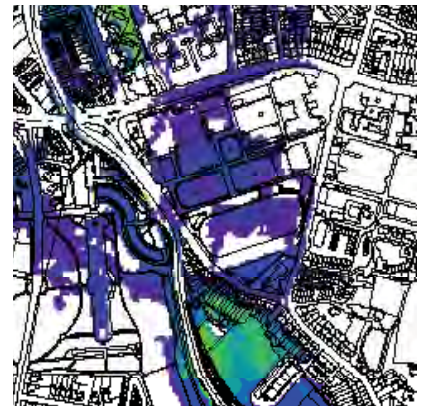
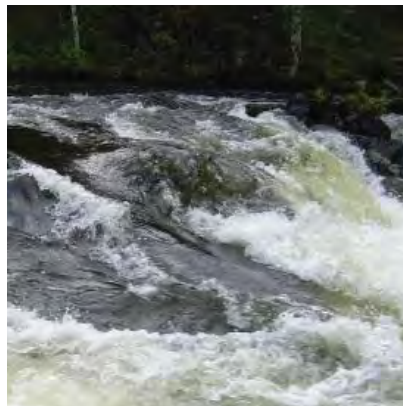


North Western - Neagh Bann CFRAM Study

UoM 06 Hydrology Report

IBE0700Rp0008





North Western – Neagh Bann CFRAM Study

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APPENDICES

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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
EV1	Extreme Value Type 1 (distribution) (=Gumbel distribution)
EPA	Environmental Protection Agency
FARL	Flood Attenuation for Rivers and Lakes
FEH	Flood Estimation Handbook
FEM FRAM	Fingal East Meath 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)
NBIRDB	Neagh Bann International River Basin District
NDTM	National Digital Terrain Model
NWIRBD	North Western International River Basin District
OD	Ordnance Datum
OPW	Office of Public Works
OSi	Ordnance Survey Ireland
PFRA	Preliminary Flood Risk Assessment
PCD	Physical Catchment Descriptor(s)
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)
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 North Western – Neagh Bann Catchment Flood Risk Assessment and Management (CFRAM) Study in March 2012. The North Western – Neagh Bann CFRAM Study was the sixth and last CFRAM 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 North Western International River Basin District (IRBD) covers an area of 12,320 km² with approximately 7,400 km² of that area in the Republic of Ireland. It includes two Units of Management (UoMs), UoM 01 (Donegal) and UoM 36 (Erne). It takes in all of County Donegal as well as parts of Leitrim, Cavan, Monaghan, Longford and Sligo. There is a high level of flood risk within the North Western IRBD, with significant coastal flooding in County Donegal as well as areas of fluvial flooding throughout the district.

The Neagh Bann IRBD covers an area of 8,120 km² with approximately 2,010 km² of that area in Ireland. It represents one single Unit of Management, UoM 06 (Neagh Bann) which is covered in this hydrology report.

UoM 06 includes hydrometric areas 03 and 06. It covers an area of 1,779 km² and includes the majority of County Louth, much of County Monaghan and parts of Meath and Cavan. The principal rivers in UoM 06 are the Fane, Glyde and Dee rivers (which flow eastwards into the Irish Sea) and the Blackwater River (which flows over the border into Northern Ireland in the northern reaches of the UoM).

UoM 06 is predominantly rural with the largest urban areas being Dundalk, Monaghan and Ardee. Smaller towns and villages include Castleblayney and Carrickmacross. Much of UoM 06 is given over to agriculture with some small areas of forestry and peatland cover.

Within UoM 06 there are nine Areas for Further Assessment (AFA) which were reported to the EU in March 2012. These are: Monaghan; Iniskeen; Carrickmacross; Ardee; Carlingford; Greenore; Dundalk & Blackrock South; Annagassan; and Termonfeckin. There are no Individual Risk Receptors identified for further assessment within UoM 06.

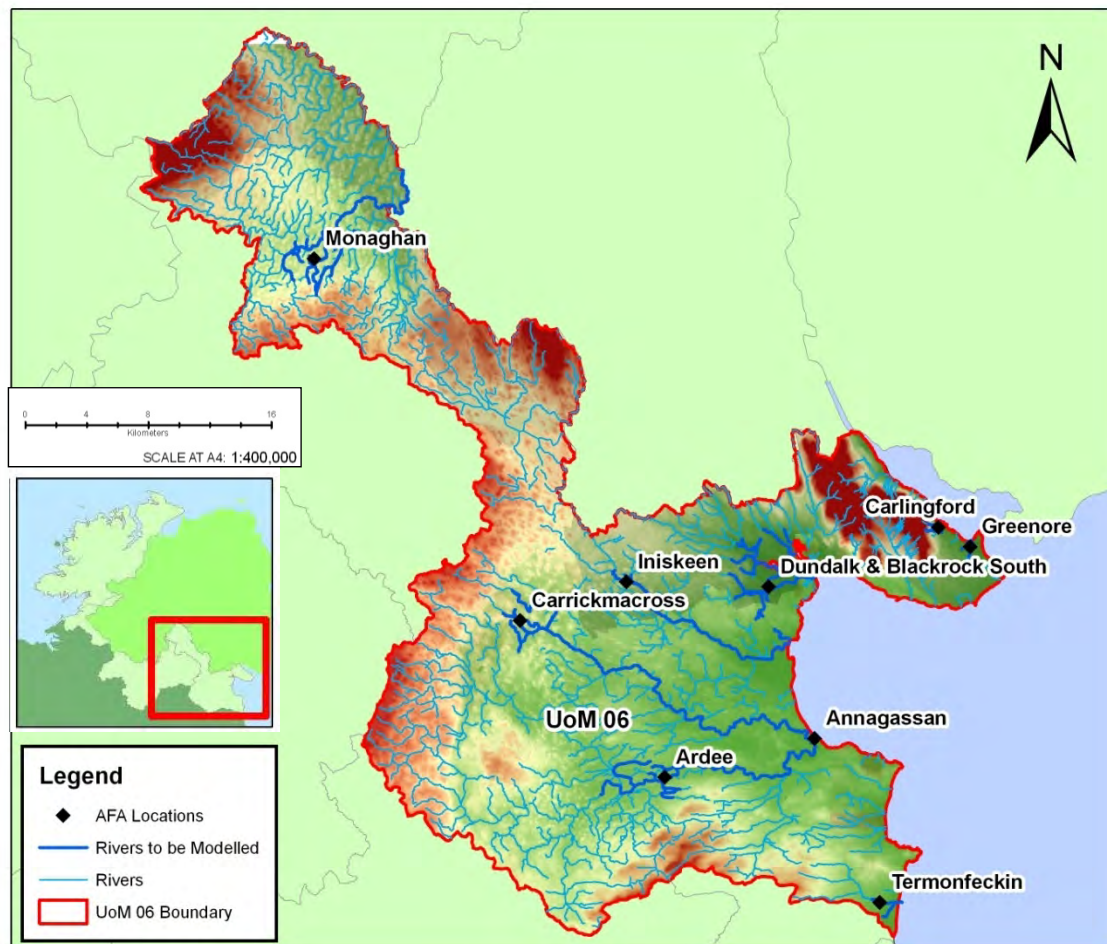


Figure 1.1: UoM 06 AFA Locations and Extents

In accordance with the North West – Neagh Bann River Basin Districts Catchment-based Flood Risk Assessment and Management (CFRAM) Study, Stage II Project Brief (hereinafter referred to as the North Western – Neagh Bann CFRAM Study Brief) only those areas not afforded protection by existing or planned schemes are considered in full as part of this Study. For other areas within AFAs benefiting from existing flood relief schemes, assessment under the North Western – Neagh Bann CFRAM Study will be limited to development and appraisal of maintenance and management options and the consideration of any implications associated with potential development as identified in relevant spatial planning documents. No such areas have been identified within the North Western – Neagh Bann study area. It should be noted that areas subject to minor works are not considered as having schemes in place. The AFAs and the flood risk source to be considered within UoM 06 as part of this study are listed in Table 1.1.

AFA	Fluvial	Coastal	AFA	Fluvial	Coastal
Monaghan	✓	-	Greenore	✓	✓
Iniskeen	✓	-	Dundalk & Blackrock South	✓	✓
Carrickmacross	✓	-	Annagassan	✓	✓
Ardee	✓	-	Termonfeckin	✓	✓
Carlingford	✓	✓	Total	9	5

Table 1.1: Fluvial and Coastal Flood Risk at each AFA

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. The details of the methodologies used and the preliminary hydrological analysis are provided in the Inception Report 'IBE0700Rp0003_UoM 06 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 will provide details of the results of the hydrological analysis and design flow estimation and summarise the outputs from the analysis which will be taken forward as inputs for the hydraulic modelling. Discussion will be provided within this report on the outputs in terms of the degree of confidence which 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 results from the historic flood analysis as this is contained within the Inception Report for UoM 06.

1.2 SUMMARY OF THE AVAILABLE DATA

1.2.1 Summary of Available Hydrometric Data

Hydrometric data is available at 23 hydrometric gauge station locations within UoM 06 as shown in Figure 1.2 below. Eighteen of these stations have water level and flow data available (three of which are operated by the Department of Agriculture and Rural Development (DARD) Rivers Agency (Northern Ireland)).

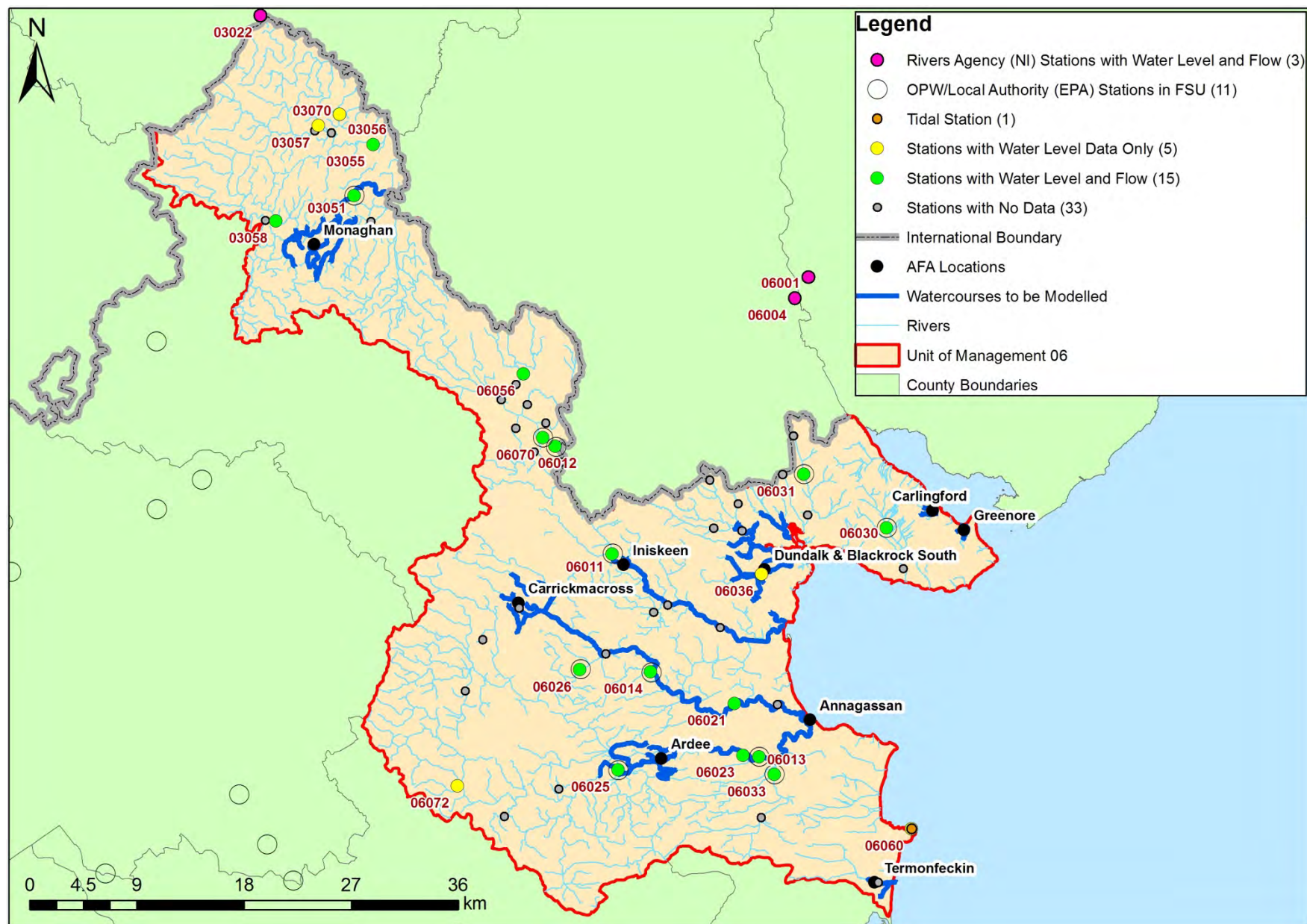


Figure 1.2: Hydrometric Data Availability

Of the 18 stations with flow data available, six stations are located on watercourses to be modelled. Five of these stations were rated under FSU as having a rating classification such that there was sufficient confidence in the rating for use within FSU (A1, A2 or B). Four of the stations were given a rating of A1 indicating that there is confidence in the rating up to at least $1.3 \times Q_{med}$. This is the highest classification for stations taken forward for use within FSU and indicates certainty in flood flows recorded for extreme flood events (above Q_{med}). One of the stations has a rating of B indicating that confidence in the rating is limited to Q_{med} . This is the minimum classification for which stations were taken forward for use within FSU and indicates that there is uncertainty in the flood flows recorded for extreme flood events (above Q_{med}). There is one tidal gauge along the coast of the Unit of Management at Port Oriel between the Annagassan and Termonfeckin AFAs.

1.2.2 Summary of Available Meteorological Data

Observed rainfall data from a number of different sources is available within and in close proximity to UoM 06:

- Met Éireann daily and hourly rainfall gauges within the Neagh Bann IRBD and beyond. There are no hourly gauges within UoM 06. Clones and Ballyhaise hourly stations are located to the west of UoM 06 in Counties Monaghan and Cavan.
- National Roads Authority sub-daily precipitation sensor information has become available since the project inception phase. Data has been received for six locations within UoM 06. The information consists of varying time steps but generally at 20 minutes and 1 hour spacing. The information is of unknown accuracy as the sensor technology has been developed primarily for the identification of precipitation type rather than high accuracy rainfall recording.
- The UK Met Office daily and hourly rainfall gauge information for gauges within Northern Ireland but in close proximity to the border has become available since the project inception phase. Four hourly gauges are in proximity to the extents of UoM 06 at Derrylin, Glenanne, Killowen and Katesbridge.

Historical time series rainfall 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. 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 relation to UoM 06 the only hourly rainfall station used in hydrological analysis is the Met Éireann hourly gauge at Clones (1951 – 2008). It is the closest gauge to the only rainfall runoff model that was constructed (to inform the hydraulic model for Monaghan AFA) and is of high enough temporal resolution and accuracy to be of use. This hourly rainfall dataset is processed and supplied by the national meteorological authority (Met Éireann) and is considered to be of high accuracy. Given that this data is being used as input to a

rainfall run-off model which is used as a complimentary design flow estimation technique, checking for errors in the data is undertaken through the calibration of the rainfall run-off model and only where it is found that calibration to hydrometric data could not be achieved. Further details of the rainfall-runoff model constructed within UoM 06 are in Section 4.1.

A data collection meeting held prior to commencement of the Study (between RPS, HydroLogic, OPW and Met Éireann) identified an opportunity for exploring the use and benefits of rainfall radar data in hydrological analysis. Trials undertaken within the Eastern Study area demonstrated that there were benefits to be had by using gauge adjusted radar as opposed to using rain gauge data only to drive rainfall run-off models. RPS reviewed the extents of the radar coverage in relation to the NW – NB Study area and found there to be some coverage of the NB Study area from both the Met Office radar at Castor Bay and the Met Éireann radar at Dublin Airport. However the study area is generally well gauged and there were only a few locations where the use of high resolution rainfall data would be required to produce a simulated, calibrated and extended hydrometric gauge record. In addition there is already high temporal resolution rainfall data from the hourly gauge at Clones and the Met Office gauge at Glenanne in close proximity to the potentially benefitting catchments. Processing of the radar records into gauge adjusted, gridded and catchment aggregated time series was therefore not considered necessary within the Study area.

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 is generally the same as for hourly rainfall data. Figure 1.3 shows the locations of all of the rain gauges available and the availability of historic information at the hourly rainfall gauges.



Figure 1.3: Meteorological Data Availability

2 METHODOLOGY REVIEW

The methodologies for hydrological analysis and design flow estimation were developed based on the current best practice and detailed in the UoM 06 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 discuss amendments to the catchment boundaries that have become apparent and must be considered in the hydrological analysis.

2.1 HYDROLOGICAL ANALYSIS

The main tasks of hydrological analysis of 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 5. This analysis was undertaken prior to the receipt of survey information which would have allowed the progression of the North Western – Neagh Bann CFRAM Study gauge station rating reviews identified within the UoM 06 Inception Report. Following completion of the rating reviews there was not found to be significant uncertainty in the ratings of the three 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 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 and as such it is not necessary to re-analyse the pooling groups. However where growth curves are based on a single site analysis where it has been shown that there is 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 USE OF METEOROLOGICAL DATA

Chapter 1.2.2 details where high resolution temporal rainfall data required as input to rainfall run-off models is available within UoM 06 and discusses how the availability of hourly stations within close proximity to potentially benefitting catchments negates the need for radar data. The good availability of meteorological data in the form of hourly rainfall data within close proximity to the catchment identified at station 03051 for rainfall runoff modelling provides the high temporal resolution data needed for driving the rainfall runoff model undertaken. This was the only location identified where rainfall data could be used within a calibrated, hydrological model to enhance the available flow data through simulation of a long term record. Elsewhere, the good availability of A1 and A2 stations already provides high confidence in flow data such that there is no need for additional hydrological modelling or in the case of the ungauged catchments and sub-catchments no meaningful calibration of a model could be achieved.

Within the NW-NB CFRAM Study methodology rainfall run-off data is used within calibrated (to hydrometric gauge data) hydrological catchment models to provide additional simulated catchment flow data to bring greater confidence to statistical design flow estimates and provide additional (simulated) historical flow data for model calibration. In the case of UoM 06, most of the hydrometric stations located on modelled watercourses have a high level of confidence associated with them. To this end, one rain-runoff model was deemed to have potential benefit in augmenting the AMAX series and associated confidence in flow data of Station 03051 on the Monaghan Blackwater. Hourly rainfall data from the Met Éireann Clones gauge was used to provide detailed temporal resolution in this model as discussed in Section 4.1 and Appendix C.

