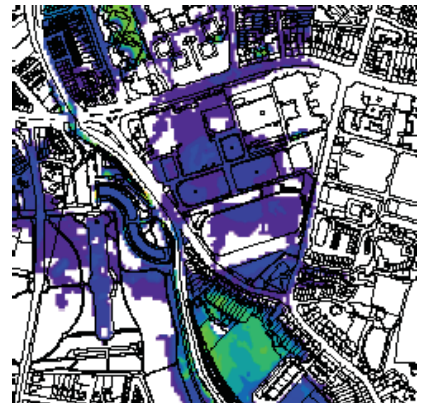
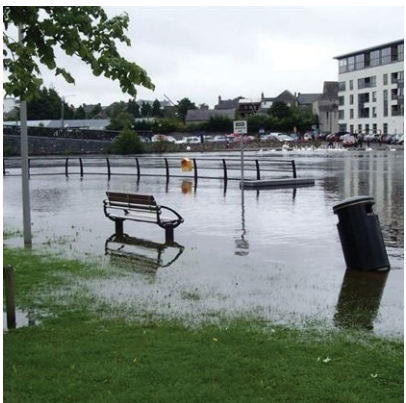
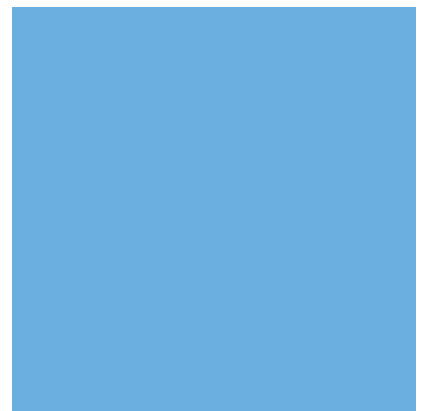




South Eastern CFRAM Study

HA 15 Hydrology Report

IBE0601Rp0010





South Eastern CFRAM Study

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ABBREVIATIONS

AEP	Annual Exceedance Probability
AFA	Area for Further Assessment
AFF	At-site Flood Frequency
AMAX	Annual Maximum flood series
AREA	Catchment Area
BFI	Base Flow Index
CFRAM	Catchment Flood Risk Assessment and Management
CORINE	Coordination of Information on the Environment
C4i	Community Climate Change Consortium for Ireland
DTM	Digital Terrain Model
ERBD	Eastern River Basin District
EV1	Extreme Value Type 1 (distribution) (=Gumbel distribution)
EPA	Environmental Protection Agency
FARL	Flood Attenuation for Rivers and Lakes
FEH	Flood Estimation Handbook
FEM-FRAMS	Fingal East Meath Catchment Flood Risk Assessment and Management Study
FRA	Flood Risk Assessment
FRMP	Flood Risk Management Plan
FSR	Flood Studies Report
FSSR 16	Flood Studies Supplementary Report No. 16
FSU	Flood Studies Update
GC	Growth Curve
GDSDS	Greater Dublin Strategic Drainage Study
GEV	Generalised Extreme Value (distribution)
GLO	General Logistic (distribution)
GSI	Geological Survey of Ireland
HA	Hydrometric Area
HEFS	High End Future Scenario (Climate Change)
HEP	Hydrological Estimation Point

HPW	High Priority Watercourse
HWA	Hydrograph Width Analysis
IH124	Institute of Hydrology Report No. 124
IPCC	Intergovernmental Panel on Climate Change
LA	Local Authority
LN2	2 Parameter Log Normal (distribution)
L-CV	Coefficient of L variation
MPW	Medium Priority Watercourse
MRFS	Mid Range Future Scenario (Climate Change)
NDTM	National Digital Terrain Model
OD	Ordnance Datum
OPW	Office of Public Works
OSi	Ordnance Survey Ireland
PFRA	Preliminary Flood Risk Assessment
Q_{med}	median of AMAX flood series
$Q_{bar} / QBAR$	mean average of AMAX flood series
RBD	River Basin District
RFF	Regional Flood Frequency
ROI	Region of Influence
SAAR	Standard Average Annual Rainfall (mm)
SERBD	South Eastern River Basin District
SuDS	Sustainable Urban Drainage
UAF	Urban Adjustment Factor
UoM	Unit of Management

1 INTRODUCTION

The Office of Public Works (OPW) commissioned RPS to undertake the South Eastern Catchment Flood Risk Assessment and Management Study (South Eastern CFRAM Study) in July 2011. The South Eastern CFRAM Study was the third catchment flood risk management study to be commissioned in Ireland under the EC Directive on the Assessment and Management of Flood Risks 2007 as implemented in Ireland by SI 122 of 2010 European Communities (Assessment and Management of Flood Risks) Regulations 2010.

The South Eastern CFRAM Study covers an area of approximately 12,857 km² and includes six Units of Management / Hydrometric Areas (Unit of Management Boundaries match the Hydrometric Area boundaries within the overall Study area). These are HA/UoM 11 (Owenavorrhagh), HA/UoM 12 (Slaney and Wexford Harbour), HA/UoM 13 (Ballyteigue - Bannow), HA/UoM 14 (Barrow), HA/UoM 15 (Nore), and HA/UoM17 (Colligan – Mahon). HA/UoM16 (Suir) is also within the South Eastern area but is covered by the Suir pilot CFRAM Study and covers an area of approximately 3,452 km². There is a high level of flood risk within the South Eastern CFRAM Study area with significant coastal and fluvial flooding events having occurred in the past.

HA15 is a predominantly rural catchment in an Irish context, with the largest urban area being Kilkenny. Smaller towns and villages include Thomastown, Callan and Castlecomer in County Kilkenny and Durrow, Rathdowney and Mountrath in County Laois. The rich soils are particularly suitable for agriculture and much of the area is given over to tillage and grassland.

Within HA15 there are 11 Areas for Further Assessment (AFA) as shown in Table 1.1 and Figure 1.1.

Table 1.1: Fluvial and Coastal Flood Risk at each AFA

AFA	Fluvial	Coastal	AFA	Fluvial	Coastal
Mountrath	✓	-	Kilkenny (Breagagh)	✓	-
Ballyroan	✓	-	Callan	✓	-
Rathdowney	✓	-	Thomastown	✓	-
Ballyragget	✓	-	Ballyhale	✓	-
Freshford	✓	-	Inistioge	✓	-
Kilkenny (Nore)	✓	-			
Total			11	11	0

Although Borris in Ossory is not an AFA the modelling extent includes the watercourse through this town.

The principal source of flood risk within HA15 is fluvial flooding at all of the AFAs.

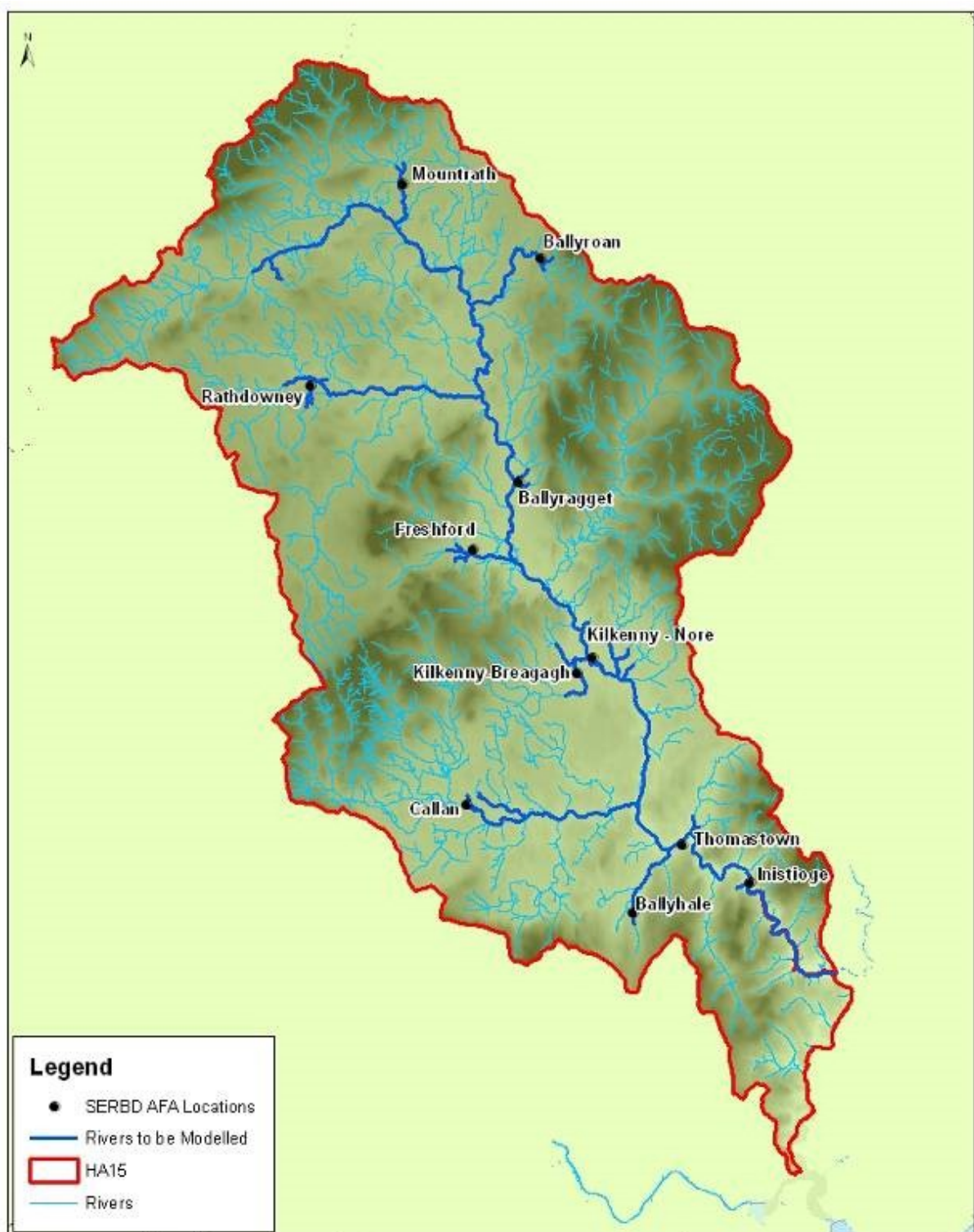


Figure 1.1: HA15 AFA Locations and Extents

1.1 OBJECTIVE OF THIS HYDROLOGY REPORT

The principal objective of this Hydrology Report is to provide detail on the outputs from the processes of hydrological analysis and design flow estimation for HA15. The details of the methodologies used and the preliminary hydrological analysis are provided in the Inception Report 'IBE0601Rp0008_HA15 Inception Report_F02' (RPS, 2012). This report provides a review and summary of the methodologies used as well as details of any amendments to the methodologies since completion of the Inception Report. The report also provides details of the results of the hydrological analysis and design flow estimation and summarises the outputs from the analysis which will be taken forward as inputs for the hydraulic modelling. Discussion is provided within this report on the outputs in terms of the degree of confidence that can be attached to the outputs and the opportunities for providing greater certainty for future studies, including opportunities for improving the observed data used to inform the study.

This report does not include details of the data collection process, flood history within the AFAs or methodology and outcome of the historic flood analysis (except where this is used to inform the design flow estimation) as this is contained within the Inception Report for HA15.

1.2 SUMMARY OF THE AVAILABLE DATA

1.2.1 Summary of Available Hydrometric Data

Hydrometric data is available at 21 hydrometric gauge station locations within HA15 as shown in Figure 1.2.

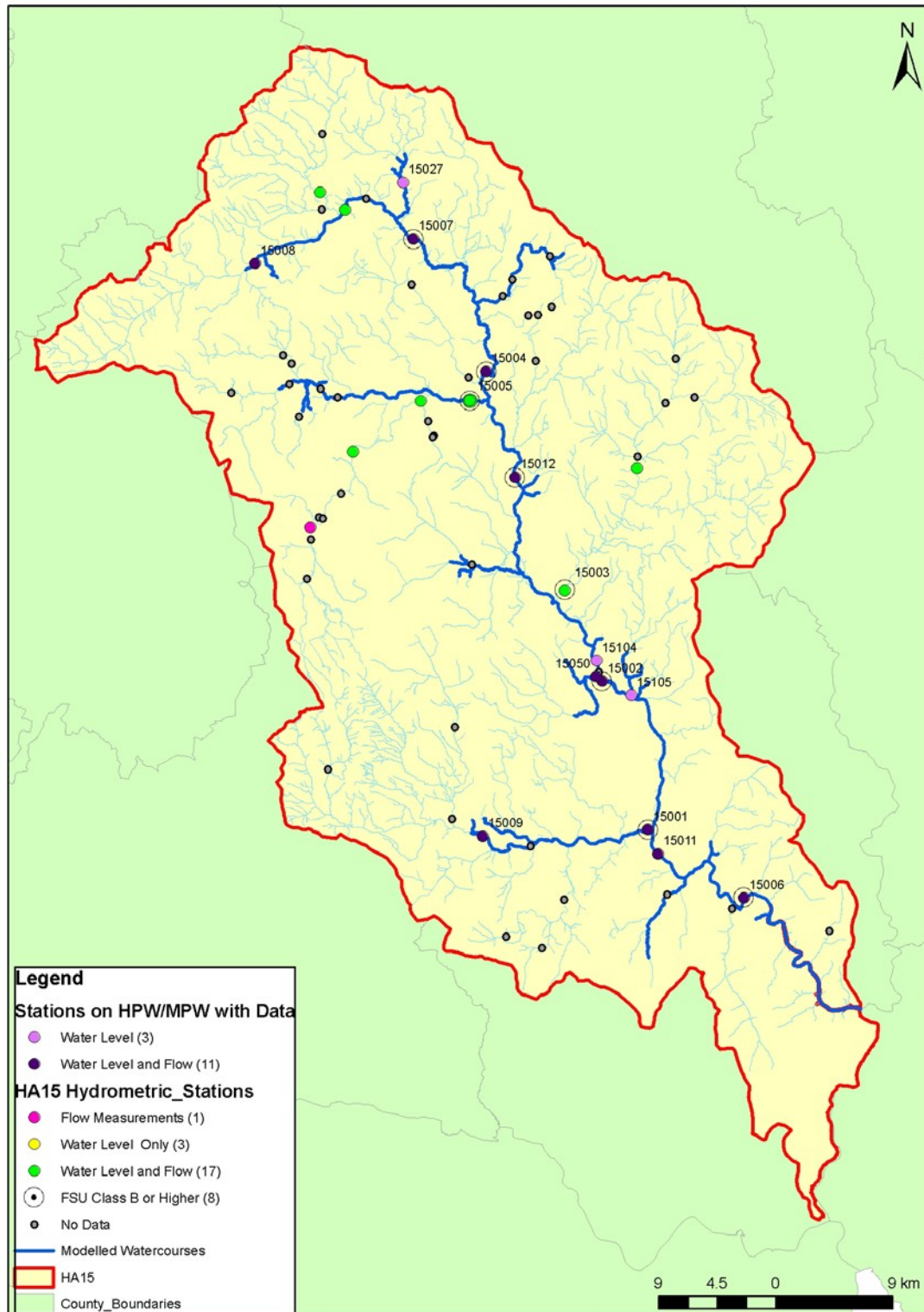


Figure 1.2: Hydrometric Data Availability

Fourteen of these stations are located on the watercourses to be modelled (HPW/MPW) and are labelled according to station number on Figure 1.2.

Within HA15, eight stations were classed as B or higher under the FSU in 2004 meaning that there is confidence in flow data up to the value of Q_{med} at least. These stations are circled on Figure 1.2. Seven of these stations are located on watercourses to be modelled (HPW/MPW). The eighth is located on the non-modelled River Dinin just upstream of its confluence with the River Nore (15003) and is also labelled on Figure 1.2.

Focussing on the River Nore itself (excluding its tributaries that are to be modelled), there are seven hydrometric stations that have flow data available to various extents for use in this study:

- Borris in Ossory (15008– OPW) has continuous flow data available for 1972 to 2011 but ratings are not developed / confirmed by OPW. As such it does not have a classification under FSU.
- Kilbricken (15007 – OPW) has continuous flow data available from 1972 to 2011. The FSU classification designated in 2004 was A2 but OPW Hydrometrics have advised that the rating is not reliable due to the bridge at the station regularly getting blocked with debris with frequent maintenance not occurring. As such it has not been a priority for flow gauging in recent years and AMAX series is not reliable due to issues at the station.
- Mc Mahons Bridge (15004 – OPW) has continuous flow data available from 1972 to 2011 but OPW technicians have recently observed that the recorded water level is much higher than would be expected during times of flood and it is difficult to know if the water is being backed up by an obstruction downstream e.g. branches stuck in the bridge downstream. FSU classification was A2 as designated in 2004, but this recent observation is to be noted.
- Ballyragget (15012 – EPA / Kilkenny County Council). Continuous flow measurements are available from 1988 to 1999 with a FSU classification of B. EPA advised that the stage discharge relationship was compromised when a tree got caught at the weir which acted as a control at the station (date of occurrence not specified), and that serious erosion of the weir took place rendering it impossible to calibrate water level to flow rates since 1999.
- John's Bridge (15002 – OPW) has continuous flow data available from 1953 to 2011. FSU classification is A1.
- Mount Juliet (15011 – OPW) has continuous flow data from 1945 to 2011 (with several gaps) and a FSU classification of C meaning that a well defined rating is available to approximately $0.8 \times Q_{med}$ and as such this gauge was not included in the FSU.
- Brownsbarn (15006 – OPW) has continuous flow data from 1972 to 2011 and has a FSU classification of A2.

In the South Eastern CFRAM Study project brief (ref. 2200/RP/001, March 2011), two hydrometric stations within HA15 – stations 15006 and 15011- were recommended for CFRAM Study rating review

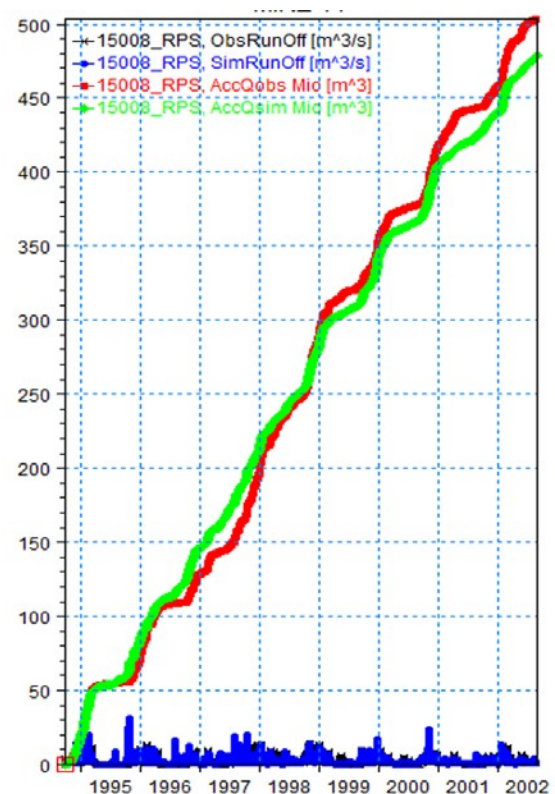
which is discussed further in Chapter 3. Two additional stations were specified for this task following a review of the AFAs and associated hydrological requirements in June 2012. These stations are 15009 and 15007.

In general HA15 can be considered to be a moderately well gauged catchment with five of the ten watercourse models having at least one hydrometric gauge station with flow data available. Four of these five models have gauging stations which have an FSU rating classification or are subject to rating review such that confidence in the rating at Q_{med} is achieved. However station specific issues such as those outlined above must be considered. Further details on the data availability at hydrometric gauge stations within HA15 can be found in Appendix A.

1.2.2 Additional Simulated Flow Data

As discussed in the Inception Report and in various sections of this report additional flow data has been simulated at various (HEP gauging stations) through the application of rainfall data in catchment scale run-off models. Applied rainfall data was derived from rainfall radar if available or rain gauge data with high enough temporal resolution, refer to Section 1.2.4, 2.3 and Chapter 4 for details. This additional, simulated layer of flow data has been used to aid design flow estimation. This flow data will also be used during the hydraulic modelling calibration phase in order to provide simulated historic flood hydrographs where no flood event flow data currently exists which can be matched against recorded levels and / or mapped flood extents. Each model has been considered on an individual basis against the available flow data and calibration has been achieved based on a range of goodness of fit measures and on visual inspection of the mass balance and flow trace graphs, examples of which are shown in Figure 1.3 and Figure 1.4 for the modelled catchment to Borris in Ossory (15008 – OPW) hydrometric gauging station.

Figure 1.3: Water mass balance between observed and simulated catchment at Borris in Ossory (15008)



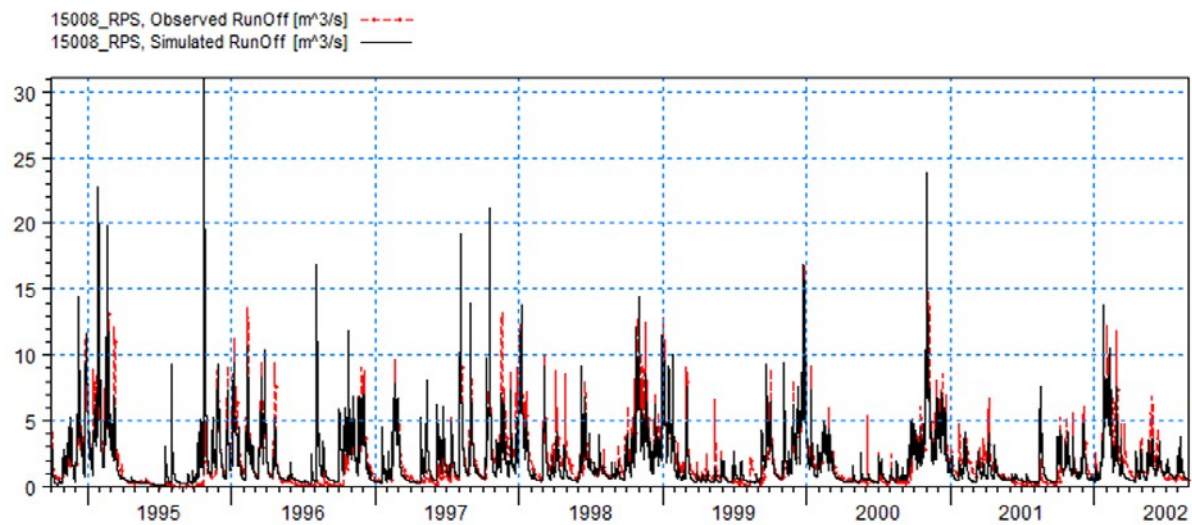


Figure 1.4: Observed and simulated flow trace for catchment at Borris in Ossory (15008)

Issues with the rating curve or gaps in flow data can lead to erroneous goodness of fit measures. It is therefore not possible to make a meaningful summary of the calibration of this simulated data against available flow data from all hydrometric gauging stations and each model must be considered on an individual basis. Results of the calibration process and a summary of the output flow data are contained within Appendix E.

1.2.3 Summary of Available Meteorological Data

Meteorological data is available from a number of Met Éireann daily and hourly rain gauges within the South Eastern RBD and beyond which has the potential to be used within the hydrological analysis. In particular, within the RPS methodology the historical time series data can be used as an input to catchment scale hydrological rainfall run-off models to simulate a continuous flow record within a catchment. High resolution temporal data is required to achieve the required accuracy within the hydrological models and as such hourly time series data is required. There is one Met Éireann hourly rain gauge within HA15 itself, at Kilkenny. Hourly stations are also located at Johnstown Castle and Rosslare in HA12 and Oak Park in HA14. Combinations of data from these stations can be used as inputs to the hydrological modelling by using the area weighted thiessen polygons method to interpolate data at geographical locations between the stations. Daily rainfall data is not considered to be of a high enough temporal resolution to be used as direct input for hydrological modelling on its own but can be used along with the hourly data to inform the spatial distribution of hourly rainfall data within the catchments.

In addition to the observed historical rainfall data available at the aforementioned rain gauge locations, further meteorological information is required as input to hydrological models namely observed evaporation, soil moisture deficits and potential evapotranspiration data. Historical time series data is available for these parameters at Met Éireann synoptic weather stations. The locations at which

historical data is available are generally the same as for hourly rainfall data namely Kilkenny, Oak Park, Johnstown Castle and Rosslare. This additional meteorological data was found to be of sufficient availability to be used as input to the hydrological models. Figure 1.5 shows the locations of all of the rain gauges and the availability of historic information at the hourly rainfall gauges.

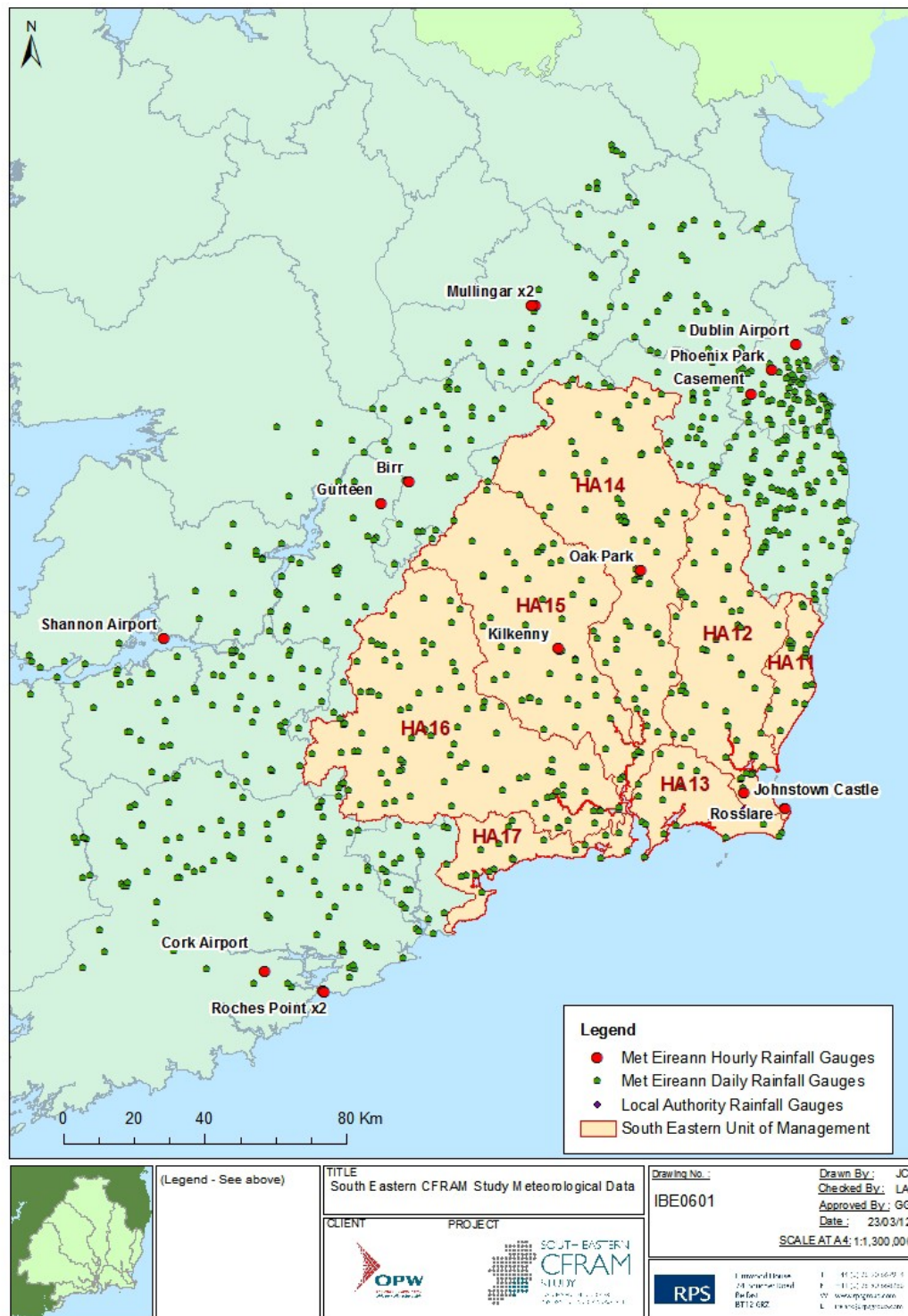


Figure 1.5: Meteorological Data Availability

1.2.4 Rainfall Radar

A data collection meeting held at the beginning of the Eastern CFRAM Study (between RPS, HydroLogic, OPW and Met Éireann) identified an opportunity for exploring the use and benefits of rainfall radar data in hydrological analysis. A radar trial was undertaken on the Dodder catchment and is reported in 'IBE0600Rp0007 Eastern CFRAM Study, Dublin Radar Data Analysis for the Dodder Catchment, Stage 1' (RPS / Hydrologic, 2012) whereby data from the Dublin radar was adjusted against the available rain gauge data to produce an adjusted hourly gridded time series of rainfall data. When compared to the area-weighted derived rainfall series from the gauge data alone, the use of the radar data was shown to bring significant improvements to the rainfall data for rainfall run-off modelling input in terms of spatial distribution of the rainfall, the peak discharges and the timing of the peak discharges. Simulated hydrograph shapes and the overall water balance error margins were also shown to be significantly improved. A further analysis was also undertaken remote from the Dublin radar in order to quantify the benefits at a location further away from the radar. The Athboy River within HA07 was chosen as a suitable location for the trial and the results of the analysis are presented in the report 'IBE0600Rp0013 Athboy Radar Analysis' (RPS).

Subsequently OPW approved the processing of historical data from the Met Éireann radar stations located at Dublin Airport and Shannon for the entire South Eastern CFRAM Study area using information that was received covering the time period from January 1998 to May 2010. Following initial screening of both the radar information and the available rain gauge information which is required for adjustment of the radar observed rainfall sums the following dataset was processed for use in the South East CFRAM Study:

- Hourly PCR (Pulse Compression Radar) data on a 1 x 1 km grid (480km x 480km total grid) covering the entire calendar years 1998–2009.

Following processing of this radar dataset rainfall sums are available for every hour, for the majority of 1km² grid squares of the South Eastern CFRAM Study area for the calendar years 1998 - 2009. There is a limitation to the extent of radar coverage from Dublin and/or Shannon in the South Eastern CFRAM Study Area. The south east corner is covered by neither. As such processed radar data is not available for two hydraulic models at the downstream end of HA15 (Ballyhale and Inistioge), with partial coverage of the Thomastown model.

During the processing the rainfall sums were adjusted spatially and temporally so as to match the daily and hourly sums at the rain gauges and as such RPS considers this processed dataset to be of high accuracy and high resolution where it is available.

Full details of the methodology, datasets used and outcomes of the Dublin and Shannon radar and rain gauge data processing for the South Eastern CFRAM Study area can be found in Appendix B. Hydrological NAM modelling to represent the catchments at seven gauging stations within HA15 have been undertaken. Rainfall radar input has been used at four of these stations. Beam blockages prevented its use at Stations 15004, 15007 and 15011. Detail on each NAM model undertaken is provided within Chapter 4 under each Hydraulic Model as applicable.

2 METHODOLOGY REVIEW

The methodologies for hydrological analysis and design flow estimation were developed based on the current best practice and are detailed in the HA15 Inception Report. In the intervening period there have been a number of developments both in best practice, and the hydrological analysis tools which are available such that it is prudent that the overall methodology is reviewed and discussed. As well as a review of the methodology this chapter seeks to identify changes to the catchment that have become apparent and must be considered in the hydrological analysis.

2.1 HYDROLOGICAL ANALYSIS

The main tasks of hydrological analysis for existing gauge data have been undertaken based on the best practice guidance for Irish catchments contained within the Flood Studies Update. The analysis of the data available from the hydrometric gauge stations shown in Figure 1.2 has been carried out based on the guidance contained within FSU Work Packages 2.1 'Hydrological Data Preparation' and 2.2 'Flood Frequency Analysis' and is detailed in Chapter 4. This analysis was undertaken prior to the receipt of survey information which would have allowed the progression of the South Eastern CFRAM Study gauge station rating reviews identified within the HA15 Inception Report. Following completion of the rating reviews at the four stations identified uncertainty in the ratings was found at one out of the four stations. The rating reviews, the new rating relationships and the consequences of the rating reviews for hydrological analysis are discussed in detail in chapter 3 of this report. The following elements of hydrological analysis have been assessed against the potential impact of uncertainty in the rating and mitigation measures and / or re-analysis undertaken to ensure the robustness of the hydrological analysis:

- Gauged Index Flood Flow (Q_{med}) – Where there has been shown to be uncertainty in the rating within the range of flows up to and around Q_{med} , the Annual Maxima (AMAX) flow series has been re-processed using the revised rating. The use of the gauged Q_{med} in design flow estimation is further discussed in 2.2.1.
- Single site (historic) flood frequency analysis – As the estimated frequency of a flood event is a function of the ranking of the event within the AMAX series, and this will not change following re-processing of the AMAX series, this will have little impact on the outputs of this study.
- Growth Curve Development – The inclusion of gauge years within pooled flood frequency analysis that have a high degree of uncertainty could have a skewing effect within the frequency analysis but the effect will be diluted within a pooling group (where it is assumed other gauge years have a high degree of confidence). The cumulative effect of uncertainty in both directions at multiple gauges may also have a cancelling effect within a pooling group and as such it is not necessary to re-analyse the pooling groups. However where growth curves are based on a single site analysis that has uncertainty in the rating, the single site

analysis has been re-analysed with the re-processed AMAX data based on the revised rating relationship.

2.2 METEOROLOGICAL ANALYSIS

Sections 1.2.2, 1.2.3 and 1.2.4 discuss how a wide range of meteorological data, both rain gauge and radar based, has been brought together to cover the entire South Eastern CFRAM Study area such that all areas are covered by high resolution spatial and temporal historical rainfall data. The methodology does not seek to analyse the raw rainfall sums which have been produced from the processing of the data but rather seeks to interpret this data through rainfall run-off modelling and simulation of the resulting flows in the catchments and sub-catchments. The modelling techniques used result in a wealth of additional (simulated) historical flow data at relevant gauging stations within the catchments which is directly relevant to fluvial modelling and which therefore adds statistical robustness to the traditional analysis techniques.

2.3 DESIGN FLOW ESTIMATION

The estimation of design flows is based on a methodology combining the available best practice guidance for Irish catchments and hydrological catchment rainfall run-off modelling to augment the available gauged data with simulated flow data. The methodologies for estimation of the various elements which make up the design flow estimates to be used for modelling are detailed below.

2.3.1 Index Flood Flow Estimation

Estimation of the Index Flood Flow is required for all catchments and sub-catchments to be analysed under the CFRAM Study with each sub-catchment defined by a Hydrological Estimation Point (HEP). The methodologies for estimation of design flow vary depending on whether or not the catchment is gauged and also on how the run-off from the catchments impacts upon the Area for Further Assessment (AFA). The hierarchy of methodologies is discussed below.

2.3.1.1 Gauged Index Flood Flow (Q_{med})

HEPs have been located at all hydrometric gauging stations where flow data is available and these HEPs are subject to hydrological catchment scale rainfall run-off modelling, where it is deemed that an improvement in the AMAX series and flow trace can be gained from the rainfall runoff model output. This was the case for seven gauging stations in HA15. The methodology for this is described in detail within the HA15 Inception Report. In addition one hydrometric gauging station within HA15 has been shown to have significant uncertainty (affected the Q_{med} by 10% or more) in the existing rating at flood flows following CFRAMS rating review. The gauged Q_{med} to be used for design flow estimation is improved using simulated data from the AMAX series derived from the rainfall run-off model constructed for the catchment at the gauge station (where applicable). This has a number of advantages:

- An AMAX series is simulated for the duration of the meteorological records which are generally between 50 – 70 years in length giving greater statistical confidence in the Q_{med} value.
- The modelled catchment characteristics reflect present day (derived from the current CORINE 2006 land use and GSI data sets) conditions and as such are not subject to changes in flood flow behaviour over time due to changing catchment conditions (as may be the case with historic gauge records).

It must be noted however that the run-off models are calibrated against the gauge records so in theory there is the potential for any error in the gauge records to be carried over into the rainfall run-off models. As such the following mitigation measure has been taken to ensure that the effect of uncertainty at the hydrometric gauging station is not replicated in the rainfall run-off model:

- Catchment scale rainfall run-off (NAM) models are calibrated only to the range of the flow trace at gauging stations where there is certainty in the rating. For example where there is an FSU A2 classification of the rating the rainfall run-off model will be calibrated on flow values up 1.3 times Q_{med} only. Where there is no FSU classification the calibration will be carried out on the range of flows for which spot gaugings are available (i.e. not on flows based on an extrapolated rating curve).

Conversely to this potential for error in the rainfall run-off model, if the calibration is carried out against a period for which there is certainty in the gauged flows then it is possible that the model will replicate historic event flood flows which are beyond the confidence of the gauging station rating (i.e. based on an extrapolated relationship between water level and flow) more accurately than the gauge station has recorded (where there is uncertainty in the rating).

The simulated AMAX series and subsequent Q_{med} will be considered alongside the existing AMAX series and Q_{med} to achieve the most robust estimate of the gauged Q_{med} . Where for example there is confidence in the rating at Q_{med} (FSU A1, A2 & B classification or post rating review) and the gauge record is sufficiently long such that the statistical standard error as detailed in FSU WP 2.3, Table 2 is lower than that of the rainfall run-off models within the catchment (Appendix E) then the Q_{med} at the gauge is preferred.

2.3.1.2 Ungauged Index Flood Flow (Q_{med})

The ungauged catchment descriptor based method **FSU WP 2.3 'Flood Estimation in Ungauged Catchments'** has been used to derive estimates of Q_{med} for all catchments including those that are small and ungauged. This is in accordance with recently published guidance "Guidance Note 21 - *CFRAM guidance note on flood estimation for ungauged catchments*". This guidance note drew on the finding that alternative methods for small catchments (Flood Studies Report, NERC, 1975; IH Report 124, Marshall and Baylis, 1994) do not have enough empirical support in Ireland and draw on

older and cruder datasets than FSU. Therefore, in the first instance, the FSU 7-variable ungauged catchment descriptor equation (Work Package 2.3) is used to calculate an estimate of the Index Flood Flow at all HEPs and where available, gauge records or catchment run-off models are used to adjust / improve the estimate as the design flow estimation is developed.

The FSU methodology outlined in WP 2.3 recommends that all estimates based on the seven parameter catchment descriptor equation are adjusted based on the most hydrologically similar gauged site. The adjustment factor is applied to the regression equation estimate at the subject catchment and can be described in simple terms as the gauged Q_{med} divided by the regression equation estimated Q_{med} at the most hydrologically similar gauged site. Hydrological analysis tools developed by OPW as part of the FSU identify 216 gauge locations which are described as 'Pivotal Sites' following analysis of the data available as part of FSU WP 2.1 'Hydrological Data Preparation'. Rather than be restricted to the list of Pivotal Sites RPS has used the results of the rainfall run-off modelling at gauging stations (both FSU pivotal sites and other gauged locations) to build a higher density of gauge sites for which data is available on which to base adjustment. As such the adjustment of ungauged estimates of Q_{med} considers a number of sources of gauged data upon which to base adjustments:

1. Rainfall run-off (NAM) model results discussed in 2.3.1.1 where these are available upstream or downstream of the subject site.
2. FSU pivotal sites database
3. Other gauge sites where due to rating review there is confidence in the observed Q_{med} .

2.3.2 Growth Curve / Factor Development

Growth curves have been developed based on single site and pooled analysis of gauged hydrometric data based on the FSU methodology set out in Work Packages 2.1 and 2.2. Due to CFRAM Study programme constraints it was not possible to include the simulated AMAX series years at gauging stations within the analysis and as such all analysis is based on the recorded data only. Full details and discussion of the results can be found in Chapter 4.

2.3.3 Design Flow Hydrographs

The design flow hydrograph methodology for the South Eastern CFRAM Study centres around FSU Work Package 3.1 'Hydrograph Width Analysis' and uses the tools developed by OPW for analysing flood hydrographs at gauged sites supplemented with the additional simulated continuous flow data derived from the catchment rainfall run-off (NAM) models. Since the completion of the Inception Report the methodology for deriving design flow hydrographs has been developed further following the release of the FSU Hydrograph Shape Generator version 5 and further development of the rainfall run-off (NAM) methodology. As such the hydrograph shapes are generated based on the following methods:

1. At all rainfall run-off modelled HEPs simulated continuous flow records are now available such that a range of past flood events can be analysed. The method utilises the Hydrograph Width Analysis (HWA) software developed as part of FSU WP 3.1 to analyse these simulated flow records to produce median width, semi-dimensionless hydrographs for design events. The methodology requires the conversion of the continuous flow trace data into the required HWA specific format (.tsf file) before historic events are isolated and analysed. This methodology will provide the larger inflow hydrographs which will drive the hydraulic models.
2. At most other HEPs within HA15 hydrographs will be generated using the recently released FSU Hydrograph Shape generator version 5 developed by OPW. This tool increases the list of Pivotal Sites from which median hydrograph shape parameters can be borrowed based on the hydrological similarity of the Pivotal Site when compared to the subject site. The release of version 5 of this tool has increased the pool of Pivotal Sites to over 150. RPS trialling of this version of the FSU Hydrograph Shape Generator in CFRAMS has found that the generated hydrograph shapes provide a reasonably good fit when compared to the observed and simulated (NAM) hydrographs within the catchment.
3. At a few locations it was not be possible to find a suitable Pivotal Site from which a comparable hydrograph shape could be borrowed, particularly for the very small sub-catchments. In this instance hydrograph shapes have been generated using the Flood Studies Supplementary Report (FSSR) 16 Unit Hydrograph method.

Design hydrographs were developed at all HEPs. It was originally intended that at the smallest inflow / tributary HEPs continuous point flows could be input. However it is now envisaged that the hydrograph will be critical in some of the smallest watercourses which are restricted by culverts / bridges where flood volume as opposed to flood flow becomes the critical characteristic of a flood. One example of this may be the Finnan HPW in the Ballyragget (Model 1) where application of continuous point flows at the upstream limit of the hydraulic model could lead to an unrealistic build up of water behind culvert structures where this is the critical flood mechanism.

2.4 HYDROLOGY PROCESS REVIEW

Following developments in best practice and guidance documents and the refinement of the RPS methodology through its application on the South Eastern CFRAM Study the hydrology process has been amended slightly from that which was presented in the HA15 Inception Report (summarised previously in Figure 5.2 of report IBE0601Rp0008_HA15 Inception Report_F02). The revised process flow chart which has been applied in carrying out the hydrological analysis and design flow estimation for HA15 is presented in Figure 2.1.

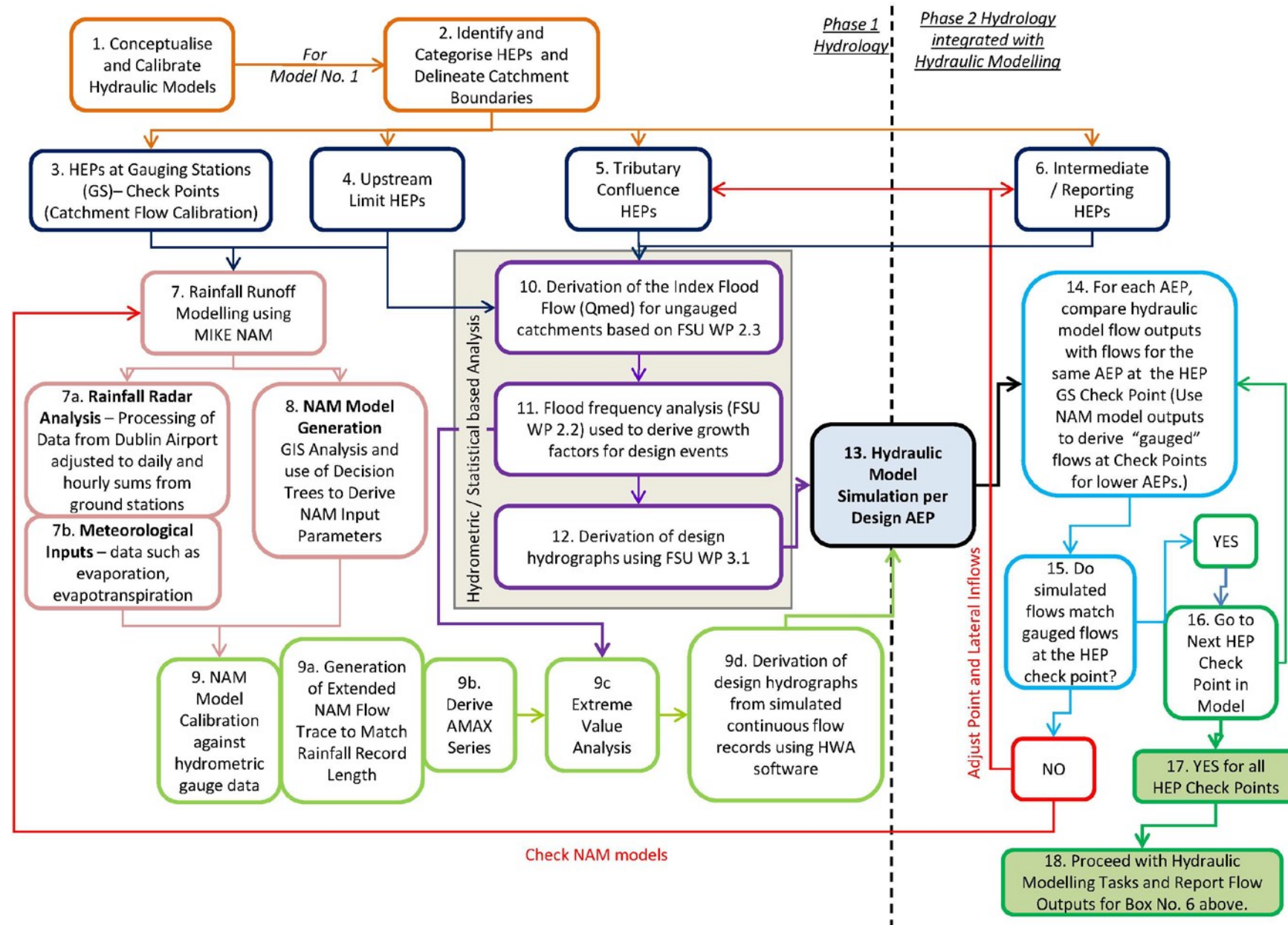


Figure 2.1: Hydrology Process Flow Chart

2.5 CATCHMENT BOUNDARY REVIEW

In line with the CFRAM Study Stage 1 Project Brief (ref. 2149/RP/002/F, May 2010) section 6.3, RPS have delineated the catchment boundaries at HEPs using the FSU derived ungauged and gauged catchment boundaries as a starting point. For details of the full methodology for undertaking this review see HA15 Inception Report section 5.3.2. Following the completion of this process a number of the catchment boundaries were amended and in a number of catchments the boundaries were amended significantly. Table 2.1 gives a summary of the changes in the catchment area at CFRAMS HEP points when compared to the equivalent FSU catchment from which they were derived.

Table 2.1: Summary of Catchment Boundary Review

Change in Catchment Area	Number of HEPs
New Catchment Delineated	12
No change	44
0 – 10%	65
Greater than 10%	9
Total	130

Not all the catchments related to HEPs that are required to be considered within HA15 were previously delineated. Some of the catchments relate to small streams and land drains which were previously too small to be considered under FSU and as such RPS delineated these catchments using a combination of mapping, aerial photography and the National Digital Height Model (NDHM). In two cases, HEPs were relocated to pick up tributaries observed via walkover survey that were in the wrong location on the HA15_Rivers polyline GIS layer (OSI 50k mapping). The review concluded that 43% of catchments were already accurately delineated or were newly delineated but 57% of the catchments delineated under FSU were found not to be representative of the NDHM, the mapping or draft survey information. The most common reason for amendment in HA15 was due to inspection of topography from the aforementioned sources. Nine of the catchments (7%) were found to have margins of error of over 10%. These catchments ranged from 1.163 to 23.786 km² in catchment area.

3 HYDROMETRIC GAUGE STATION RATING REVIEWS

As a follow on from the recommendations of Work Package 2.1 of the FSU, a task was included in the South Eastern CFRAM Study brief to undertake further rating review of a subset of hydrometric stations. Following the completion of the risk review stage and finalisation of the AFA locations a total of four hydrometric stations were specified for rating review. These stations were chosen for rating review by OPW as they had available continuous flow data, were located on watercourses to be modelled and were deemed under FSU Work Package 2.1 as currently having a rating quality classification that could be improved upon (i.e. there may be some uncertainty in the rating at extreme flood flows).

3.1 METHODOLOGY

The methodology for carrying out rating reviews entailed the following general steps:

1. Gauge station reach of watercourse was surveyed in detail (site visit, cross sections and LiDAR survey). Rating review survey was prioritised ahead of survey required for hydraulic modelling.
2. A hydraulic model was constructed of the reach of the watercourse from sufficient distance upstream to a sufficient distance downstream of the gauge station.
3. Spot gauged flows were replicated within the model and the model calibrated in order to achieve the observed measured water levels at the gauge station location.
4. When calibration was achieved flows were increased from zero to above the highest design flow (>0.1% AEP event) and the corresponding modelled water levels at the gauge location recorded.
5. The stage (water level minus gauge station staff zero level) versus discharge results were plotted to determine the modelled stage discharge (Q-h) relationship.
6. The existing Q-h relationship was reviewed in light of the modelled relationship and the existing reliable limit of the Q-h relationship extended up to the limit of the modelled flows. In some cases where the existing Q-h relationship had been extrapolated beyond the highest gauged flow (for practical reasons) the modelled Q-h relationship may vary significantly and as such the reliability of the existing gauged flood flows is called into question.

The hydrometric stations specified for this analysis within HA15 are shown in Table 3.1.

3.2 RATING REVIEW RESULTS

The current rating quality classification assigned under the FSU for each station (if available) and whether the rating review indicated that there was significant uncertainty in the existing rating, defined as a difference in Q_{med} of more than 10%, is stated in Table 3.1.

Table 3.1: Existing Rating Quality Classification for Rating Review Stations in HA15

Station Number	Station Name	FSU Station Rating Quality Classification	Significant Uncertainty Identified in current rating
15006	Brownsbarn	A2	NO
15011	Mount Juliet	C	NO
15009	Callan	B	YES
15007	Kilbricken	A2	N/A

A1 sites – Confirmed ratings good for flood flows well above Q_{med} with the highest gauged flow greater than $1.3 \times Q_{med}$ and/or with a good confidence of extrapolation up to 2 times Q_{med} , bank full or, using suitable survey data, including flows across the floodplain.

A2 sites – ratings confirmed to measure Q_{med} and up to around 1.3 times the flow above Q_{med} . Would have at least one gauging to confirm and have a good confidence in the extrapolation.

B sites – Flows can be determined up to Q_{med} with confidence. Some high flow gaugings must be around the Q_{med} value. Suitable for flows up to Q_{med} . These were sites where the flows and the rating was well defined up to Q_{med} i.e. the highest gauged flow was at least equal to or very close to Q_{med} , say at least $0.95 Q_{med}$ and no significant change in channel geometry was known to occur at or about the corresponding stage.

C sites – possible for extrapolation up to Q_{med} . These are sites where there was a well defined rating up to say at least $0.8 \times Q_{med}$. Not useable for the FSU.

U sites – sites where the data is totally unusable for determining high flows. These are sites that did not possess 10 years of data or more, had water level only records or sites where it is not possible to record flows and develop stage discharge relationships. Not useable for FSU.

As well as the uncertainty in the existing ratings some gauging station ratings are limited such that they do not cover the range of flood flows other than through extrapolation of the stage discharge relationship. As a result of this all of the AMAX series level data has been re-processed into AMAX flow data using the revised rating derived from the rating review models and the revised AMAX series

flow data presented in Table 3.2 below. Full details of the individual rating reviews can be found in Appendix C.

Table 3.2: AMAX Series Data Before and After Rating Review

	Brownsbarn 15006		Mount Juliet 15011		Callan 15009		Kilbricken 15007	
	Exist (m ³ /s)	RR (m ³ /s)	Exist (m ³ /s)	RR (m ³ /s)	Exist (m ³ /s)	RR (m ³ /s)	Exist (m ³ /s)	RR (m ³ /s)
1946			446.0	446.48				
1947			325.7	318.19				
1948			272.5	262.08				
1949			190.4	175.26				
1950			211.0	190.09				
1951			193.5	177.69				
1952			105.1	104.16				
1953			232.2	211.68				
1954	338.90	346.1	323.4	315.76				
1955	N/A	n/a	N/A	N/A				
1956	315.74	324.2	272.5	262.08				
1957	288.30	298.5	280.8	270.81	43.32			
1958	221.89	230.9	242.1	226.26	35.31			
1959	198.76	207.3	191.3	175.95	28.18			
1960	411.02	452.0	341.1	334.47	35.31			
1961	195.95	204.4	183.3	169.40	50.06			
1962	246.22	255.7	205.3	186.05	25.26			
1963	255.66	265.3	237.3	219.17	41.27			
1964	326.34	334.2	299.8	290.77	42.98			
1965	355.39	368.0	295.4	286.21	47.90			
1966	324.56	332.5	285.3	275.57	38.91			
1967	283.29	293.4	244.0	229.14	35.18			
1968	449.52	510.9	350.0	343.97	27.77			
1969	N/A	N/A	N/A	N/A	45.98			
1970	246.22	255.7	254.0	242.72	23.45			
1971	295.05	304.8	300.6	291.65	34.54			
1972	276.66	286.6	N/A	N/A	29.87			
1973	337.09	344.4	314.7	306.55	38.12			
1974	288.30	288.3	244.0	229.14	41.47			
1975	162.45	162.5	N/A	N/A	34.86			
1976	278.31	278.3	N/A	N/A	23.31			
1977	346.19	342.7	347.8	341.62	26.74	71.63		
1978	403.12	422.2	319.1	311.22	34.86	63.20		
1979	399.19	416.4	341.1	334.47	38.18	72.73		
1980	289.98	290.0	260.1	249.12	41.20	63.20	46.04	N/A
1981	270.12	270.1	226.4	198.30	38.18	36.00	36.08	N/A
1982	313.99	312.8	284.9	270.81	36.44	46.95	56.18	N/A
1983	337.09	334.2	276.6	262.08	41.78	50.08	55.41	N/A
1984	220.41	220.4	N/A	N/A	43.15	34.13	49.89	N/A
1985	414.99	419.3	332.2	320.48	35.15	79.58	56.57	N/A
1986	240.03	229.4	224.3	196.86	55.54	34.45	49.49	N/A
1987	303.59	303.2	260.1	244.94	37.19	44.75	50.29	N/A
1988	281.62	281.6	N/A	N/A	42.57	39.22	48.28	N/A
1989	357.24	354.2	N/A	N/A	39.85	74.97	64.34	N/A
1990	244.67	244.7	228.3	199.94	54.04	39.22	51.08	N/A
1991	258.84	258.8	252.8	236.23	39.85	34.76	46.94	N/A
1992	218.93	218.9	203.1	185.35	37.52	70.53	50.43	N/A
1993	273.38	273.4	241.0	226.65	49.92	37.91	53.45	N/A
1994	368.47	370.8	323.8	317.74	36.80	66.28	70.56	N/A

	Brownsbarn 15006		Mount Juliet 15011		Callan 15009		Kilbricken 15007	
	Exist (m ³ /s)	RR (m ³ /s)	Exist (m ³ /s)	RR (m ³ /s)	Exist (m ³ /s)	RR (m ³ /s)	Exist (m ³ /s)	RR (m ³ /s)
1995	387.54	399.0	329.6	323.84	48.00	79.58	52.44	N/A
1996	257.24	257.2	237.8	221.85	52.37	64.21	50.93	N/A
1997	377.95	384.8	336.1	330.76	47.29	77.25	60.62	N/A
1998	360.97	359.7	327.4	321.55	51.63	70.53	58.04	N/A
1999	275.02	275.0	255.5	245.63	49.44	64.21	57.53	N/A
2000	376.04	382.0	315.1	308.50	47.29	62.19	59.07	N/A
2001	223.38	223.4	209.3	189.73	46.58	32.55	53.45	N/A
2002	353.54	349.6	314.6	307.90	32.55	50.08	49.43	N/A
2003	140.17	140.2	151.5	144.79	42.05	31.31	50.93	N/A
2004	377.95	384.8	N/A	336.95	31.31	103.95	63.21	N/A
2005	205.86	205.9	209.3	189.73	59.16	63.20		
2006	310.51	309.6	337.6	332.30	46.93	74.97		
2007	369.60	372.4	349.3	344.75	50.90	107.21		
2008	321.02	319.3	301.9	294.46	60.17	62.19		
2009	412.01	435.5	403.1	402.20	46.58	85.61		
2010			303.7	296.39		79.58		
2011			248.9	238.14		64.21		
						77.25		
Q _{med}	299.32	304.0	274.54	262.08	41.23	63.2	53.45	N/A
% Diff.		1.6%		-5.6%		53.2%		N/A

 Denotes data taken forward for use in FSU. Rating considered to have confidence up to Q_{med}

The rating review at the Brownsbarn gauging station (15006) found good agreement between the modelled and existing developed rating curve. At Q_{med} there was found to be less than 2% difference and as such the observed Q_{med} value can be taken forward for design flow estimation with confidence.

The rating review at the Mount Juliet gauging station (15011) found fair agreement between the modelled and the existing rating curve within the limits of the existing rating (up to a stage height of 1.7m). Following application of the rating review equations it was found that the revised Q_{med} (at a stage height of approximately 3m) was 5.6% lower than the existing based on the OPW rating equations. The rating review does not therefore indicate that there is significant uncertainty at Q_{med} and the observed value can be taken forward with confidence.

The rating review at the Callan gauging station (15007) found a significant difference between the modelled and existing developed rating curve. At Q_{med} there was found to be more than 50% difference and as such the observed Q_{med} value taken forward for design flow estimation is that from the CFRAM Study rating review (63.2 cumecs). The reviewed rating is only applied since 1997 when the staff gauge was lowered by 270mm (refer to Appendix C).

The rating review at the Kilbricken gauging station (15009) found that there was poor agreement between the modelled Q-h relationship and the existing rating curve. The modelled reaches are within a 1D only model reach and it is considered that this reach, with areas of floodplain below the top of

bank, cannot be adequately represented within a 1D only model. For this reason a modelled rating was not developed and no assessment on the certainty of the existing Q_{med} value can be made.

3.3 IMPACT OF RATING REVIEWS ON HYDROLOGICAL ANALYSIS

As discussed in Chapter 2, Methodology Review much of the hydrological analysis was undertaken prior to survey information at the relevant gauging stations being available and the rating reviews carried out. As such it is necessary to quantify the potential impact on the hydrological analysis and identify where re-analysis or mitigation to minimise the potential impact is required. The various elements of the hydrological analysis and design flow estimation are listed below and a summary of the potential impact and the proposed mitigation measures is detailed.

Table 3.3: Summary of Rating Review Effects and Mitigation

Hydrological Analysis	Potential Effects of Uncertainty in the Rating	Potential Impact	Mitigation
Gauged Q_{med}	Most uncertainty with poor rating likely at flood flows and as such there could be uncertainty in AMAX series. Will affect Q_{med} at sites with a classification lower than B. Not critical under RPS methodology as NAM model Q_{med} will be taken forward. Gauged Q_{med} used for verification purposes.	Medium	Re-assess Q_{med} for FSU classified sites of C or U for verification of NAM Q_{med}
Ungauged Q_{med}	An issue where an ungauged catchment is adjusted based on a pivotal site with high uncertainty. As Pivotal Sites are taken from A1, A2 & B classification they are unlikely to be affected.	Low	None required
Historic flood frequency analysis	Flood frequency is a function of the ranking of events within the AMAX series, the position in the ranking is unlikely to be affected by adjusting all the values of the series (i.e. unless just adjusting a specific gauge period) but the flood flow figure must be revised used for calibration.	Medium	Frequency re-analysis not required. Where event flows are used for hydraulic model calibration historic flows must be re-calculated
Growth curve development	The inclusion of gauge years within pooled flood frequency analysis that have a high degree of uncertainty could skew the pooled frequency analysis but the effect will be diluted within a group (where it is assumed other gauge years have a high degree of confidence). The cumulative effect of uncertainty in both directions at multiple gauges may also have a cancelling out effect within a pooling group.	Medium / Low	At gauges where there has been shown to be uncertainty, re-assess single site analysis to check that it is within 95th percentile confidence limits of the pooled analysis.

Hydrological Analysis	Potential Effects of Uncertainty in the Rating	Potential Impact	Mitigation
Rainfall run-off / NAM model calibration	Catchment scale rainfall run-off or NAM models are calibrated to the flow trace at gauging stations. If there is uncertainty in the flow trace (most likely at higher flood flows) then this could lead to poor calibration and the error carried over to the run-off model.	Medium	At gauges where there has been shown to be uncertainty, calibrate the rainfall run-off (NAM) model to the medium or low flows.
Hydraulic model calibration	Calibration of hydraulic models is undertaken at extreme flood flows where highest degree of uncertainty could be present. Model calibration therefore dependant on upper limits of gauge rating.	High	Reassess calibration event flows where necessary
Hydrograph Shape Generation	Uncertainty would affect values but semi-dimensionless shape will not change (Q is expressed factorially from 0 to 1).	Low	None required

Following the rating reviews carried out for HA15 a high degree of uncertainty was found at the Callan gauging station and as such the revised Q_{med} value from the rating review was taken forward as the basis for design flows at the gauging station location and for adjustment where it had been used as a pivotal site. This resulted in a significant amendment to the design flows. The single site analysis was also reviewed as well as re-processing of the flow data for calibration events. At this station the opportunity for the error to affect the rainfall run-off model was minimised as calibration was focussed on the low to mid-range flows.

4 INDEX FLOOD FLOW ESTIMATION

The first component in producing design flows within the majority of best practice methods widely used in the UK and Ireland is to derive the Index Flood Flow which within the FSU guidance is defined as the median value of the annual maximum flood flow series or Q_{med} . The methodologies being used in this study are detailed in the HA15 Inception Report and are reviewed in chapter 2 of this report. As discussed the methods combine best practice statistical methods with rainfall run-off (NAM) modelling techniques. This chapter details the Index Flood Flow estimation at each of the HEPs within HA15 on a model by model basis, including a discussion on the confidence and comparison of the outputs from the considered methodologies.

HA15 had originally been divided into eight hydrodynamic models, primarily based on the requirement within the modelling software to have only one continuous modelled floodplain per model. Following a subsequent review of the complexity of the individual hydrodynamic models it was decided to further split some models to reduce their complexity. Therefore the Erkina River from Rathdowney has been split from the upper Nore model and the model covering the lower reaches of the Nore has been split between Thomastown and Inistioge. There are now ten models instead of eight which were identified in the HA15 Inception Report (IBE0601Rp0008). The ten models included in HA15 are shown in Figure 4.1.

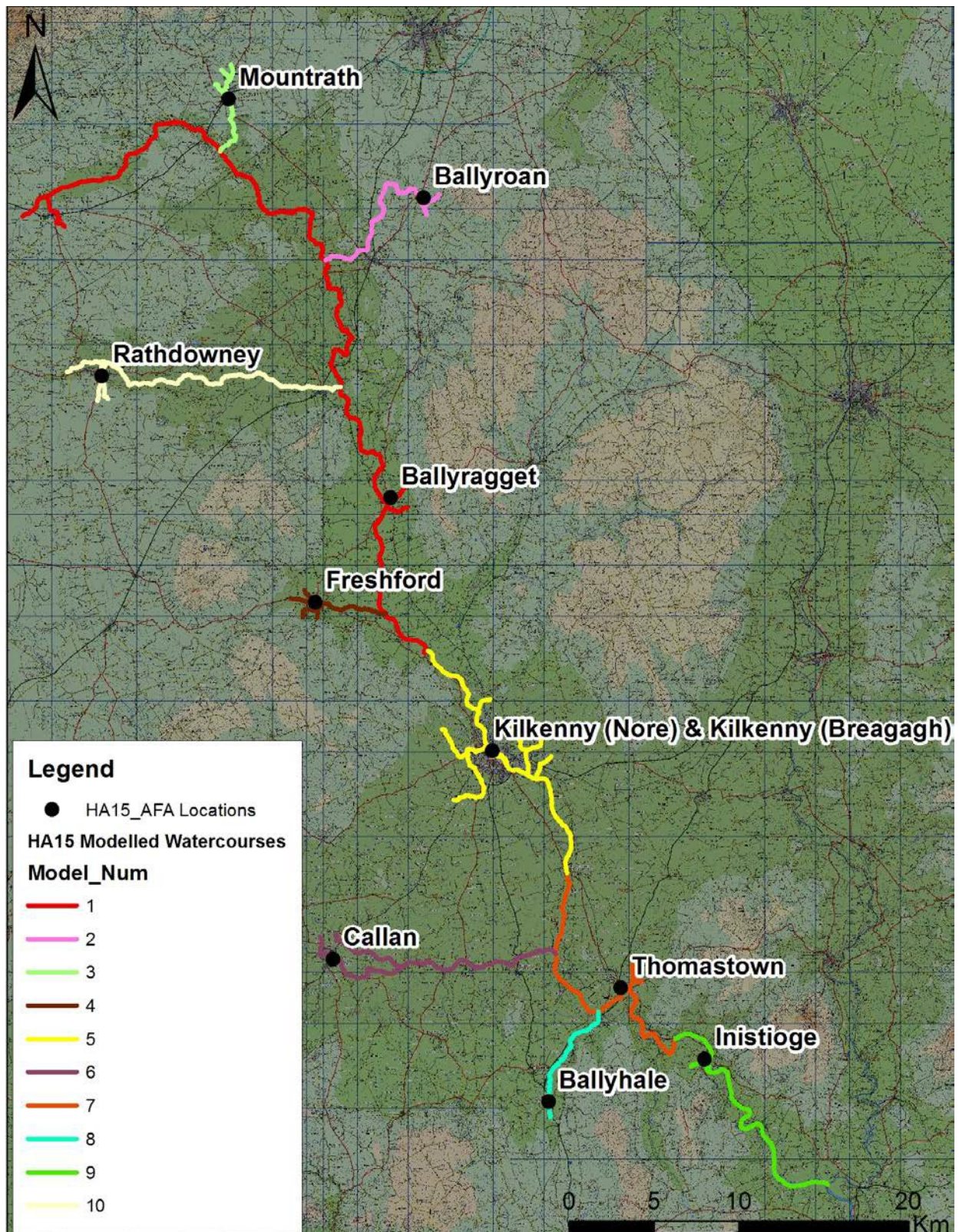


Figure 4.1: HA15 Watercourses to be Modelled

4.1 MODEL 1 – BALLYRAGGET

Model 1 constitutes the upper reaches of the River Nore from Borris in Ossory to approximately 11km downstream of Ballyragget AFA. The Nore main channel is MPW for the majority of the modelled reach. The Derryvorigan tributary which is located in Borris in Ossory is a HPW. As the River Nore flows through the outskirts of Ballyragget, it becomes a HPW. Two tributaries of the Nore running through Ballyragget itself, the Finnan and Donaghmore are also HPWs. Separately modelled tributaries enter the Nore along the length of Model 1 (Gloreen Stream, Model 2; Mountrath River, Model 3; Nuenna River, Model 4 and Erkina River, Model 10).

The contributing catchment to Model 1 is predominantly rural (0.8% urbanised).

The Ballyragget model can be considered to represent a well gauged catchment with four gauging stations located along the length of the River Nore from Borris in Ossory to Ballyragget. The station at Borris in Ossory (15008) has a reliable rating up to approximately $9\text{m}^3/\text{s}$ with a Q_{med} of $14\text{m}^3/\text{s}$ (35 years of data). It was not included in the FSU. Two stations have FSU Classifications of A2, Mc Mahons Bridge (15004) and Kilbricken (15007). However a discrepancy associated with gauged Q_{med} values at these A2 stations as provided to the Study was identified. Station 15004 has a lower gauged Q_{med} ($38.8\text{m}^3/\text{s}$) than 15007 ($52.44\text{m}^3/\text{s}$) despite being downstream of it. Subsequently it was advised by OPW hydrometrics that a reliable rating is not available at station 15007 and there is uncertainty with recorded water levels in flood conditions at station 15004, as previously outlined (refer to Section 1.2.1).

Station 15012 is located approximately 1km upstream of Ballyragget and is an EPA station. EPA advised that the B rating is only applicable up to 1999 due to erosion damage at the station, and so confidence in flow values up to Q_{med} are limited to data before this time. The observed Q_{med} of $78.4\text{m}^3/\text{s}$ is therefore derived from 9 years of hydrological AMAX data and as such does not have the highest degree of statistical certainty.

The total catchment area of the model at the downstream extent is 1242km^2 . The HEPs and associated sub-catchments of the Ballyragget model are shown in Figure 4.2.



Rainfall run-off models (NAM) have been developed of the contributing catchments to each gauging station in order to simulate longer AMAX series and increase confidence in the Q_{med} . The NAM models were calibrated against the low to mid range continuous flow trace at each gauging station where corresponding gauge adjusted radar based hourly rainfall sums for the catchment were available. Using the adjusted radar based rainfall sums and observed rainfall sums from surrounding rain gauges a continuous flow trace was simulated for the period 1954 to 2010. An AMAX series was extracted from the continuous flow trace and the simulated Q_{med} calculated for each station.

Following this process it was noted that there was significant discrepancy between simulated and gauged Q_{med} values moving downstream and poor calibration measures were noted in the NAM models at stations 15004 (McMahons Bridge) and 15007 (Kilbricken). At this stage further discussions were held with OPW Hydrometrics and it was found that there is very low confidence in the Kilbricken gauge (15007) despite its A2 classification under FSU. As a result of this the NAM models for 15004 and 15007 were re-run based on NAM catchment parameters which were derived from interpolation between the upstream (15008) and downstream (15012) NAM models, where it was considered better calibration had been achieved, and simulated Q_{med} values re-calculated (as opposed to those derived from achieving optimal calibration against the gauge record). The results of all the Q_{med} values were then validated against estimates derived from the FSU ungauged catchment descriptor based method and found to be proportionally consistent.

The outputs of the NAM models have provided greater confidence in index flows with longer AMAX series and greater statistical certainty. The uncertainty associated with decreasing index flows moving downstream between 15007 and 15004 has been removed as illustrated below:

- Station 15008_RPS $Q_{med \text{ gauge}} = 17.34 \text{m}^3/\text{s}; Q_{med \text{ sim}} = 14.5 \text{m}^3/\text{s}$
- Station 15007_RPS $Q_{med \text{ gauge}} = 52.44 \text{m}^3/\text{s}; Q_{med \text{ sim}} = 41.44 \text{m}^3/\text{s}$
- Station 15004_RPS $Q_{med \text{ gauge}} = 38.8 \text{m}^3/\text{s}; Q_{med \text{ sim}} = 51.83 \text{m}^3/\text{s}$
- Station 15012_RPS $Q_{med \text{ gauge}} = 78.4 \text{m}^3/\text{s}; Q_{med \text{ sim}} = 83.9 \text{m}^3/\text{s}$

The simulated Q_{med} values at each of these stations were then used to adjust the FSU predicted values at each HEP within Model 1 as appropriate. The estimated Q_{med} values for the various HEPs within Model 1 are shown in Table 4.1.

Table 4.1: Q_{med} Values for Model 1

Node ID_CFRAMS	AREA (km ²)	Q_{med} (m ³ /s)	Preferred Estimation Methodology
15_994_1_RPS	109.63	13.25	FSU
15_1461_8	5.63	1.54	FSU
15008_RPS	116.54	14.50	NAM
15_306_2_RPS	1.66	0.27	FSU
15_306_8_RPS	3.84	0.74	FSU
15_1455_7	7.76	2.90	FSU
15_911_5	100.82	23.84	FSU
15_1003_4_RPS	57.73	18.26	FSU
15007_RPS	339.00	41.44	NAM
15_923_2_RPS	65.60	8.59	FSU
15_1060_5_RPS	5.46	0.70	FSU
15_1938_5_RPS	39.37	5.10	FSU
15_1813_11_RPS	8.60	1.43	FSU
15004_RPS	488.70	51.83	NAM
15_1749_11_RPS	69.15	6.40	FSU
15_198_10_RPS	380.43	29.49	FSU
15_910_2_RPS	94.72	12.60	FSU
15012_RPS	1055.40	82.92	NAM
15_1965_2_RPS	2.22	0.53	FSU
15_1965_5_RPS	3.67	0.84	FSU
15_420_3	1.69	0.38	FSU
15_420_6_RPS	2.30	0.53	FSU
15_479_6	22.55	3.17	FSU
15_946_2_RPS	16.57	2.35	FSU
15_1824_6_RPS	92.18	19.64	FSU
15_944_2	9.84	1.45	FSU
15_1850_6_RPS	1241.94	92.91	FSU

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input flows

MODEL 2 - BALLYROAN

The Ballyroan model includes the Gloreen Stream, a tributary of the River Nore the confluence of which is between Poormansbridge and The Warren. The Ballyroan AFA is affected by the Gloreen Stream. Three gauging stations are located on the reach but no flow data is available.

The total contributing catchment area at the downstream end of the model is 39.4km², with approximately 15km² of this area entering the model above Ballyroan. This includes a HPW tributary of the Gloreen Stream which flows through Ballyroan from Cullenagh Mountain. Downstream of the AFA a number of small tributaries join the Gloreen Stream before it enters the River Nore.

The Ballyroan model and its HEPs are shown in Figure 4.3.

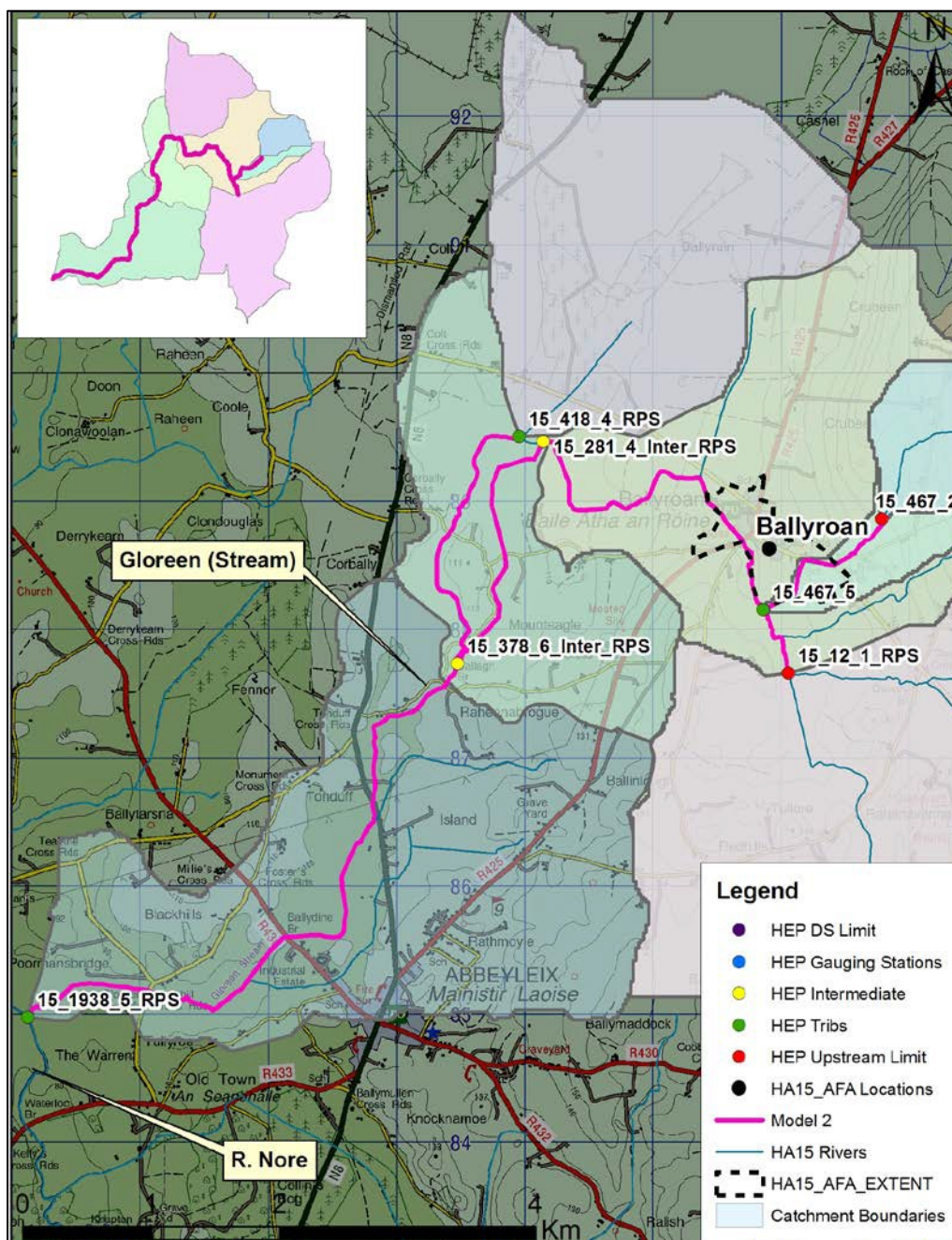


Figure 4.3: Model 2 HEPs and Catchment Boundaries

No rainfall run-off models have been developed for Model 2 due to the small size of the sub-catchments and lack of gauged data upon which to calibrate. However, the gauging stations on the Nore River have been subject to hydrological modelling which improved their record length and AMAX statistical certainty and as such their use as pivotal sites for adjusting index flow using FSU methods.

