- 3-10
- 10-30
- 30-100
- 100-200
- 200+

Title

Slope

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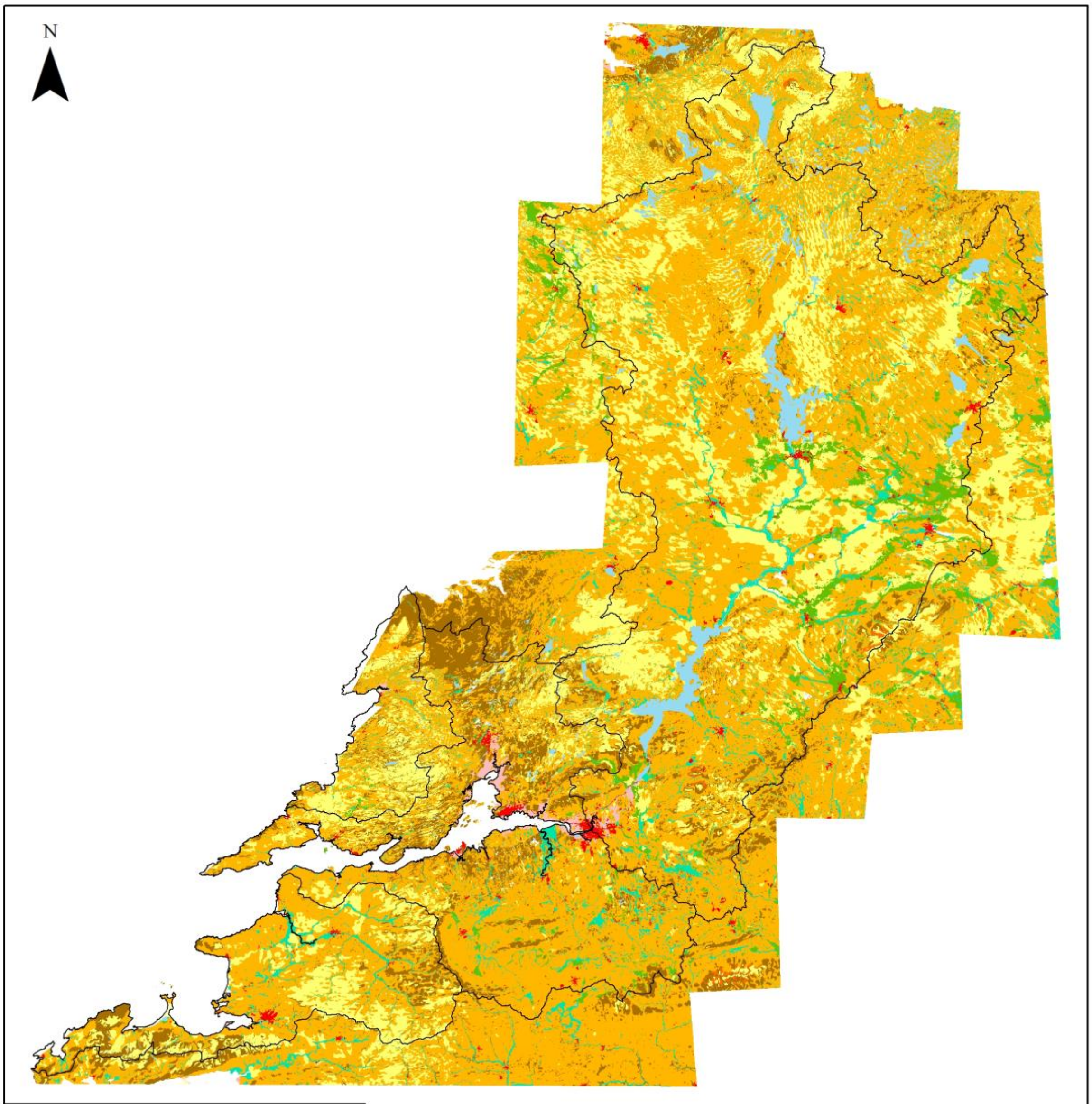

Shannon Catchment

Soils

- Alluvium
- Bedrock at surface
- Glaciolacustrine/Glaciofluvial
- Made ground
- Marine deposits - silts/clays
- Peat
- Sand
- Scree
- Tills
- Water