2.3 DESIGN FLOW ESTIMATION

The estimation of design flows is based on the best practice guidance for Irish catchments generally as outlined in the Flood Studies Update (FSU) and supplemented with other methodologies where these are considered more appropriate. The methodologies for estimation of the various elements which make up the design flow estimates to be used for hydraulic 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 preferred methodologies for estimation of design flow vary depending on the size, whether or not the catchment is gauged and also based on how the run-off from the catchments impacts upon the AFA. However a comprehensive, hierarchical approach is being taken to index flood flow estimation whereby all the specified methodologies available at each HEP are employed to estimate the index

flood flow and to provide robustness to the estimates. For example, 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, rating reviews and other applicable methodologies are used to adjust / improve the estimate as the design flow estimation is developed. The hierarchy of preferred 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. In the case of UoM 06 there are six gauging stations with flow data located directly on modelled watercourses, three of which are subject to a review of the rating using hydraulic modelling. Following rating review it can be considered that these gauging stations will have confidence in the rating at Q_{med} or above. Five of the nine designated fluvial models include watercourses which are gauged as indicated by Table 2.1.

Model Number	AFA	Station	FSU Classification	Rating Review
1	Monaghan	03051 Faulkland	B	No
5	Iniskeen	06011 Moyles Mill	A1	Yes
6	Carrickmacross	06014 Tallanstown	A1	No
7	Ardee	06025 Burley	A1	Yes
		06013 Charleville	A1	No
8	Annagassan	06021 Mansfieldstown	Not Rated	Yes

Table 2.1: UoM 06 Models with Gauging Stations

Station 06013, Charleville is located at the downstream end of the Ardee Model, which is the upstream end of the Annagassan Model. Similarly, Station 06014 Tallanstown is located at the downstream end of the Carrickmacross Model, which is the upstream end of the northern branch of the Annagassan Model.

2.3.1.2 Ungauged Index Flood Flow (Q_{med})

At all catchments the ungauged catchment descriptor based method **FSU WP 2.3 'Flood Estimation in Ungauged Catchments'** has been used, to derive estimates of Q_{med} , including small ungauged catchments. 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 Bayliss, 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 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 the 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'.

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. 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 NW-NB CFRAM Study centres around FSU Work Package 3.1 'Hydrograph Width Analysis' and uses the tools developed by the OPW for analysing flood hydrographs at gauged sites. 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). As such the hydrograph shapes are generated based on the following methods:

1. At HEPs representing larger catchments (generally 10km^2 or larger) within UoM 06 hydrographs will be generated using the recently released Hydrograph Shape generator (version 5) developed by the 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
2.) hydrographs across the Eastern and South Eastern Study areas. The NAM hydrograph output at Hydrometric Station 03051 has been used as a pivotal site in deriving hydrograph inputs within Model 1. Data for this station has not been included within the FSU hydrograph shape generator and as such the longer, more complete simulated NAM record was

processed using the FSU hydrograph width analysis software tool – refer to Sections 4.1 and 6.1.1 for further details.

3. At HEPs representing smaller ungauged catchments (generally less than 10km²) it may not be possible to find a suitable Pivotal Site from which a comparable hydrograph shape can be borrowed, particularly for the very small sub-catchments representing tributary headwaters. In this instance hydrograph shapes have been generated using the Flood Studies Supplementary Report (FSSR) 16 Unit Hydrograph method.

Design hydrographs have been developed at all HEPs. It was originally intended that at the smallest inflow / tributary HEPs that continuous point flows could be input. However analysis of this method found that the hydrograph was 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. Examples of this are urban watercourses within Monaghan, Dundalk, Carrickmacross and Ardee where existing culvert and channel structures may surcharge and as such the event flood volume may be a critical factor. Application of continuous point flows on the upstream reaches of the hydraulic models 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 RPS methodology through its application on the NW-NB CFRAM Study the hydrology process has been amended slightly from that which has been presented in the UoM 06 Inception Report (summarised previously in Figure 5.2 of report IBE0700Rp0002_UoM 06 Inception Report_F02). The revised process flow chart which has been applied in carrying out the hydrological analysis and design flow estimation for UoM 06 is presented in Figure 2.1. It is worth noting that the core methodologies employed within the Study are statistically based. These approaches do not require the identification of critical storms as the method ensures that the correct frequency conditions are achieved through checking the developing modelled hydrograph moving down through the catchment and adjusting the timings and peaks on the lateral inflow and tributary point inflows where necessary. This is the process shown in boxes 14 and 15 within Figure 2.1.

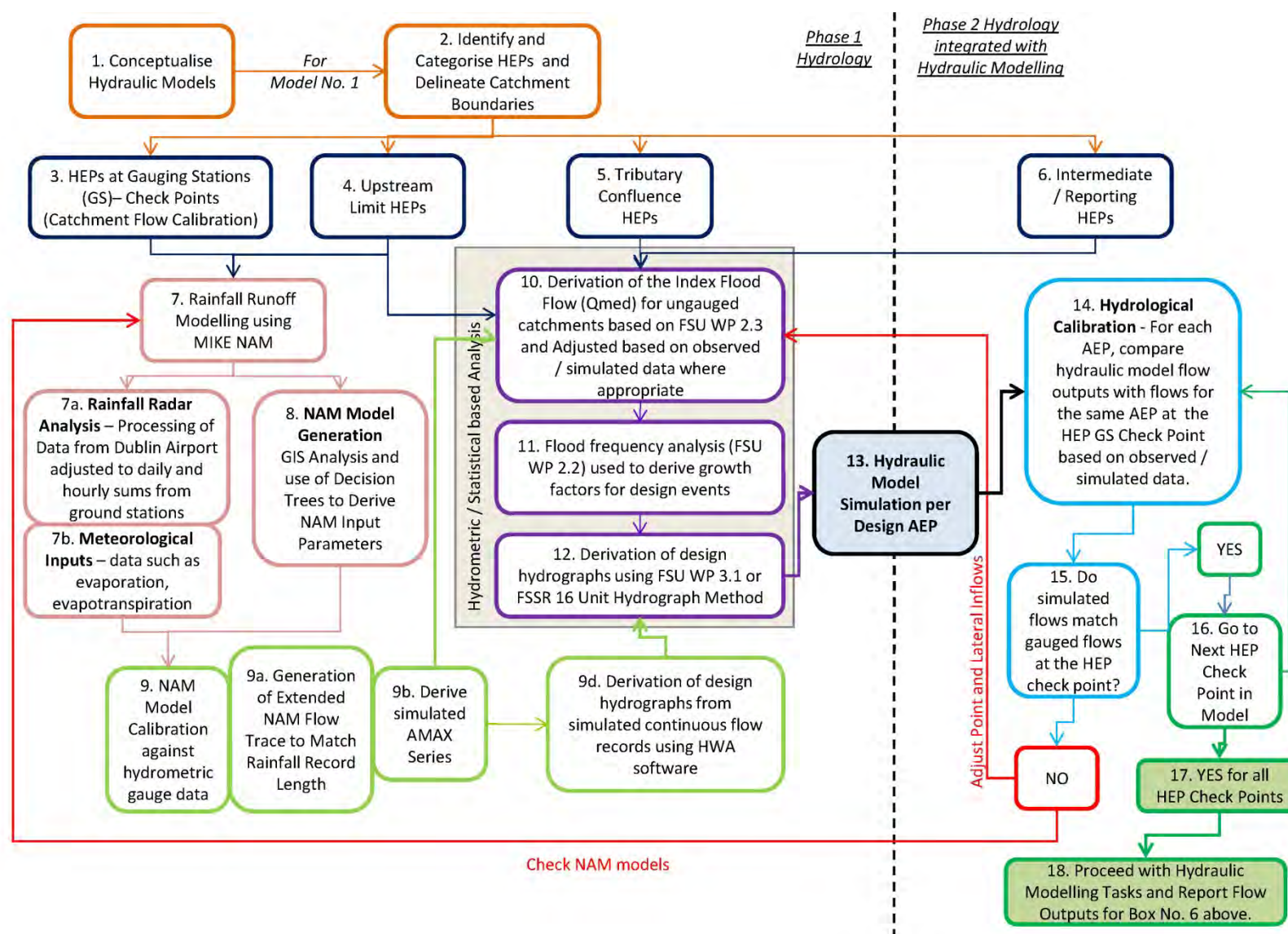


Figure 2.1: Hydrology Process Flow Chart

2.5 CATCHMENT BOUNDARY REVIEW AND HYDROLOGICAL ESTIMATION POINTS

In line with the CFRAM Study Stage 1 Project Brief (ref. 2149/RP/002/F, May 2010) Section 6.3, RPS delineated the catchment boundaries at HEPs using the FSU derived ungauged and gauged catchment boundaries as a starting point. In addition to the FSU delineated catchments, sub-catchments relating to cross border catchments were also provided by the Rivers Agency and where provided these tended to capture cross-border catchments more accurately and as such were used as the starting point for review. For details of the full methodology for undertaking this review see UoM 06 Inception Report Section 5.3.2.

2.5.1 Catchment Boundary Review

Following the completion of the review process a number of the catchment boundaries were amended and in several cases the catchments boundaries were changed by more than 10%. Table 2.2 gives a summary of the changes in the catchment area at CFRAMS HEP points when compared to the equivalent FSU / Rivers Agency catchment from which they were derived.

Change in Catchment Area	Number of HEPs	% of HEPs
New Catchment Delineated	36	23
No change	17	11
0 – 10%	50	32
Greater than 10%	54	34
Total	157	100

Table 2.2: Summary of Catchment Boundary Review

Not all the catchments related to HEPs that are required to be considered within UoM 06 were previously delineated. Some of the catchments relate to small streams and land drains which were too small to be considered under FSU and as such RPS defined these previously un-delineated HEP catchments using a combination of mapping, aerial photography and the National Digital Height Model (NDHM). In addition many of the cross border catchments were not captured accurately appearing to be cut-off at either the border / boundary of UoM 06 or at the extents of the NDHM. As discussed, the Rivers Agency provided catchment boundaries for all of the cross border catchments where these eventually discharged to the sea in Northern Ireland which aided delineation of cross border catchments in particular.

The review concluded that 23% of HEPs required new delineation. For the rest of the HEPs, the pre-existing FSU ungauged catchments were already accurately delineated in 55% of cases but the remainder required modification by more than 10% since they were found not to be representative of the NDHM, the mapping or

draft survey information. The most common reason for amendment in the case of UoM 06 was replacement of the FSU catchment with the equivalent Rivers Agency catchment, which occurred in 90 cases without further RPS change and a further 26 cases with additional changes made by RPS.

Figure 2.2 provides an overview of the difference between CFRAM Study catchments (RPS) and the FSU catchments from which they originated.

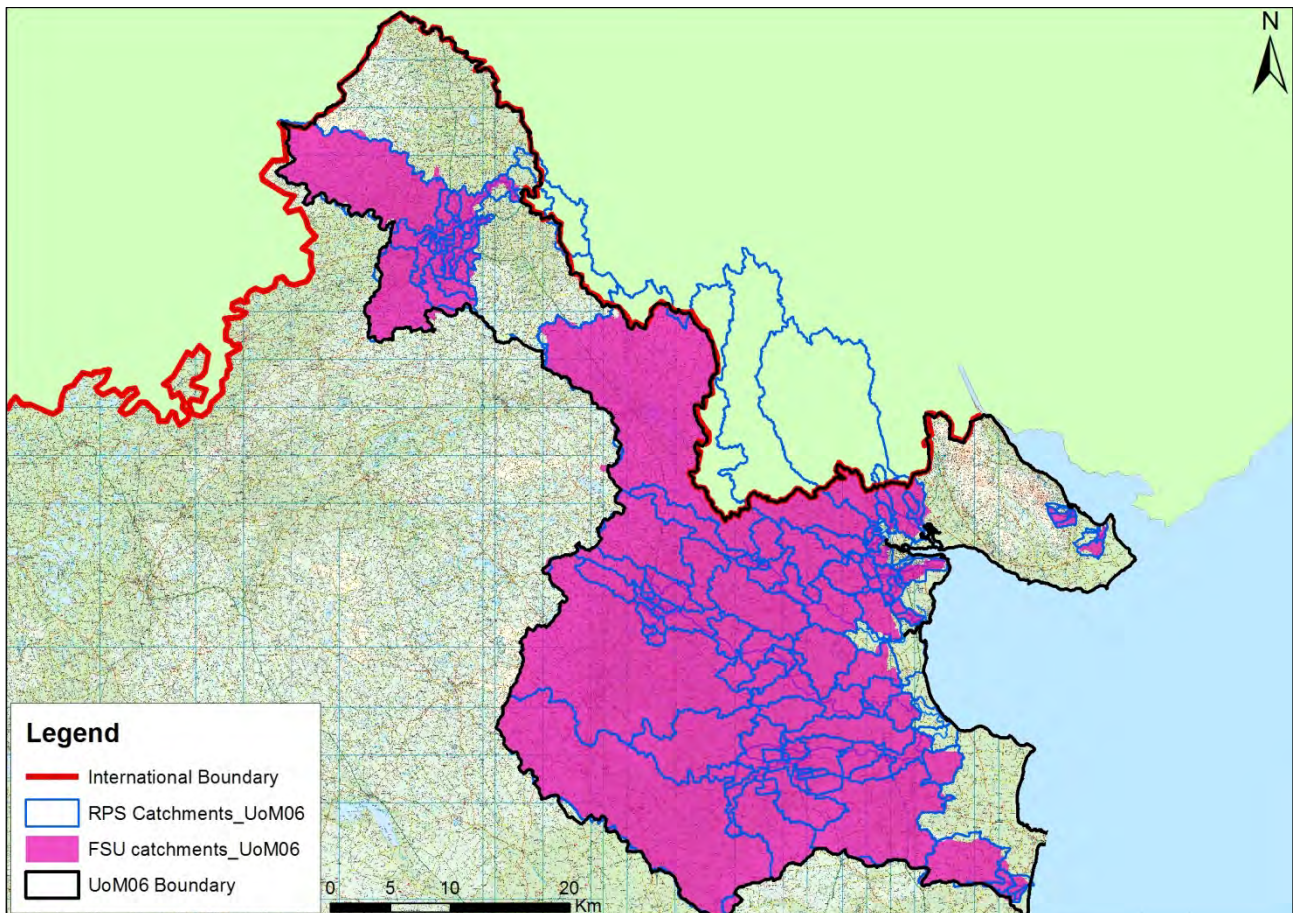


Figure 2.2: UoM 06 Catchment Boundary Comparison

An example of a significant change to the FSU dataset is shown on Figure 2.3. This occurred on the Cor River in County Monaghan which joins with the Monaghan Blackwater at the border with Northern Ireland before flowing northwards through County Armagh. In assigning a HEP node to this confluence as part of hydraulic Model 1, it was noticed that an FSU node was not available. Closer inspection revealed that the EPA blue line network was erroneous at this point and did not accurately represent the Cor River. In fact the Cor River is broken into small segments on the EPA blue line network such that the small branch that meets the Blackwater was too small to be picked up by the FSU. As a result FSU catchment descriptors or outline were not available here. RPS rectified the error for CFRAM Study purposes by delineating a new HEP node (06_385_4_RPS) and an associated catchment boundary as shown on Figure 2.3. Physical Catchment Descriptors (PCDs) were derived for this new catchment based on mapping, aerial photography, digital height models and Rivers Agency defined catchment information.

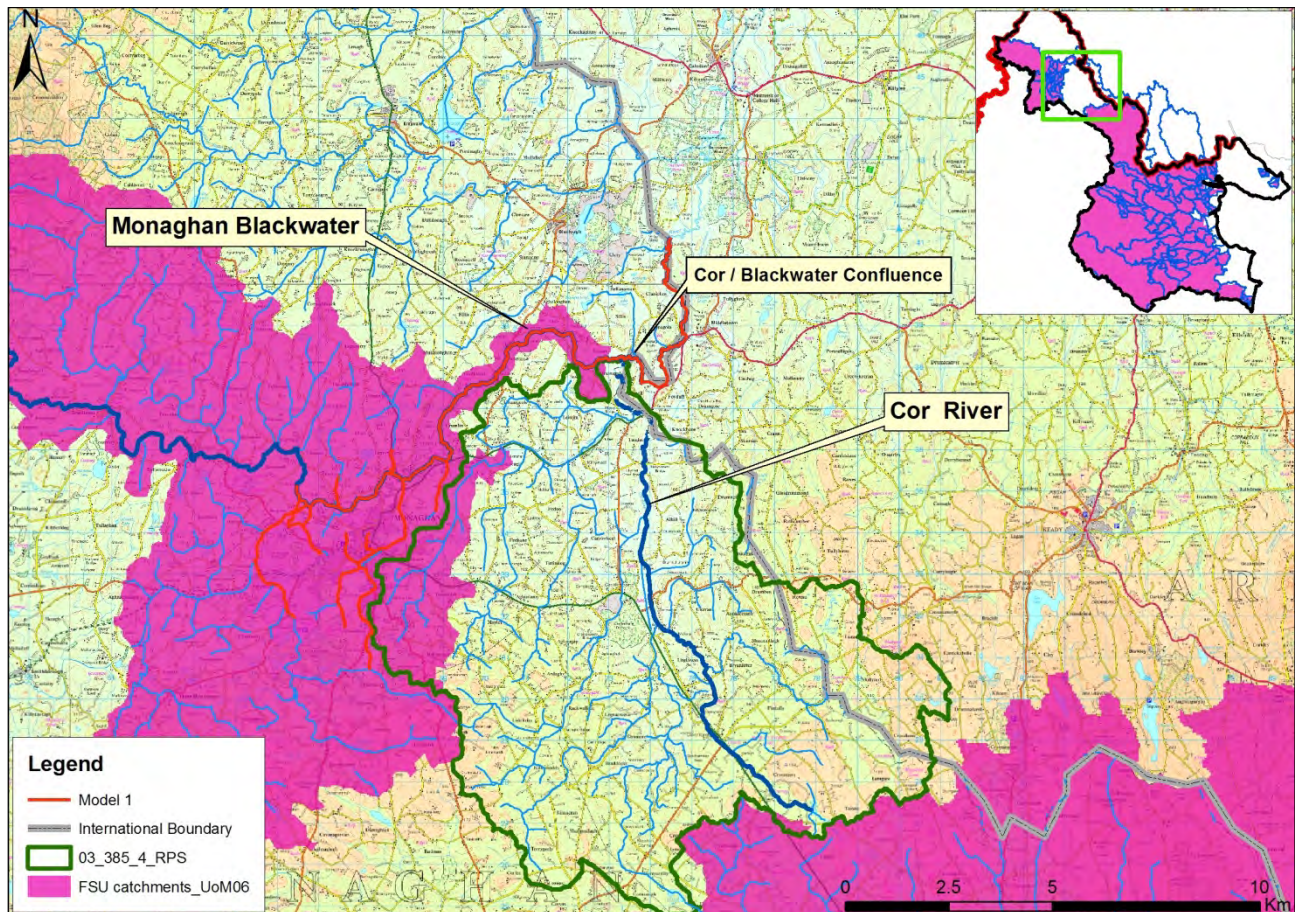


Figure 2.3: Cor River - Missing FSU node and catchment rectified for CFRAM Study

2.5.2 Hydrological Estimation Points

HEPs are defined within hydraulic models at their upstream limits, at tributary confluences (greater than 5km^2), at intermediate locations along modelled reaches, at hydrometric stations and at their downstream limits. For full details on this refer to the UoM 06 Inception Report. Each defined HEP was given a Node Identification Code for the CFRAM Study termed "NODE_ID_CFRAMS". The starting point for this ID code was the FSU NODE ID at which gauged or ungauged catchment descriptors are defined. This ID is in three parts as follows:

e.g. 06_1234_1

where '06' denotes the relevant hydrometric area, '1234' denotes the river ID and '1' denotes the position of the FSU node along the river centreline (for gauged HEPs, the "06_1234" notation is replaced with the station number). This NODE ID was used in the first instance for HEP identification but was adapted for the CFRAM Study under the following conditions:

06_1234 - catchment descriptors and catchment area are based on FSU database;

06_1234_RPS – catchment descriptors and catchment area are based on FSU database but the catchment area has been edited by RPS;

06_1234_RA – catchment descriptors and catchment area are based on FSU database but the catchment area has been replaced with that of the catchment provided by Rivers Agency;

06_1234_RARPS – catchment descriptors and catchment area are based on FSU database but catchment area has been replaced with that of the catchment provided by Rivers Agency and has been further edited by RPS.