The estimated Q_{med} values for the various HEPs within Model 2 are shown in Table 4.2.

Table 4.2: Q_{med} Values for Model 2

Node ID_CFRAMS	AREA (km²)	Q_{med} (m³/s)	Preferred Estimation Methodology
15_12_1_RPS	11.12	2.32	FSU
15_467_2	1.59	0.40	FSU
15_467_5	2.48	0.62	FSU
15_281_4_Inter_RPS	19.62	3.02	FSU
15_418_4_RPS	6.04	0.48	FSU
15_418_5_RPS	7.8	0.6	FSU
15_378_6_Inter_RPS	30.8	4.16	FSU
15_1938_5_RPS	39.37	5.10	FSU

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input

4.2 MODEL 3 – MOUNTRATH

The Mountrath model includes the Mountrath River, a tributary of the River Nore with its confluence south of Castletown. The Mountrath AFA is affected by the Mountrath River and two of its tributaries. A gauging station is located on the Mountrath River (15027 – EPA) but flow data is not available.

Downstream of the AFA a number of small tributaries join the Mountrath River but the largest portion of the catchment contributes to the model upstream of Mountrath. The contributing catchment area at the downstream limit of the model is 57.7km². The HEPs and catchment boundaries are shown in Figure 4.4.

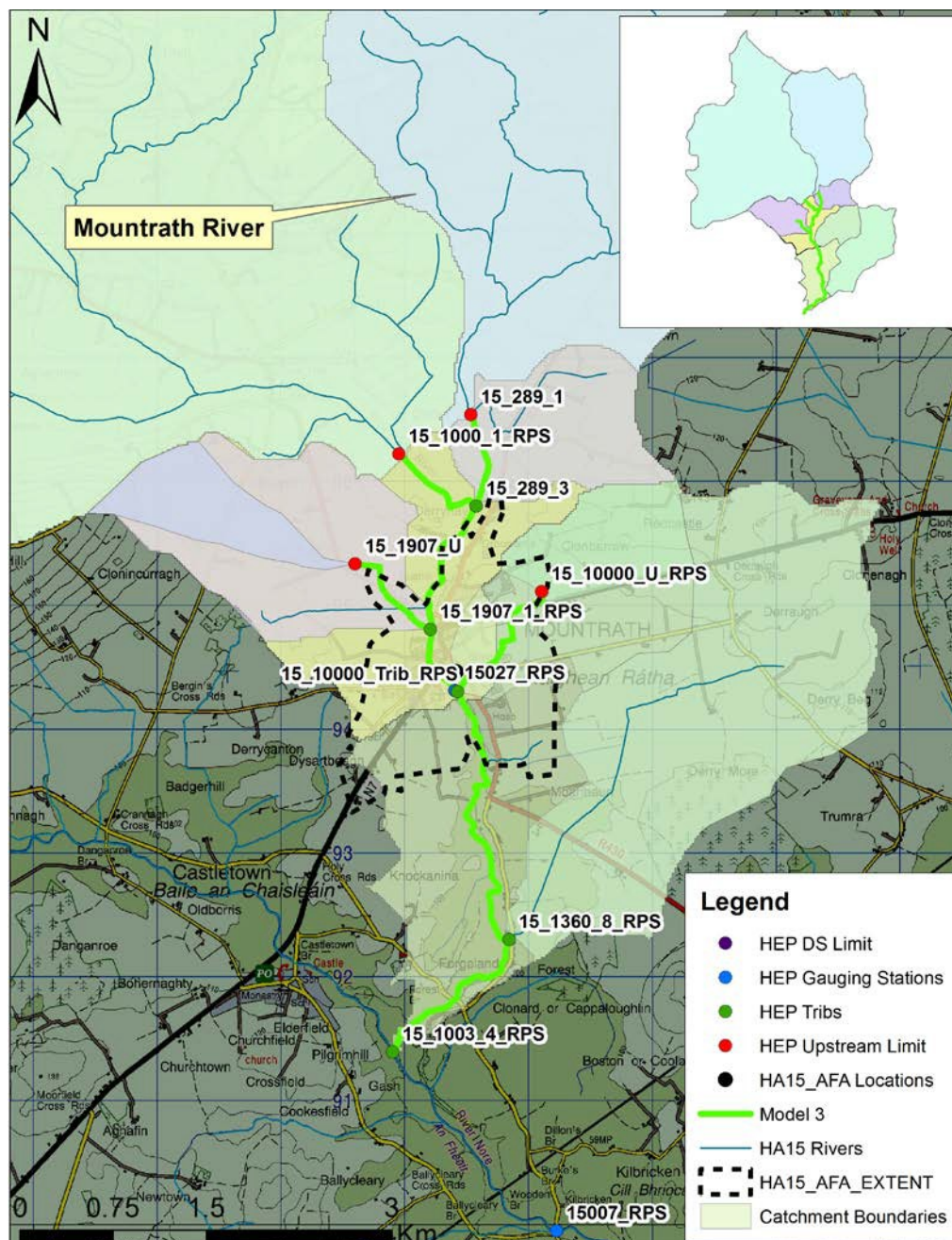


Figure 4.4: Model 3 HEPs and Catchment Boundaries

No rainfall run-off models have been developed for Model 3 due to the lack of gauged data upon which to calibrate. However, the gauging stations on the Nore River have been subject to hydrological modelling which improved their record length and AMAX statistical certainty and as such their use as pivotal sites for adjusting Q_{med} flow using FSU methods.

The estimated Q_{med} values for the various HEPs within Model 3 are shown in Table 4.3.

Table 4.3: Q_{med} Values for Model 3

Node ID_CFRAMS	AREA (km ²)	Q_{med} (m ³ /s)	Preferred Estimation Methodology
15_1000_1_RPS	26.71	8.38	FSU
15_289_1	13.47	4.67	FSU
15_289_3	15.00	4.81	FSU
15_1907_1_RPS	2.86	0.76	FSU
15_1907_U_RPS	0.86	0.24	FSU
15027_RPS	46.72	14.12	FSU
15_10000_U_RPS	0.99	0.31	FSU
15_10000_Trib_RPS	2.32	0.92	FSU
15_1360_8_RPS	6.40	1.22	FSU
15_1003_4_RPS	57.73	15.51	FSU

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input flows

4.3 MODEL 4 – FRESHFORD

The Freshford model includes the Nuenna River, a tributary of the River Nore. The Freshford AFA is affected by the Nuenna River and three of its tributaries which join the Nuenna within the AFA extent. There is one gauging station located within Freshford itself but no flow data is available (Station 15039).

Downstream of the AFA the Arigna River joins the Nuenna River but the largest portion of the catchment contributes to the model upstream of Freshford. The total contributing catchment area at the downstream limit of the model is 92km². The HEPs and catchment boundaries are shown in Figure 4.5

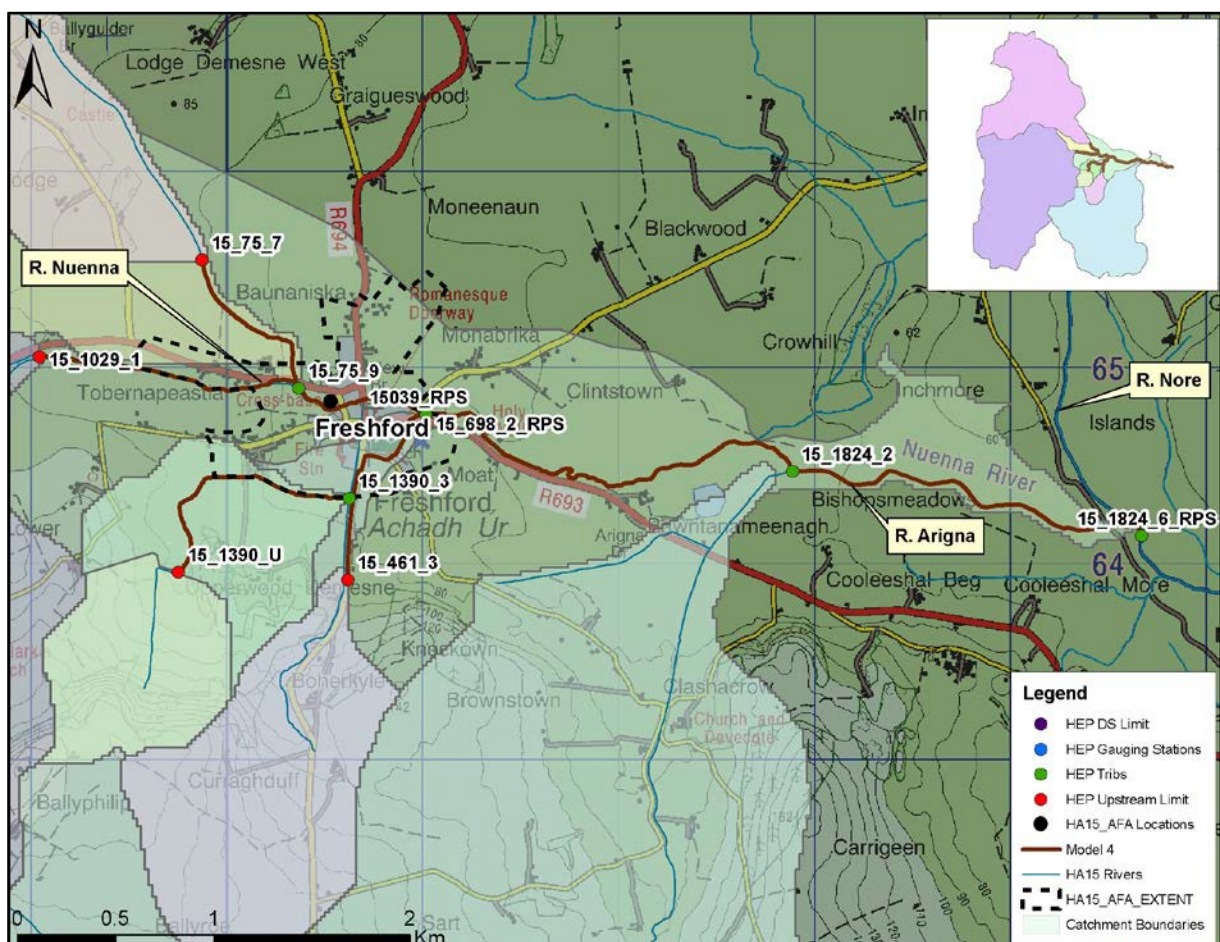


Figure 4.5: Model 4 Freshford

No rainfall run-off models have been developed for Model 4 due to the lack of gauged data upon which to calibrate. A review of pivotal site options for the HEPs revealed a high degree of scatter and no clear trend for upwards or downwards adjustment of initial Q_{med} estimates using catchment descriptors. Adjustment using geographically closest sites on the River Nore resulted in Q_{med} values above the 68%ile confidence limit, whilst the most hydrologically similar sites varied between upwards adjustment, downwards adjustment, and negligible change (the latter being the case for the most hydrologically similar site). However following public consultation on the draft flood maps strong evidence was produced indicating that the flood extents for all return periods were underestimated.

Significant changes to the model did not increase the extents by the degree indicated by the public consultation and as such the pivotal site selection was revisited. The Blackfriars Bridge gauging station (15050) on the River Breagagh is both geographically close and hydrologically similar. This station had not be considered in the original assessment of pivotal sites as the station was not classified under FSU however given the evidence from the public consultation and the additional certainty in the Q_{med} following rainfall run-off modelling of the catchment as part of this Study, it was considered appropriate to apply a significant upwards adjustment (33%) based on this station.

The estimated Q_{med} values for the various HEPs within Model 4 are shown in Table 4.4.

Table 4.4: Q_{med} Values for Model 4

Node ID_CFRAMS	AREA (km²)	Q_{med} (m³/s)	Preferred Estimation Methodology
15_1029_1	34.92	5.72	FSU
15_75_7	24.91	6.44	FSU
15_75_9	25.97	6.62	FSU
15_461_3	1.57	0.51	FSU
15_1390_U	0.79	0.26	FSU
15_1390_3	1.61	0.47	FSU
15_698_2_RPS	3.42	0.98	FSU
15_1824_2	23.18	5.38	FSU
15_1824_6_RPS	92.18	19.64	FSU

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input flows

4.4 MODEL 5 KILKENNY (NORE) AND KILKENNY (BREAGAGH)

Model 5 represents the Kilkenny AFA and encompasses the mid to lower reaches of the River Nore, the River Breagagh, the River Pococke and associated tributaries. The Kilkenny AFA is affected by these watercourses. The River Breagagh joins the River Nore from the west in Kilkenny City; the River Pococke meets the Nore at the downstream end of the AFA. An additional High Priority Watercourse (HPW) enters the River Nore approximately 0.7km further downstream.

The total contributing area at the downstream limit of the model is 1744.5km². 71% of this area comprises Model 1 upstream. A significant tributary, the River Dinin, enters the River Nore at the upstream limit of Model 5 (where Model 1 ends). The contributing area of the River Dinin catchment is almost 300km² and makes up 17% of the total catchment area for Model 5. A further 4% of the total contributing area comes from the River Breagagh catchment, and 2% from the River Pococke catchment.

There are three gauging stations located within Model 5 on the River Nore:

- Station 15104 Sycamores – OPW – no flow data available
- Station 15002 Johns Bridge – OPW – was classified “A2” under FSU in 2004 - there is confidence in flow values up to around 1.3 times Q_{med} . Q_{med} gauged is 216 m³/s (based on AMAX series from 1953 to 2009, but missing 2002 – 2005 during flood relief works).
- Station 15105 Archers Grove – OPW – no flow data available

There is one gauging station located within Model 5 on the River Breagagh:

- Station 15050 Blackfriar's Bridge – OPW – classified “C” under FSU, therefore confidence in flow values only extends to 0.8 x Q_{med} . OPW hydrometrics have also advised that the rating is not reliable post May 2004. A new rating is required following the installation of a data logger after the flood relief works at the end of 2005. The FSU ungauged catchment descriptor based equation predicts Q_{med} at 8.02 cumecs.

There is also a gauging station located on the River Dinin upstream of its confluence with the River Nore:

Station 15003 Dinin Bridge, OPW – was classified as “A2” under FSU in 2004. Q_{med} gauged is 151.14m³/s based on AMAX series from 1954 to 2009 consecutively. The limit of the reliable rating is 118 m³/s.

Excluding the extent of Model 1, the contributing catchment area is approximately 3% urbanised including Kilkenny and environs, Castlecomer and Bennettsbridge.

The extent of Model 5 is shown in Figure 4.6.

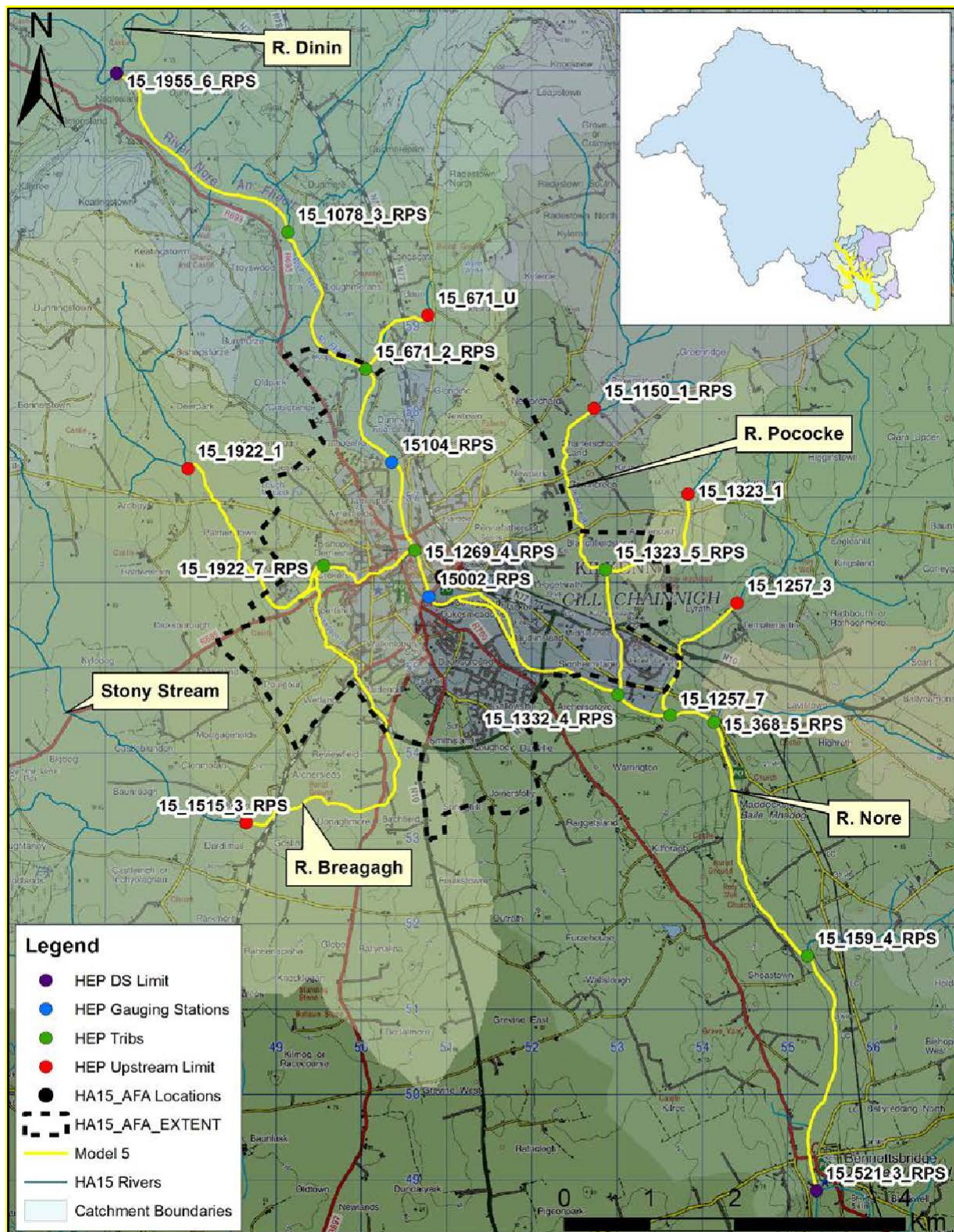


Figure 4.6: Model 5 HEPs and Catchment Boundaries

Since Station 15002 Johns Bridge is an A2 classified station, and has a median hydrograph available for use through the FSU (it is a Hydrograph Shape Generator pivotal site), a rainfall runoff model has not been constructed as there is already high confidence in the gauge.

A rainfall run-off model was developed to represent the catchment at the Blackfriar's Bridge gauging station (15050) in order to create an extended simulated AMAX series at this gauging station. The rainfall run-off (NAM) model was calibrated using high resolution rainfall data from the adjusted radar sums and the nearby hourly rainfall gauging station No. 3613 in Kilkenny and good calibration against medium to low observed flows (1996 to 2003) was achieved (there is uncertainty in the gauge at / above Q_{med}). The extended AMAX series (1957 – 2010) has a median flood flow of $11.1\text{m}^3/\text{s}$.

Q_{med} estimates at the various HEPs were derived based using FSU catchment descriptor based equation and adjusted based on the gauge at John's Bridge (Nore) or Blackfriar's Bridge (Breagagh) where appropriate. However the HEP marking the Dinin River tributary where it joins the River Nore (15_1955_6, refer to Figure 4.6) was adjusted using the upstream pivotal site at Dinin Bridge (Station 15003).

The estimated Q_{med} values for the various HEPs within Model 5 are shown in Table 4.5 overleaf.

It is worth noting that Station 15003 (Dinin Bridge) has a high adjustment factor of 3.3 due to the significant difference between the Q_{med} value estimated using catchment descriptors (FSU WP 2.3), $Q_{med\ pcd}$ and the gauged Q_{med} . Since there is high confidence in the gauge, and this HEP is located just downstream, it is considered appropriate to use this station as a pivotal site. As a consequence the calculated Q_{med} flow of $149\text{m}^3/\text{s}$ coming from the River Dinin tributary is relatively high and not reflected by the magnitude of Q_{med} flows on the River Nore downstream (i.e. HEPs 15104_RPS AND 15002_RPS).

Since completion of the draft report, OPW's FSU team have updated BFI values for pivotal sites (gauging stations) to better reflect the observed BFI value¹. This has resulted in an increase to the predicted Q_{med} value at station 15003 and a decrease in the associated adjustment factor, which is now 2.4 instead of 3.3. If we take 2.4 for adjustment, the resulting Q_{med} value is $107.84\text{m}^3/\text{s}$ which is considered more reasonable.

The Kilkenny Flood Relief Scheme was completed in 2005. It consisted of a combination of river widening and deepening, flood walls, embankments and associated drainage works. The effect on Q_{med} flows within the River Nore pre- and post scheme is discussed in Section 7.4.3.

¹ Whilst the revised BFI values have not been published in time for use in CFRAMS, it was considered prudent to include it in this case given the significance of the adjustment factor on the tributary in terms of input flow to the hydraulic model.

Table 4.5: Q_{med} Values for Model 5

Node ID_CFRAMS	AREA (km²)	Qmed (m³/s)	Preferred Estimation Methodology
15_1850_6_RPS	1241.94	92.91	Input from Model 1
15_1955_6_RPS	299.85	107.84	FSU
15_1078_3_RPS	7.68	2.58	FSU
15_671_U	2.18	0.49	FSU
15_671_2_RPS	4.33	0.97	FSU
15104_RPS	1567.50	208.04	FSU
15_1515_3_RPS	44.20	8.40	FSU
15_1922_1	7.27	1.74	FSU
15_1922_7_RPS	10.21	2.11	FSU
15050_RPS	70.90	11.10	NAM
15_1269_4_RPS	70.99	11.14	FSU
15002_RPS	1642.23	216.00	FSU
15_1150_1_RPS	28.66	7.93	FSU
15_1323_1	1.63	0.28	FSU
15_1323_5_RPS	2.43	0.49	FSU
15_1332_4_RPS	36.08	9.17	FSU
15_1257_3	13.23	2.68	FSU
15_1257_7	15.09	3.02	FSU
15_368_5_RPS	12.51	2.36	FSU
15_159_4_RPS	11.42	2.08	FSU
15_521_3_RPS	1744.54	229.19	FSU

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input flows

4.5 MODEL 6 - CALLAN

Model 6 represents the Kings River and associated tributaries. The Callan AFA is affected by these watercourses. The Kings River joins the River Nore from the west approximately 6km upstream of Thomastown. The total contributing catchment area at the downstream end of the model is 444km² with approximately 45% of this entering the model upstream of the AFA.

The extent of Model 6, its HEPs and the Kings River catchment are shown in Figure 4.7.

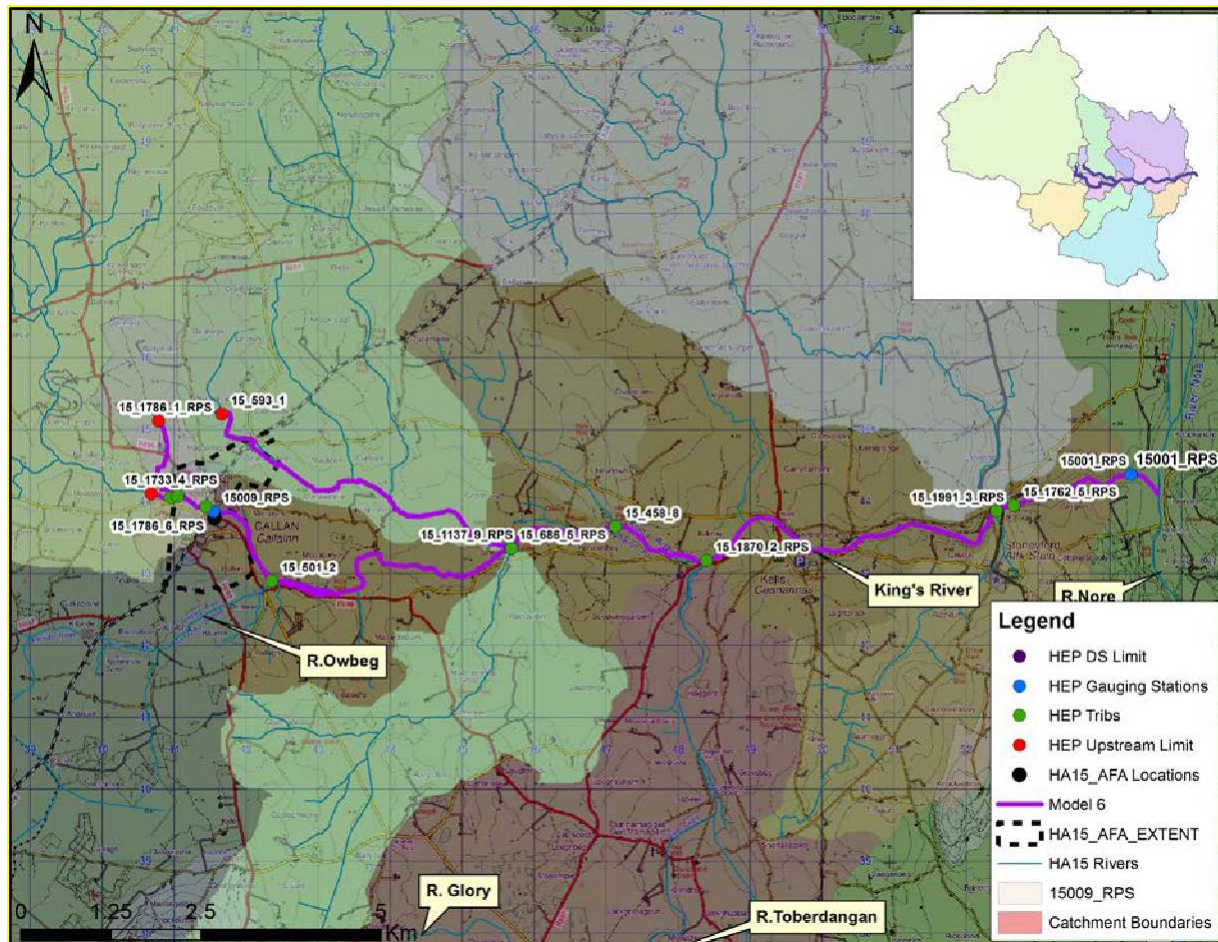


Figure 4.7: Model 6 HEPs and Catchment Boundaries

Two gauging stations are located along the modelled reach.

Station 15009 Callan, is located within the Callan AFA and was classified “B2 under FSU in 2004 and as such is not included as a FSU pivotal site. There is confidence in the gauge up to a maximum of Q_{med} (41.23 m³/s, 1956 – 2009). Q_{med} was updated for this station to 63.2 m³/s following CFRAM rating review (refer to Chapter 3).

Station 15001 Annamult is located at the downstream end of Model 6 just before its confluence with the River Nore (Model 7), and was classified “A2” under FSU in 2004. There is confidence in the

gauge up to around 1.3 times above Q_{med} (89.58 m³/s from 1954 to 2009 with 8 years missing from the AMAX series).

A rainfall run-off model was constructed for Station 15009 using rainfall radar data supplemented by hourly rainfall data at gauge 3613 in Kilkenny. It was calibrated against observed medium to low flows to increase confidence in the Q_{med} value and provide a median hydrograph shape. The resulting Q_{med} value is 40.78 m³/s. Station 15001 was not subject to hydrological modelling given the high degree of confidence already in the gauge, including Q_{med} and hydrograph shape.

Q_{med} estimates at the various HEPs were derived based on catchment descriptor based estimates and adjusted based on the NAM output at Callan or the gauge at Annamult as appropriate. The estimated Q_{med} values for the various HEPs within Model 6 are shown in Table 4.6.

As outlined in Section 4.5, the recent change in adjustment factors as a result of updated BFI values at pivotal sites can result in significant changes to Q_{med} flows. This is the case for Station 15001 (Annamult) where the adjustment factor was reduced by 15%. It was therefore considered prudent to apply the revised adjustment factor to the associated six HEPs which includes the downstream limit HEP that enters the River Nore within Model 7 (refer to Section 4.7).

Table 4.6: Q_{med} Values for Model 6

Node ID_CFRAMS	AREA (km ²)	Q_{med} (m ³ /s)	Preferred Estimation Methodology
15_1733_4_RPS	199.64	62.54	FSU
15_1786_1_RPS	1.45	0.12	FSU
15_1786_4_RPS	2.24	0.37	FSU
15_1786_5_RPS	0.05	0.01	FSU
15_1786_6_RPS	0.09	0.03	FSU
15009_RPS	202.77	63.20	NAM
15_501_2	33.64	5.22	FSU
15_593_1	2.00	0.51	FSU
15_1678_11_RPS	20.44	3.38	FSU
15_686_5_RPS	29.33	4.81	FSU
15_1137_9_RPS	16.45	2.75	FSU
15_458_8	6.45	0.93	FSU
15_1869_2_RPS	299.27	80.95	FSU
15_1870_2_RPS	70.62	9.65	FSU
15_1991_3_RPS	10.93	1.71	FSU
15_1762_5_RPS	47.02	4.93	FSU
15001_RPS	443.64	89.58	Gauged Q_{med}
15_1819_6_RPS	443.78	89.66	FSU

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input flows

4.6 MODEL 7 – THOMASTOWN

Model 7 represents the Thomastown AFA and encompasses the River Nore upstream and downstream of its extent, and associated tributaries. The total contributing area at the downstream limit of the model is 2417km². 71% of this comes from Model 5 upstream, 18% from the Kings River and 2% from the Arrigle tributary, with the rest from minor tributaries and lateral catchment. There are two gauging stations located along the length of this Model:

- Mount Juliet (15011 – OPW) has continuous flow data from 1945 to 2011 (with several gaps) and a FSU classification of C meaning that a well defined rating is available to approximately 0.8 x Q_{med} and as such this gauge was not included in the FSU.
- Brownsbarn (15006 – OPW) has continuous flow data from 1972 to 2011 and has a FSU classification of A2, therefore there is confidence in the gauged data up to approximately 1.3 times the flow above Q_{med} .

The modelled extents and HEPs are shown in Figure 4.8.

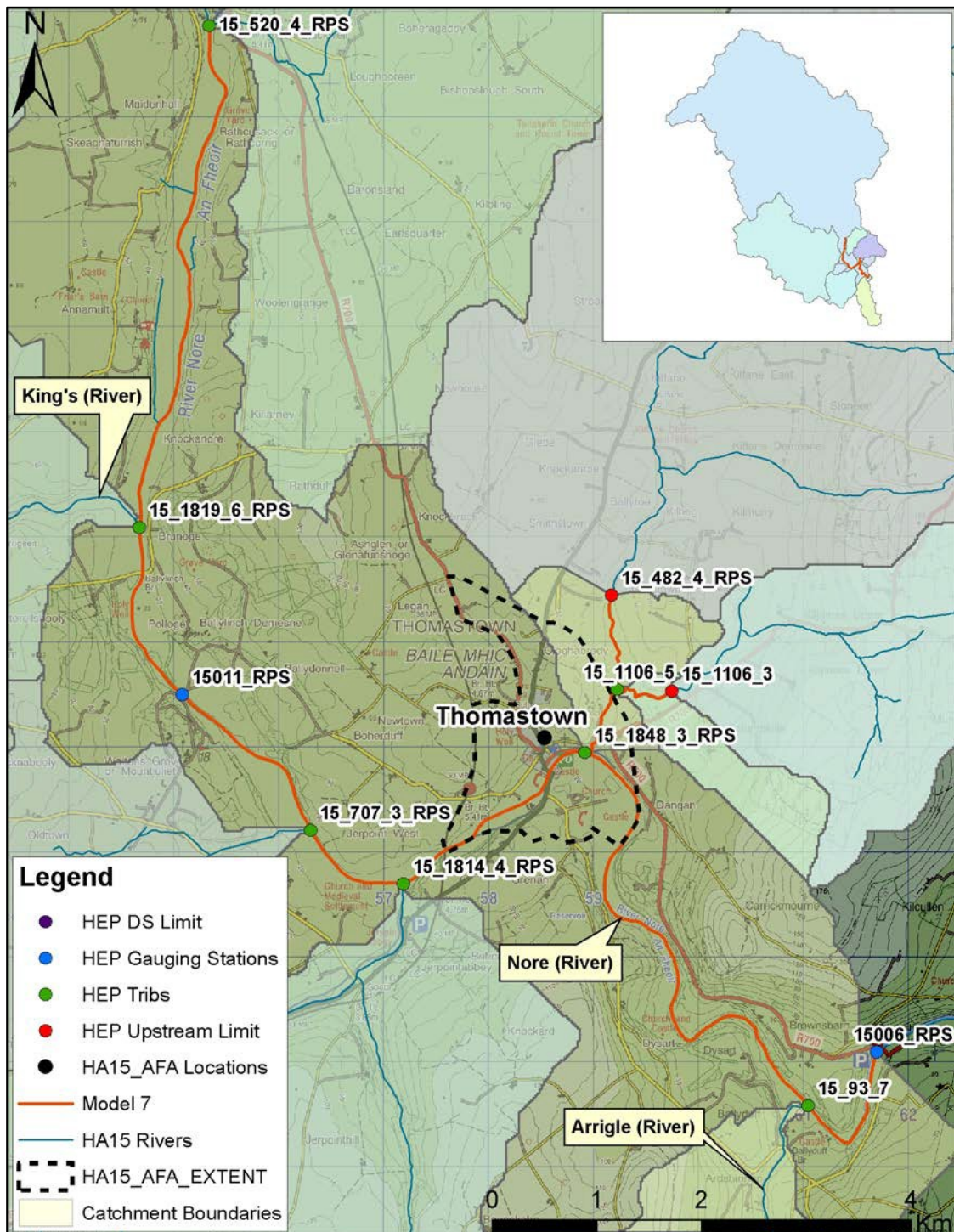


Figure 4.8: Model 7 Catchment Boundaries and HEPs

Since Station 15006 Brownsbar is an A2 classified station, and has a median hydrograph available for use through the FSU (Hydrograph Shape Generator pivotal site), a rainfall runoff model has not been constructed as there is already high confidence in the gauge.

A catchment rainfall run-off model was developed to represent the catchment at the Mount Juliet gauging station (15011) in order to create an extended simulated AMAX series at the gauging station. The rainfall run-off (NAM) model was calibrated using area-weighted derived rainfall data from the

nearby hourly rainfall gauging stations in Kilkenny, Oak Park, Gurteen and Birr, since radar coverage is not available at this location. Good calibration against medium to low observed flows (1991 to 2010) was achieved. The extended AMAX series (1955 – 2010) has a median flood flow of $278.3 \text{ m}^3/\text{s}$.

Q_{med} estimates at the various HEPs were derived using the FSU catchment descriptor based equation and adjusted based on the gauge at Brownsbarn or Mount Juliet as appropriate. The estimated Q_{med} values for the various HEPs are shown in Table 4.7.

Table 4.7: Q_{med} Values for Model 7

Node ID_CFRAMS	AREA (km^2)	Q_{med} (m^3/s)	Preferred Estimation Methodology
15_521_3_RPS	1744.54	229.19	FSU
15_520_4_RPS	21.50	2.93	FSU
15_1819_6_RPS	443.78	89.66	FSU
15011_RPS	2223.77	278.30	NAM
15_707_3_RPS	8.26	2.10	FSU
15_1814_4_RPS	63.72	10.95	FSU
15_482_4_RPS	38.71	8.32	FSU
15_1106_3	7.03	2.46	FSU
15_1106_5	8.28	2.66	FSU
15_1848_3_RPS	48.79	10.21	FSU
15_93_7	46.92	10.70	FSU
15006_RPS	2416.89	299.00	Gauging Station (A2)

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input flows

4.7 MODEL 8 - BALLYHALE

The Ballyhale model includes the Little Arrigle River, a tributary of the River Nore. The Ballyhale AFA is affected by a tributary of the Little Arrigle River the confluence of which is downstream of the AFA extent. There is one gauging station located along the model length, downstream of Ballyhale but no flow data is available (Station15046, Jerpoint Hill). The HEPs and catchment boundaries are shown in Figure 4.9.

No rainfall run-off models have been developed for Model 8 due to the lack of gauged data upon which to calibrate. A review of pivotal site options identified a trend for upwards adjustment of $Q_{med\ pcd}$ with Station 15001 (Annamult) selected as the geographically closest.

The estimated Q_{med} values for the various HEPs within Model 8 are shown in Table 4.8.

Table 4.8: Q_{med} Values for Model 8

Node ID_CFRAMS	AREA (km ²)	Q_{med} (m ³ /s)	Preferred Estimation Methodology
15_1358_3_RPS	10.81	1.9	FSU
15_1182_7_RPS	13.19	1.73	FSU
15_1212_7	15.09	2.24	FSU
15_1337_12_RPS	10.10	2.57	FSU
15_1814_4_RPS	63.72	10.09	FSU

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input flows.

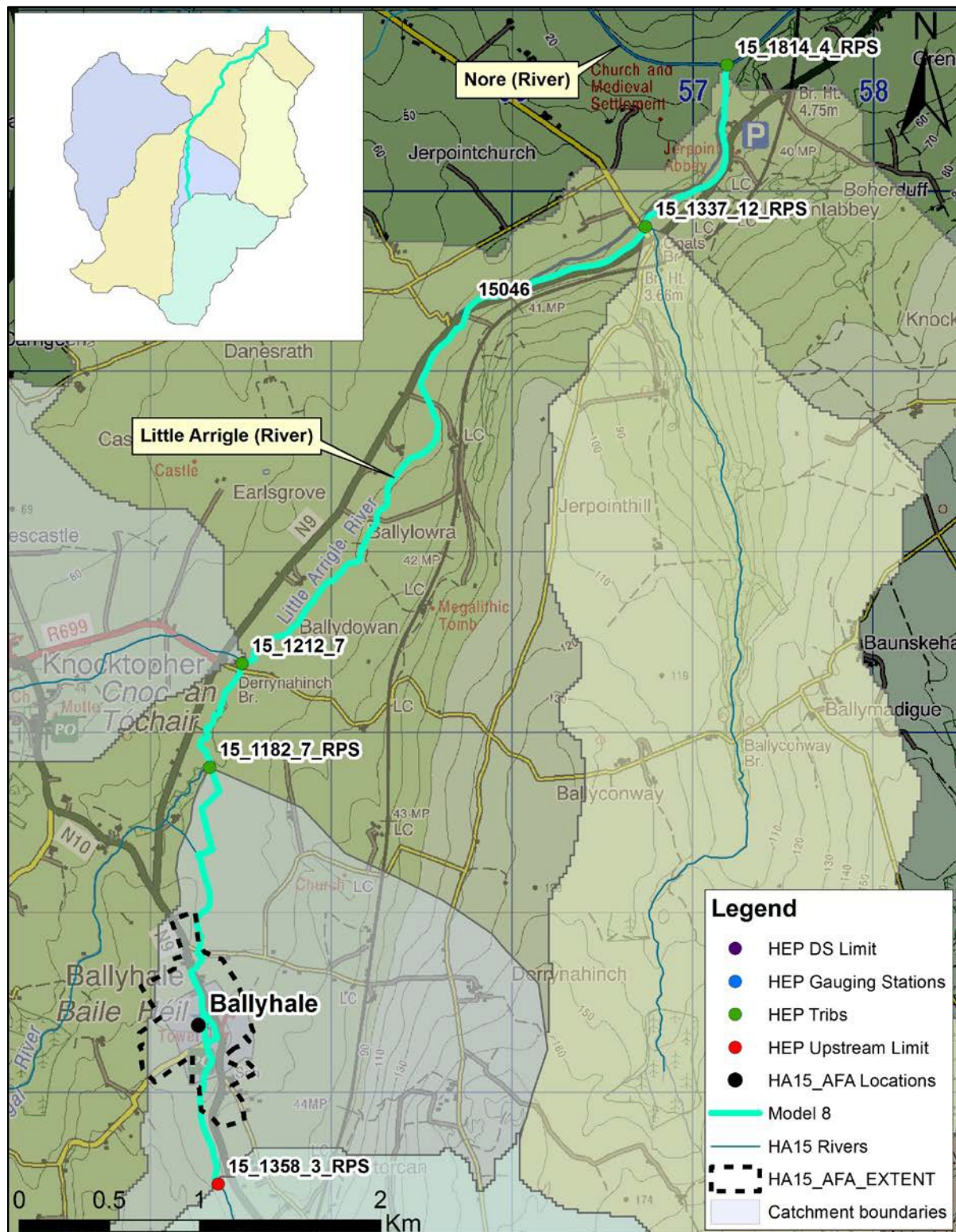


Figure 4.9: Model 8 Catchment Boundaries and HEPs

4.8 MODEL 9 – INISTIOGE

Model 9 represents the Inistioge AFA and encompasses the most downstream reach of the River Nore prior to joining the Upper Barrow Nore Estuary. The Inistioge AFA is affected by the River Nore and a small tributary of the Nore flowing from the west which is also included as a HPW within the model.

The total contributing area at the downstream limit of the model is 2519km² i.e. the entire Nore catchment. 96% of this area enters Model 9 at the upstream limit (downstream output from Thomastown Model 7). The modelled tributary which meets the Nore within Inistioge has a total contributing area of 4.5km². Downstream of the AFA, several small steep-slope tributaries enter the River Nore, the largest of which is the Clodiagh River (14km²). The Nore catchment as a whole is predominantly rural.

The aforementioned Brownsbarn gauge (15006 – OPW) is located at the upstream limit of the Model.

The modelled extents, contributing catchments and HEPs are shown in Figure 4.10. As indicated by the orange outline on the map, the Nore is tidally influenced along most of Model 9.

Since Station 15006 Brownsbarn is an A2 classified station, and has a median hydrograph available for use through the FSU (Hydrograph Shape Generator pivotal site), a rainfall runoff model has not been constructed as there is already high confidence in this gauge. This station was used as a pivotal site to adjust the index flows for Model 9. However in the case of the smaller tributaries entering the Nore, a review of pivotal site options revealed that using Station 15006 pushed the resulting Q_{med} values above the 68%ile upper limit. Therefore as an alternative, the most suitable geographically close station was used (Station 14013 or 15001 as appropriate). The estimated Q_{med} values for the various HEPs within Model 9 are shown in Table 4.9.

Table 4.9: Q_{med} Values for Model 9

Node ID_CFRAMS	AREA (km ²)	Q_{med} (m ³ /s)	Preferred Estimation Methodology
15006_RPS	2416.89	299.30	Gauging Station (A2)
15_1511_8	10.08	2.26	FSU
15_650_7	14.22	2.83	FSU
15_1996_U	3.59	1.01	FSU
15_1996_1	4.52	1.29	FSU
15_2002_9	8.77	1.62	FSU
15_2008_6	14.20	3.17	FSU
15_2014_4	6.44	1.36	FSU
15_2016_2	7.46	1.53	FSU
15_1839_1	2519.25	305.56	FSU

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input flows

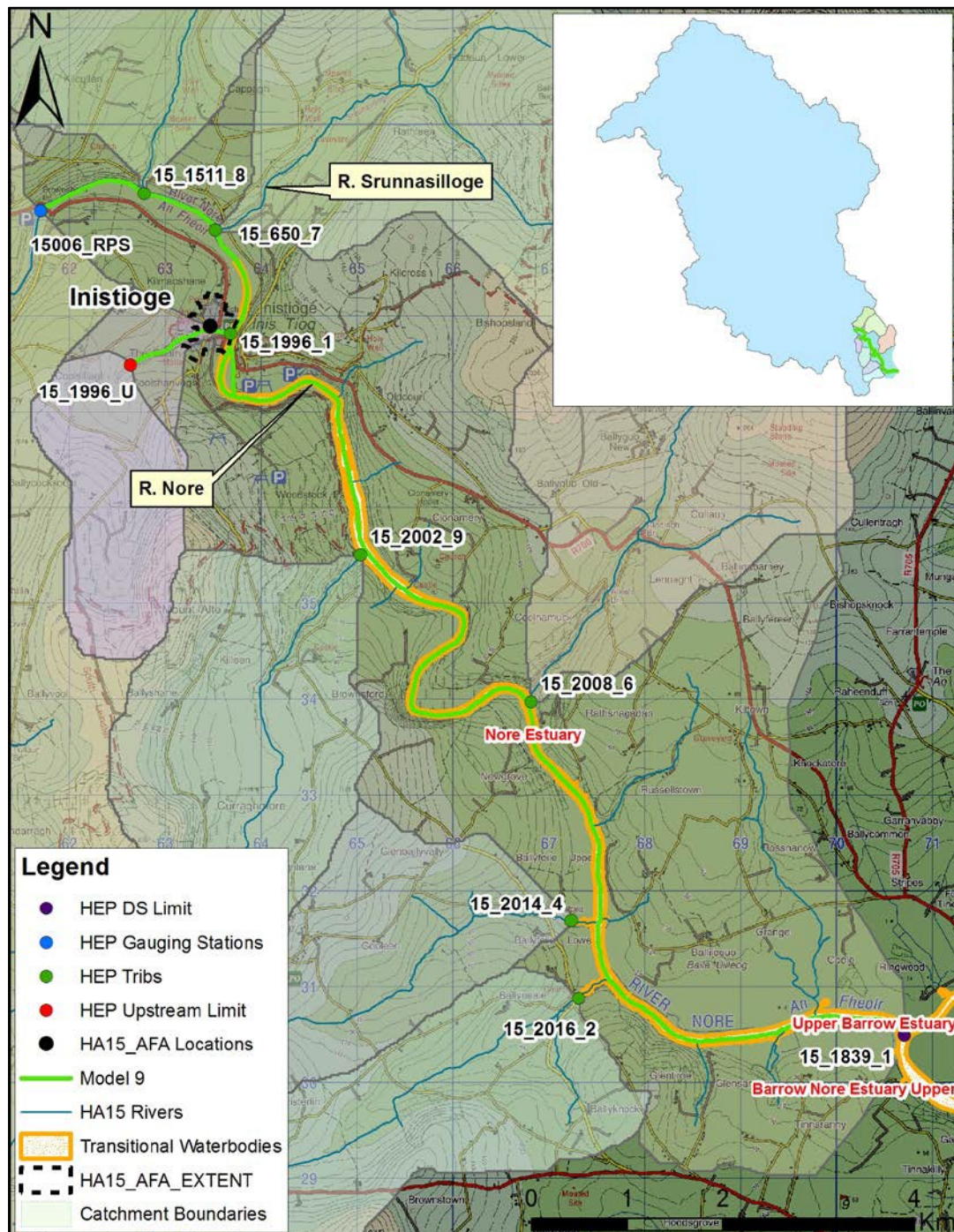


Figure 4.10: Model 9 Catchment Boundaries and HEPs

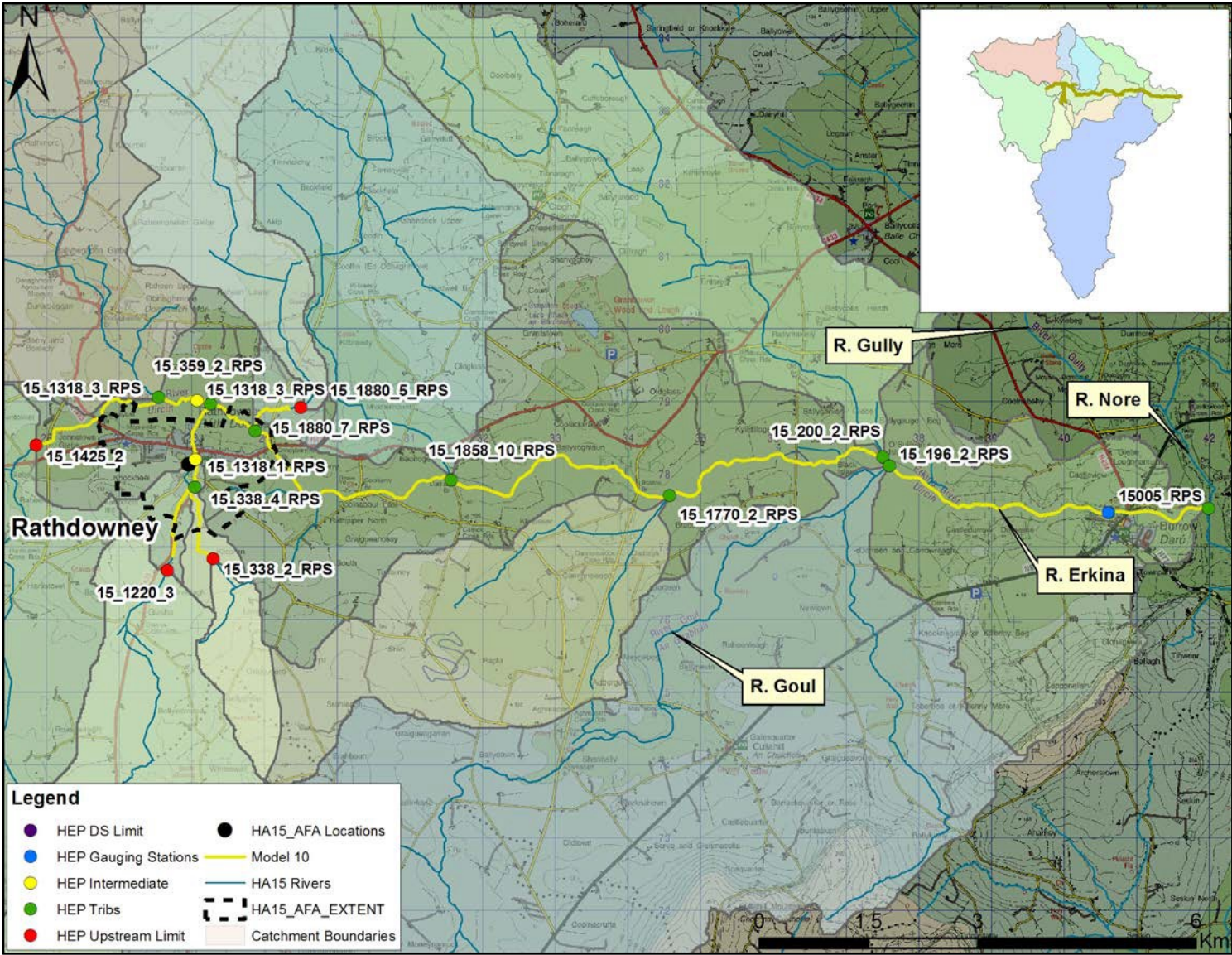
4.9 MODEL 10 – RATHDOWNEY

Model 10 encompasses the Erkina River and its tributaries. The Erkina River is a tributary of the River Nore. The Rathdowney AFA is affected by a tributary of the Erkina River the confluence of which is located just north of the AFA extent. The Erkina River itself is a MPW, the tributaries in and around Rathdowney AFA are HPWs.

There is one gauging station located along the model length, Station 15005 Durrow Foot Bridge. This Station is classified as A1 under FSU pre 1972 and Class B post 1972 (when a data logger was installed). Q_{med} is 27.44 m³/s, 1954-2004, with 1974 data missing).

The total contributing catchment area at the downstream limit of the model is 380km². Almost half of this comes from the Goul River sub catchment which joins the Erkina River approximately 11km downstream of Rathdowney AFA. The HPWs directly affecting Rathdowney have a total contributing area of 15km². The HEPs and catchment boundaries are shown in Figure4.11.

Since Station 15005 Durrow Ft is an A1/B classified station, with 50 years of useable data and has a median hydrograph available for use through the FSU (Hydrograph Shape Generator pivotal site), a rainfall runoff model has not been constructed as there is already good confidence in the gauge. This station was used as a pivotal site to adjust the index flows for Model 10.



The estimated Q_{med} values for the various HEPs within Model 10 are shown in Table 4.10.

Table 4.10: Q_{med} Values for Model 10

Node ID_CFRAMS	AREA (km ²)	Q_{med} (m ³ /s)	Preferred Estimation Methodology
15_1425_2	60.10	5.62	FSU
15_359_2_RPS	40.09	4.03	FSU
15_1220_3	11.95	1.15	FSU
15_338_2_RPS	1.94	0.28	FSU
15_338_4_RPS	2.57	0.41	FSU
15_1318_1_RPS	15.46	1.62	FSU
15_1318_3_RPS	15.76	1.72	FSU
15_1880_5_RPS	10.77	1.51	FSU
15_1880_7_RPS	11.58	1.58	FSU
15_1858_10_RPS	15.29	1.85	FSU
15_1770_2_RPS	11.47	1.06	FSU
15_200_2_RPS	18.08	2.20	FSU
15_196_2_RPS	168.10	13.63	FSU
15005	379.00	27.44	FSU
15_198_10_RPS	380.43	27.53	FSU

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input flows

4.10 INDEX FLOOD FLOW CONFIDENCE LIMITS

4.10.1 Gauged Q_{med}

As has been shown previously HA15 is a moderately well gauged catchment with 50% of the models having some gauge data available upon which estimates of flood flow can be based. The use of rainfall run-off modelling techniques can bring additional confidence at stations where the station rating is questionable at Q_{med} , the length of AMAX series is short such that statistical confidence in the Q_{med} value is diminished or where the behaviour of the catchment may have changed over time.

Rainfall run off models which have been completed to date for the South Eastern CFRAM Study area have been considered by RPS in order to measure the accuracy of the models at predicting Q_{med} . Models representing catchments at hydrometric gauging stations which were considered useable for FSU (see FSU WP 2.1) had the NAM model simulated Q_{med} values compared against the station observed Q_{med} values to see if the calibrated NAM models were replicating the gauged Q_{med} values. Three of these stations (B or above) have calibrated rainfall run-off models constructed. The results of the comparable simulated and observed Q_{med} values are shown in Table 4.11 below.

Table 4.11: Calibrated NAM Model Q_{med} Accuracy

Station Number	Station Name	FSU AMAX Years	FSU Classification	Observed Q_{med} Value (for FSU AMAX years)	Simulated Q_{med} Value (for FSU AMAX Years)	% Error
15004	McMahons Bridge	1954 – 2004	A2	37.3	49.5	32.9
15007	Kilbricken	1980 - 2004	A2	52.4	42.2	19.5
15012	Ballyragget	1988 - 2004	B	77.1	83.9	8.8
Average Error						20.4

As shown in Table 4.11 there are in some cases quite significant discrepancies between the NAM modelled Q_{med} values and those observed at the FSU gauging stations. However as discussed in Section 4.1 there is significant uncertainty associated with the observed records at 15004 and 15007 despite their A2 rating classifications. As such the Ballyragget gauging station is the only reliable record which can be considered for comparison within HA15 and at this station there is fair agreement (<10%) between the NAM modelled and observed Q_{med} values when the same periods of record are considered.

In relation to the accuracy it should also be noted these models are calibrated against the gauge records themselves and as such we would expect them to replicate the results. The ability to replicate the reliable record does however give us some degree of confidence in the models ability to extend the AMAX series and fill in record gaps.

4.10.2 Ungauged Q_{med}

The estimation of Q_{med} for the ungauged catchments within this study focuses on the FSU (WP 2.3) statistical based method where a regression equation is used based on catchment descriptors.

The FSU method for Flood Estimation in ungauged Catchments (WP 2.3) is based on a regression equation derived from data from 190 hydrometric gauge stations across Ireland, only eight of which are for catchments less than 25km². The factorial standard error (FSE) associated with Q_{med} estimation using FSU (WP 2.3) is 1.37. The IH124 method has traditionally been preferred for catchments less than 25km² in area as the data upon which the regression equation was derived is much more weighted towards smaller catchments. This has a higher factorial standard error of 1.64. However recent guidance has shifted towards the use of FSU WP 2.3 for all Irish ungauged catchments as discussed in Section 2.3.1.2 (based on recent CFRAM Study Guidance), and as such it has been applied to all ungauged catchments in this Study.

5 FLOOD FREQUENCY ANALYSIS AND GROWTH CURVE DEVELOPMENT

5.1 OBJECTIVE AND SCOPE

This chapter deals with the estimation of flood growth curves for the River Nore catchment (Hydrometric Area HA15). The estimated growth curves will be used in determining the peak design flood flows for all Hydrological Estimation Points (HEP) located on the modelled tributary and main river channels within Hydrometric Area HA15.

The scope of this chapter includes:

- (i) Selection of a statistical distribution suitable for regional flood frequency analysis,
- (ii) Selection of pooling region and groups, and
- (iii) Growth curve estimation,

5.2 METHODOLOGY

5.2.1 Selection of Statistical Distribution

The suitable distributions for the Annual Maximum (AMAX) series for all hydrometric gauging sites located within HA15 were determined based on the statistical distribution fitting technique described in the Flood Studies Update (FSU) Programme Work Package 2.2 “Frequency Analysis” (OPW, 2009), UK Flood Estimation Handbook (FEH) (Institute of Hydrology, 1999) and 1975 Flood Studies Report (NERC, 1975).

5.2.2 Forming a Pooling Region and Groups

The pooling group associated with each of the growth curves was formed based on the Region-of-Influence (ROI) approach (Burn, 1990) recommended in FSU (2009). The region from which the AMAX series were pooled to form a pooling group for each of the growth curves was selected based on the similarity in catchment characteristics (both climatic and physiographic) in the neighbouring geographical region.

5.2.3 Growth Curve Development

Growth curves for each of the HEP locations were developed / estimated in accordance with the methodologies set out in the FSU, FSR and FEH studies. The Hosking and Wallis (1997) proposed L-Moment theories were used in estimating the parameters of the statistical distributions. The growth curve estimation process was automated through development of a FORTRAN 90 language based computational program.

5.2.4 Limitations in the FEH and FSU Studies

There is no explicit guidance provided in FEH or FSU for dealing with the issues surrounding production of a large number of growth factors within a river system and the associated problems with consistency and transition from growth curve to growth curve. For the River Nore catchment, a catchment descriptor based generalised growth curve estimation method, as discussed later was used to deal with this real world problem.

5.3 DATA AND STATISTICAL PROPERTIES

5.3.1 Flood Data

The AMAX series for all hydrometric gauging sites located within the River Nore catchment were obtained from the OPW and the EPA. In addition to these, flow records from neighbouring catchments were also collected to form a pooling region for growth curve analysis. The AMAX series and continuous flood records for 92 gauging sites were obtained for up to 2011. There are climatic differences between the eastern and other parts of the country and restricting the choice of pooling stations to the eastern and south-eastern regions along with HA06, should ensure an additional degree of homogeneity. In particular, it was felt that the catchments of the Shannon hydrometric areas, many of which are large and flat, would not necessarily be homogeneous with the Eastern and South-Eastern HAs and therefore would not make any additional useful contribution to the development of growth curves for the East and South-Eastern HAs. In the light of the large number of AMAX values (3,336 station-years) available in the eastern and south-eastern HAs, it is not considered necessary to extend the pooling region to the entire country.

Table 5.1 presents the locations details, record lengths and some of the catchment characteristics of these hydrometric stations, while Figure 5.1 illustrates their spatial distribution in the region. The majority of the 92 stations have A1 & A2 rating quality classification (refer to Section 3.2 for the definition of the rating quality classifications of the hydrometric gauges). The record lengths in these gauging stations vary from 9 to 70 years with a total of 3,336 station-years of AMAX series. The River Nore catchment has 570 station-years of AMAX series from 14 hydrometric gaugingsites.

Table 5.1: Hydrometric Station Summary

Stations	Waterbody	Location	Record Length (Years)	Area (Km ²)	SAAR (Mm)	BFI	FARL	Gauge Rating Classification
6011	Fane	Moyles Mill	51	229.19	1028.98	0.708	0.874	A1
6012	Annalong	Subsidiary Intake	53	162.80	1046.24	0.680	0.831	
6013	Dee	Charleville	35	309.15	873.08	0.617	0.971	A1
6014	Glyde	Tallanstown	35	270.38	927.45	0.634	0.927	A1
6025	Dee	Burley	36	175.98	908.31	0.615	0.956	A1
7001	Tremblestown	Tremblestown	42	151.31	913.24	0.700	0.996	A2
7002	Deel [Raharney]	Killyon	51	284.97	920.53	0.780	0.929	A2
7003	Blackwater (Enfield)	Castlerickard	51	181.51	809.22	0.649	1.000	A1 & B
7004	Blackwater (Kells)	Stramatt	53	245.74	1007.88	0.619	0.772	A2
7005	Boyne	Trim	52	1332.17	879.71	0.721	0.983	A1
7006	Moynalty	Fyanstown	49	177.45	936.67	0.552	0.990	A2
7007	Boyne	Boyne Aqueduct	50	441.18	870.98	0.663	1.000	A1 & B
7009	Boyne	Navan Weir	34	1658.19	868.55	0.713	0.911	A1
7010	Blackwater (Kells)	Liscartan	51	699.75	948.29	0.658	0.798	A1 & A2
7011	Blackwater (Kells)	O'daly's Br.	49	281.74	1003.32	0.678	0.965	A2 & B
7012	Boyne	Slane Castle	70	2460.27	890.06	0.678	0.893	A1
7017	Moynalty	Rosehill	11	70.64	991.74	0.516	0.993	
7023	Athboy	Athboy	9	100.10	950.81	0.717	0.995	
7033	Blackwater (Kells)	Virginia Hatchery	30	124.94	1032.22	0.439	0.893	A2
8002	Delvin	Naul	24	33.43	791.12	0.597	1.000	A1
8003	Broadmeadow	Fieldstown	18	83.59	826.00	0.466	0.880	B
8005	Sluice	Kinsaley Hall	23	9.17	710.76	0.523	1.000	A2
8007	Broadmeadow	Ashbourne	21	37.94	845.02	0.399	1.000	B
8008	Broadmeadow	Broadmeadow	28	107.92	810.61	0.487	0.999	A2
8009	Ward	Balheary	15	61.64	767.09	0.545	0.999	A1
8010	Garristown St.	Garristown S.W.	13	1.13	818.92	0.682	1.000	
8011	Nanny	Duleek D/S	28	181.77	819.49	0.520	0.999	B
8012	Stream	Ballyboghill	17	25.95	798.70	0.524	0.999	B
9001	Ryewater	Leixlip	54	209.63	783.26	0.507	1.000	A1
9002	Griffeen	Lucan	25	34.95	754.75	0.674	0.958	A1
9010	Dodder	Waldron's Bridge	57	94.26	955.04	0.561	0.993	A1
9011	Slang	Frankfort	19	5.46	772.95	0.563	0.986	B
9024	Morell	Morell Bridge	9	98.75	851.99	0.705	0.987	

Stations	Waterbody	Location	Record Length (Years)	Area (Km ²)	SAAR (Mm)	BFI	FARL	Gauge Rating Classification
9035	Camac	Killeen Road	15	37.14	794.21	0.673	0.932	B
9048	Ryewater	Anne's Bridge	10	59.35	805.54	0.474	1.000	
9049	Lyreen	Maynooth	10	87.52	768.17	0.473	1.000	
10002	Avonmore	Rathdrum	52	230.89	1530.19	0.538	0.986	B
10004	Glenmacnass	Laragh	14	30.57	1700.39	0.436	0.997	
10021	Shanganagh	Common's Road	30	32.51	799.07	0.654	0.997	A1
10022	Cabinteely	Carrickmines	17	12.94	821.92	0.600	1.000	A1
10028	Aughrim	Knocknamohill	22	202.92	1396.92	0.788	0.999	B
10038	Stream	Druids Glen	10	16.14	914.40	0.618	1.000	
11001	Owenavorrigh	Boleany	38	155.11	931.07	0.489	0.999	A1
12001	Slaney	Scarawalsh	55	1030.75	1167.31	0.716	0.999	A2
12002	Slaney	Enniscorthy	31	1319.92	1129.33	0.714	1.000	
12013	Slaney	Rathvilly	35	204.39	1383.48	0.743	0.999	B
13002	Corock	Fouk's Mill	25	62.96	1043.79	0.733	1.000	
14003	Barrow	Borness	27	206.73	1160.51	0.532	1.000	
14004	Figile	Clonbulloge	53	268.85	838.67	0.537	1.000	
14005	Barrow	Portarlinton	53	405.48	1014.90	0.501	1.000	A2
14006	Barrow	Pass Br	56	1063.59	899.07	0.571	1.000	A1
14007	Stradbally	Derrybrock	30	118.59	814.07	0.642	1.000	A1
14009	Cushina	Cushina	30	68.35	831.24	0.667	1.000	A2
14011	Slate	Rathangan	31	162.30	806.97	0.600	0.999	A1
14013	Burren	Ballinacarrig	55	154.40	887.98	0.701	0.999	A2
14018	Barrow	Royal Oak	67	2419.40	857.46	0.665	1.000	A1
14019	Barrow	Levitstown	57	1697.28	861.46	0.624	0.999	A1
14022	Barrow	Barrow New Bridge	12	2069.53	855.63	0.652	0.999	
14029	Barrow	Graiguenamanagh U/S	52	2778.15	876.50	0.688	0.999	A2
14031	Tully	Japanese Gdns	10	13.00	826.06	0.650	1.000	
14033	Owenass	Mountmellick	10	78.89	1145.22	0.454	0.999	B
14034	Barrow	Bestfield Lock	17	2057.36	856.05	0.652	0.999	A2
14101	Boghlone	Kyleclonhobert	9	9.60	929.15	0.554	1.000	
15001	Kings	Annamult	48	444.35	935.24	0.514	0.997	A2
15002	Nore	John's Br.	53	1644.07	945.44	0.625	0.730	A2
15003	Dinin	Dinin Br.	56	299.17	933.86	0.381	0.998	A2
15004	Nore	McMahon's Br.	56	488.7	1067.46	0.594	0.999	A2
15005	Erkina	Durrow Ft. Br.	55	379.37	884.96	0.712	0.999	B
15006	Nore	Brownsbarn	54	2418.27	941.92	0.633	0.997	
15007	Nore	Kilbricken	35	339.76	1123.04	0.594	1.000	A2

Stations	Waterbody	Location	Record Length (Years)	Area (Km ²)	SAAR (Mm)	BFI	FARL	Gauge Rating Classification
15008	Nore	Borris In Ossory	35	116.22	943.75	0.533	0.993	
15009	Kings	Callan	54	203.14	940.19	0.540	1.000	
15010	Goul	Ballyboodin	31	159.06	886.97	0.657	0.997	
15011	Nore	Mount Juliet	57	2225.79	938.02	0.618	0.999	
15012	Nore	Ballyragget	16	1056.80	974.00	0.682	0.999	B
15021	Delour	Annagh	11	67.05	1358.56	0.651	1.000	
15041	Goul	Ballinfrase	9	135.39	889.60	0.634	0.996	
16001	Drish	Athlummon	38	135.06	916.42	0.606	1.000	A2
16002	Suir	Beakstown	56	485.70	932.15	0.634	0.999	A2
16003	Clodiagh	Rathkennan	56	243.20	1192.01	0.550	1.000	A2
16004	Suir	Thurles	55	228.74	941.36	0.579	1.000	A2
16005	Multeen	Aughnagross	35	84.00	1153.57	0.560	0.994	A2
16006	Multeen	Ballinaclogh	38	75.80	1115.82	0.587	0.999	B
16007	Aherlow	Killardry	56	273.26	1330.55	0.578	0.999	B
16008	Suir	New Bridge	56	1090.25	1029.63	0.635	0.998	A2
16009	Suir	Caher Park	57	1582.69	1078.57	0.631	0.998	A2
16010	Anner	Anner	38	437.10	985.24	0.624	0.999	
16011	Suir	Clonmel	71	2143.67	1124.95	0.670	0.993	A1
16012	Tar	Tar Br.	46	229.63	1320.79	0.628	0.999	B
16013	Nire	Fourmilewater	45	93.58	1471.29	0.539	0.993	B
16051	Rossestown	Clobanna	13	34.19	895.27	0.676	1.000	B
17002	Tay River	Fox Castle	10	33.50	1554.00	n.a.	n.a.	

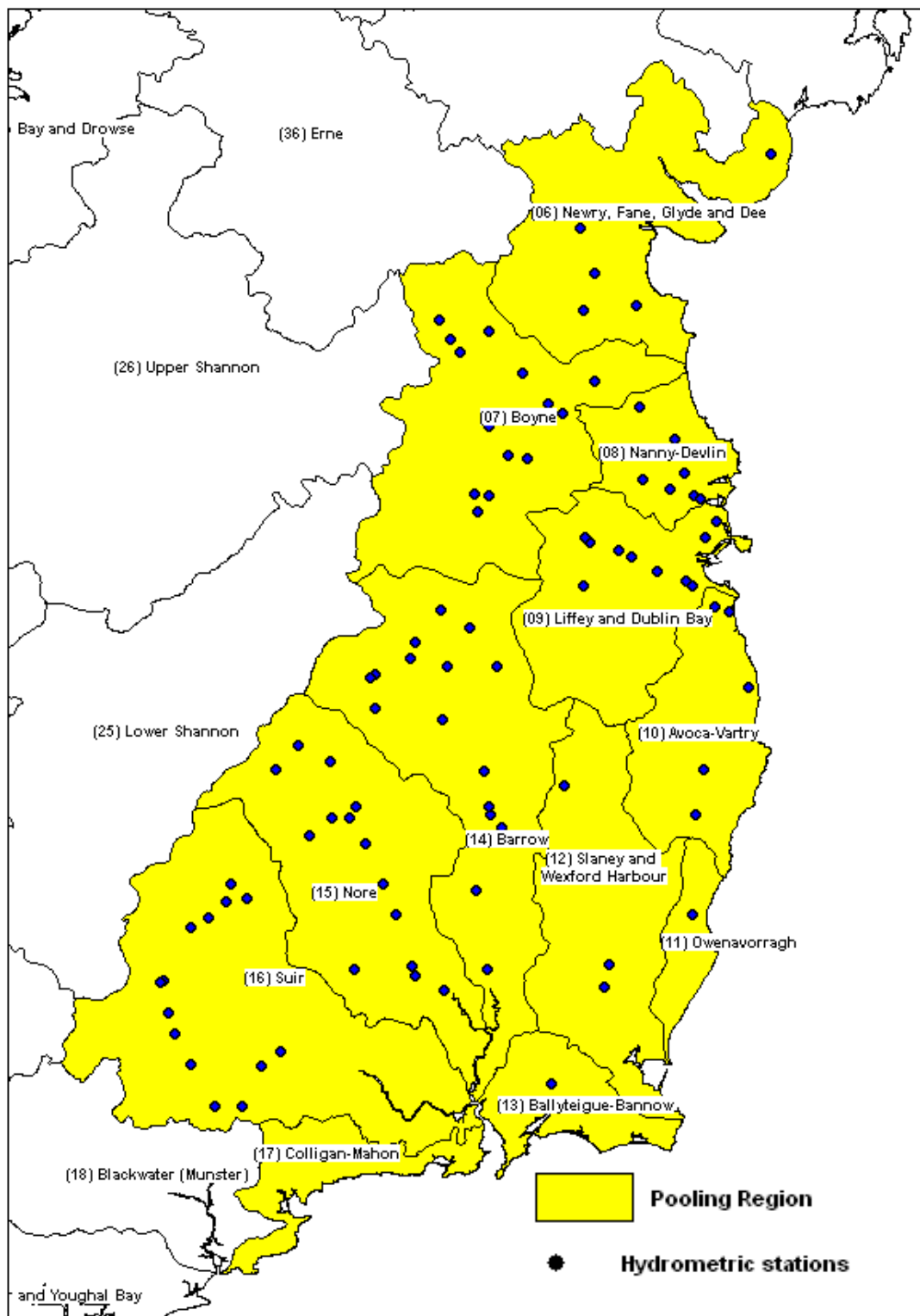


Figure 5.1: Locations of 92 Gauging Stations

5.3.2 Pooling Region Catchment Physiographic and Climatic Characteristic Data

In addition to the AMAX series, some catchment physiographic and climatic characteristics information including the catchment sizes (AREA), Standard Average Annual Rainfall (SAAR), catchment Base Flow Index (BFI) and the Flood Attenuation by Reservoirs and Lakes (FARL) Index for all 92 stations were also obtained from OPW. Table 5.2 presents a summary of these catchment characteristics. Catchment sizes range from 1.13 to 2778.15 km² with a median value of 182 km², SAAR values range from 711 to 1700 mm with a median value of 927 mm. The BFI values vary from 0.381 to 0.788, while the FARL values range from 0.730 to 1.0.

Table 5.2: Summary of Catchment physiographic and climatic characteristics of Pooling Region

Characteristics	Minimum	Maximum	Average	Median	HA15 Median
AREA (km ²)	1.13	2778.15	489.17	181.77	283.19
SAAR (mm)	710.76	1700.39	967.15	927.45	916.89
BFI	0.381	0.788	0.608	0.624	0.671
FARL	0.730	1.000	0.979	0.999	0.974

Furthermore the relative frequencies of the AREA, SAAR and BFI values within the 92 stations are also presented in Figure 5.2, Figure 5.3 and Figure 5.4 respectively. It can be seen from Figure 5.2 that the majority of the catchment areas in the selected sites fall in the range of 100 to 500 km². Figure 5.3 shows that the SAAR values in the majority of the stations range from 800 to 1000 mm and very few stations have SAAR values more than 1400 mm. Similarly, Figure 5.4 shows the relative frequency of the BFI values within the 92 catchments. It can be seen from this figure that the BFI values in the majority of the 92 catchment areas range from 0.5 to 0.75.