0 25 50 Kilometres

Title

Soil Type

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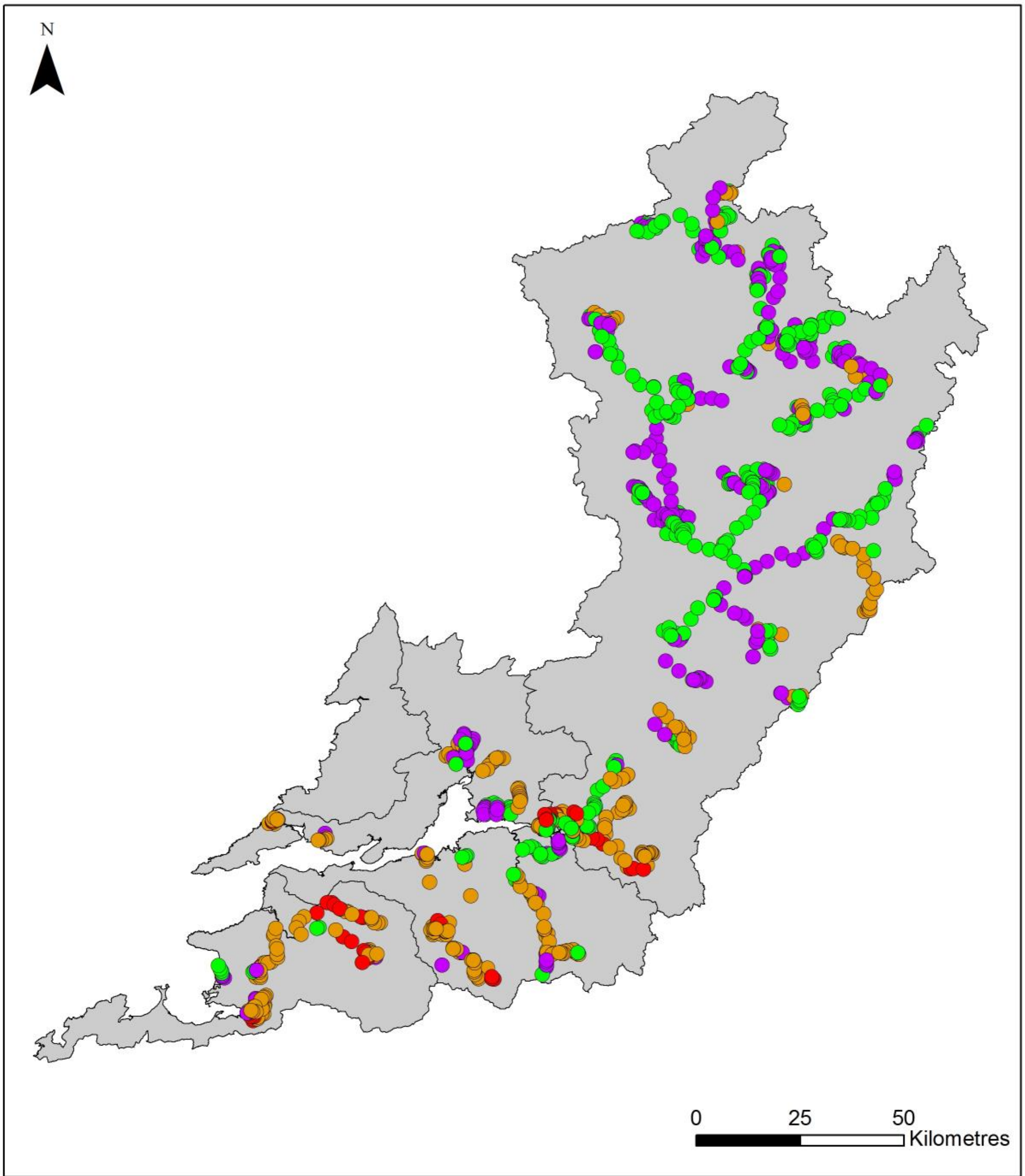

Key

Shannon Catchment

Stream Power

(Wm2)

- <10
- 10-50
- 50-300
- 300-1000

Title

Stream Power

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