The IDs for each HEP are tabulated for each hydraulic model in Chapter 4 and Appendix D.

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 North Western – Neagh Bann CFRAM Study brief to undertake further rating review of a subset of hydrometric gauging stations. Following the completion of the risk review stage and finalisation of the AFA locations three hydrometric stations were specified for rating review. The three stations to be taken forward for review were chosen for rating review by the OPW as they had available continuous flow data, were located on (or just upstream or downstream of) 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 entails the following general steps:

1. Gauge station reach of watercourse is surveyed in detail (site visit, cross sections and LiDAR survey). Rating review survey is prioritised ahead of survey required for hydraulic modelling.
2. A hydraulic model is constructed of the reach of the watercourse from sufficient distance upstream to a sufficient distance downstream of the gauge station. Where rating review reaches have been modelled separately from the main AFA model, the main AFA model will be calibrated to the results of rating review to ensure consistency.
3. Spot gauged flows are replicated within the model using design flow hydrographs and model parameters adjusted within realistic limits in order to achieve the corresponding recorded water levels at the gauge station location.
4. When calibration is achieved flows are increased from zero to above the highest design flow (>0.1% AEP event) and the corresponding modelled water levels at the gauge location are recorded.
5. The stage (water level minus gauge station staff zero level) versus discharge results are plotted to determine the modelled stage discharge (Q-h) relationship.
6. The existing Q-h relationship is reviewed in light of the modelled relationship and the existing reliable limit of the Q-h relationship is extended up to the limit of the modelled flows. In some cases where the existing Q-h relationship has 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.

Three hydrometric stations have been specified for this analysis within UoM 06 and 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 is significant uncertainty in the existing rating, defined as a difference in Q_{med} of more than 10%, is stated in Table 3.1.

Station Number	Station Name	Final Station Rating Quality Classification	Significant Uncertainty Identified in current rating
06011	Moyles Mill	A1	No
06021	Mansfieldstown	Not Rated	No
06025	Burley	A1	No

Table 3.1: Existing Rating Quality Classification for Rating Review Stations in UoM 06

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 flood plain.

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 B.

Table 3.2: AMAX Series Data Before and After Rating Review

	06011 Moyles Mill		06021 Mansfieldstown		06025 Burley	
	Exist (m³/s)	RR (m³/s)	Exist (m³/s)	RR (m³/s)	Exist (m³/s)	RR (m³/s)
1955			21.48	n.a.		
1956			27.20	n.a.		
1957	12.34		21.48	n.a.		
1958	21.07		33.00	n.a.		
1959	15.39		21.19	n.a.		
1960	14.20		28.70	n.a.		
1961	15.70		22.05	n.a.		
1962	13.39		18.10	n.a.		
1963	18.84		22.05	n.a.		
1964	19.49		26.75	n.a.		
1965	18.14		31.15	n.a.		
1966	18.84		25.71	n.a.		
1967	13.39		29.77	n.a.		
1968	15.39		30.07	n.a.		
1969	13.56		23.94	n.a.		
1970	10.94		17.68	n.a.		
1971	13.39		18.51	n.a.		
1972	10.90		13.02	11.97		
1973	13.31		22.35	21.15		
1974	14.37		19.78	19.78		
1975	11.29		15.41	15.41	12.53	12.55
1976	19.13		19.73	19.73	16.66	16.69
1977	11.68		15.29	15.29	12.80	12.82
1978	26.36		30.24	34.22	20.04	20.09
1979	16.91		23.81	23.81	20.49	20.53
1980	17.14		23.69	23.69	18.21	18.25
1981	17.04		22.23	22.23	17.90	17.93
1982	17.04		14.75	14.75	16.86	16.90
1983	19.35		21.99	21.99	18.74	18.78
1984	11.98		22.47	22.47	18.53	18.57
1985	12.49		15.41	15.41	18.64	18.68
1986	14.20		18.92	18.92	13.91	13.94
1987	15.16		21.87	21.87	19.28	19.32
1988	15.45		17.77	17.77	17.69	17.73
1989	12.74		23.81	23.81	19.06	19.11
1990	14.88		24.80	25.15	19.06	19.11
1991	19.03		18.92	19.27	19.72	19.76
1992	12.87		18.22	18.22	14.97	15.00
1993	14.88		27.42	29.42	18.96	19.00
1994	16.89		23.61	23.61	19.17	19.22
1995	19.99		29.91	33.59	23.46	23.78

	06011 Moyles Mill		06021 Mansfieldstown		06025 Burley	
	Exist (m³/s)	RR (m³/s)	Exist (m³/s)		Exist (m³/s)	RR (m³/s)
1996	15.16		15.23	15.23	18.64	18.68
1997	15.73		16.12	16.12	16.76	16.79
1998	14.88		16.90	16.90	21.04	21.09
1999	17.49		12.74	12.74	14.68	14.70
2000	19.51		20.13	20.13	23.57	23.96
2001	19.35		17.58	17.58	19.61	19.65
2002	19.67		20.61	20.61	22.76	22.81
2003	11.98		15.01	15.01	14.48	14.51
2004	18.10		18.73	18.73	21.44	21.49
2005	14.61		17.58	17.58	17.27	17.31
2006	18.10		22.28	22.28	17.90	17.93
2007	17.49		22.76	22.76	23.27	23.50
2008	11.98		15.23	15.23	18.53	18.57
2009	26.21		27.74	29.94	22.12	22.18
2010			23.74	23.74		
2011			25.60	26.44		
Q _{med}	15.39		21.87 ¹	19.96	18.69	18.68
FSU	15.39				18.64	
% Diff.	n/a		-8.7%		0.22%	



Denotes data taken forward for use in FSU. Rating considered to have confidence up to at least 1.3 x Q_{med} (both A1 stations)

Note ¹: Not rated under FSU, no indication from OPW Hydrometrics that data is poor. Highest Gauged Flow is 35.96m³/s. Therefore HGF/Q_{med} = 1.67 which suggests an A rated station.

Not all of the record length of existing AMAX series data has been re-assessed given the new rating. Initially the revised ratings generally have only been applied to the period of the existing OPW / EPA rating. Where there has been a significant change in the rating during this period and the period is less than 14 years RPS have applied the rating back further such that there is statistical confidence in the revised Q_{med} value.

The rating review at the Moyles Mill gauging station (06025) found good agreement with the existing rating curve at flood flows but could not improve upon the existing rating. However there was an element of uncertainty due to the fact that the last spot gauging was taken 16 years ago. Since the station has an A1 classification, the existing FSU Q_{med} is considered the most appropriate value to be taken forward as the basis for design flow estimation.

The rating review at the Mansfieldstown gauging station (06021) found good agreement between the modelled and existing OPW developed rating curve. At Q_{med} there was found to be less than 10% difference and as such the observed Q_{med} value can be taken forward for design flow estimation with confidence.

The rating review at the Burley Bridge gauging station (06025) found good agreement between the modelled and existing OPW developed rating curve. At Q_{med} there was found to be 0.22% difference and as such the observed Q_{med} value can be taken forward for design flow estimation with confidence.

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 such that the rating reviews can be 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 are detailed (Table 3.3).

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.	Medium	Re-assess Q_{med} for FSU classified sites of C or U
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 for calibration.	Medium	Frequency re-analysis not required. Where event flows are used for calibration historic flows must be re-calculated

Hydrological Analysis	Potential Effects of Uncertainty in the Rating	Potential Impact	Mitigation
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.
Hydraulic model calibration	Calibration of hydraulic models is undertaken at extreme flood flows where highest degree of uncertainty could be present. Model calibration therefore dependent 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

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 UoM 06 Inception Report and are reviewed in Chapter 2 of this report. As discussed the methods combine best practice statistical methods. This chapter details the Index Flood Flow estimation at each of the HEPs within UoM 06 on a model by model basis, including a discussion on the confidence and comparison of the outputs from the considered methodologies. There are nine models included in UoM 06 and these are shown in Figure 4.1.

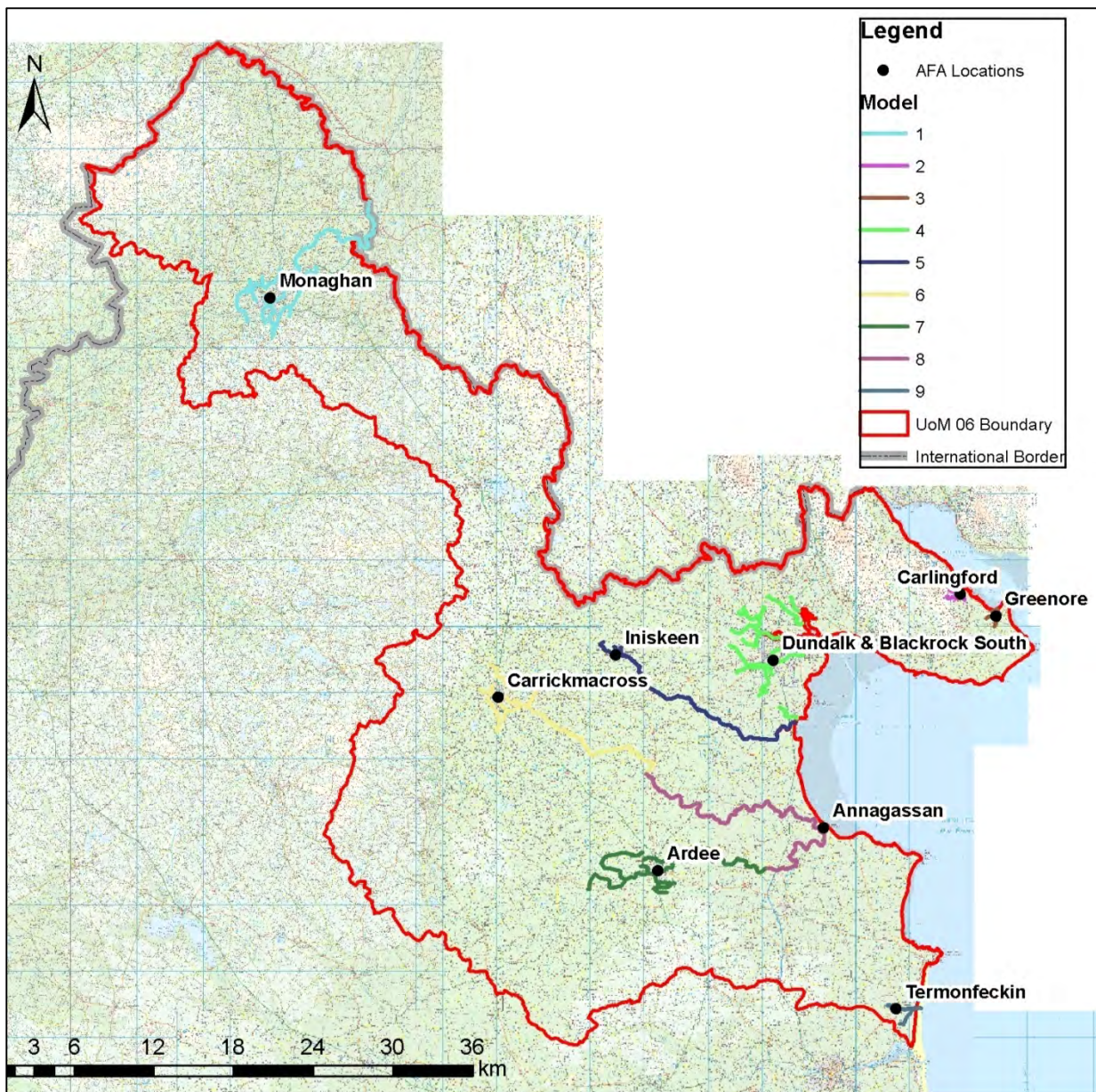


Figure 4.1: UoM 06 Watercourses to be Modelled

4.1 MODEL 1 – MONAGHAN

Model 1 is divided into two parts, Model 1a and Model 1b, both of which affect the Monaghan AFA.

The Monaghan Blackwater River flows from west to east through County Monaghan before joining the River Cor at the international boundary between Ireland and Northern Ireland. The River Cor itself then forms the international boundary line as it flows northwards to join the Ulster Blackwater in County Armagh. Monaghan AFA is directly affected by the Monaghan Blackwater but also by several of its small tributaries flowing from south to north through Monaghan Town and its environs before entering the Monaghan Blackwater main channel. These tributaries constitute the upstream reaches of Model 1a which then extends along the River Blackwater past its confluence with the River Cor and ends at the townland of White Hill on the border with County Armagh. The total catchment of Model 1a is 275km² at the downstream limit and is characterised by drumlin landscape and several small lakes. The HEPs and associated sub-catchments of the Model 1a are shown in Figure 4.2.

Model 1b constitutes the Killygowan watercourse which is located to the east of Monaghan town and flows from south to north towards the Ulster Canal. Model 1b also includes a tributary of the Killygowan called the Ballymacforban Stream. The downstream limit of Model 1b is at the confluence of the Killygowan watercourse and the Ulster Canal. The catchment area at this point is 7km². The catchment of Model 1b and the Ulster Canal is thought to drain into the River Cor upstream of the confluence point with the Monaghan Blackwater. This confluence point is located on Model 1a at HEP 03_385_4_RPS. The HEPs and associated sub-catchments of both models are shown in Figure 4.2 and Figure 4.3.