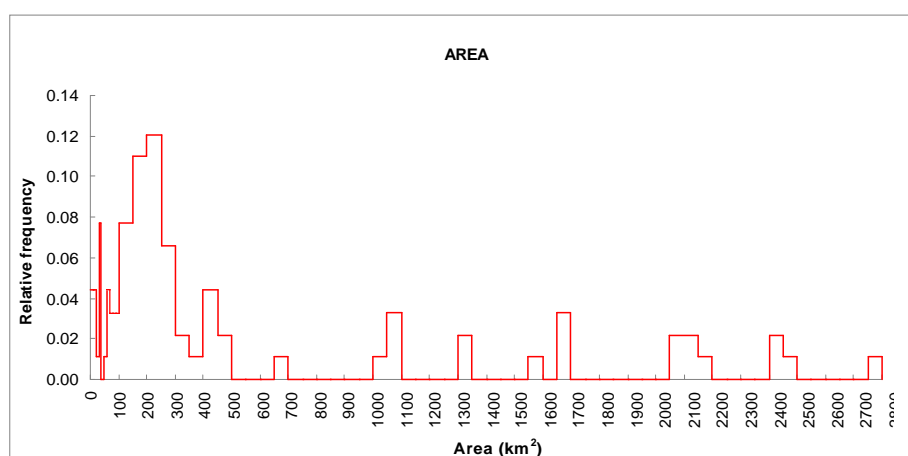


Figure 5.2: Relative frequencies of catchments sizes (AREA) within the selected 92 stations

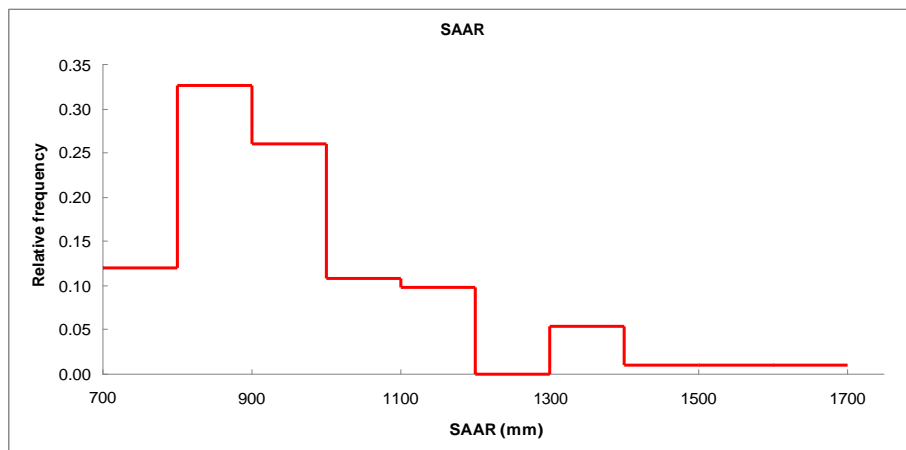


Figure 5.3: Relative frequencies of the SAAR values within the selected 92 stations

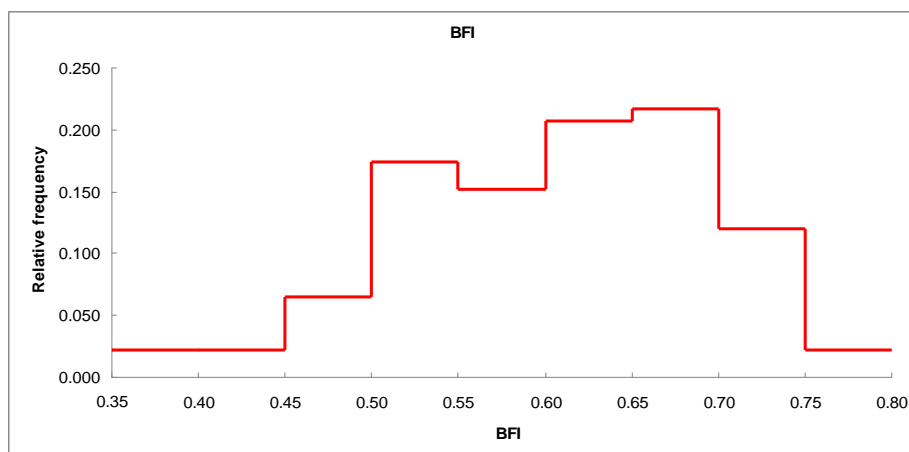


Figure 5.4: Relative frequencies of the BFI values within the selected 92 stations

5.3.3 Statistical Properties of the AMAX series

Table 5.3 provides a summary of the statistical properties of the AMAX series for all 92 gauging sites. The median annual maximum flows (Q_{med}) range from 0.47 to 299.32 m³/s with an average value of 53.83 m³/s. The L-CV values range from 0.052 to 0.415 with an average value of 0.198, while the L-Skewness values range from -0.181 to 0.488 with an average value of 0.166 which is approximately equal to the theoretical L-Skewness of EV1 distribution. Figure 5.5 shows the L-CV versus L-Skewness diagram for the 92 AMAX series with the values associated with the River Nore catchment shown in red.

Table 5.3: Statistical properties of 92 AMAX Series

Parameters	Minimum	Maximum	Average	Median
Record Lengths (years)	9	71	37	35
Mean Flow (m ³ /s)	0.49	303.45	56.56	27.16
Median Flow (m ³ /s)	0.47	299.32	53.83	25.42
L-CV	0.052	0.415	0.198	0.182
L-skewness	-0.181	0.488	0.166	0.163
L-kurtosis	-0.127	0.426	0.155	0.139

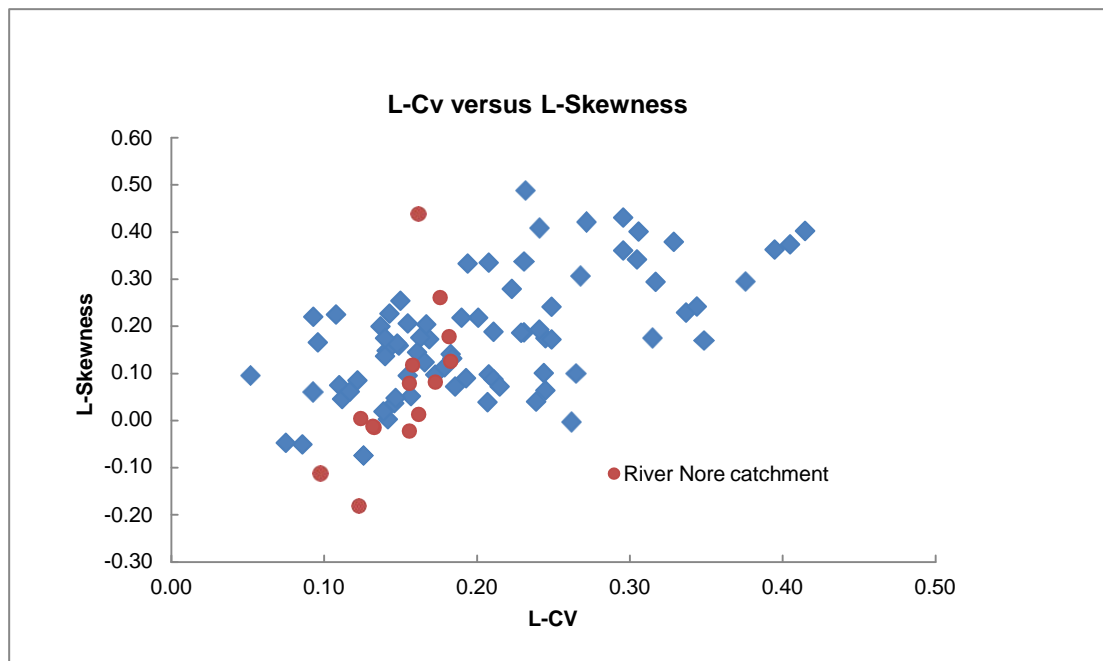


Figure 5.5: L-Moment Ratio Diagram (L-CV versus L-Skewness) for 92 AMAX series

5.4 STATISTICAL DISTRIBUTION

The individual gauging site's AMAX series were fitted to four flood like distributions, namely EV1, GEV, GLO and LN2 distributions. The EV1 and LN2 distributions are two-parameter distributions while the GLO and GEV distributions each have three-parameters.

The choice of distributions used for this study was guided by the findings in the FSU Report (September, 2009). In the case of 2-parameter distributions, the FSU Work Package 2.2 report states (Section 4.2, page 40) *"It can be deduced from the linear patterns that Irish flood data are more likely to be distributed as EV1 or LN2 rather than Logistic distribution (LO) among 2-parameter distributions"*. Therefore the elimination of LO as a 2-parameter distribution is robustly based on a study of all relevant Irish data. Also, FSU concentrated on GEV and GLO from among the available 3-parameter distributions. The lack of emphasis on LN3 by FSU was possibly based on the L-kurtosis vs. L-skewness moment ratio diagram (FSU WP 2.2 Report, Figure 3.10, page 30) and that one could be used as a surrogate for the other. Then, because of the overwhelmingly central role, traditionally played by GEV in flood frequency analysis, the FSU decided to base its analysis using the GEV rather than LN3. The same reasoning was adopted for the present study.

Based on the visual inspections of the probability plots of all 92 AMAX series, it was found that the three-parameter distributions provide better fits to the majority of the 92 AMAX series. Between the GEV and GLO distributions, the GLO distribution was found to be the better. In the GLO distribution, out of 92 frequency curves, 80 showed concave upward shape, 5 convex upward and 7 straight lines. In the GEV distribution, 35 showed concave upward shape, 41 showed convex upward and 16 are of straight line type. In the River Nore catchment, the GLO distribution was found to be the best suited to the AMAX series (10 concave upward and 4 convex upward). In the case of the GEV distribution, 2 showed concave upward shape, 11 showed convex upward and one showed a straight line. Table 5.4 presents the summary results of the visual assessments of the probability plots for all 92 AMAX series. It should be noted here that one reason for the change of concave / convex upwards shapes seen in GEV and GLO is due to the difference in abscissa used in the probability plots i.e. $EV1y = -\ln\{-\ln(1-1/T)\}$ for GEV distribution and $GLOy = -\ln\{1/(T-1)\}$ for GLO distribution.

Table 5.4: Summary results of probability plots assessments (EV1, GEV & GLO distributions) for all 92 AMAX series

Distrib ution	No. distribution in each quality ranks (1, 2 & 3)			Fitted line type
	Rank 1 (very good)	Rank 2 (good)	Rank 3 (fair)	
EV1	18	12	62	All straight line
LN2	18	33	41	All concave upward (At Log n scale)
GEV	20	56	16	16 – straight line (GEV type I) 35 – concave upward (GEV Type II) 41 – convex upward (GEV Type III)
GLO	54	24	14	7 – straight line, 80 – concave upward & 5 – convex upward

A study carried out in University College Dublin (UCD) by S. Ahilan et al. (2012) on 143 stations countrywide in Ireland found that the AMAX series of the majority of hydrometric stations located in the Eastern and South Eastern regions follow the GEV type III distribution.

5.5 GROWTH CURVE ESTIMATION POINTS

In order to estimate the peak design flows for each of the 127 HEPs located on the modelled watercourses in HA15 using the 'index-flood' method (FEH, 1999; FSU, 2009), growth curves for each of the HEPs are required. The selection of the HEPs was based on the hydraulic model conceptualisation of the modelled watercourses within each of the AFAs in HA15. For the integration of hydrological input to the hydraulic model and also for the calibration and verification of the hydraulic models the HEPs were identified at the following locations on the modelled watercourses:

- HEPs at the upstream limit of model,
- HEPs where tributaries enter the modelled channels,
- HEPs at gauged stations on modelled channels,
- HEPs at intermediate points on the modelled channels, and
- HEPs at downstream limit of model.

The details of the selection process for the HEPs are discussed in the HA15 Inception Report (section 5.3). Table 5.5 presents a summary of the catchment characteristics associated with the 127 HEPs in HA15. The catchment areas vary from close to 0 (at the top of modelled tributaries) to 2519 km². The SAAR values range from 822 to 1399 mm while the BFI values vary from 0.442 to 0.713.

Table 5.5: Summary of the catchment characteristics associated with the 127 HEPs

Catchment descriptors	Minimum	Maximum	Average	Median
AREA (km ²)	0.05	2519	174	15
SAAR (mm)	822	1399	953	935
BFI	0.442	0.713	0.611	0.623

Based on the similarity of the catchment characteristics for these HEPs with the selected gauging sites located within the pooling region, growth curves for all HEPs with areas greater than 5 km² were estimated. Almost 95% of the selected gauging sites in the pooled region have catchment areas more than 5 km². Therefore, the pooling groups for the HEPs with catchment areas less than 5 km² would not be the homogeneous groups and the errors in the estimated growth curves would be larger.

There are very few AMAX series with catchment areas less than 10 km² available within the selected pooling region (i.e. pooling regions of the entire country and regional). These will not achieve the required pooling group size of 500 station-years. Therefore estimation of the regional growth curves for any HEP with a catchment area less than 10 km² through pooling AMAX series' from larger catchments are unlikely to be accurate. Therefore all HEPs with catchment areas less than 10 km² are considered to have the same growth curve. Based on these considerations, 99 HEPs (out of 127) were initially selected as points for the estimation of growth curves within HA15 but as discussed in Section 5.8.2 this was extended to 426 with the addition of a further 327 Growth Curve Estimation Points (GC_EPs) in order to aid rationalisation of the growth factors. Figure 5.6 shows the spatial distribution of these HEPs on the modelled watercourses in HA15.

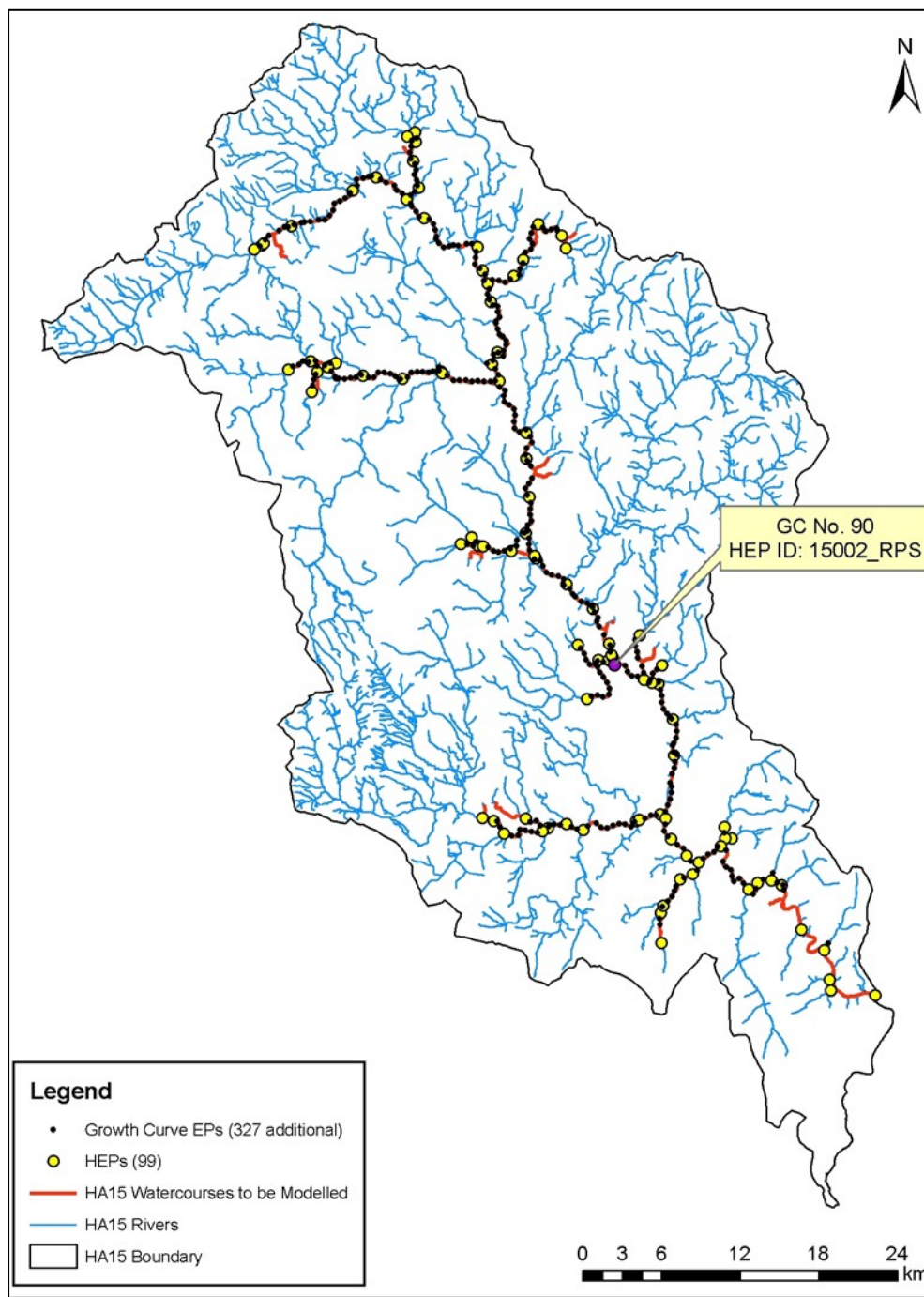


Figure 5.6: Spatial distribution of the HEPs on the modelled watercourses in HA15

5.6 POOLING REGION AND GROUP FOR GROWTH CURVE ESTIMATION

5.6.1 Pooling Region

Based on the similarity of climatic characteristics, it has been decided that the AMAX series from both the Eastern and South Eastern CFRAM study areas and also from hydrometric area 06 (HA06 – Newry, Fane, Glyde and Dee) will be pooled to form a pooling group for growth curve estimation for HA15. The pooling region for this study therefore covers the eastern and south-eastern parts of Ireland. Figure 5.1 illustrates the extent of the pooling region. A summary of the statistical properties of all AMAX series and their associated catchment characteristics is presented in Table 5.3 and Table 5.2 respectively.

The values of AREA, SAAR and BFI encountered in the 127 HEPs are summarised by their minimum, maximum, average and median values in Table 5.5. The details of the selection process for the HEPs are discussed in the HA15 Inception Report (section 5.3). Table 5.5 also presents a summary of the catchment characteristics associated with the 127 HEPs in HA15. The catchment areas vary from close to 0 (at the top of modelled tributaries) to 2519 km². The SAAR values range from 822 to 1399 mm while the BFI values vary from 0.442 to 0.713.

Comparison of these with the histograms of AREA, SAAR and BFI for the 92 stations selected for pooling purposes (Figure 5.2 to Figure 5.4) show a good overlap, which indicates that the 92 stations provide good coverage for the range of catchments encountered in the HEPs in HA15.

5.6.2 Pooling Group

Pooling groups can be formed on the basis of geographical proximity to the subject site. However in the UK FEH study (1999) it was found that such pooling groups were less homogeneous than those formed by the Region of Influence (FSU) approach of the type proposed by Burn (1990). The Region of Influence (FSU) approach selects stations, which are nearest to the subject site in catchment descriptor space, to form the pooling group for that subject site. In the FSU studies a distance measure in terms of three catchment descriptors of AREA, SAAR and BFI was used in forming a pooling group. The recommended distance measure in the FSU studies is:

$$d_{ij} = \sqrt{1.7 \left(\frac{\ln AREA_i - \ln AREA_j}{\sigma_{\ln AREA}} \right)^2 + \left(\frac{\ln SAAR_i - \ln SAAR_j}{\sigma_{\ln SAAR}} \right)^2 + 0.2 \left(\frac{BFI_i - BFI_j}{\sigma_{BFI}} \right)^2} \quad (5.1)$$

Where i is the subject site and $j=1,2,\dots,M$ are the donor sites.

In this study, the pooling group was formed based on the above distance measure. The size of the pooling groups was determined based on the FEH recommended 5T rules (i.e. the total number of station-years of data to be included when estimating the T-year flood should be at least 5T). The donor sites associated with this pooling group size were selected based on the lowest distance measures among the available gauging sites in the pooling region.

5.7 GROWTH CURVE ESTIMATION

5.7.1 Choice of Growth Curve Distributions

In the ‘index-flood’ method one of the major assumptions is that the frequency distributions at different sites in the pooled group are identical apart from a scale factor, which is the median flow (Q_{med}).

As discussed in Section 5.4, the three-parameter GEV and GLO distributions were found to be better suited distribution for most of the 92 AMAX series than the two-parameter distributions. Furthermore, it can be seen from the L-moment ratio diagram for these 92 AMAX series as shown in Figure 5.7 that the GEV distribution provides better fits than the GLO distribution, since the theoretical values of the GEV distribution’s L-Skewness and L-Kurtosis pass centrally through the observed L-moments ratios of the 92 AMAX series.

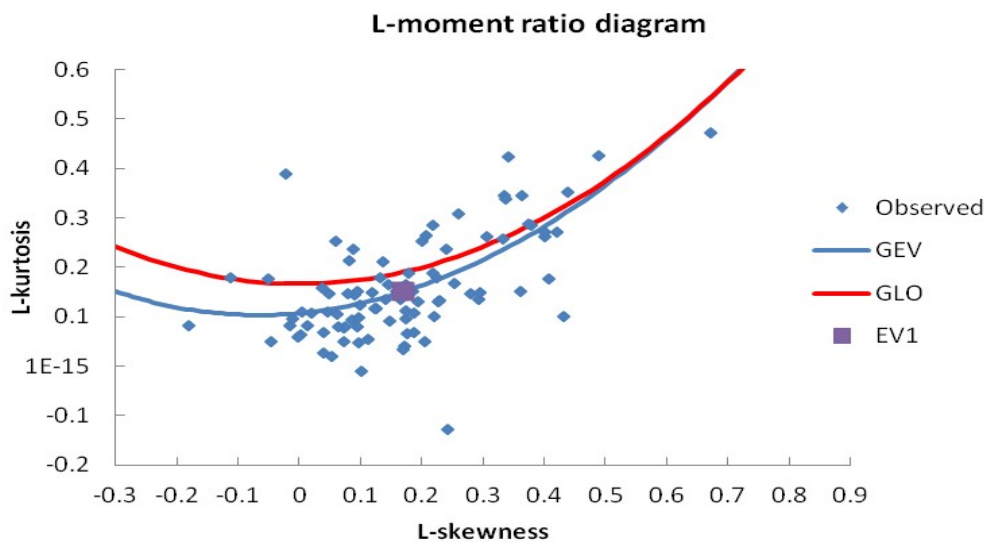


Figure 5.7: L-moment ratio diagram (L-skewness versus L-kurtosis)

Based on the above, the GEV distribution can be adopted as the best candidate distribution for the regional growth curve for the River Nore catchment. However, since the probability plots show that the GLO distribution is also suitable, this distribution is also considered as a candidate distribution for the regional growth curve estimation. Although the two-parameter distributions exhibit more bias in the regional flood frequency estimates as compared to the three-parameter distributions, the two-parameter EV1 distribution is also used in the growth curve estimation process for comparison purposes and to replace the GEV or GLO growth curve when the shape displayed by either of these two distributions is convex upward in order to avoid potential underestimation of extreme event growth factors.

5.7.2 Estimation of Growth Curves

The algebraic equations of the EV1, GEV and GLO growth curves and associated parameters are given below:

EV1 distribution:

$$\text{Growth Curve: } x_T = 1 + \beta(\ln(\ln 2) - \ln(-\ln(1 - 1/T))) \quad (5.2)$$

$$\text{Parameter: } \beta = \frac{t_2}{\ln 2 - t_2 [\gamma + \ln(\ln 2)]} \quad (5.3)$$

where, t_2 is the L-coefficient of variation (L-CV) and γ is Euler's constant = 0.5772.

GEV distribution:

$$\text{Growth Curve: } x_T = 1 + \frac{\beta}{t_2} \left[(\ln 2)^k - \left(\ln \frac{T}{T-1} \right)^k \right], \quad k \neq 0 \quad (5.4)$$

The parameters k and β are estimated from sample t_2 =L-CV and sample t_3 =L-skewness as follows:
[Hosking & Wallis (1997, p.196)]

$$k = 7.8590c + 2.9554c^2 \text{ where } c = \frac{2}{3 + t_3} - \frac{\ln 2}{\ln 3} \quad (5.5)$$

$$\beta = \frac{kt_3}{t_2(\Gamma(1+k) - (\ln 2)^k) + \Gamma(1+k)(1 - 2^{-k})} \quad (5.6)$$

GLO distribution:

$$\text{Growth Curve: } x_T = 1 + \frac{\beta}{k} (1 - \{T-1\}^{-k}), \quad k \neq 0 \quad (5.7)$$

The parameters k and β are estimated from sample t_2 =L-CV and sample t_3 =L-skewness as follows
[Hosking & Wallis (1997, p.197)]:

$$k = -t_3 \text{ and } \beta = \frac{kt_2 \sin(\pi k)}{k\pi(k + t_2^2) - t_2 \sin(\pi k)} \quad (5.8)$$

The pooled regional values of the t_2 (L-CV) and t_3 (L-skewness) have been estimated as the weighted average values of corresponding at-site sample values weighted by the at-site record lengths. These values were equated to the expressions for these quantities written in terms of the distribution's unknown parameters as given above and the resulting equations are solved for the unknown parameters.

5.7.3 Examination of Growth Curve Shape

Growth curves for all of the selected 99 HEPs for a range of Annual Exceedance Probabilities (AEPs) were estimated in accordance with the above methodologies. An examination of the derived shapes of the growth curves showed that, because of the fixed shape distribution, the EV1 growth curves are of straight-line type for all 99 HEPs, while in the GEV and GLO distribution cases growth curves take either the concave upwards (upward bend) or convex upwards (downward bend) shapes based on the skewness of the pooled group. In the GEV distribution case, out of 99 curves, 28 showed convex upward shape, 61 showed concave upward shape and 10 showed almost a straight line; while in the GLO distribution case, all 99 curves showed the concave upward shape (Table 5.6).

Table 5.6: Growth curves shape summary

Distribution	Growth Curve Shape
EV1	All straight lines
GEV	28 - convex upward 61 – concave upward 10 – straight line
GLO	All concave upward

An assessment of the suitability of the above three growth curve distributions was carried out by examining the suitability of these distributions in fitting the AMAX series in the pooling groups associated with all 99 HEPs. In other words, for a particular HEP, the pooled growth curves, based on EV1, GEV and GLO, were superimposed on the standardised probability plots of the AMAX series which form the pooling group (typically 10 to 12 such series). A visual comparison of the suitability of the growth curves was made and recorded, as done in for example HEP No. 90 (River Nore at McMahon's Bridge) of the 99 HEPs selected for the growth curve analysis in HA15. HEP No. 90 was selected to illustrate the composition of one pooling group.

In estimating the pooled growth curve for HEP No.90, 546 station-years of records from 11 sites were pooled. Figure 5.6 shows the location of this HEP. Table 5.7 shows the catchment characteristics, statistical properties and estimated distance measures for each of the sites from the subject HEP.

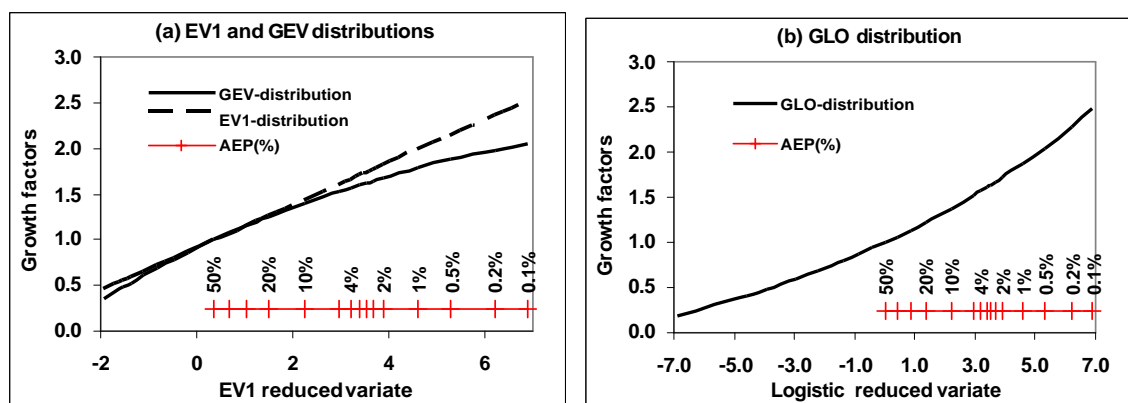
Table 5.7: Catchment descriptors for all pooled sites for growth curve No.90

Hydrometric stations	Record length (years)	AREA (km ²)	SAAR (mm)	BFI	Qmean (m ³ /s)	Specific Qmean (m ³ /s/km ²)	L-CV	L-skew	L-kur	dij
15004	56	488.7	1067.46	0.594	37.13	0.076	0.158	0.118	0.150	0.005
15007	35	339.76	1123.04	0.594	46.53	0.137	0.098	-0.112	0.180	0.428
16010	38	437.10	985.24	0.624	44.76	0.102	0.117	0.061	0.105	0.502
14005	53	405.48	1014.90	0.501	50.80	0.125	0.137	0.200	0.253	0.589
07004	53	245.74	1007.88	0.619	19.82	0.081	0.149	0.159	0.151	0.686
07011	49	281.74	1003.32	0.678	26.71	0.095	0.245	0.175	0.096	0.736
16008	56	1090.25	1029.63	0.635	91.75	0.084	0.075	-0.047	0.049	0.745
16002	56	485.70	932.15	0.634	55.70	0.115	0.161	0.145	0.165	0.818
07010	51	699.75	948.29	0.658	54.68	0.078	0.265	0.099	0.123	0.826
15001	48	444.35	935.24	0.514	90.02	0.203	0.162	0.013	0.083	0.881
06011	51	229.19	1028.98	0.708	15.91	0.069	0.110	0.075	0.080	0.902
Subject site (Growth Curve EP-90)	-	488.70	1067.46	0.594	-	-	0.154*	0.087*	-	-

*Pooled regional values

It can be seen from Table 5.7 that the subject site's catchment characteristics are well placed within the pooled sites' catchment descriptor space. The subject site has an upstream catchment area of 488.70 km², SAAR and BFI values of 1067.46 mm and 0.594 respectively which are located approximately at the median locations of the pooled sites' corresponding values.

The estimated pooled average L-CV and L-Skewness are 0.154 and 0.087 respectively. This suggests that the pooled growth curve would follow a distribution which has L-Skewness less than that of the EV1 distribution (0.167). Figure 5.8 shows the estimated EV1, GEV and GLO growth curves for the growth curve No. 90. The GEV growth curve is a convex upward shaped curve while the GLO one is a concave upward shaped curve.

**Figure 5.8: Pooled Growth Curve 90 - (a) EV1 and GEV distributions; (b) GLO distributions**

An assessment of the at-site GEV and GLO growth curves were carried out through a visual inspection of their individual probability plots. A summary of this assessment is provided Table 5.8.

Table 5.8: Frequency curve shapes of the individual site's AMAX series associated with the pooled group No. 90

Hydrometric stations	Individual at-site growth curves		
	GEV (EV1y Plot)	GLO (Loy Plot)	Comparison of performances (visual)
15004	Mild convex upward	Mild concave upward	Both fit equally well to the observed records
15007	Moderate convex upward	Straight line	GEV fits slightly better
16010	Mild convex upward	Mild concave upward	Both fit equally well to the observed records
14005	Mild concave upward	Moderate concave upward	GLO fits better
07004	Straight line	Mild concave upward	GLO fits slightly better
07011	Straight line	Mild concave upward	GLO fits slightly better
16008	Mild convex upward	Mild concave upward	GEV fits slightly better
16002	Mild concave upward	Moderate concave upward	GLO fits better
07010	Mild convex upward	Mild concave upward	GLO fits slightly better
15001	Moderate convex upward	Straight line	GEV fits slightly better
06011	Mild convex upward	Mild concave upward	GLO fits slightly better

The above assessment shows that both the GEV and GLO distributions fit the observed at-site records quite well at all eleven sites with a slightly better performance by the GLO distribution. In the case of GEV distribution seven sites showed convex upward shaped curves (mild to moderate), two concave upward and two sites showed straight lines. While in the GLO distribution case, nine showed concave upward curves and the two remaining sites showed straight lines. This suggests that, the shape of the pooled growth curves in the case of GEV distribution can be expected as convex upward while for the GLO distribution case it would be concave upward.

Table 5.9 shows the estimated growth factors for a range of AEPs for Growth Curve No. 90. The estimated 1% AEP growth factors for the EV1, GEV and GLO distributions are 1.986, 1.782 and 1.878 respectively.

Table 5.9: Estimated growth factors for Growth Curve No. 90

AEP (%)	EV1	GEV	GLO
50	1.000	1.000	1.000
20	1.264	1.254	1.229
10	1.439	1.403	1.376
5	1.607	1.532	1.522
2	1.824	1.682	1.720
1	1.986	1.782	1.878
0.5	2.148	1.873	2.046
0.1	2.524	2.055	2.473

5.7.4 Recommended Growth Curve Distribution for the River Nore Catchment

The following factors were considered to select an appropriate growth curve distribution for the River Nore catchment area:

- (i) Suitability of a distribution in fitting the individual at-site records,
- (ii) No. of distribution parameters, and
- (iii) Shape of the pooled growth curve

A visual examination of the at-site frequency curves for all 92 gauging sites showed that the AMAX series for most of these sites can be described slightly better by the GLO distribution than by the EV1 and GEV distributions.

The number of distribution parameters also plays an important role in deriving an appropriate growth curve. The fixed skewness two-parameter distributions generally suffer from large biases, particularly at the upper tail of the distribution. The three-parameter distributions, in contrast, suffer from larger standard error though they are less biased. However this standard error is generally reduced by the pooled estimation process. The use of two-parameter distributions such as the Gumbel distribution is not therefore recommended in regional frequency analysis (Hosking and Wallis, 1996). The use of a two-parameter distribution is beneficial only if the investigator has complete confidence that the at site distribution's L-Skewness and L-kurtosis are close to those of the frequency distributions. As discussed in Section 5.7.1, the L-CV and L-Skewness of most of the sites in the Pooling Region differ from those of the theoretical values of the EV1 distribution. This suggests that a three-parameter distribution would be more appropriate to describe the growth curves for the River Nore catchment.

The shape of the growth curve also plays an important role in the design and operation of the flood management scheme for a river catchment. It is generally not considered appropriate to have a growth curve with the convex upward shape. A significant number of the GEV growth curves showed convex upward shape (28 out 99). In contrast, all 99 GLO growth curves are of concave upward shape.

The estimated 1%-AEP GLO growth factor is slightly greater than the GEV growth factor, for almost all 99 growth curves by an amount of 0.1 to 5% (refer to Table 5.9). This is largely due to the concavity noted above. Figure 5.9 shows a comparison of the GEV, GLO and EV1 growth curves for growth curve No. 90, all plotted in the EV1 probability plot.

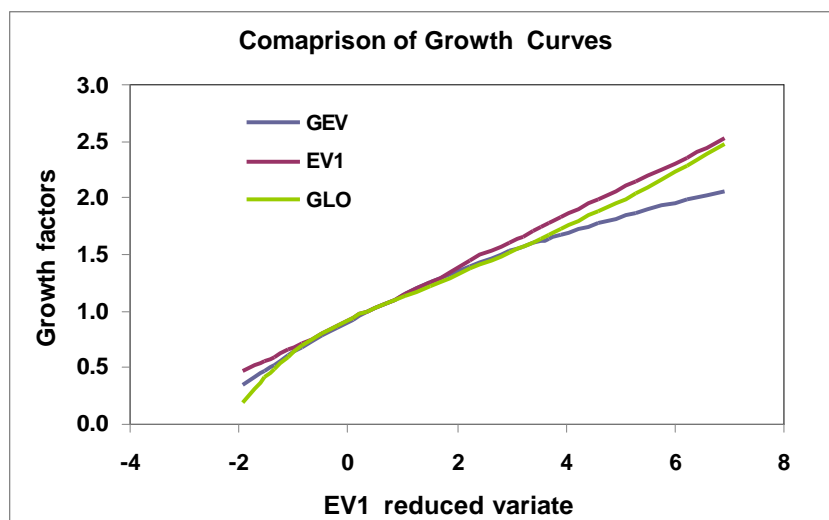


Figure 5.9: Comparison of EV1, GEV and GLO growth curves on the EV1-y probability plot (Growth Curve No. 90)

Based on the above, it is recommended to adopt the GLO distribution derived concave upward shape growth curve for the River Nore catchment. Figure 5.10 shows the estimated 99 GLO growth curves for the River Nore catchment.

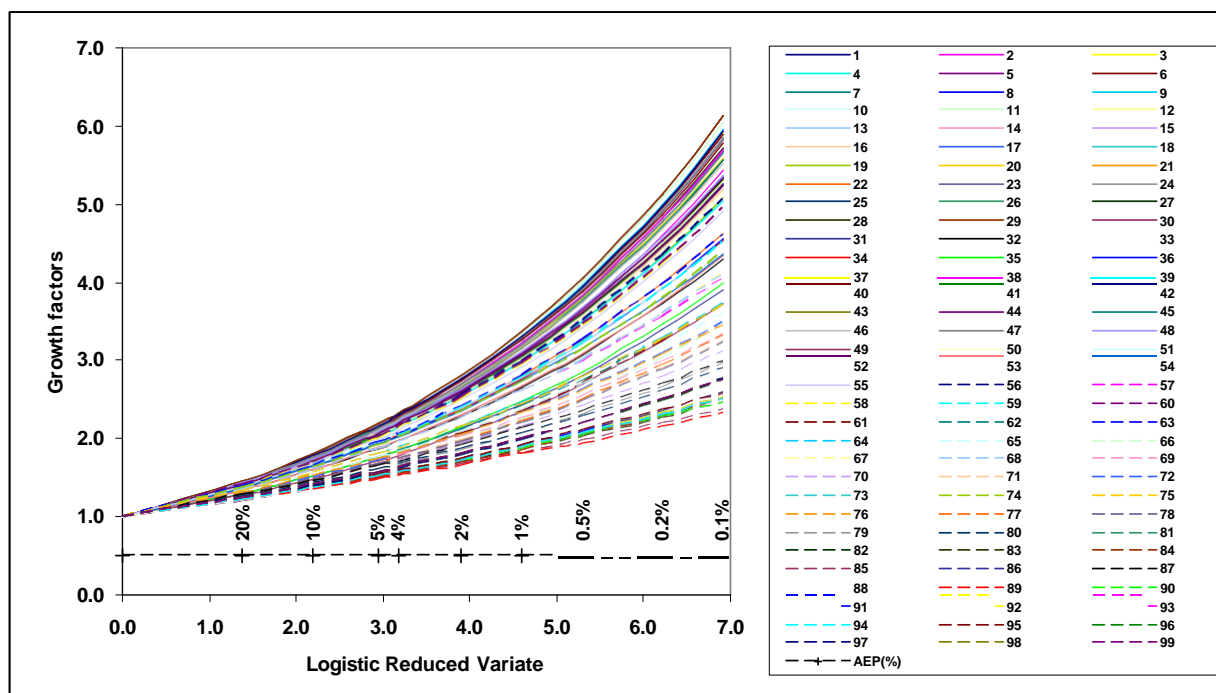


Figure 5.10: GLO growth curves for 99 HEPs in the River Nore Catchment

5.8 RATIONALISATION OF GROWTH CURVES

5.8.1 Relationship of Growth Factors with Catchment Characteristics

In order to reduce the number of growth curves to a practical number, the relationship between the estimated growth factors for a range of AEPs and the relevant catchment descriptors was examined. The catchment descriptors used were the AREA, SAAR and BFI. Figures 5.11, 5.12 and 5.13 show the variations of growth factors with AREA, SAAR and BFI respectively for all 99 HEPs.

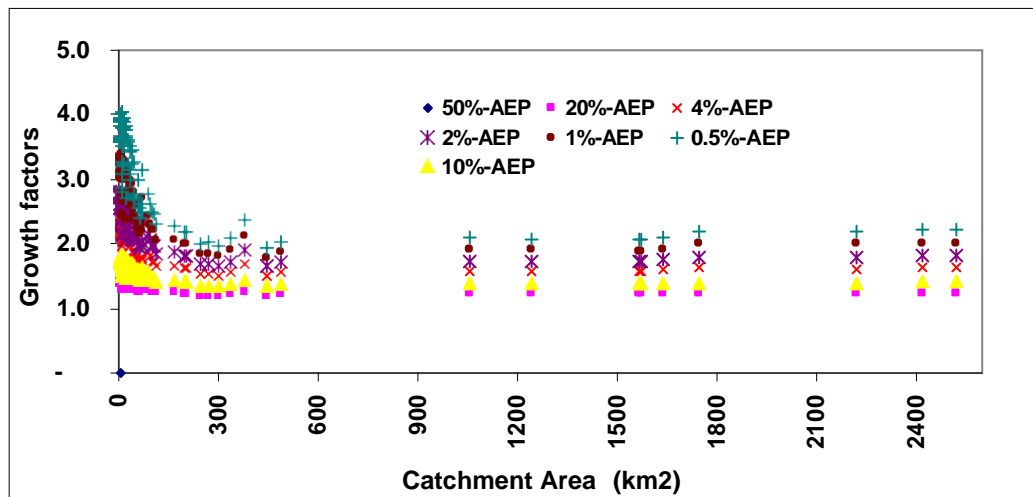


Figure 5.11: Relationship of growth factors with catchment areas for 99 HEPs

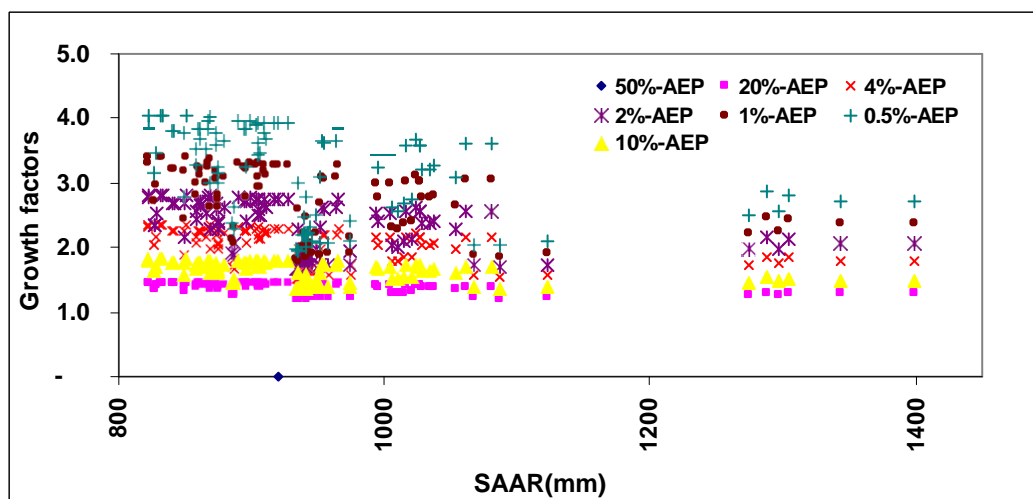


Figure 5.12: Relationship of growth factors with SAAR for 99 HEPs

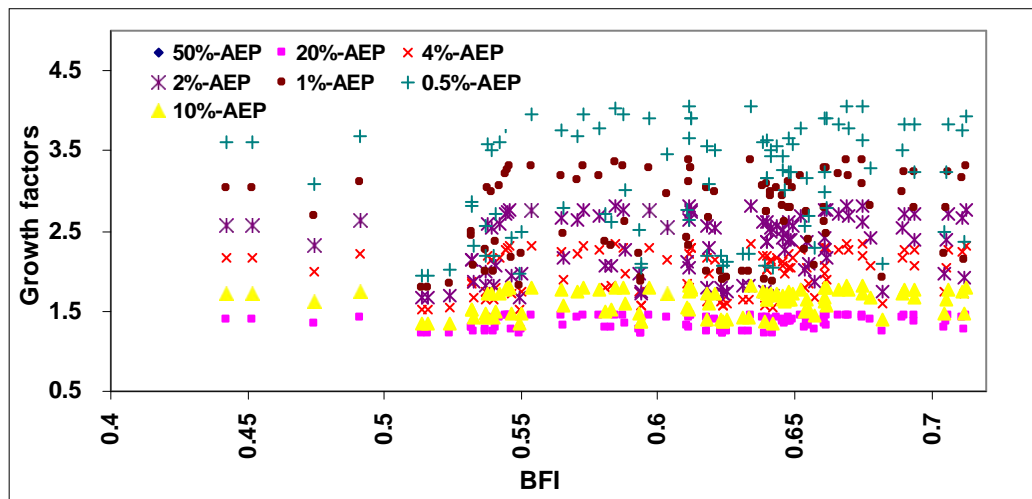


Figure 5.13: Relationship of growth factors with BFI for 99 HEPs

It can be seen from the above figures that the growth factors generally increase with a decrease in catchment sizes. However this rate of increase is larger for the catchment areas less than 400 km² and also for the larger AEPs growth factors. This can be attributed to the smaller upland catchment areas where catchment response time is shorter and where no flow attenuation is available. For the larger catchments flow attenuation is generally provided by lakes and wider downstream channels. For catchment areas larger than 900 km² the growth factors do not change noticeably with any further increase in catchment area. No particular patterns in the relationships of the growth factors with the SAAR and BFI values were found.

5.8.2 Generalised Growth Curves

Based on the findings as discussed in Section 5.8.1, growth curves for the River Nore catchment were further generalised based on catchment size. To examine further the relationship of the catchment size with the growth factors and also to generalise the growth factor estimates, an additional 327 growth curve estimation points with various catchment sizes were selected on the modelled watercourses. Figure 5.6 shows the spatial distribution of these points. The catchment physiographic and climatic characteristics data associated with these additional growth curve estimation points were obtained from OPW.

Figure 5.14 shows the variation of the estimated growth factors for a range of AEPs and catchment sizes for all 426 HEPs (99 HEPs plus 327 additional points). Similar catchment size-growth factor relationships were found in this case as were found in the 99 HEPs case. It can be seen from this figure that the growth factors for catchment areas greater than 900 km² do not change appreciably with the increase in catchment size. However, the variations in growth factors for the smaller catchment sizes are very significant.

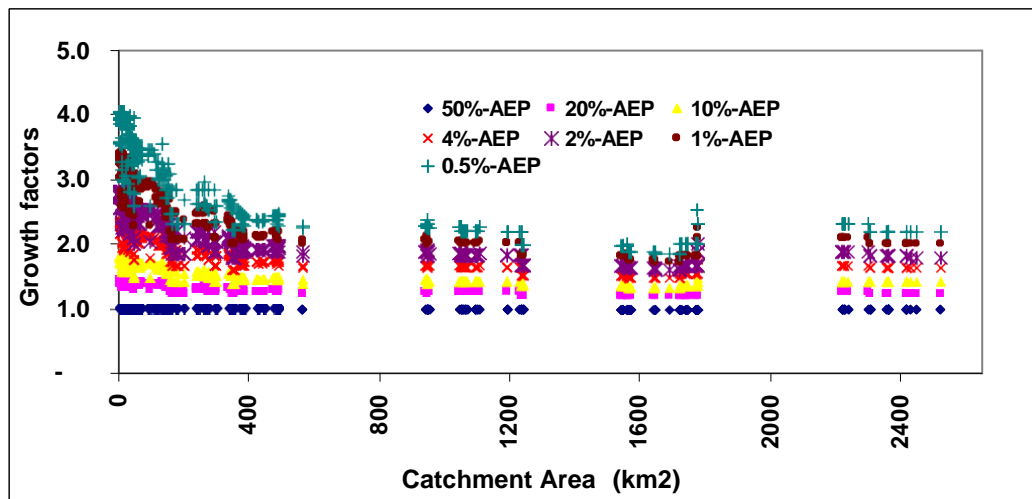


Figure 5.14: Relationship of growth factors with catchment areas (for 426 growth curve estimation points)

As a result of the above growth curves are generalised based on ranges of catchment size as shown below:

1. AREA < 10 km²
2. 10 < AREA ≤ 25 km²
3. 25 < AREA ≤ 50 km²
4. 50 < AREA ≤ 100 km²
5. 100 < AREA ≤ 200 km²
6. 200 < AREA ≤ 400 km²
7. 400 < AREA ≤ 600 km²
8. 600 < AREA ≤ 800 km²
9. 800 < AREA ≤ 1200 km²
10. AREA > 1200 km²

Table 5.10 shows the estimated average and median growth factors for the above 10 categories of growth curves along with their associated group standard deviations for a range of AEPs. The number of HEPs used for the standard deviation calculation in each of the catchment size categories is presented in column 2 of Table 5.10.

It can be seen from this that the standard deviations in the 1% AEP growth factors in these catchment size categories range from 1.2% to 28%. The highest variations were found in the catchment size categories of 2, 3, 4 and 5. Hence, it is considered that the growth factors for all HEPs with catchment sizes falling in these catchment area categories (i.e. from 10 to 200 km²) be estimated from the separate growth curve estimation process. In other words, separate growth curves should be estimated for all HEPs with the catchment areas falling in range of 10 to 200 km². All HEPs with catchment areas less than 10 km² are considered to have the same growth curve. For the remaining categories the median growth curves should be used.

Table 5.10: Growth curve estimation summary

Catchment size range	No of HEPs in size range		Growth factors								
		AEP (%)	50%	20%	10%	5%	2%	1%	0.50%	0.20%	0.10%
		Return Period (years)	2	5	10	20	50	100	200	500	1000
1. AREA < 10 km ²	26	Average	1.000	1.435	1.765	2.132	2.704	3.221	3.829	4.803	5.696
		Median	1.000	1.444	1.784	2.162	2.752	3.282	3.905	4.908	5.829
		St. dev	0.000	0.020	0.037	0.058	0.094	0.130	0.176	0.255	0.333
2. 10 < AREA <= 25 km ²	51	Average	1.000	1.417	1.730	2.075	2.607	3.084	3.642	4.527	5.333
		Median	1.000	1.435	1.762	2.123	2.678	3.177	3.758	4.695	5.552
		St. dev	0.000	0.040	0.074	0.114	0.182	0.248	0.330	0.469	0.603
3. 25 < AREA <= 50 km ²	59	Average	1.000	1.372	1.645	1.941	2.388	2.781	3.234	3.939	4.569
		Median	1.000	1.398	1.691	2.011	2.497	2.928	3.424	4.206	4.908
		St. dev	0.000	0.050	0.090	0.136	0.211	0.281	0.365	0.504	0.636
4. 50 < AREA <= 100 km ²	38	Average	1.000	1.329	1.562	1.809	2.172	2.485	2.837	3.373	3.841
		Median	1.000	1.327	1.557	1.797	2.147	2.445	2.777	3.277	3.709
		St. dev	0.000	0.036	0.065	0.098	0.151	0.200	0.259	0.356	0.446
5. 100 < AREA <= 200 km ²	48	Average	1.000	1.268	1.449	1.635	1.899	2.119	2.358	2.710	3.007
		Median	1.000	1.266	1.444	1.625	1.879	2.089	2.316	2.664	2.961
		St. dev	0.000	0.014	0.023	0.033	0.049	0.064	0.082	0.111	0.139
6. 200 < AREA <= 400 km ²	64	Average	1.000	1.228	1.380	1.533	1.748	1.924	2.115	2.391	2.621
		Median	1.000	1.225	1.375	1.525	1.736	1.909	2.095	2.363	2.586
		St. dev	0.000	0.010	0.018	0.028	0.043	0.057	0.075	0.103	0.129

Catchment size range	No of HEPs in size range		Growth factors								
		AEP (%)	50%	20%	10%	5%	2%	1%	0.50%	0.20%	0.10%
		Return Period (years)	2	5	10	20	50	100	200	500	1000
7. 400 < AREA ≤ 600 km ²	33	Average	1.000	1.222	1.367	1.511	1.710	1.869	2.039	2.282	2.481
		Median	1.000	1.228	1.377	1.526	1.731	1.897	2.074	2.327	2.527
		St. dev	0.000	0.012	0.020	0.028	0.039	0.050	0.061	0.080	0.095
8. 600 < AREA ≤ 800 km ²	-	Average	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Median	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		St. dev	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9. 800 < AREA ≤ 1200 km ²	30	Average	1.000	1.235	1.387	1.539	1.748	1.916	2.094	2.348	2.556
		Median	1.000	1.235	1.386	1.537	1.743	1.909	2.084	2.333	2.535
		St. dev	0.000	0.001	0.003	0.005	0.008	0.012	0.016	0.023	0.030
10. AREA > 1200 km ²	77	Average	1.000	1.236	1.391	1.549	1.769	1.948	2.141	2.420	2.651
		Median	1.000	1.235	1.390	1.550	1.775	1.960	2.161	2.454	2.699
		St. dev	0.000	0.006	0.012	0.020	0.033	0.045	0.061	0.086	0.111

Thus for the River Nore catchment the above mentioned 10 categories of catchment size have been reduced to 6 categories (hereafter called Growth Curve Groups) as presented in Table 5.10. The estimated growth curve types in each category are also presented.

Table 5.10: Growth Curve (GC) Groups

Growth Curve Group No.	Catchment size range	Growth curves type / estimation process
1	AREA ≤ 10 km ²	Use median growth curve
2	10 < AREA ≤ 200 km ²	Use individual growth curve
3	200 < AREA ≤ 400 km ²	Use median growth curve
4	400 < AREA ≤ 800 km ²	Use median growth curve
5	800 < AREA ≤ 1200 km ²	Use median growth curve
6	AREA > 1200 km ²	Use median growth curve

Table 5.11 presents the estimated growth factors for a range of AEPs for each of the above growth curve groups.

Table 5.11: Growth factors for range of AEPs

GC Group No.	Catchment size range	GLO - Growth factors									
		AEP 50%	AEP 20%	AEP 10%	AEP 5%	AEP 4%	AEP 2%	AEP 1%	AEP 0.5%	AEP 0.2%	AEP 0.1%
1	AREA ≤ 10 km ²	1.000	1.444	1.784	2.162	2.295	2.752	3.282	3.905	4.908	5.829
2	10 < AREA ≤ 200 km ²	1.000	1.248 to 1.456	1.412 to 1.807	1.577 to 2.200	1.632 to 2.339	1.809 to 2.818	1.997 to 3.383	2.201 to 4.051	2.494 to 5.132	2.737 to 6.132
3	200 < AREA ≤ 400 km ²	1.000	1.225	1.375	1.525	1.575	1.736	1.909	2.095	2.363	2.586
4	400 < AREA ≤ 800 km ²	1.000	1.228	1.377	1.526	1.575	1.731	1.897	2.074	2.327	2.527
5	800 < AREA ≤ 1200 km ²	1.000	1.235	1.386	1.537	1.586	1.743	1.909	2.084	2.333	2.535
6	AREA > 1200 km ²	1.000	1.235	1.390	1.550	1.603	1.775	1.960	2.161	2.454	2.699

Figure 5.15 shows the estimated growth curves (GLO) for all growth curve groups except for the GC group No. 2 (10 < AREA ≤ 200 km²).

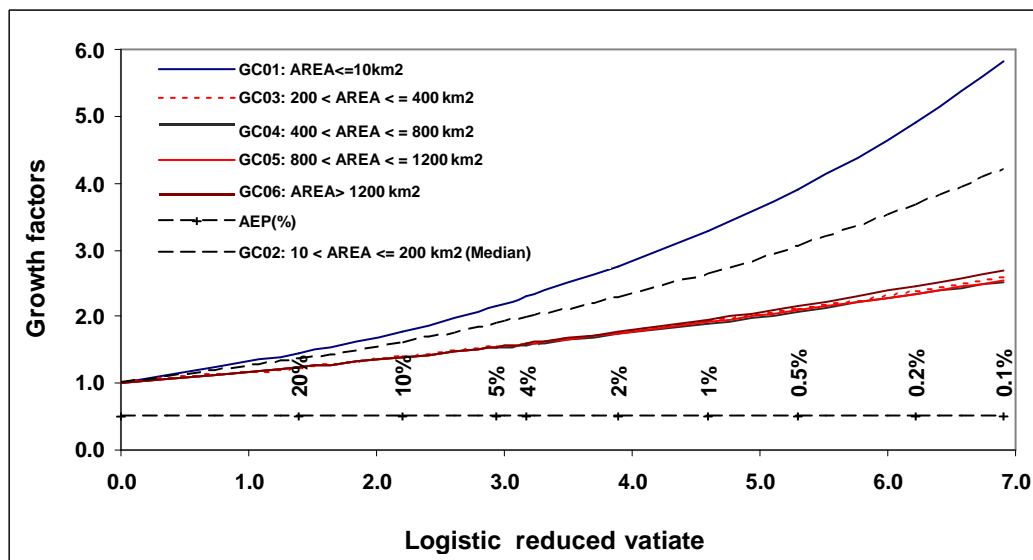


Figure 5.15: GLO growth curves for all Growth Curve Groups (6 No.)

The uncertainties associated with the above growth curve estimates are expressed in terms of 95% confidence interval of these estimates and were estimated from the following relationship:

$$X_T (95\% ile) = X_T \pm 1.96 \times se(X_T) \quad (5.8)$$

The standard error (se) of the growth curves is estimated in accordance with the FSU recommended methodology.

Table 5.12 presents the estimated standard errors in terms of percentage of the estimated growth factor for a range of AEPs. The upper and lower limits of the confidence interval were estimated using the above mentioned Eq. 5.8. For example, for the GC Group No. 4, the estimated 1%-AEP growth factor is 1.897 and the associated 95% upper and lower confidence limits are 2.093 and 1.701 respectively. Figure 5.16 shows the estimated growth curve along with the 95% upper and lower confidence limits for GC Group No. 4.

Table 5.12: Estimated percentage standard errors for growth factors (XT) for a range of AEPs (source FSU Work- Package 2.2 “Frequency Analysis” Final Report – Section 13.3)

Return periods (years)	Annual Exceedance probabilities (%)	Se (X_T) %
2	50%	0.60
5	20%	1.00
10	10%	1.80
20	5%	2.77
25	4%	3.00
50	2%	3.90
100	1%	5.00
200	0.5%	5.94
500	0.2%	7.30
1000	0.1%	8.30

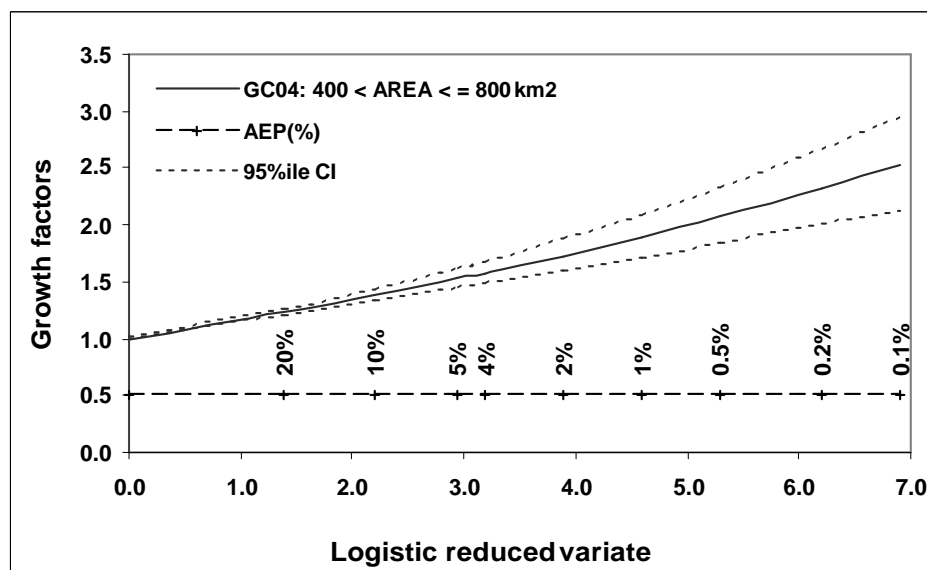


Figure 5.16: Growth Curve for GC Group No. 4 with 95% confidence limits

5.8.3 Comparison of the at-site growth curves with the pooled growth curves

The FSU programme recommended that “*in the event that the at-site estimate of Q-T relation is steeper than the pooled one then consideration will have to be given to using a combination of the at-site estimate and the pooled estimate for design flow estimation*”. In light of this, the at-site frequency curves (Q-T) for each of the gauging sites located only on the modelled watercourses (10 No. gauging sites) in HA15 were examined and compared with the relevant pooled frequency curves. In the case where the pooled frequency curve is flatter than the at-site curve, the design growth curves/factors should be estimated from the at-site records. If the pooled growth curve is convex upwards then a two parameter distribution should be fitted to the pooled growth curve so as to avoid the upper bound.

Further the FSU study recommended that “*If a very large flood is observed during the period of records the question arises as to whether it should over-ride any more modest estimate of Q_T obtained by a pooling group approach or whether a weighted combination of the pooling group estimate and the at-site estimate should be adopted. If a combination is used the weights to be given to the two components of the combination cannot be specified by any rule based on scientific evidence but must be chosen in an arbitrary, however one would hope a reasonable way.*”

Table 5.13 shows the hydrometric gauges (10 gauging sites) located on the HA15 modelled watercourses. The estimated pooled growth curves associated with these gauges are also included.

Table 5.13: Hydrometric gauging stations located on the modelled watercourses in HA15 hydrometric area

Stations	Waterbody	Location	Approx. Catchment Area (km ²)	Growth Curve Group No.
15001	Kings	Annamult	444	GC04
15002	Nore	John's Bridge	1642	GC06
15004	Nore	McMahons Bridge	489	GC04
15005	Erkina	Durrow Foot Bridge	379	GC03
15006	Nore	Brownsbarn	2417	GC06
15007	Nore	Kilbricken	339	GC03
15008	Nore	Borris in Ossory	117	GC02
15009	Kings	Callan	203	GC03
15011	Nore	Mount Juliet	2224	GC06
15012	Nore	Ballyragget	1055	GC05

Figure 5.18 shows the comparisons of the At-site and Regional Flood Frequency (AFF & RFF) curves for the above mentioned hydrometric gauging sites. The EV1 distribution was used for these

comparisons. In addition to the frequency curves, the 95%ile confidence intervals associated with the regional estimates were also included in these plots. The EV1 straight line was used as an indicative descriptor of the at-site distribution, rather than a GEV or GLO curve, because the latter when fitted at-site, is liable to be misleading because of the large standard error involved in the shape parameter particularly. This was used for those stations where the individual AMAX series standardised growth curves differed considerably from the pooling growth curve. In such cases, EV1 regional growth curves were used instead of GLO curves; because the nature of the adjustment implies that an appropriate curved shape could not be determined with more accuracy than that of a straight line i.e. persevering with a curved growth curve in such cases would be an “illusion of accuracy”.

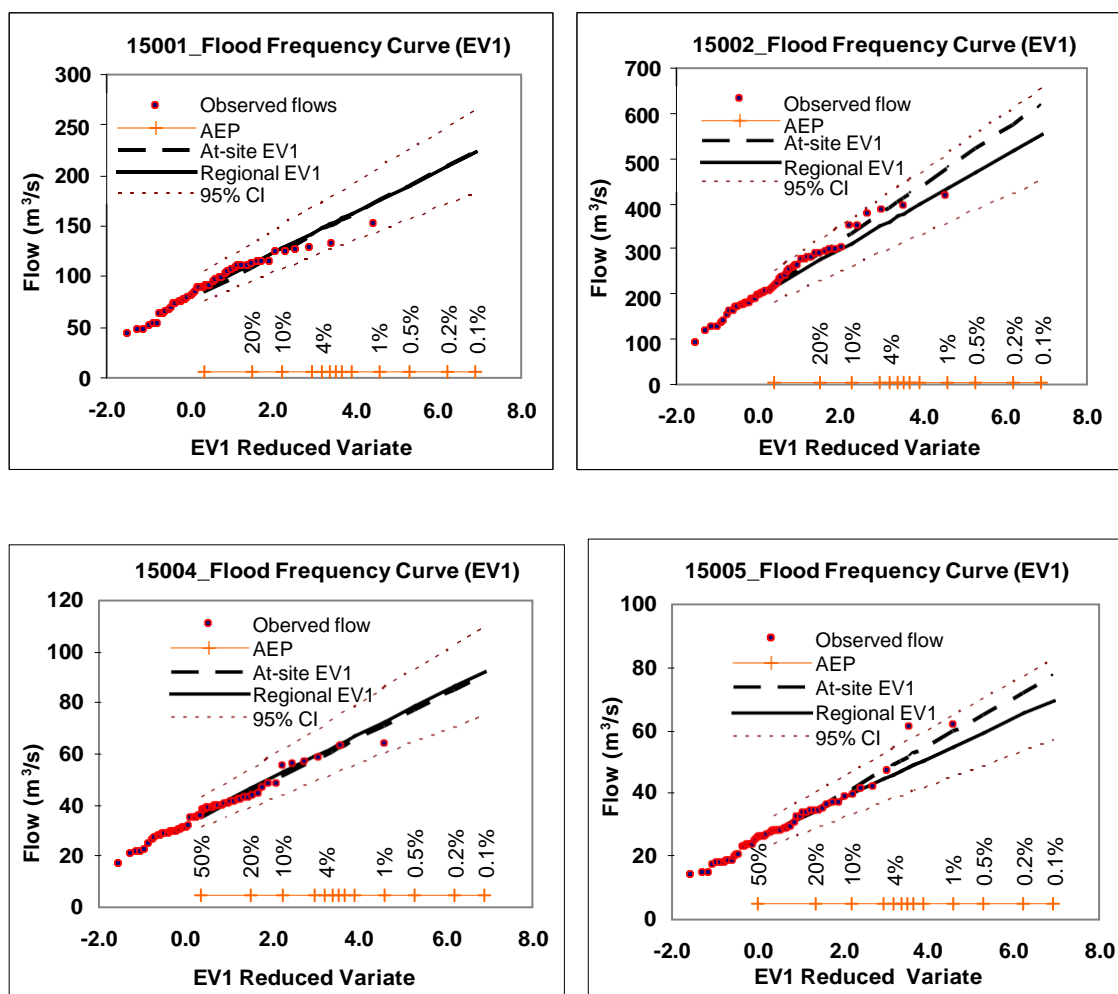


Figure 5.17: The at-site and pooled frequency curves along with the 95% confidence intervals – continued overleaf

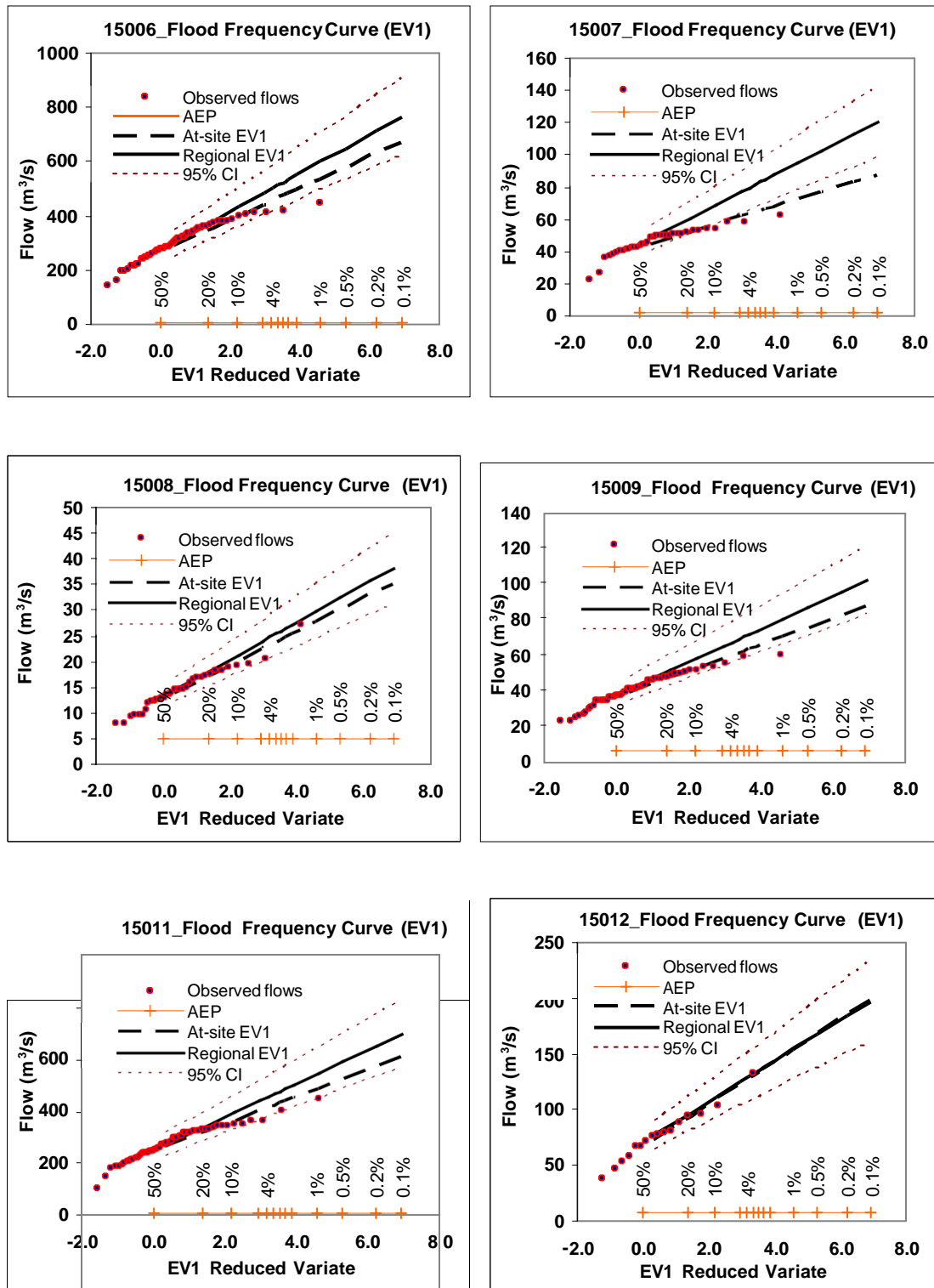


Figure 5.18 (cont'd): The at-site and pooled frequency curves along with the 95% confidence intervals

It can be seen from Figure 5.18 that at 2 sites (out of 10), the AFF curves are slightly steeper than the RFF curves, suggesting that the regional curves slightly underestimate when compared with a number of observed floods at these stations. However, these at-site growth curves fall within the 95%ile confidence limits of the estimated associated regional growth curves.

If an AFF curve lies below the confidence limits of the RFF curve then we consider it prudent to adopt the RFF curve as the design curve, on the basis that the observed flood record has, by chance, fallen below the regional average and that there is a chance or possibility that the record of the next 20 or 30 years will revert to resembling the RFF curve rather than reproduce a re-occurrence of the recent past. It has to be acknowledged that this type of decision may lead to a degree of over-design but it is recommended that this be knowingly accepted.

On the other hand if an AFF curve lies above the RFF curve, then we consider it prudent to take account of both when deciding on the design curve/flood. This could be done by calculating a weighted average of the two curves. The relative weights should be decided, on a case by case basis, following examination of the degree of difference between the two curves, including consideration of the confidence limits of the RFF curve, shape of the at-site probability plot and the number of observed large outliers in the data series.

Based on the above, the design growth curves for all HEPs located in close proximity to the above stations have been estimated from their relevant regional growth curves.

5.8.4 Growth factors for all HEPs in the River Nore catchment

Based on the catchment sizes associated with each of the 127 HEPs, the relevant estimated growth factors for a range of AEPs are presented in Table 5.14.

Table 5.14: Growth factors for all 127 HEPs for a range of AEPs for the River Nore catchment (HA15)

Node No.	Node ID_CFRAMS	AREA (km ²)	Growth factors (X_T)								
			1% AEP			0.2% AEP			0.1% AEP		
			Lower 95%ile	X_T	Upper 95%ile	Lower 95%ile	X_T	Upper 95%ile	Lower 95%ile	X_T	Upper 95%ile
1	15_198_10_RPS	380.43	1.722	1.909	2.096	2.025	2.363	2.701	2.165	2.586	3.007
2	15_946_2_RPS	16.57	2.982	3.306	3.630	4.268	4.981	5.694	4.969	5.934	6.899
3	15_1938_5_RPS	39.37	2.654	2.942	3.230	3.629	4.235	4.841	4.140	4.944	5.748
4	15004_RPS	488.70	1.711	1.897	2.083	1.994	2.327	2.660	2.116	2.527	2.938
5	15007_RPS	339.00	1.722	1.909	2.096	2.025	2.363	2.701	2.165	2.586	3.007
6	15012_RPS	1055.40	1.722	1.909	2.096	1.999	2.333	2.667	2.123	2.535	2.947
7	15035_RPS	267.80	1.722	1.909	2.096	2.025	2.363	2.701	2.165	2.586	3.007
8	15_1003_4_RPS	57.73	2.036	2.257	2.478	2.597	3.031	3.465	2.883	3.443	4.003
9	15_1965_5_RPS	3.67	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
10	15_420_6_RPS	2.30	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
11	15_994_1_RPS	109.63	1.991	2.207	2.423	2.467	2.879	3.291	2.699	3.223	3.747
12	15_306_2_RPS	1.66	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
13	15_306_8_RPS	3.84	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
14	15_1425_2	60.10	2.362	2.619	2.876	3.086	3.601	4.116	3.450	4.120	4.790
15	15_1220_3	11.95	2.912	3.228	3.544	4.123	4.811	5.499	4.775	5.703	6.631
16	15_338_2_RPS	1.94	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
17	15_1318_3_RPS	0.26	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
18	15_1880_7_RPS	11.58	2.802	3.106	3.410	3.882	4.530	5.178	4.451	5.316	6.181
19	15_420_3	1.69	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
20	15_1965_2_RPS	2.22	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
21	15_1461_8	5.63	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
22	15_1455_7	7.76	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
23	15_911_5	100.82	2.005	2.223	2.441	2.523	2.944	3.365	2.782	3.322	3.862
24	15_923_2_RPS	65.60	1.951	2.163	2.375	2.392	2.791	3.190	2.602	3.108	3.614
25	15_1060_5_RPS	5.46	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
26	15_1813_11_RPS	8.60	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
27	15_1749_11_RPS	69.15	2.007	2.225	2.443	2.487	2.902	3.317	2.719	3.247	3.775
28	15_359_2_RPS	40.09	2.513	2.786	3.059	3.351	3.910	4.469	3.778	4.512	5.246
29	15_1880_5_RPS	10.77	2.960	3.282	3.604	4.200	4.901	5.602	4.867	5.813	6.759
30	15_1770_2_RPS	11.47	2.912	3.228	3.544	4.123	4.811	5.499	4.775	5.703	6.631
31	15_1858_10_RPS	15.29	2.913	3.229	3.545	4.122	4.810	5.498	4.773	5.700	6.627
32	15_200_2_RPS	18.08	2.858	3.168	3.478	4.023	4.695	5.367	4.649	5.552	6.455

Node No.	Node ID_CFRAMS	AREA (km ²)	Growth factors (X _T)								
			1% AEP			0.2% AEP			0.1% AEP		
			Lower 95%ile	X _T	Upper 95%ile	Lower 95%ile	X _T	Upper 95%ile	Lower 95%ile	X _T	Upper 95%ile
33	15_196_2_RPS	168.10	1.873	2.076	2.279	2.246	2.621	2.996	2.420	2.890	3.360
34	15_910_2_RPS	94.72	2.099	2.327	2.555	2.627	3.066	3.505	2.885	3.445	4.005
35	15_479_6	22.55	2.879	3.192	3.505	4.041	4.716	5.391	4.662	5.568	6.474
36	15_1824_6_RPS	92.18	2.212	2.452	2.692	2.812	3.281	3.750	3.106	3.709	4.312
37	15_944_2	9.84	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
38	15008_RPS	116.54	1.874	2.078	2.282	2.283	2.664	3.045	2.479	2.961	3.443
39	15_698_2_RPS	3.42	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
40	15_338_4_RPS	2.57	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
41	15_1318_3_Inter	0.18	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
42	15_1318_1_RPS	15.46	2.699	2.992	3.285	3.694	4.311	4.928	4.215	5.034	5.853
43	15_1850_6_RPS	1241.94	1.768	1.960	2.152	2.103	2.454	2.805	2.260	2.699	3.138
44	15027_RPS	46.72	2.133	2.365	2.597	2.788	3.254	3.720	3.129	3.737	4.345
45	15_289_1	13.47	2.211	2.451	2.691	2.907	3.392	3.877	3.268	3.903	4.538
46	15_1000_1_RPS	26.71	2.133	2.365	2.597	2.788	3.254	3.720	3.129	3.737	4.345
47	15_289_3	15.00	2.239	2.482	2.725	2.968	3.464	3.960	3.350	4.001	4.652
48	15_1360_8_RPS	6.40	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
49	15_467_5	2.48	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
50	15028	35.47	2.641	2.928	3.215	3.602	4.203	4.804	4.104	4.901	5.698
51	15032	15.94	2.950	3.270	3.590	4.176	4.873	5.570	4.835	5.774	6.713
52	15054	32.00	2.772	3.073	3.374	3.840	4.481	5.122	4.404	5.260	6.116
53	15_12_1_RPS	11.12	2.974	3.297	3.620	4.225	4.930	5.635	4.899	5.851	6.803
54	15_467_2	1.59	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
55	15_418_4_RPS	6.04	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
56	15039_RPS	61.94	2.357	2.613	2.869	3.077	3.591	4.105	3.440	4.108	4.776
57	15_1390_3	1.61	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
58	15_75_9	25.97	2.819	3.125	3.431	3.918	4.572	5.226	4.500	5.374	6.248
59	15_75_7	24.91	2.898	3.213	3.528	4.087	4.769	5.451	4.724	5.642	6.560
60	15_1390_U	0.79	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
61	15_461_3	1.57	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
62	15_1029_1	34.92	2.469	2.737	3.005	3.256	3.800	4.344	3.655	4.365	5.075
63	15_1824_2	23.18	2.863	3.174	3.485	4.014	4.684	5.354	4.629	5.528	6.427
64	15_1323_5_RPS	2.43	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
65	15_1257_7	15.09	2.515	2.788	3.061	3.369	3.931	4.493	3.807	4.547	5.287
66	15_1269_4_RPS	70.99	2.459	2.726	2.993	3.259	3.803	4.347	3.667	4.379	5.091

Node No.	Node ID_CFRAMS	AREA (km ²)	Growth factors (X _T)								
			1% AEP			0.2% AEP			0.1% AEP		
			Lower 95%ile	X _T	Upper 95%ile	Lower 95%ile	X _T	Upper 95%ile	Lower 95%ile	X _T	Upper 95%ile
67	15_1332_4_RPS	36.08	2.698	2.991	3.284	3.711	4.331	4.951	4.244	5.069	5.894
68	15_671_2_RPS	4.33	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
69	15_1922_7_RPS	10.21	3.051	3.383	3.715	4.398	5.132	5.866	5.134	6.132	7.130
70	15002_RPS	1642.23	1.768	1.960	2.152	2.103	2.454	2.805	2.260	2.699	3.138
71	15040	1571.76	1.768	1.960	2.152	2.103	2.454	2.805	2.260	2.699	3.138
72	15050_RPS	70.90	2.459	2.726	2.993	3.259	3.803	4.347	3.667	4.379	5.091
73	15104_RPS	1567.49	1.768	1.960	2.152	2.103	2.454	2.805	2.260	2.699	3.138
74	15105	<10km2	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
75	15_1323_1	1.63	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
76	15_1922_1	7.27	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
77	15_1257_3	13.23	2.884	3.197	3.510	4.055	4.732	5.409	4.682	5.592	6.502
78	15_1515_3_RPS	44.20	2.675	2.966	3.257	3.645	4.254	4.863	4.150	4.956	5.762
79	15_1955_6_RPS	299.85	1.722	1.909	2.096	2.025	2.363	2.701	2.165	2.586	3.007
80	15_1078_3_RPS	7.68	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
81	15_1150_1_RPS	28.66	2.744	3.042	3.340	3.774	4.404	5.034	4.315	5.153	5.991
82	15_368_5_RPS	12.51	3.051	3.383	3.715	4.398	5.132	5.866	5.134	6.132	7.130
83	15_159_4_RPS	11.42	3.051	3.383	3.715	4.398	5.132	5.866	5.134	6.132	7.130
84	15_671_U	2.18	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
85	15_521_3_RPS	1744.54	1.768	1.960	2.152	2.103	2.454	2.805	2.260	2.699	3.138
86	15001_RPS	443.64	1.711	1.897	2.083	1.994	2.327	2.660	2.116	2.527	2.938
87	15009_RPS	202.77	1.722	1.909	2.096	2.025	2.363	2.701	2.165	2.586	3.007
88	15023	243.82	1.722	1.909	2.096	2.025	2.363	2.701	2.165	2.586	3.007
89	15_1786_4_RPS	2.24	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
90	15_593_1	2.00	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
91	15_1786_1_RPS	1.45	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
92	15_1733_4_RPS	199.64	1.801	1.997	2.193	2.137	2.494	2.851	2.292	2.737	3.182
93	15_1786_5_RPS	0.05	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
94	15_1786_6_RPS	0.09	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
95	15_501_2	33.64	2.414	2.676	2.938	3.213	3.750	4.287	3.627	4.332	5.037
96	15_157_3	6.94	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
97	15_686_5_RPS	29.33	2.520	2.794	3.068	3.357	3.918	4.479	3.785	4.520	5.255
98	15_458_8	6.45	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
99	15_1870_2_RPS	70.62	2.099	2.327	2.555	2.654	3.097	3.540	2.927	3.496	4.065
100	15_1991_3_RPS	10.93	2.960	3.282	3.604	4.200	4.901	5.602	4.867	5.813	6.759

Node No.	Node ID_CFRAMS	AREA (km ²)	Growth factors (X_T)								
			1% AEP			0.2% AEP			0.1% AEP		
			Lower 95%ile	X_T	Upper 95%ile	Lower 95%ile	X_T	Upper 95%ile	Lower 95%ile	X_T	Upper 95%ile
101	15_1762_5_RPS	47.02	2.545	2.822	3.099	3.406	3.975	4.544	3.848	4.596	5.344
102	15_1137_9_RPS	16.45	2.751	3.050	3.349	3.827	4.466	5.105	4.400	5.255	6.110
103	15_1106_5	8.28	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
104	15_1814_4_RPS	63.72	2.054	2.277	2.500	2.557	2.984	3.411	2.800	3.344	3.888
105	15_1819_6_RPS	443.78	1.711	1.897	2.083	1.994	2.327	2.660	2.116	2.527	2.938
106	15_1848_3_RPS	48.79	2.218	2.459	2.700	2.820	3.291	3.762	3.116	3.721	4.326
107	15006_RPS	2416.89	1.768	1.960	2.152	2.103	2.454	2.805	2.260	2.699	3.138
108	15011_RPS	2223.77	1.768	1.960	2.152	2.103	2.454	2.805	2.260	2.699	3.138
109	15_1106_3	7.03	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
110	15_482_4_RPS	38.71	2.351	2.606	2.861	3.051	3.560	4.069	3.400	4.060	4.720
111	15_520_4_RPS	21.50	2.796	3.100	3.404	3.891	4.541	5.191	4.473	5.342	6.211
112	15_707_3_RPS	8.26	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
113	15_93_7	46.92	2.181	2.418	2.655	2.799	3.266	3.733	3.108	3.712	4.316
114	15_1511_8	10.08	2.701	2.995	3.289	3.722	4.344	4.966	4.262	5.090	5.918
115	15_650_7	14.22	2.506	2.778	3.050	3.358	3.919	4.480	3.799	4.537	5.275
116	15_2002_9	8.77	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
117	15_2008_6	14.20	2.398	2.659	2.920	3.192	3.725	4.258	3.602	4.302	5.002
118	15_2016_2	7.46	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
119	15_2014_4	6.44	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
120	15_1996_U	3.59	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
121	15_1996_1	4.52	2.960	3.282	3.604	4.206	4.908	5.610	4.881	5.829	6.777
122	15_1839_1	2519.25	1.768	1.960	2.152	2.103	2.454	2.805	2.260	2.699	3.138
123	15046	49.78	2.145	2.378	2.611	2.721	3.175	3.629	3.004	3.588	4.172
124	15_1358_3_RPS	10.81	2.530	2.805	3.080	3.411	3.981	4.551	3.870	4.622	5.374
125	15_1337_12_RPS	10.10	2.701	2.995	3.289	3.722	4.344	4.966	4.262	5.090	5.918
126	15_1212_7	15.09	2.884	3.197	3.510	4.055	4.732	5.409	4.682	5.592	6.502
127	15_1358_8_RPS	14.64	2.506	2.778	3.050	3.358	3.919	4.480	3.799	4.537	5.275

The design flood flows for any required AEP can be calculated by multiplying the Index Flood, Q_{med} of each HEP by the above estimated relevant growth factors. The Q_{med} at gauged sites is estimated from the observed AMAX series supplemented with additional simulated gauge years through rainfall run-off modelling (MIKE NAM). For the ungauged sites Q_{med} is be estimated from the FSU recommended catchment descriptors based methodology and through the use of rainfall run-off (MIKE NAM) modelling to simulate flow records and hence produce a simulated AMAX record at the ungauged site.

It should be noted here that any uncertainties in the design flood estimates obtained from the index-flood method generally result from the uncertainties associated with both the index-flood (Q_{med}) and growth factor estimates. The uncertainties in the growth factor estimates can result both from the sampling variability and misspecification of the growth curve distribution. The sampling error is considered to be small due to the larger record lengths (pooled records) used in the estimation process.

Furthermore, it should also be noted here that, any allowances for future climate change in the design flood flow estimate should be applied to the median flow estimates. Any effects of the climate change on the growth curves are expected to be minimal.

5.9 COMPARISON WITH FSR GROWTH FACTORS

A comparison of the estimated growth factors for the River Nore catchment was carried out with the FSR and the Suir CFRAM Study growth factors for a range of AEPs as shown in Table 5.15.

All growth curves were indexed to the median annual maximum flows (Q_{med}).

Table 5.15: Study growth factors compared with FSR, Suir CFRAM Study and Kilkenny Flood Relief Scheme growth factors

AEP (%)	50%	20%	10%	4%	2%	1%	0.5%	0.2%	0.1%
River Nore Catchment (HA15)	1.000	1.225 to 1.456	1.375 to 1.807	1.575 to 2.339	1.731 to 2.818	1.897 to 3.383	2.074 to 4.051	2.327 to 5.132	2.527 to 6.132
Average of HA15	1.000	1.379	1.659	2.072	2.433	2.847	3.327	4.085	4.769
Suir CFRAM Study (main channel)	1.00	1.22	1.35	-	1.61	1.72	1.82	1.95	2.05
FSR	1.000	1.260	1.450	1.630	1.870	2.060	2.620	2.530	2.750
Kilkenny Flood Relief Scheme**	1.048	1.338	1.558	1.848	2.068	2.288	2.508	2.798	Not available

** taken from EVA analysis of Stn 15002 based on post 1981 AMAX as provided by OPW)

Table 5.15 indicates that the study area growth factors (average values) are slightly higher than the FSR growth factors, with the difference between them increasing with return period. Comparison of the Suir CFRAM Study growth factors for the main channel are comparable with the River Nore growth factors at the lower end of the range (which relate to main channel /larger catchments) but the Nore growth curve is steeper at higher return periods. The Kilkenny Flood Relief Scheme growth factors for

the River Nore are steeper than the CFRAM Study growth factors which is to be expected since these are based on a single site analysis of Station 15002 rather than a pooling region.

5.10 GROWTH CURVE DEVELOPMENT SUMMARY

Growth curves for all HEPs were estimated from the regional flood frequency analysis technique as recommended in the FEH, FSU and FSR studies (Region of Influence Approach).

Annual Maximum Flow Records (AMAX) from the 92 hydrometric stations located in the Eastern and South Eastern Region of Ireland were pooled for estimating the pooled growth curves for 127 HEPs. The selection of this pooling region was based on the similarity of catchment characteristics both in terms of climatic and physiographic characteristics. The size of a pooling group associated with each of the HEPs was determined based on the FEH recommended 5T rule (with a minimum of 500 station-years AMAX series for each pooled growth curve). The pooling process was based on the FSU recommended catchment characteristics based (AREA, SAAR and BFI) distance measures between the subject and donor sites.

The statistical distribution suitable for a pooled growth curve was determined based on a number of factors such as - the suitability of this distribution for fitting the contributory stations' at-site AMAX series, the number of distribution parameters and shape of the growth curves (concave upward or convex upward). Four flood like distributions namely, the EV1, LN2, GEV and GLO distributions were considered. The three-parameter GLO distribution was found to be the best suited distribution in all respects and therefore was chosen as the growth curve distribution for all HEPs in the River Nore catchment (HA15).

Initially, growth curves for each of the 127 HEPs in HA15 were estimated separately. Subsequently, the number of growth curves was reduced based on their relationship with the catchment areas. It was found that the growth factors generally increase with the decrease in catchment sizes. This increase rate is larger for the catchment areas less than 400 km² and also for the larger AEP growth factors. For any catchment areas larger than 900 km² the growth factors remained unchanged with any further increase in catchment area. Based on this the following 6 generalised growth curve groups were recommended for the River Nore catchment:

1. GC group No. 1: AREA < 10 km²
2. GC group No. 2: 10 < AREA ≤ 200 km²
3. GC group No. 3: 200 < AREA ≤ 400 km²
4. GC group No. 4: 400 < AREA ≤ 800 km²
5. GC group No. 5: 800 < AREA ≤ 1200 km²
6. GC group No. 6: AREA > 1200 km²

It was decided that the growth factors for all HEPs with catchment sizes ranging from 10 to 200 km² (Growth Curve Group No. 2) be estimated from the separate growth curve estimation process. For the remaining growth curve groups the median growth curves will be used. HEPs with catchment areas larger than 1200 km² have almost the same growth factors.

The estimated 1% AEP growth factors for the River Nore catchment vary from 1.897 to 3.383 depending on the catchment sizes. Growth factors for the smaller catchments are larger than those of the larger catchments.

6 DESIGN FLOWS

6.1 DESIGN FLOW HYDROGRAPHS

Following estimation of the Index Flood Flow (Q_{med}) and growth factors for each HEP it is possible to estimate the peak design flows for a range of Annual Exceedance Probabilities (AEPs). All of the design flows which will be used for hydraulic modelling input are detailed in Appendix D. The final component of estimating the fluvial design flows is to ascertain the profile of the design flow hydrograph for each HEP, i.e. the profile of the flow over time as a flood event rises from its base flow to achieve the peak design flow (rising limb) and then as the flood flow rate decreases and the watercourse returns to more normal flows (recession limb). As discussed in Chapter 2 of this report the methodology for this study has been developed further since production of the Inception Report and as such three methodologies have been used within HA15 to derive the design flow hydrograph shapes (widths) such that these can be applied to a range of design events:

1. Analysis of simulated historic hydrograph width at all rainfall run-off modelling points based on guidance within FSU WP 3.1 'HydrographWidth Analysis';
2. FSU Hydrograph Shape generation tool (developed from FSU WP 3.1) for all other HEPs with the exception of 3 (below);
3. FSSR 16 Unit Hydrograph method for small (catchment less than 5 km²) where no suitable pivotal site is available.

6.1.1 Rainfall Run-off (NAM) Modelling and HWA

There are two processes involved in the first method which combines the outputs of the catchment based rainfall run-off modelling with the Hydrograph Width Analysis software developed as part of FSU WP 3.1. The catchment rainfall run-off modelling has been carried out using the NAM (Nedbør-Afrstrømnings-Model) component of the MIKE 11 software

developed by the Danish Institute of Hydrology (DHI).

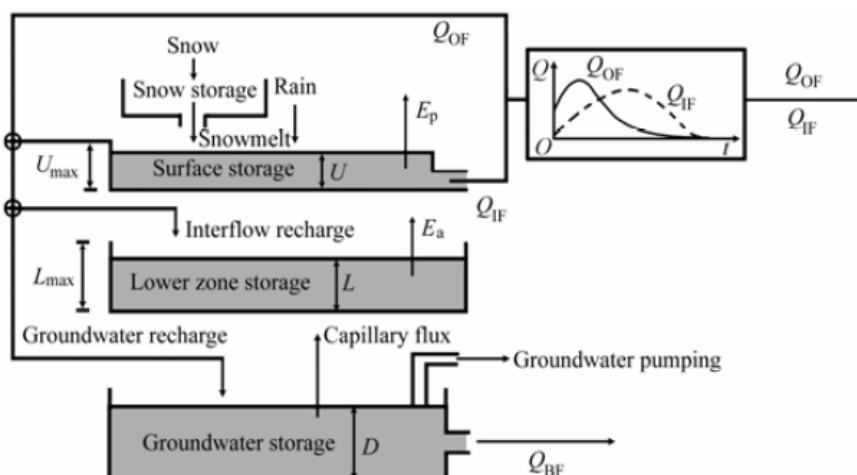


Figure 6.1: NAM Conceptual Model

With the correct catchment parameters and meteorological inputs the NAM replicates the simulated run-off from the catchment at desired time intervals. This continuous flow trace is comparable to the flow record that can be derived from level recordings at a hydrometric gauging station and as such can be analysed in a similar way.

The HWA software has been researched and developed by NUI Galway as part of FSU WP 3.1 (Hydrograph Width Analysis). It is a user friendly windows based software program which was designed to facilitate data-processing, information-extraction and design flood hydrograph production for the wealth of flow data available from hydrometric gauging stations. The first step in the processing of the information is to convert the file into a formatted text file in a file format derived as part of the HWA software development. Once a continuous flow text file in the correct format has been produced from the NAM outputs the software can then accept the full flow simulated record for analysis. The following general steps are then followed:

1. Input data and identify the events for hydrograph analysis, in this case we identify the annual maxima (AMAX) events
2. Isolated hydrographs are de-coupled from complex flood events, i.e. a number of peaks can be present in a flood hydrograph and as such we seek to isolate the largest of the peaks for analysis.
3. The selected hydrographs are analysed to determine the median width at each 5%ile step of their peak flow
4. Irregular parts of the hydrograph shape are discarded
5. A smoothed gamma curve is fitted to the median width hydrograph

Following these steps a parametric semi-dimensionless hydrograph is created (i.e. the hydrograph does not have a flow value on the y axis but rather is defined in height terms by the percentage of the peak flow). The result of these steps applied to the continuous flow trace from the NAM model for the Hydrometric Station 15009 (model no. 6) is shown in Figure 6.2.

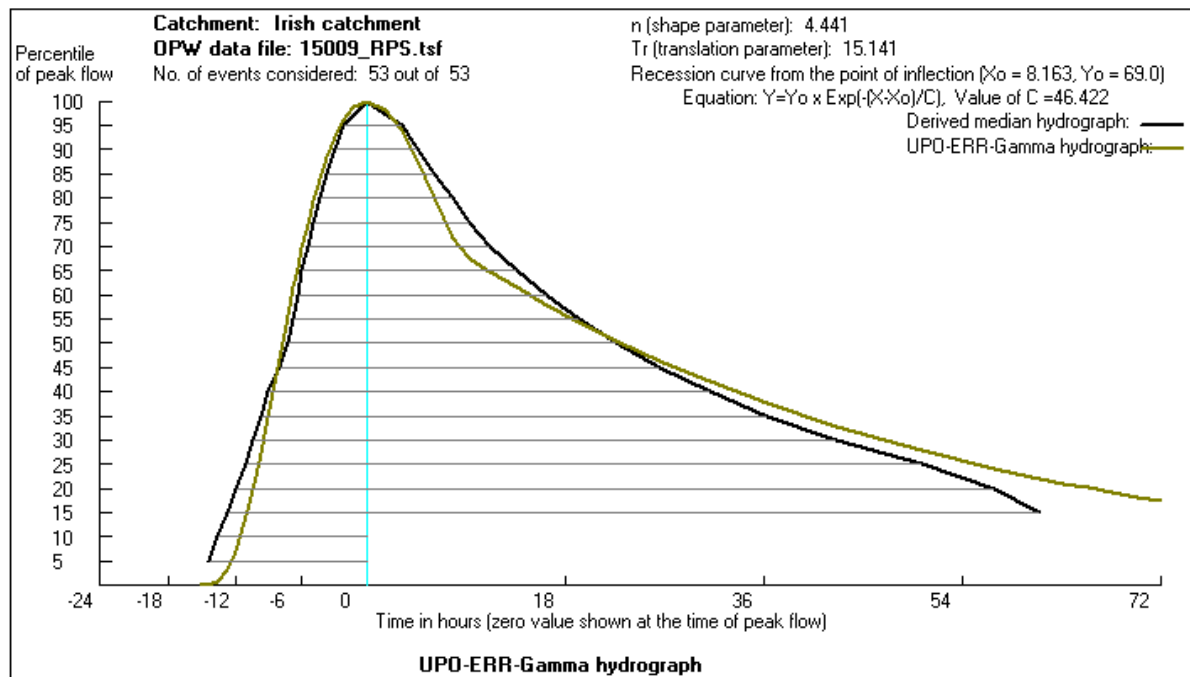


Figure 6.2: Median Semi-dimensionless Hydrograph with Fitted Gamma Curve

As is demonstrated in Figure 6.2 the hydrograph width is defined in time (hours) around a zero value which represents the peak. The peak itself represents 100% of the peak flood flow and as such can be applied to all of the design flood flow peak values. There is one further element, the base flow, which must be combined with the hydrograph peak flow and shape to arrive at the final design hydrograph.

The base flow is calculated as per the recommendations of WP 3.1 and is a function of the catchment descriptors Standardised Average Annual Rainfall (SAAR), Catchment Wetness Index (CWI) and Area. The semi dimensionless hydrographs can then be scaled to fit a range of design flows as shown in Figure 6.3. Median hydrographs at each of the NAM modelled HEPs within HA15 are contained within Appendix E.

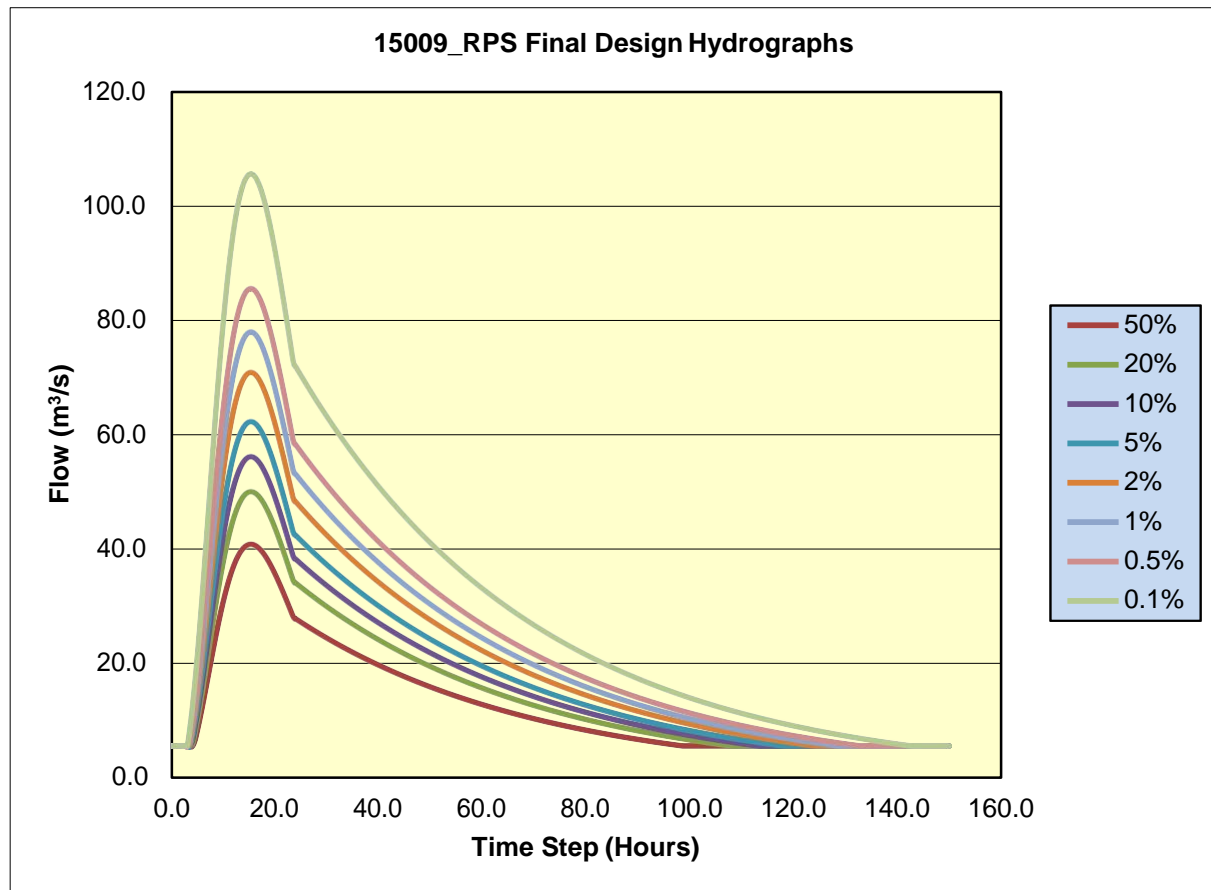


Figure 6.3: Design Flow Hydrographs for HEP Node 15009_RPS

One further benefit of the rainfall runoff models is that a further layer of simulated hydrometric data is available for calibration of the hydraulic models. Events which may be outside the continuous flow record period of the gauge are now available through the simulated time series flow data at NAM modelling points. No continuous level information is available as the models are spatially dimensionless (i.e. they are not hydraulic models with inputted topographical survey information) but the simulated flow information can be used to replicate the recorded flood extents for historic events not previously captured.

6.1.2 FSU Hydrograph Shape Generator

For all of the HEPs which have not been subject to rainfall run-off modelling and which are not directly upstream or downstream of a NAM modelled HEP node such that the median hydrograph from the neighbouring HEP can be applied, the Hydrograph Shape Generator tool developed as an output from FSU WP 3.1 is used to derive the design hydrograph. The Hydrograph Shape Generator Tool is an excel spreadsheet containing a library of parametric, semi-dimensionless hydrograph shapes derived from gauge records of pivotal sites using the HWA software previously discussed. Based on hydrological similarity, a pivotal site hydrograph is 'borrowed' and applied at the subject site (in this case the CFRAMS HEP) based on catchment descriptors. One potential issue with the use of the

Hydrograph Shape Generator tool is the lack of small catchments from which suitably short hydrographs are available. This, along with overly long receding limbs on hydrographs, was particularly noticeable in earlier versions of the software but is much improved with the addition of further pivotal sites to bring the number within the library up to 145. Within HA15 the latest version of the software (version 5) was found to provide suitable hydrograph shapes for approximately 50 of the HEPs.

6.1.3 FSSR 16 Unit Hydrograph Method

In some instances it was found that Pivotal Sites could not be found which were sufficiently hydrologically similar to the subject catchment such that hydrograph shape parameters could be borrowed and a hydrograph generated as per Section 6.1.2. This was particularly the case for the very small watercourses entering the River Nore main channel or small urban watercourses affecting AFAs. The FSSR 16 Unit Hydrograph method was used for these catchments whereby semi dimensionless hydrographs were derived with the same time-step as used for the other hydrographs within the model using the ISIS FSSR 16 UH tool.

Following the application of these methodologies hydrographs are available for application within the hydraulic model. Using Model 1, Ballyragget as an example, the input hydrographs for small tributaries (HEPs) are shown for the 1% AEP event in Figure 6.4.

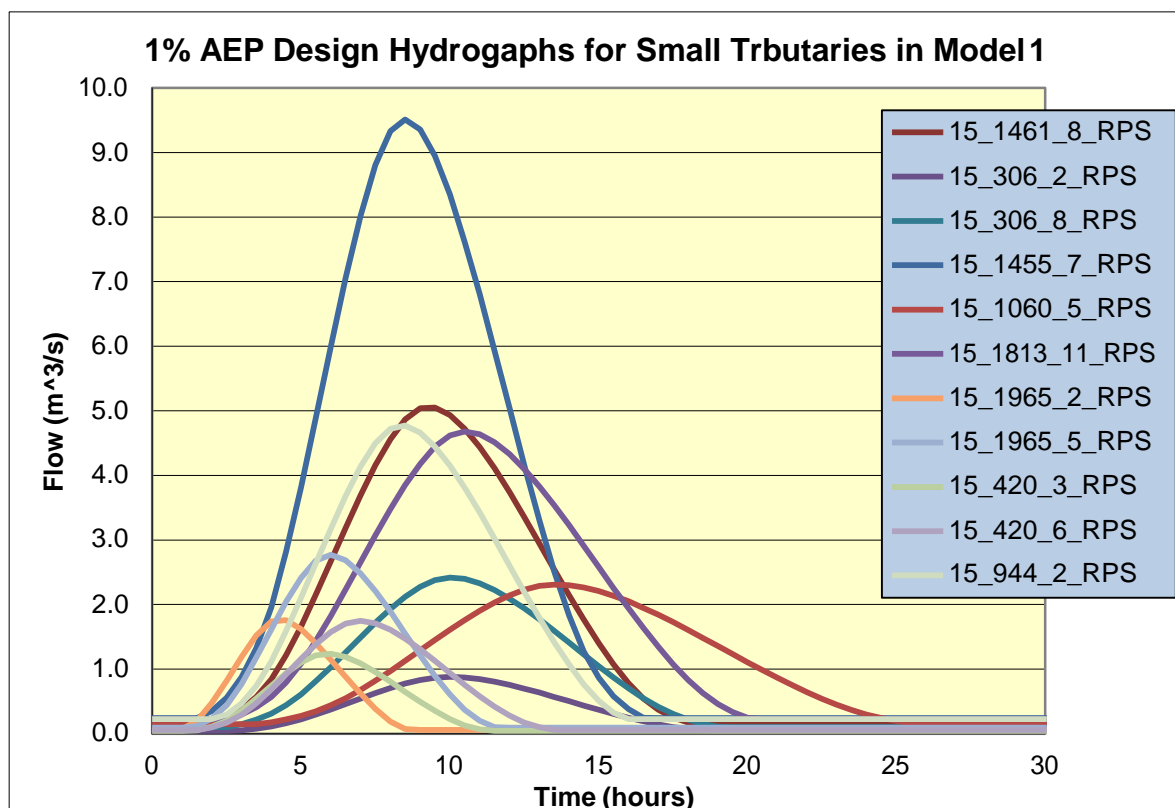


Figure 6.4: 1% AEP Hydrographs for the Small Tributaries in Model 1

6.2 JOINT PROBABILITY

Joint probability is a consideration within HA15 in relation to the occurrence of fluvial – fluvial events (where extreme flood events on tributaries and the main channel of rivers coincide) and also at the downstream tidal reaches of HA15 where tidal – fluvial events become a consideration at Inistioge where the River Nore becomes the tidal Nore Estuary.

6.2.1 Fluvial – Fluvial

There are modelled watercourse confluence points within every model in HA15, with the largest confluence between the River Nore and River Barrow at the downstream end of the Inistioge Model. At these confluence points consideration must be given to the probability of coincidence of flood flows within the model. In order to minimise the need for joint probability analysis within the models RPS has split the Nore system into ten models such that the hydrological conditions which cause the flood event have a low degree of variance across the model extents. In addition RPS has specified a high number of HEPs so that as we move down the model, i.e. past confluence points, the hydraulic modeller has to hand the design flows downstream of the confluence point such that they can check that the sum of the inflows within the tributary and the main channel are creating the correct frequency conditions downstream of the confluence point. Where these conditions are not being achieved the modeller will adjust the flows depending on the relationship between catchment descriptors of the main channel and tributary such that the joint probability relationship can be determined to create the correct frequency conditions downstream of the confluence point. This is a modelling consideration and may require an iterative approach. These adjustments will be carried out in line with the guidance provided in FSU WP 3.4 'Guidance for River Basin Modelling' and detailed in the Hydraulic Modelling report.

6.2.2 Fluvial – Coastal

In terms of the CFRAM Study and HA15 this category of joint probability is relevant to the Inistioge model (no. 9) which is tidally influenced along its entire reach. The tidal effect at the downstream boundary must be considered through the output flood levels.

Three-variable joint probability is considered under fluvial-coastal analysis as sea level, waves and river flow could all be a consideration in tidal AFAs. However in this case, the wave element can be immediately eliminated as Inistioge is well within the Nore Estuary which leads to the Barrow, Suir, Nore Estuary and Waterford Harbour before reaching the Celtic Sea some 45km downstream.

Coastal flooding is not a risk in Inistioge AFA and as such, tidal influence is not expected to be significant in terms of combining with extreme river flows. Model 9 (Inistioge) terminates at its confluence with the River Barrow which is also tidally influenced, as the rivers join and become the Barrow Nore tidal Estuary. The downstream boundary conditions of the Inistioge model will be derived from the hydraulic model outputs of the River Barrow at this point (refer to UoM 14 hydrology and hydraulics reports for joint probability analysis) and as such, anytidal influence will be captured.

7 FUTURE ENVIRONMENTAL AND CATCHMENT CHANGES

There are a number of future potential changes which may affect the outputs of this study and as such it is prudent that they are identified and their potential impact quantified so that the outputs can accommodate these changes as much as practically possible. This chapter outlines potential environmental changes such as climate change and changes to the catchment such as afforestation and changing land use. HA15 is a predominantly rural catchment with much of the land given over to tillage and grassland. The largest urban area is Kilkenny City located on the banks of the River Nore and River Breaghagh. Urbanisation along with potential management and policy changes are considered in this chapter. The design flow estimations for Mid-Range and High End Future Scenarios (MRFS and HEFS) that have been calculated based on the findings of this chapter are included in Appendix C for each HEP.

7.1 CLIMATE CHANGE

According to the United Nations Intergovernmental Panel on Climate Change (2007) there is “unequivocal” evidence of climate change and furthermore:

"most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."

(Climate Change 2007, IPCC, Fourth Assessment Report AR4)

Further to this carbon dioxide levels in the atmosphere were observed at over 400 parts per million in Hawaii. This is considered a milestone threshold and is at a level last thought to have occurred several million years ago when the Arctic was ice free and sea levels were up to 40m higher.²

The effects of climate change on flood risk management are obvious but in terms of fluvial flooding they are not straightforward to quantify. Changes in sea level have direct impact on coastal flooding and a range of predictions on projected sea level rise are available. A number of meteorological projections are also available for changes in rainfall but these have a wide degree of variance particularly from season to season and are difficult to translate into river flow.

7.1.1 HA15 Context

Research into climate change in Ireland is coordinated by Met Éireann through the Community Climate Change Consortium for Ireland (www.c4i.ie). Research summarised in the report ‘Ireland in a Warmer World – Scientific Predictions of the Irish Climate in the 21st Century’ (Mc Grath *et al*, 2008) seeks to quantify the impact of climate change on Irish hydrology and considers the impacts on nine Irish catchments all of which were outside HA15 but includes the Suir (HA16) and the Barrow (HA14). The ensemble scenario modelling from the regional climate change model predicts that between the

² www.theguardian.com/environment/2013/may/10

two periods of 1961 – 2000 and 2021 – 2060 Ireland is likely to experience more precipitation in autumn and winter (5 – 10%) and less precipitation in summer (5 – 10%). Between the periods of 1961 – 2000 and 2060 – 2099 this trend is likely to continue with increases of 15 – 20% generally, but up to 25% in the northern half of the country in autumn and drier summers of up to 10 – 18%.

The report seeks to further quantify the impact on hydrology in Ireland through the use of a HBV-Light conceptual rainfall run-off model (provided by Prof. Jan Seibert of Stockholm University) to simulate the effects of climate change on stream flow within the nine Irish catchments. The HBV-Light conceptual rainfall run-off model of the Suir catchment (HA16) was calibrated using historical meteorological data against the hydrometric gauge record at the Clonmel gauging station (16011). Validation of the model found that the Suir model was well calibrated when it came to simulating the seasonal cycle of mean monthly and mean winter flow with only slight over-estimation. However simulated annual maximum daily mean flow is overestimated. Risk outputs from the model can be considered to be over-estimated. The HBV-Light conceptual rainfall run-off model of the Barrow catchment (HA14) was calibrated using historical meteorological data against the hydrometric gauge record at the Royal Oak gauging station (14018). Validation of the model found that the Barrow model was not quite as well calibrated when it came to simulating the mean winter and summer flows. The flows were overestimated when compared against the observed historic data from the gauging station at Royal Oak and as such the risk outputs from the model can be considered to be overestimated. Following simulation of the meteorological climate change ensembles within the run-off models the following observations were made in both catchments for the changes between the periods (1961 – 2000) and (2021 – 2060):

- Reductions in mean daily summer flow of up to 60% and increases in mean winter flow of up to 20% within both catchments;
- The risk of extremely high winter flows is expected to almost double in the Suir. Mixed results were obtained for the Barrow where the flows associated with certain return periods in the past will have a greater return period in the future, which is explained by the effect of damped and even hydrographs resulting in a longer time scale to respond to changes in precipitation than faster responding catchments;
- No definite increase in annual maximum daily mean flow is expected in either the Suir or Barrow catchment.

7.1.2 Sea Level Rise

Research from c4i summarised in the aforementioned report states that sea levels around Ireland have been rising at an annual rate of 3.5mm per year for the period 1993 – 2003 which is higher than the longer term rate of 1.8mm per year for the period 1963 – 2003. This trend is likely to be reflected in the Southern Region with a 'net trend' (allowing for isostatic adjustment of the earth's crust) of 3.1-3.5mm per year; and more modest in the Irish Sea with a 'net trend' of 2.3 – 2.7mm per year. On top of this the report notes that storm surges are likely to increase in frequency.

7.2 AFFORESTATION

7.2.1 Afforestation in HA15

There is much legislation governing forestry practices in Ireland but it is implemented through the document 'Growing for the Future – A Strategic Plan for the Development of the Forestry Sector in Ireland' (Department for Agriculture, Food & Forestry, 1996). The plan points out that over the period from 1986 to 1996 afforestation saw quite a dramatic growth in Ireland from a level of approximately 70 km² annually to almost 240 km² annually in 1996 largely driven by a growth in private forestry activities. Within HA15 however the current forest coverage as recorded in the 2006 CORINE land maps for the hydrometric area / UoM is shown in Figure 7.1.

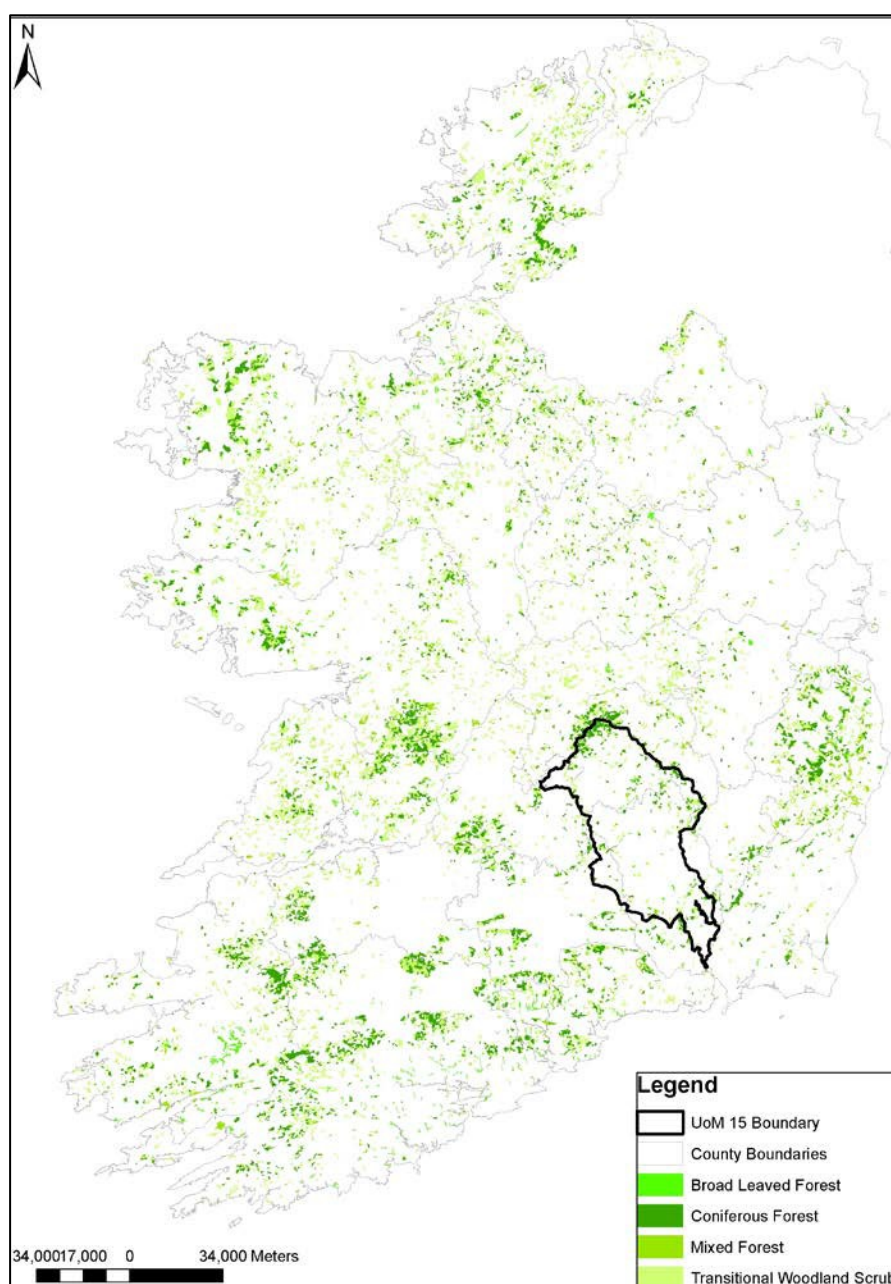


Figure 7.1: CORINE 2006 Forest Coverage in HA15 Compared to the rest of Ireland

The total forested area, including transitional woodland scrub, within HA15 is 308km² which is approximately 12% of the total area. The average for the country is approximately 10%. The densest coverage is at the northern tip of the UoM on the southern slopes of the Slieve Bloom Mountains. Comparison of the CORINE 2006 database to the 2000 database indicates that there has been some increase in the forested area as shown in Figure 7.2.

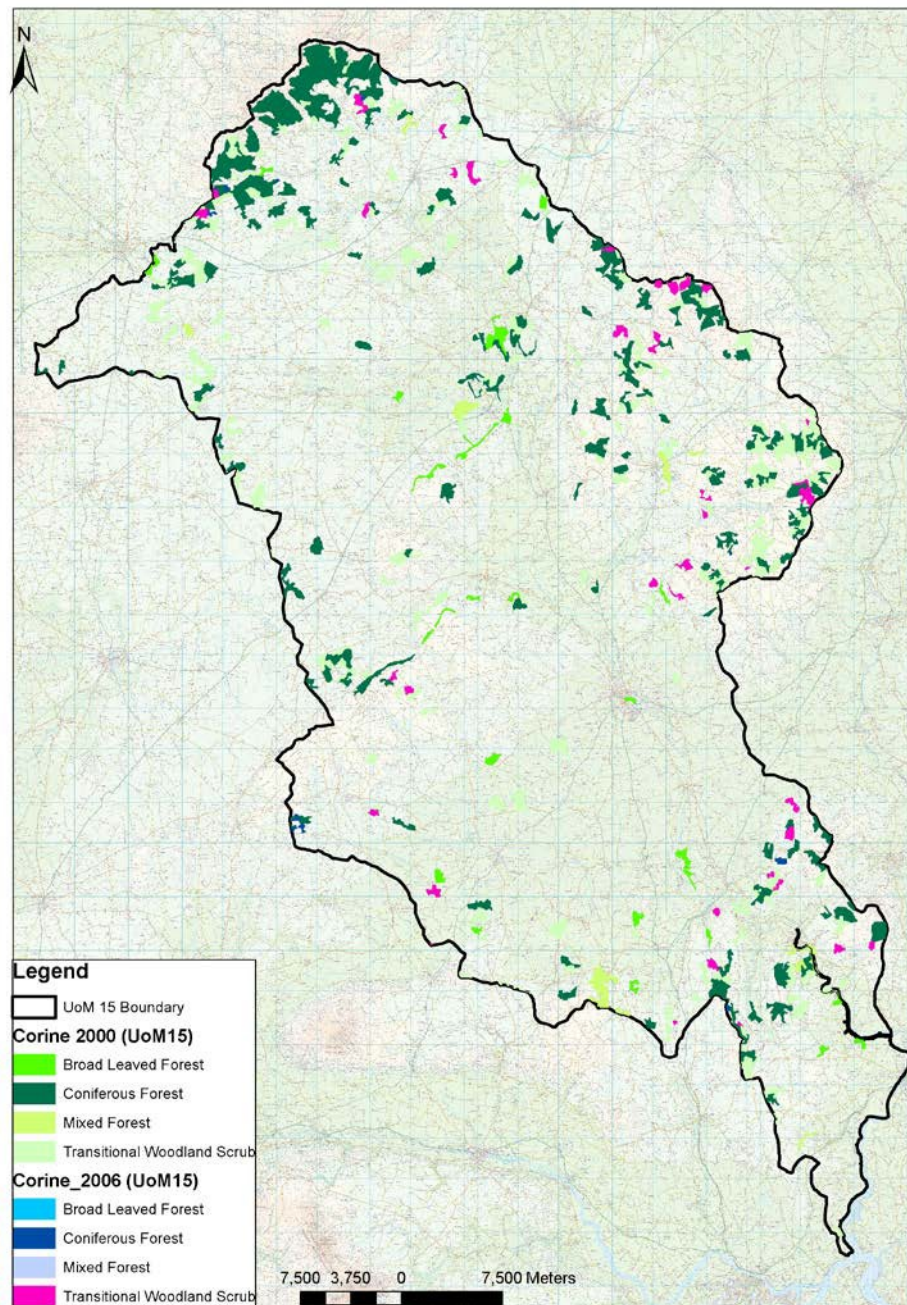


Figure 7.2: Forest Coverage Changes in HA15

As can be seen from Figure 7.2 there appears to be an increase in the amount of forested area overall but the increase has mostly been in transitional woodland scrub as opposed to actual forest. The areas of forest from the two periods of the CORINE 2006 database are broken down further in Table 7.1.

Table 7.1: Afforestation from 2000 to 2006

	CORINE 2000		CORINE 2006		Change		Annualised Change	
	Area (km ²)	% of catch.	Area (km ²)	% of catch.	Area (km ²)	% of catch.	Area (km ²)	% of catch.
Forest	172	6.6	164	6.3	-8.0	-0.3	-1.3	-0.05
Transitional Woodland Scrub	117	4.5	144	5.5	+27.0	+1.0	+4.5	+0.17
Total	289	11.1	308	11.9	+19.0	+0.7	+3.2	+0.12
Total Countrywide	6,631	9.4	7,087	10.1	456	+ 0.65	76	+0.11

From Table 7.1 it can be seen that total forest / woodland scrub has increased in HA15 between 2000 and 2006 but the actual forest coverage has dropped slightly. When considered together the total area of forest / woodland scrub as a proportion of the catchment is slightly higher than the national average of approximately 10%. The rate of increase between 2000 and 2006 is also slightly higher than the national average of + 0.11% per year. If the annualised increase in afforestation were to continue for the next 100 years it would more than double the forest coverage in HA15 from 308 km² (11.9%) to 628 km² (24.2%).

The strategic plan sets out a target for the increase of forest area to 11,890 km² by 2035 in order to achieve a critical mass for a successful high-value added pulp and paper processing industry and this is the main driver behind the increases in forested area. If this value is to be realised nationally the rates of forestation will need to double compared to the change observed between 2000 and 2006.

7.2.2 Impact on Hydrology

A number of studies have been carried out on a range of catchments in an attempt to capture the effects of afforestation on run-off rates and water yields. The DEFRA (UK) report 'Review of impacts of rural land use management on flood generation' (2004) considers a number of case studies where the effects of afforestation on the catchment run-off were considered. The report concluded that the effects of afforestation are complex and change over time. A summary of the main findings in relation to afforestation are given below in relation to the River Irthing catchment in the north of England:

- Water yield tends to be less from forest than pasture;
- In the Coalburn sub-catchment (1.5 km²) study peak flows were found to increase by 20% in the first 5 years and times to peak decreased, with the effect reducing over time (to 5% after 20 years). The time to peak was also reduced;

- In the overall River Irthing catchment (335 km²) the same effect was observed but to a much smaller degree.

The Coalburn catchment provides lessons which may be relevant to parts of HA15. The overall impact of afforestation is likely to be negligible in the greater Nore catchment considering the small proportion of forested land, and likely increase in proportion of forest coverage in the catchment. However the models receiving waters from upland areas may be susceptible to the potential effects of afforestation and as such some sensitivity analysis of the effects of afforestation would be prudent. As such it is recommended that sensitivity analysis to quantify the effects of potential afforestation is analysed at:

- Model 1 – Ballyragget (HEPs on upper reaches)
- Model 2 – Ballyroan
- Model 3 – Mountrath
- Model 7 – Thomastown (modelled tributaries)

In each of these models the effects of afforestation will be modelled using the following recommended adjustments to the input parameters:

Table 7.2: Allowances for Effects of Forestation / Afforestation (100 year time horizon)

Mid Range Future Scenario (MRFS)	High End Future Scenario (HEFS)
- 1/6 Tp ¹	- 1/3 Tp ¹ + 10% SPR ²

Note 1: Reduce the time to peak (Tp) by one sixth / one third: This allows for potential accelerated run-off that may arise as a result of drainage of afforested land

Note 2: Add 10% to the Standard Percentage Run-off (SPR) rate: This allows for increased run-off rates that may arise following felling of forestry

(Extracted from 'Assessment of Potential Future Scenarios for Flood Risk Management' OPW, 2009)

7.3 LAND USE AND URBANISATION

The proportion of people living in urban areas (classified as towns with a population of 1,500 or more) has increased dramatically in recent years with a nationwide increase of over 10% in the total urban population recorded between the 2006 census and the 2011 census. The total population within HA15 has increased by varying degrees since 1991 as demonstrated by Table 7.3.

Table 7.3: Population Growth in the Counties of HA15 (Source: Central Statistics Office of Ireland, CSO)

		1991	1996	2002	2006	2011
Carlow	Population (Number)	40,942	41,616	46,014	50,349	54,612
	Actual Change Since Previous Census (Number)	-46	674	4,398	4,335	4,263
	Population Change Since Previous Census (%)	-0.11	1.6	10.6	9.4	8.5
*Kilkenny	Population (Number)	73,635	75,336	80,339	87,558	95,419
	Actual Change Since Previous Census (Number)	449	1,701	5,003	7,219	7,861
	Population Change Since Previous Census (%)	0.61	2.3	6.6	9	9
*Laois	Population (Number)	52,314	52,945	58,774	67,059	80,559
	Actual Change Since Previous Census (Number)	-970	631	5,829	8,285	13,500
	Population Change Since Previous Census (%)	-1.8	1.2	11	14.1	20.1
Offaly	Population (Number)	58,494	59,117	63,663	70,868	76,867
	Actual Change Since Previous Census (Number)	-1,341	623	4,546	7,205	5,819
	Population Change Since Previous Census (%)	-2.24	1.1	7.7	11.3	8.2
North Tipperary	Population (Number)	57,854	58,021	61,010	66,023	70,332
	Actual Change Since Previous Census (Number)	-1,668	167	2,989	5,013	4,299
	Population Change Since Previous Census (%)	-2.8	0.3	5.2	8.2	6.5
South Tipperary	Population (Number)	74,918	75,514	79,121	83,221	88,432
	Actual Change Since Previous Census (Number)	-2,179	596	3,607	4,100	5,211
	Population Change Since Previous Census (%)	-2.8	0.8	4.8	5.2	6.3

*Counties containing AFAs are highlighted.

As Table 7.3 indicates, counties containing HA15 AFAs, Kilkenny and Laois have seen significant population rise since 1991. In particular Laois' population has risen by 10% or above for the last three record periods, with a rise of over 20% between 2006 and 2011.

No county showed an increase in the share of the rural population since 2006 and as such the data would suggest that the population growth within HA15 has been almost entirely within the urban centres.

Table 7.4 confirms that urban population growth within the urban AFAs (population > 1500) for the period 2006 – 2011 has been significant ranging from 10.1% in Kilkenny up to 31.6% in Callan over the five year census period.

Table 7.4: Population Growth within Urban AFAs (Source: CSO)

Urban Area	County	Population 2011	Increase Since 2006 (%)
Mountrath	Laois	1,661	15.7
Kilkenny	Kilkenny	24,423	10.1
Thomastown	Kilkenny	2,273	23.7
Callan	Kilkenny	2,330	31.6

The total percentage population growth in these AFAs however is 12.7% for the period 2006 – 2011 which equates to an average annual growth rate of approximately 2.4%. To determine if these changes translate into equivalent increases in urbanised areas we must examine the CORINE database within HA15 and the changes from 2000 to 2006. A simple comparison of the datasets within HA15 appears to show that there has been a modest increase in artificial surfaces within HA15 from 33 km² in 2000 to 36 km² in 2006 which represents an increase of just over 9% in six years (see Figure 7.3).

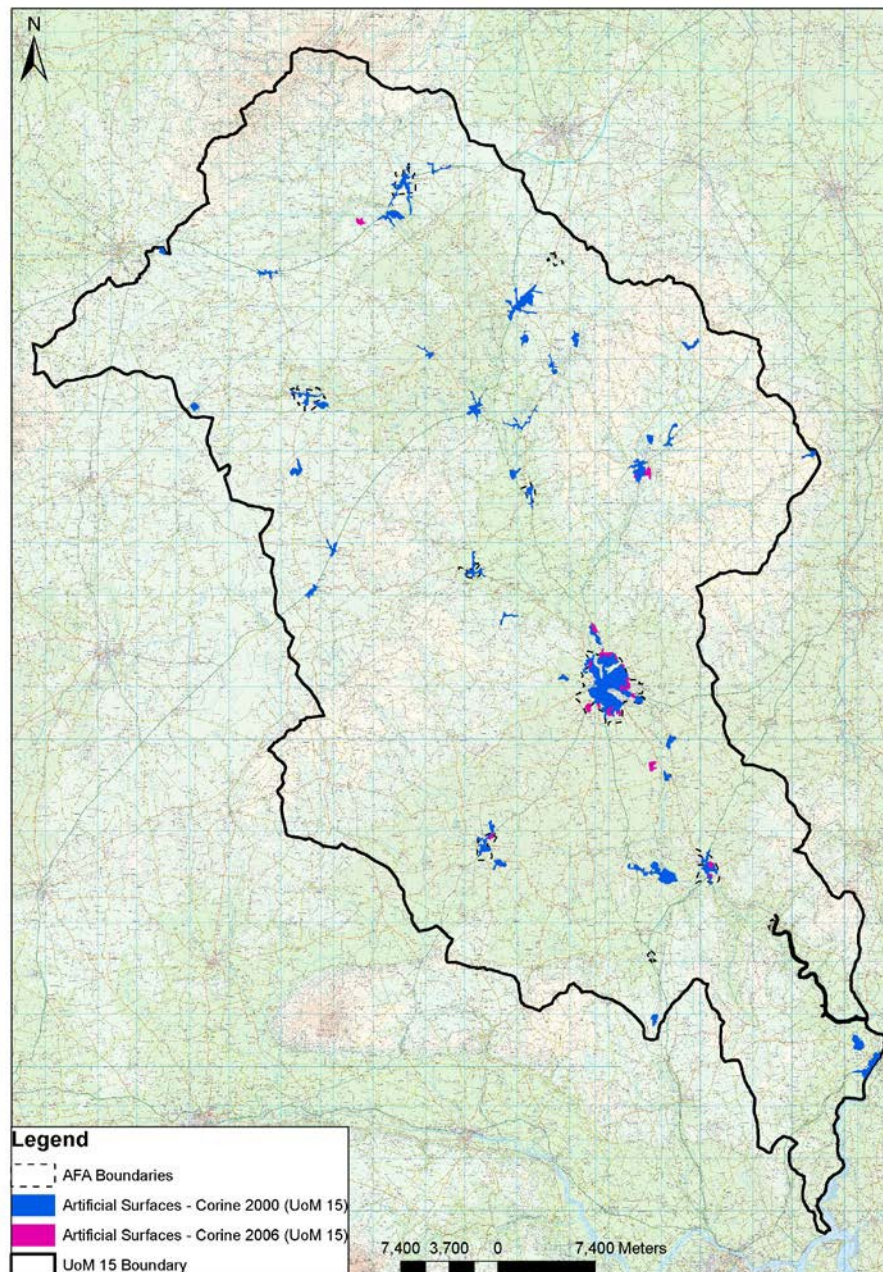


Figure 7.3: HA15 CORINE Artificial Surfaces (2000 /2006)

Closer inspection of the CORINE datasets shows that a notable proportion of this growth in artificial surfaces is due to changes outside the urban areas. There are 0.8 km² of additional quarries within HA15 which accounts for 27% of the additional artificial surfaces. Although these surfaces are generally impermeable and increase run-off they will not affect the AFAs directly and as such for a more representative picture of the increase in urbanisation, the areas of hardstanding within the AFA extents were compared. The only AFAs with an increase in the extent of artificial surfaces are:

- Kilkenny 17.6% increase (2.7% annually)
- Thomastown 21% increase (3.2% annually)
- Callan 11% increase (1.8% annually)

The annual growth rate in the artificial surfaces within all HA15 AFA extents is 1.4%.

The CSO has also produced Regional Population Predictions for the period of 2011 - 2026 based on a number of scenarios considering birth rates and emigration. Under all the modelled scenarios the South East region is set to experience strong population growth.

Under the M0F1 Traditional model, which tends to reflect longer term growth trends, the projected rise for the region in the 15 year period equals 8.6% equating to an average annual growth rate of 0.6%. Under the M2F1 Recent model, which tends to reflect more recent growth rates, the projected rise in population is 27% equating to an annual average growth rate of 1.8%. Any estimation of the rate of urbanisation should consider the three measures of recent growth which have been examined along with the projected population increases from the CSO for the region. These are summarised in Table 7.5 below.

Table 7.5: Historic Urbanisation Growth Indicators

	Population in HA15 AFA Counties 1991 - 2011	Population in HA15 Urban AFAs 2006 – 2011	Artificial Surfaces (CORINE) within HA15 AFA Extent 2000 - 2006	CSO M0F1 Population Projection 2011 - 2016	CSO M2F1 Population Projection 2011 - 2016
Average Annual Growth Rate (%)	1.4%	2.5%	2.1%	0.6%	1.8%

It is clear from the data and projections available that future urbanisation growth rates in HA15 are likely to be around 1% per annum. At the high end of projections a rate of approximately 3% appears realistic for HA15. Continuation of these growth rates for 100 years, the period to be considered for the CFRAM Study future scenario, would lead to the Nore catchment area becoming 10% and 16% urbanised respectively.

7.3.1 Impact of Urbanisation on Hydrology

The effect of urbanisation on run-off is well documented. The transformation from natural surfaces to artificial surfaces, which in almost all cases are less permeable, increases surface run-off such that it is generally faster and more intense. If we consider the FSU 'URBEXT' catchment descriptor at the most downstream hydrometric gauge in the catchment (Brownsbarn) currently at 0.88 which represents the percentage of urbanisation within the Nore catchment, the URBEXT could potentially rise to between 10.1% urbanised (based on growth of 2% per annum) and 16.4% urbanised (based on growth of 2.5% per annum). Based on the FSU equation (WP 2.3) for index flow estimation (Q_{med}) using catchment descriptors the Urban Adjustment Factor (UAF) for the Nore catchment would vary as follows for the 100 year high end (HEFS) and mid range (MRFS) future scenarios:

Table 7.6: Potential Effect of Urbanisation on Qmed Flow in HA15

	Growth Rate	URBEXT ²	UAFS ¹	Total Catchment Q _{med} Flow m ³ /s
Present Day	n.a.	0.88	1.013	299.30
100 Year MRFS	2.0% p.a.	10.05	1.152	340.49
100 Year HEFS	2.5% p.a.	16.39	1.252	369.96

Note 1: Urban Adjustment Factor $(UAF) = (1 + URBEXT/100)^{1.482}$

Note 2: URBEXT is the percentage of urbanisation in the catchment

The effect of the likely significant urbanisation on the index flood flow in Nore main channel at the gauging station 15006 (Brownsbarn) is shown in Table 7.6. It can be seen that the effect of urbanisation on the total catchment could be to increase the flood flow by approximately 24%. These figures will be applied to the HA15 hydraulic models.

The upper limit of the urbanisation estimates does not however reflect the potential for total urbanisation around the small tributary catchments affecting AFAs with higher rates of urbanisation and the localised impact on these tributaries as a result. For example, Kilkenny and Thomastown experienced rates of 3% and 3.5% annual growth in urban extent between 2000 and 2006. If 3.5% p.a. growth were to be taken as the 100 year HEFS across the entire catchment, the resulting urban extent would be 43% with a Q_{med} flow of 503 m³/s - an increase of 68% from present day. This value has not been selected as the 100 year HEFS as it is not considered representative of projected urban growth across HA15 based on Table 7.6. However, such localised projections affecting small tributary catchments of AFAs must be considered on a case by case basis, taking into account planning policies such as Kilkenny's designation as a development hub in the National Spatial Strategy 2002 - 2020.

The allowances for urbanisation are based on a robust analysis of population growth, recent increases in artificial surfaces and population projections from CSO. However this is based on extrapolation of current growth rates which are dependent on complex social, economic and environmental factors. Furthermore the estimation of the Urban Adjustment Factor under FSU is based on data from existing urban catchments and therefore does not reflect the impact of recent policy changes and changes to drainage design guidelines where the emphasis is on developments replicating the existing 'greenfield' flow regime through attenuation and sustainable urban drainage systems. The adoption of these growth factors on top of high end scenarios for climate change could lead to flood flows and extents which have an extremely low joint probability.

7.4 HYDROGEOMORPHOLOGY

Hydrogeomorphology refers to the interacting hydrological, geological and surface processes which occur within a watercourse and its floodplain. Erosion and deposition of sediment are natural river processes that can be exacerbated by anthropogenic pressures such as land use practices and arterial drainage.

7.4.1 Channel Typology

As part of national Water Framework Directive studies on hydromorphology through River Basin District projects a national channel typology dataset was defined for Irish rivers³. It classified river channels into channel type at 100m node points along each reach. It is based on four key descriptors which categorise rivers according to channel type. Table 7.7 below outlines the four main channel types and how these relate to valley confinement, sinuosity, channel slope and geology.

Table 7.7: Channel Types and Associated Descriptors

Channel Type	Confinement	Sinuosity	Slope	Geology
StepPool / Cascade	High	Low	High	Solid
Bedrock	High	Low	Variable	Solid
Riffle & Pool	Low - Moderate	Moderate	Moderate	Drift / Alluvium
Lowland Meander	Low	High	Low	Drift / Alluvium

Typical undisturbed channel behaviour in terms of flow is described as follows for each of the channel types shown.

Bedrock:

Boulders and cobbles often exposed, but few isolated pools

Overbank flows uncommon. Morphology only changes in very large floods.

Cascade and step-pool:

At low flows, many of the largest particles (boulders, cobbles) may be exposed, but there should be continuous flow with few isolated pools

Pool-riffle:

Gravel bars may be exposed in low water conditions, but gravels and cobbles in riffles as well as logs and snags are mainly submerged.

³ (http://www.wfdireland.ie/docs/20_FreshwaterMorphology/CompassInformatics_MorphologyReport)

Lowland Meandering:

In low flow conditions some bars or islands may be exposed, but water fills the majority of the channel.

In the national context, the Nore is a relatively low slope, low energy meandering system. There are pockets of higher slope, pool riffle type channels flowing from the Slieve Bloom and Slieve Ardagh Mountains and the River Dinin catchment as indicated by Figure 7.4 and 7.5.

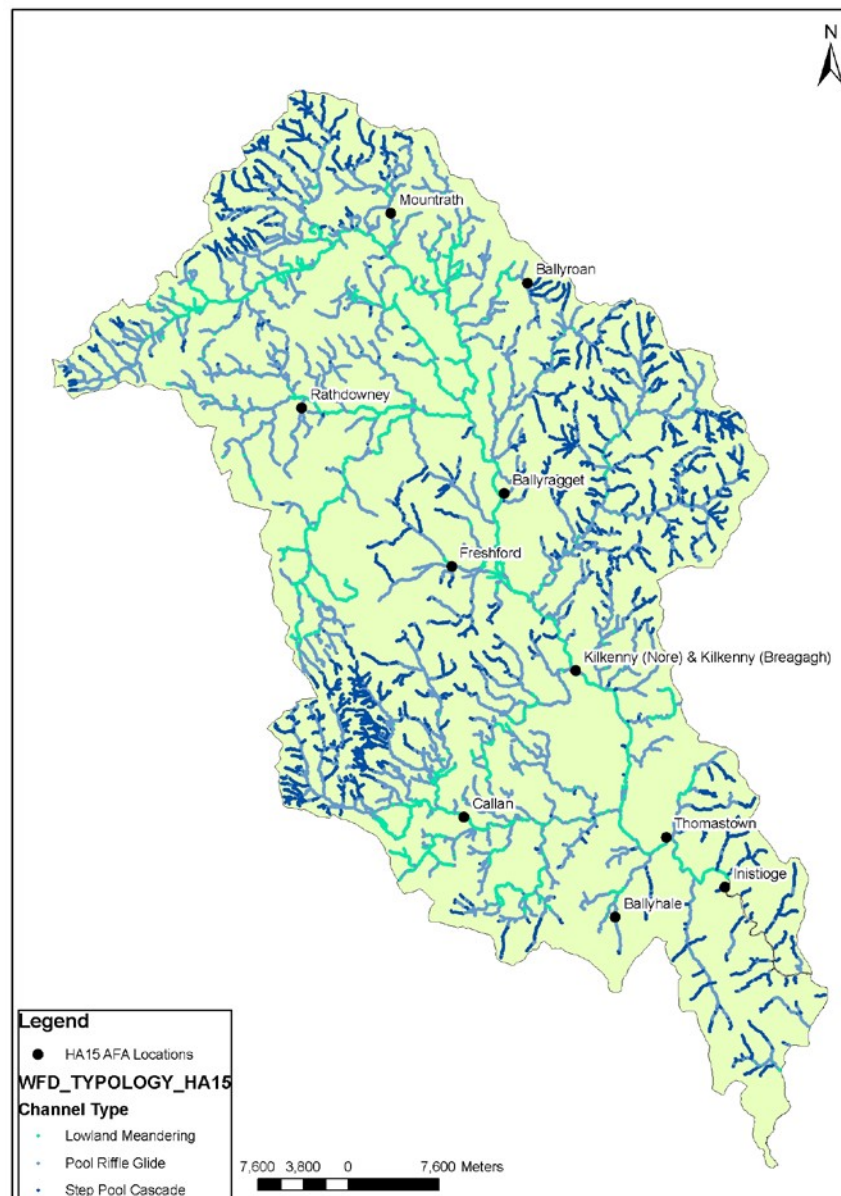


Figure 7.4: WFD Channel Typology HA15

As indicated by Figure 7.4, the Nore main channel is classified as lowland meandering for all modelled reaches from Borris in Ossory to Inistioge. Modelled tributaries of the River Nore are predominantly pool riffle glide with the exception of the Erkina River at Rathdowney which is also lowland meandering. The River Dinin is a significant tributary of the Nore, upstream of Kilkenny AFA. This river

is a high energy system reflected by its predominance of step pool cascade and pool riffle channels over the entire upland catchment.

These channel types also represent the change in channel slope from relatively steep to relatively shallow moving downstream. Figure 7.5 indicates the change in channel steepness across the catchment. It can be seen that the steepest channels are in the upper reaches to the north of the catchment (Slieve Bloom Mountains) to a maximum of 0.304 (in other words to 1 in 3). The headwaters of the Kings River in the Slieve Ardagh Mountains range have a maximum slope of approximately 0.07 (1 in 14), as do the tributaries of the River Dinin to the east of the catchment.

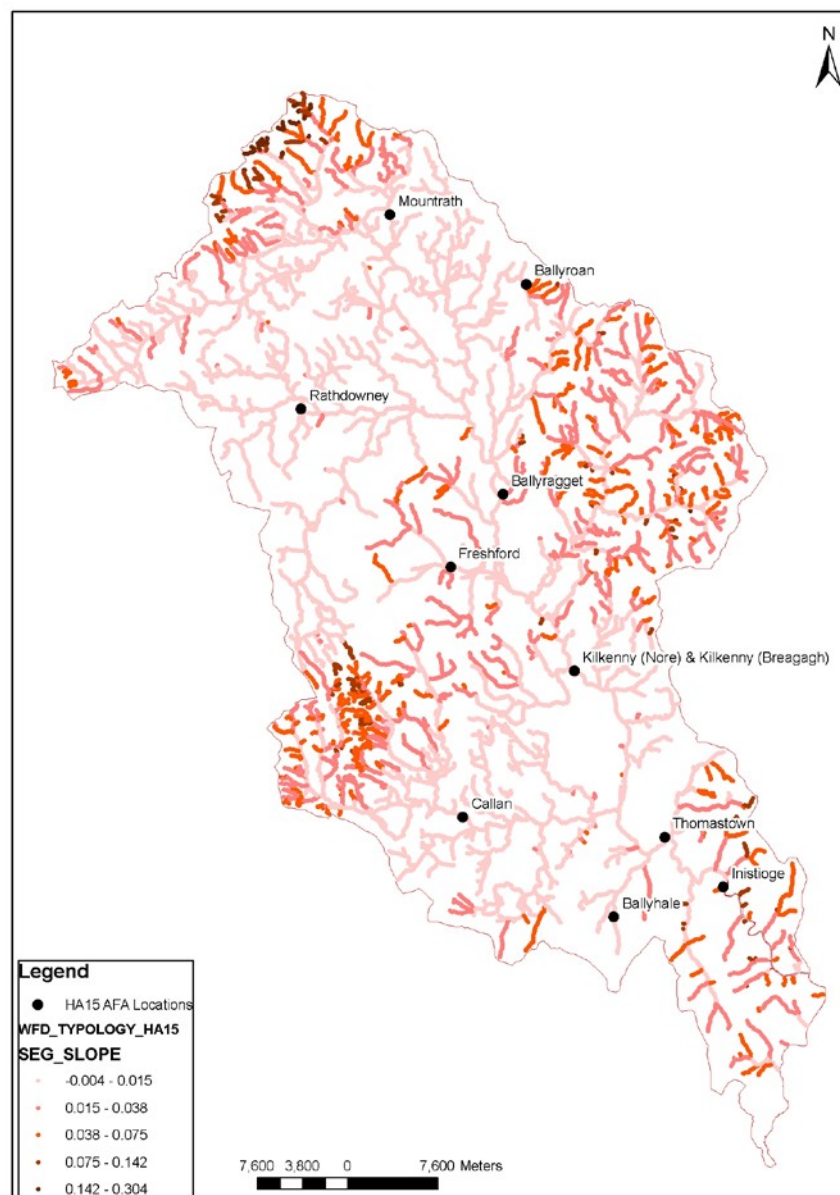


Figure 7.5: Changes in Channel Slope HA15

These channel types are typical of Irish catchments. Sediment transport, erosion and deposition are natural morphological processes. It is expected that the upper reaches will be more dynamic and as the river moves to the lower lands, sediment is accumulated and transported. Sediment deposition is

expected where the channel meanders and loses energy. Based on Figure 7.4 and Figure 7.5 the AFAs that could be affected by sediment deposition are:

- Mountrath
- Callan
- Kilkenny

This only becomes an issue if too much sediment is transported from the upper reaches and deposited causing channel capacity issues or localised damage to flood defence structures from scour.

7.4.2 Land Use

Figure 7.6 illustrates the land use types within HA15. It is essentially a rural catchment typified by pasture (72% of the catchment area), and non-irrigated arable land (11%). There are pockets of peat bog, forestry (as discussed in Section 7.2) in upland areas. The predominance of pasture over arable land suggests that in general, the level of exposed soil is limited within the catchment and therefore sediment loss to the watercourses will be limited.

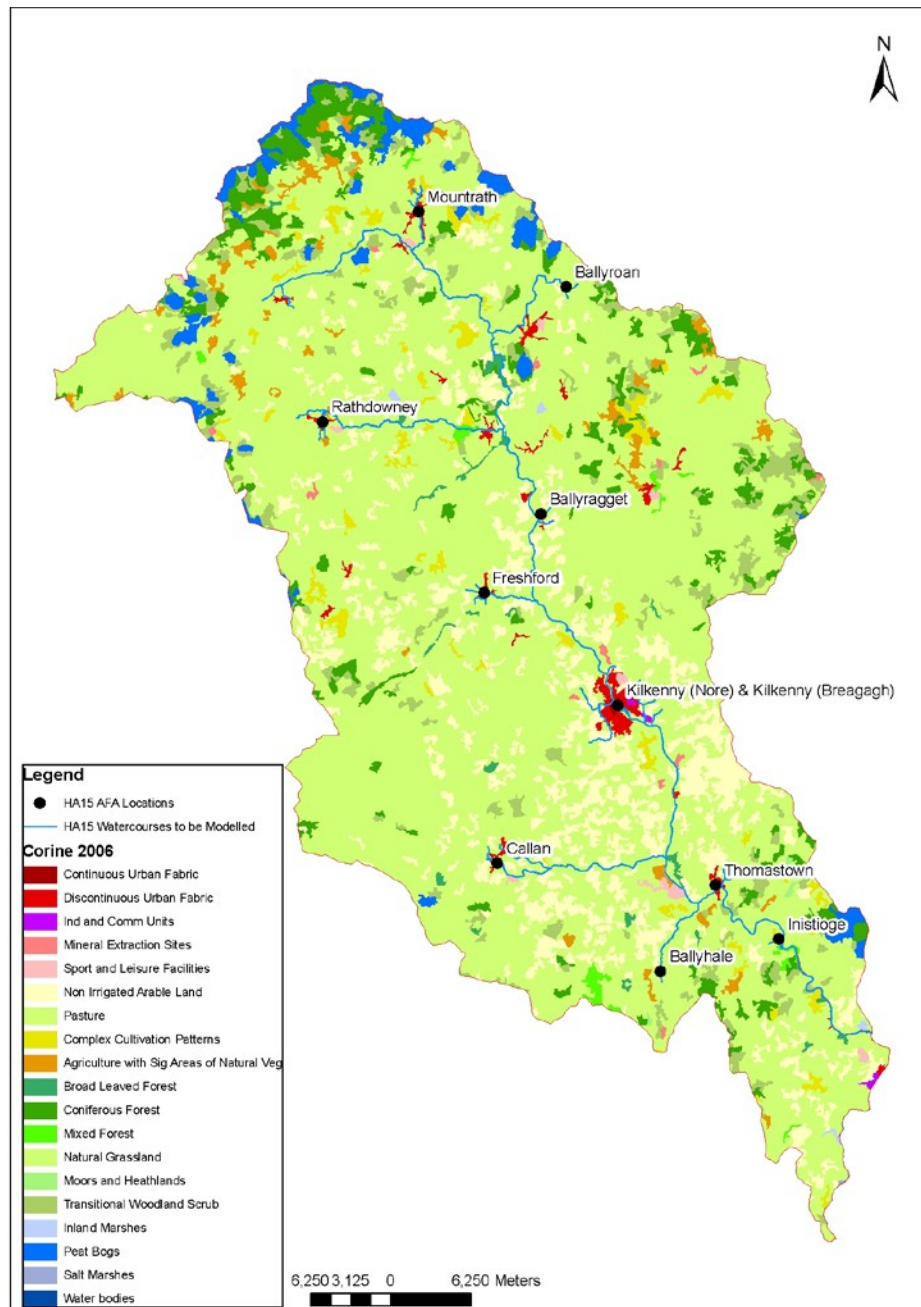


Figure 7.6: HA15 Land Use (CORINE 2006)

A sediment study on the River Nore has recently been undertaken by the Environmental Protection Agency (Walsh et al, 2012) with one of the key aims being to measure silt accumulation along the River during base flow conditions. Whilst this study was primarily focussed on freshwater pearl mussel preservation, fisheries and water quality the results are of interest from a siltation point of view in flood risk management. Sediment traps were employed at Kilbricken and Ballyragget for a four week period and estimated mean sediment rates of $8.73\text{g/m}^2/\text{day}$ and $8.83\text{g/m}^2/\text{day}$ recorded respectively. Suspended solid results for the River Nore from January to March 2012 showed a mean concentration of 8mg/l which was stated as being well below the standard of 25mg/l in the Freshwater Fish Directive and Irish Salmonid Regulations suggesting that siltation is not an issue in the River Nore.

The River Dinin is a significant tributary of the Nore, upstream of Kilkenny. It is a high energy system with high bank erosion due to the physical and geological nature of the river catchment in conjunction with socio-economic practices (Nore Suir Rivers Trust, 2012). The transportation of sediment and subsequent deposition within the Kilkenny City AFA is identified for further consideration under hydraulic modelling.

The impact of hydro-geomorphological changes on the Nore system ultimately applies to the performance of flood risk management options. The impact of sediment transport and deposition within the AFAs highlighted here will be considered further under the hydraulic modelling of options stage of the CFRAM Study.

7.4.3 Arterial Drainage

A further consideration in HA15 is the potential effect of arterial drainage on watercourse channel and floodplain geo-morphology. The original Arterial Drainage Act, 1945 was a result of the Browne Commission which examined the issue of flooding and the improvement of land through drainage works and was mainly focussed on the agricultural context. Following flood events in the mid to late 80s the emphasis on flood management shifted to the protection of urban areas and as such the Arterial Drainage Amendment Act was passed in 1995. This widened the scope of the act to cover the provision of localised flood relief schemes. The OPW have used the Arterial Drainage Acts to implement various catchment wide drainage and flood relief schemes. Arterial drainage scheme works may consist of dredging of the existing watercourse channels, installation of field drains / drainage ditches and the construction of earthen embankments using dredged material to protect agricultural land.

The extent of the watercourses affected by arterial drainage within HA 15 is captured in the FSU physical catchment descriptors defined under FSU Work Package 5.3. The catchment descriptor nodes which have a length of arterial drainage defined within the catchment are shown in Figure 7.7. As indicated, the only reach affected is that downstream of Kilkenny Flood Relief Scheme.