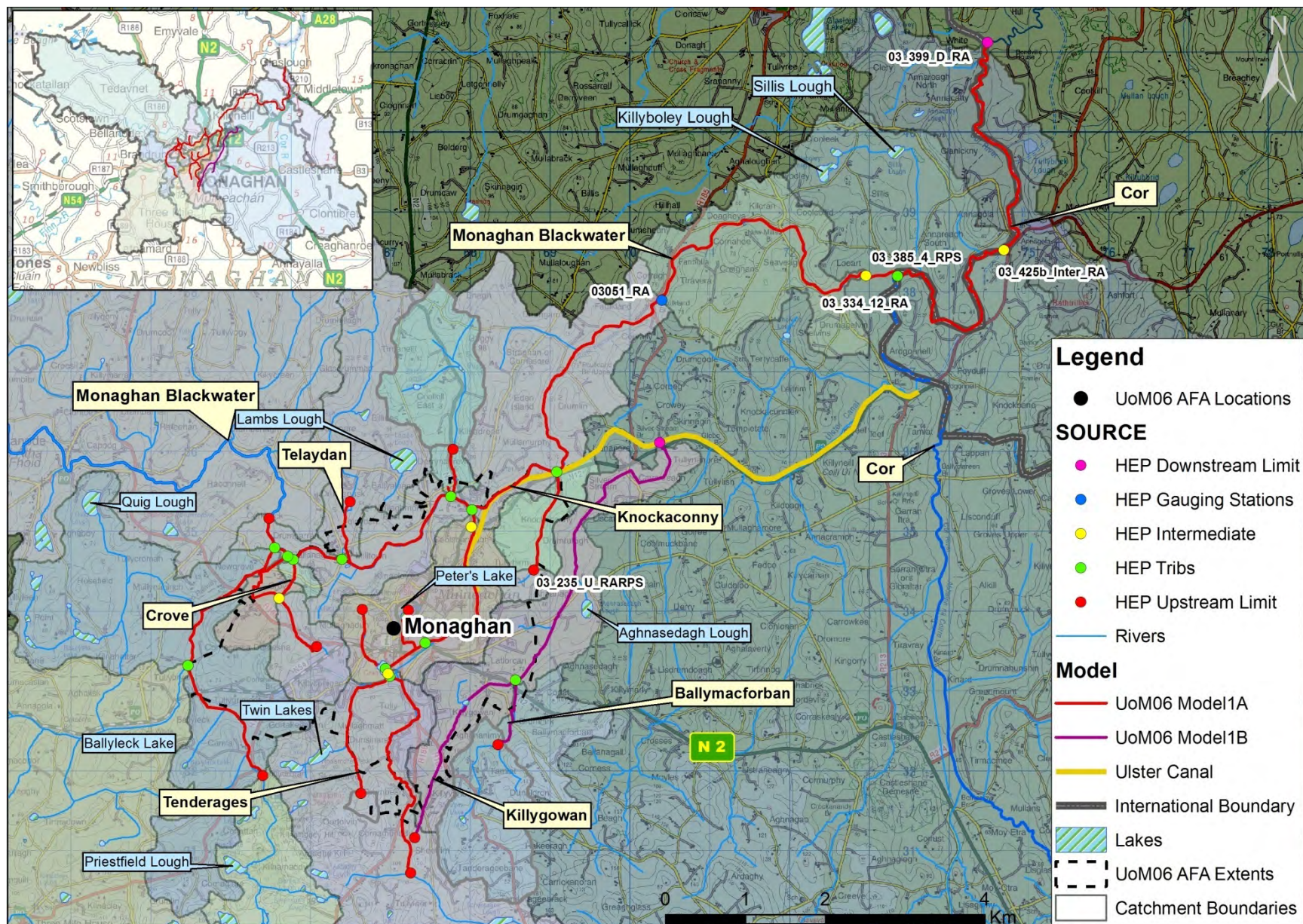


Figure 4.2: Model 1 HEPs and Catchment Boundaries

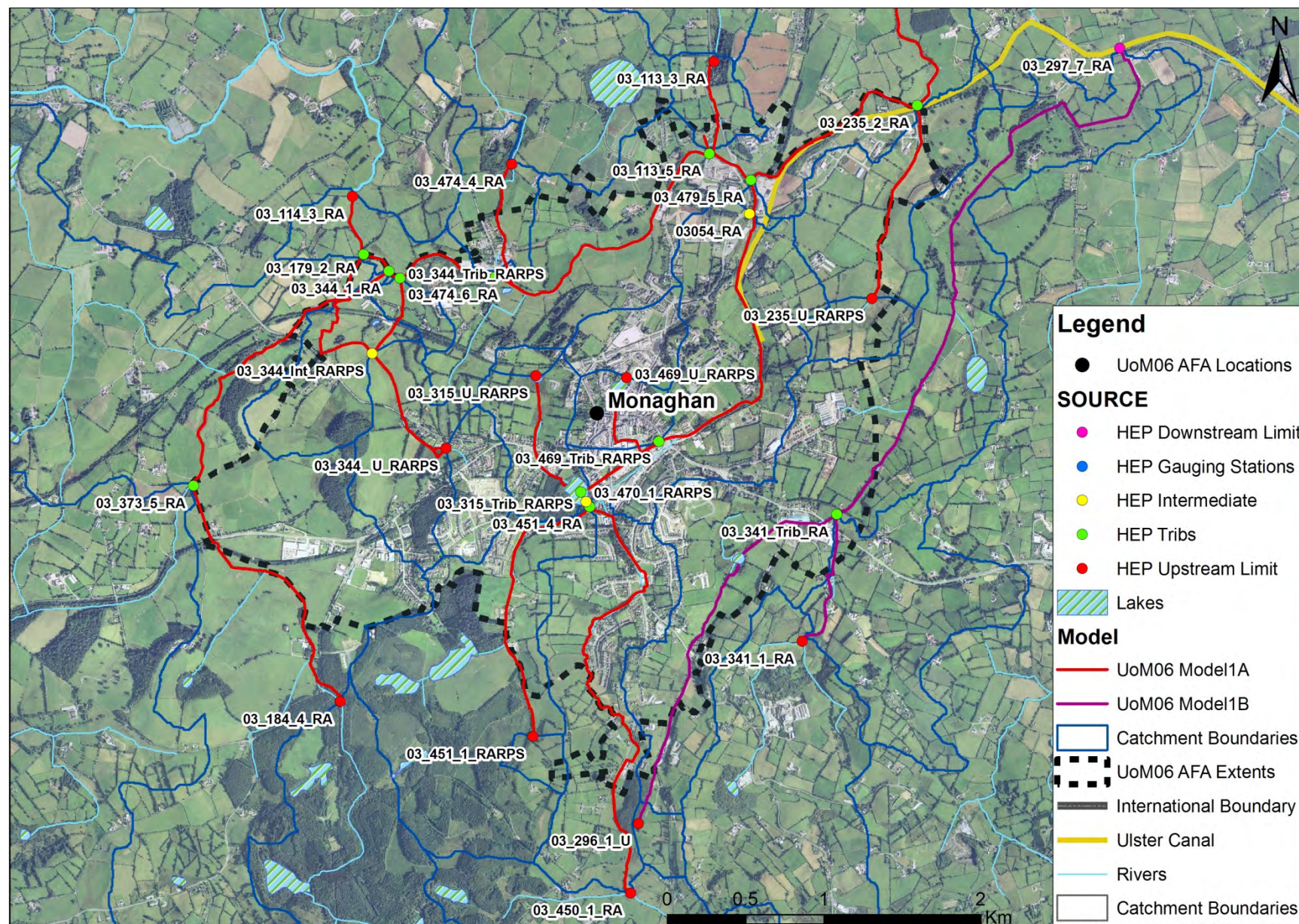


Figure 4.3: Model 1 HEPs and Catchment Boundaries within AFA Extents Only

There is one gauging station within Model 1a (03051, Faulkland) operated by Monaghan County Council which is located on the River Blackwater downstream of Monaghan AFA. It has 15 years of FSU data (1990 – 2004) and is classified as B under FSU meaning there is confidence in recorded flows up to Q_{med} ($40.1\text{m}^3/\text{s}$).

In order to simulate an increased period of record and to increase confidence in Q_{med} a rainfall run-off model was constructed at Station 03051 and calibrated against observed medium to low flows. The input precipitation data was taken from the nearby Met Éireann hourly rain gauge at Clones (1951 – 2008) with calibration to flow data undertaken for the available corresponding 15 minute time series. Optimum calibration of the model was achieved with NAM model parameters which were adjusted outside the normal range however it was considered that this was appropriate in support of improved calibration. The resulting NAM model was found to be reasonably well calibrated to the hydrometric data both in terms of mass balance and based on a visual inspection of the flow trace for the calibration period (particularly medium to low flows). Analysis of the simulated flow record yielded a Q_{med} value of $40.7\text{m}^3/\text{s}$ which provides a degree of validation of the observed value due to their similarity. Since the NAM model calibration was found to be in good agreement with the observed record and increases the length of the AMAX series from 1951 to 2010, it was decided to adopt the slightly higher simulated Q_{med} value of $40.7\text{m}^3/\text{s}$ for subsequent analysis. Refer to Appendix C for NAM model outputs.

The NAM output Q_{med} for Station 03051 has been taken forward as the pivotal site Q_{med} value used for adjustment of the Physical Catchment Descriptor (PCD) based estimates of Q_{med} for all HEPs on the main channel of Model 1a. The difference between $Q_{med\text{ gauged NAM}}$ and $Q_{med\text{ pcd}}$ as predicted based on the FSU regression equation using PCDs is small and so the adjustment factor of 0.9 results in reductions of initial Q_{med} estimations in Model 1a by 10%. (The average adjustment factor for all 216 pivotal sites in the FSU database is 1.09, i.e. an upwards adjustment of just under 10%).

A review of geographically close and hydrologically similar sites against many of the tributary HEPs was undertaken. On the tributaries of the Monaghan Blackwater no clear pattern suggesting the FSU catchment descriptor based equation under or over estimates was evident and as such estimates based on PCDs were unadjusted. A review of the HEPs located on the watercourse system that flows through the centre of the AFA (linking the Tenderages watercourse, Twin Lakes and Peter's Lake to the Blackwater) against hydrologically similar pivotal sites did support upwards adjustment. Further to this initial model calibration attempts found that initial, unadjusted estimates when entered into the model were found not to replicate historical flooding through the centre of the AFA and intermediate check point flows were not being achieved downstream of the town centre. In light of this an upwards adjustment factor of 1.33 based on the pivotal site Rochfort (25034) was applied. This pivotal site was found to rank consistently high on the list of hydrologically similar pivotal sites to a range of HEPs on this watercourse system.

Model 1b represents an ungauged relatively small catchment (7km^2 at downstream limit). Q_{med} was calculated using FSU ungauged estimation. A review of geographically close and hydrologically

similar pivotal sites against the HEPs indicated a trend for no adjustment amongst geographically close sites (at the downstream limit HEP, six of the seven options yield a Q_{med} result practically equal to $Q_{med\ pcd}$), and a high degree of scatter amongst the hydrologically similar sites but with an average adjustment factor within the seven most hydrologically similar pivotal sites of 1.13. However initial model calibration attempts found that initial, unadjusted estimates when entered into the model were found not to replicate historical flooding within Model 1b and the downstream check point flows were not being achieved. In light of this an upwards adjustment factor of 1.13 based on the average from the seven most hydrologically similar pivotal sites was applied to achieve design flow calibration and the best hydraulic model calibration within the range of realistic model parameters.

The estimated Q_{med} values for the various HEPs within Model 1a and 1b are shown in Table 4.1.

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

Model 1a			
Node ID_CFRAMS	AREA (km²)	Q_{med} (m³/s)	Estimation Methodology
03_114_3_RA	74.50	34.76	FSU (Adjusted – 03051)
03_184_4_RA	7.14	1.19	FSU (Unadjusted)
03_373_5_RA	29.07	7.81	FSU (Unadjusted)
03_179_2_RA	44.03	9.55	FSU (Unadjusted)
03_344_U_RARPS	0.33	0.19	FSU (Unadjusted)
03_344_Int_RARPS	1.01	0.54	FSU (Unadjusted)
03_344_1_RA	1.62	0.84	FSU (Unadjusted)
03_344_Trib_RARPS	0.13	0.06	FSU (Unadjusted)
03_474_4_RA	2.59	0.40	FSU (Unadjusted)
03_474_6_RA	3.00	0.45	FSU (Unadjusted)
03_113_3_RA	1.88	0.22	FSU (Unadjusted)
03_113_5_RA	2.13	0.49	FSU (Unadjusted)
03_450_1_RA	3.52	0.89	FSU (Adjusted – 25034)
03_451_1_RARPS	0.10	0.01	FSU (Adjusted – 25034)
03_451_4_RA	2.13	0.34	FSU (Adjusted – 25034)
03_315_U_RARPS	0.07	0.01	FSU (Adjusted – 25034)

Model 1a			
Node ID_CFRAMS	AREA (km²)	Q_{med} (m³/s)	Estimation Methodology
03_315_Trib_RARPS	0.54	0.23	FSU (Adjusted – 25034)
03_469_U_RARPS	0.32	0.19	FSU (Adjusted – 25034)
03_469_Trib_RARPS	0.58	0.43	FSU (Adjusted – 25034)
03054_RA	9.84	2.97	FSU (Unadjusted)
03_479_5_RA	9.87	2.97	FSU (Unadjusted)
03_235_U_RARPS	0.23	0.06	FSU (Unadjusted)
03_235_2_RA	1.17	0.24	FSU (Unadjusted)
03051_RA	142.97	40.70	G.S. Simulated / Observed
03_334_12_RA	146.78	38.51	FSU (Adjusted – 03051)
03_425b_Inter_RA	257.31	50.19	FSU (Adjusted – 03051)
03_399_D_RA	275.11	53.43	FSU (Adjusted – 03051)
Model 1b			
Node ID_CFRAMS	AREA (km²)	Q_{med} (m³/s)	Estimation Methodology
03_296_1_U	1.00	0.37	FSU (Adjusted based on ave. of hydrologically similar pivotal site)
03_341_1_RA	1.96	0.62	
03_341_Trib_RA	3.20	0.98	
03_297_7_RA	7.02	2.04	

Table 4.1: Q_{med} Values for Model 1a and Model 1b

4.2 MODEL 2 – CARLINGFORD

Carlingford AFA is located at the foot of Carlingford Mountain and Slieve Foye and on the shores of Carlingford Lough. Fluvial flood risk emanates from three small watercourses. Model 2a represents one small steep watercourse which rises in the eastern foothills of Carlingford Mountain/Slieve Foy and flows eastwards to the harbour within the village. The catchment area at the downstream limit HEPs is 0.9km^2 .

Model 2b represents another steep watercourse from the mountains and a tributary that flows through the relatively flat lands to the south of the village. The catchment area at the downstream limit HEP (where it discharges to the harbour) is 2.7km^2 .

The HEPs and associated sub-catchments of the Carlingford model are shown in Figure 4.4.

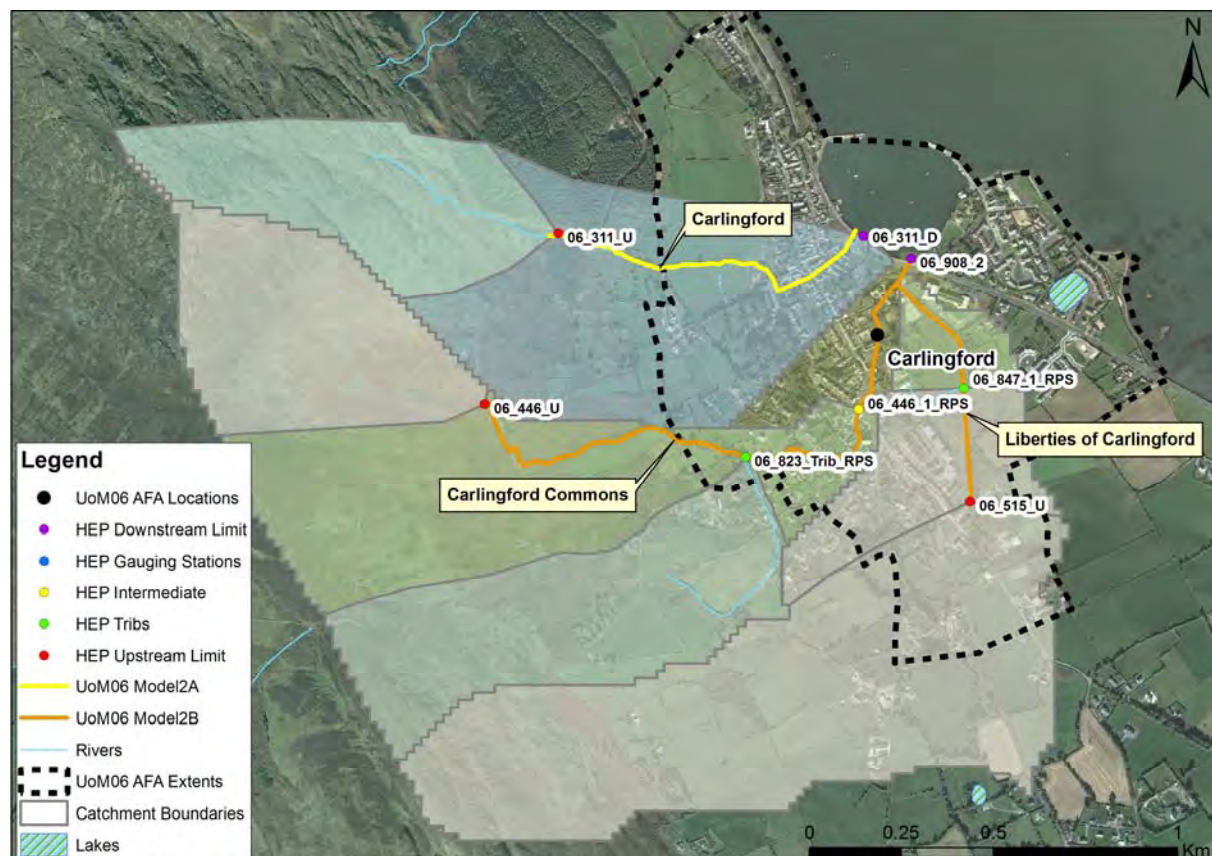


Figure 4.4: Model 2 HEPs and Catchment Boundaries

There are no gauging station sites within the modelled reaches and as such the model is considered to be ungauged for the purposes of flow estimation.

The nearest (hydrologically and geographically) pivotal site (06030, Ballygoly) is operated by Louth County Council and is located 3km south west of the modelled catchment on the Big River which

receives small steep tributaries flowing down the western foothills of Slieve Foy. It is rated as B under FSU so confidence in flow values is limited to Q_{med} . There is considerable difference between $Q_{med\ gauged}$ and Q_{med} as predicted based on the FSU regression equation with PCDs ($Q_{med\ pcd}$) resulting in an adjustment factor of 1.71.

A review of all pivotal site options was undertaken where a trend towards upwards adjustment was found at most of the geographically and/or hydrologically similar sites. The average adjustment factor was found to be 1.22 for geographically close and 1.10 for hydrologically similar pivotal sites and although not as high as the Ballygoly adjustment factor none of the sites can be considered as representative. The Ballygoly station represents data from a small catchment in the Cooley Mountains and from a catchment which drains part of the same land form (Slieve Foy) which forms most of the subject catchment area. As such the adjustment factor of 1.71 is considered appropriate and has been applied to all of the catchment descriptor based estimates within the modelled reaches. The resulting 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

Model 2a			
Node ID_CFRAMS	AREA (km²)	Q_{med} (m³/s)	Estimation Methodology
06_311_U	0.34	0.42	FSU (Adjusted - 06030)
06_311_D	0.91	1.12	FSU (Adjusted - 06030)
Model 2b			
Node ID_CFRAMS	AREA (km²)	Q_{med} (m³/s)	Estimation Methodology
06_446_U	0.36	0.44	FSU (Adjusted - 06030)
06_863_Trib_RPS	0.73	0.96	FSU (Adjusted - 06030)
06_446_1_RPS	1.39	1.79	FSU (Adjusted - 06030)
06_515_U	0.89	0.37	FSU (Adjusted - 06030)
06_847_1	1.09	0.82	FSU (Adjusted - 06030)
06_908_2	2.65	3.27	FSU (Adjusted - 06030)

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

4.3 MODEL 3 - GREENORE

Greenore AFA is located approximately 3km south west of Carlingford on the shores of Carlingford Lough with Greenore Point situated to the north east. The surrounding lands are relatively flat and primarily used for pasture and arable crops. Fluvial flood risk emanates from two small watercourses which drain the surrounding land and flow from south to north through Greenore to discharge to Carlingford Lough. Model 3a represents the Mullatee watercourse and a small tributary which has a catchment area of 1.7km² at its downstream limit. Model 3b represents the Millgrange watercourse which has a catchment area of 3km² at its downstream limit.

The HEPs and associated sub-catchments of the Greenore models are shown in Figure 4.5.

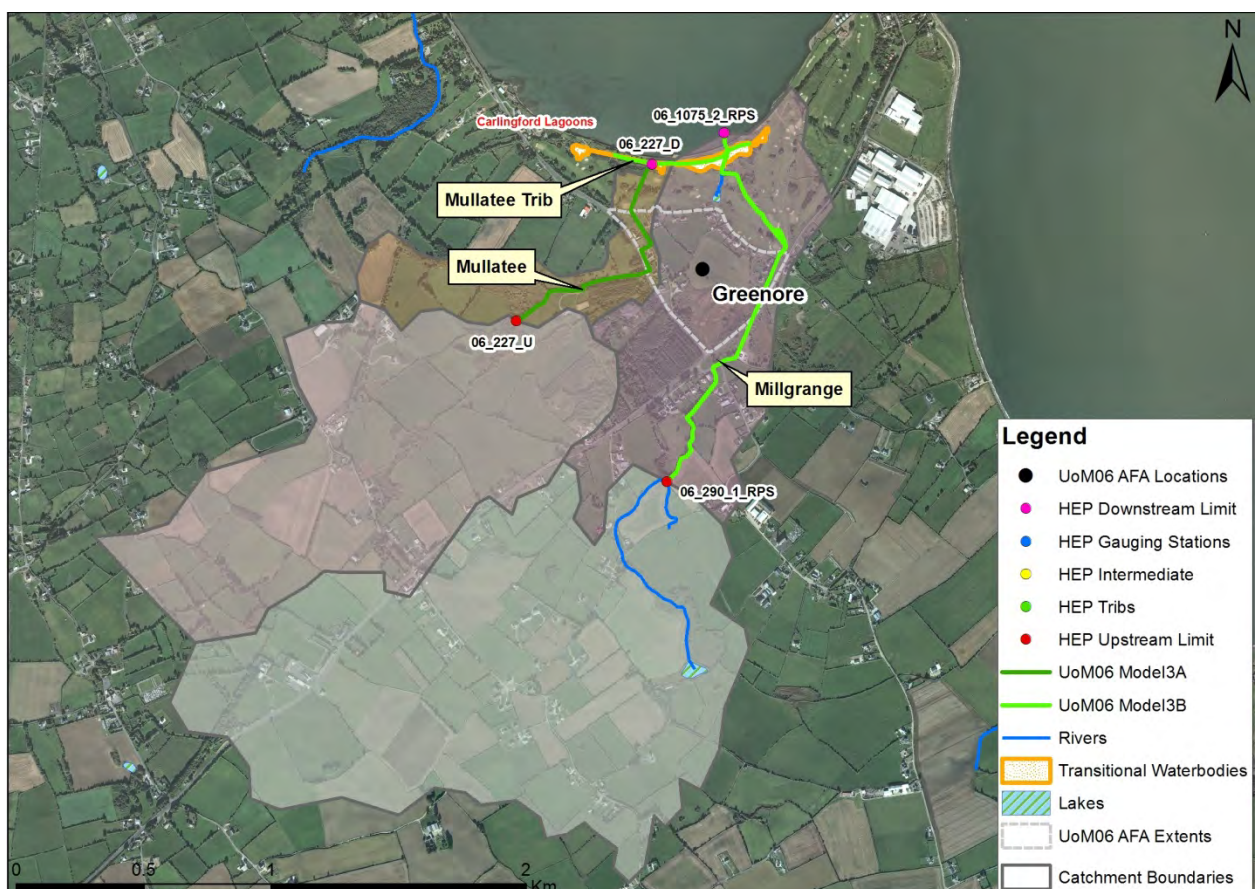


Figure 4.5: Model 3 HEPs and Catchment Boundaries

There are no gauging station sites within the modelled reaches and as such the model is considered to be ungauged for the purposes of flow estimation.

As is the case for Model 2, the nearest (hydrologically and geographically) pivotal site (06030, Ballygoly) and for the reasons outlined in Section 4.2, it is not considered appropriate for adoption as a pivotal site.

The nearest (geographically) pivotal site (06030, Ballygoly) is operated by Louth County Council and is located 5km west of the modelled catchment on the Big River which receives small steep tributaries flowing down the western foothills of Slieve Foy. It is rated as B under FSU so confidence in flow values is limited to Q_{med} . There is considerable difference between $Q_{med \text{ gauged}}$ and Q_{med} as predicted based on the FSU regression equation with PCDs ($Q_{med \text{ pcd}}$) resulting in an adjustment factor of 1.71.

A review of all pivotal site options was undertaken where a trend towards upwards adjustment was found at most of the geographically and/or hydrologically similar sites. The average adjustment factor was found to be 1.17 for geographically close and 1.06 for hydrologically similar pivotal sites. The most hydrologically similar pivotal site was found to be Rochfort (25034) with an adjustment factor of 1.33 with Ballygoly sixth on the list. However due to the geographical proximity of the site and as it is directly representative of catchment run-off in the Cooley Peninsula it is considered appropriate to adjust catchment descriptor based estimates of Q_{med} using this station as a pivotal site along with the Rochfort site resulting in a composite adjustment factor of 1.52. The resulting 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 (km²)	Q_{med} (m³/s)	Estimation Methodology
Model 3a			
06_227_U	1.37	0.40	FSU (Adjusted – 06030 & 25034)
06_227_D	1.69	0.49	FSU (Adjusted – 06030 & 25034)
Model 3b			
06_290_1_RPS	2.15	0.66	FSU (Adjusted – 06030 & 25034)
06_1075_2_RPS	3.04	0.94	FSU (Adjusted – 06030 & 25034)

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

4.4 MODEL 4 – DUNDALK AND BLACKROCK SOUTH

Dundalk and Blackrock South is located on Dundalk Harbour and extends southwards along the shores of Dundalk Bay to encompass the coastal village of Blackrock. Its western boundary is such that Dundalk and its environs are included within the overall AFA. The Castletown River is the largest river within the model which originates as the White Water and Tullyvullan Rivers approximately 25km north in Newtownhamilton, County Armagh. The Castletown River flows in a south-westerly direction before entering Castletown Estuary in Dundalk north. It is tidally influenced as far upstream as HEP 06_1087_13_RA. Its total catchment area at the downstream limit is 239km². Pasture is the predominant land use at over 95% coverage.

Model 4 has been divided into six sub models, Models 4a to 4f to separately discuss the hydraulically separate models simulating flood risk to Dundalk AFA.

Models 4a and 4b represent the Aghaboys and Ballynahattin watercourses which rise in the Tievecrom and Daaikilmore Mountains near Forkhill in County Armagh. They flow in a south easterly direction beneath the M1 motorway, and north of Dundalk Racecourse before reaching Ballymascanlan Estuary. The catchment areas at the downstream limits for Model 4a and 4b are 5.5km² and 10km² respectively. Figure 4.6 overleaf indicates the Model extents, HEPs and catchment boundaries.

Model 4c represents the watercourses that potentially pose fluvial flood risk to Dundalk north. This includes the aforementioned Castletown River and all urban tributaries which enter it before it reaches Castletown estuary. The Kilcurry, Stranacarry and Acarreagh watercourses are all tributaries of the Castletown River that are included in Model 4c. It must be noted that the Kilcurry River catchment is largely located within Northern Ireland yet the FSU physical catchment descriptors only consider the portion of the catchment located within the Republic of Ireland. As such catchment descriptors were adjusted based on orthophotography, mapping and digital height models from both sides of the border to reflect the total catchment. Figure 4.7 overleaf indicates the Model extents, HEPs and catchment boundaries.

Model 4d represents the watercourses that potentially pose fluvial flood risk to Dundalk south. This includes the Blackwater River which flows through the Marshes Upper and Lower before discharging to Dundalk Bay (catchment area 23km²); and the Marshes Lower urban watercourse and tributaries which flow through Marshes Lower before discharging to Castletown Estuary (catchment area 17.5km²). Figure 4.8 overleaf indicates the Model extents, HEPs and catchment boundaries.

Model 4e represents two watercourse that potentially pose fluvial flood risk to Blackrock. Model 4e flows through the townlands of Haggardtown Cross and Green Gates before flowing through Blackrock and discharging to Dundalk Bay. It is a small and very flat watercourse which drains agricultural lands and has a catchment area of 2.8km² at the downstream limit of the model. The Blackrock watercourse drains an area of mixed industrial and agricultural land in south Dundalk

before flowing through residential areas of Blackrock and discharging to Dundalk Bay. This watercourse is also flat and drains a largely urbanised catchment area of 3.2km². Physical catchment descriptors were not delineated for the Blackrock watercourse and as such these were estimated based on mapping, aerial photography, digital height mapping and nearby FSU catchment descriptors. Figure 4.9 overleaf indicates the Model extents, HEPs and catchment boundaries.