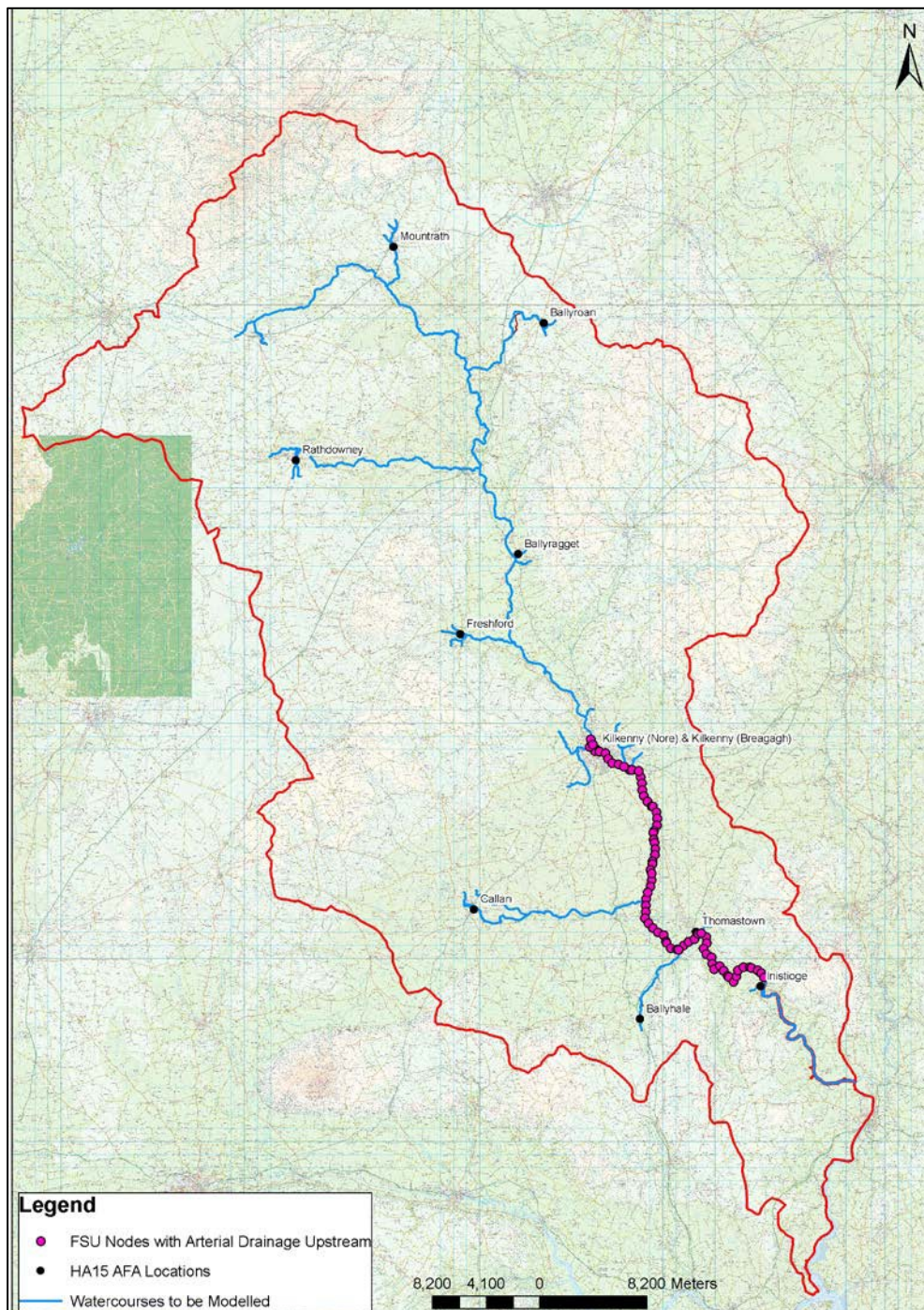


Figure 7.7: Watercourses affected by arterial drainage in HA15

Historical channelisation was undertaken in the Borris in Ossory, Gully, Erkina and Goul Drainage Districts prior to the original Arterial Drainage Act in 1945. However they no longer have an impact as they are not within OPW's remit to undertake maintenance and will have as such returned to a naturalised state. Therefore in terms of exacerbating sediment load within the Nore system, this historical drainage is not a consideration.

7.4.3.1 The Impact of Arterial Drainage Scheme on HA15 Hydrology

The effect of arterial drainage within HA15 is limited to the River Nore downstream of Kilkenny due to the Flood Relief Scheme which was completed in 2005. This consisted of a combination of river widening and deepening, flood walls, embankments, and associated drainage works. In the short term, sediment loss to the river during the works would have been mitigated through environmental management measures. The long term effect of the scheme is to increase channel conveyance capacity.

The effect of arterial drainage schemes across Ireland was considered in FSU WP 2.3 Flood Estimation in Ungauged Catchments through the analysis of gauging station records where there was a pre and post arterial drainage scheme record. Analysis of the gauge station record showed a wide degree of variance in the pre and post arterial drainage index flood flow (Q_{med}) values but the average change was to increase the Q_{med} value by approximately 50%⁴. This is in line with previous research carried out on Irish catchments which suggested that arterial drainage schemes can lead to significant changes in peak discharge of up to 60% (Bailey and Bree 1981).

In the case of Kilkenny Flood Relief Scheme, post drainage data is only from 2006 and as such there is not a long record for robust statistical analysis. However the pre drainage and post drainage Q_{med} values at hydrometric stations 15002 and 15006 have been compared as shown in Table 7.8. Station 15002 is at Johns Bridge in Kilkenny City and Station 15006 is at Brownsbarn at the downstream end of the Nore catchment, 3.5km upstream of Inistioge.

Table 7.8: Q_{med} values at Hydrometric Stations pre and post Kilkenny Flood Relief Scheme

Station	Name	Q_{med} pre-scheme (1953 to 2002) m^3/s	Q_{med} post scheme (2006 to 2009) m^3/s	Factorial Difference
15002	Johns Bridge	216	278	1.29
15011	Mount Juliet	271	359	1.32
15006	Brownsbarn	289	345	1.19

Table 7.8 indicates an increase in the Q_{med} since the completion of the drainage works although caution is exercised with these values given their extrapolation above reliable limits. The long term effect on Q_{med} is not yet known.

The hydrological analysis and design flow estimation undertaken as part of this study seek to represent as accurately as possible the present day scenario. The ARTDRAIN2 FSU catchment descriptor is included in the ungauged index flow estimation equation where applicable. All of the catchment rainfall run-off models have been generated using the CORINE 2006 database and GSI datasets and have been calibrated against post scheme continuous flow data where available. As

⁴ Extracted from Table 13 of FSU Work Package 2.3

such the hydrological inputs derived so far for modelling are considered to accurately reflect the effect of arterial drainage and should represent the best estimates of the present day scenario.

7.4.4 River Continuity

River continuity is primarily an environmental concept relating to the linear nature of the river eco system and its disruption due to man made structures such as weirs and dams which alter river flow and can impede fish migration. It is a morphological pressure which has been given consideration under the Water Framework Directive. Any collated data is of use from a flood risk management perspective as it provides information on such structures and as such can be accounted for in terms of flow regulation in hydraulic modelling.

In 2008, the Southern Regional Fisheries Board (now Inland Fisheries) conducted a walkover survey of the Nore catchment to record and visually assess all channel structures in terms of their risk as barriers to fish migration. As indicated by Figure 7.8, 92 structures including bridges, culverts and weirs were recorded.

The risk of impassability may also be an indication of significant hydraulic control and as such is useful in hydraulic modelling. The visual risk assessment designated 20 out of 92 recorded structures as impassable or high risk in terms of fish migration. These include weirs at Mountrath, Rathdowney, Kilkenny City and Callan; culverts within Kilkenny City; and bridges at Rathdowney, Freshford, Ballyhale and Inistioge. The channel and structure survey undertaken specifically for the South Eastern CFRAM Study includes full geometric survey of these structures and as such ensures their inclusion in the hydraulic modelling phase.

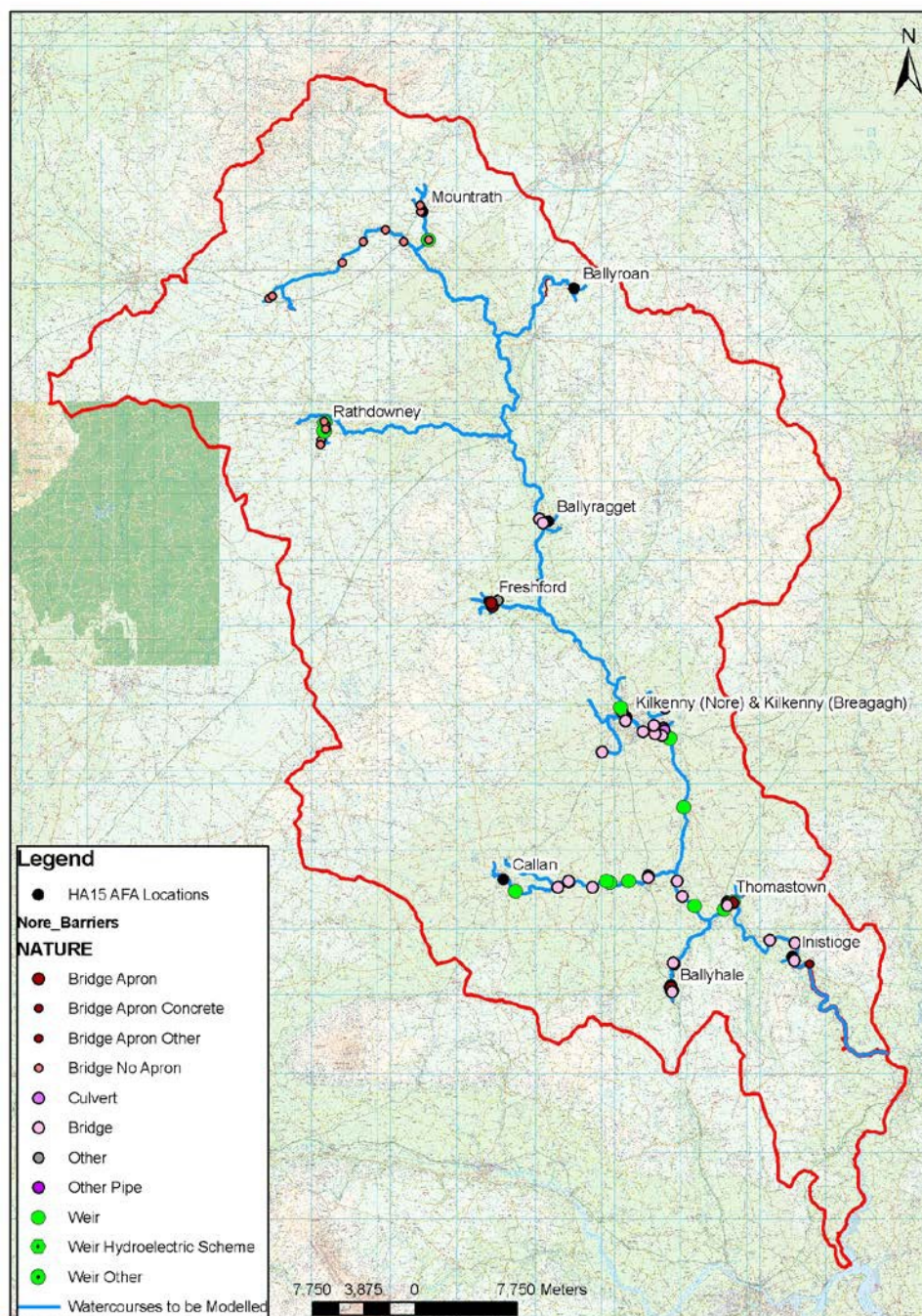


Figure 7.8: Nore Channel Structures (Southern Regional Fisheries Board, 2008)

7.5 FUTURE SCENARIOS FOR FLOOD RISK MANAGEMENT

OPW does not have a specific policy for the design of flood relief schemes but has produced a draft guidance note 'Assessment of Potential Future Scenarios for Flood Risk Management' (OPW, 2009). The document gives guidance on the allowances for future scenarios based on climate change (including allowing for the isostatic movement of the earth's crust), urbanisation and afforestation. Table 1 from the guidance has been adapted for the purposes of this study to take into account catchment specific effects and is presented here as the basis (Table 7.9) for the design flow adjustment for the mid range (MRFS) and high end (HEFS) future scenarios.

Table 7.9: HA15 Allowances for Future Scenarios (100 year time horizon)

	MRFS	HEFS
Extreme Rainfall Depths	+ 20%	+ 30%
Flood Flows	+ 20%	+ 30%
Mean Sea Level Rise	+ 500mm	+ 1000mm
Urbanisation	UAF ³ of 1.15 Urban W.C. UAF ⁴ of 1.25	UAF ³ of 1.25 Urban W.C. UAF ⁴ of 1.7
Afforestation	- 1/6 Tp ¹	- 1/3 Tp ¹ + 10% SPR ²

Note 1: Reduce the time to peak (Tp) by one sixth / one third: This allows for potential accelerated run-off that may arise as a result of drainage of afforested land

Note 2: Add 10% to the Standard Percentage Run-off (SPR) rate: This allows for increased run-off rates that may arise following felling of forestry

Note 3: UAF (Urban Adjustment Factor) to be applied to 'greenfield' flow estimates.

Note 4: UAF (Urban Adjustment Factor) for small urban tributaries within AFA extents. To be assessed on a case by case basis.

Policy to Aid Flood Reduction

Considering the projected growth in population predicted within HA15 the main future change which could increase flood risk is urbanisation of the catchment. If not managed correctly rapid urbanisation could lead to large swathes of the catchment becoming hard paved and drained through conventional drainage systems which are designed to remove water from the urban area quickly and efficiently. This could have potentially significant implications for fluvial flooding as the flood flows in the watercourses and rivers would intensify. Some of the smaller watercourses in particular could become prone to flash flooding if they become urbanised.

Sustainable Urban Drainage (SuDS) policy has been about for over a decade now in the UK and Ireland. The term covers a range of practices and design options that aim to replicate the pre-development surface water run-off characteristics of the undeveloped catchment following development both in terms of water quality but more importantly, from the perspective of flood risk management, in terms of run-off peak flow, intensity and volume. Typical measures include soft engineered solutions such as filter strips, swales, ponds and wetlands and hard engineered solutions such as permeable paving, 'grey water' recycling, underground storage and flow control devices. The implementation of successful SuDS requires a joined up policy that covers planning, design, construction and maintenance. One of the biggest issues surrounding SuDS implementation is long term ownership and maintenance although the long term benefits of SuDS can be shown to outweigh the costs associated with these issues.

If a comprehensive SuDS policy is implemented covering planning, implementation and maintenance, then the impacts of urbanisation on flood flows can be substantially mitigated.

8 SENSITIVITY AND UNCERTAINTY

Hydrological analysis and design flow estimation are probabilistic assessments which originate from observed data. The long term conditions which affect the observations, whether they are climatic or catchment, have been shown to varying degrees to be changing over time. Further to this the degree of uncertainty within the sub-catchments analysed under the South Eastern CFRAM Study varies greatly due to the quality and availability of observed data. The factors which may affect the quality of both the analysed historic events and the estimation of the future design events are listed below:

- Hydrometric data record length and gaps
- Hydrometric data quality (classified in terms of the rating confidence under FSU WP 2.1)
- High quality meteorological data availability
- Calibration quality of hydrological models (generally a result of all of the above)
- Standard error of flow estimation (catchment descriptor based) techniques
- Future catchment changes, urbanisation, afforestation etc.
- Climate change

The above list is not exhaustive but seeks to identify the main potential sources of uncertainty in the hydrological analysis. Further to these the list of factors which could potentially affect the uncertainty and sensitivity of the assessment of flood risk under the South Eastern CFRAM Study is subject to additional uncertainties and sensitivities related to the hydraulic modelling and mapping stages. Examples of some of the modelling considerations which will further affect the sensitivity / uncertainty of the CFRAM Study outputs going forward from the hydrological analysis are past and future culvert blockage and survey error (amongst others). These considerations will be considered through the hydraulic modelling and mapping report along with the hydrological considerations listed here to build a complete picture of uncertainty / sensitivity of Study outputs.

It is not possible to make a quantitative assessment of all of the uncertainties as some of the factors are extremely complex. Nevertheless it is important that an assessment is made such that the results can be taken forward and built upon through the subsequent phases of the study. It is also important that the potential sources of uncertainty in the hydrological analysis and design flow estimation are flagged such that the integrated process of refining the hydrological inputs and achieving model calibration can be achieved more efficiently through a targeted approach. A qualitative assessment has therefore been undertaken to assess the potential for uncertainty / sensitivity for each of the models and is provided in this chapter. The assessed risk of uncertainty is to be built upon as the study progresses through the hydraulic modelling and mapping stages. Following completion of the present day and future scenario models the assessed cumulative uncertainties can be rationalised into a sensitivity / uncertainty factor for each scenario such that a series of hydraulic model runs can be performed which will inform the margin of error on the flood extent maps.

8.1 UNCERTAINTY / SENSITIVITY ASSESSMENT MODEL BY MODEL

Table 8.1: Assessment of contributing factors and cumulative effect of uncertainty / sensitivity in the hydrological analysis

Model No.	Model Name	Uncertainty / Sensitivity – Present Day Scenario				Uncertainty / Sensitivity – Future Scenarios			Notes
		Observed Flow Data ¹	Simulated Flow Data ²	Catchment Data ³	Ungauged Flow Estimates ⁴	Forest-ation ⁵	Urban-isation ⁶	Climate Change ⁷	
1	Ballyragget	High/Medium	Medium	Low	Medium	Medium/Low	Medium	Medium	Four gauging stations on main channel but uncertainty associated with Qmed values – decrease moving downstream. NAM models bring some certainty by resolving this issue. Modelled tribs ungauged. Uncertainty with afforestation as a future change, limited to upper reaches of the model only.
2	Ballyroan	-	-	Low	High/Medium	Medium	Medium	Medium	Ungauged catchment. Forestry at headwaters of catchment.
3	Mountrath	-	-	Low	High/Medium	Medium	Medium	Medium	Ungauged catchment. Forestry at headwaters of catchment,
4	Freshford	-	-	Low	High/Medium	Low	Medium	Medium	Ungauged catchment.
5	Kilkenny (Nore) & Kilkenny (Breaghagh)	Medium	Medium/Low	Medium	Medium/Low	Low	High/Medium	Medium	Two gauges – one on Breaghagh (C), one on Nore (A2 with > 50 years data), Rainfall runoff model conducted for Breaghagh gauge and good calibration achieved to increase certainty. Modelled tribs ungauged.
6	Callan	Medium/Low	Medium	Low	Medium	Low	Medium	Medium	Two gauges available (B and A2 classifications). >50 years of data. 15009 (B) for rating review, rainfall runoff model conducted using pre-rating review Q data 2007 to 2010. Good calibration achieved but on a relatively short period of time.
7	Thomastown	Medium	Medium	Medium	Medium	Medium/Low	High/Medium	Medium	Two gauges on main channel (C and A2 with > 30 years data). Rainfall runoff model for C gauge improved certainty. Good calibration against medium to low flows, but radar data not available for input, nearby hourly gauges used. Modelled

Model No.	Model Name	Uncertainty / Sensitivity – Present Day Scenario				Uncertainty / Sensitivity – Future Scenarios			Notes
		Observed Flow Data ¹	Simulated Flow Data ²	Catchment Data ³	Ungauged Flow Estimates ⁴	Forest-ation ⁵	Urban-isation ⁶	Climate Change ⁷	
									tribs ungauged.
8	Ballyhale	-	-	Low	High/Medium	Low	Medium	Medium	Ungauged catchment
9	Inistioge	Medium/Low	-	Low	Medium/Low	Low	Medium	Medium	Good A2 gauge at upstream end of the model (15006 > 30 years data) which has been used for index flow adjustment in the model but no data at downstream end.
	Rathdowney	Medium/Low	-	Low	Medium/Low	Low	Medium	Medium	Good gauge at downstream end of model (A1/B> 50 years of data). Modelled tribs within AFA are ungauged.

¹ Observed flow data left dashed where there is no gauged data to inform the flood flow estimation for the model.

² Simulated data refers to data output from rainfall run-off models. This has not been possible on totally ungauged catchments, and not undertaken where there is already good confidence in the gauge.

³ Catchment data refers to delineated catchment extents or catchment descriptors. May have been subject to change since FSU due to urbanisation, afforestation, arterial drainage scheme.

⁴ Ungauged flow estimates based on FSU WP 2.3. Dependent on 1, 2 & 3 above. Where high quality gauge data is available along modelled reach upon which adjustment can be performed then uncertainty is considered low. Where no gauge data is available within catchment then certainty is considered medium to high. Uncertainty greater in smaller, urbanised catchments where ungauged estimation methodologies are considered to be more sensitive.

⁵ See Section 8.2 Considered to be low risk of uncertainty to hydrological analysis in HA15 with the exception of Ballyragget (upper reaches only); Ballyroan, Mountrath, Thomastown (HPW tribs in AFA)

⁶ See Section 8.3 Considered generally to be a medium risk of uncertainty to hydrological analysis with higher risk in Kilkenny and Thomastown.

⁷ See Section 8.1 Considered a medium risk of uncertainty to hydrological analysis in all cases due to the large range of projections.

8.2 CONCLUSIONS OF SENSITIVITY ANALYSIS

The assessment of uncertainty and sensitivity in each category is relative within HA15. The assessment of uncertainty as being medium or high does not suggest that the analysis is poor but rather in the context of the full suite of design flow estimation techniques being employed in the South Eastern CFRAM Study that uncertainty in that category is towards the higher end of the range. For example the modelled watercourses which affect the Ballyroan AFA are small ungauged and mainly rural but are well defined in terms of catchment data. However the ungauged flow estimates have been designated as having a medium to high uncertainty as the FSU ungauged catchment index flow estimate has been adjustment using a gauge on the Nore main channel as opposed to within the catchment itself since there are none available. The ungauged estimates have therefore been labelled as having a medium to high degree of uncertainty yet the procedure for estimating and adjusting is in line with best practice and would be consistent with the recommended estimation methodology for a typical ungauged rural Irish catchment. Furthermore the adjustment performance of pivotal sites has been improved where necessary using rainfall runoff modelling. Given that HA15 is a moderately well gauged catchment, the largest degree of uncertainty for the present day scenarios is attributed to the ungauged catchments.

In the future scenarios climate change has been defined as a potential source of medium uncertainty due to the inherent uncertainties surrounding climate change science and how these will translate into changes in fluvial flood flows in Ireland. It has not been assigned a higher risk as it is not considered to be any more uncertain than urbanisation which is generally a source of medium uncertainty in the prediction of future flood flows. Thomastown and Kilkenny AFAs have been attributed high/medium uncertainty based on observed higher growth rates and the fact that Kilkenny is a development hub in the National Spatial Strategy (2002 – 2020). The complex social, cultural and economic factors which affect urbanisation are difficult to predict for a 100 year time horizon. However there is also the effect of sustainable drainage to consider which adds a further degree of uncertainty depending on the extent to which it is successfully implemented. There is a high degree of certainty that there will be little afforestation within the middle and lower reaches of the Nore catchment and as such this is only a significant source of uncertainty in Mountrath, Ballyroan, Ballyragget (upper reaches of Nore only) and Thomastown (tributaries only).

9 CONCLUSIONS

Good hydrometric data exists for the main channel of the Nore. Hydrometric data is limited on the tributaries of the Nore but where it exists, it is generally of good quality i.e. River Erkina, River Dinin, and Kings River. The River Breagagh enters the River Nore at Kilkenny and is gauged but with confidence in flow values limited to $0.8 \times Q_{med}$. High quality meteorological data exists for application in the hydrological analysis of HA15 following the processing of the Dublin and Shannon Airport radar data as part of the Study but there are gaps in radar availability at the south east corner such that Ballyhale and Inistioge AFAs are missing, and Thomastown AFA partially missing. A comprehensive methodology has been applied combining the latest FSU statistically based and modelling based techniques for analysis. Rainfall run-off techniques have been particularly useful within HA15 in the instances where gauge records exist but are of such high uncertainty or short record that the gauge records could not be used with any confidence in the prediction of the index flood flow or subsequent adjustment of index flows at relevant ungauged HEPs (Mc Mahons Bridge, Kilbricken and Mount Juliet on the Nore; Blackfriars Bridge on the Breagagh; and Callan on Kings River). Where catchment rainfall run-off modelling has been applied this has been done in addition to the FSU statistically based method such that an additional layer of simulated historic data is available. The results from both approaches are cross checked against one another such as to provide the most robust analysis possible to take forward for design flow estimation.

There is a fair degree of potential uncertainty within the ungauged tributary catchments where estimates of flood flow are derived from catchment descriptor based estimates and direct adjustment based on gauge data within the sub-catchment is not possible. Geographically closest gauging stations with high confidence in the data or improved certainty due to rainfall runoff modelling have been used to adjust index flow estimates at these catchments and therefore provide some improvement. The calibration of the hydraulic models to historic flood data and observed evidence will further help to screen out design flow estimates which are not reflective of the actual behaviour of these sub-catchments.

There are many potential future changes to the catchment, margins of error and uncertainties which must be considered within the study. However the cumulative application of worst case scenarios, one on top of the other could lead to erroneous flood extents which do not take into account the diminishing cumulative joint probability of these factors. For this reason this report has separated future HA15 changes that have a high degree of certainty in the projections from those changes which are less certain. Future changes which have a relatively higher degree of uncertainty, along with margins of error and other uncertainties have been risk assessed individually. This risk assessment is to be taken forward and built upon through the hydraulic modelling phase with the ultimate goal of providing a single error margin for the flood extent maps on an AFA by AFA basis. This rationalised single error margin is designed to inform end users in a practical way as to the varying degree of caution with which mapped flood extents are to be treated.

9.1 SUMMARY OF THE RESULTS AND GENERAL PATTERNS

The HA15 catchment can be characterised hydrologically as follows:

- The catchment has a wide range of climatic and physiographic characteristics. The drier, lowland areas to the centre moving towards the coast have SAAR values as low as 817mm while the upper catchment in the Slieve Bloom Mountains has SAAR values of up to 1620mm.
- Hydrometric data is generally good but variable quality and availability, mainly focused on the Nore main channel and significant tributaries. 50% of models have hydrometric data of varying quality to work with.
- Meteorological data is of good quality and availability in the catchment, particularly following the processing of rainfall data from the Dublin and Shannon Airport radar.
- Flood behaviour when defined in terms of the growth curve, i.e. in orders of magnitude greater than the median event, on average is slightly higher than would have been thought based on older methodologies (FSR).
- The 1% AEP flood event ranges from approximately 1.9 (Nore main channel) to 3.4 times larger than the median flood flow depending on catchment size. This compares to approximately 2 under FSR.
- Growth factor increases with decreasing catchment size.

Design flow estimation is the primary output of this study and has been developed based on the analysis contained in this report. This analysis is based on previous observed data and estimation / modelling techniques. This analysis will require further validation through the calibration of the hydraulic models. As modelling progresses there may be some elements of the hydrological analysis that might need to be questioned and interrogated further. This is reflective of best practice in hydrology / hydraulic modelling for flood risk assessment. RPS believe that through complementing statistical analysis techniques with rainfall run-off modelling, the design flow estimation has as high a degree of certainty as is possible prior to calibration / validation and that this will save time and increase accuracy as HA15 moves into the hydraulic modelling phase of the CFRAM Study process. Nevertheless the modelling may necessitate the adjustment of some of the design flows and as such any adjustments made will be summarised within the Hydraulic Modelling Report.

9.2 RISKS IDENTIFIED

The main potential source of uncertainty in the analysis is due to a lack of hydrometric gauge data in the smaller ungauged catchments which are the main source of fluvial flood risk in many of the AFAs. This has been mitigated as much as possible by the use of a comprehensive range of analysis and

estimation techniques from statistical, catchment descriptor based estimates in line with the most recent CFRAM guidance to the use of rainfall run-off modelling.

After this cycle of the South Eastern CFRAM Study the main potential adverse impact on the hydrological performance of the catchment is the effect of urbanisation. If the increase in urban extent in some AFAs continues at a rate of 3 to 3.5% annually, there is the potential for this to increase flood risk significantly particularly within AFAs affected by small tributaries if this leads to development which is unsustainable from a drainage perspective. However urban growth rate projections across HA15 as a whole is more likely to be 2% or 2.5% at the higher end, when present and projected data are considered together. This would result in an increase in urban extent of between 10 and 16% which is not as dramatic as projections in other hydrometric areas along Ireland's eastern seaboard.

9.3 OPPORTUNITIES / RECOMMENDATIONS

This study presents two potential opportunities to improve the hydrological analysis further in the next cycle of the South Eastern CFRAM Study:

1. Four hydrometric gauging stations were identified for rating review in HA15 yet survey information and hydraulic models will be available for up to a further 17 following completion of the study. All of the other stations on the modelled watercourses would benefit to some degree by carrying out a rating review using the hydraulic models / survey, if only to bring confidence to future extreme flood flow measurement. At best it may be possible to estimate historic flows at gauging stations which are currently water level only.
2. The rainfall run-off modelling carried out as part of this study has, due to programme and data constraints, been carried out following hydrological analysis of the gauge station data. The run-off modelling has effectively created a layer of additional simulated historic gauge station years for all of the gauge stations. This data has been utilised in the design flow estimation but could potentially be used to provide further statistical confidence to estimates of historic flood frequency or may even be used to inform hydrograph shape generation in future studies.

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APPENDIX A

HA15 HYDROMETRIC DATA STATUS TABLE

Hydrometric Data Status Table

HA15 - Hydromteric Stations

[illegible]

Key

	Annual Max Data
	Daily Data
	15 Min Data

APPENDIX B

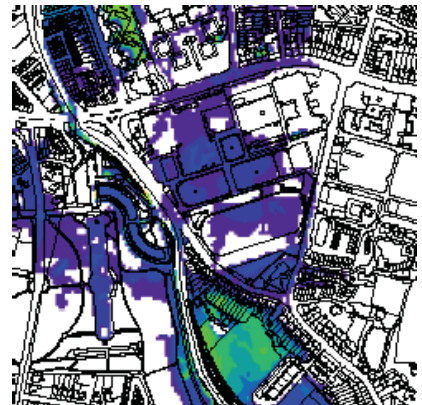
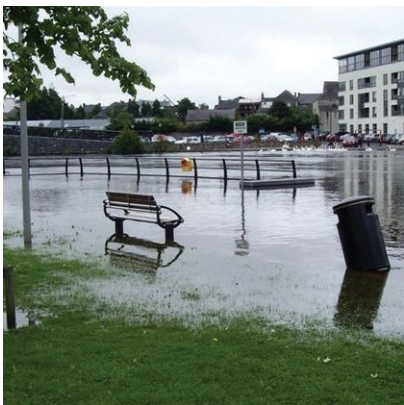
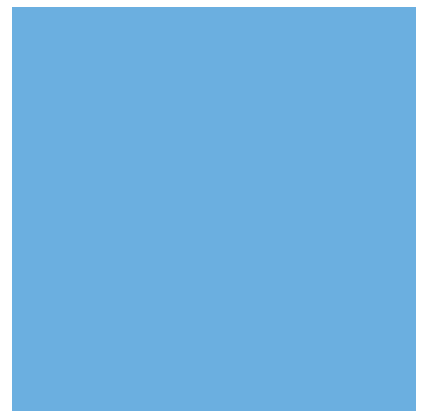
ANALYSIS OF THE DUBLIN AND SHANNON AIRPORT RADAR DATA



South Eastern CFRAM Study

Stage 3 Radar Report

IBE060 | Rp0009



Analysis of the Dublin and Shannon Radar Data for the SECFRAM Study Area (Stage 3 – Draft Final Report)

DOCUMENT CONTROL SHEET

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Project Title	South Eastern CFRAM Study (Radar analysis project, Stage 3)					
Document Title	Analysis of Dublin and Shannon radar data for the SECFRAM Study Area					
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LIST OF ABBREVIATIONS

AAD	Annual Average Damages
AEP	Annual Exceedance Probability
AFA	Area for Further Assessment
AFR	Area of Flood Risk
CAPPI	Constant Altitude Plan Position Indicator. Radar measurements are taken from several elevations of the radar to always have a measurement at approximately the same altitude in the atmosphere. The advantage of this method is that effects such as clutter close to the radar can be compensated, the disadvantage is that there are disruptions at the edge of each elevation used.
CFRAM	Catchment Flood Risk Assessment and Management
DEM	Digital Elevation Model
DTM	Digital Terrain Model
EPS	Ensemble Prediction System
FSU	Flood Study Update
HA	Hydrolometric Area
HDF5	European data format for delivery of full volume radar data
HEP	Hydrological Estimation Point
HRU	Hydrological Response Unit
IDW	Inverse Distance Weighted interpolation
NAM	Hydrological modelling system (DHI)
OPW	Office of the Public Works
PAC	Precipitation Accumulation (radar)
PCR	Pseudo CAPPI Rainfall (radar)
PPI	Plan Position Indicator. Radar measurement of one fixed elevation. This means that data from larger distances are measured higher above ground than data close to the radar.
RRB	Met Éireann radar data format for 15 minute CAPPI data
SCOUT	Radar and rain gauge data processing software, property of hydro & meteo GmbH & Co. KG.
TimeView	Time series analysis tool, property of Hydrotec Engineers GmbH.
UFV	Data format: one time series format consisting of a header and data pairs "date/time value".

1 INTRODUCTION

1.1 CONTEXT

Radar measured rainfall data is nowadays a common means of deriving spatially and temporally detailed rainfall information for a multitude of applications. The work required to produce rainfall information of reliable quality requires quality control for the data from both the radar and the ground based stations and the subsequent merging of these two data sources. Rainfall data produced in this way can be supplied as sub-daily time series for different spatial scales.

1.2 STUDY OBJECTIVES

The main objectives of the Stage 3 analysis of the Dublin and Shannon radar data for the South Eastern CFRAM study area were:

1. Carry out radar data quality analysis and correction of the Dublin and Shannon radar data for the South Eastern CFRAM study area using daily and sub-daily available rain gauges.
2. Produce gauge-adjusted radar rainfall data sets for the period 1998-2010 for the Study Area in order to provide quality spatio-temporal rainfall input for the hydrological rainfall-runoff analysis.
3. Provide a brief report outlining the work done and the main findings.

1.3 METHODOLOGY

The methodology for merging the available rainfall data sources into a spatial hydro-meteorological radar derived dataset included:

- Preparation and quality control of the rain gauge rainfall data;
- Quality control of the available radar data;
- Radar correction (adjustment) using the rain gauge data;
- Review of events (high-flow, heavy rainfall) for further hydrological analysis;
- Reporting and result presentation.

2 AVAILABLE AND DELIVERED RAW DATA

Due to the overall time constraints of the South Eastern CFRAM Study, and the need to complete the radar analysis before hydraulic modelling commenced to avoid causing programme delay, all data to be used in the analyses had to be available for processing by 8th August 2012. All radar data was received in time, however post May 2010 rain gauge data (complete dataset to May 2010 was delivered at study inception) was delivered later¹ and could not be used for processing during this stage. Therefore, the final set of quality controlled and rain gauge adjusted radar data is limited in time and terminates at the end of 2009.

Data for the geographical organisation and presentation of radar and rain gauge data in form of station coordinates, boundaries of counties, catchments and relevant municipalities was also made available prior to the cut-off date.

2.1 DATA DELIVERED ON TIME

The radar data from the Met Éireann, Dublin and Shannon radars received on time were as follows:

Dublin:

- | | | | |
|-------------------|-----------|-------------------|------------------------|
| • PCR data | 1h | 480x480 km | 1/1998 – 7/2012 |
| • PAC data | 1h | 200x200 km | 1/1998 – 7/2012 |
| • RRB data | 15 min | 200x200 km | 10/2005 – 7/2012 |
| • HDF5 data | 5 min | 240 km polar | 2/2011 – 7/2012 |

Shannon:

- | | | | |
|-------------------|-----------|-------------------|------------------------|
| • PCR data | 1h | 480x480 km | 1/1998 – 7/2012 |
| • PAC data | 1h | 200x200 km | 8/1997 – 7/2012 |
| • RRB data | 15 min | 200x200 km | 10/2005 – 7/2012 |
| • HDF5 data | 5 min | 240 km polar | 3/2011 – 7/2012 |

Rain gauge data, as indicated below, had already been delivered by OPW at study inception however this did not encompass the full duration of the radar data but ended within the first half of 2010:

- 986 stations overall
- 16 hourly stations

¹ At the time of cutoff on August 8th, no information was available about the delay in delivery to be expected, after the data request issued on July 10th. The project partners were in constant contact with OPW on this matter, but had to start processing data due to the brief project duration for this task of two months. This was also communicated during the meeting at Met Éireann on August 20th 2012.

2.2 DATA DELIVERED LATER

Rain gauge data for the period June 2010 to the end of May 2012 was not received until after the 8th August 2012 deadline and was therefore not included in this Stage of the work. Due to the need for concurrent rain gauge and radar data to produce the adjusted radar product, the product only extends to the end of 2009 (the last complete year of available data). No reliable rainfall estimation would have been possible for the later period without rain gauge data.

2.3 SELECTED DATA FOR PROCESSING

To produce adjusted radar data for the SECFRAM study area, it is necessary to have the catchment area covered by concurrent radar data and rain gauge data.

The first step of selecting data for processing involved reviewing the spatial and temporal coverage of the study area and the processing interval in the supplied data. It turned out that many stations did not have data for the time interval where radar data was available. A summary of all the stations provided at project outset (generally covering the east of the Republic of Ireland) is indicated below:

- 986 station time series were available from study inception
- 303 stations had data between 1998 – 2010, but not for the full time span
- 75 stations had complete data 1998 – 2010

It was originally intended that radar data with a 15 min temporal resolution would be processed but following receipt of the radar products it was found that only the radar products PCR and HDF5 cover all areas. For the HDF5 product no concurrent rain gauge data was available due to the missing temporal overlap of rain gauge station data (ending in 2010) and HDF5 radar data (starting in February/March 2011). Therefore, the hourly PCR product was selected for processing throughout Stages II and III of the project.

Figure 1 shows the rain gauge stations for which data is available for the period 1998 – 2010 and the extent limitation of the 200 x 200 km radar coverage.

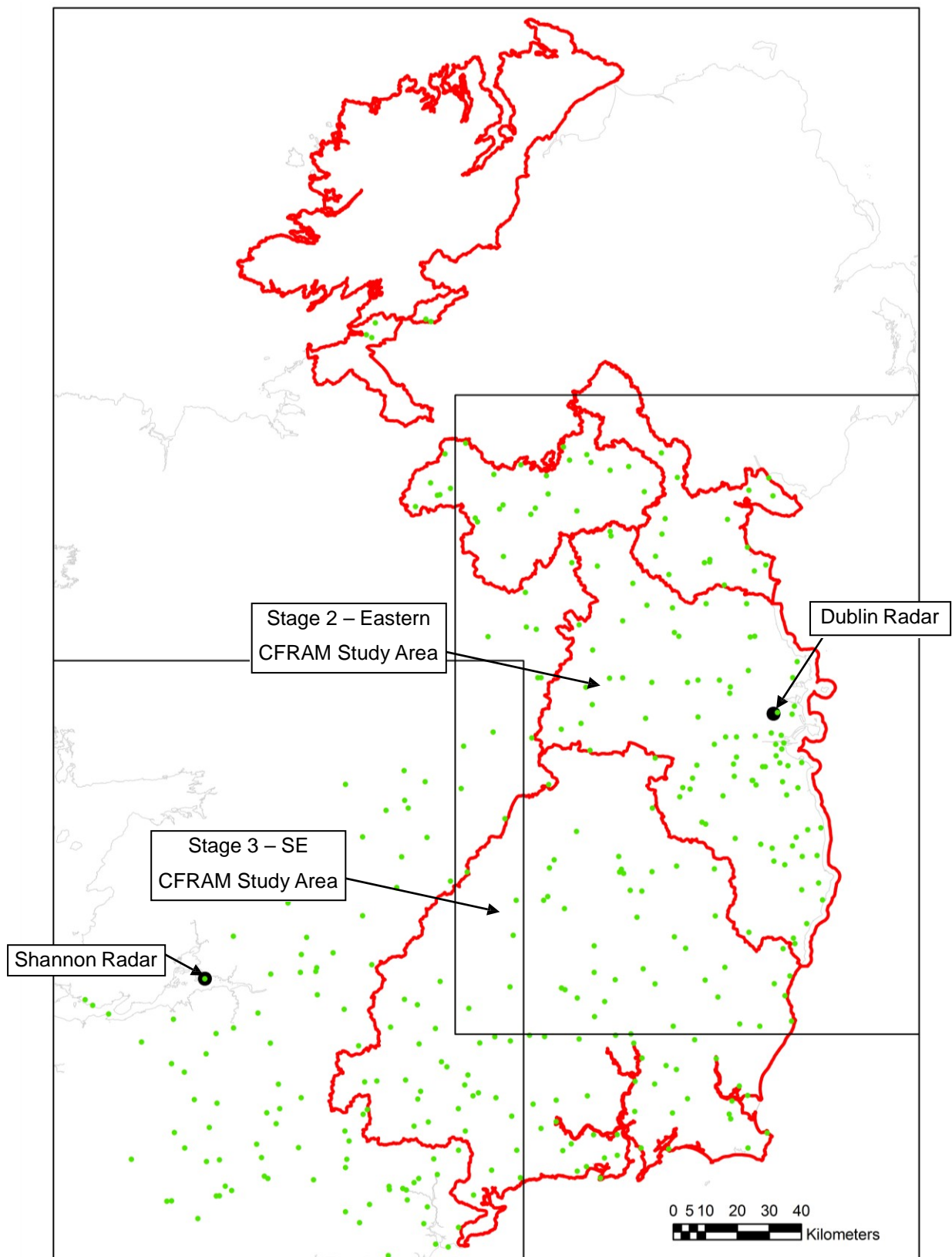


Figure 1. Rain gauge stations with data within the period 1998 – 2010 (coloured dots) and radar coverage 200 x 200 km for Dublin and Shannon radars (rectangles). The black points are the locations of Dublin and Shannon radar and the red boundaries are the Hydrometric Areas.

3 PREPARATION OF THE DATA

3.1 ANCILLARY DATA

Data for the geographical organisation and presentation of radar and rain gauge data in the form of station coordinates, boundaries of counties, catchments and relevant municipalities had to be pre-processed (format transformation) for use in the proprietary SCOUT precipitation processing system.

3.2 RAIN GAUGE DATA

Quality control of the rain gauge measurements is a required preliminary step before the data can be used in connection with radar data. The following quality control steps were undertaken since the data did not include all the necessary information on quality (further quality indicator information was provided after the cut-off date for information but further processing was nevertheless required):

1. *Re-formatting of the incoming data:* the data was reformatted from text format or Excel to a time series format suitable to be used for further processing. Here, UVF format was selected.
2. *Check for missing time intervals:* gaps in the data were detected and flagged.
3. *Check for values which are too high / outliers:* A check was performed on the data. The criterion was that the data of the checked station had to be in accordance with the values of the neighbouring stations: a value was considered too high if it was twice as high as the next value in rank. All daily values that were too high could be attributed to multi-day sums. Multi-day sums were a very frequent observation hampering further use of the data in radar data adjustment.
4. *Suspicious time intervals were documented and invalidated:* Time intervals where the data was missing but not set to undefined and time intervals where data was too high were documented and set to undefined values. All findings were documented in the rain gauge data quality overview (Appendix A).

The quality of the rain gauges led to a lower number of gauges which could be used for cross-comparison to radar and for radar data adjustment.

Of the 378 stations time series with data within the time interval 1998 – 2010 mentioned in section 2.3

- 50 were outside the study areas
- 55 had poor data
- 10 had hourly and daily data – so only the hourly data were used
- 263 time series remained for adjustment

Appendix B gives the list of stations that were finally used for adjustment.

3.3 RADAR DATA

The PCR data product provides data on a Cartesian grid (1 km grid length) as hourly sum in [mm] in form of a CAPPI. The usability of the Dublin data was high (97.1%). Additionally, due to incomplete data in the data base, a further 3% of the available data could not be used, consequently this data had to be removed manually. With Shannon radar, more data format errors were encountered so that several

radar images were not fully available and could not be exploited. For this radar, images from more than 90% of the observation time interval could be used.

Since this PCR data product does not permit in-depth quality control and correction, e.g. for beam blockage or bright band effects (see Figure 2), the following quality corrections were carried out:

1. Correction of the permanent clutter pixels or areas (rings);
2. Correction of areas with a clear long-term overestimation or underestimation of rainfall

For these purposes, daily sum images have been produced by SCOUT and analyzed in detail.

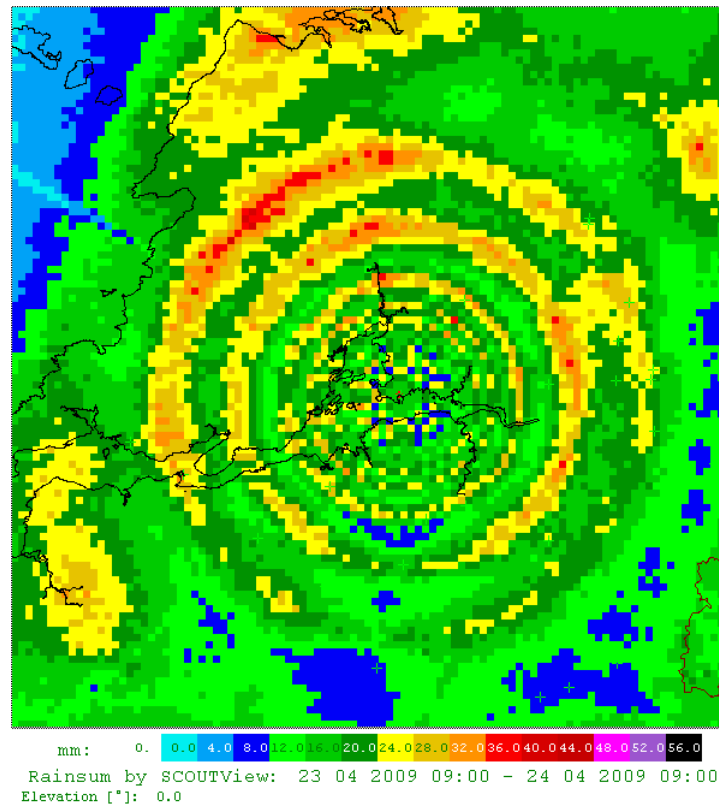


Figure 2. Bright band effect on a Shannon CAPPI product: the radar beam intersects the melting layer at each elevation and thus produces a multiple ring structure. The coastline is marked in black.

4 QUALITY CONTROL OF THE DATA

4.1 RAIN GAUGES

Quality control of the rain gauge measurements is a required preliminary step before the data can be used in conjunction with radar data. At the time of data processing, quality code information was both incomplete and not entirely suitable for the purposes of radar adjustment. Therefore the following steps were undertaken:

1. Re-formatting of the incoming data
2. Checking for missing time intervals
3. Checking for outliers through double mass analysis
4. Suspicious time intervals are documented and invalidated

The delivered data from sub-daily rain gauges (16 stations) was of good quality. However, the number of these stations is far too low for adjustment of radar data alone on the basis of this data.

The data from daily rain gauges contained numerous problems, which were addressed:

- The rainfall value registered was the one for the previous or following day (time shifts)
- Daily values often showed 0 mm although rainfall had occurred according to readings from neighbouring stations or the radar
- The data for some of the rain gauges contained multi-day sums which cannot be checked or disassembled easily

More than 3000 time intervals had to be invalidated manually in the rain gauge data base because of the above observations. Details can be found in Appendix A.

4.2 DUBLIN RADAR DATA

Data from the Dublin radar station was quality checked and processed as follows:

1. correction for clutter by a pixel-wise clutter map (only clutter in and nearby the study area)
2. correction for no rain images (in case of strong clutter problems)
3. smoothing of images (to reduce the effects of rings – over- and underestimations – due to the CAPPI product)

The observations of clutter and beam blockage with Dublin radar were variable in time, due to different versions of the radar software, maintenance, and construction of new buildings or new interfering emitters. Therefore, several clutter maps have been produced, each of them appropriate for a well-defined time interval only.

Clutter constitutes a major issue for the quality of Dublin radar. Although most clutter areas are outside the study area (e.g. Northern Ireland, Wales, see Figure 3), they occasionally cause problems within the study area and so required manual radar data inspection and processing.

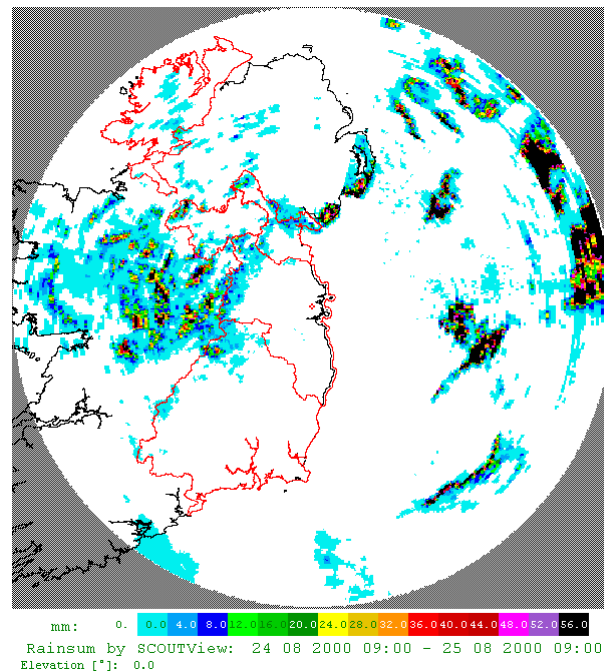


Figure 3. Clutter areas on a clear day

The radar beam blockage is limited for the Eastern CFRAM Study Area, the blocked areas are small since they are quite close to the radar, however there is a high degree of blockage for the South Eastern CFRAM Study area (Figure 4).

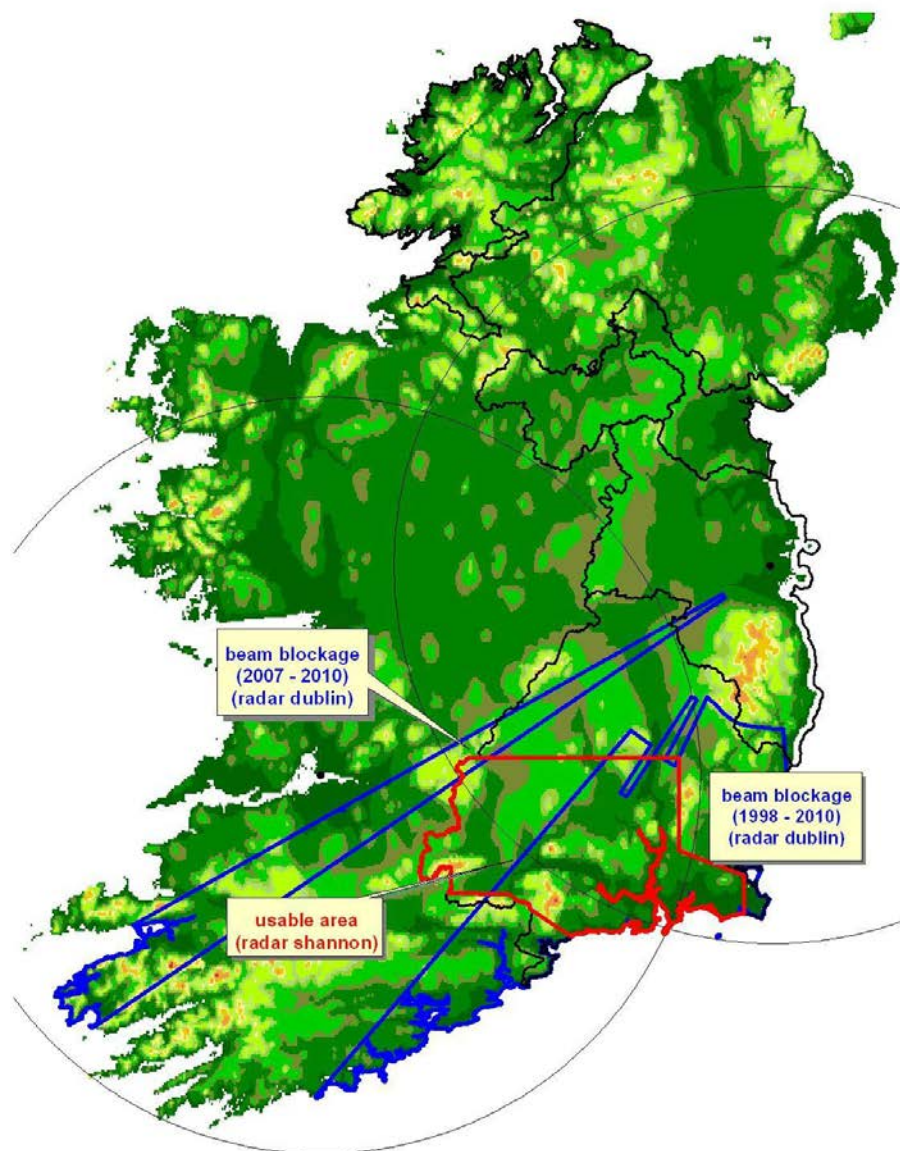


Figure 4. Beam blockage areas for Dublin radar and useable areas for Shannon radar

4.3 SHANNON RADAR DATA

Data from the Shannon radar station was quality checked and processed as follows:

- correction for clutter by a pixel-wise clutter map (only clutter in and nearby the study area)
- correction for no rain images (in case of strong clutter problems)
- smoothing of images (to reduce the effects of rings – over- and underestimations – due to the CAPPI product)

Shannon radar plays an important role for the SECFRAM study area. However, data from the Shannon radar has more temporal gaps and data errors than the data for the Dublin radar. Beam blockage for Shannon radar can be observed for many eastern directions. Consequently the SECFRAM areas where data from Shannon radar is better than Dublin radar is limited to the red area in Figure 4.

5 RADAR ADJUSTMENT TO RAIN GAUGES

5.1 GENERAL PROCEDURE

The adjustment itself was performed in such a way that the daily rain gauge measurements are taken as reference value for the corresponding radar pixels. Thus, the daily radar sum at each gauge point is identical to the rain gauge sum. In between rain gauges, the correction factor to obtain the identical values is interpolated, (Wilson / Brandes, 1979) using an Inverse Distance Weighted (IDW) interpolation. Particular problems arose from the numerous multi-day sums in the rain gauge data which had to be individually identified and eliminated as well as a number of format errors in the radar data leading to gaps in the radar data.

5.2 MULTI-DAY ADJUSTMENT

Due to the numerous multi-day sums, the adjustment procedure for daily values briefly described above, had to be extended: the comparison intervals between rain gauge data and radar data to determine the correction factor were set to three days instead of one day. The correction factor was then determined for the day in the middle of the three day interval, additionally using data from the previous and the following day. Thus, weekend sums could be taken into account; however, the precision for single days was decreased.

5.3 RESULTS OF DUBLIN RADAR ANALYSIS

The data produced from analysis of the radar information proved to be reliable for most of the study area in terms of the derived yearly total when compared to actual gauge data. . The derived data clearly offers improvement in spatial and temporal resolution of precipitation patterns over the current situation of sparsely distributed daily only gauges. Figure 5 shows on the left hand side the yearly sum of the incoming radar data, and on the right hand side the yearly sum after quality control and adjustment. Clearly visible is the elimination of clutter on the Northern Irish coast and the increase of the average yearly sum from approximately 300 mm to more than 900 mm. Other issues, such as the blocked radar beam towards the southwest of the radar, remain and may locally affect the subsequent application of the data.

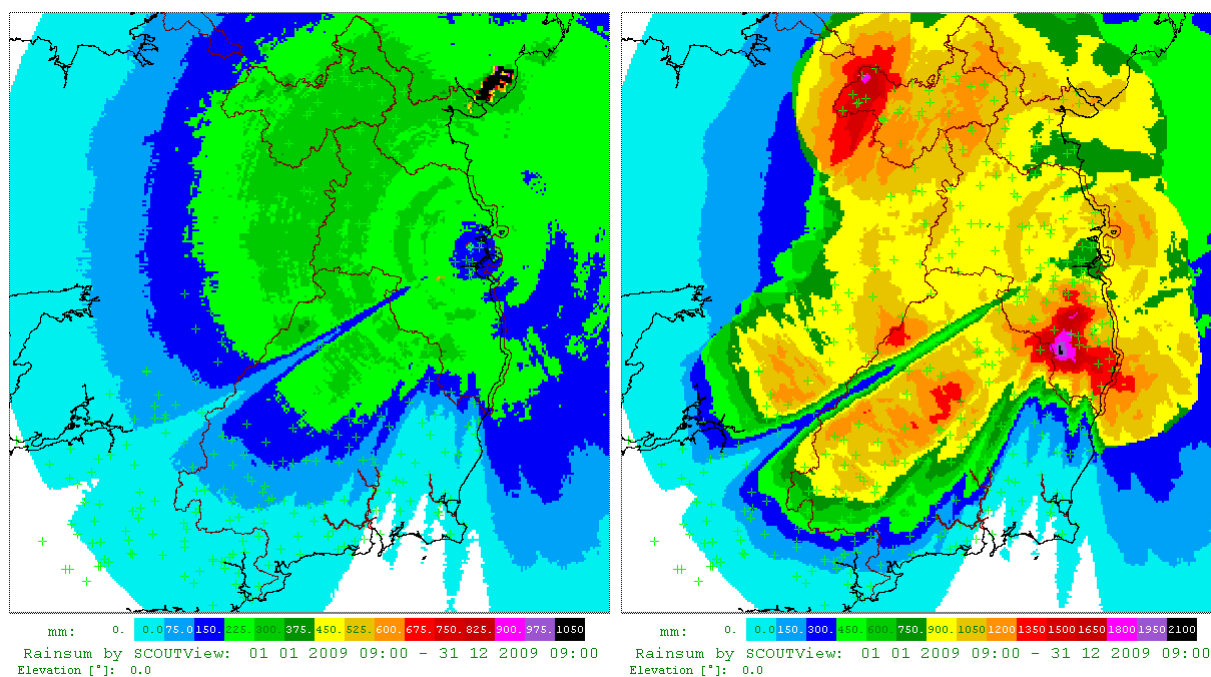


Figure 5: Yearly sum of the original radar data (left) and quality controlled and adjusted radar data (right)

Figure 6 gives an assessment of the data quality for Dublin radar in terms of the factors between the rain gauges and the adjusted radar over the whole observation period.

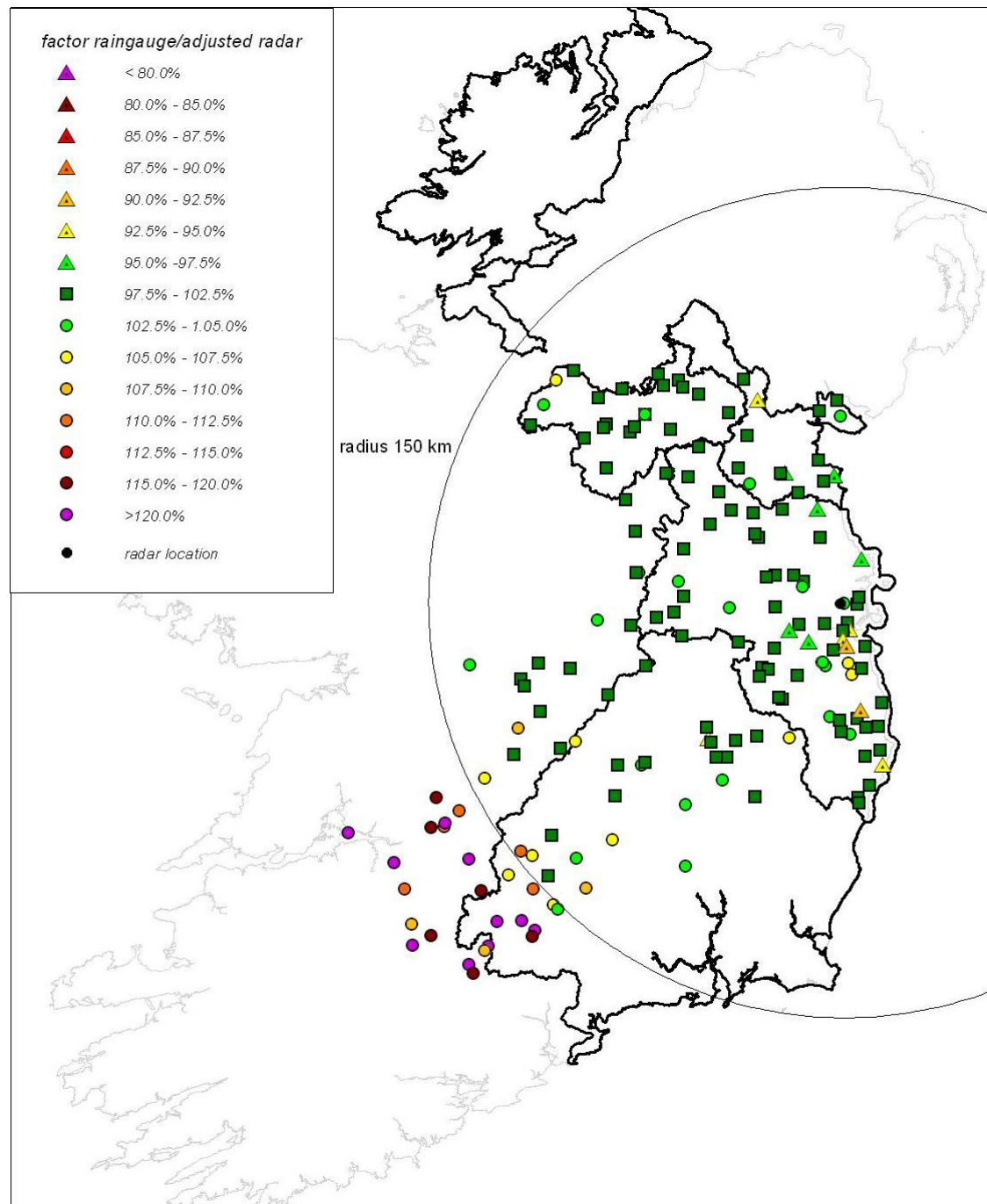


Figure 6: Dublin radar: Factor between adjusted radar and rain gauges for those areas where the radar is not blocked

5.4 RESULTS OF SHANNON RADAR ANALYSIS

The data produced from analysis of the Shannon Radar data proved to be more reliable than the Dublin Radar data for the part of the study area indicated in Figure 4. The radar derived data clearly improves

on the current status where daily gauge data has not been systematically quality controlled prior to delivery to RPS.

Figure 7 shows on the left hand side the yearly sum of the incoming radar data, and on the right hand side the yearly sum after quality control and adjustment. Clearly visible is the elimination of the data outliers towards the South East and the increase of the average yearly sum by approximately 50%. Other issues, like the blocked radar beam towards the East of the radar, remain and can considerably restrict the subsequent application of the data for these areas.

Figure 8 gives an assessment of the data quality for Shannon radar. Shown are the factors between the rain gauges and the adjusted radar over the whole observation period. Green colour indicates good adjustment quality, orange and red colours denote unsatisfactory results.

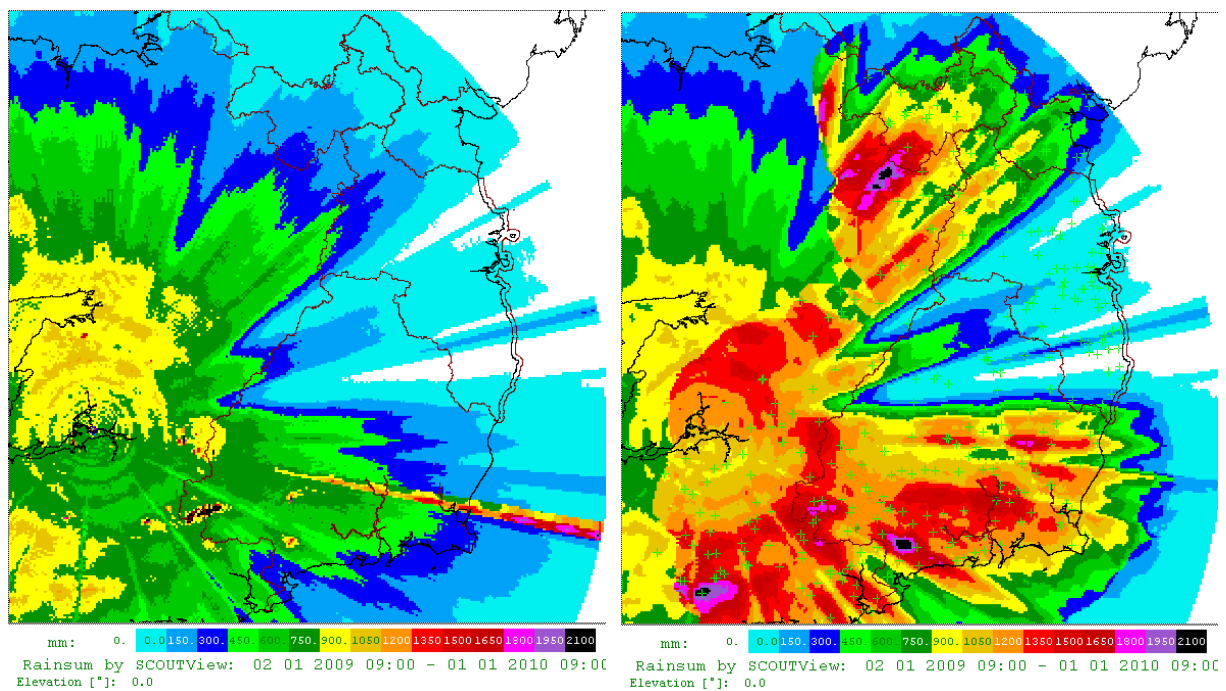


Figure 7: Yearly sum of the original radar data (left) and quality controlled and adjusted radar data (right)

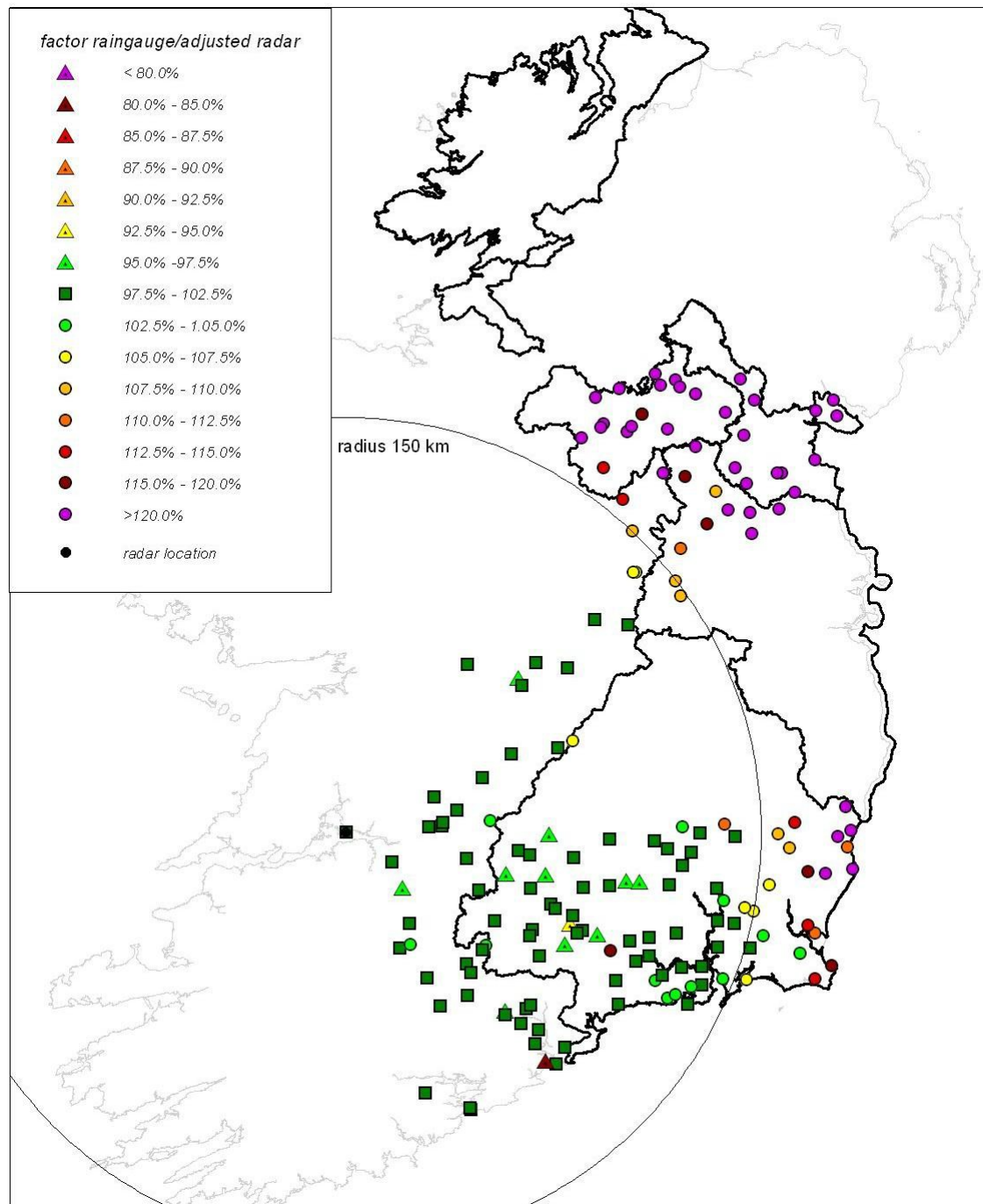


Figure 8: Shannon radar: Factor between adjusted radar and rain gauges for those areas where the radar is not blocked

As a consequence of the above documented data quality checks, the gauge-adjusted radar data may have some shortcomings, which are important to mention and should be taken into account as inputs to the hydrological modelling:

1. The rainfall rates derived from radar data are expected to have an uncertainty generally within $\pm 20\%$ when checked against the rainfall gauges within the defined useable areas for a range

of durations. The degree of uncertainty varies spatially, due to distance from the radar, distance from rainfall gauges (adjustment points) and due to proximity to other clutter blockage effects.

2. An area with beam blockage exists to the south west of Dublin radar (see Figure 4) from April 2007. In this region, the weighted area-average of the rain gauges should be used for the hydrological modelling after April 2007 – the produced radar data from Dublin radar can only be used until this date for this region. The Shannon radar also suffers from blockage in this region also.
3. Reliability of the radar derived data is less for 2010 due to the incomplete time series of rain gauge data for the entire year of 2010; the radar data for 2010 (and later) need to be adjusted with the corresponding rain gauge data.
4. For the area south of the Wicklow mountains, no reliable radar data could be produced, neither from Dublin radar (blocked) nor from Shannon radar (distance too large) – here (quality controlled) station data should be used instead
5. For hydrological modelling, modellers should be aware of the possibility of incorrect scaling due to multi-day sums. That is adjacent days with 10 and 50 mm of precipitation may be attributed 50 mm and 10 mm instead after adjustment. This has been implemented in the NAM model generation tool that flags such rainfall events to be manually inspected and compared to river gauges data (flow data).
6. Due to the time constraints and the urgency of producing the gauge-adjusted radar data, it is important to note the following quality checks and implement proper procedures in the modelling process:
 - Limited control of the results and further validation of the generated rainfall time series (which includes the analyses of all days with suspiciously high deviations from the station measurement) was carried out. This will be a part of the hydrological modelling (calibration and model validation process);
 - Radar measurement values due to temporal clutter may have produced false rainfall values in areas where there was no or minimal rainfall. This is flagged to the modellers and they have developed a quality check of the rainfall data in correlation to the measured runoff (flows) at the gauging stations) in order to take this effect into account.

6 STAGE 3 CONCLUSIONS AND OUTLOOK

The Stage 3 analysis of the Shannon and Dublin radar data for the South Eastern CFRAM Study Area indicated the following conclusions:

1. Quality controlled and adjusted radar data is now available on a 1 km National Irish grid with a 1-hour time step for the period January 1998 to December 2009 (12 years).
2. The spatio-temporal comparison between the radar data and the rain gauge data shows that both radars underestimates rainfall on average by a factor of 3 to 5, compared to the rain gauge observations.
3. The Shannon radar is only of relevance for a small region within the SE CFRAM study area and not for the Eastern CFRAM study area, both due to numerous beam blockages to the east of the radar. For other areas (South, Southwest and West) we expect Shannon radar to provide good results.
4. The gauge-adjusted radar data is better quality controlled than the rain gauges used up to now for modelling purposes;
5. The gauge-adjusted radar data provides rainfall data to a much higher resolution in time and space than rain gauge data alone which can substantially improve the hydrological and hydrodynamic modelling results for the purposes of producing the flood hazard and flood risk maps under the South Eastern CFRAM Study and potentially other flood studies.
6. The data set provides substantial information for large areas between rain gauge sites where no information has been available to date
7. Real-time gauge-adjusted radar rainfall time series for any of the 1x1 km grids would prove beneficial for flood forecasting and early warning and will improve the lead time. When this radar information is combined with the existing and the planned hydrometric stations (water levels and flow), the combined effect will lead to better calibrated and validated hydrological and hydrodynamic operational models
8. The gauge-adjusted radar data results can be used to optimise the location of daily and sub-daily rain gauges using probabilistic and information theory analyses.
9. The gauge-adjusted radar rainfall dataset that has been developed in the framework of the CFRAM Studies can also be used for many other flood, drought and water quality related studies (i.e. for developing water balances, evaluation of historical flood events, EU Water Framework Directive related catchment analysis, calibration of models). To take full advantage of the possibilities of this dataset, it will be beneficial to set-up a web portal, as outlined in the proposed Stage 4. With this portal OPW or other institutions could easily access and use the enormous amount of historical data for their studies.

Since the preparation time of the data, additional rain gauge data sets have become available, covering the time frame up to June 2012. Since radar data is already available for this time interval, the extension of the quality controlled and adjusted radar data for the years 2010, 2011 and the first half of 2012

(during which time some significant flood events occurred in the study area) is now feasible and recommended.

Since February 2011, radar data is also available as polar volume² data with a 5 minute time step. This constitutes a major data improvement because this polar data can be quality controlled and corrected (e.g. beam blockage) to a higher level of resolution and accuracy than the CAPPI data. Also, the shorter time step of 5 minutes provides data which is suitable for urban catchment simulations.

Finally, other areas of Ireland would benefit from the same type of data – the methodologies are established and trials such as this have proven the benefits of this approach.

7 RECOMMENDATIONS

1. Processing of rain gauge and radar data for 2010 –2012
2. Preparation of adjusted radar data for other CFRAM study areas in Ireland
3. Continuous retrieval of polar volume radar measurements (task for Met Éireann)
4. Use of radar data for the simulation of extreme events for use in flood forecasting

8 ACKNOWLEDGEMENTS

We are grateful for the discussions with Met Éireann which helped to improve the quality of the data production.

9 REFERENCES

Wilson, J.W. and Brandes E.A. (1979). Radar measurement of rainfall – A summary, *Bull. of the American Meteorological Society*, 60, 1048-1058.

² Polar volume data is radar data in polar coordinates centered around the radar site with measurements in different heights, possible through the use of several elevation angles of the radar beam for its scanning. Such data is much better to quality control and permits analysis of rainfall measurements in different vertical layers. The use of this data is likely to produce rainfall values of a better quality than the CAPPI data used for this project.

APPENDIX A

RAIN GAUGE DATA QUALITY CONTROL RESULTS

Explanation for the observations in the following table – comparison was made with the closest other gauges and with radar measurements.