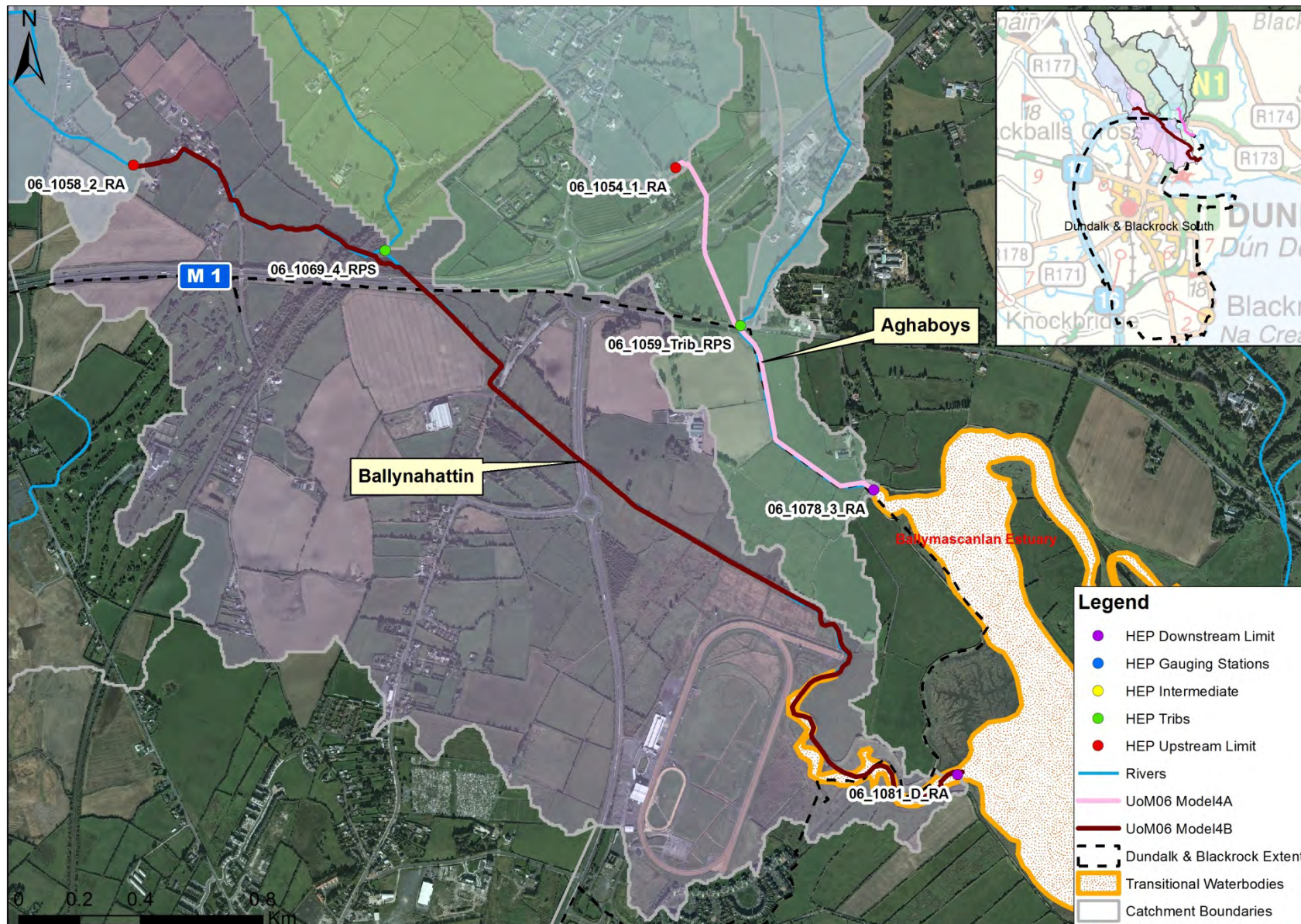


Figure 4.6: Model 4a and Model 4b HEPs and Catchment Boundaries



Figure 4.7: Model 4c HEPs and Catchment Boundaries

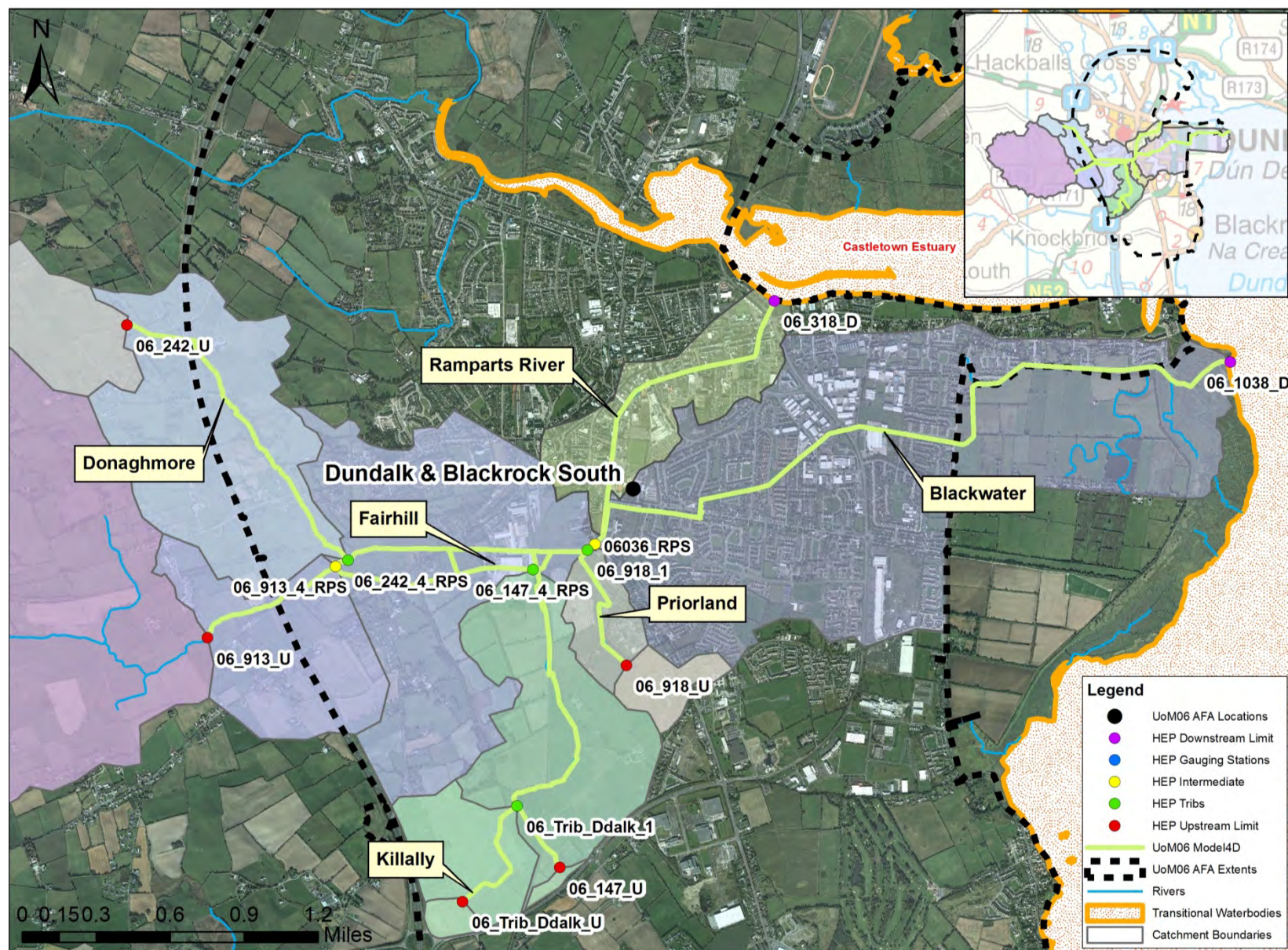


Figure 4.8: Model 4d HEPs and Catchment Boundaries

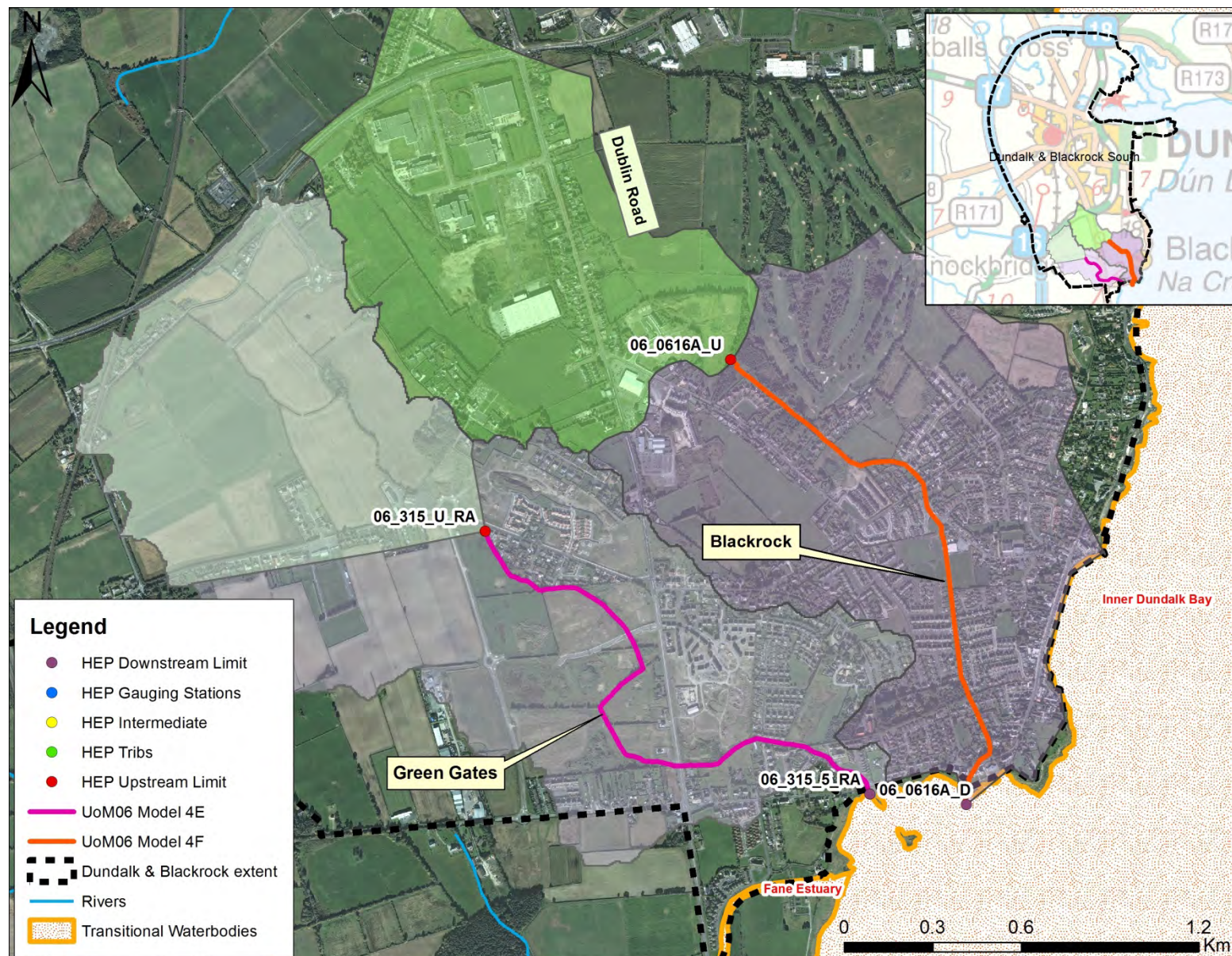


Figure 4.9: Model 4e and Model 4f HEPs and Catchment Boundaries

There is one staff gauge station located at Ladyswell within Dundalk south but it records water level only and has no flow data available. Models 4a to 4f are ungauged. Hydrometric Station 06031, Curralhir is operated by Louth County Council and is located on the Flurry River near the M1 Motorway at the foot of Blacks Mountain approximately 1.5km north of Ravensdale. It is geographically closest to Dundalk and has a catchment area of 46km². The Flurry River is a tributary of Ballymascanlan estuary as are the watercourses in Models 4a and 4b. It has 10 years of data and is rated A2 under FSU with confidence in flow values up to 1.3 times Q_{med} . There is a considerable difference between $Q_{med\ gauged}$ and Q_{med} as predicted based on the FSU regression equation with PCDs ($Q_{med\ pcd}$) which results in a very high adjustment factor of 2.03. This would more than double initial flow estimates within the Dundalk Models if adopted as a pivotal site. Furthermore much of the Flurry River catchment is contained across the border in Northern Ireland and as such there is considerable uncertainty in the physical catchment descriptors which largely consider spatial datasets which do not extent into Northern Ireland. In light of this initial adjustments which were heavily influenced by this nearby and hydrologically similar pivotal site with a high adjustment factor have been revised to such that the effect of this pivotal site is reduced.

All of the sub-models and the significant sub-catchments within the models were reviewed against the FSU list of pivotal sites to determine if there were indications that the FSU physical catchment descriptor based Q_{med} values were over or under estimated for sites that were either geographically close or hydrologically similar. Generally the geographically closest pivotal sites to the Model 4 catchments indicate a mixed pattern with catchments over 100km² indicating that the equation over estimates and catchments less than 100km² in area indicating under estimation. The only catchment within Model 4 which is over 100km² in area is the Castletown River (Model 4c) which has a total catchment area of 240km². A review of this catchment against the full list of hydrologically similar sites indicates a strong trend towards over estimation with the average adjustment factor from the seven most hydrologically similar sites of 0.78. A review of the seven nearest sites geographically reveals an average adjustment factor of 1.12 but this is heavily influenced by the two small catchments to the north on the Flurry and Big Rivers (06030 and 06031) which are hydrologically quite different and in the case of the Curralhir station on the Flurry (06031) has high uncertainty within the adjustment factor. With these sites discounted the average of the geographically closest sites is reduced to 0.82. In light of this it is considered appropriate to apply an adjustment factor that considers the average of the geographically close and hydrologically similar sites of 0.8 to the Q_{med} flows in the Castletown River.

All of the other Model 4 catchments are small (less than 25km²) and all when reviewed against the full list of FSU hydrologically similar sites did not indicate a clear pattern towards under or over estimation against similar types of catchments nationally. Average adjustment factors for the seven most hydrologically similar pivotal sites to each catchment generally ranged from 0.96 to 1.04 but with one catchment with an average adjustment factor of 1.14 (Dundalk Blackwater – Model 4c). However the smaller pivotal sites within HA06 do indicate a strong trend towards under estimation and although there is some uncertainty in the data it is felt that these stations should be taken into account. As such adjustment factors for the smaller catchments have been derived from an average of the seven most hydrologically similar pivotal sites for each sub-catchment plus the three smaller HA06 pivotal sites 06030, 06031 and 06033 (maximum catchment area 55km²). This

resulted in adjustment factors ranging from 1.18 to 1.24 and these have been applied to the ungauged PCD based estimates as shown in Table 4.4.

Table 4.4: Q_{med} Values for Model 4

Node ID_CFRAMS	AREA (km ²)	Q _{med} (m ³ /s)	Estimation Methodology
Model 4a			
06_1054_1_RA	1.36	0.61	FSU (Adjusted on average of hydrologically similar & 06030, 06031 & 06033 – AdjFac 1.18)
06_1059_Trib_RPS	3.17	1.02	
06_1078_3_RA	5.50	1.97	
Model 4b			
06_1058_2_RA	2.08	0.55	FSU (Adjusted on average of hydrologically similar & 06030, 06031 & 06033 – AdjFac 1.20)
06_1069_4_RPS	4.31	1.61	
06_1081_D_RA	10.43	2.34	
Model 4c			
06_991_2_RA	117.17	17.03	FSU (Adjusted on average of hydrologically similar & large catchments within HA06 – AdjFac 0.80)
06_600_2_RA	103.28	13.28	
06_600_4_RA	104.08	13.30	
06032_RA	221.73	27.65	
06_1084_1_RA	222.04	27.68	
06_1055_U	0.10	0.03	FSU (Adjusted on average of hydrologically similar & 06030, 06031 & 06033 – AdjFac 1.18)
06_1055_2_RA	2.31	0.56	
06_1087_U_RA	6.04	1.16	FSU (Adjusted on average of hydrologically similar & 06030, 06031 & 06033 – AdjFac 1.22)
06_1087_13_RA	7.43	1.51	
06_1089_U	0.04	0.02	FSU (Adjusted on average of hydrologically similar & 06030, 06031 & 06033 – AdjFac 1.24)
06_1089_4_RA	2.70	1.10	
06_DDalk_D_RARPS	239.30	28.46	FSU (Adjusted on average of hydrologically similar & large catchments within HA06 –

Node ID_CFRAMS	AREA (km ²)	Q _{med} (m ³ /s)	Estimation Methodology
			AdjFac 0.80)
Model 4d			
06_913_U	8.21	1.27	FSU
06_913_4_RPS	9.38	1.50	(Adjusted on average of hydrologically similar & 06030, 06031 & 06033 – AdjFac 1.30)
06_242_U	0.72	0.22	FSU
06_242_4_RPS	2.78	0.72	(Adjusted on average of hydrologically similar & 06030, 06031 & 06033 – AdjFac 1.24)
06_147_U	0.03	0.00	FSU (Adjusted on average of hydrologically similar & 06030, 06031 & 06033 – AdjFac 1.24)
06_Trib_Ddalk_U	0.07	0.01	
06_Trib_Ddalk_1	0.63	0.04	
06_147_4_RPS	2.15	0.42	
06_918_U	0.22	0.05	
06_918_1	0.53	0.11	
06036_RPS	17.39	3.00	FSU
06_1038_D	5.45	2.09	(Adjusted on average of hydrologically similar & 06030, 06031 & 06033 – AdjFac 1.23)
06_318_D	0.96	0.43	
Model 4e			
06_315_U_RA	1.13	0.17	FSU
06_315_5_RA	2.79	0.43	(Adjusted on average of hydrologically similar & 06030, 06031 & 06033 – AdjFac 1.24)
Model 4f			
06_0616A_U	1.37	0.34	FSU
06_0616A_D	3.21	0.69	(Adjusted on average of hydrologically similar & 06030, 06031 & 06033 – AdjFac 1.24)

4.5 MODEL 5 – INISKEEN

The Iniskeen AFA is located in County Monaghan on the River Fane approximately 20km upstream from its mouth at Dundalk Bay in County Louth.

The River Fane is abstracted from to provide drinking water in the Dundalk area. The entire Fane system begins with Lough Muckno at the upstream end (located east of Castleblayney). The Clarebane River flows between Lough Muckno and Lough Ross, which is located on the international boundary with Northern Ireland. Lough Ross is used by Newry and Mourne District Council as drinking water supply. The River Fane flows from Lough Ross, back into Ireland and through Iniskeen before discharging to Dundalk Bay. An intake at Stephenstown and Cavan Hill provides water in the Dundalk area, approximately 20km downstream from Lough Muckno. This system operated under gravity until 1987. During this time, the River Fane often had low flows due to the level of abstraction, but also the inability of the system to adequately replenish itself from groundwater. To address this problem by ensuring compensation flows, a low flow augmentation scheme was built between 1987 and 1990. This scheme involved the construction of headworks at Lough Muckno to supplement flow deficiency in the River Fane and ensure adequate supply in Lough Ross for the Newry and Mourne water supply. The overall effect of the headworks is to decelerate the natural rate of lake level recession when needed.

The Fane catchment area at the downstream limit of Model 5 is 338km². The catchment area at Moyles Mill upstream of Iniskeen AFA is 229km². The HEPs and associated sub-catchments of the Iniskeen model are shown in Figure 4.10.

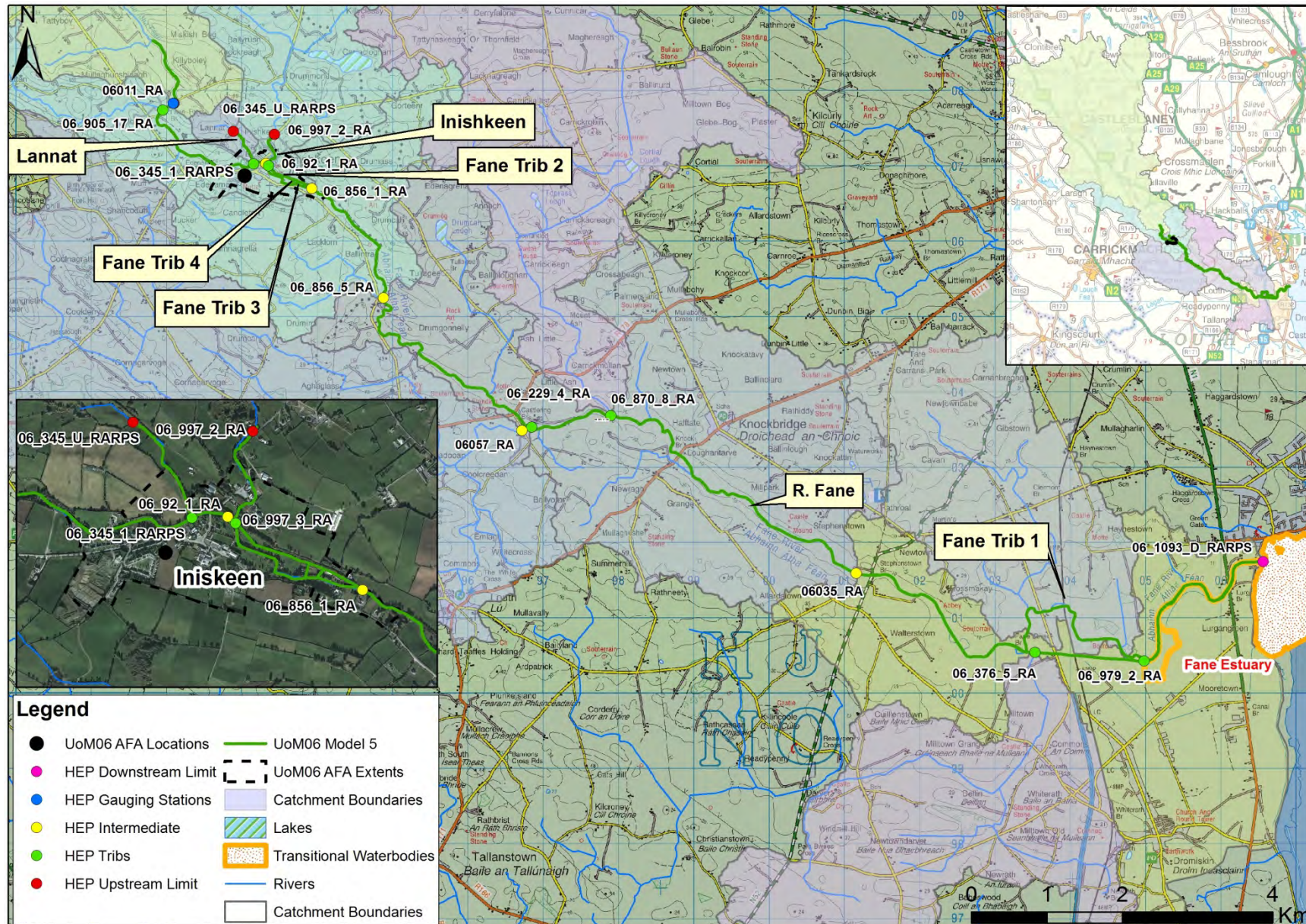


Figure 4.10: Model 5 HEPs and Catchment Boundaries

Hydrometric Station 06011 (Moyle Mill), operated by OPW is located on the River Fane upstream of Iniskeen. It is an A1 station with > 40 years of data and confidence in flow values up to at least 1.3 times Q_{med} . Its location on the River Fane downstream of Lough Muckno means that the long term effect of the Lough and headworks on flood flow just upstream of the AFA is inherently captured within the record. It has been used as a pivotal site for all HEPs along the River Fane within Model 5 with an adjustment factor of 0.86. However the small HEPs denoting tributaries entering the River Fane have not been adjusted based on this pivotal site as they were not found to be hydrologically similar. These tributaries are generally much smaller (less than 5% of the catchment for tributaries directly affecting the AFA) and are not directly affected by the attenuation effect of Lough Muckno. A review of the tributary HEPs against all FSU pivotal sites revealed no clear trend towards upwards or downwards adjustment. For example at HEP 06_905_17_RA (tributary of the Fane entering at Fane River Bridge just downstream of Moyle Mill) 50% of the pivotal site options denote upwards adjustment and 50% denote downwards adjustment. Furthermore, half of the results are either above or below the confidence limits associated with the initial FSU estimation based on PCDs. Since there is no clear pivotal site selection and no trend indication for adjustment it is considered prudent in this case not to adjust the tributary HEPs. The estimated Q_{med} values for the various HEPs within Model 5 are shown in Table 4.5.

Table 4.5: Q_{med} Values for Model 5

Node ID_CFRAMS	AREA (km ²)	Q_{med} (m ³ /s)	Estimation Methodology
06011_RA	208.62	15.39	Gauge Station
06_905_17_RA	13.42	1.97	FSU (Unadjusted)
06_345_U_RARPS	0.27	0.07	FSU (Unadjusted)
06_345_1_RARPS	0.41	0.10	FSU (Unadjusted)
06_92_1_RA	224.02	17.37	FSU (Adjusted – 06011)
06_997_2_RA	6.95	0.98	FSU (Unadjusted)
06_997_3_RA	7.02	1.04	FSU (Unadjusted)
06_856_1_RA	231.50	18.02	F FSU (Adjusted – 06011)
06_856_5_RA	237.48	18.33	FSU (Adjusted – 06011)
06057_RA	29.13	3.97	FSU (Unadjusted)
06_229_4_RA	29.20	3.98	FSU (Unadjusted)
06_870_8_RA	15.76	1.80	FSU (Unadjusted)

Node ID_CFRAMS	AREA (km ²)	Q _{med} (m ³ /s)	Estimation Methodology
06035_RA	301.64	25.81	FSU (Adjusted – 06011)
06_376_5_RA	11.75	1.14	FSU (Unadjusted)
06_979_2_RA	9.83	1.54	FSU (Unadjusted)
06_1093_D_RARPS	338.46	28.93	FSU (Adjusted – 06011)

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

4.6 MODEL 6 – CARRICKMACROSS

Carrickmacross AFA is at fluvial flood risk from the Longfield River and several of its tributaries. The Longfield River rises in the drumlins to the north west of Carrickmacross and flows in a south east direction through the AFA where it is joined by three tributaries, all of which are included in Model 6. Three small lakes are located along the Longfield River (Naglack, Moynalty and one smaller unnamed Lough) just downstream of the AFA extent. The Longfield River joins the Lagan River approximately 12km downstream from Carrickmacross to become the River Glyde. Model 6 terminates at Tallanstown approximately 18km downstream from Carrickmacross. The downstream limit is denoted by gauging station 06014 on the River Glyde and has a total catchment area of 271km². The HEPs and associated sub-catchments of the Carrickmacross model are shown in Figure 4.11.