Multi-day sum – misleading daily values

No precipitation – the station did not record precipitation, but neighbouring stations did

uncertain partition into single days – the values recorded do not appear to represent the date given

implausible – the values are very different from neighbouring recordings

very high precipitation – the values are too high to appear plausible

Consequences:

Gap defined – This data was defined as a gap in the dataset

station no.	start	end	observation	consequence
8823	09.07.2001	14.07.2001	multi-day sum/uncertain partition into single days	gap defined
8823	05.08.2001	07.08.2001	multi-day sum	gap defined
8823	08.02.2002	10.02.2002	multi-day sum	gap defined
8823	25.04.2002	14.05.2002	multi-day sum	gap defined
8823	01/06/2002	30/06/2002	no precipitation	gap defined
8823	07.07.2002	13.07.2002	multi-day sum	gap defined
8823	01.08.2002	01.10.2002	no precipitation	gap defined
8823	24.10.2002	28.10.2002	multi-day sum	gap defined
8823	07.11.2002	09.11.2002	uncertain partition into single days	gap defined
8823	27.12.2002	31.12.2002	multi-day sum/uncertain partition into single days	gap defined
8823	01/05/2003	31/05/2003	no precipitation	gap defined
8823	01.07.2003	01.08.2003	no precipitation	gap defined
8823	18.09.2003	23.09.2003	multi-day sum	gap defined
8823	22.10.2003	16.12.2003	multi-day sum	gap defined
8823	03.02.2004	05.02.2004	multi-day sum	gap defined
8823	02.03.2004	05.03.2004	multi-day sum	gap defined
8823	17.04.2004	19.04.2004	multi-day sum	gap defined
8823	10.06.2004	20.06.2004	multi-day sum/uncertain partition into single days	gap defined
8823	01.07.2004	01.08.2004	no precipitation	gap defined
8823	01/09/2004	30/09/2004	no precipitation	gap defined
8823	22.10.2004	25.10.2004	multi-day sum	gap defined
8823	17.11.2004	19.11.2004	multi-day sum	gap defined
8823	27.12.2004	29.12.2004	multi-day sum	gap defined
8823	06.02.2005	08.02.2005	multi-day sum	gap defined
8823	23.02.2005	25.02.2005	multi-day sum	gap defined
8823	01.07.2005	01.08.2005	no precipitation	gap defined
8823	01.09.2005	01.10.2005	no precipitation	gap defined
8823	01.11.2005	01.12.2005	no precipitation	gap defined
8823	16.03.2006	19.03.2006	multi-day sum	gap defined
8823	25.05.2006	27.05.2006	multi-day sum	gap defined
8823	29.06.2006	01.07.2006	multi-day sum	gap defined
8823	10.11.2006	20.11.2006	multi-day sum/uncertain partition into single days	gap defined
8823	01/12/2006	31/12/2006	no precipitation	gap defined
8823	01/02/2007	28/02/2007	no precipitation	gap defined
8823	11.06.2007	14.06.2007	multi-day sum	gap defined
8823	13.08.2007	15.08.2007	uncertain partition into single days	gap defined
8823	01.09.2007	01.10.2007	no precipitation	gap defined
8823	01.11.2007	01.12.2007	no precipitation	gap defined
8823	27.12.2007	29.12.2007	multi-day sum	gap defined
8823	01/01/2008	31/01/2008	no precipitation	gap defined
8823	31.01.2008	31.12.2009	multi-day sum/uncertain partition into single days	gap defined
8912	17.04.2004	19.04.2004	multi-day sum	gap defined
8912	28.09.2004	01.10.2004	multi-day sum	gap defined
8912	19.11.2004	21.11.2004	multi-day sum	gap defined
8912	14.04.2005	17.04.2005	multi-day sum	gap defined
8912	22.05.2005	24.05.2005	multi-day sum	gap defined
8912	17.11.2005	19.11.2005	multi-day sum	gap defined
8912	16.01.2006	21.01.2006	multi-day sum	gap defined
8912	16.01.2007	18.01.2007	multi-day sum	gap defined
8912	15.10.2007	24.10.2007	multi-day sum	gap defined
8912	27.11.2007	29.11.2007	multi-day sum	gap defined
8912	02.02.2008	04.02.2008	multi-day sum	gap defined
8912	13.09.2008	15.09.2008	uncertain partition into single days	gap defined
8912	08.11.2008	10.11.2008	multi-day sum	gap defined
8912	25.03.2009	15.04.2009	uncertain partition into single days	gap defined
8912	05.10.2009	07.10.2009	multi-day sum	gap defined
8912	23.12.2009	31.12.2009	multi-day sum	gap defined
8923	31.08.1998	02.09.1998	multi-day sum	gap defined
8923	11.12.1998	13.12.1998	multi-day sum	gap defined
8923	20.05.1999	25.05.1999	multi-day sum	gap defined
8923	01.07.1999	01.08.1999	no precipitation	gap defined
8923	07.02.2000	11.02.2000	multi-day sum	gap defined
9023	02.01.1998	08.01.1998	multi-day sum	gap defined
9023	01.09.1998	01.10.1998	no precipitation	gap defined
9023	09.10.1998	13.10.1998	uncertain partition into single days	gap defined
9112	20.01.2007	22.01.2007	multi-day sum	gap defined
9112	21.05.2008	05.06.2008	multi-day sum	gap defined

- SAMPLE ONLY -

station no.	start	end	observation	consequence
9112	26.11.2008	28.11.2008	multi-day sum	gap defined
9112	14.05.2009	16.05.2009	multi-day sum	gap defined
9112	16.06.2009	18.06.2009	multi-day sum	gap defined
9112	05.10.2009	10.10.2009	multi-day sum/uncertain partition into single days	gap defined
9112	17.12.2009	31.12.2009	multi-day sum	gap defined
9123	20.06.1998	01.08.1998	multi-day sum	gap defined
9123	11.11.1998	15.11.1998	multi-day sum	gap defined
9123	22.11.1998	25.11.1998	multi-day sum	gap defined
9123	03.01.1999	05.01.1999	multi-day sum	gap defined
9123	27.05.1999	29.05.1999	multi-day sum	gap defined
9123	19.06.1999	21.06.1999	multi-day sum	gap defined
9123	22.09.1999	24.09.1999	multi-day sum	gap defined
9123	25.12.1999	27.12.1999	multi-day sum	gap defined
9123	07.01.2000	09.01.2000	multi-day sum	gap defined
9123	25.02.2000	28.02.2000	multi-day sum	gap defined
9123	24.05.2000	26.05.2000	multi-day sum	gap defined
9123	18.08.2000	22.08.2000	multi-day sum	gap defined
9123	28.09.2000	02.06.2001	multi-day sum/uncertain partition into single days	gap defined
9123	08.08.2001	08.09.2001	multi-day sum/uncertain partition into single days	gap defined
9123	23.01.2002	12.03.2002	multi-day sum/uncertain partition into single days	gap defined
9123	28.05.2002	04.07.2002	multi-day sum/uncertain partition into single days	gap defined
9123	29.08.2002	31.08.2002	multi-day sum	gap defined
9123	01/10/2002	30/11/2002	no precipitation	gap defined
9123	08.12.2002	21.05.2003	multi-day sum/uncertain partition into single days	gap defined
9123	01.07.2003	01.08.2003	no precipitation	gap defined
9123	28.08.2003	30.08.2003	multi-day sum	gap defined
9123	30.10.2003	01.11.2003	multi-day sum/uncertain partition into single days	gap defined
9123	14.11.2003	17.11.2003	multi-day sum/uncertain partition into single days	gap defined
9123	11.03.2004	14.03.2004	multi-day sum	gap defined
9123	20.03.2004	22.03.2004	multi-day sum	gap defined
9123	18.06.2004	01.08.2004	multi-day sum/uncertain partition into single days	gap defined
9123	01/08/2004	31/08/2004	no precipitation	gap defined
9123	17.11.2004	21.11.2004	multi-day sum	gap defined
9123	24.12.2004	26.12.2004	multi-day sum	gap defined
9123	04.02.2005	16.03.2005	multi-day sum/uncertain partition into single days	gap defined
9123	16.04.2005	20.02.2006	multi-day sum/uncertain partition into single days	gap defined
9123	12.04.2006	31.08.2006	uncertain partition into single days	gap defined
9212	17.12.2009	30.12.2009	multi-day sum	gap defined
9223	25.06.1998	27.07.1998	multi-day sum	gap defined
9223	05.07.1999	30.07.1999	multi-day sum	gap defined
9223	01.10.1999	05.10.1999	multi-day sum	gap defined
9223	27.07.2000	08.08.2000	multi-day sum	gap defined
9223	30.07.2001	10.08.2001	multi-day sum	gap defined
9223	04.07.2002	08.07.2002	multi-day sum	gap defined
9223	18.08.2006	20.08.2006	multi-day sum	gap defined
9312	03.12.2008	05.12.2008	multi-day sum	gap defined
9312	26.05.2009	28.05.2009	multi-day sum	gap defined
9423	01.09.1999	31.10.1999	station not trustful - cause: multi-day sums	gap defined
9623	01.03.2004	30.06.2005	station not trustful - cause: multi-day sums	gap defined
9813	01.01.2001	31.12.2009	no precipitation	gap defined
9907	02.01.1998	30.11.2009	no precipitation	gap defined

- SAMPLE ONLY -

APPENDIX B

RAIN GAUGE STATIONS USED FOR ADJUSTMENT

STATION_NO	file name	NAME	CATCHMENT	AREA	HEIGHT	X	Y
1004H	n1004H.uvf	Roches_Point_hourly	4	SE	43	183100	60100
1075H	n1075H.uvf	ROCHES_POINT_2_hourly	4	SE	40	182779	60625
1475H	n1475H.uvf	GURTEEN_hourly	19	SE	75	199467	198376
2437H	n2437H.uvf	CLONES_hourly	37	E	89	250000	326300
2615H	n2615H.uvf	Rosslare_hourly	15	E	26	313700	112200
2922H	n2922H.uvf	Mullingar_2_hourly	22	E	101	242000	254300
3613H	n3613H.uvf	Kilkenny_hourly	13	SE	65	249400	157400
3723H	n3723H.uvf	CASEMENT AERODROME_hourly	23	E	94	304100	229500
375H	n375H.uvf	OAK_PARK_hourly	14	E	62	273000	179500
3904H	n3904H.uvf	Cork_Airport_hourly	4	SE	155	166500	66200
475H	n475H.uvf	JOHNSTOWN_CASTLE_hourly	15	E	52	302300	116600
4919H	n4919H.uvf	Birr_hourly	19	SE	72	207400	204400
518H	n518H.uvf	Shannon_Airport_hourly	18	E	4	137900	160300
532H	n532H.uvf	Dublin_Airport_hourly	32	E	71	316900	243400
675H	n675H.uvf	BALLYHAISE_hourly	37	E	78	245200	311600
875H	n875H.uvf	MULLINGAR_hourly	22	E	101	243000	254300
108	n0108.uvf	FOULKESMILLS_LONGRAIGUE	8	SE	71	284100	118400
332	n0332.uvf	SKERRIES_MILVERTON_HALL	32	E	64	323100	259300
422	n0422.uvf	TYRRELLSPASS	22	E	101	240100	235500
538	n0538.uvf	DUNDALK_ANNASKEAGH_W_W	38	E	61	308000	312800
638	n0638.uvf	NOBBER	38	E	60	283000	286500
707	n0707.uvf	BELLELAKE_FILTERSTN	7	SE	34	266800	105200
737	n0737.uvf	BALLYHAISE_AGR_COLL	37	E	67	245200	311600
820	n0820.uvf	MONEYSTOWN	20	E	207	319200	195900
907	n0907.uvf	MONATRAYEAST	7	SE	55	214000	76600
908	n0908.uvf	DUNCANNON	8	SE	34	274300	107500
915	n0915.uvf	JOHNSTOWN_CASTLE	15	E	49	302300	116600
931	n0931.uvf	KELLS_HEADFORT	31	E	67	276100	276900
1007	n1007.uvf	GRANGE_BALLYLANGADON	7	SE	101	217200	82700
1008	n1008.uvf	TACUMSHANE	8	SE	24	307700	107500
1020	n1020.uvf	ARKLOW_W_W	20	E	34	321900	173000
1024	n1024.uvf	ROUNDWOOD_FILTER_BEDS	24	E	195	321600	201800
1106	n1106.uvf	CAPPOQUIN_MT_MELLERAY	6	SE	213	209500	104100
1107	n1107.uvf	FENOR_ISLANDTARSNEY	7	SE	73	254300	100300
1108	n1108.uvf	BANNOW	8	SE	15	282900	107200
1116	n1116.uvf	CAHORE_KILMICHAEL_HOUSE	16	E	30	321300	147100
1207	n1207.uvf	TRAMORE_KNOCKANDUFF	7	SE	55	257200	101700
1208	n1208.uvf	TAGHMON_KILGARVAN	8	SE	58	288800	122900
1216	n1216.uvf	GOREY_TREATMENT_WORKS	16	E	40	315900	158800
1232	n1232.uvf	KINSALEY_AGR_RES_STN	32	E	19	321500	242900
1237	n1237.uvf	CARRIGALLEN_G_S	37	E	88	223100	302900
1307	n1307.uvf	WATERFORDAIRPORT	7	SE	30	262800	104400
1308	n1308.uvf	OLDROSS_DUNANORE	8	SE	93	278500	127500
1332	n1332.uvf	MALAHIDE_CASTLE	32	E	18	322200	245400
1338	n1338.uvf	OMEATH	38	E	12	314200	316600
1407	n1407.uvf	DUNGARVAN_CARRIGLEA	7	SE	18	221900	92800
1416	n1416.uvf	MONAMOLIN	16	E	91	311400	145500
1420	n1420.uvf	GLENMACNASS	20	E	238	311700	202300
1507	n1507.uvf	KILMACTHOMAS_GRAIGUERUSH	7	SE	88	235400	106800
1516	n1516.uvf	KILDERMOT	16	E	53	320800	161200
1616	n1616.uvf	COOLGREANEY_ST_MARTINS	16	E	67	318700	169700
1637	n1637.uvf	KESHCARRIGAN_G_S	37	E	69	203800	307700

1707	n1707.uvf	Fenor_Tramore	7	SE	32	261600	98100
1712	n1712.uvf	KNOCKADERRYRESV_NO_1	12	SE	71	249800	106700
1716	n1716.uvf	ARDAMINE_HOUSE_MIDDLETOWN_HSE	16	E	72	319300	155000
1719	n1719.uvf	BANAGHER_CANALHSE	19	SE	37	200400	216000
1723	n1723.uvf	DUBLIN_PHOENIX_PARK	23	E	49	310000	236100
1807	n1807.uvf	STRADBALLY	7	SE	76	236500	98200
1812	n1812.uvf	WATERFORD_TYCOR	12	SE	49	259400	111600
1830	n1830.uvf	GRANARD_SPRINGSTOWN	30	E	70	238100	280900
1838	n1838.uvf	ARDEE_ST_BRIGID_S_HOSP	38	E	32	295700	290400
1923	n1923.uvf	GLENASMOLE_D_C_W_W	23	E	158	309000	222200
2012	n2012.uvf	CASHEL_BALLINAMONA	12	SE	80	204900	140000
2030	n2030.uvf	BALLYJAMESDUFF_KILCULLY	30	E	125	252600	290200
2037	n2037.uvf	CUILCAGH_MTNS	37	E	290	213000	324100
2038	n2038.uvf	CARRICKMACROSS_DUNOGE	38	E	88	281800	303900
2112	n2112.uvf	CLONMEL_BALLINGARRANE	12	SE	73	217100	119800
2115	n2115.uvf	HACKETSTOWN_VOC_SCH	15	E	189	297500	179900
2230	n2230.uvf	COOLE_COOLURE	30	E	73	241500	269400
2322	n2322.uvf	BOORA	22	E	58	218000	219700
2324	n2324.uvf	ENNISKERRY_KILMALIN	24	E	274	319800	217700
2332	n2332.uvf	BELLEWSTOWN_COLLIERTOWN	32	E	123	308400	267000
2411	n2411.uvf	KILMALLOCK_G_S	11	SE	89	160900	127400
2415	n2415.uvf	GLEN_IMAAL_FOR_STN	15	E	213	297200	194600
2420	n2420.uvf	OLDBRIDGE_OAKVIEW	20	E	335	315300	201100
2423	n2423.uvf	DUBLIN_CLONTARF	23	E	5	318100	236300
2432	n2432.uvf	RATOATH	32	E	91	302200	251400
2520	n2520.uvf	TINAHELY_MUCKLAGH	20	E	107	308000	174800
2523	n2523.uvf	DUBLIN_RINGSEND	23	E	7	318900	233900
2531	n2531.uvf	NAVAN	31	E	50	286100	267200
2532	n2532.uvf	DUNSHAUGHLIN_LAGORE	32	E	105	298800	253500
2620	n2620.uvf	LARAGH_TROOPERSTOWN	20	E	162	315800	197000
2632	n2632.uvf	FAIRYHOUSE_RACECOURSE	32	E	91	302000	249400
2638	n2638.uvf	ARDEE_BOHARNAMOE	38	E	31	294100	290200
2719	n2719.uvf	KILTORMER	19	SE	78	181900	221000
2720	n2720.uvf	ARKLOW_COOLADANGAN_HOUSE	20	E	61	322400	171300
2737	n2737.uvf	ROCKCORRY	37	E	99	264600	319000
2824	n2824.uvf	GLENEALY_KILMACURRAGH_PARK	24	E	122	324500	188100
2924	n2924.uvf	BALLYMAN_BRAY	24	E	171	323300	219900
2931	n2931.uvf	WARRENTOWN	31	E	90	292100	253500
2938	n2938.uvf	MELLIFONT_ABBEY	38	E	183	300300	283200
3015	n3015.uvf	CLONROCHE	15	E	116	285300	132000
3037	n3037.uvf	SWANLINBAR	37	E	69	219400	327500
3038	n3038.uvf	KINGSCOURT_GYPSUM	38	E	67	278800	292200
3124	n3124.uvf	ASHFORD_GLANMORE_GARDENS	24	E	110	324700	198500
3138	n3138.uvf	CASTLEBLAYNEY_DRUMGRISTON	38	E	117	285600	316800
3222	n3222.uvf	CLONASLEE_WATERWORKS_2	22	E	131	231700	210300
3224	n3224.uvf	WICKLOW_BALLINTESKIN	24	E	46	329800	190200
3238	n3238.uvf	CASTLEBELLINGHAM_LYNNS	38	E	21	307500	295000
3322	n3322.uvf	BELMONT_MILLS	22	E	46	206800	221800
3323	n3323.uvf	POULAPHUCA_GEN_STN	23	E	174	294500	208600
3324	n3324.uvf	ARKLOW_BALLYRICHARD_HOUSE	24	E	70	326100	177500
3331	n3331.uvf	TIMAHOE_SOUTH	31	E	88	278700	229200
3338	n3338.uvf	CLOGHER_HEAD_PORT	38	E	27	313300	289500
3422	n3422.uvf	GEASHILL	22	E	85	245400	220900

3431	n3431.uvf	DERRYGREENAGH	31	E	90	249300	238200
3438	n3438.uvf	RIVERSTOWN_GLENMORE_UPPER	38	E	165	315500	311000
3513	n3513.uvf	SLIEVEBLOOMMTNS_NEALSTOWN	13	SE	219	219900	193600
3522	n3522.uvf	HORSELEAP	22	E	72	228000	237300
3524	n3524.uvf	BALLYEDMONDUFF_HOUSE	24	E	335	318500	221800
3538	n3538.uvf	TOGHER_BARMEATH_CASTLE	38	E	79	309700	287600
3606	n3606.uvf	FERMOY_MOOREPARK	6	SE	55	181900	101400
3613	n3613.uvf	Kilkenny	13	SE	66	249400	157400
3623	n3623.uvf	NAAS_OSBERSTOWN	23	E	84	287300	220000
3624	n3624.uvf	KILCOOLE_TREATMENT_PLANT	24	E	9	330500	207400
3637	n3637.uvf	NEWBLISS_DRUMSHANNON	37	E	137	257300	323900
3706	n3706.uvf	RATHUIRC_FOR_STN	6	SE	131	157300	118500
3731	n3731.uvf	DUNSANY_GRANGE	31	E	90	288800	252800
3738	n3738.uvf	DUNDALK_KNOCKBRIDGE	38	E	59	301300	303700
3823	n3823.uvf	BALLYMORE_EUSTACE_D_C_W_W	23	E	172	293300	209200
3824	n3824.uvf	BALLYNAHINCH	24	E	287	322800	204500
3831	n3831.uvf	DROGHEDA_KILLINEER	31	E	47	307300	277400
3838	n3838.uvf	CASTLEBLAYNEY_CARRICKASLANE	38	E	122	280600	324400
3923	n3923.uvf	DUBLIN_MERRION_SQUARE	23	E	13	316400	233500
3924	n3924.uvf	ASHFORD_CRONYKEERY	24	E	15	329300	198800
3937	n3937.uvf	AUGHNASHEELAN_MISKAWN	37	E	155	208500	315100
4006	n4006.uvf	KNOCKANORE	6	SE	122	207500	89100
4013	n4013.uvf	COON	13	SE	178	259600	170600
4031	n4031.uvf	BAILIEBORO_DUNEENA	31	E	158	264600	299900
4037	n4037.uvf	LOUGH_GOWNA_GLENBROOK	37	E	91	231200	292100
4106	n4106.uvf	YOUGHAL_GLENDINEW_W	6	SE	107	206400	83900
4113	n4113.uvf	CALLAN_MOONARCHE	13	SE	79	239400	142700
4137	n4137.uvf	CAVAN_DRUMCONNICK	37	E	88	239800	305300
4213	n4213.uvf	PARKNAHOWNCULLAHILL	13	SE	110	234300	173900
4215	n4215.uvf	BUNCLODY_CORRAGH	15	E	116	294300	159900
4223	n4223.uvf	LEIXLIP_GEN_STN	23	E	42	300700	235800
4237	n4237.uvf	NEWBLISS_CRAPPAGH	37	E	113	258600	321500
4331	n4331.uvf	RATHWIRE	31	E	98	257000	251300
4337	n4337.uvf	CAVAN_LORETO_COLLEGE	37	E	64	241200	307200
4413	n4413.uvf	TULLAROAN_BALLYBEAGH	13	SE	299	233300	157800
4415	n4415.uvf	TULLOW_WATERWORKS	15	E	76	284700	173400
4512	n4512.uvf	RATHGORMACK	12	SE	160	233800	117400
4513	n4513.uvf	KILKENNY_LAVISTOWNHOUSE_2	13	SE	52	254300	154300
4514	n4514.uvf	JOHN_F_KENNEDY_PARK	14	E	70	272300	118900
4515	n4515.uvf	TULLOW_ARDOYNE_GLEBE	15	E	79	288200	169800
4531	n4531.uvf	NAVAN_TARA_MINES	31	E	52	284700	268400
4537	n4537.uvf	KILLESHANDRA_TOWN_LAKE	37	E	61	231100	308200
4612	n4612.uvf	CAHIR_VOC_SCH	12	SE	53	205400	125200
4615	n4615.uvf	BOOLAVOGUE_KNOCKAVOCCA	15	E	73	305100	146200
4631	n4631.uvf	KINNEGAD_MULLINGAR_ROAD	31	E	82	259000	245900
4637	n4637.uvf	BALLYCONNELL_MULLAGHDUFF	37	E	84	228200	317700
4713	n4713.uvf	ABBEYLEIX	13	SE	104	243800	184800
4715	n4715.uvf	FERNS_3	15	E	61	298300	154600
4719	n4719.uvf	NEWPORT_KILLOSCULLY	19	SE	180	178000	168400
4811	n4811.uvf	PATRICKSWELL_DOONEEN	11	SE	27	154500	149600
4813	n4813.uvf	CALLAN_MALLARDSTOWN	13	SE	70	244100	142300
4815	n4815.uvf	WEXFORD_WILDFOWL_RESERVE	15	E	1	307600	123900
4819	n4819.uvf	SILVERMINESMTNS_CURREENY	19	SE	312	190100	164700

4831	n4831.uvf	CORBETSTOWN	31	E	80	255500	240000
4906	n4906.uvf	CONNA_CARRIGEENHILL	6	SE	70	195500	95500
4913	n4913.uvf	THOMASTOWN_MT_JULIET	13	SE	49	254900	141500
4915	n4915.uvf	CAIM_MONGLASS	15	E	61	291000	141300
4919	n4919.uvf	Birr	19	SE	73	207400	204400
5012	n5012.uvf	BANSHA_AHERLOWW_W	12	SE	128	191700	128400
5013	n5013.uvf	DUNGARVAN_CASTLEFIELD	13	SE	75	259700	148500
5015	n5015.uvf	CARNEW_CRONYHORN	15	E	76	300500	163900
5031	n5031.uvf	WILKINSTOWN_YELLOW_RIVER	31	E	61	284100	276100
5037	n5037.uvf	BELTURBET_NAUGHAN	37	E	76	236700	320700
5114	n5114.uvf	ATHY_ST_JOSEPH_S_TERRACE	14	E	61	268100	194500
5131	n5131.uvf	KILSKYRE_ROBINSTOWN	31	E	87	268500	272000
5213	n5213.uvf	BALLACOLLA_FARRENHOUSE	13	SE	116	235200	184800
5214	n5214.uvf	COOLGREANY_CASTLEWARREN	14	E	262	259600	162300
5215	n5215.uvf	CASTLEBRIDGE_SEWAGE_WORKS	15	E	9	305000	126800
5231	n5231.uvf	SLANE_ARDCALF	31	E	125	294600	277400
5306	n5306.uvf	MOUNTRUSSELL	6	SE	195	161300	119800
5313	n5313.uvf	BALLYROAN_OATLANDS	13	SE	134	245100	186000
5323	n5323.uvf	NAAS_C_B_S	23	E	98	289600	219500
5331	n5331.uvf	DELVIN_CASTLE_G_C	31	E	91	259100	262900
5406	n5406.uvf	GALTEEMOUNTAINS_SKEHEENARINKY	6	SE	335	188700	119500
5411	n5411.uvf	KILFINNANE_EDUCATIONCENTRE	11	SE	165	168000	123200
5414	n5414.uvf	CASTLEDERMOT_KILKEA_HOUSE	14	E	85	274500	187700
5415	n5415.uvf	CLONROCHE_KNOXTOWN	15	E	117	282100	133200
5419	n5419.uvf	NEWPORT_VOC_SCH	19	SE	61	172600	162600
5431	n5431.uvf	VIRGINIA_MURMOD	31	E	122	260600	289100
5437	n5437.uvf	SHANTONAGH_TOOA	37	E	152	275300	312300
5506	n5506.uvf	BALLINAMULT_DOON	6	SE	168	217200	106800
5512	n5512.uvf	CLONMEL_REDMONDSTOWN	12	SE	64	223400	124700
5514	n5514.uvf	PAULSTOWN_SHANKHILL_CASTLE	14	E	63	266200	160000
5523	n5523.uvf	GLENASMOLE_CASTLEKELLY	23	E	183	310200	220800
5531	n5531.uvf	MOYNALTY_SHANCARNAN	31	E	91	271700	283700
5537	n5537.uvf	CLONES_DUNSEARK	37	E	137	251900	322200
5613	n5613.uvf	KILKENNY_Greenshill	13	SE	61	250500	156900
5623	n5623.uvf	GLENASMOLE_SUPT_S_LODGE	23	E	152	309200	222200
5631	n5631.uvf	ENFIELD_NEWCASTLE_HOUSE	31	E	91	275700	241600
5637	n5637.uvf	TULLYCO_ARTONAGH	37	E	140	254200	306300
5714	n5714.uvf	NEW_ROSS_W_W	14	E	64	272400	128300
5811	n5811.uvf	MEANUS	11	SE	50	158400	140200
5819	n5819.uvf	NENAGH_CONNOLLYPARK	19	SE	55	187200	180000
5837	n5837.uvf	KILLESHANDRA_BAWN	37	E	72	230000	306900
5912	n5912.uvf	PILTOWN_KILDALTONAGR_COLL	12	SE	18	247700	122400
5914	n5914.uvf	BAGENALSTOWN_KILDREENAGH	14	E	128	274900	163400
5919	n5919.uvf	CASTLECONNELL	19	SE	37	167800	162300
6019	n6019.uvf	KILLALOEDOCKS	19	SE	40	169700	173200
6114	n6114.uvf	POLLMOUNTY_FISH_FARM	14	E	24	274600	135600
6119	n6119.uvf	ROSCREA_NEWROAD	19	SE	111	214700	190800
6312	n6312.uvf	MULLINAHONE_KILLAGHY	12	SE	76	233400	140900
6314	n6314.uvf	EDENDERRY_BALLINLA	14	E	91	258300	231600
6319	n6319.uvf	BANAGHERMALTINGCOMPANY	19	SE	46	201500	213600
6323	n6323.uvf	MILLTOWN_GOLF_CLUB	23	E	30	316500	229900
6406	n6406.uvf	TALLOWKILMORE	6	SE	104	201200	91300
6412	n6412.uvf	CAHIRPARKII	12	SE	61	204500	122800

6414	n6414.uvf	ATHY_CHANTERLANDS	14	E	61	268800	193200
6419	n6419.uvf	COOGALOWERDOON	19	SE	88	181500	150800
6512	n6512.uvf	DUNDRUM_STOOKW_W	12	SE	183	200300	153900
6514	n6514.uvf	GOWRAN	14	E	55	262900	153200
6614	n6614.uvf	GRANGE_CON	14	E	157	285400	195500
6619	n6619.uvf	CLOUGHJORDAN_DEERPARK	19	SE	107	197900	188800
6623	n6623.uvf	BALLYBODEN	23	E	107	313100	226500
6712	n6712.uvf	LITTLETONIIB_NAM	12	SE	126	220400	151100
6714	n6714.uvf	KILBERRY_2	14	E	61	267300	198500
6719	n6719.uvf	LIMERICKJUNCTION_SOLOHEAD	19	SE	101	186000	139400
6812	n6812.uvf	CARRICK_ON_SUIR_2	12	SE	18	240500	121200
6814	n6814.uvf	GRAIGUENAMANAGH_BALLYOGAN_HOUSE	14	E	30	272000	140200
6912	n6912.uvf	MULLINAVAT_GLENDONNELL	12	SE	94	257500	123800
6914	n6914.uvf	GARRYHILL_MILLTOWN	14	E	107	278600	158700
6919	n6919.uvf	NEWPORT_COOLE	19	SE	72	172900	163800
7014	n7014.uvf	ATHY_LEVITSTOWN	14	E	61	270900	187900
7112	n7112.uvf	FETHARD_PARSONSHILL	12	SE	165	223800	140300
7114	n7114.uvf	MOONE_STERRICK_HALL	14	E	107	277700	193700
7412	n7412.uvf	ADAMSTOWN	12	SE	46	252400	108800
7512	n7512.uvf	CASHEL_BALLYKELLY	12	SE	110	210000	144800
7606	n7606.uvf	GALTEEW_W_LOUGHANANNA	6	SE	209	187400	118000
7612	n7612.uvf	CASHEL_BALLYDOYLEHOUSE	12	SE	123	211900	134400
7806	n7806.uvf	MITCHELSTOWMN_CORKSTREET	6	SE	91	181700	112800
7812	n7812.uvf	CLOGHEEN_CASTLEGRACE	12	SE	46	203300	114300
7906	n7906.uvf	BALLYHOOLY_CASTLEBLAGH	6	SE	140	171900	97600
8006	n8006.uvf	GLENCAIRN_TOURTANEHOUSE	6	SE	34	203300	96700
8012	n8012.uvf	DUNDRUM_GARRYDUFF	12	SE	94	196000	145200
8106	n8106.uvf	CAPPOQUIN_STATIONHOUSE	6	SE	30	210600	99200
8112	n8112.uvf	CLONOLTY_CLOGHER	12	SE	82	204400	152200
8123	n8123.uvf	CELBRIDGE_ARDRASS_HOUSE	23	E	62	297200	233500
8206	n8206.uvf	MITCHELSTOWN_GLENATLUCKEY	6	SE	168	183000	109700
8212	n8212.uvf	PORTLAW_MAYFIELD_2	12	SE	8	247700	115700
8306	n8306.uvf	SHANBALLYMORE	6	SE	75	167200	107600
8312	n8312.uvf	CASHEL_CASTLEBLAKE	12	SE	96	213600	132800
8406	n8406.uvf	CONNA_CASTLEVIEW	6	SE	30	195600	94500
8412	n8412.uvf	CLONMEL_ORCHARDSTOWN	12	SE	69	219100	127200
8506	n8506.uvf	LISMORE	6	SE	53	204800	98000
8512	n8512.uvf	FAITHLEGG_GOLFCLUB	12	SE	30	266800	111700
8612	n8612.uvf	ARDFINNAN_GARRYDUFF	12	SE	56	207800	115600
8623	n8623.uvf	BLESSINGTON_HEMPSTOWN	23	E	213	299900	217400
8706	n8706.uvf	kilworthy_kilally	6	SE	108	182300	104000
8712	n8712.uvf	THURLESRACECOURSE	12	SE	110	211500	159500
8812	n8812.uvf	SLIEVENAMONG_C	12	SE	67	220100	130300
8823	n8823.uvf	STRAFFAN_TURNINGS	23	E	70	291700	227000
8912	n8912.uvf	PORTLAW_BALLYVALLICAN	12	SE	85	243000	113600
8923	n8923.uvf	NAAS_NEWLAND_NORTH	23	E	93	286400	217100
9023	n9023.uvf	DUNDRUM_DROMARTIN	23	E	64	317700	227700
9112	n9112.uvf	KILSHEELAN	12	SE	72	228900	123200
9123	n9123.uvf	BARROCKSTOWN	23	E	84	292100	242000
9212	n9212.uvf	CLONMELRACECOURSE	12	SE	72	221700	123800
9223	n9223.uvf	DUN_LAOGHAIRE	23	E	30	324500	227800
9312	n9312.uvf	CAHIR_TOUREEN	12	SE	72	200700	128700

APPENDIX C

RATING REVIEW

BROWNSBARN (15006)

Gauging station 15006 is located in County Kilkenny on the River Nore. The River Nore is 140km in length, rising in North Tipperary and draining into the Celtic Sea at Waterford. The gauge is located 1.5km north-west of Inistioge town, on the upstream face of R700 Road Bridge (261735E 139142N). The river cross section is approximately 50m wide with the lowest bed level of 3.46m OD Malin and bank levels of 8.24m OD Malin for left bank, 7.56m OD Malin for right bank. The current OPW staff gauge zero level is 4.39m OD Malin. The surveyed staff gauge zero level is 4.42 OD Malin which is 0.03m higher. The OPW staff gauge zero has been used for the purposes of this review such that the model is considered relative to the spot gaugings and rating curve. The location of the gauging station and modelled watercourse are shown in Figure 1 below:

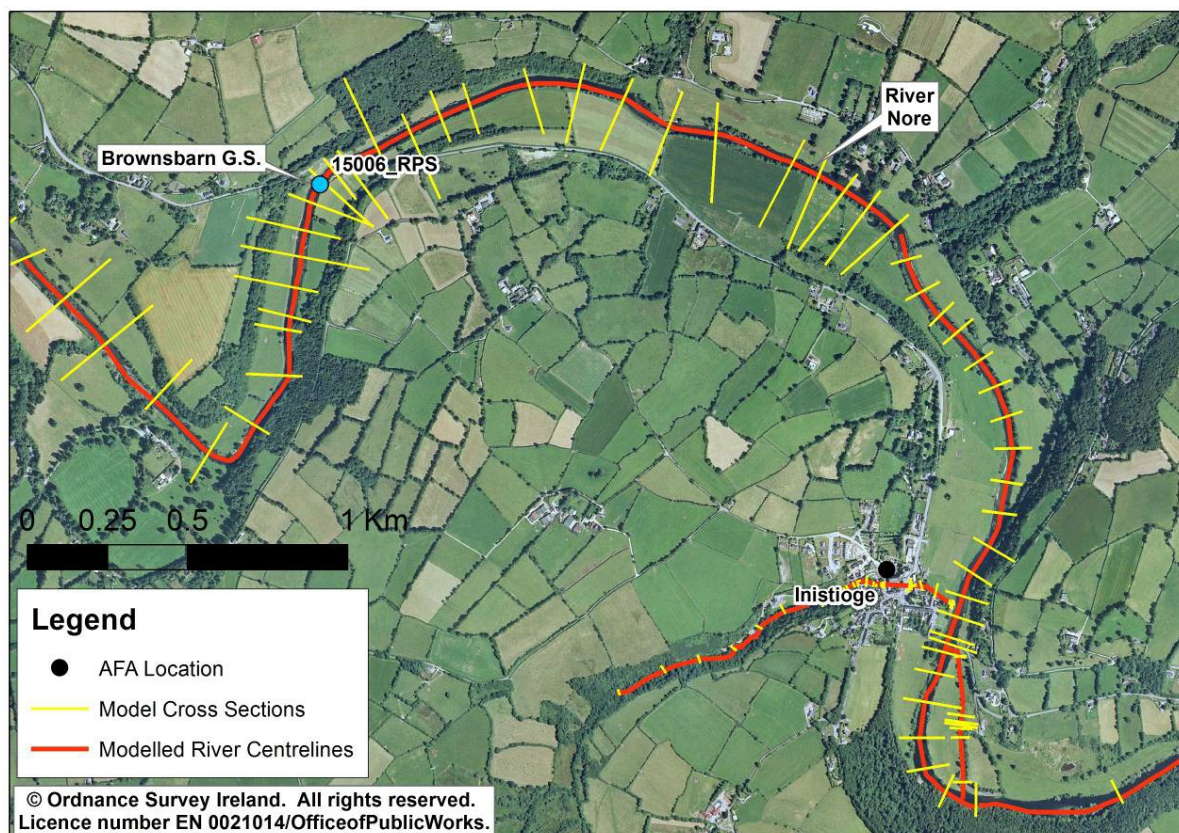


Figure 1: Gauging Station Location

The gauge is managed by the OPW and is currently active. Continuous water level and derived flow records have been provided from January 1972 to March 2011. There are 241 spot water level and flow gaugings recorded for this site from December 1945 to October 2009. The largest spot gauging is 317.15 m³/s recorded on 6th December 1960. Q_{med} for this site is estimated to be 299.3m³/s.

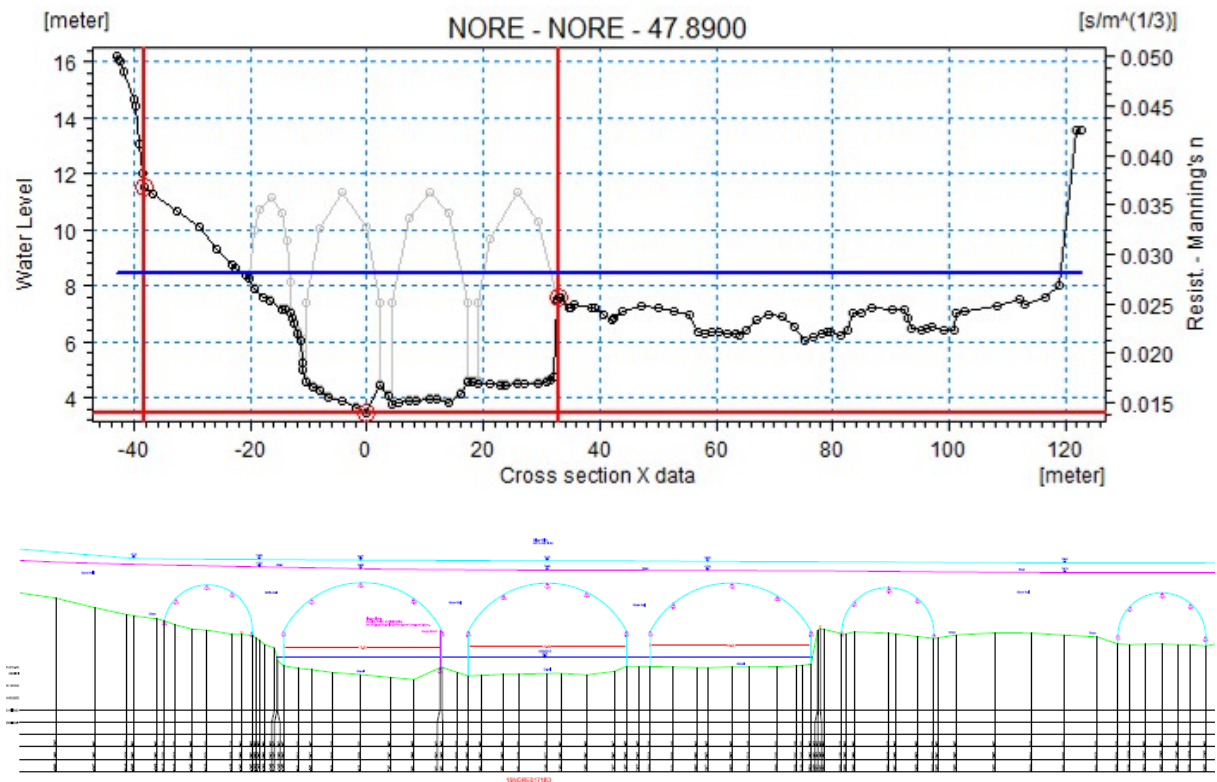


Figure 2: 1D Model Cross-Section at gauge location (Top); Critical structure survey Cross-Section immediately downstream of gauge location (Bottom)



Figure 3: Critical bridge structure photo immediately downstream of gauge (Top); Photo of bridge and staff gauge (looking downstream) (Bottom)

The modelled reach extends approximately 0.4km upstream of the gauge and 17.3km downstream of the gauge. The 1D model covers the entire length of this reach. The downstream extent of the model is located at the confluence of the River Nore (chainage 17323) and the River Barrow. The gauge is located on the upstream face of a bridge structure (8 arches). Four of the bridge arches are modelled within the 1D extents of the model and the other four are modelled as 1D structures within the 2D domain. There are an additional 10 bridge structures downstream of the gauge. The upstream and downstream approaches to the gauge are fairly meandering with wide floodplains. There are 402 cross sections included in the 1D hydraulic model for the Nore reach. The upstream boundary input was set with a hydrograph with a peak flow of $807.69 \text{ m}^3/\text{s}$ equivalent to an estimated 0.1% AEP event.

The OPW have described the rating standard at the Brownsbarn station a data quality code of 36 up to 1.37m and 56 up to 3.23m above staff gauge zero (SG0). Meaning that flow is estimated using a rating curve which is considered to be of fair quality and may contain a fair degree of error up to 1.37m

above SG0. Above 1.98m to 3.23m flow data is estimated using an extrapolated rating curve of which the reliability is unknown and it should be treated with caution. A national review under FSU classified Brownsbarn as an A2 quality rating meaning it is considered suitable for flows up to 1.3 times Q_{med} (299.3 m^3/s). A2 sites have a good degree of confidence in the extrapolated rating. The highest flow spot gauging is 317.15.

The results of the rating review are shown below in Figure 4 and Table 1. The graph demonstrates the derived RPS rating curve and shows the comparison between the OPW rating curve (which consists of 2 equations which have been retained) and spot gaugings.

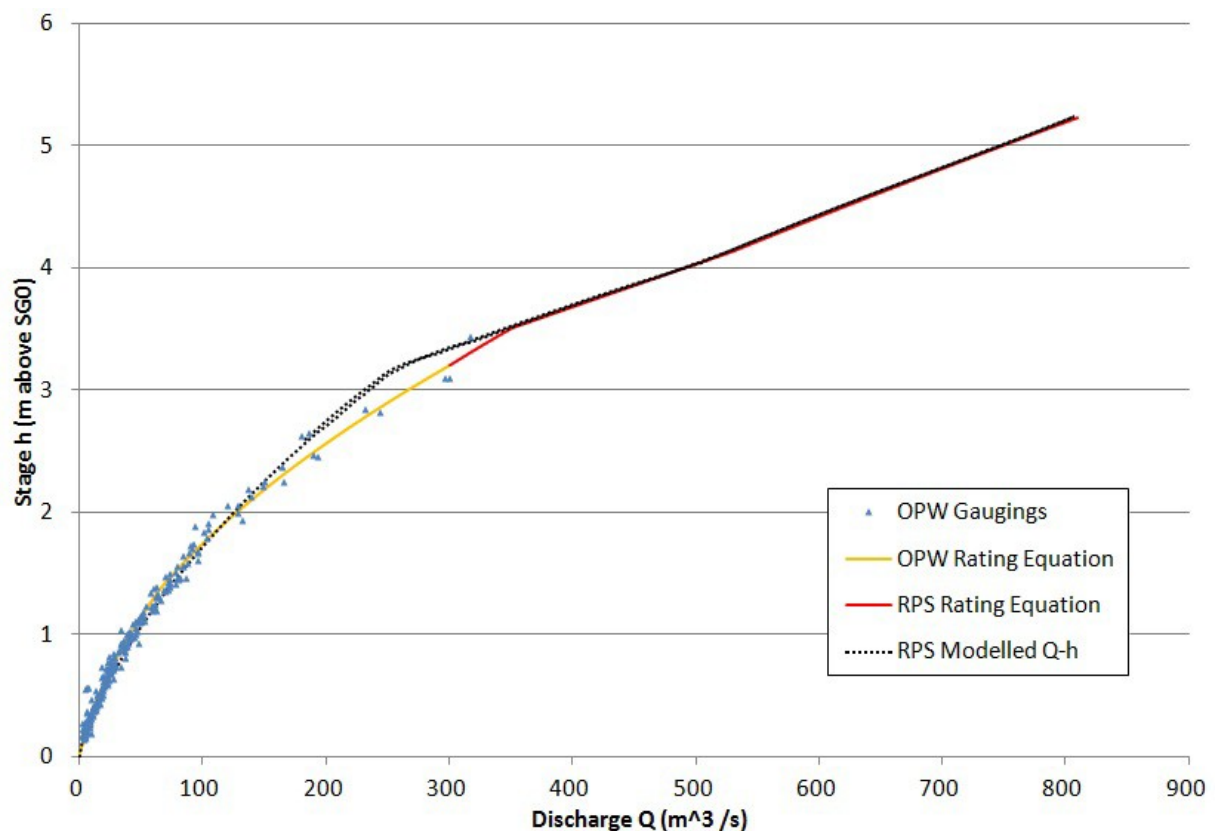


Figure 4: Comparison of Existing OPW Rating Curve and RPS Rating Curve for all flows

Section	Min Stage (m)	Max Stage (m)	C	a	b
1	0	1.3	35	0.12	1.59
2	1.3	3.2	31	0.12	1.892
3	3.2	3.508	2.793	2.136	2.793
4	3.508	4.138	92.719	-1.318	1.698
5	4.138	5.356	139.302	-1.316	1.289

Where: $Q = C(h+a)^b$ and h = stage readings (metres)

Note: Sections 1 & 2 are existing OPW rating curve segments

Table 1: Rating Equations for Gauge 15006

Figure 4 shows that the RPS rating curve is well calibrated to the spot gaugings and matches the existing rating across the range of which it is known to be reliable. During calibration the model was adjusted to focus best fit of the modelled rating to the highest spot gaugings. During initial calibration attempts, the low flow portion of the modelled Q-h could not be made to fit the low flow spot gaugings despite testing the full range of model adjustment parameters. Only the upstream face of the bridge was surveyed, a review of the survey downstream of the bridge suggested that it may be the case that the surveyed cross sections taken at intervals did not capture the highest bed level downstream of the gauge and this low flow control point may not be represented. To account for this a cross section was interpolated 10m downstream of the controlling cross section (15NORE01710) and the z values on the bottom of the channel were increased by 0.19m. This resulted in good calibration to the low flow spot gaugings. A Manning's n value of 0.02 was applied to the bridge structure and 0.028 was applied to the cross section within the 1D portion of the model. This is within the usual limits for a clean, slightly meandering channel with minimal vegetation on the banks and is considered a fair value for this reach. A floodplain roughness value of 0.034 was applied to the 2D portion of the model.

KILBRICKEN (15007)

Gauge 15007 is located in County Laois on the River Nore. The River Nore is 140km in length, rising in North Tipperary and draining into the Celtic Sea at Waterford. The gauge is located 0.5km south of Kilbricken village, on the upstream of Kilbricken Road Bridge (236220N 190265E). The Mountrath River is a tributary of the Nore; its confluence is approximately 2km upstream of the gauge station. The river cross section is approximately 39m wide with the lowest bed level of 83.87m OD Malin and bank levels of 88.36m OD Malin for left bank, 88.38m OD Malin for right bank. As stated in the survey data provided the gauge zero ordnance level is currently 84.615m OD (Malin).

The gauge is managed by the OPW and is currently active. Continuous water level and derived flow records have been provided from 1992 to 2010.

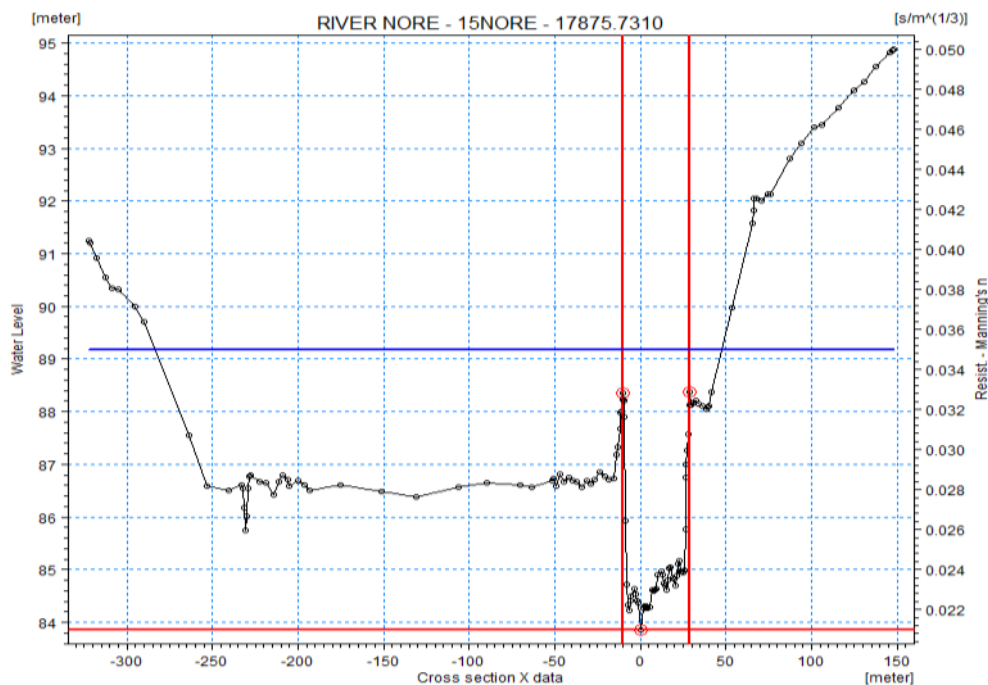


Figure 1: Model Cross-Section at Gauge Location (Top); Photo of gauge location (Bottom)

The study reach extends approximately 17.8km upstream of the gauge and 46.6km downstream of the gauge. The 1D model covers the entire length of this reach. The downstream extent of the model is located 2.8km upstream of Kilkenny town centre. The gauge is located on the upstream face of a bridge structure (7 arches). There are an additional 7 bridge structures upstream of the gauge and a further 12 bridge structures downstream. The upstream and downstream approaches to the gauge are fairly meandering. There are 899 cross sections included in the 1D hydraulic model for the Nore reach. The upstream boundary input was set with a hydrograph with a peak flow of $42.68 \text{ m}^3/\text{s}$ equivalent to an estimated 0.1% AEP event. Manning's n values were adjusted to describe the channel and flood plain roughness to replicate vegetation growth and produce a realistic model of the flow conditions.

The OPW have described the rating standard at Kilbricken gauge as 'good' on the HydroNet website. The National Review under FSU Work Package 2.1 rated the Kilbricken gauge with a quality classification of A2. The Q_{med} value from OPW for the station is $53.45 \text{ m}^3/\text{s}$ but there is a very low confidence in the Kilbricken gauge as there is a significant discrepancy between this Q_{med} value and the Q_{med} value of a gauge upstream (McMahons Bridge - 15004). For the purposes of the rating review the OPW rating equation is considered valid up to the level of the highest spot gauging of 2.5m.

The results of the rating review are shown below in Figures 1 and 2. The graphs demonstrate the derived RPS rating curve and show the comparison between the OPW rating curve (which consists of two equations) and spot gaugings.

During the model build process, low flows did not match the OPW rating curve. A review of the cross-sections downstream of the bridge structure suggests that it is likely a low flow control point has been missed. In addition to this, only one face of the bridge structure was surveyed, as such the downstream face could have a low control point. To account for this a cross-section was interpolated 5m downstream of the bridge structure, and the z values increased by 0.4m. Manning's values n of 0.035 and 0.045 were applied to the cross section. The Manning's value of 0.035 with the low flow control point resulted in the best fit rating curve; Figure 2 below shows a comparison of the different low flow curves.

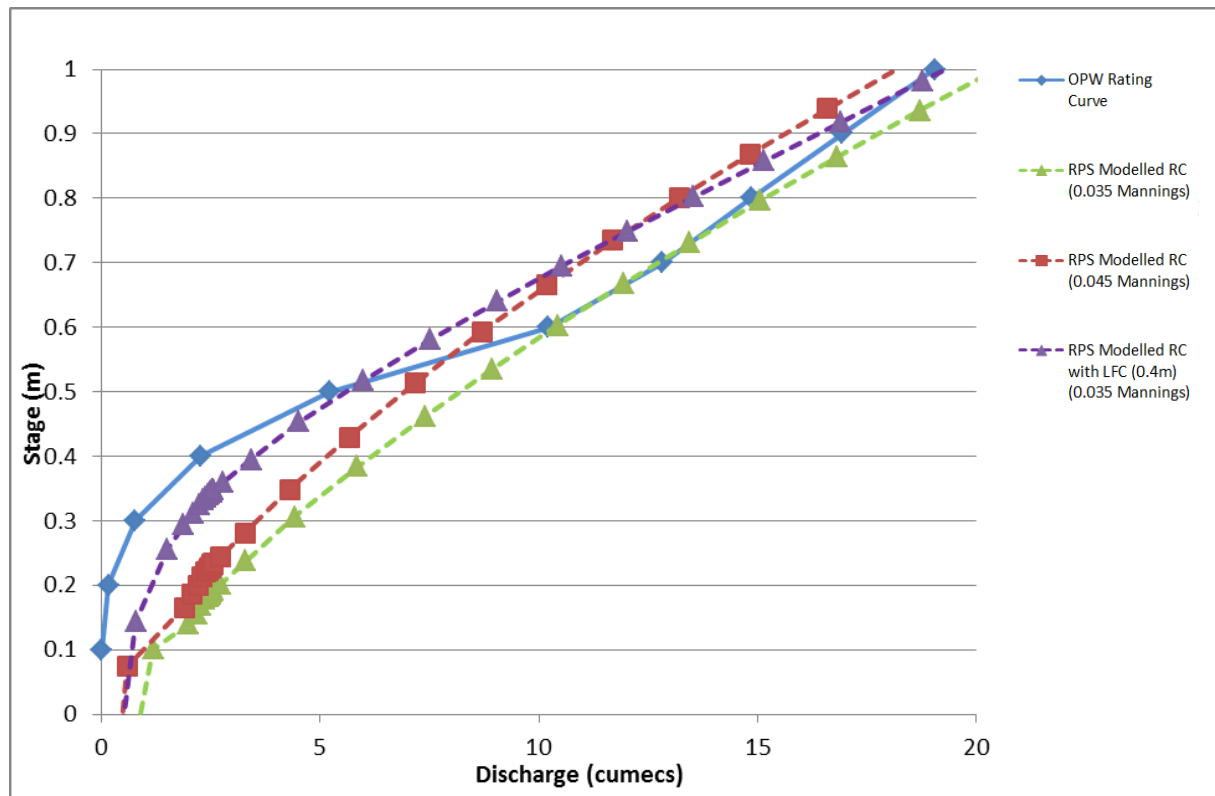


Figure 2: Comparison of RPS Rating Curves at low flows with the OPW Rating Curve

Two 1D only models were run; one with in channel only flow, and one extended to represent both in channel and out of channel flow. The in channel only model produced a reliable rating curve up to $131.76\text{m}^3/\text{s}$ at top of bank (stage 3.74m ; 88.36m OD Malin), above this, flow is glass walled and so not accurately representing water levels. The extended model represents the floodplain adjacent to the main channel as well as the main channel. In this case, the floodplain is lower than the top of bank level. The 1D model does not distinguish between floodplain and channel, as such, out of channel flow is shown before the water level reaches top of bank. Therefore, the 1D model represents higher discharge at lower stage making the rating curve unreliable above this level. As such, the rating curve for this model is only reliable up to $22.95\text{m}^3/\text{s}$ (stage of 1.13m ; 85.74m OD Malin).

Figure 3 shows that the models accurately represent the OPW rating curve based on the lower flow gaugings up to the $19.05\text{m}^3/\text{s}$ (approx. 1m stage; 85.62m OD Malin). Above this the curves diverge to simulate higher discharges than the OPW rating curve.

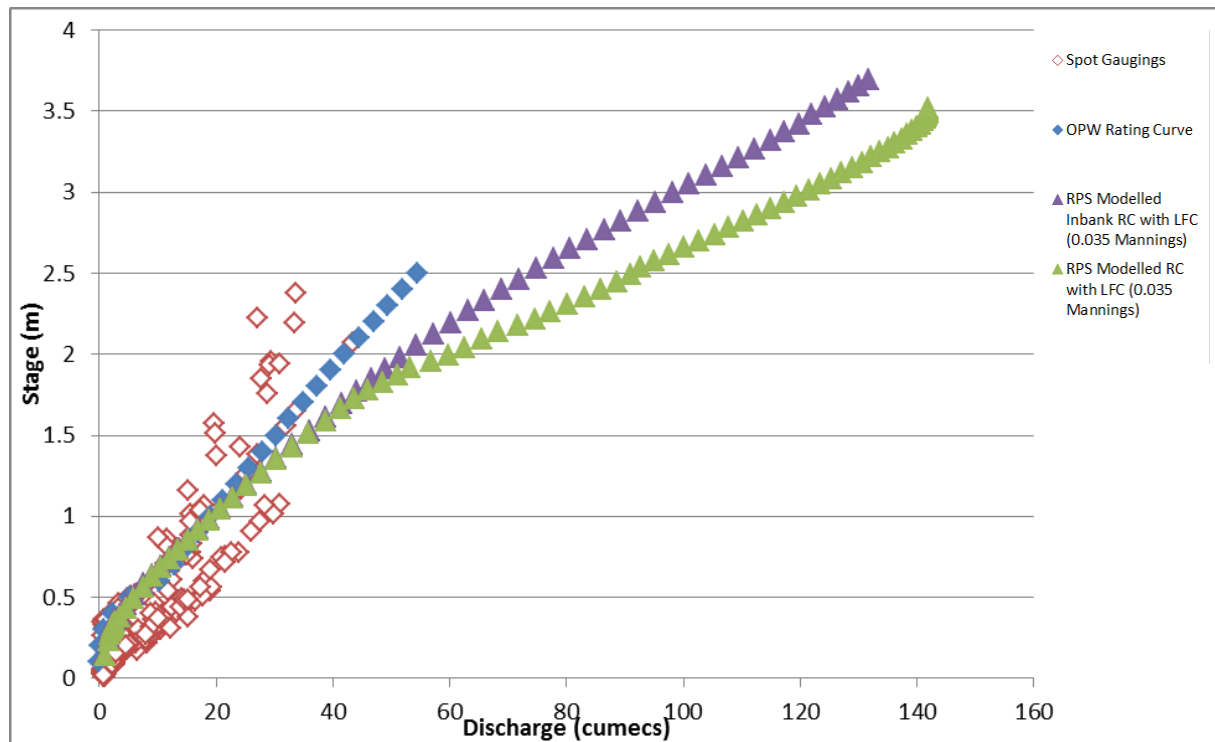


Figure 3: Comparison of Existing OPW Rating Curve, OPW Gaugings and RPS Rating Curve for all flows

A rating curve equation has not been calculated as the RPS modelled rating curve and OPW rating curve do not match. In this case, the surrounding floodplain is lower than the top of bank, as such, using a 1D model for the rating review limits the reliability of the modelled rating curve for out of channel flows.

CALLAN (15009)

The gauging station at Callan (15009) is located on the Kings River 128m west of Callan, County Kilkenny approximately 5.6km upstream of its confluence with the Skeaghcloran River. The staff gauge and recorder house are located on the left hand bank of an open channel section immediately downstream of a footbridge. The channel is approximately 17m wide with a minimum bed level of 60.07m OD Malin and bank levels of 62.165m OD Malin (Left bank) and 63.59m OD Malin (Right bank). The current OPW ordnance level of the gauge zero is 63.02m OD Poolbeg which is approximately 27mm lower than the Study surveyed level 60.347m OD Malin however the OPW SG0 level was used for consistency with the existing rating and spot gaugings. The location of the gauging station is shown in Figure 1 below.

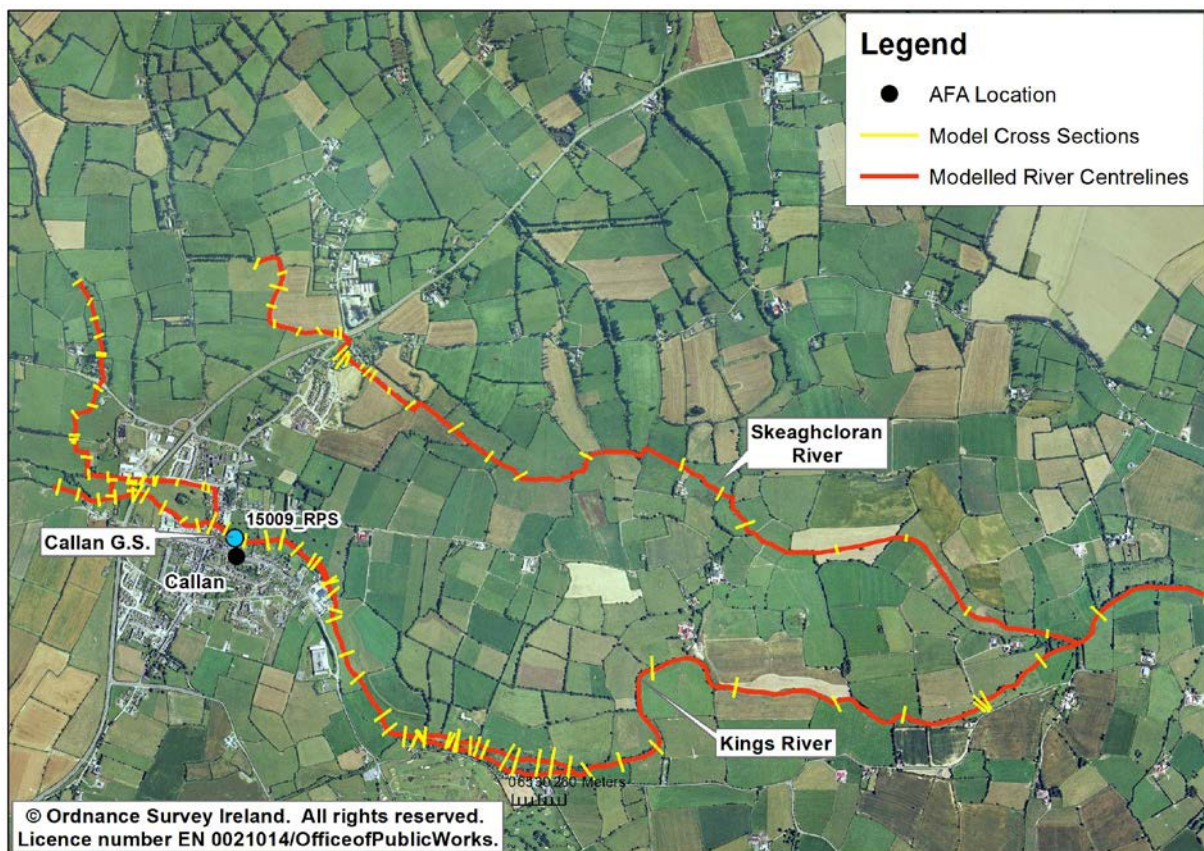


Figure 1: Location of Gauging Station

The gauge is managed by the OPW and is currently active. Continuous water level and derived flow records have been provided from 1956 to 2009. There have been 12 reviews of the rating for this site. There are 54 spot water level and flow gaugings recorded for this site from 25th September 57 to the 1st November 2009. Q_{med} for this site is estimated to be 41.08m³/s.

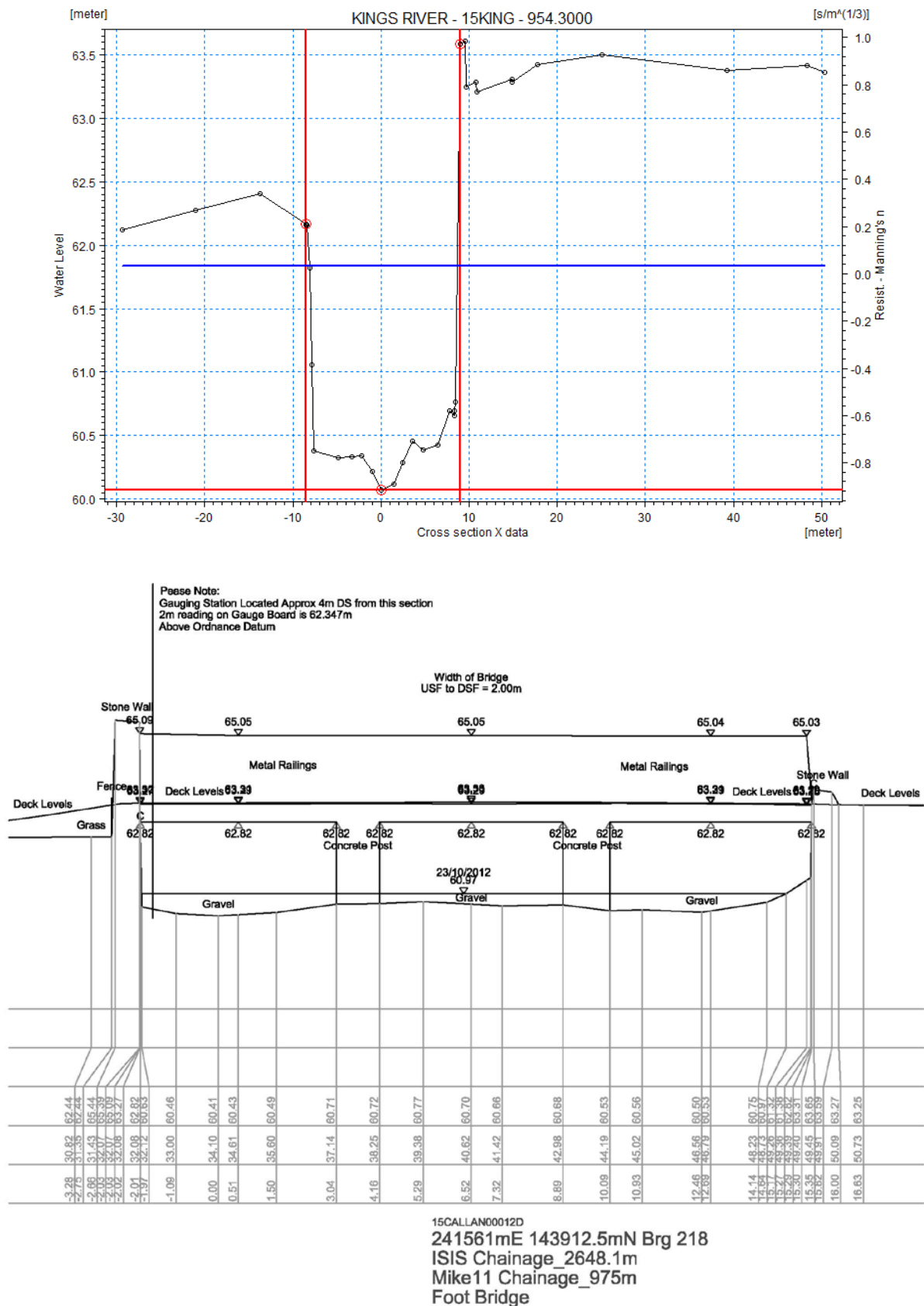


Figure 2: Model Cross-Section at gauge location (Top); Surveyed Cross-Section immediately upstream of gauge (Bottom)



Figure 3: Critical bridge structure photo immediately upstream of gauge (Top); Photo of bridge & AR housing (looking upstream) (Bottom)

The study reach extends approximately 652m upstream and 766m downstream of the gauge. There is an additional bridge structure upstream of the gauge and a further 6 downstream. There are also 3 weir structures along this reach. There are 507 cross-sections included in the model for the Kings River reach. The downstream boundary condition applied to the model was calculated as the critical flow Q-h relationship. The upstream boundary input was set with a hydrograph with a peak flow of $111.9\text{m}^3/\text{s}$ equivalent to an estimated 0.1% AEP event. Manning's n values were adjusted to describe the channel and flood plain roughness, replicate vegetation within the channel and produce a realistic model of the flow conditions.

The OPW have assigned the rating standard at the Callan station a data quality code of 36 up to 1.98m and 56 up to 3m above staff gauge zero. This means that the flow data is estimated using a rating curve that is considered to be of fair quality and may contain a fair degree of error up to 1.98m. Above 1.98m to 3m flow data is estimated using an extrapolated rating curve of which the reliability is unknown and it should be treated with caution. A national review under FSU classified Callan station

as a B quality rating meaning it is considered suitable for flows up to Q_{med} . Flows can be determined up to Q_{med} with confidence. B sites have a well defined rating up to Q_{med} i.e. the highest gauged flow was at least equal to or very close to Q_{med} , say at least $0.95 Q_{med}$ and no significant change in channel geometry was known to occur at or about the corresponding stage. The highest flow spot gauging is $44.46 \text{ m}^3/\text{s}$ although this was taken prior to 1976 when the staff gauge was lowered by 270mm. For the purposes of the rating review the OPW rating curve has been considered valid up to 1.86m as this is just above the highest gauged flow (post 1976) and is the point at which the modelled Q-h and rating diverge.

The results of the rating review are shown below in Figure 4 and Table 1. The graph demonstrates the derived RPS rating curve and shows the comparison between the OPW rating curve (which consists of 2 equations) and spot gaugings.

Section	Min Stage (m)	Max Stage (m)	C	a	b
1	0	0.46	28.1226	-0.115	2.44
2	0.46	1.86	15.866	-0.193	1.535
3	1.86	2.073	7.441	-0.176	2.959
4	2.073	2.463	10.243	-0.370	2.957
5	2.463	2.518	19.616	-0.775	2.932
6	2.518	2.594	25.318	-0.675	2.247

Where: $Q = C(h+a)^b$ and h = stage readings (metres)

Note: Section 1&2 are existing OPW rating curve segments

Table 1: Rating equation values for gauging station 15009

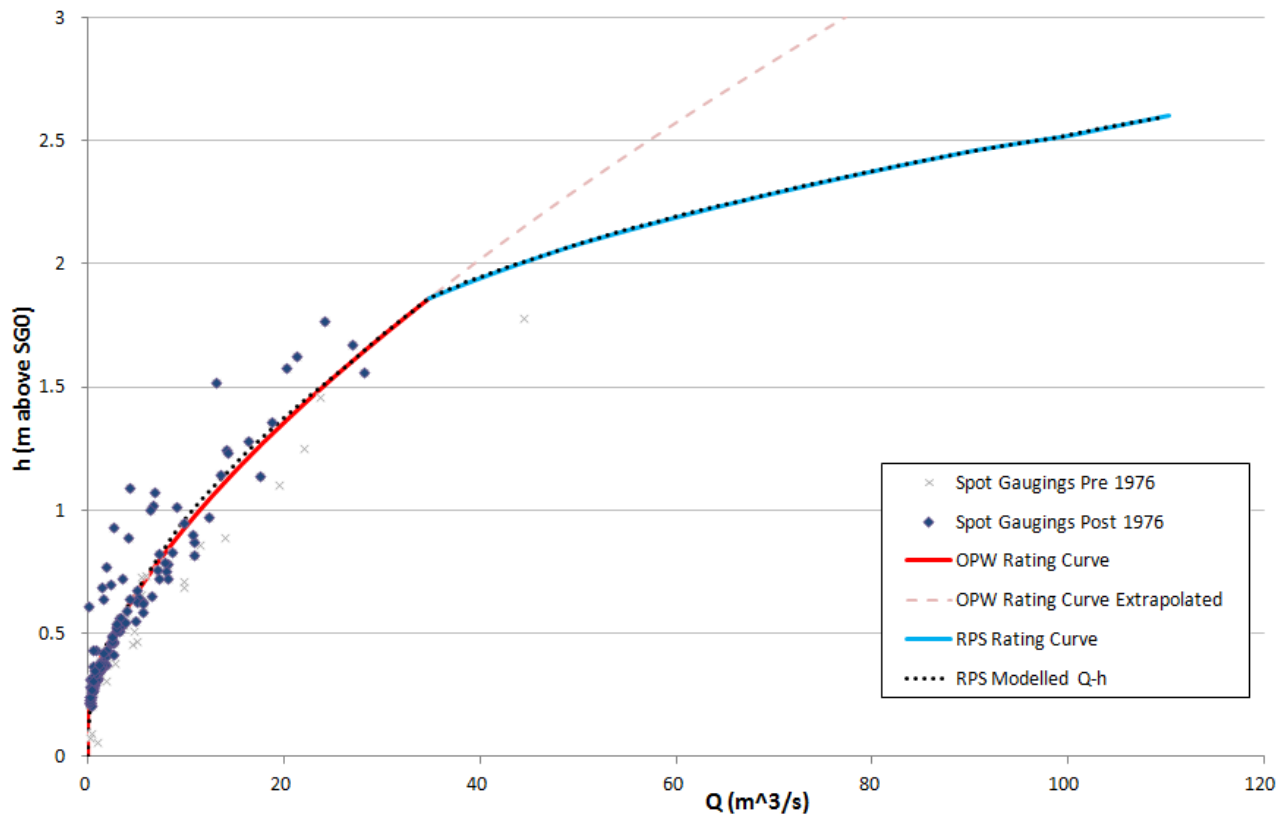


Figure 4: Comparison of Existing OPW Rating Curve, OPW Gaugings and RPS Rating Curve for all flows

Figure 4 shows that both the model curve and the existing OPW rating equation are well calibrated to the highest spot gauging, and the model results validate the existing OPW equations up to 1.86m above SG0. During the model build process, low flows did not match the OPW rating curve. A review of the cross-sections downstream of the bridge structure suggest that is likely a low flow control point has been missed. In addition to this, only one face of the bridge structure was surveyed, as such the downstream face could have a low flow control point. To account for this a cross-section was interpolated 4m downstream of the gauge location, and the z values increased by 0.3m. A Manning's n value of 0.035 was applied to the cross section in order to achieve calibration as this resulted in the closest fitting rating curve. This is within range of values expected for clean, straight natural channels.

MOUNT JULIET (15011)

The gauging station at Mount Juliet (15011) is located on the River Nore 3.4km west of Thomastown, County Kilkenny approximately 2.9km upstream of its confluence with the Little Arrigle River. The staff gauge and recorder house are located on the right hand bank of an open channel section immediately upstream of a bridge. The channel is approximately 43.5m wide with a minimum bed level of 19.29m OD Poolbeg and bank levels of 22.12m OD Poolbeg (Left bank) and 23.88m OD Poolbeg (Right bank). The current OPW ordnance level of the gauge zero is 21.10m OD Poolbeg. The surveyed staff gauge zero is 22.16m OD Poolbeg which 0.06m higher. The OPW staff gauge zero has been used for the purpose of this review such that the model is considered relative to the spot gaugings and rating curve. The location of the gauging station and modelled watercourse are shown in Figure 1 below:

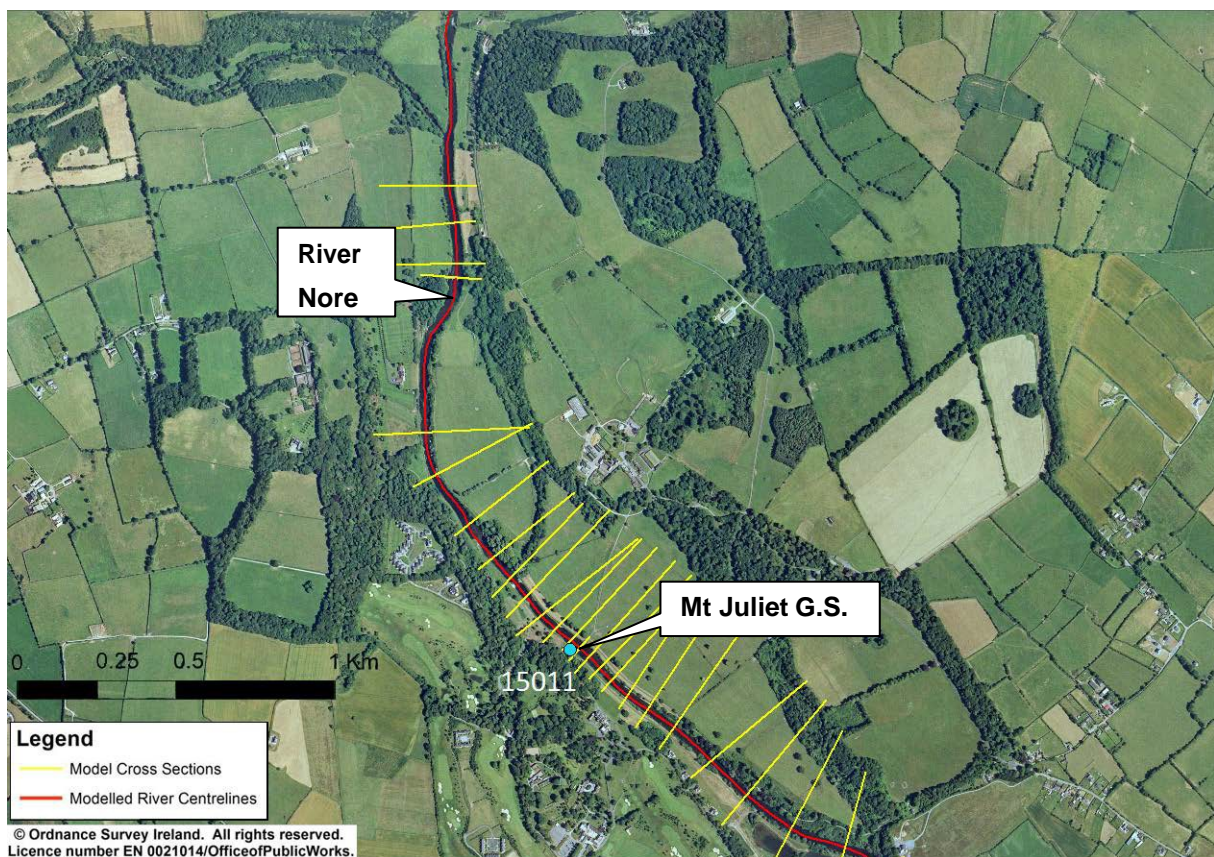


Figure 9 Gauging Station Location

The gauge is managed by the OPW and is currently active. Continuous water level and derived flow records have been provided from December 1979 to March 2011. There is a stable gravel bed and natural channel control at this site, negligible weed growth is also noted. Three reviews of the rating have been undertaken for this station. There are 65 water levels and flow spot gaugings recorded for the site from the 13th August 1946 to the 20th November 2009. Q_{med} for this site is estimated to be 274.5m³/s.