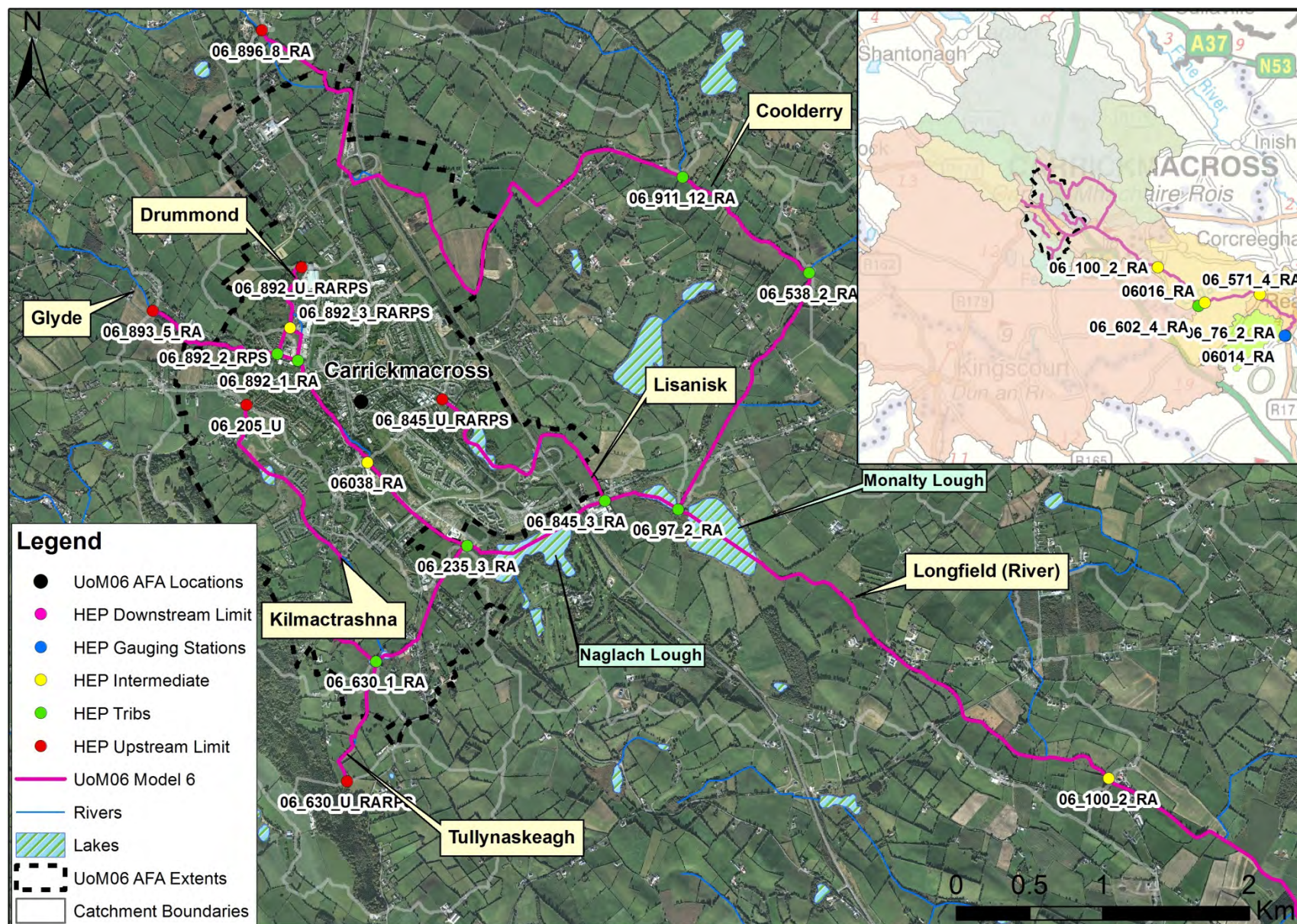


Figure 4.11: Model 6 Catchment Boundaries and HEPs

Hydrometric station 06014 at Tallanstown forms the downstream limit of Model 6. It is operated by OPW, has over 40 years of data and is rated as A1 under FSU. Interestingly, the difference between Q_{med} gauged and $Q_{med\ pcd}$ for this station is significant such that the associated adjustment factor is relatively low at 0.65 which is between the 68th and 95th percentile confidence interval limits of $Q_{med\ pcd}$. However given the high confidence in the flow data at the station and that it is located directly on the modelled reaches it has been used as a pivotal site for adjustment (and therefore reduction) of initial Q_{med} estimations on the Longfield River.

The Lagan River enters the model at HEP Tributary 06_602_4_RA. The Hydrometric Station 06026, Aclint is located on the Lagan River and is an OPW station rated A1/A2 under FSU. This station has been used to adjust the initial Q_{med} estimation at HEP 06_602_4_RA, again with a relatively low adjustment factor of 0.57.

However the small HEPs denoting tributaries entering the Longfield River and/or its tributaries have not been adjusted. A review of each tributary catchment against the full FSU list of pivotal sites generally revealed no clear trend towards upwards or downwards adjustment. For example at HEP 06_896_8_RA (tributary of the Longfield) seven of the 14 pivotal site options denote downwards adjustment, six denote upwards adjustment and one denotes no change. The average Q_{med} result using downward pivotal sites is 1.24 whereas the average result using upward pivotal sites is 2.57. The range of these values reflects the high degree of scatter and lack of a clear trend for adjustment in either direction. Since there is no clear pivotal site selection and no trend indication for adjustment it is considered appropriate in this case not to adjust the tributary HEPs, all of which are less than 10km² in area with relatively small flows. The estimated Q_{med} values for the various HEPs within Model 6 are shown in Table 4.6.

Table 4.6: Q_{med} values for Model 6

Node ID_CFRAMS	AREA (km ²)	Q_{med} (m ³ /s)	Estimation Methodology
06_893_5_RA	7.50	0.82	FSU (Adjusted – 06014)
06_892_U_RARPS	0.65	0.10	FSU (Unadjusted)
06_892_3_RARPS	1.13	0.23	FSU (Unadjusted)
06_892_1_RA	1.15	0.23	FSU (Unadjusted)
06_892_2_RPS	0.02	0.02	FSU (Unadjusted)
06038_RA	10.17	1.40	FSU (Adjusted – 06014)
06_205_U	0.50	0.07	FSU (Unadjusted)

Node ID_CFRAMS	AREA (km ²)	Q _{med} (m ³ /s)	Estimation Methodology
06_630_U_RARPS	1.26	0.22	FSU (Unadjusted)
06_630_1_RA	2.09	0.36	FSU (Unadjusted)
06_235_3_RA	5.04	0.71	FSU (Unadjusted)
06_845_U_RARPS	0.51	0.18	FSU (Unadjusted)
06_845_3_RA	1.58	0.43	FSU (Unadjusted)
06_896_8_RA	7.18	1.75	FSU (Unadjusted)
06_911_12_RA	35.18	2.98	FSU (Adjusted – 06014)
06_538_2_RA	12.94	1.97	FSU (Adjusted – 06014)
06_97_2_RA	63.51	5.10	FSU (Adjusted – 06014)
06_100_2_RA	88.54	7.94	FSU (Adjusted – 06014)
06_602_4_RA	158.15	12.59	FSU (Adjusted – 06026)
06016_RA	259.88	21.46	FSU (Adjusted – 06014)
06_571_4_RA	267.60	21.46	FSU (Adjusted – 06014)
06014_RA	270.70	21.46	FSU (Adjusted – 06014)

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

4.7 MODEL 7 – ARDEE

Ardee AFA is located in County Louth and is at fluvial flood risk from the River Dee and several of its tributaries. The River Dee rises at Muff Lough in the drumlins to the north west of Ardee in County Cavan and flows in a south east direction, bypassing the town of Nobber in County Meath before turning and flowing north east towards Ardee. From here it flows eastwards towards its confluence with the River Glyde near its mouth in Annagassan. The Dee is joined by four tributaries within Ardee which are also included in Model 7. The largest of these tributaries is the River Garra which rises in the drumlins north west of Ardee and forms the border between County Meath and Louth at this location. It has a catchment area of 50km² at its confluence with the River Dee approximately 1km upstream of Ardee. Model 7 terminates at Charleville approximately 9km downstream from Ardee. The downstream limit is denoted by gauging station 06013 on the River Dee and has a total catchment area of 308km². The HEPs and associated sub-catchments of the Ardee model are shown in Figure 4.12.

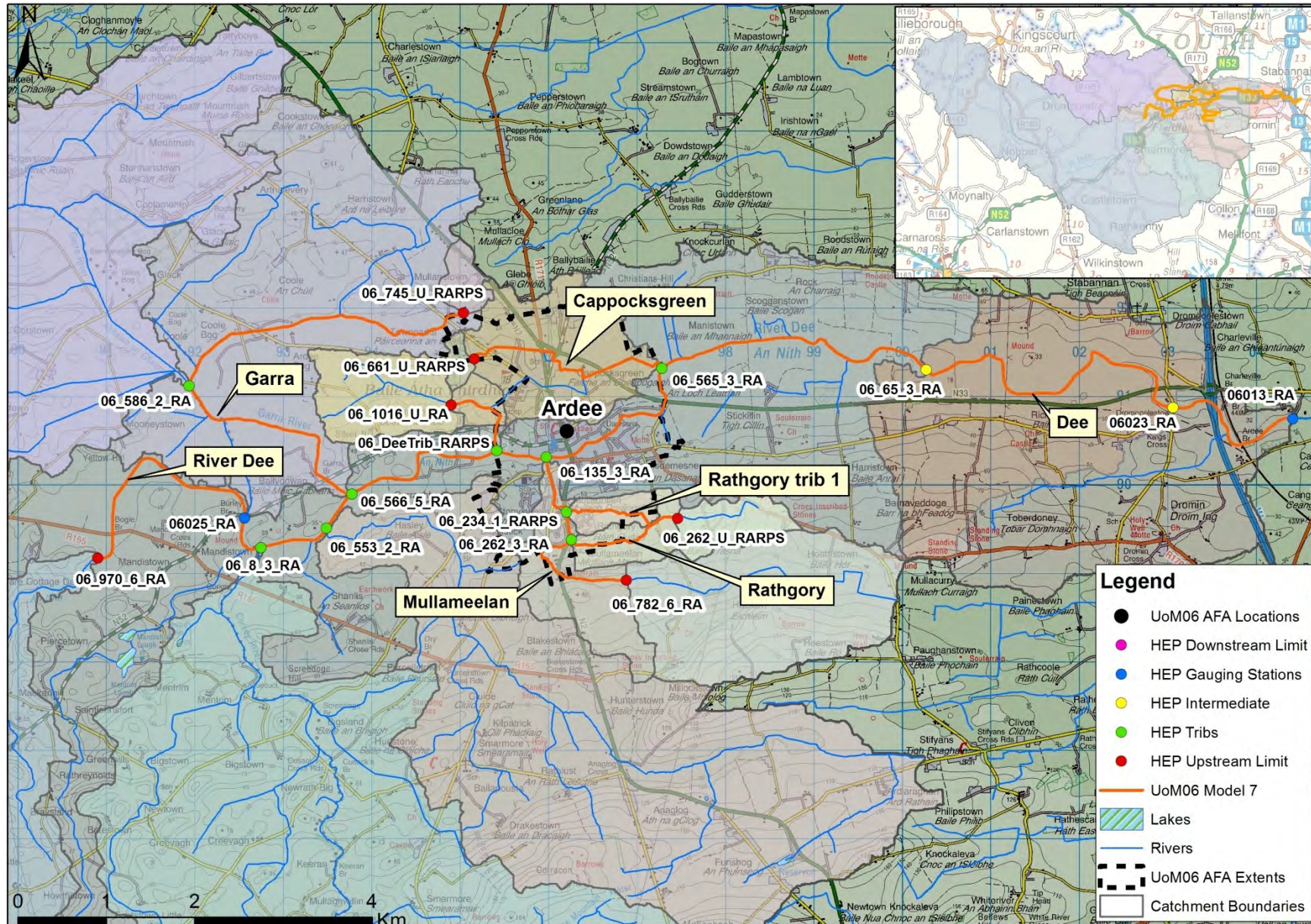


Figure 4.12: Model 7 Catchment Boundaries and HEPs

Hydrometric station 06025, Burley is located on the River Dee approximately 1.8km upstream from its confluence with the Garra River. This station is operated by OPW, has 40 years of data and is rated A1 under FSU. As is the case with Station 06014 in Model 6, the difference between $Q_{med\ gauged}$ and $Q_{med\ pcd}$ for this station is significant such that the associated adjustment factor is relatively low at 0.72 which is just outside the 68th percentile confidence interval limits of $Q_{med\ pcd}$. Given the high confidence in the flow data at the station it has been used as a pivotal site for adjustment (and therefore reduction) of initial Q_{med} estimations on the modelled upper reaches of the River Dee including the tributary inflow from the Corkey River.

Hydrometric station 06023, Dromgoolestown is located on the River Dee near the downstream limit but flow data is not available.

Hydrometric station 06013 at Charleville Weir forms the downstream limit of Model 7. It is operated by OPW, has over 40 years of flow data and is rated as A1 under FSU. Again, the difference between $Q_{med\ gauged}$ and $Q_{med\ pcd}$ for this station is significant such that the associated adjustment factor is relatively low at 0.64 which is between the 68th and 95th percentile confidence interval limits of $Q_{med\ pcd}$. However given the high confidence in the flow data at the station it has been used as a pivotal site for adjustment (and therefore reduction) of initial Q_{med} estimations on the modelled lower reaches of River Dee.

As was the case for Model 6, there is no clear pivotal site selection and no trend indication for adjustment of small tributary HEPs, all of which are less than 10km² in area with relatively small flows. Therefore it is considered appropriate not to adjust them. The estimated Q_{med} values for the various HEPs within Model 7 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)	Estimation Methodology
06_970_6_RA	168.59	18.34	FSU (Adjusted – 6025)
06025_RA	173.28	18.64	FSU (Adjusted – 6025)
06_8_3_RA	26.91	4.29	FSU (Adjusted – 6025)
06_553_2_RA	15.70	2.51	FSU (Adjusted – 6025)
06_745_U_RARPS	0.32	0.03	FSU (Unadjusted)
06_586_2_RA	39.51	4.55	FSU (Adjusted – 6025)
06_566_5_RA	50.41	5.54	FSU (Adjusted – 6025)
06_1016_U_RA	1.43	0.18	FSU (Unadjusted)

Node ID_CFRAMS	AREA (km²)	Q_{med} (m³/s)	Estimation Methodology
06_Deetrib_RARPS	1.76	0.22	FSU (Unadjusted)
06_782_6_RA	4.06	0.84	FSU (Unadjusted)
06_262_U_RARPS	0.66	0.14	FSU (Unadjusted)
06_262_3_RA	1.24	0.26	FSU (Unadjusted)
06_234_1_RARPS	0.35	0.10	FSU (Unadjusted)
06_135_3_RA	7.19	1.60	FSU (Unadjusted)
06_661_U_RARPS	0.15	0.02	FSU (Unadjusted)
06_565_3_RA	4.33	0.86	FSU (Unadjusted)
06_65_3_RA	296.19	26.60	FSU (Adjusted – 6013)
06023_RA	302.77	26.85	FSU (Adjusted – 6013)
06013_RA	307.98	27.37	FSU (Adjusted – 6013)

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

4.8 MODEL 8 – ANNAGASSAN

Annagassan AFA is located on the shores of Dundalk Bay in County Louth. In terms of fluvial flood risk it is located at the mouth of the River Glyde, which is also joined by the River Dee within the AFA extent. To this end, it is linked to both Model 6 (Carrickmacross) and Model 7 (Ardee). Model 8 includes both the River Glyde and Dee as they continue downstream beyond the limits of Model 6 and Model 7 to Annagassan and Dundalk Bay. The total catchment area of Model 8 at its downstream limit is 750km². Both rivers meander through relatively flat lowlands within Model 8 before reaching the AFA itself. The predominant land use is pasture and arable crops. The HEPs and associated sub-catchments of the Annagassan model are shown in Figure 4.13.

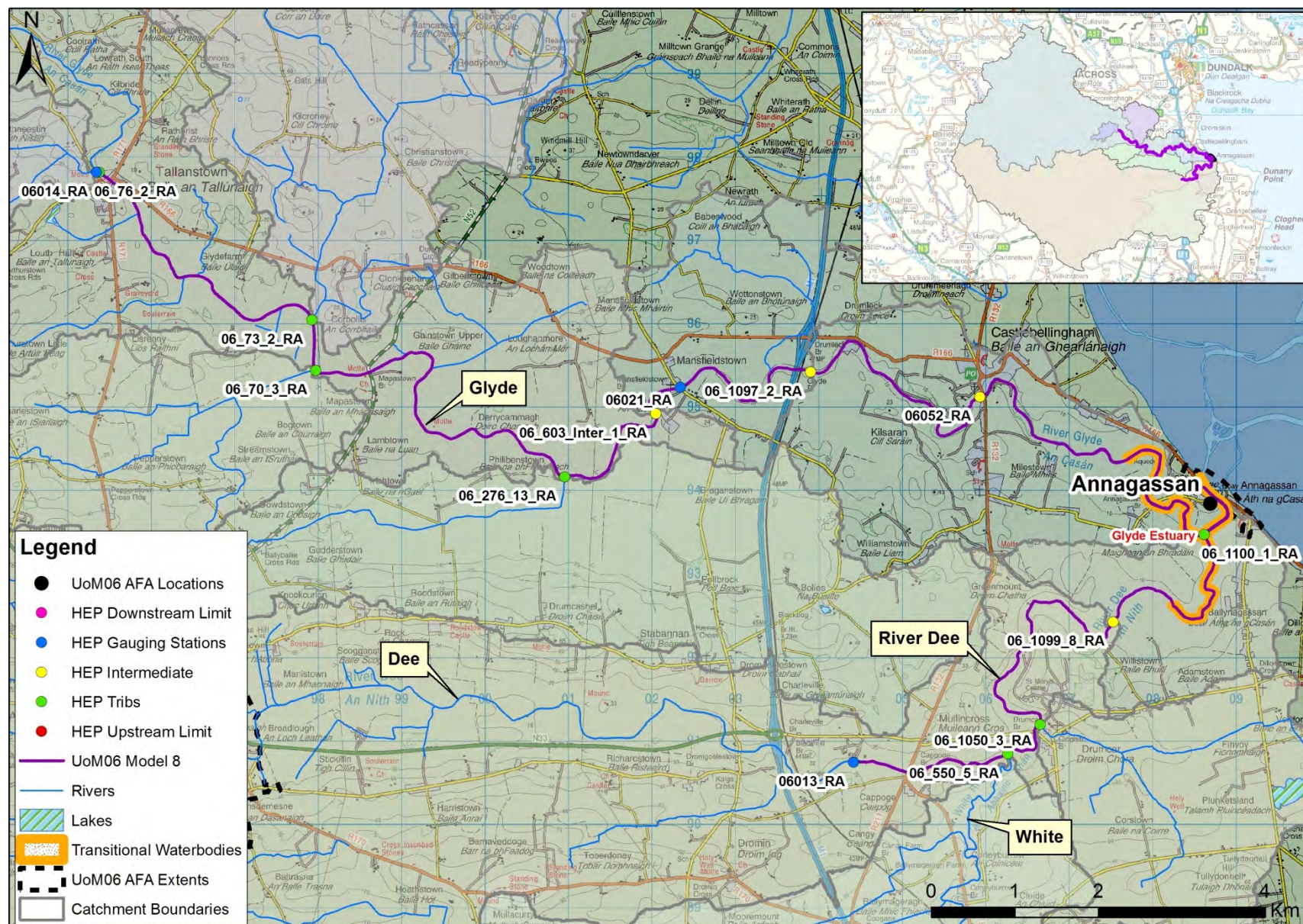


Figure 4.13: Model 8 Catchment Boundaries and HEPs

Hydrometric station 06014 at Tallanstown forms the upstream limit of Model 8 on the River Glyde – refer to Section 4.6 for details. It has been used as the pivotal site for adjusting initial Q_{med} estimates on the HEPs located on the upper reaches of Model 8 on the River Glyde.