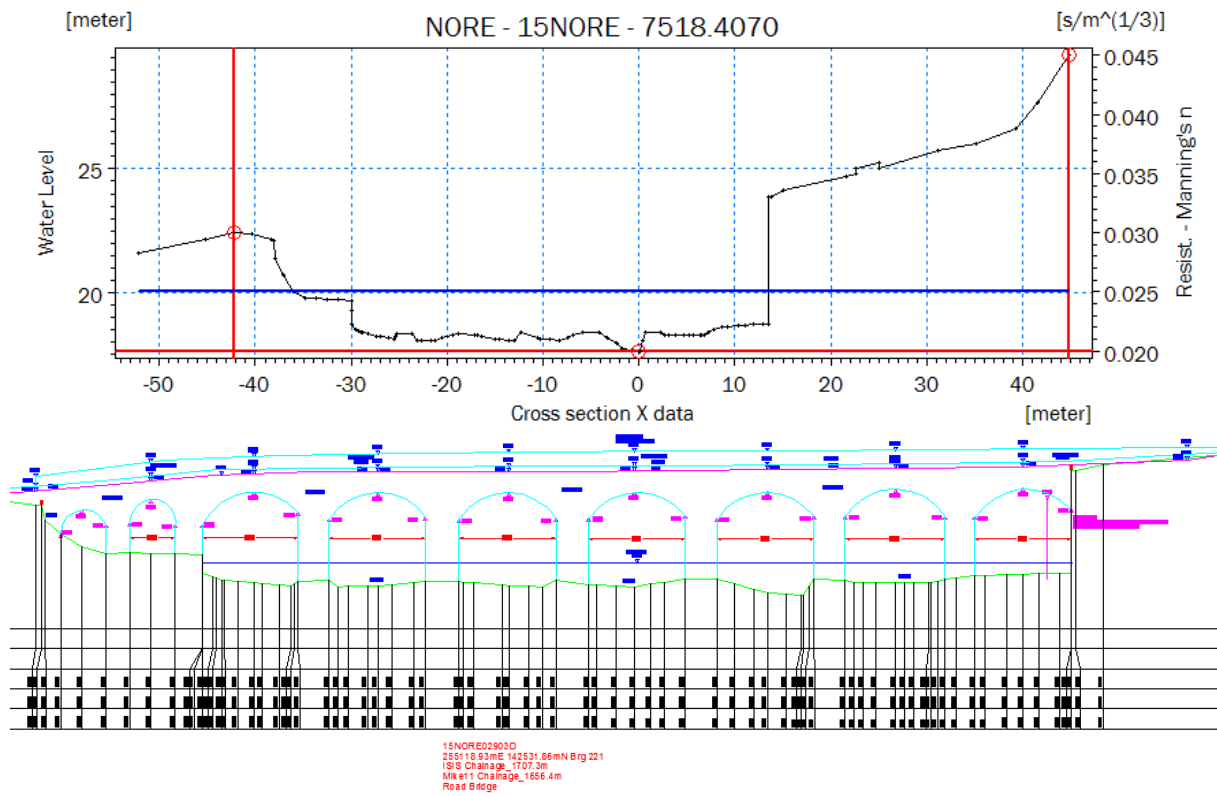


Figure 10 1D Model Cross-section at gauge location (Top); Control structure survey cross-section (Bottom)



Figure 11 Critical bridge structure photo 7m downstream of gauge (Top); Photo of staff gauge (looking upstream) (Bottom)

The modelled reach extends approximately 7.5km upstream of the gauge and 12.5km downstream of the gauge. The downstream extent of the model is located on the River Nore (Ch 20361), at the upstream extent of the Inistioge model. The gauge is located 7m upstream of the Mt Juliet Bridge structure (9 arches). The gauge is located on a 1D only reach of the model, all 9 of the bridge arches are modelled within the 1D extent. There are an additional two bridge structures upstream of the gauge and an additional two bridge structures downstream of the gauge. The upstream approach to the gauge is fairly straight, the downstream approach to the gauge is slightly meandering, and both upstream and downstream approaches to the gauge have wide floodplains. There are 132 cross sections included in the 1D hydraulic model for the Nore reach. The upstream boundary input was set with a hydrograph with a peak flow of flow of $618.59 \text{ m}^3/\text{s}$ equivalent to a 0.1% AEP event.

The OPW have described the rating standard at the Mt Juliet station with a data quality code of 36 from 0m up to 0.29m above staff gauge zero, meaning it is considered acceptable quality for general use, but may contain a fair degree of error. Above 0.29m up to 1.2m above staff gauge zero the OPW have described the rating standard at the Mt Juliet station a data quality code of 6, this rating standard is unclassified, has not been tested against actual water level and flow data and the data must be treated with caution. Above 1.2m up to 1.7m above staff gauge zero the OPW have described the rating at the Mt Juliet station as a data quality code of 16, this rating standard is unclassified, has not been tested against actual water level and flow data and the data must be treated with caution. Above 1.7m above staff gauge zero the OPW have described the rating with a data quality code of 56 which means the flow data is estimated using an extrapolated curve and inspected or corrected water level data and therefor the reliability of the data is unknown and must be treated with caution. A national review under FSU classified Mt Juliet as a C quality rating meaning it was not included in the FSU.

The results of the rating review are shown in Figure 4 and Table 1. The graph demonstrates the derived RPS rating curve and shows the comparison between the OPW rating curve (which consists of three equations which have been retained) and spot gaugings. Figure 4 demonstrates that the RPS rating curve is well calibrated to the spot gaugings and matches this existing rating.

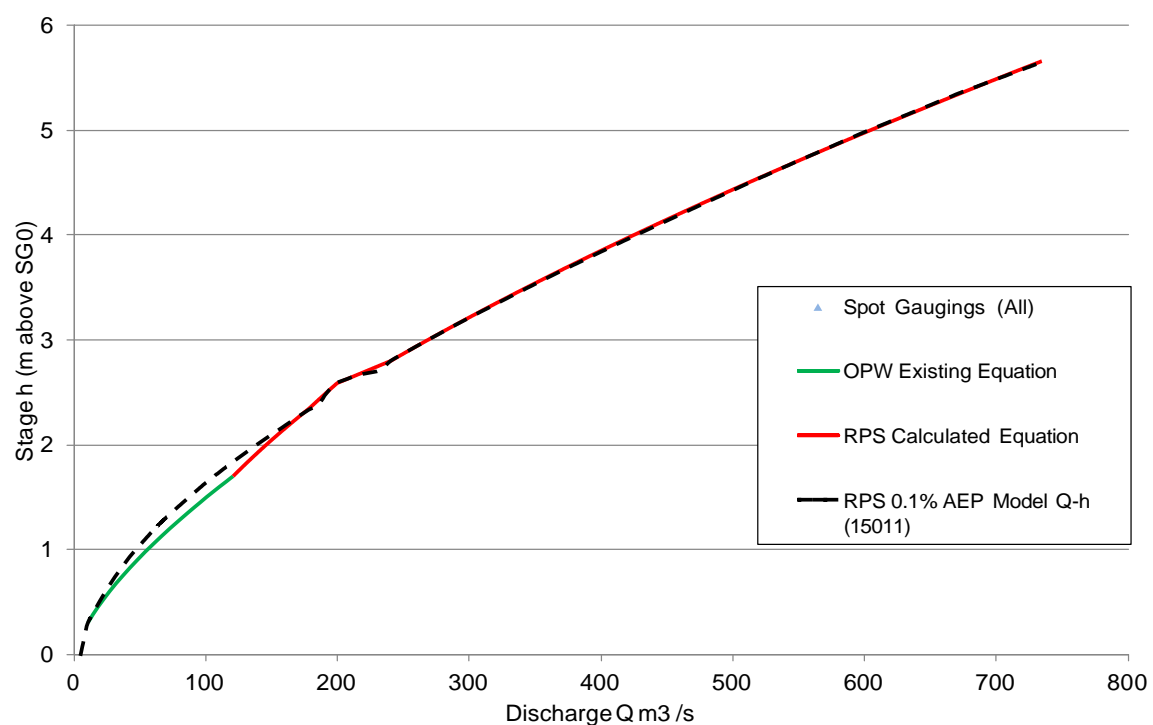


Figure 12 Comparison of Existing OPW Rating Curve and RPS Rating Curve for allflows

Table 2 Rating Equations for Gauge 15011

Section	Min Stage (m)	Max Stage (m)	C	a	b
1	0	0.29	52	0.05	1.5
2	0.29	1.2	52	0.05	1.5
3	1.2	1.7	52	0.05	1.5
4	1.7	2.34	5.821	1.893	2.369
5	2.34	2.58	5.968	2.287	2.215
6	2.58	2.8	199.364	1.588	0.966
7	2.8	8.66	92.6196	0.1197	1.5396

Where: $Q = C(h+a)^b$ and h = stage readings (metres)

Note: Sections 1 to 3 are existing OPW rating curve segments

During calibration the model was adjusted to focus best fit of the modelled rating to the highest spot gaugings. During initial calibration attempts the modelled Q-h was not in close agreement with the highest spot gaugings. A Manning's n value of 0.018 was applied to the bridge structure, 0.2 for Inflow and 0.2 Outflow loss coefficients were applied to the bridge structure openings. A Manning's n value of 0.025 was applied to the cross section within the 1D portion of the model. This is towards the lower limit for a clean, straight channel with minimal vegetation on banks, a review of the survey photography and aerial photography of the river confirmed that this is a fair value for this reach.

APPENDIX D

DESIGN FLOWS FOR MODELLING INPUT

Model 1 - Ballyragget

Node ID_CFRAMS	AREA (km ²)	Q _{med}	Flows for AEP								Model number
			50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	
15_994_1_RPS	109.63	13.25	13.25	16.94	19.51	22.16	26.00	29.23	32.81	42.69	Model 1
15_1461_8_RPS	5.63	1.54	1.54	2.22	2.75	3.33	4.24	5.05	6.01	8.97	Model 1
15008_RPS	116.54	14.50	14.50	18.17	20.69	23.29	27.01	30.13	33.55	42.93	Model 1
Top-up between 15_994_1_RPS & 15008_RPS	1.29	0.21	0.21	0.27	0.30	0.34	0.40	0.44	0.49	0.63	Model 1
15_306_2_RPS	1.66	0.27	0.27	0.39	0.48	0.58	0.74	0.88	1.05	1.56	Model 1
15_306_8_RPS	3.84	0.74	0.74	1.06	1.31	1.59	2.03	2.42	2.88	4.29	Model 1
Top Up between 15_306_2 and 15_306_8_RPS	2.18	0.40	0.40	0.58	0.72	0.87	1.11	1.32	1.57	2.34	Model 1
15_1455_7_RPS	7.76	2.90	2.90	4.18	5.17	6.26	7.97	9.51	11.31	16.89	Model 1
15_911_5	100.82	23.84	23.84	30.35	34.92	39.79	46.89	52.99	59.83	79.19	Model 1
15_1003_4_RPS	57.73	18.26	18.26	23.22	26.80	30.61	36.27	41.20	46.77	62.85	Model 1
15007_RPS	339.00	41.44	41.44	50.76	56.98	63.20	71.94	79.11	86.82	107.16	Model 1
Top-up between 15008_RPS & 15007_RPS	52.32	7.12	7.12	8.72	9.79	10.85	12.35	13.59	14.91	18.40	Model 1
15_923_2_RPS	65.60	8.59	8.59	10.95	12.55	14.22	16.59	18.57	20.74	26.68	Model 1
15_1060_5_RPS	5.46	0.70	0.70	1.01	1.25	1.52	1.93	2.31	2.74	4.10	Model 1
15_1938_5_RPS	39.37	5.10	5.10	7.13	8.64	10.28	12.78	15.00	17.57	25.21	Model 1
15_1813_11_RPS	8.60	1.43	1.43	2.06	2.54	3.08	3.92	4.68	5.57	8.31	Model 1
15004_RPS	488.70	51.83	51.83	63.65	71.37	79.09	89.72	98.32	107.50	130.97	Model 1
Top-up between 15007_RPS and 15004_RPS	30.67	3.87	3.87	4.76	5.33	5.91	6.70	7.35	8.03	9.79	Model 1
15_1749_11_RPS	69.15	6.40	6.40	8.23	9.48	10.79	12.66	14.25	15.99	20.79	Model 1
15_198_10_RPS	380.43	26.49	26.49	32.45	36.43	40.40	45.99	50.57	55.50	68.51	Model 1
15_910_2_RPS	94.72	12.60	12.60	16.47	19.14	21.92	25.93	29.32	33.06	43.40	Model 1
15012_RPS	1055.40	82.92	82.92	102.40	114.92	127.44	144.52	158.28	172.79	210.19	Model 1

Model 1 - Ballyragget

Node ID_CFRAMS	AREA (km ²)	Q _{med}	Flows for AEP								Model number
			50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	
Top-up between 15004_RPS and 15012_RPS	22.41	2.27	2.27	2.80	3.15	3.49	3.96	4.33	4.73	5.76	Model 1
15_1965_2_RPS	2.22	0.53	0.53	0.77	0.95	1.16	1.47	1.76	2.09	3.12	Model 1
15_1965_5_RPS	3.67	0.84	0.84	1.22	1.50	1.82	2.32	2.77	3.29	4.91	Model 1
Top-up between 15_1965_2_RPS & 15_1965_5_RPS	1.45	0.35	0.35	0.51	0.63	0.77	0.97	1.16	1.38	2.06	Model 1
15_420_3_RPS	1.69	0.38	0.38	0.54	0.67	0.81	1.04	1.24	1.47	2.20	Model 1
15_420_6_RPS	2.30	0.53	0.53	0.77	0.95	1.15	1.47	1.75	2.08	3.11	Model 1
Top up between 15_420_2 and 15_420_6_RPS	0.61	0.15	0.15	0.22	0.27	0.33	0.42	0.50	0.60	0.89	Model 1
15_479_6	22.55	3.17	3.17	4.55	5.60	6.75	8.52	10.12	11.98	17.65	Model 1
15_946_2_RPS	16.57	2.35	2.35	3.39	4.20	5.09	6.49	7.77	9.27	13.94	Model 1
15_1824_6_RPS	92.18	19.64	19.64	26.14	30.68	35.41	42.31	48.16	54.66	72.85	Model 1
15_944_2_RPS	9.84	1.45	1.45	2.10	2.59	3.14	4.00	4.77	5.67	8.47	Model 1
15_1850_6_RPS	1241.94	92.91	92.91	114.74	129.14	144.01	164.91	182.10	200.77	250.76	Model 1
Top-up between 15012_RPS & 15_1850_6_RPS	39.42	3.66	3.66	4.53	5.09	5.68	6.51	7.18	7.92	9.89	Model 1

Input flows - note input flows from other models - hydrographs provided here, check when other models are running

Top-up flows. These flows should be entered laterally

Check flows. Modellers should check to make sure these flows are being reached at each HEP

Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Node ID_CFRAMS	AREA (km ²)	MRFS Flows for AEP								HEFS Flows for AEP			Model number
		50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	10% (10)	1% (100)	0.1% (1000)	
15_994_1_RPS	109.63	16.53	21.15	24.35	27.66	32.45	36.49	40.95	53.29	29.92	44.83	65.47	Model 1
15_1461_8_RPS	5.63	1.92	2.77	3.43	4.15	5.29	6.31	7.50	11.20	4.21	7.75	13.76	Model 1
15008_RPS	116.54	18.07	22.64	25.78	29.02	33.66	37.54	41.81	53.50	31.68	46.13	65.73	Model 1
Top-up between 15_994_1_RPS & 15008_RPS	1.29	0.26	0.33	0.38	0.43	0.49	0.55	0.61	0.78	0.46	0.68	0.96	Model 1
15_306_2_RPS	1.66	0.32	0.46	0.57	0.69	0.88	1.05	1.25	1.87	0.65	1.19	2.12	Model 1
15_306_8_RPS	3.84	1.00	1.44	1.78	2.16	2.74	3.27	3.89	5.81	3.24	5.96	10.58	Model 1
Top Up between 15_306_2 and 15_306_8_RPS	2.18	0.59	0.85	1.05	1.27	1.62	1.93	2.29	3.42	1.91	3.51	6.23	Model 1
15_1455_7_RPS	7.76	3.48	5.02	6.20	7.52	9.57	11.41	13.58	20.27	7.07	13.01	23.11	Model 1
15_911_5	100.82	29.76	37.89	43.60	49.67	58.54	66.16	74.71	98.87	58.93	89.42	133.62	Model 1
15_1003_4_RPS	57.73	23.52	29.92	34.53	39.45	46.74	53.09	60.26	80.99	50.53	77.69	118.51	Model 1
15007_RPS	339.00	51.19	62.70	70.38	78.06	88.86	97.71	107.23	132.37	86.47	120.05	162.62	Model 1
Top-up between 15008_RPS & 15007_RPS	52.32	8.89	10.89	12.22	13.55	15.43	16.96	18.62	22.98	15.01	20.84	28.23	Model 1
15_923_2_RPS	65.60	10.67	13.61	15.60	17.67	20.62	23.08	25.78	33.17	19.17	28.36	40.75	Model 1
15_1060_5_RPS	5.46	0.84	1.22	1.50	1.82	2.32	2.77	3.29	4.91	1.72	3.16	5.61	Model 1
15_1938_5_RPS	39.37	6.54	9.15	11.08	13.18	16.39	19.24	22.52	32.33	16.40	28.48	47.86	Model 1
15_1813_11_RPS	8.60	1.82	2.64	3.26	3.95	5.02	5.99	7.13	10.64	4.79	8.81	15.64	Model 1
15004_RPS	488.70	63.85	78.41	87.92	97.44	110.52	121.12	132.43	161.35	108.02	148.81	198.23	Model 1
Top-up between 15007_RPS and 15004_RPS	30.67	4.77	5.86	6.57	7.28	8.26	9.05	9.89	12.05	8.07	11.12	14.81	Model 1
15_1749_11_RPS	69.15	7.94	10.20	11.75	13.37	15.70	17.66	19.81	25.77	14.44	21.69	31.66	Model 1

Model 2 - Ballyroan

Node ID_CFRAMS	AREA (km ²)	Q _{med}	Flows for AEP								Model number
			50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	
15_12_1_RPS	11.12	2.32	2.32	3.36	4.15	5.03	6.40	7.64	9.09	13.55	Model 2
15_467_2	1.59	0.40	0.40	0.58	0.72	0.87	1.11	1.32	1.57	2.34	Model 2
15_467_5	2.48	0.62	0.62	0.89	1.10	1.33	1.69	2.02	2.40	3.59	Model 2
Top-up between 15_467_2 & 15_467_5	0.89	0.24	0.24	0.34	0.42	0.51	0.65	0.77	0.92	1.37	Model 2
15_281_4_Inter_RPS	19.62	3.02	3.02	4.37	5.39	6.53	8.29	9.88	11.74	17.44	Model 2
Top-up between 15_12_1_RPS & 15_281_4_Inter_RPS	6.02	1.15	1.15	1.66	2.05	2.48	3.16	3.77	4.48	6.69	Model 2
15_418_4_RPS	6.04	0.48	0.48	0.69	0.85	1.03	1.31	1.56	1.86	2.77	Model 2
15_418_5_RPS	7.8	0.60	0.60	0.87	1.08	1.31	1.66	1.98	2.36	3.52	Model 2
Top-up between 15_418_4_RPS & 15_418_5_RPS	1.76	0.15	0.15	0.22	0.27	0.32	0.41	0.49	0.59	0.87	Model 2
15_378_6_Inter_RPS	30.80	4.16	4.16	5.91	7.21	8.64	10.83	12.78	15.05	21.88	Model 2
Top-up between 15_378_6_Inter_RPS & 15_281_4_Inter_RPS	3.38	0.52	0.52	0.74	0.91	1.09	1.37	1.61	1.90	2.76	Model 2
15_1938_5_RPS	39.37	5.10	5.10	7.13	8.64	10.28	12.78	15.00	17.57	25.21	Model 2
Top-up between 15_378_6_RPS & 15_1938_5_RPS	8.57	1.22	1.22	1.71	2.07	2.46	3.06	3.59	4.21	6.04	Model 2

Input flows - note input flows from other models - hydrographs provided here, check when other models are running

Top-up flows. These flows should be entered laterally

Check flows. Modellers should check to make sure these flows are being reached at each HEP

Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Node ID_CFRAMS	AREA (km ²)	MRFS Flows for AEP								HEFS Flows for AEP			Model number
		50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	10% (10)	1% (100)	0.1% (1000)	
15_12_1_RPS	11.12	2.89	4.19	5.17	6.27	7.97	9.52	11.33	16.89	6.36	11.69	20.75	Model 2
15_467_2	1.59	0.48	0.70	0.86	1.04	1.33	1.58	1.88	2.81	1.03	1.89	3.35	Model 2
15_467_5	2.48	0.77	1.11	1.37	1.66	2.12	2.52	3.00	4.48	1.85	3.41	6.05	Model 2
Top-up between 15_467_2 & 15_467_5	0.89	0.29	0.42	0.52	0.64	0.81	0.96	1.15	1.71	0.64	1.18	2.10	Model 2
15_281_4_Inter_RPS	19.62	3.77	5.45	6.73	8.14	10.34	12.32	14.64	21.75	8.26	15.13	26.72	Model 2
Top-up between 15_12_1_RPS & 15_281_4_Inter_RPS	6.02	1.43	2.07	2.56	3.10	3.94	4.70	5.59	8.35	3.14	5.78	10.26	Model 2
15_418_4_RPS	6.04	0.59	0.86	1.06	1.28	1.63	1.95	2.32	3.46	1.43	2.63	4.67	Model 2
15_418_5_RPS	7.8	0.75	1.09	1.34	1.63	2.07	2.47	2.94	4.39	1.82	3.34	5.94	Model 2
Top-up between 15_418_4_RPS & 15_418_5_RPS	1.76	0.19	0.27	0.33	0.40	0.51	0.61	0.73	1.09	0.41	0.75	1.34	Model 2
15_378_6_Inter_RPS	30.80	5.19	7.37	8.99	10.77	13.51	15.95	18.78	27.30	11.05	19.59	33.54	Model 2
Top-up between 15_378_6_Inter_RPS & 15_281_4_Inter_RPS	3.38	0.65	0.93	1.13	1.36	1.70	2.01	2.37	3.44	1.39	2.47	4.23	Model 2
15_1938_5_RPS	39.37	6.54	9.15	11.08	13.18	16.39	19.24	22.53	32.33	16.38	28.45	47.81	Model 2
Top-up between 15_378_6_RPS & 15_1938_5_RPS	8.57	1.57	2.19	2.65	3.16	3.93	4.61	5.40	7.75	3.92	6.82	11.46	Model 2

Input flows

Top-up flows. These flows should be entered laterally

Check flows. Modellers should check to make sure these flows are being reached at each HEP

Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Model 3 - Mountrath

Node ID_CFRAMS	AREA (km ²)	Q _{med}	Flows for AEP								Model number
			50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	
15_1000_1_RPS	26.71	8.38	8.38	10.77	12.51	14.41	17.28	19.81	22.72	31.31	Model 3
15_289_1_RPS	13.47	4.67	4.67	6.09	7.13	8.26	9.96	11.46	13.18	18.24	Model 3
15_289_3_RPS	15.00	4.81	4.81	6.27	7.36	8.54	10.34	11.93	13.77	19.23	Model 3
Top-up between 15_289_1_RPS and 15_289_3_RPS	1.53	0.57	0.57	0.74	0.87	1.01	1.22	1.41	1.62	2.27	Model 3
15_1907_1	2.86	0.76	0.76	1.10	1.36	1.65	2.10	2.51	2.98	4.45	Model 3
15_1907_U	0.86	0.24	0.24	0.34	0.42	0.51	0.65	0.78	0.92	1.38	Model 4
Top-up between 15_1907_U & 15_1907_1	2.00	0.55	0.55	0.79	0.97	1.18	1.50	1.79	2.13	3.18	Model 5
15027_RPS	46.72	14.12	14.12	18.15	21.08	24.29	29.13	33.40	38.30	52.78	Model 3
Top-up between 15_1000_1_RPS & 15027_RPS	2.15	0.79	0.79	1.01	1.18	1.36	1.63	1.87	2.14	2.95	Model 3
15_10000_U_RPS	0.99	0.31	0.31	0.45	0.55	0.67	0.85	1.02	1.21	1.81	Model 3
15_10000_Trib_RPS	2.32	0.92	0.92	1.34	1.65	2.00	2.54	3.04	3.61	5.39	Model 3
Top-up between 15_10000_U_RPS & 15_10000_Trib_RPS	1.32	0.66	0.66	0.96	1.18	1.43	1.82	2.17	2.58	3.86	Model 3
15_1360_8_RPS	6.40	1.22	1.22	1.76	2.17	2.63	3.35	4.00	4.76	7.10	Model 3
15_1003_4_RPS	57.73	15.51	15.51	19.73	22.77	26.01	30.82	35.01	39.74	53.40	Model 3
Top-up between 15027_RPS & 15_1003_4_RPS	2.58	0.84	0.66	0.84	0.97	1.11	1.31	1.49	1.70	2.28	Model 3

Input flows

Top-up flows. These flows should be entered laterally

Check flows. Modellers should check to make sure these flows are being reached at each HEP

Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Node ID_CFRAMS	AREA (km ²)	MRFS Flows for AEP								HEFS Flows for AEP			Model number
		50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	10% (10)	1% (100)	0.1% (1000)	
15_1000_1_RPS	26.71	10.46	13.44	15.61	17.99	21.57	24.73	28.36	39.08	21.10	33.43	52.82	Model 3
15_289_1_RPS	13.47	5.84	7.60	8.90	10.31	12.44	14.30	16.45	22.78	12.03	19.33	30.78	Model 3
15_289_3_RPS	15.00	6.00	7.83	9.18	10.66	12.90	14.88	17.18	23.99	12.41	20.11	32.42	Model 3
Top-up between 15_289_1_RPS and 15_289_3_RPS	1.53	0.71	0.92	1.08	1.26	1.52	1.75	2.02	2.83	1.33	2.15	3.47	Model 3
15_1907_1	2.86	0.99	1.43	1.76	2.14	2.72	3.25	3.86	5.77	1.99	3.67	6.52	Model 3
15_1907_U	0.86	0.30	0.43	0.53	0.64	0.81	0.97	1.15	1.72	0.65	1.19	2.12	Model 4
Top-up between 15_1907_U & 15_1907_1	2.00	1.14	1.65	2.03	2.47	3.14	3.74	4.45	6.65	3.01	5.53	9.83	Model 5
15027_RPS	46.72	17.73	22.78	26.47	30.49	36.58	41.93	48.08	66.25	35.76	56.64	89.50	Model 3
Top-up between 15_1000_1_RPS & 15027_RPS	2.15	0.99	1.27	1.48	1.71	2.05	2.34	2.69	3.71	2.00	3.17	5.01	Model 3
15_10000_U_RPS	0.99	0.39	0.56	0.69	0.84	1.06	1.27	1.51	2.26	1.78	3.29	5.84	Model 3
15_10000_Trib_RPS	2.32	1.50	2.18	2.69	3.26	4.14	4.96	5.89	8.79	3.96	7.30	12.95	Model 3
Top-up between 15_10000_U_RPS & 15_10000_Trib_RPS	1.32	1.21	1.76	2.17	2.63	3.34	3.98	4.74	7.09	2.35	4.32	7.68	Model 3
15_1360_8_RPS	6.40	1.63	2.36	2.91	3.53	4.49	5.36	6.38	9.52	5.11	9.41	16.71	Model 3
15_1003_4_RPS	57.73	23.52	29.92	34.53	39.45	46.74	53.09	60.26	80.99	55.58	85.46	130.36	Model 3
Top-up between 15027_RPS & 15_1003_4_RPS	2.58	0.85	1.08	1.25	1.43	1.68	1.92	2.19	2.93	1.88	2.88	4.41	Model 3

Input flows - note input flows from other models - hydrographs provided here, check when other models are running

Top-up flows. These flows should be entered laterally

Check flows. Modellers should check to make sure these flows are being reached at each HEP

Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Model 4 - Freshford

Node ID_CFRAMS	AREA (km ²)	Q _{med}	Flows for AEP								Model number
			50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	
15_1029_1	34.916	5.72	5.72	7.88	9.43	11.07	13.52	15.64	18.05	24.95	Model 4
15_75_7	24.91	6.44	6.44	9.25	11.38	13.74	17.39	20.68	24.54	36.32	Model 4
15_75_9	25.973	6.62	6.62	9.45	11.58	13.91	17.49	20.68	24.39	35.56	Model 4
Top-up between 15_75_7 & 15_75_9	1.063	0.32	0.32	0.45	0.55	0.67	0.84	0.99	1.17	1.70	Model 4
15_461_3	1.574	0.51	0.51	0.73	0.91	1.10	1.40	1.67	1.98	2.96	Model 4
15_1390_U	0.79	0.26	0.26	0.38	0.47	0.57	0.73	0.87	1.03	1.54	Model 4
15_1390_3	1.607	0.47	0.47	0.69	0.85	1.03	1.31	1.56	1.85	2.77	Model 4
Top-up between 15_1390_U & 1390_3	0.817	0.25	0.25	0.36	0.45	0.54	0.69	0.83	0.98	1.47	Model 4
15_698_2_RPS	3.419	0.98	0.98	1.42	1.75	2.12	2.70	3.22	3.84	5.73	Model 4
Top-up between 15_461_3 & 15_698_2_RPS	0.238	0.08	0.08	0.12	0.14	0.17	0.22	0.27	0.32	0.47	Model 4
15_1824_2	23.18	5.38	5.38	7.71	9.46	11.40	14.39	17.08	20.21	29.74	Model 4
15_1824_6_RPS	92.183	19.64	19.64	26.14	30.68	35.41	42.31	48.16	54.66	72.85	Model 4
Top-up between 15_1029_1 & 15_1824_6_RPS	4.695	1.21	1.21	1.61	1.88	2.18	2.60	2.96	3.36	4.48	Model 4

	Input flows - note input flows from other models - hydrographs provided here, check when other models are running
	Top-up flows. These flows should be entered laterally
	Check flows. Modellers should check to make sure these flows are being reached at each HEP
	Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Node ID_CFRAMS	AREA (km ²)	MRFS Flows for AEP								HEFS Flows for AEP			Model number
		50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	10% (10)	1% (100)	0.1% (1000)	
15_1029_1	34.916	7.14	9.83	11.77	13.82	16.88	19.53	22.53	31.15	14.46	23.99	38.26	Model 4
15_75_7	24.91	8.04	11.55	14.21	17.15	21.70	25.82	30.63	45.34	17.45	31.72	55.70	Model 4
15_75_9	25.973	8.49	12.13	14.85	17.84	22.44	26.53	31.29	45.62	18.46	32.97	56.69	Model 4
Top-up between 15_75_7 & 15_75_9	1.063	0.69	0.99	1.21	1.46	1.83	2.17	2.56	3.73	1.79	3.20	5.51	Model 4
15_461_3	1.574	0.63	0.92	1.13	1.37	1.74	2.08	2.48	3.69	1.39	2.56	4.54	Model 4
15_1390_U	0.79	0.33	0.48	0.59	0.71	0.91	1.08	1.29	1.92	0.72	1.33	2.36	Model 4
15_1390_3	1.607	0.80	1.15	1.42	1.72	2.19	2.61	3.11	4.64	1.96	3.60	6.39	Model 4
Top-up between 15_1390_U & 1390_3	0.817	0.54	0.78	0.97	1.17	1.49	1.78	2.12	3.16	1.43	2.63	4.67	Model 4
15_698_2_RPS	3.419	1.42	2.05	2.54	3.07	3.91	4.67	5.55	8.29	3.36	6.18	10.98	Model 4
Top-up between 15_461_3 & 15_698_2_RPS	0.238	0.17	0.24	0.30	0.36	0.46	0.55	0.66	0.98	0.44	0.82	1.45	Model 4
15_1824_2	23.18	6.70	9.59	11.78	14.19	17.90	21.25	25.15	37.01	14.47	26.11	45.47	Model 4
15_1824_6_RPS	92.183	24.83	33.05	38.79	44.77	53.49	60.89	69.11	92.10	47.96	75.29	113.89	Model 4
Top-up between 15_1029_1 & 15_1824_6_RPS	4.695	1.50	2.00	2.35	2.71	3.24	3.68	4.18	5.57	2.88	4.52	6.84	Model 4

Input flows - note input flows from other models - hydrographs provided here, check when other models are running

Top-up flows. These flows should be entered laterally

Check flows. Modellers should check to make sure these flows are being reached at each HEP

Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Model 05 - Kilkenny

Node ID_CFRAMS	AREA (km ²)	Qmed	Flows for AEP								Model number
			50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	
15_1850_6_RPS	1,241.94	92.91	92.91	114.74	129.14	144.01	164.91	182.10	200.77	250.76	Model 1
15_1955_6_RPS	299.85	107.84	107.84	132.10	148.28	164.45	187.21	205.86	225.92	278.87	Model 5
15_1078_3_RPS	7.68	2.58	2.58	3.72	4.59	5.57	7.09	8.45	10.06	15.01	Model 5
15_671_U	2.18	0.49	0.49	0.71	0.88	1.07	1.36	1.62	1.93	2.88	Model 5
15_671_2_RPS	4.33	0.97	0.97	1.40	1.74	2.10	2.68	3.19	3.80	5.67	Model 5
Top-up between 15_671_U & 15_671_2_RPS	2.15	0.51	0.51	0.73	0.90	1.09	1.39	1.66	1.97	2.95	Model 5
15104_RPS	1,567.50	208.04	208.04	256.93	289.17	322.46	369.27	407.75	449.57	561.49	Model 5
Top-up between 15_1850_6_RPS & 15104_RPS	13.70	3.85	3.85	4.75	5.35	5.97	6.83	7.55	8.32	10.39	Model 5
15_1515_3_RPS	44.20	8.40	8.40	11.83	14.36	17.10	21.26	24.93	29.15	41.65	Model 5
15_1922_1	7.27	1.74	1.74	2.51	3.11	3.77	4.79	5.72	6.80	10.15	Model 5
15_1922_7_RPS	10.21	2.11	2.11	3.07	3.81	4.64	5.94	7.13	8.54	12.93	Model 5
Top-up between 15_1922_1 & 15_1922_7_RPS	2.94	0.66	0.66	0.96	1.19	1.44	1.85	2.22	2.66	4.03	Model 5
15050_RPS	70.90	11.10	11.10	15.22	18.18	21.37	26.12	30.26	34.97	48.61	Model 5
Top-up between 15050_RPS & 15_1515_3_RPS	16.49	2.83	2.83	3.88	4.64	5.45	6.66	7.71	8.91	12.39	Model 5
15_1269_4_RPS	70.99	11.14	11.14	15.27	18.24	21.44	26.20	30.35	35.08	48.76	Model 5
Top-up between 15050_RPS & 15_1269_4_RPS	0.09	0.02	0.02	0.03	0.04	0.04	0.05	0.06	0.07	0.10	Model 5
15002_RPS	1,642.23	216.00	216.00	266.76	300.24	334.80	383.40	423.36	466.78	582.98	Model 5
Top-up between 15104_RPS & 15002_RPS	3.74	0.72	0.72	0.89	1.00	1.12	1.28	1.41	1.56	1.95	Model 5
15_1150_1_RPS	28.66	7.93	7.93	11.25	13.71	16.39	20.49	24.12	28.32	40.86	Model 5
15_1323_1	1.63	0.28	0.28	0.41	0.51	0.62	0.78	0.93	1.11	1.66	Model 5
15_1323_5_RPS	2.43	0.49	0.49	0.71	0.87	1.06	1.35	1.61	1.91	2.85	Model 5
Top-up between 15_1323_1 &	0.81	0.17	0.17	0.25	0.31	0.38	0.48	0.57	0.68	1.01	Model 5

Model 05 - Kilkenny

Node ID_CFRAMS	AREA (km ²)	Qmed	Flows for AEP								Model number
			50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	
15_1323_5_RPS											
15_1332_4_RPS	36.08	9.17	9.17	12.89	15.66	18.69	23.31	27.43	32.21	46.49	Model 5
Top-up between 15_1332_4_RPS & 15_1150_1_RPS	5.00	1.44	1.44	2.02	2.46	2.93	3.66	4.30	5.05	7.29	Model 5
15_1257_3	13.23	2.68	2.68	3.84	4.72	5.70	7.20	8.56	10.14	14.97	Model 5
15_1257_7	15.09	3.02	3.02	4.34	5.33	6.43	8.14	9.67	11.45	16.91	Model 5
Top-up between 15_1257_3 & 15_1257_7	1.87	0.43	0.43	0.59	0.70	0.83	1.02	1.19	1.38	1.94	Model 5
15_368_5_RPS	12.51	2.36	2.36	3.44	4.27	5.19	6.65	7.99	9.56	14.48	Model 5
15_161_2	1,718.60	225.57	225.57	278.58	313.55	349.64	400.39	442.13	487.47	608.82	Model 5
15_159_4_RPS	11.42	2.08	2.08	3.02	3.75	4.57	5.85	7.02	8.41	12.73	Model 5
15_521_3_RPS	1,744.54	229.19	229.19	283.05	318.58	355.25	406.81	449.21	495.28	618.59	Model 5
Top-up between 15002_RPS & 15_521_3_RPS	14.52	2.43	2.43	3.00	3.38	3.77	4.32	4.77	5.25	6.56	Model 5

Input flows - note input flows from other models - hydrographs provided here, check when other models are running

Top-up flows. These flows should be entered laterally

Check flows. Modellers should check to make sure these flows are being reached at each HEP

Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Node ID_CFRAMS	AREA (km ²)	MRFS Flows for AEP								HEFS Flows for AEP			Model number
		50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	10% (10)	1% (100)	0.1% (1000)	
15_1850_6_RPS	1,241.94	114.62	141.55	159.32	177.66	203.45	224.65	247.69	309.35	195.74	276.00	380.07	Model 5
15_1955_6_RPS	299.85	133.47	163.50	183.52	203.54	231.70	254.79	279.61	345.15	225.47	313.03	424.04	Model 5
15_1078_3_RPS	7.68	3.21	4.64	5.73	6.95	8.84	10.55	12.55	18.73	7.04	12.96	23.01	Model 5
15_671_U	2.18	0.62	0.89	1.10	1.33	1.69	2.02	2.40	3.59	1.35	2.48	4.41	Model 5

Node ID_CFRAMS	AREA (km ²)	MRFS Flows for AEP								HEFS Flows for AEP			Model number
		50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	10% (10)	1% (100)	0.1% (1000)	
15_671_2_RPS	4.33	1.21	1.75	2.17	2.62	3.34	3.98	4.74	7.08	2.66	4.89	8.69	Model 5
Top-up between 15_671_U & 15_671_2_RPS	2.15	1.11	1.60	1.97	2.39	3.04	3.63	4.32	6.45	2.92	5.36	9.53	Model 5
15104_RPS	1,567.50	256.60	316.91	356.68	397.74	455.47	502.94	554.52	692.57	438.21	617.91	850.89	Model 5
Top-up between 15_1850_6_RPS & 15104_RPS	13.70	4.75	5.87	6.60	7.36	8.43	9.31	10.27	12.82	8.11	11.44	15.75	Model 5
15_1515_3_RPS	44.20	10.49	14.77	17.93	21.35	26.54	31.12	36.40	52.00	22.03	38.23	63.88	Model 5
15_1922_1	7.27	2.17	3.14	3.88	4.70	5.98	7.14	8.49	12.67	4.77	8.77	15.57	Model 5
15_1922_7_RPS	10.21	2.61	3.80	4.72	5.74	7.36	8.83	10.58	16.01	5.98	11.20	20.29	Model 5
Top-up between 15_1922_1 & 15_1922_7_RPS	2.94	0.88	1.28	1.59	1.94	2.49	2.98	3.57	5.41	2.51	4.69	8.50	Model 5
15050_RPS	70.90	13.32	18.26	21.82	25.64	31.34	36.31	41.96	58.33	23.64	39.34	63.19	Model 5
Top-up between 15050_RPS & 15_1515_3_RPS	16.49	5.97	8.18	9.78	11.49	14.05	16.27	18.81	26.14	14.46	24.06	38.65	Model 5
15_1269_4_RPS	70.99	14.22	19.50	23.30	27.38	33.46	38.77	44.80	62.28	33.90	56.41	90.62	Model 5
Top-up between 15050_RPS & 15_1269_4_RPS	0.09	0.05	0.06	0.08	0.09	0.11	0.13	0.15	0.21	0.11	0.19	0.31	Model 5
15002_RPS	1,642.23	259.20	320.11	360.29	401.76	460.08	508.03	560.13	699.58	390.31	550.37	757.88	Model 5
Top-up between 15104_RPS & 15002_RPS	3.74	1.56	1.92	2.16	2.41	2.76	3.05	3.36	4.20	3.20	4.51	6.21	Model 5
15_1150_1_RPS	28.66	9.90	14.05	17.11	20.46	25.58	30.11	35.36	51.01	21.03	36.99	62.66	Model 5
15_1323_1	1.63	0.36	0.51	0.63	0.77	0.98	1.17	1.39	2.07	0.78	1.43	2.54	Model 5

Node ID_CFRAMS	AREA (km ²)	MRFS Flows for AEP								HEFS Flows for AEP			Model number
		50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	10% (10)	1% (100)	0.1% (1000)	
15_1323_5_RPS	2.43	0.61	0.88	1.09	1.32	1.68	2.01	2.39	3.56	1.34	2.46	4.38	Model 5
Top-up between 15_1323_1 & 15_1323_5_RPS	0.81	0.22	0.31	0.39	0.47	0.60	0.71	0.85	1.27	0.48	0.88	1.55	Model 5
15_1332_4_RPS	36.08	11.47	16.12	19.59	23.37	29.15	34.30	40.27	58.13	25.97	45.49	77.09	Model 5
Top-up between 15_1332_4_RPS & 15_1150_1_RPS	5.00	3.07	4.32	5.24	6.26	7.80	9.18	10.78	15.56	7.75	13.58	23.01	Model 5
15_1257_3	13.23	3.34	4.80	5.90	7.11	8.99	10.68	12.66	18.69	7.24	13.13	22.96	Model 5
15_1257_7	15.09	3.75	5.39	6.62	7.98	10.09	11.99	14.21	20.97	8.13	14.73	25.77	Model 5
Top-up between 15_1257_3 & 15_1257_7	1.87	0.93	1.28	1.53	1.81	2.22	2.59	3.00	4.22	2.27	3.82	6.23	Model 5
15_368_5_RPS	12.51	2.95	4.29	5.32	6.48	8.30	9.97	11.94	18.07	6.54	12.25	22.20	Model 5
15_161_2	1,718.60	278.01	343.34	386.43	430.92	493.47	544.90	600.78	750.35	480.34	677.31	932.69	Model 5
15_159_4_RPS	11.42	2.59	3.77	4.68	5.70	7.30	8.77	10.50	15.89	5.75	10.77	19.53	Model 5
15_521_3_RPS	1,744.54	282.47	348.85	392.63	437.83	501.38	553.64	610.41	762.38	488.04	688.17	947.64	Model 5
Top-up between 15002_RPS & 15_521_3_RPS	14.52	3.00	3.70	4.17	4.65	5.32	5.88	6.48	8.09	5.18	7.30	10.06	Model 5

	Input flows
	Top-up flows. These flows should be entered laterally
	Check flows. Modellers should check to make sure these flows are being reached at each HEP Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Model 06 - Callan

Node ID_CFRAMS	AREA (km ²)	Qmed	Flows for AEP								Model number
			50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	
15_1733_4_RPS	199.64	62.54	62.54	76.61	85.99	95.37	108.57	119.39	131.02	161.72	Model 6
15_1786_1_RPS	1.45	0.12	0.12	0.17	0.21	0.25	0.32	0.38	0.46	0.68	Model 6
15_1786_4_RPS	2.24	0.37	0.37	0.54	0.66	0.81	1.03	1.22	1.46	2.17	Model 6
Top-up between 15_1786_1_RPS & 15_1786_4_RPS	0.78	0.14	0.14	0.20	0.25	0.30	0.38	0.46	0.54	0.81	Model 6
15_1786_5_RPS	0.05	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.04	0.06	Model 6
15_1786_6_RPS	0.09	0.03	0.03	0.04	0.05	0.06	0.07	0.09	0.11	0.16	Model 6
15009_RPS	202.77	63.20	63.20	77.42	86.90	96.38	109.72	120.65	132.40	163.44	Model 6
Top-up between 15_1733_4_RPS & 15009_RPS	0.75	0.20	0.20	0.24	0.27	0.30	0.35	0.38	0.42	0.52	Model 6
15_501_2	33.64	5.22	5.22	7.06	8.40	9.85	12.04	13.96	16.16	22.60	Model 6
15_593_1	2.00	0.51	0.51	0.73	0.90	1.09	1.39	1.66	1.98	2.95	Model 6
15_1678_11_RPS	20.44	3.38	3.38	4.80	5.87	7.04	8.85	10.46	12.35	18.03	Model 6
15_686_5_RPS	29.33	4.81	4.81	6.65	7.99	9.42	11.56	13.43	15.56	21.73	Model 6
Top-up between 15_593_1 & 15_686_5_RPS	6.89	1.21	1.21	1.68	2.02	2.38	2.92	3.39	3.93	5.49	Model 6
15_1137_9_RPS	16.45	2.75	2.75	3.88	4.73	5.66	7.10	8.39	9.90	14.46	Model 6
15_458_8	6.45	0.93	0.93	1.35	1.67	2.02	2.57	3.07	3.65	5.45	Model 6
15_1869_2_RPS	299.27	80.95	80.95	99.16	111.30	123.44	140.52	154.53	169.58	209.33	Model 6
Top-up between 15009_RPS & 15_1869_2_RPS	10.63	2.11	2.11	2.59	2.90	3.22	3.66	4.03	4.42	5.46	Model 6
15_1870_2_RPS	70.62	9.65	9.65	12.54	14.56	16.69	19.80	22.46	25.42	33.74	Model 6
15_1991_3_RPS	10.93	1.71	1.71	2.48	3.06	3.70	4.71	5.62	6.68	9.95	Model 6
15_1762_5_RPS	47.02	4.93	4.93	6.83	8.22	9.71	11.95	13.90	16.13	22.64	Model 6
15001_RPS	443.64	89.58	89.58	110.00	123.35	136.70	155.06	169.93	185.79	226.37	Model 6
Top-up between 15_1869_2_RPS & 15001_RPS	15.82	3.03	3.03	3.72	4.17	4.62	5.24	5.74	6.27	7.65	Model 6
15_1819_6_RPS	443.78	89.66	89.66	110.11	123.47	136.83	155.21	170.09	185.96	226.58	Model 6

	Input flows - note input flows from other models - hydrographs provided here, check when other models are running
	Top-up flows. These flows should be entered laterally
	Check flows. Modellers should check to make sure these flows are being reached at each HEP
	Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Node ID_CFRAMS	AREA (km ²)	MRFS Flows for AEP								HEFS Flows for AEP			Model number
		50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	10% (10)	1% (100)	0.1% (1000)	
15_1733_4_RPS	199.64	78.07	95.63	107.34	119.05	135.53	149.03	163.55	201.89	131.88	183.10	248.03	Model 6
15_1786_1_RPS	1.45	0.15	0.21	0.26	0.32	0.40	0.48	0.57	0.85	0.32	0.59	1.05	Model 6
15_1786_4_RPS	2.24	0.51	0.73	0.90	1.10	1.39	1.66	1.98	2.95	1.41	2.58	4.59	Model 6
Top-up between 15_1786_1_RPS & 15_1786_4_RPS	0.78	0.19	0.27	0.34	0.41	0.52	0.62	0.74	1.10	0.53	0.97	1.72	Model 6
15_1786_5_RPS	0.05	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.13	0.06	0.11	0.20	Model 6
15_1786_6_RPS	0.09	0.06	0.09	0.11	0.13	0.16	0.19	0.23	0.34	0.16	0.29	0.51	Model 6
15009_RPS	202.77	78.64	96.33	108.13	119.92	136.52	150.12	164.75	203.36	132.84	184.44	249.84	Model 6
Top-up between 15_1733_4_RPS & 15009_RPS	0.75	0.44	0.53	0.60	0.66	0.76	0.83	0.91	1.13	0.88	1.23	1.66	Model 6
15_501_2	33.64	6.50	8.79	10.47	12.28	15.00	17.39	20.13	28.15	12.86	21.37	34.59	Model 6
15_593_1	2.00	0.65	0.94	1.16	1.40	1.78	2.13	2.53	3.78	1.70	3.12	5.54	Model 6
15_1678_11_RPS	20.44	4.21	5.99	7.32	8.79	11.04	13.06	15.41	22.51	9.00	16.05	27.66	Model 6
15_686_5_RPS	29.33	5.95	8.24	9.90	11.67	14.32	16.64	19.27	26.92	12.57	21.14	34.19	Model 6
Top-up between 15_593_1 & 15_686_5_RPS	6.89	1.53	2.12	2.55	3.00	3.69	4.28	4.96	6.93	3.24	5.44	8.80	Model 6
15_1137_9_RPS	16.45	3.43	4.84	5.90	7.07	8.86	10.48	12.35	18.05	7.25	12.87	22.17	Model 6
15_458_8	6.45	1.17	1.68	2.08	2.52	3.21	3.83	4.56	6.80	2.56	4.71	8.36	Model 6
15_1869_2_RPS	299.27	100.56	123.18	138.26	153.35	174.56	191.96	210.66	260.04	169.87	235.84	319.48	Model 6

Node ID_CFRAMS	AREA (km ²)	MRFS Flows for AEP								HEFS Flows for AEP			Model number
		50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	10% (10)	1% (100)	0.1% (1000)	
Top-up between 15009_RPS & 15_1869_2_RPS	10.63	2.64	3.23	3.62	4.02	4.58	5.03	5.52	6.82	4.45	6.18	8.37	Model 6
15_1870_2_RPS	70.62	12.05	15.65	18.18	20.84	24.72	28.03	31.73	42.11	22.33	34.44	51.74	Model 6
15_1991_3_RPS	10.93	2.14	3.09	3.82	4.62	5.88	7.01	8.34	12.42	4.69	8.61	15.25	Model 6
15_1762_5_RPS	47.02	6.15	8.53	10.26	12.12	14.91	17.36	20.14	28.27	12.60	21.32	34.73	Model 6
15001_RPS	443.64	111.44	136.85	153.45	170.06	192.90	211.40	231.13	281.61	188.53	259.73	345.98	Model 6
Top-up between 15_1869_2_RPS & 15001_RPS	15.82	3.76	4.62	5.18	5.74	6.52	7.14	7.81	9.51	6.37	8.77	11.69	Model 6

Input flows

Top-up flows. These flows should be entered laterally

Check flows. Modellers should check to make sure these flows are being reached at each HEP

Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Model 7 - Thomastown

Node ID_CFRAMS	AREA (km ²)	Qmed	Flows for AEP								Model number
			50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	
15_521_3_RPS	1744.54	229.19	229.19	283.05	318.58	355.25	406.81	449.21	495.28	618.59	Model 7
15_520_4_RPS	21.50	2.93	2.93	4.16	5.08	6.10	7.67	9.07	10.70	15.63	Model 7
15_1819_6_RPS	443.78	89.66	89.66	110.11	123.47	136.83	155.21	170.09	185.96	226.58	Model 6
15011_RPS	2223.77	278.30	278.30	343.70	386.84	431.37	493.98	545.47	601.41	751.13	Model 7
Top-up between 15_521_3_RPS & 15011_RPS	13.95	2.40	2.40	2.97	3.34	3.72	4.26	4.71	5.19	6.48	Model 7
15_707_3_RPS	8.26	2.10	2.10	3.04	3.75	4.54	5.78	6.90	8.21	12.25	Model 7
15_1814_4_RPS	63.72	10.95	10.95	14.21	16.45	18.77	22.13	24.94	28.05	36.63	Model 8
15_482_4_RPS	38.71	8.32	8.32	11.28	13.38	15.61	18.87	21.68	24.83	33.77	Model 7
15_1106_3	7.03	2.46	2.46	3.56	4.40	5.33	6.78	8.09	9.62	14.37	Model 7
15_1106_5	8.28	2.66	2.66	3.84	4.75	5.75	7.32	8.73	10.39	15.51	Model 7
Top-up between 15_1106_3 & 15_1106_5	1.24	0.45	0.45	0.65	0.80	0.97	1.24	1.48	1.76	2.63	Model 7
15_1848_3_RPS	48.79	10.21	10.21	13.60	15.97	18.45	22.06	25.11	28.51	38.00	Model 7
Top-up between 15_482_4_RPS & 15_1848_3_RPS	1.81	0.47	0.47	0.62	0.73	0.84	1.01	1.15	1.30	1.73	Model 7
15_93_7	46.92	10.70	10.70	14.05	16.43	18.94	22.67	25.87	29.46	39.71	Model 7
15006_RPS	2416.89	299.00	299.00	369.27	415.61	463.45	530.73	586.04	646.14	807.00	Model 7
Top-up between 15011_RPS & 15006_RPS	25.43	4.19	4.19	5.18	5.83	6.50	7.44	8.22	9.06	11.31	Model 7

Node ID_CFRAMS	AREA (km ²)	MRFS Flows for AEP								HEFS Flows for AEP			Model number
		50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	10% (10)	1% (100)	0.1% (1000)	
15_521_3_RPS	1744.54	282.47	348.85	392.63	437.83	501.38	553.64	610.41	762.38	488.04	688.17	947.64	Model 7
15_520_4_RPS	21.50	3.64	5.18	6.33	7.60	9.55	11.29	13.32	19.46	7.78	13.87	23.90	Model 7
15_1819_6_RPS	443.78	111.56	137.00	153.62	170.24	193.11	211.63	231.38	281.91	188.73	260.01	346.35	Model 6

Node ID_CFRAMS	AREA (km ²)	MRFS Flows for AEP								HEFS Flows for AEP			Model number
		50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	10% (10)	1% (100)	0.1% (1000)	
15011_RPS	2223.77	342.78	423.33	476.46	531.30	608.43	671.84	740.74	925.16	585.37	825.42	1136.6 3	Model 7
Top-up between 15_521_3_RPS & 15011_RPS	13.95	2.96	3.65	4.11	4.59	5.25	5.80	6.39	7.99	5.05	7.13	9.81	Model 7
15_707_3_RPS	8.26	2.62	3.79	4.68	5.67	7.22	8.61	10.25	15.30	5.75	10.58	18.79	Model 7
15_1814_4_RPS	63.72	13.32	17.27	20.00	22.82	26.90	30.32	34.10	44.53	21.67	32.85	48.24	Model 8
15_482_4_RPS	38.71	10.18	13.81	16.38	19.10	23.10	26.54	30.39	41.34	18.94	30.68	47.80	Model 7
15_1106_3	7.03	2.96	4.27	5.28	6.39	8.14	9.71	11.55	17.24	6.02	11.08	19.68	Model 7
15_1106_5	8.28	3.19	4.61	5.70	6.90	8.79	10.48	12.47	18.62	6.51	11.97	21.26	Model 7
Top-up between 15_1106_3 & 15_1106_5	1.24	0.56	0.81	1.00	1.22	1.55	1.85	2.20	3.28	1.23	2.27	4.03	Model 7
15_1848_3_RPS	48.79	12.66	16.86	19.80	22.87	27.34	31.12	35.34	47.10	24.32	38.24	57.86	Model 7
Top-up between 15_482_4_RPS & 15_1848_3_RPS	1.81	0.58	0.77	0.90	1.04	1.25	1.42	1.61	2.15	1.11	1.75	2.64	Model 7
15_93_7	46.92	12.84	16.85	19.72	22.73	27.20	31.04	35.35	47.65	22.51	35.44	54.41	Model 7
15006_RPS	2416.89	368.44	455.02	512.13	571.08	653.98	722.14	796.20	994.42	629.20	887.21	1221.7 3	Model 7
Top-up between 15011_RPS & 15006_RPS	25.43	5.17	6.38	7.18	8.01	9.17	10.12	11.16	13.94	8.82	12.44	17.13	Model 7

	Input flows - note input flows from other models - hydrographs provided here, check when other models are running
	Top-up flows. These flows should be entered laterally
	Check flows. Modellers should check to make sure these flows are being reached at each HEP
	Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Model 08 - Ballyhale

Node ID_CFRAMS	AREA (km ²)	Q _{med}	Flows for AEP								Model number
			50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	
15_1358_3_RPS	10.81	1.90	1.90	2.62	3.14	3.71	4.57	5.34	6.21	8.79	Model 8
15_1182_7_RPS	13.19	1.73	1.73	2.37	2.85	3.35	4.12	4.80	5.57	7.84	Model 8
15_1212_7	15.09	2.24	2.24	3.22	3.95	4.77	6.03	7.16	8.49	12.53	Model 8
15_1337_12_RPS	10.10	2.57	2.57	3.61	4.39	5.24	6.54	7.70	9.05	13.09	Model 8
15_1814_4_RPS	63.72	10.09	10.09	13.09	15.16	17.30	20.39	22.98	25.85	33.75	Model 8
Top-up between 15_1358_3_RPS & 15_1814_4_RPS	14.53	2.53	2.53	3.28	3.79	4.33	5.10	5.75	6.47	8.45	Model 8

Node ID_CFRAMS	AREA (km ²)	MRFS Flows for AEP								HEFS Flows for AEP			Model number
		50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	10% (10)	1% (100)	0.1% (1000)	
15_1358_3_RPS	10.81	2.33	3.20	3.85	4.55	5.60	6.53	7.60	10.76	4.45	7.55	12.44	Model 8
15_1182_7_RPS	13.19	2.16	2.96	3.55	4.19	5.15	5.99	6.95	9.78	4.36	7.36	12.02	Model 8
15_1212_7	15.09	2.80	4.02	4.93	5.95	7.53	8.94	10.60	15.64	6.06	10.99	19.22	Model 8
15_1337_12_RPS	10.10	3.15	4.42	5.38	6.41	8.01	9.43	11.08	16.03	6.21	10.90	18.53	Model 8
15_1814_4_RPS	63.72	12.60	16.34	18.92	21.60	25.45	28.69	32.27	42.13	23.25	35.25	51.76	Model 8
Top-up between 15_1358_3_RPS & 15_1814_4_RPS	14.53	3.15	4.09	4.74	5.40	6.37	7.18	8.08	10.54	5.82	8.82	12.95	Model 8

	Input flows
	Top-up flows. These flows should be entered laterally
	Check flows. Modellers should check to make sure these flows are being reached at each HEP
	Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Model 09 - Inistioge

Node ID_CFRAMS	AREA (km ²)	Q _{med}	Flows for AEP								Model number
			50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	
15006_RPS	2416.89	299.30	299.30	369.64	416.03	463.92	531.26	586.63	646.79	807.81	Model 9
15_1511_8	10.08	2.26	2.26	3.17	3.85	4.60	5.74	6.76	7.94	11.49	Model 9
15_650_7	14.22	2.83	2.83	3.90	4.67	5.51	6.77	7.88	9.14	12.86	Model 9
15_1996_U	3.59	1.01	1.01	1.46	1.81	2.19	2.79	3.32	3.95	5.90	Model 9
15_1996_1	4.52	1.29	1.29	1.86	2.30	2.78	3.54	4.23	5.03	7.51	Model 9
Top-up between 15_1358_3_RPS & 15_1358_8_RPS	0.93	0.20	0.20	0.29	0.36	0.44	0.56	0.66	0.79	1.18	Model 9
15_2002_9	8.77	1.62	1.62	2.34	2.89	3.50	4.46	5.31	6.32	9.44	Model 9
15_2008_6	14.20	3.17	3.17	4.27	5.08	5.95	7.26	8.42	9.74	13.62	Model 9
15_2014_4	6.44	1.36	1.36	1.97	2.43	2.94	3.75	4.47	5.32	7.94	Model 9
15_2016_2	7.46	1.53	1.53	2.21	2.74	3.32	4.22	5.03	5.99	8.94	Model 9
15_1839_1	2519.25	305.56	305.56	377.36	424.73	473.62	542.37	598.89	660.31	824.70	Model 9
Top-up between 15006_RPS & 15_1839_1	36.67	5.81	5.81	7.17	8.07	9.00	10.31	11.38	12.55	15.67	Model 9

Input flows

Top-up flows. These flows should be entered laterally

Check flows. Modellers should check to make sure these flows are being reached at each HEP

Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Node ID_CFRAMS	AREA (km ²)	MRFS Flows for AEP								HEFS Flows for AEP			Model number
		50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	10% (10)	1% (100)	0.1% (1000)	
15006_RPS	2416.89	368.44	455.02	512.13	571.08	653.98	722.14	796.20	994.42	629.20	887.21	1221.73	Model 9
15_1511_8	10.08	2.76	3.88	4.72	5.63	7.03	8.28	9.72	14.07	5.46	9.57	16.27	Model 9
15_650_7	14.22	3.47	4.77	5.72	6.74	8.28	9.64	11.19	15.74	6.61	11.15	18.20	Model 9
15_1996_U	3.59	1.26	1.83	2.25	2.73	3.48	4.15	4.94	7.37	2.77	5.10	9.05	Model 9
15_1996_1	4.52	1.54	2.22	2.74	3.32	4.23	5.05	6.00	8.96	3.17	5.83	10.36	Model 9
Top-up between 15_1358_3_RPS & 15_1358_8_RPS	0.93	0.43	0.62	0.77	0.93	1.19	1.42	1.69	2.52	1.14	2.10	3.72	Model 9
15_2002_9	8.77	2.02	2.92	3.61	4.37	5.56	6.63	7.89	11.78	4.43	8.15	14.47	Model 9
15_2008_6	14.20	3.88	5.23	6.22	7.28	8.89	10.30	11.92	16.67	7.19	11.91	19.27	Model 9
15_2014_4	6.44	1.70	2.45	3.03	3.67	4.68	5.58	6.64	9.91	3.72	6.85	12.17	Model 9
15_2016_2	7.46	1.91	2.76	3.41	4.14	5.27	6.28	7.47	11.16	4.20	7.72	13.71	Model 9
15_1839_1	2,519.25	376.57	465.07	523.43	583.69	668.41	738.08	813.77	1016.37	643.08	906.79	1248.69	Model 9
Top-up between 15006_RPS & 15_1839_1	36.67	7.16	8.84	9.95	11.09	12.70	14.02	15.46	19.31	12.22	17.23	23.73	Model 9

	Input flows
	Top-up flows. These flows should be entered laterally
	Check flows. Modellers should check to make sure these flows are being reached at each HEP
	Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Model 10 - Rathdowney

Node ID_CFRAMS	AREA (km ²)	Q _{med}	Flows for AEP								Model number
			50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	
15_1425_2	60.10	5.62	5.62	7.61	9.04	10.55	12.79	14.73	16.91	23.17	Model 10
15_359_2_RPS	40.09	4.03	4.03	5.57	6.68	7.87	9.67	11.22	13.01	18.18	Model 10
15_1220_3	11.95	1.15	1.15	1.65	2.03	2.46	3.12	3.71	4.41	6.56	Model 10
15_338_2_RPS	1.94	0.28	0.28	0.40	0.50	0.61	0.77	0.92	1.09	1.63	Model 10
15_338_4_RPS	2.57	0.41	0.41	0.59	0.73	0.89	1.13	1.35	1.60	2.39	Model 10
Top-up between 15_338_2_RPS & 15_338_4_RPS	0.64	0.11	0.11	0.16	0.20	0.24	0.30	0.36	0.43	0.64	Model 10
15_1318_1_RPS	15.46	1.62	1.62	2.29	2.78	3.31	4.13	4.85	5.68	8.16	Model 10
Top-up between 15_1220_3 & 15_1318_1_RPS	0.94	0.12	0.12	0.17	0.21	0.25	0.31	0.36	0.43	0.61	Model 10
15_1318_3_RPS	15.76	1.72	1.72	2.49	3.07	3.72	4.74	5.65	6.72	10.03	Model 10
Top up between 15_1318_1 & 15_1318_3	0.30	0.04	0.04	0.06	0.07	0.09	0.11	0.14	0.16	0.24	Model 10
15_1880_5_RPS	10.77	1.51	1.51	2.18	2.70	3.27	4.15	4.95	5.89	8.77	Model 10
15_1880_7_RPS	11.58	1.58	1.58	2.26	2.77	3.32	4.17	4.92	5.80	8.42	Model 10
Top-up between 15_1880_5_RPS & 15_1880_7_RPS	0.81	0.13	0.13	0.19	0.23	0.27	0.34	0.41	0.48	0.70	Model 10
15_1858_10_RPS	15.29	1.85	1.85	2.67	3.28	3.97	5.03	5.99	7.12	10.57	Model 10
15_1770_2_RPS	11.47	1.06	1.06	1.52	1.88	2.27	2.88	3.42	4.07	6.05	Model 10
15_200_2_RPS	18.08	2.20	2.20	3.14	3.86	4.64	5.87	6.97	8.27	12.22	Model 10
15_196_2_RPS	168.10	13.63	13.63	17.23	19.62	22.06	25.48	28.29	31.32	39.39	Model 10
15005.00	379.00	27.44	27.44	33.61	37.73	41.85	47.64	52.38	57.49	70.96	Model 10
15_198_10_RPS	380.43	27.53	27.53	33.72	37.85	41.98	47.79	52.56	57.68	71.19	Model 10
Top-up between 15_1425_2 & 15_198_10_RPS	84.60	6.73	6.73	8.24	9.25	10.26	11.68	12.85	14.10	17.40	Model 10

Node ID_CFRAMS	AREA (km ²)	MRFS Flows for AEP								HEFS Flows for AEP			Model number
		50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)	10% (10)	1% (100)	0.1% (1000)	
15_1425_2	60.10	7.02	9.51	11.28	13.17	15.97	18.39	21.11	28.92	13.86	22.59	35.53	Model 10
15_359_2_RPS	40.09	5.03	6.95	8.34	9.83	12.07	14.01	16.24	22.69	10.25	17.22	27.88	Model 10
15_1220_3	11.95	1.44	2.06	2.54	3.07	3.89	4.63	5.51	8.19	3.12	5.69	10.06	Model 10
15_338_2_RPS	1.94	0.36	0.52	0.64	0.77	0.99	1.18	1.40	2.09	0.78	1.44	2.56	Model 10
15_338_4_RPS	2.57	0.51	0.74	0.91	1.11	1.41	1.68	2.00	2.98	1.06	1.94	3.45	Model 10
Top-up between 15_338_2_RPS & 15_338_4_RPS	0.64	0.19	0.28	0.34	0.42	0.53	0.63	0.75	1.12	0.66	1.22	2.17	Model 10
15_1318_1_RPS	15.46	2.01	2.84	3.45	4.11	5.12	6.02	7.05	10.12	4.11	7.17	12.07	Model 10
Top-up between 15_1220_3 & 15_1318_1_RPS	0.94	0.20	0.29	0.35	0.42	0.52	0.61	0.71	1.02	0.47	0.81	1.37	Model 10
15_1318_3_RPS	15.76	2.17	3.13	3.87	4.69	5.97	7.12	8.47	12.64	5.31	9.76	17.34	Model 10
Top up between 15_1318_1 & 15_1318_3	0.30	0.09	0.13	0.16	0.19	0.24	0.29	0.35	0.52	0.23	0.43	0.76	Model 10
15_1880_5_RPS	10.77	1.88	2.73	3.37	4.08	5.18	6.18	7.35	10.94	4.14	7.59	13.45	Model 10
15_1880_7_RPS	11.58	1.94	2.77	3.39	4.06	5.10	6.02	7.10	10.31	3.92	6.97	11.93	Model 10
Top-up between 15_1880_5_RPS & 15_1880_7_RPS	0.81	0.16	0.23	0.28	0.34	0.43	0.51	0.60	0.87	0.35	0.62	1.07	Model 10
15_1858_10_RPS	15.29	2.27	3.26	4.02	4.86	6.16	7.33	8.71	12.94	5.03	9.18	16.21	Model 10
15_1770_2_RPS	11.47	1.30	1.87	2.30	2.78	3.52	4.19	4.98	7.41	2.88	5.25	9.28	Model 10
15_200_2_RPS	18.08	2.75	3.92	4.81	5.80	7.33	8.70	10.32	15.26	5.91	10.69	18.74	Model 10
15_196_2_RPS	168.10	16.88	21.34	24.31	27.34	31.57	35.05	38.80	48.80	27.69	39.92	55.58	Model 10
15005.00	379.00	34.02	41.67	46.77	51.88	59.06	64.94	71.27	87.97	57.47	79.78	108.08	Model 10
15_198_10_RPS	380.43	34.05	41.71	46.82	51.92	59.11	65.00	71.33	88.05	57.52	79.86	108.18	Model 10
Top-up between 15_1425_2 & 15_198_10_RPS	84.60	8.32	10.20	11.45	12.69	14.45	15.89	17.44	21.53	14.06	19.52	26.45	Model 10

Input flows - note input flows from other models - hydrographs provided here, check when other models are running

Top-up flows. These flows should be entered laterally

Check flows. Modellers should check to make sure these flows are being reached at each HEP

Some of these flows may be put in at the US point due to a small difference between US & DS flows.

APPENDIX E

NAM MODELLING OUTPUTS

Calibrated Mike NAM Model

Catchment code = 15050_RPS

Catchment name = Kilkenny

Catchment_Name = '15050_RPS_NAM'

Catchment_Model = 'NAM'

Catchment_Area = 61.45

Catchment_Name = '15050_RPS_URBAN'

Catchment_Model = 'Urban'

Catchment_Area = 9.44

Catchment_Name = '15050_RPS'

Catchment_Model = 'Combined'

Catchment_Area = 70.89

Parameter settings

U_Max = 22.6

L_Max = 163

CQOF = 0.717

CKIF = 361.6

CK1 = 12.9

CK12_DIF = true

CK2 = 6.8867

TOF = 0.302

TIF = 0.437

TG = 0.99

CKBF = 4999.36

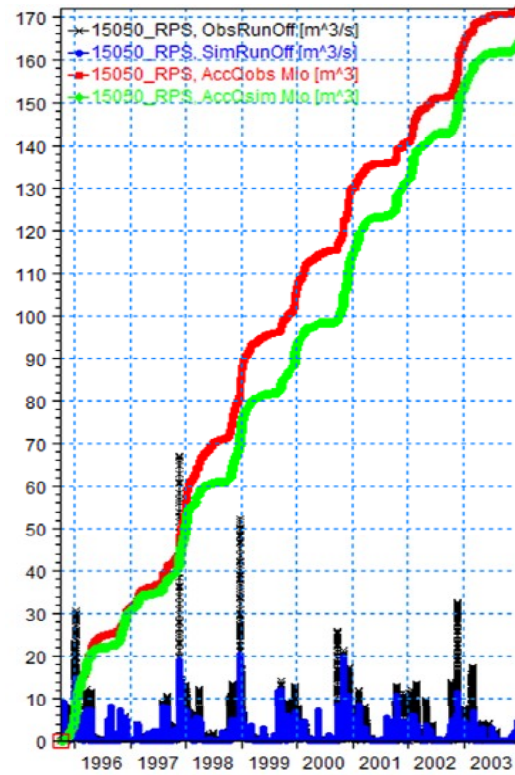
Calibration period

start = 1995, 10, 2, 0, 0

end = 2003, 12, 31, 21, 45, 0

Precipitation data source

station	3613	1
radar	12	1



Error measures with missing values (as shown in the figures)

R2 = 0.67

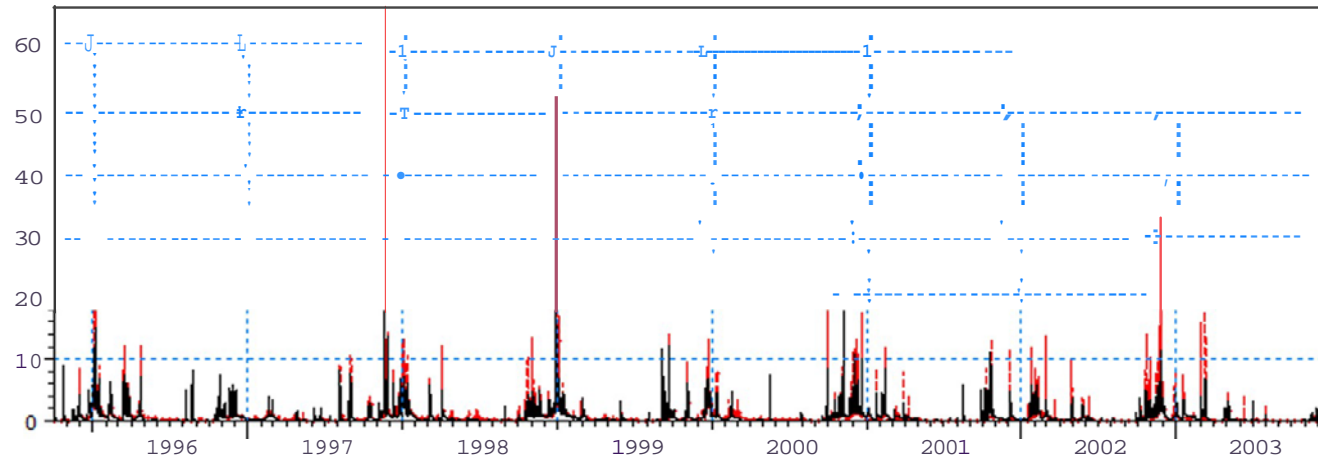
Error measures without missing values

RMSE(Q) = 0.9037

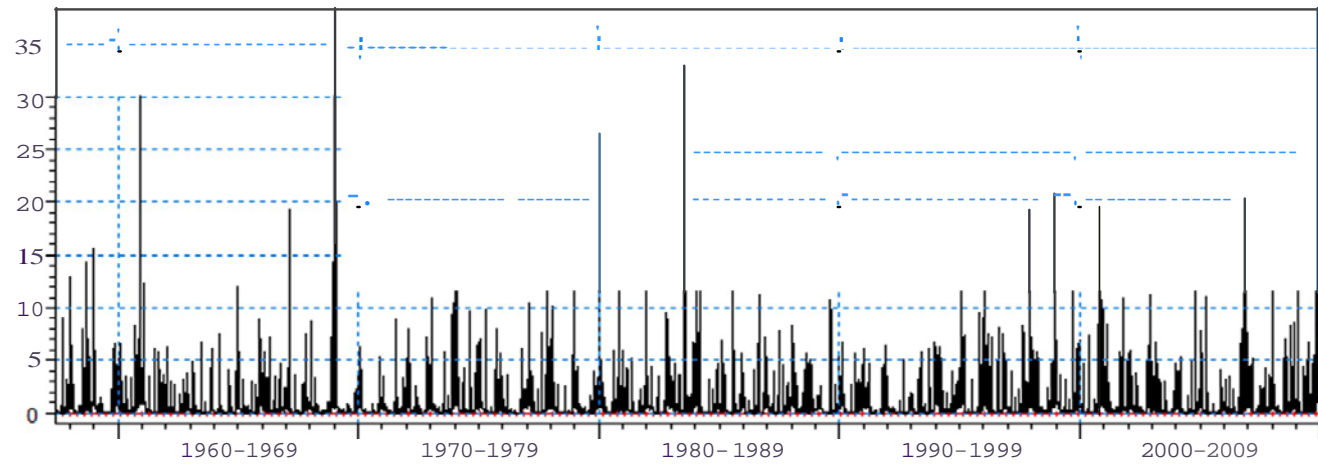
Peak-weighted RMSE(Q) = 21.78

R2 = 0.67

1SOSO_RPS, Observed Runoff [m³/s]
1SOSO_RPS, Simulated Runoff [m³/s]



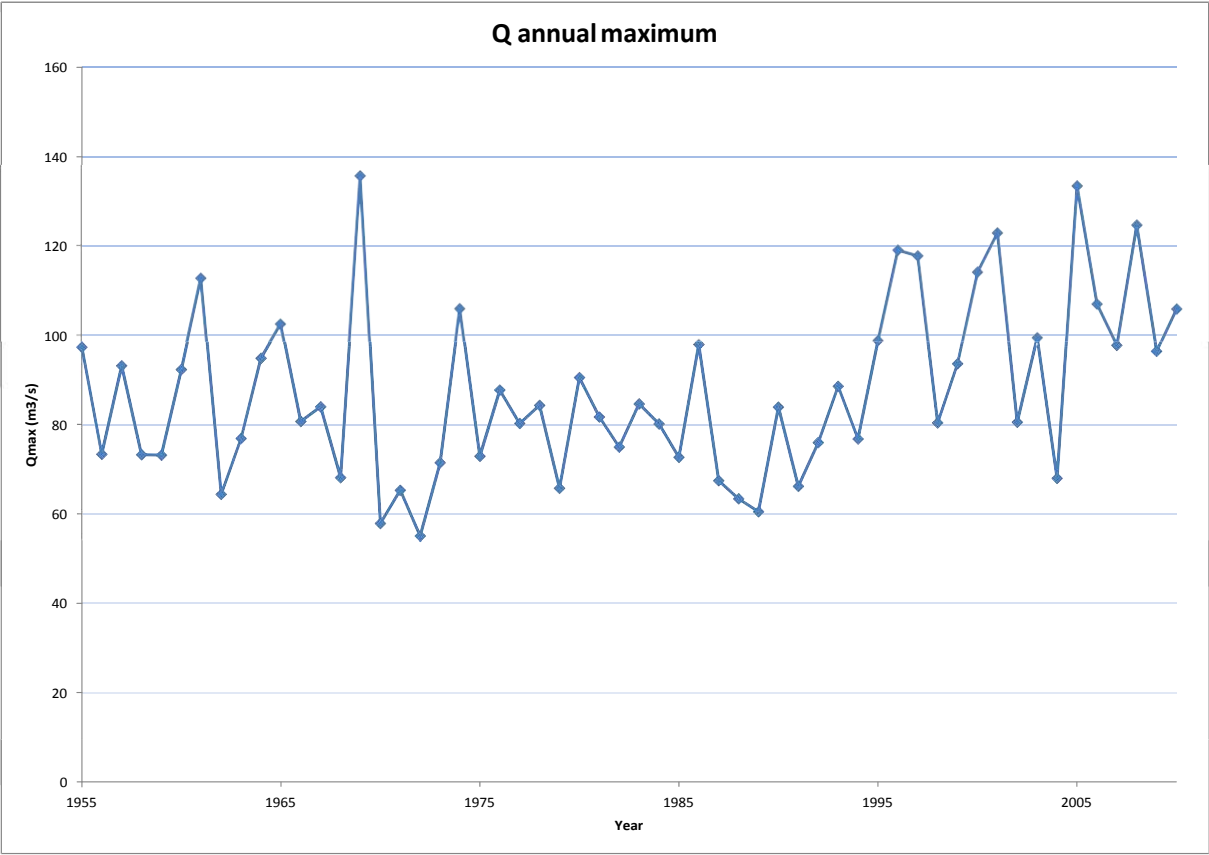
15050_RPS, Observed Runoff [m³/s]
1SOSO_RPS, Simulated Runoff [m³/s]



Q annual maximum
(1st October - 30th September)

Datetime	Qmax	Year
08/12/1954 18:00	97.2732	1955
06/09/1956 18:30	73.3198	1956
25/09/1957 08:15	93.107	1957
03/09/1958 08:30	73.2187	1958
20/12/1958 01:15	73.1181	1959
10/10/1959 21:15	92.261	1960
04/12/1960 07:30	112.7027	1961
30/09/1962 04:15	64.3575	1962
05/11/1962 17:15	76.8405	1963
30/10/1963 19:45	94.802	1964
13/12/1964 04:15	102.471	1965
17/11/1965 21:30	80.6566	1966
23/02/1967 02:30	83.936	1967
09/01/1968 09:00	68.1055	1968
25/12/1968 00:45	135.5477	1969
22/12/1969 00:00	57.8412	1970
01/08/1971 20:15	65.2702	1971
20/11/1971 22:15	55.0428	1972
12/11/1972 21:15	71.4303	1973
01/12/1973 09:15	105.8955	1974
18/09/1975 04:00	72.8794	1975
02/10/1975 20:45	87.6777	1976
12/10/1976 07:15	80.1964	1977
31/10/1977 09:45	84.2691	1978
28/12/1978 05:00	65.714	1979
27/12/1979 07:15	90.4747	1980
22/10/1980 19:30	81.6582	1981
14/12/1981 18:00	74.9243	1982
24/08/1983 02:00	84.5919	1983
03/08/1984 09:45	80.1017	1984
26/07/1985 09:45	72.6569	1985
26/08/1986 03:00	97.8737	1986
08/12/1986 21:30	67.4066	1987
02/02/1988 22:00	63.3571	1988
30/08/1989 18:15	60.4703	1989
06/02/1990 17:15	83.8668	1990
01/08/1991 08:45	66.1484	1991
12/09/1992 22:00	75.9391	1992
30/09/1993 07:45	88.5205	1993
01-Oct-93	76.748	1994
27/01/1995 17:30	98.7568	1995
24/10/1995 22:30	118.9567	1996
05/08/1997 17:15	117.6721	1997
18/11/1997 05:00	80.3416	1998
21/09/1999 07:45	93.5585	1999
05/11/1999 09:30	114.0517	2000
06/11/2000 05:45	122.8193	2001
04/12/2001 02:30	80.4826	2002
21/10/2002 18:30	99.4132	2003
31/10/2003 04:00	67.9402	2004
29/10/2004 06:15	133.2952	2005
03/11/2005 05:00	106.9183	2006
07/12/2006 20:30	97.6909	2007
16/08/2008 23:00	124.5474	2008
31/01/2009 20:45	96.3452	2009
20/11/2009 02:15	105.8147	2010

NAM Qmed **83.90**
FSU Qmed **96.07**
Gauge Qmed **78.00**
Est. Qmed (prop.) **80.28**



Calibrated Mike NAM Model

Catchment code = 15012_RPS

Catchment name = Ballyragget

Catchment_Name = '15012_RPS_NAM'

Catchment_Model = 'NAM'

Catchment_Area = 1043.87

Catchment_Name = '15012_RPS_URBAN'

Catchment_Model = 'Urban'

Catchment_Area = 11.53

Catchment_Name = '15012_RPS'

Catchment_Model = 'Combined'

Catchment_Area = 1055.4

Parameter settings

U_Max = 1.37

L_Max = 4.7

CQOF = 0.454

CKIF = 80

CK1 = 48

CK12_DIF = true

CK2 = 3

TOF = 0

TIF = 0

TG = 0.99

CKBF = 1317

Calibration period

start = 1991, 1, 1, 1, 0, 0

end = 1999, 4, 23, 0, 0, 0

Precipitation data source

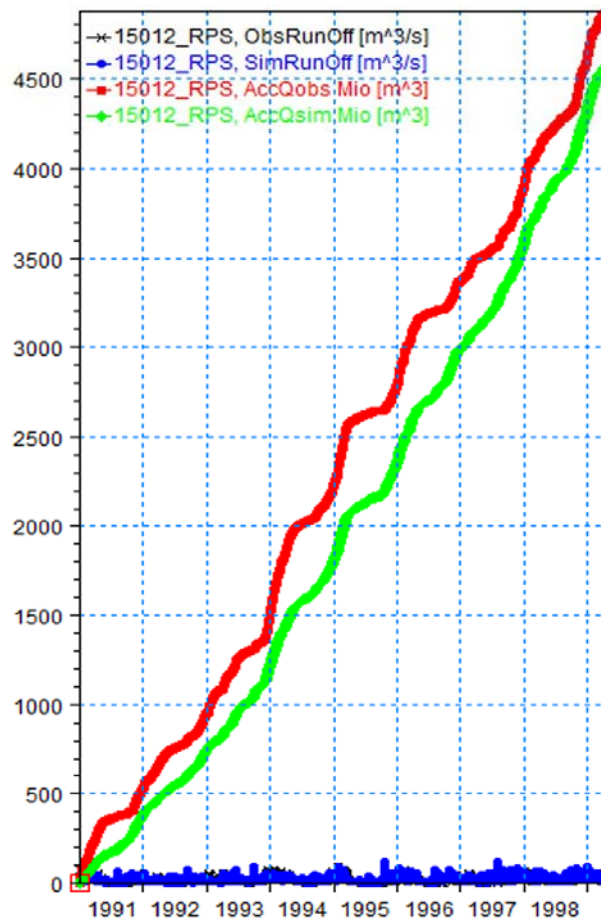
station 4919 0.403938

station 375 0.097358

station 1475 0.057345

station 3613 0.441359

radar 8 1



Error measures with missing values (as shown in the figures)

R2 = 0.577

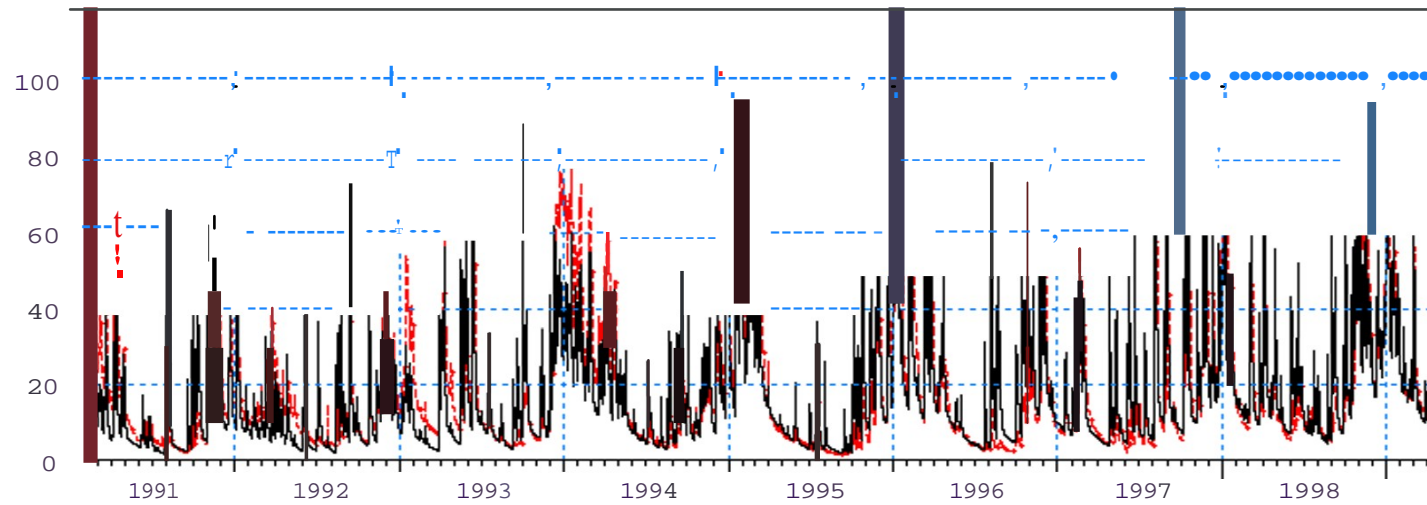
Error measures without missing values

RMSE(Q) = 17.83

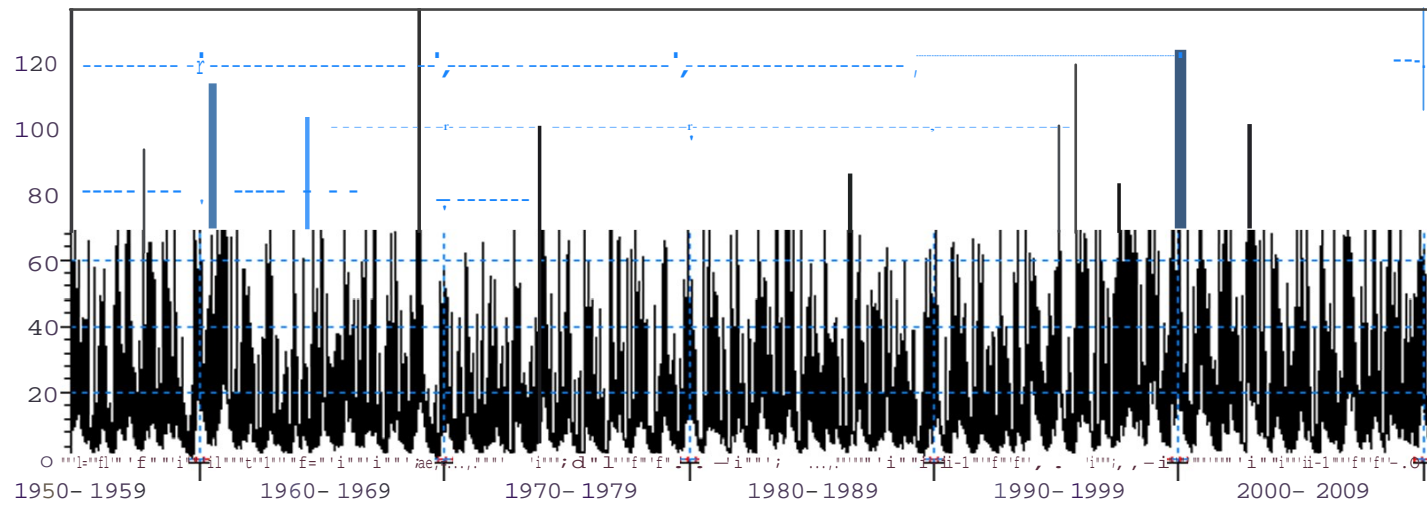
Peak-weighted RMSE(Q) = 29.02

R2 = 0.688

15012_RPS, Observe<! Runoff [m³/s]
15012_RPS, Simulate<! Runoff [m³/s]



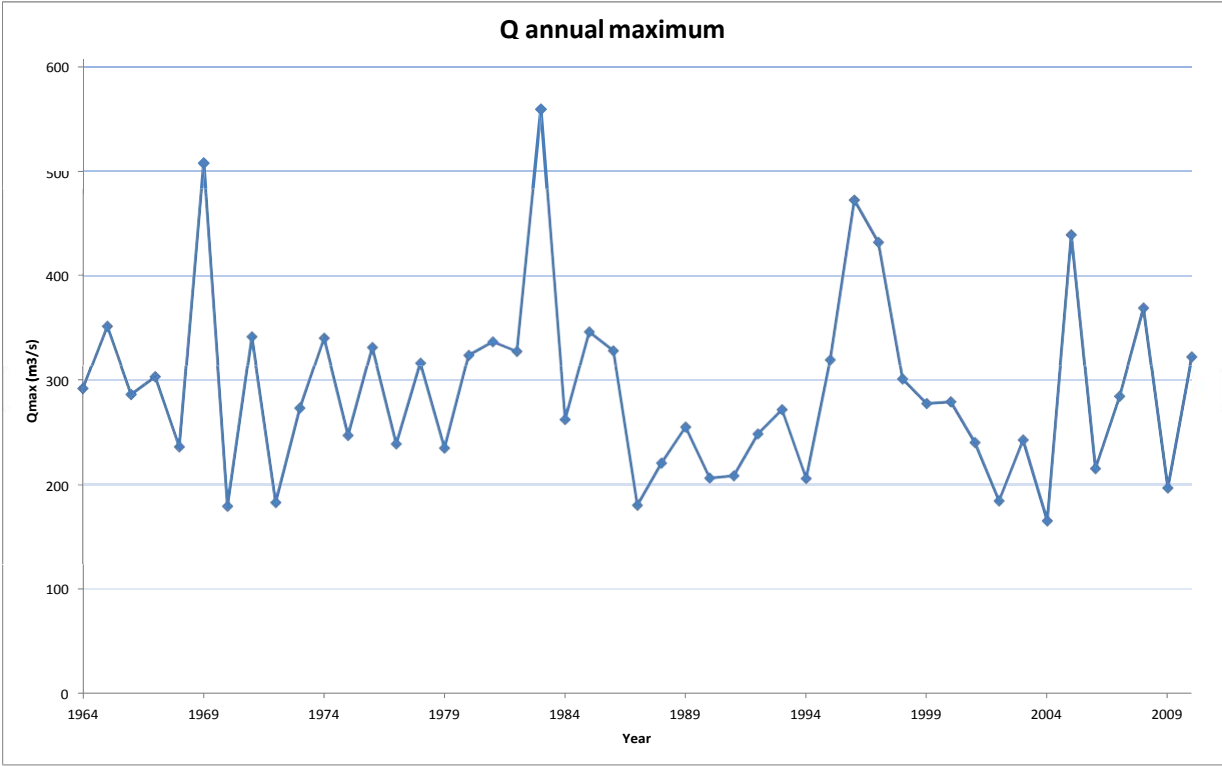
15012_RPS, Observe<! Runoff [m³/s]
15012_RPS, Simulate<! Runoff [m³/s]



Q annual maximum
(1st October - 30th September)

Datetime	Qmax	Year
08/12/1954 14:15	310.3015	1955
06/09/1956 16:15	180.5491	1956
25/09/1957 00:15	440.6289	1957
03/09/1958 02:30	319.8086	1958
19/12/1958 19:15	252.6836	1959
10/10/1959 14:15	259.7868	1960
04/12/1960 02:15	442.3971	1961
30/09/1962 00:15	202.9299	1962
05/11/1962 10:15	226.3746	1963
30/10/1963 15:15	291.9013	1964
12/12/1964 22:15	351.3042	1965
17/11/1965 14:30	286.0984	1966
22/02/1967 20:15	303.0054	1967
08/01/1968 22:15	236.2265	1968
24/12/1968 19:15	508.0051	1969
19/01/1970 15:15	179.6365	1970
01/08/1971 17:30	341.2911	1971
16/01/1972 10:30	183.2016	1972
12/11/1972 15:15	273.0924	1973
08/01/1974 10:30	339.9811	1974
29/09/1975 07:15	247.1188	1975
02/10/1975 11:30	331.1189	1976
24/08/1977 10:45	238.9233	1977
31/10/1977 02:15	316.0954	1978
28/12/1978 01:00	235.0057	1979
27/12/1979 04:15	323.5769	1980
22/10/1980 15:15	336.4867	1981
14/12/1981 14:15	327.2006	1982
17/07/1983 11:30	559.5674	1983
06/02/1984 17:45	262.1831	1984
26/07/1985 04:15	345.9232	1985
06/08/1986 16:30	327.8703	1986
16/07/1987 15:45	180.5979	1987
06/01/1988 04:15	220.7636	1988
30/08/1989 12:30	255.0878	1989
07/02/1990 17:15	206.4134	1990
28/12/1990 12:15	208.6222	1991
31/10/1991 22:45	248.5272	1992
30/09/1993 06:15	271.674	1993
01-Oct-93	206.0327	1994
27/01/1995 13:15	319.1846	1995
24/10/1995 18:15	471.8761	1996
05/08/1997 15:15	431.4791	1997
17/11/1997 21:45	300.8369	1998
21/09/1999 03:15	277.4249	1999
29/09/2000 08:30	279.1175	2000
28/09/2001 21:15	240.3219	2001
07/10/2001 19:15	184.7143	2002
27/11/2002 10:15	242.7639	2003
12/08/2004 16:45	165.7013	2004
28-Oct-04	438.6695	2005
23/09/2006 07:00	215.5633	2006
15/11/2006 18:15	284.3213	2007
10/01/2008 06:15	368.7613	2008
30/01/2009 22:15	197.0715	2009
23/11/2009 10:45	322.038	2010

NAM Qmed 278.2712
FSU Qmed 271.15
Gauge Qmed 190.73



Calibrated Mike NAM Model

Catchment code = 15011_RPS

Catchment name = Thomastown

Catchment_Name = '15011_RPS_NAM'

Catchment_Model = 'NAM'

Catchment_Area = 2192.92

Catchment_Name = '15011_RPS_URBAN'

Catchment_Model = 'Urban'

Catchment_Area = 30.85

Catchment_Name = '15011_RPS'

Catchment_Model = 'Combined'

Catchment_Area = 2223.77

Parameter settings

U_Max = 1

L_Max = 2.52

CQOF = 0.73

CKIF = 194.1

CK1 = 3

CK12_DIF = true

CK2 = 72

TOF = 0.415

TIF = 0

TG = 0

CKBF = 938.83

Calibration period

start = 1991, 1, 1, 1, 0, 0

end = 2010, 8, 29, 0, 0, 0

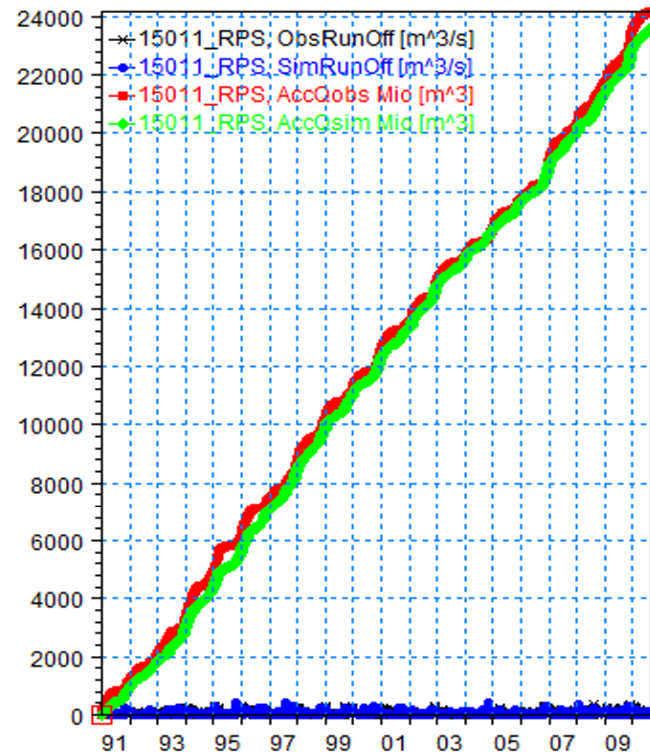
Precipitation data source

station 4919 0.191709

station 375 0.118568

station 1475 0.027216

station 3613 0.662508



Error measures with missing values (as shown in the figures)

R2 = 0.67

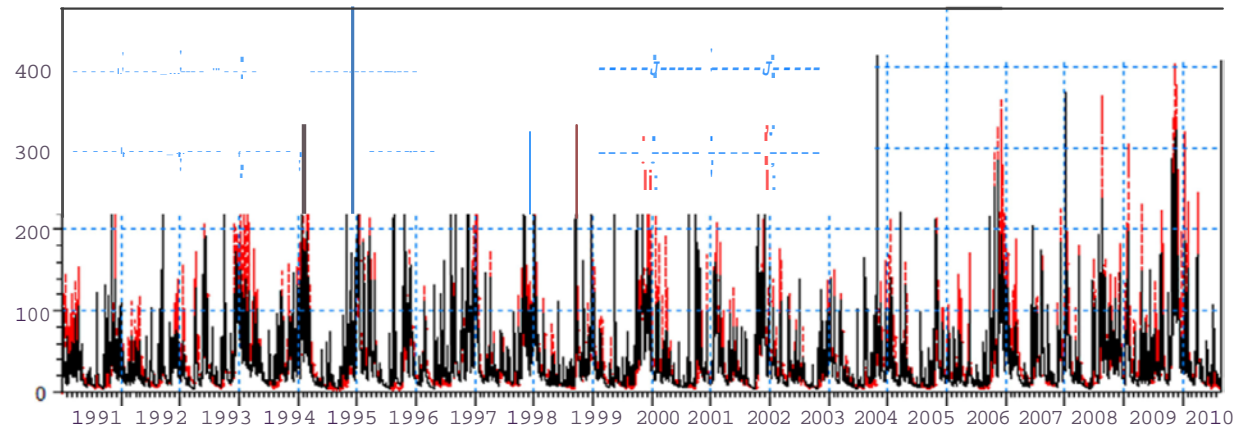
Error measures without missing values

RMSE(Q) = 23.55

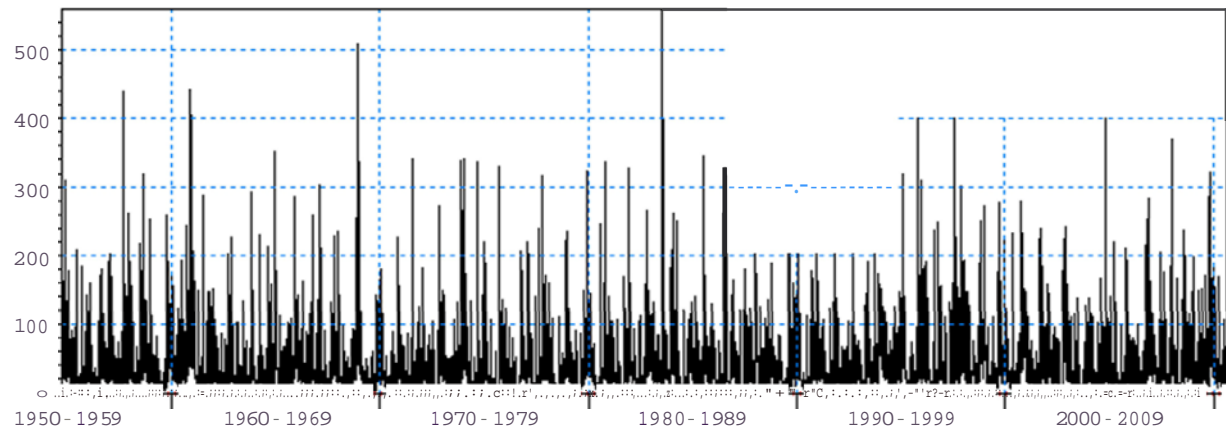
Peak-weighted RMSE(Q) = 45.62

R2 = 0.668

15011_RPS, Observed RunOff [m³/s]
15011_RPS, Simulated RunOff [m³/s]



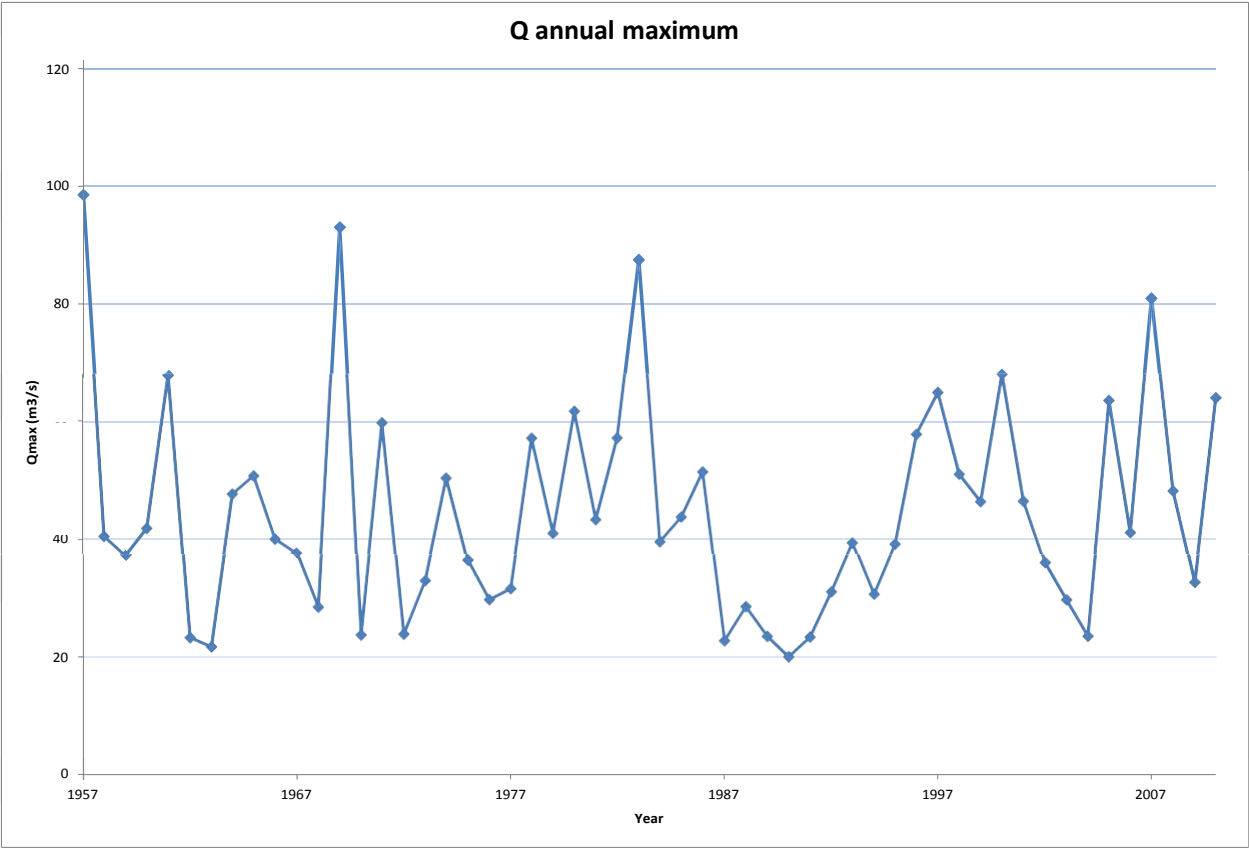
15011_RPS, Observed RunOff [m³/s]
15011_RPS, Simulated RunOff [m³/s]



Q annual maximum
(1st October - 30th September)

Datetime	Qmax	Year
25/09/1957 06:30	98.5508	1957
23/12/1957 20:45	40.5212	1958
19-Dec-58	37.2376	1959
10/10/1959 19:45	41.877	1960
04/12/1960 05:00	67.7472	1961
30/09/1962 05:30	23.334	1962
05/11/1962 19:15	21.7953	1963
30/10/1963 19:45	47.6769	1964
13/12/1964 03:45	50.7459	1965
17/11/1965 20:00	40.0622	1966
23/02/1967 02:30	37.6768	1967
17/10/1967 04:15	28.466	1968
24-Dec-68	93.0334	1969
19/01/1970 21:30	23.7923	1970
01/08/1971 19:45	59.7145	1971
02/02/1972 23:45	23.9215	1972
12/11/1972 21:45	32.9036	1973
01/12/1973 09:15	50.3642	1974
29/09/1975 10:30	36.3615	1975
02/10/1975 19:15	29.7071	1976
10/02/1977 10:30	31.5543	1977
31/10/1977 06:30	57.1075	1978
28/12/1978 03:00	41.0324	1979
27/12/1979 07:15	61.6472	1980
22/10/1980 19:45	43.3356	1981
14/12/1981 17:00	57.1353	1982
17/07/1983 16:45	87.5089	1983
06/02/1984 22:00	39.605	1984
26/07/1985 10:00	43.7947	1985
25/08/1986 22:45	51.4189	1986
17/07/1987 00:45	22.8098	1987
06/01/1988 09:00	28.5432	1988
30/08/1989 21:15	23.5465	1989
07/02/1990 22:30	20.1083	1990
28/12/1990 22:00	23.4257	1991
01/11/1991 03:15	31.03	1992
30/09/1993 09:45	39.4274	1993
01-Oct-93	30.6305	1994
27/01/1995 17:15	39.2176	1995
24/10/1995 22:00	57.7642	1996
04/08/1997 10:45	64.8488	1997
18/11/1997 01:15	51.0308	1998
21/09/1999 07:00	46.3822	1999
29/09/2000 13:15	67.9542	2000
06/11/2000 05:00	46.4681	2001
18/10/2001 01:45	35.9395	2002
08/10/2002 23:15	29.6852	2003
24/08/2004 00:45	23.5752	2004
28/10/2004 17:45	63.489	2005
23/09/2006 12:30	41.1568	2006
15/11/2006 20:00	80.9426	2007
10/01/2008 09:45	48.2055	2008
31/01/2009 21:15	32.6245	2009
01/11/2009 11:00	63.9267	2010

Qmed 40.78
Gauge Qmed 41.23
FSU Qmed 41.14



Calibrated Mike NAM Model

Catchment_Name = '15009_RPS'
Catchment_Model = 'NAM'
Catchment_Area = 202.4

Parameter settings

U_Max = 1
L_Max = 15.6
CQOF = 1
CKIF = 16.7
CK1 = 30.1
CK12_DIF = true
CK2 = 4.92
TOF = 0.5
TIF = 0
TG = 0.3499
CKBF = 500.004

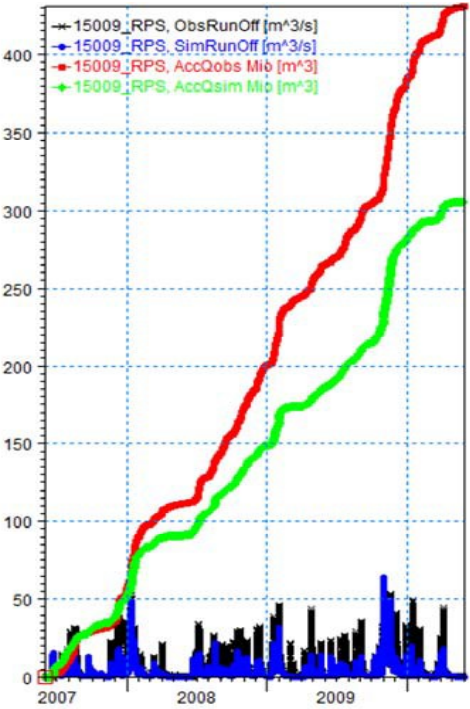
Calibration period

start = 2007, 5, 31, 4, 15, 0
end = 2008, 4, 8, 9, 0, 0

Precipitation data sources

Raingauge and radar data

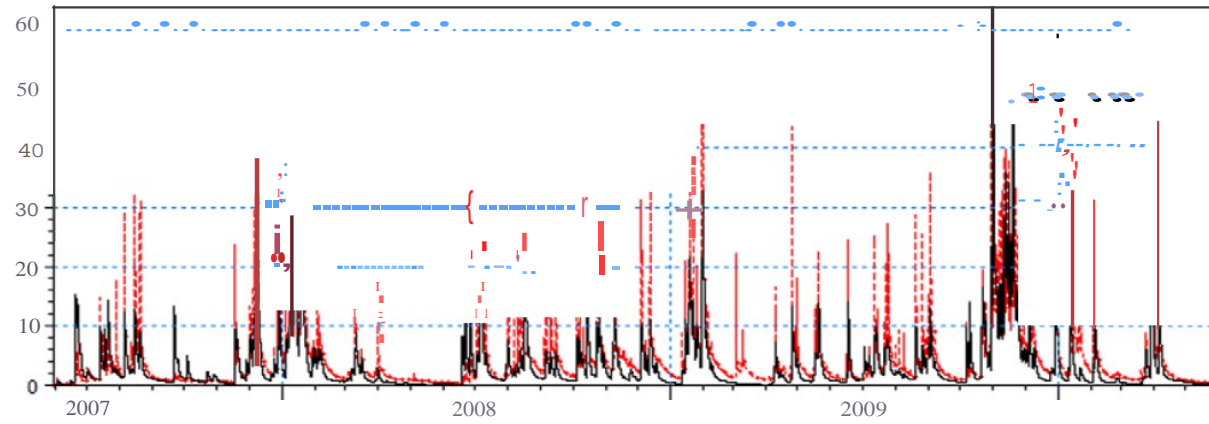
station	3613	1
radar	6	1



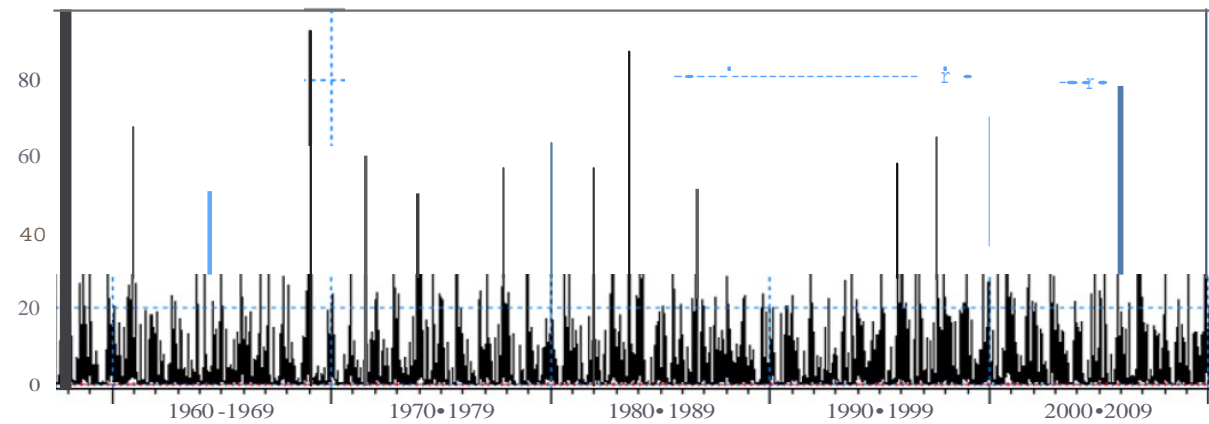
Error measures with missing values (as shown in the figures)
R2 = 0.631

Error measures without missing values
RMSE(Q) = 3.58
Peak-weighted RMSE(Q) = 13.52
R2 = 0.634

1SC109_RPS_Observed RunOff [m³/s]
1SC109_RPS_Simulated RunOff [m³/s]



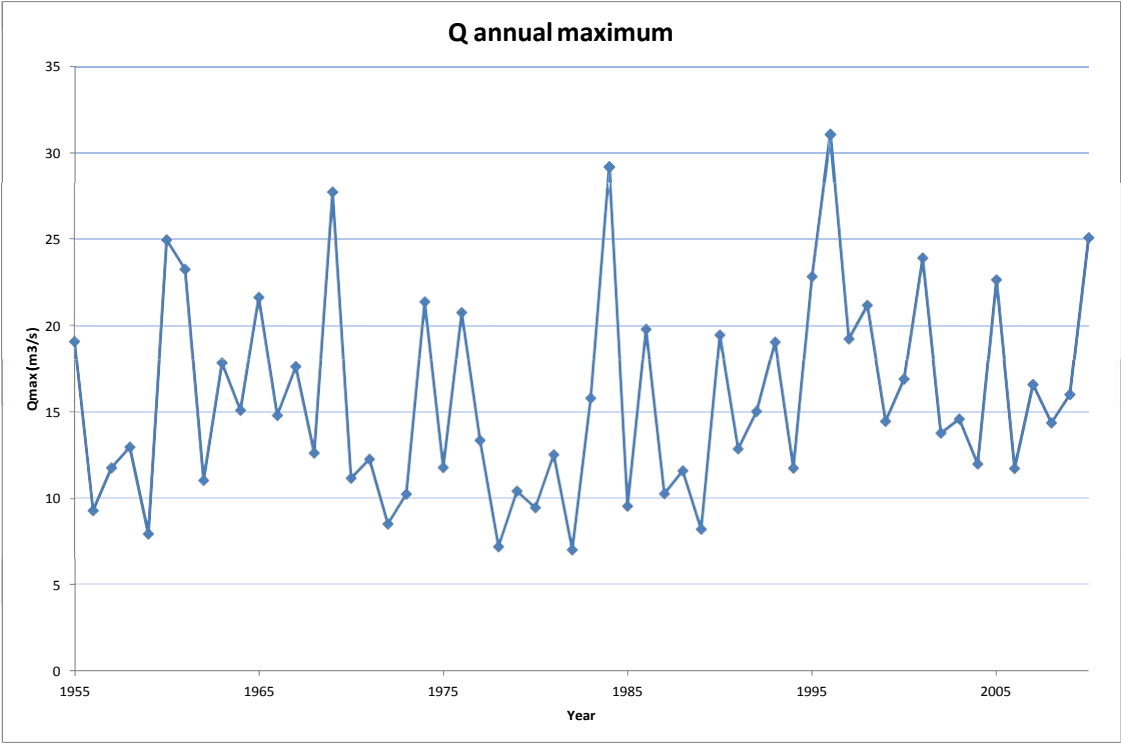
1S009_RPS_Observed Runoff [m³/s]
15009_RPS_Simulated Runoff [m³/s]



Q annual maximum
(1st October - 30th September)

Datetime	Qmax	Year
08/12/1954 14:15	19.0535	1955
26/01/1956 06:15	9.3082	1956
01/01/1957 01:15	11.7712	1957
29/10/1957 18:15	12.9653	1958
20/12/1958 02:30	7.9679	1959
27/12/1959 17:30	24.9288	1960
06/12/1960 03:15	23.2305	1961
13/12/1961 05:15	11.0508	1962
05/11/1962 10:30	17.8208	1963
18/08/1964 03:30	15.0826	1964
13/12/1964 01:15	21.6098	1965
13/08/1966 19:30	14.7925	1966
06/10/1966 04:45	17.6087	1967
02/11/1967 01:15	12.6241	1968
24/12/1968 20:15	27.6931	1969
25/04/1970 07:15	11.1729	1970
28/11/1970 02:15	12.2732	1971
20/11/1971 16:15	8.5361	1972
12/11/1972 15:30	10.2613	1973
01/12/1973 03:30	21.3522	1974
25/01/1975 05:30	11.7858	1975
02/10/1975 17:45	20.7307	1976
22/10/1976 17:30	13.3523	1977
04/02/1978 08:30	7.23	1978
14/12/1978 21:15	10.4328	1979
07/11/1979 10:30	9.4766	1980
19/09/1981 21:15	12.5324	1981
04/01/1982 20:30	7.0532	1982
23/07/1983 19:45	15.783	1983
03/08/1984 07:15	29.1875	1984
15/08/1985 15:15	9.5636	1985
30/06/1986 11:15	19.7709	1986
21/09/1987 17:45	10.2788	1987
04/01/1988 12:15	11.6062	1988
22/09/1989 00:00	8.2356	1989
06/02/1990 14:30	19.4388	1990
01/08/1991 03:30	12.8624	1991
12/09/1992 16:30	15.0228	1992
12/06/1993 02:45	19.0304	1993
08/12/1993 17:15	11.7548	1994
27/01/1995 13:15	22.8082	1995
24/10/1995 18:15	31.0644	1996
05/08/1997 13:15	19.2046	1997
17/10/1997 11:15	21.1539	1998
02/11/1998 15:15	14.4529	1999
24/12/1999 21:30	16.8861	2000
02/11/2000 18:15	23.8877	2001
23/01/2002 15:15	13.7716	2002
29/10/2002 08:15	14.5852	2003
15/01/2004 13:15	11.9915	2004
07/01/2005 20:15	22.6252	2005
21/09/2006 06:15	11.7369	2006
11/08/2007 19:15	16.5759	2007
10/01/2008 06:15	14.3613	2008
30/01/2009 22:15	15.9938	2009
23/11/2009 10:15	25.0562	2010

Qmed 14.52
Gauge Qmed 14.00
FSU Qmed 17.37



Calibrated Mike NAM Model

Catchment_Name = '15008_RPS'

Catchment_Model = 'NAM'

Catchment_Area = 116.26

Parameter settings

U_Max = 1

L_Max = 9.7

CQOF = 1

CKIF = 21.47

CK1 = 3

CK12_DIF = true

CK2 = 72

TOF = 0.404

TIF = 0.451

TG = 0.0087

CKBF = 1002.78

Calibration period

start = 1972, 10, 10, 30, 0, 0

end = 2010, 8, 29, 0, 0, 0

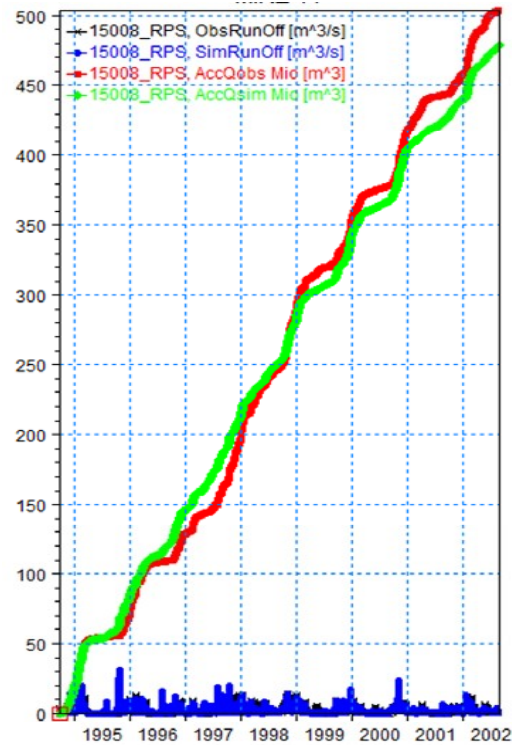
Precipitation data sources

Raingauge and radar data

station	4919	0.586333549
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station	1475	0.413666451
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radar	5	1
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Error measures with missing values (as shown in the figures)

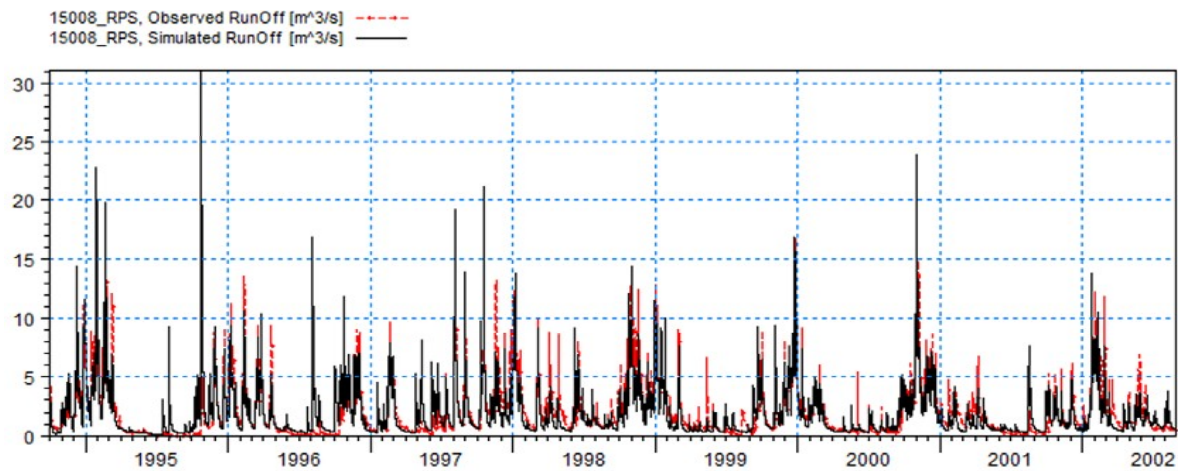
R2 = 0.720

Error measures without missing values

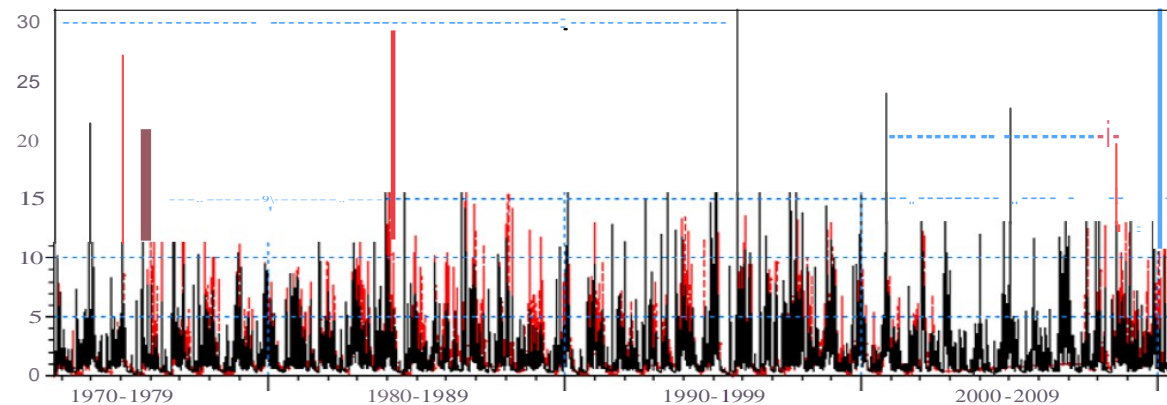
RMSE(Q) = 3.92 3.92

Peak-weighted RMSE(Q) = 6.50

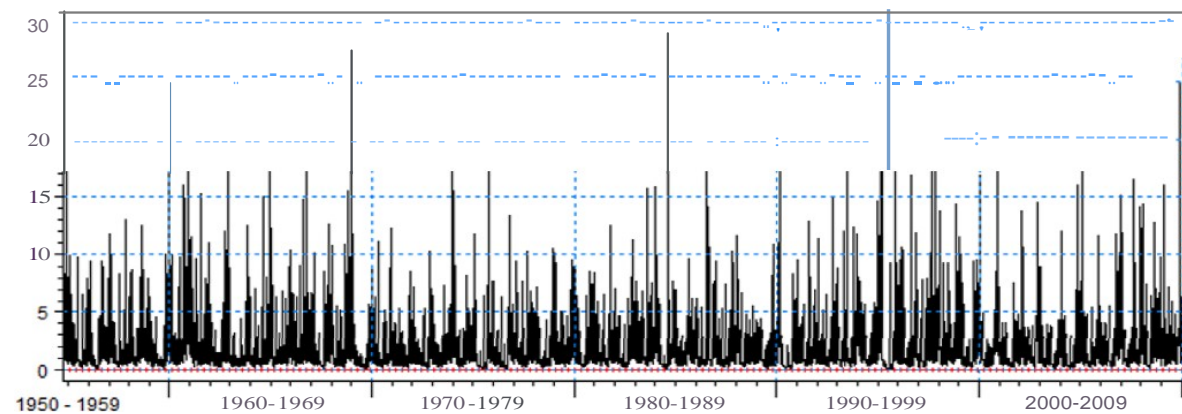
R2 = 0.755



15008_RPS_Observed RunOff (m"lfs)
15008_RPS_Simulated RunOff (m"lfs)



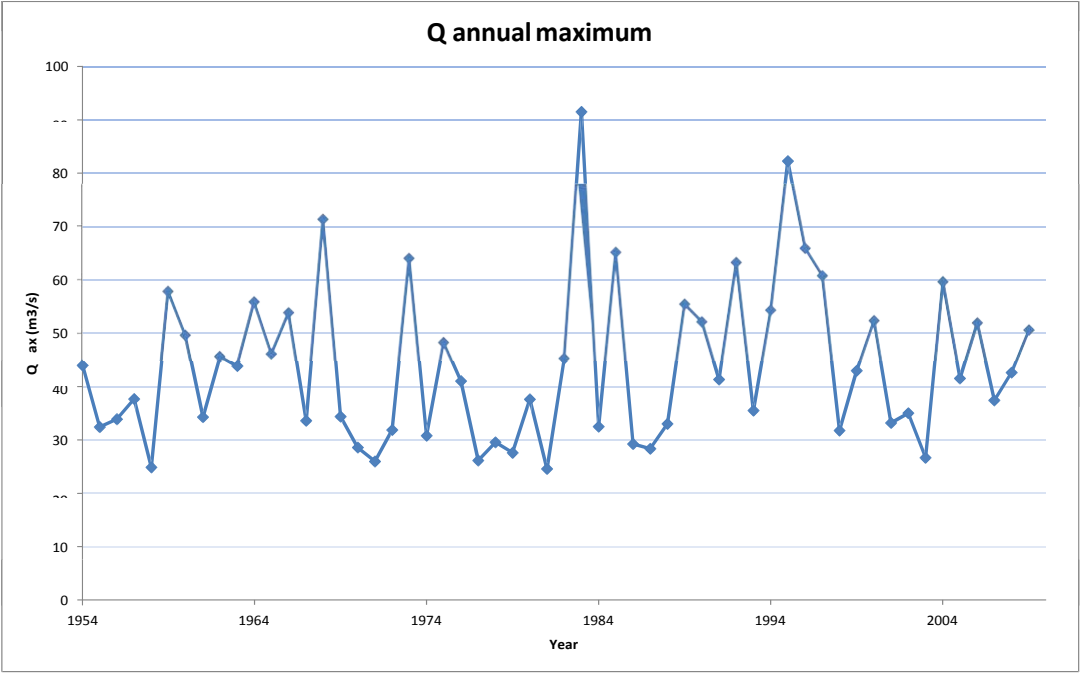
15008_RPS_Observed RunOff (m"lfs)
15008_RPS_Simulated RunOff (m"lfs)



Q annual maximum
(1st October - 30th September)

Datetime	Qmax	Year
08/12/1954 15:30	43.9813	1954
06/09/1956 17:15	32.4225	1955
23/01/1957 13:15	33.8899	1956
27/08/1958 11:30	37.6793	1957
20/12/1958 09:30	24.8525	1958
27/12/1959 17:45	57.8342	1959
06/12/1960 03:45	49.6559	1960
26/09/1962 10:15	34.2803	1961
05/11/1962 13:45	45.6662	1962
18/08/1964 04:15	43.8611	1963
13/12/1964 02:00	55.8624	1964
13/08/1966 21:00	46.1413	1965
06/10/1966 05:30	53.8499	1966
19/08/1968 14:15	33.6017	1967
24/12/1968 21:30	71.2718	1968
25/04/1970 09:00	34.3842	1969
31/10/1970 21:30	28.5737	1970
21/11/1971 15:00	25.975	1971
04/07/1973 02:00	31.862	1972
01/12/1973 06:15	63.9884	1973
18/09/1975 09:15	30.7921	1974
02/10/1975 19:00	48.2923	1975
12/10/1976 05:30	41.0365	1976
02/11/1977 01:45	26.1514	1977
15/12/1978 06:15	29.5562	1978
07/11/1979 17:45	27.5907	1979
19/09/1981 22:30	37.6109	1980
18/08/1982 11:15	24.5745	1981
23/07/1983 23:15	45.3108	1982
03/08/1984 07:45	91.5093	1983
16/08/1985 14:30	32.4926	1984
30/06/1986 13:30	65.1159	1985
21-Sep-87	29.2495	1986
22/10/1987 02:00	28.354	1987
22/09/1989 03:45	33.0058	1988
06/02/1990 15:30	55.444	1989
01/08/1991 06:30	52.1641	1990
12/09/1992 18:30	41.3329	1991
12/06/1993 04:15	63.2242	1992
01-Oct-93	35.4962	1993
27/01/1995 15:15	54.3257	1994
24/10/1995 19:30	82.2773	1995
05/08/1997 16:45	65.8616	1996
17/10/1997 16:15	60.7425	1997
21/09/1999 06:15	31.7483	1998
26/12/1999 12:30	42.9743	1999
02/11/2000 20:00	52.3643	2000
23/01/2002 17:00	33.1911	2001
29/10/2002 12:30	35.0143	2002
16/01/2004 02:45	26.6617	2003
07/01/2005 22:15	59.6229	2004
21/09/2006 08:15	41.5376	2005
11/08/2007 22:15	51.9446	2006
10/01/2008 07:15	37.4123	2007
31/01/2009 12:00	42.6297	2008
23/11/2009 11:15	50.6303	2009

NAM Qmed 41.44
FSU Qmed 48.32
Gauge Qmed 52.44
Est. Qmed (prop.) 40.38



Calibrated Mike NAM Model

Catchment code = 15007_RPS

Catchment name = Ballyragget

Catchment_Name = '15007_RPS'

Catchment_Model = 'NAM'

Catchment_Area = 335.47

Parameter settings

U_Max = 1

L_Max = 1

CQOF = 0.99

CKIF = 11.76

CK1 = 10

CK12_DIF = true

CK2 = 72

TOF = 0.534

TIF = 0

TG = 0.4222

CKBF = 743.407

Calibration period

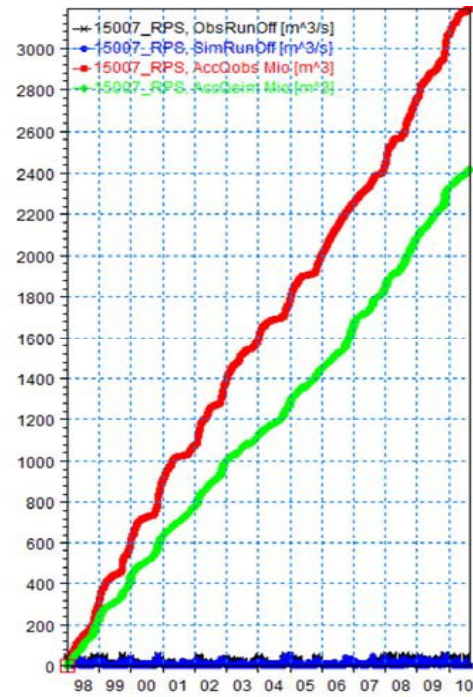
start = 1998, 1, 1, 0, 0, 0

end = 2010, 8, 30, 0, 0, 0

Precipitation data source

station 4919 0.857794

station 1475 0.142206



Error measures with missing values (as shown in the figures)

R2 = 0.492

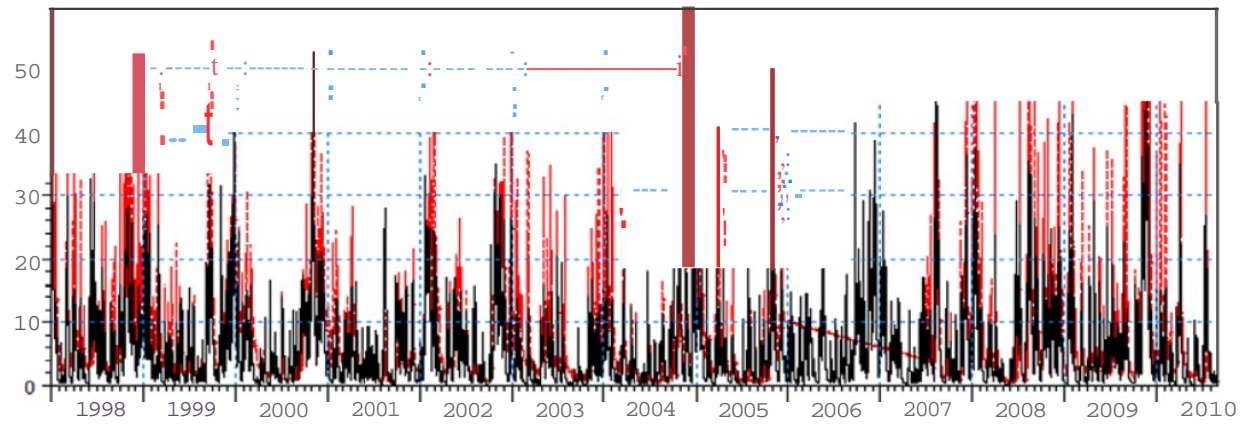
Error measures without missing values

RMSE(Q) = 5.51

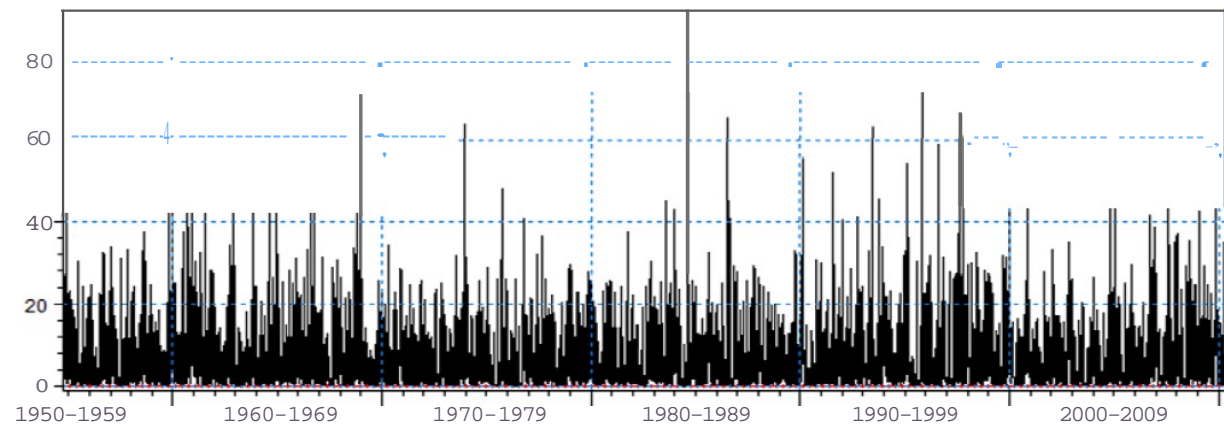
Peak-weighted RMSE(Q) = 11.10

R2 = 0.581

15007_RPS,Observed RunOff [m³/s]
15007_RPS,Sinulated Runoff [m³/s]



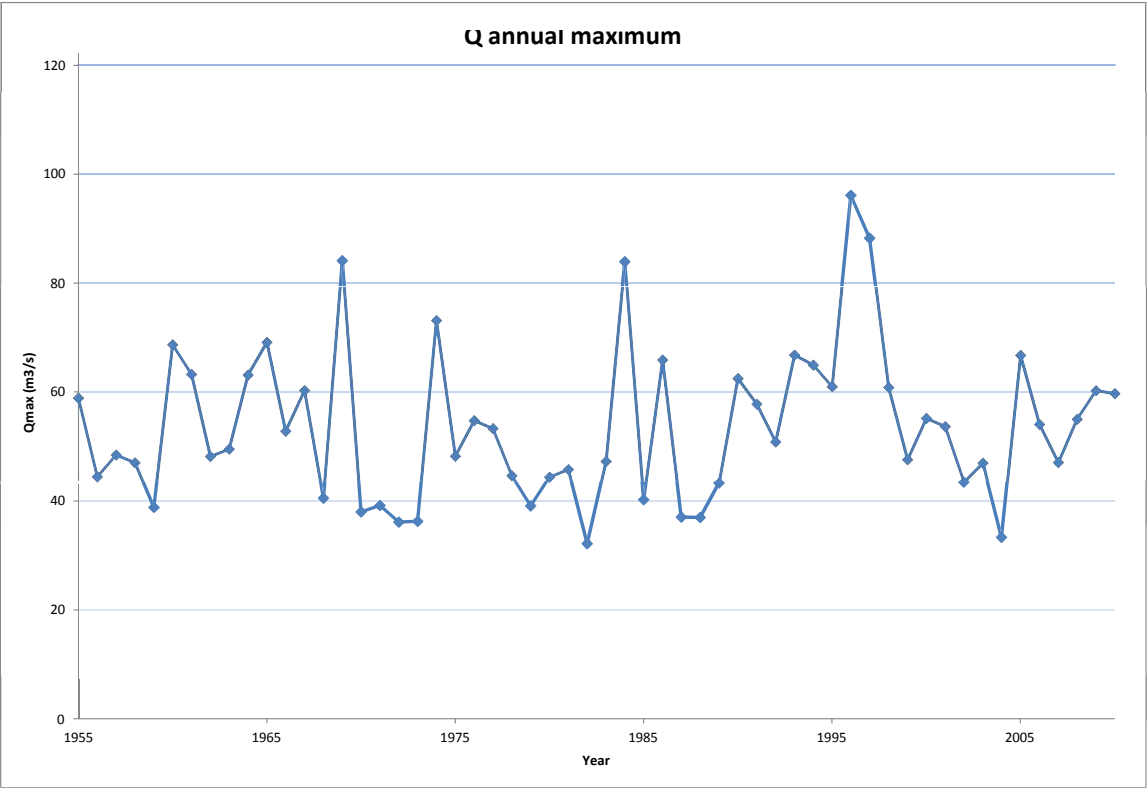
15007_RPS,Observed RunOff (m³/s)
15007_RPS,Sinulated Runoff [m³/s]



Q annual maximum
(1st October - 30th September)

Datetime	Qmax	Year
09/12/1954 12:00	58.8791	1955
07/09/1956 11:00	44.4471	1956
24/01/1957 06:30	48.4589	1957
13/07/1958 14:00	47.0194	1958
20/12/1958 17:15	38.8262	1959
11/10/1959 16:30	68.6685	1960
04/12/1960 23:30	63.246	1961
27/09/1962 04:15	48.1736	1962
06/11/1962 07:30	49.5332	1963
31/10/1963 09:30	63.1279	1964
13/12/1964 17:15	69.11	1965
18/11/1965 10:00	52.8185	1966
06/10/1966 20:15	60.27	1967
20/08/1968 07:45	40.528	1968
25/12/1968 15:30	84.1376	1969
04/11/1969 19:45	37.9967	1970
25/11/1970 13:30	39.1704	1971
21/11/1971 19:00	36.1194	1972
13/11/1972 12:45	36.2622	1973
01/12/1973 21:00	73.1144	1974
18/09/1975 14:15	48.225	1975
03/10/1975 12:30	54.7476	1976
12/10/1976 22:30	53.293	1977
02/11/1977 01:45	44.6561	1978
02/02/1979 10:15	39.0927	1979
27/12/1979 21:00	44.3914	1980
20/09/1981 21:30	45.8007	1981
15/12/1981 03:45	32.1692	1982
25/07/1983 00:00	47.2764	1983
03/08/1984 19:15	83.952	1984
16/08/1985 15:45	40.2403	1985
01/07/1986 01:30	65.8788	1986
21/10/1986 21:15	37.0243	1987
22/10/1987 09:15	36.9659	1988
22/09/1989 13:30	43.3134	1989
08/02/1990 01:45	62.471	1990
02/08/1991 02:15	57.7805	1991
13/09/1992 11:15	50.8414	1992
12/06/1993 23:45	66.7752	1993
01/10/1993 00:00	64.9376	1994
28/01/1995 05:30	60.9668	1995
25/10/1995 07:15	96.135	1996
05/08/1997 22:30	88.2657	1997
18/10/1997 07:00	60.8298	1998
21/09/1999 22:45	47.5871	1999
26/12/1999 20:15	55.169	2000
03/11/2000 12:45	53.6531	2001
24/01/2002 11:00	43.4783	2002
22/10/2002 10:15	46.9745	2003
16/01/2004 07:45	33.332	2004
29/10/2004 17:45	66.7262	2005
22/09/2006 01:15	54.0678	2006
12/08/2007 23:30	47.0667	2007
10/01/2008 21:00	55.0112	2008
01/02/2009 03:15	60.2468	2009
20/11/2009 09:45	59.7093	2010

NAM Qmed 51.83
FSU Qmed 59.55
Gauge Qmed 38.80
Est. Qmed (prop.) 49.76



Calibrated Mike NAM Model

Catchment code = 15004_RPS

Catchment name = Ballyragget

Catchment_Name = '15004_RPS_NAM'
Catchment_Model = 'NAM'
Catchment_Area = 482.42
Catchment_Name = '15004_RPS_URBAN'
Catchment_Model = 'Urban'
Catchment_Area = 6.29
Catchment_Name = '15004_RPS'
Catchment_Model = 'Combined'
Catchment_Area = 488.71

Parameter settings

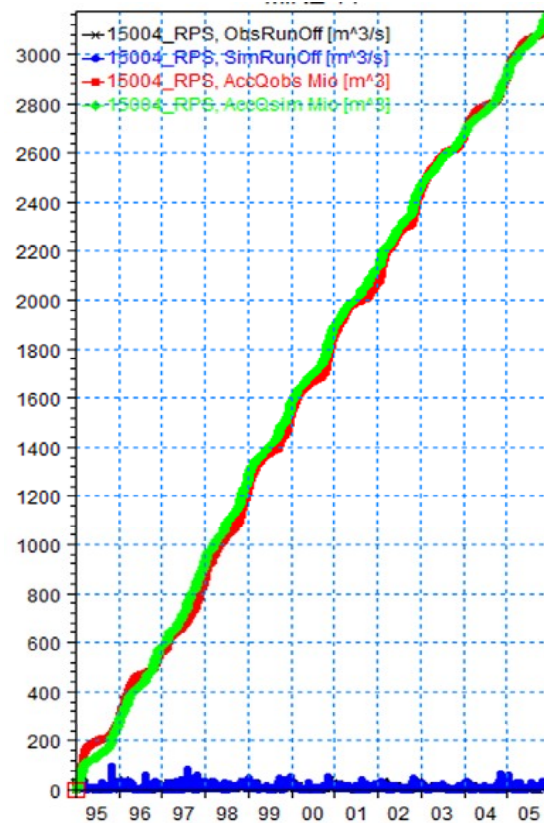
U_Max = 1
L_Max = 1
CQOF = 0.949
CKIF = 1.568
CK1 = 28.8
CK12_DIF = true
CK2 = 22.6933
TOF = 0.99
TIF = 0
TG = 0
CKBF = 4478.44

Calibration period

start = 1995, 1, 1, 0, 0
end = 2006, 1, 1, 0, 0

Precipitation data source

station	4919	0.670076
station	375	0.128777
station	1475	0.098647
station	3613	0.1025



Error measures with missing values (as shown in the figures)

R2 = 0.289

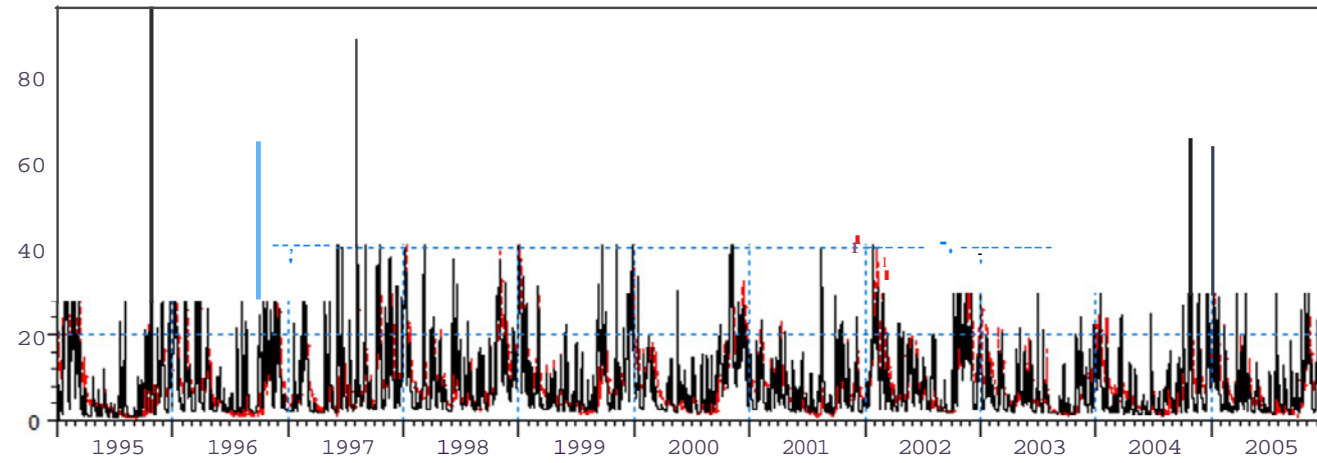
Error measures without missing values

RMSE(Q) = 6.63

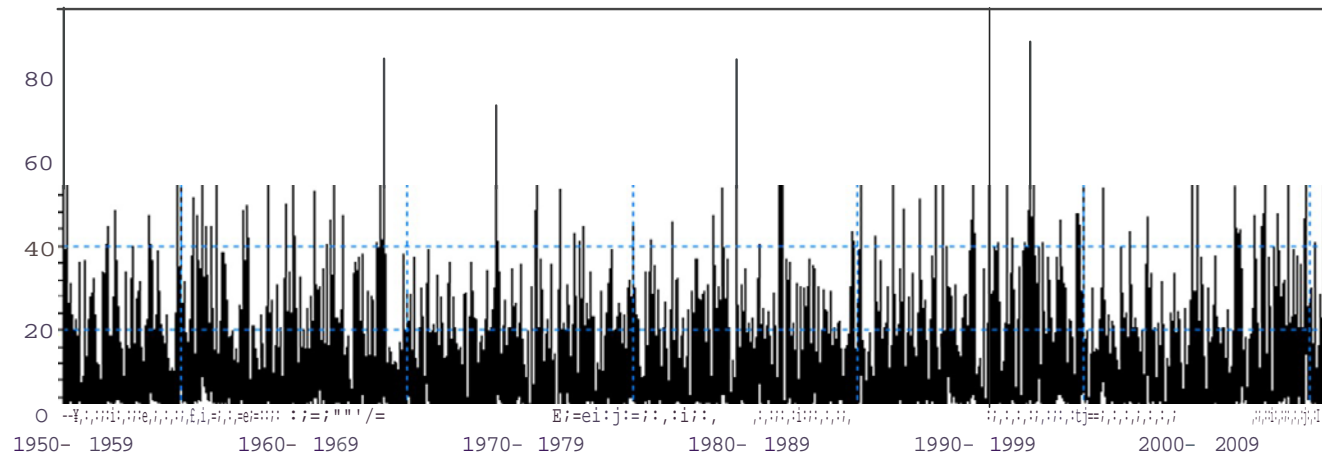
Peak-weighted RMSE(Q) = 8.99

R2 = 0.288

15004_RPS, Observed Runoff [m³/s]
15004_RPS, Simulated Runoff [m³/s]



15004_RPS, Observed RunOff [m³/s]
15004_RPS, Simulated Runoff [m³/s]



Q annual maximum
(1st October - 30th September)

Datetime	Qmax	Year
25-Sep-57	9.1331	1957
03/09/1958 02:15	14.2933	1958
19/12/1958 19:30	15.5935	1959
14/09/1960 04:00	8.3191	1960
04/12/1960 03:00	31.5951	1961
16/01/1962 02:45	6.2659	1962
11/06/1963 19:15	6.7056	1963
20/03/1964 14:30	7.512	1964
12/12/1964 22:15	12.0504	1965
17/11/1965 14:15	8.9074	1966
22/02/1967 22:45	19.3074	1967
09/01/1968 04:00	8.8348	1968
24/12/1968 20:30	38.3437	1969
19/01/1970 20:45	6.3005	1970
01/08/1971 17:15	8.8611	1971
02/02/1972 21:00	8.0243	1972
19/01/1973 19:00	10.9559	1973
01/02/1974 09:30	13.0491	1974
26/04/1975 17:15	9.8572	1975
02/10/1975 11:15	8.0432	1976
14/02/1977 07:45	10.4628	1977
31/10/1977 04:00	15.1127	1978
28/12/1978 01:15	12.1744	1979
27/12/1979 04:15	26.3757	1980
22/10/1980 15:15	17.7898	1981
14/12/1981 15:00	16.6174	1982
17/07/1983 11:00	32.8582	1983
06/02/1984 18:45	18.891	1984
26/07/1985 03:15	16.3394	1985
25/08/1986 17:00	11.2162	1986
16/07/1987 15:15	7.7651	1987
06/01/1988 06:45	8.28	1988
09/08/1989 10:00	10.7208	1989
06/02/1990 17:15	6.7903	1990
09/01/1991 08:30	6.1549	1991
25/11/1991 02:15	6.3629	1992
30/09/1993 06:15	6.1827	1993
12/12/1993 13:45	6.7163	1994
25/01/1995 20:45	13.5766	1995
07/01/1996 02:15	15.3132	1996
03/08/1997 22:15	8.2888	1997
17/11/1997 22:15	19.1527	1998
29/12/1998 23:15	20.6419	1999
29/09/2000 09:00	8.5241	2000
06/11/2000 02:15	19.5155	2001
19/10/2001 17:45	10.9971	2002
27/11/2002 14:30	11.2892	2003
12/03/2004 05:00	5.3481	2004
28/10/2004 01:15	14.447	2005
23/09/2006 07:00	7.9471	2006
15/11/2006 17:15	20.2318	2007
10/01/2008 08:00	17.3483	2008
30/01/2009 15:00	16.887	2009
20/11/2009 00:15	26.015	2010

NAM Qmed 11.10665
FSU Qmed 8.05
Gauge Qmed NaN