Hydrometric Station 06021 at Mansfieldstown is also located on the River Glyde approximately 11km downstream from the upstream limit. It is an OPW operated station with over 50 years of data. It is not rated under FSU, the reason for which is unclear. For data pre-1972 the ratio between Highest Gauged Flow and $Q_{med\ gauged}$ is 1.67, and post 1972 it is 1.46. Both of these ratios would suggest an A1 station, and there is nothing in the OPW Hydrometrics Summary to suggest problems with the station except that limit of reliability differs pre and post 1972, presumably when an automated data logger was installed. Following CFRAM Study rating review the Q_{med} value of this station is confirmed at the existing value of $21.87\ m^3/s$ and subsequently the adjustment factor from this gauging station of 0.6 is being taken forward for adjustment of all $Q_{med\ pcd}$ values from the intermediate HEP upstream (06_603_Inter_1_RA) to the downstream boundary of the model. This is broadly consistent with the adjustment factor from the pivotal site upstream on the Glyde at Tallanstown (06014) of 0.65 and indicates there is only a marginal increase of $0.4\ m^3/s$ in the Q_{med} value between the two gauging stations.

Hydrometric station 06013 at Charleville Weir forms the upstream limit of Model 8 on the River Dee – refer to Section 4.7 for details. It has been used as the pivotal site for adjusting initial Q_{med} estimates (adjustment factor of 0.64) on the HEPs located on the River Dee within Model 8, with the exception of HEP 06_550_05_RA which represents the White River tributary entering the model. FSU station (06033) at Coneyburrow Bridge on the White River itself has been used as the pivotal site for this HEP. In contrast to stations 06014, and 06013 which result in downward adjustment (refer to Sections 4.6 and 4.7 for details), this station has a relatively high adjustment factor of 1.46, which is above the national average of 1.09. Since HEP 06_550_05_RA is actually located on the White River and the B rating associated with Station 06033 indicates confidence in flow values up to Q_{med} , it is considered appropriate to use this station as the pivotal site in this case. One small tributary HEP entering the River Dee has not been adjusted due to the lack of clear pivotal site selection and no trend indication for adjustment.

Within modelled reaches of Model 8 there are three gauging stations which, following rating review have high confidence in the observed Q_{med} values. The initial HEP estimates of Q_{med} based on Physical Catchment Descriptors at non gauging station HEPs have generally been adjusted within Model 8 based on the high confidence gauge data directly upstream or downstream. Only a few HEPs representing tributary inflows are not on gauged reaches and these represent flows that are insignificant in terms of the main channels flows in the channels into which they discharge. The tributary inflows between gauging stations 06014 and 06021 are examples of such HEPs and the adjustment of these inflow estimates has been based on 06014 such that they are reduced and the likelihood of achieving the marginal increases in Q_{med} flow within the model as is evident from the gauging stations as discussed previously is maximised.

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)	Estimation Methodology
06014_RA	270.70	21.46	Observed Q_{med} (Gauging Station)
06_76_2_RA	5.62	0.68	FSU (Adjusted – 06014)
06_73_2_RA	19.52	1.43	FSU (Adjusted – 06014)
06_70_3_RA	10.19	1.07	FSU (Adjusted – 06014)
06_276_13_RA	18.97	1.34	FSU (Adjusted – 06014)
06_603_Inter_1_RA	344.37	21.86	FSU (Adjusted – 06021)
06021_RA	344.81	21.87	Observed Q_{med} (Gauging Station)
06_1097_2_RA	350.88	21.88	FSU (Adjusted – 06021)
06052_RA	357.04	21.88	FSU (Adjusted – 06021)
06013_RA	307.98	27.37	Observed Q_{med} (Gauging Station)
06_550_5_RA	61.42	22.36	FSU (Adjusted – 06033)
06_1050_3_RA	7.98	1.58	FSU (Not adjusted)
06_1099_8_RA	383.38	32.43	FSU (Adjusted – 06013)
06_1100_1_RA	387.96	32.70	FSU (Adjusted – 06013)
06_848_D_RARPS	749.54	49.56	FSU (Adjusted – 06021)

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

4.9 MODEL 9 – TERMONFECKIN

Termonfeckin is located north east of Drogheda in County Louth on the Irish Sea coast. Fluvial flood risk emanates from two small coastal watercourses, the largest of which flow eastwards through the AFA before joining the smaller tributary just north of the golf course and discharging to the sea at Termonfeckin Strand. The larger watercourse rises in the hills of Hamlinstown, Carricknashanagh and Drumshallon before making the 10km journey to the sea through relatively flat pasture lands and Termonfeckin town. The smaller watercourse which joins it from the south is very flat and drains agricultural lands whilst flowing adjacent to ribbon development behind the golf course. The total catchment area at the downstream limit of Model 9 is 28km². The contributing catchments and HEPs are shown in Figure 4.14.

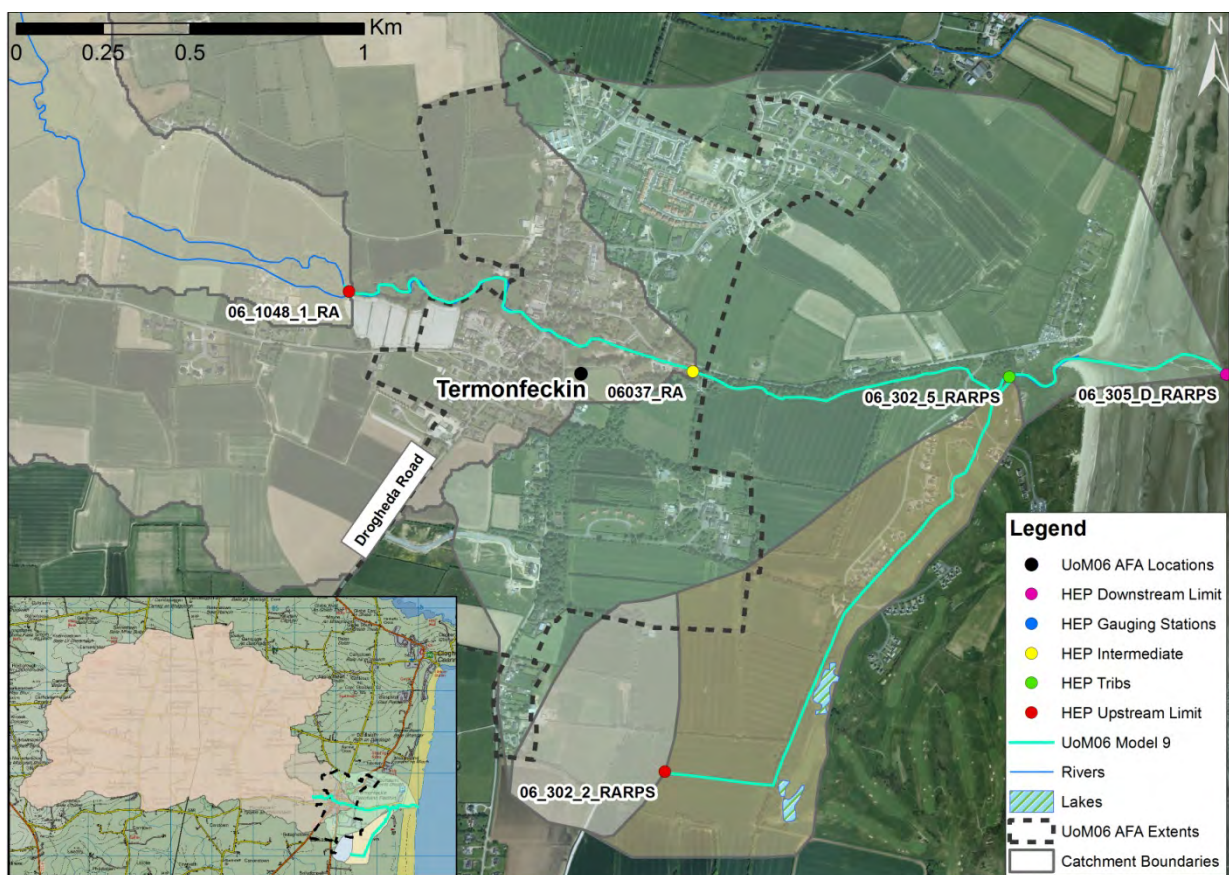


Figure 4.14: Model 9 Catchment Boundaries and HEPs

There is one gauging station located downstream of Termonfeckin (06037) but it is a staff gauge site only with no flow data available. Therefore the modelled catchment is ungauged.

A review of all pivotal site options was undertaken where a trend towards upwards adjustment was found at 9 of the 14 most geographically and/or hydrologically similar sites. The most hydrologically similar and the closest pivotal sites generally yield results around the 68%ile upper confidence limit of the FSU estimation using PCDs. The review therefore suggests that upward adjustment is appropriate

but that the adjustment factor is taken as the 68th percentile upper limit. The adjustment factor has therefore been taken as 1.37.

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)	Estimation Methodology
06_1048_1_RA	23.27	5.87	FSU (Adjusted upwards based on pivotal sites to 68 th percentile)
06037_RA	25.56	6.31	
06_302_2_RARPS	0.23	0.05	
06_302_5_RARPS	0.82	0.10	
06_305_D_RARPS	28.48	6.82	

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

Five of the nine models in UoM 06 have hydrometric stations located within them (seven stations in total). Five of these stations are rated A1 which means there is high certainty in flood flows above Q_{med} . All six FSU rated stations have data deemed to be of a high enough quality such as to be taken forward as pivotal sites within FSU (confidence in the rating at Q_{med}). Therefore UoM 06 can be considered as relatively well gauged in comparison with other Units of Management within the North Western and Neagh Bann Study areas such as UoM01 in the North-West (Co. Donegal) which is sparsely gauged.

The rating reviews in UoM 06 involve two A1 stations and one non-FSU rated station which has high quality data. The rating review of the non-FSU rated station has confirmed that the data is of high quality and the existing Q_{med} validated. Therefore the number of models with useable hydrometric stations has not increased post rating review and the impact of the rating review results has been shown not to be significant, especially in terms of index flood flow estimation.

The FSU method for Flood Estimation in Ungauged Catchments (WP 2.3) is the preferred methodology for the estimation of the index flood flow in ungauged catchments. In the first instance the index flood flow has been estimated using this method at all HEPs. The estimates are then adjusted where possible based on observed flow data with confidence at the index flood flow (Q_{med}). Data is applied from sites, in order of preference, on the modelled watercourse, just upstream or downstream of the modelled extents or from remote sites which have a gauging station representing a catchment that is deemed to be hydrologically or geographically similar to the subject site. For UoM 06 the application of gauged data directly on the modelled watercourse is applicable to five of the nine models. Two of the other four represent the catchments in the Cooley Peninsula where there is evidence from nearby gauges to indicate that the FSU physical catchment descriptor based estimates are too low and must be adjusted upwards for this particular type of catchment. Across Hydrometric Area 06 (encompassing all but the Monaghan model within UoM 06) there is a strong trend towards upward adjustment for the smaller catchments with an average adjustment factor of 1.68 for the three pivotal sites with areas between 10km^2 and 55km^2 and an average adjustment factor of 0.75 for the eight pivotal sites (with rating reviewed 06021 added) with areas between 149km^2 to 344km^2 . Figure 4.15 shows the variance of adjustment factors with area across UoM 06.

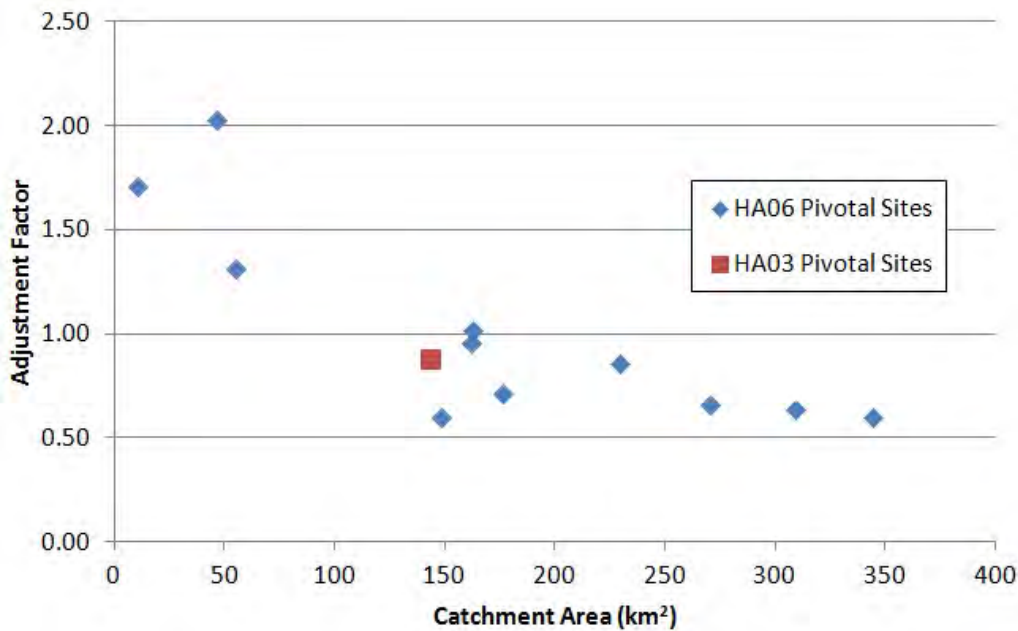


Figure 4.15: UoM 06 Adjustment Factor v Catchment Area

This trend for adjustment has generally been followed across HA06 for the ungauged models and sub-catchments where application of gauged data from the main channel is not appropriate. Local adjustments have been made based on the most appropriate pivotal sites following review against closest and hydrologically similar pivotal sites. In some instances one clear pivotal site is apparent while in others it is not clear and adjustments have been made taking an average of a number of pivotal sites deemed appropriate following consideration of a range of datasets and based on catchment understanding. The exact adjustment factor is not always an objectively defined value and is partly a knowledge and skill based judgement call in these instances. Nevertheless design flows will be reviewed again during the hydraulic analysis phase in line with Figure 2.1 and index flows revisited if model calibration outputs deem it necessary.

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 06-Neagh-Bann Unit of Management (Hydrometric Areas – HA03 and HA06) of the North Western – Neagh Bann CFRAM study areas. The estimated growth curves will be used in determining the peak design flood flows for all HEPs located on the modelled tributary and main river channels within the UoM 06 study area.

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 UoM 06 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 in terms of 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 the 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 UoM 06, a catchment characteristic based generalised growth curve estimation method, as discussed later in Sections 5.7.4 and 5.8, 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 UoM 06 were obtained from the OPW, EPA and the Rivers Agency of Northern Ireland. 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 104 gauging sites were obtained (up to 2011).

Table 5.1 presents the location details, record lengths and some of the catchment characteristics of these hydrometric stations, while Figure 5.1 illustrates their spatial distributions in the region. The majority of the 104 stations have A1 & A2 rating quality classification (refer to Section 3. for the definition of the rating quality classifications of the hydrometric gauges). The record lengths in these gauging stations vary from 9 to 71 years with a total of 3,726 station-years of AMAX series. The study river catchments within UoM 06 have 339 station-years of AMAX series from 10 hydrometric gauging sites.

There are climatic differences between the eastern and other parts of the country and restricting the choice of pooling stations to the eastern, south-eastern and north-eastern regions along with HA03 should ensure an additional degree of homogeneity. In particular it was felt that the catchments of the Shannon and Erne HAs, many of which are large and flat, would not necessarily be homogeneous with the eastern, south-eastern and north-eastern regions HAs and therefore would not make any additional useful contribution to the development of growth curves for UoM 06. In the light of the large number of AMAX values (3,726 station-years) available in the eastern, south-eastern and north-eastern HAs, it is not considered necessary to extend the pooling region to the entire country.

Table 5.1: Hydrometric Station Summary for Pooling Region (104 sites)

Station No.	Waterbody	Location	Record Length (Years)	Area (Km ²)	SAAR (Mm)	BFI	FARL	Gauge Rating Classification
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Station No.	Waterbody	Location	Record Length (Years)	Area (Km ²)	SAAR (Mm)	BFI	FARL	Gauge Rating Classification
03010	Blackwater	Maydown Bridge	43	964.93	1008.00	0.395	0.976	FEH
03017	Upper Bann	Dynes Bridge	15	315.94	1023.00	0.449	0.974	FEH
03022	Blackwater	Derrymeen Bridge	18	183.49	1143.00	0.460	0.977	FEH
03024	Cusher	Gambles Bridge	29	170.94	995.00	0.365	0.992	FEH
03033	Upper Bann	Bannfield	38	101.64	1261.00	0.471	0.951	FEH
03043	Oona	Shanmoy	26	88.59	1003.00	0.400	0.974	FEH
03051	Blackwater	Faulkland	29	143.20	1083.30	0.472	0.953	A2
06001	Clanrye	Mountmill Bridge	38	120.54	975.00	0.568	0.972	FEH
06004	Bessbrook	Carnbane	29	34.76	1055	0.584	0.917	FEH
06011	Fane	Moyles Mill	51	229.19	1028.98	0.708	0.874	A1
06012	Annalong	Subsidiary Intake	53	162.80	1046.24	0.680	0.831	A1
06013	Dee	Charleville	35	309.15	873.08	0.617	0.971	A1
06014	Glyde	Tallanstown	35	270.38	927.45	0.634	0.927	A1
06021	Glyde	Mansfieldstown	53	346.01	893.79	0.621	0.942	Not Classified
06025	Dee	Burley	36	175.98	908.31	0.615	0.956	A1
06030	Big (Louth)	Ballygoly	31	10.79	1158.35	0.625	0.972	B
06031	Flurry	Curralhir	14	46.17	930.66	0.553	1.000	A2
06033	White (Dee)	Coneyburrow Bridge	37	55.22	856.52	0.505	0.996	B
07001	Tremblestown	Tremblestown	42	151.31	913.24	0.700	0.996	A2
07002	Deel [Raharney]	Killyon	51	284.97	920.53	0.780	0.929	A2
07003	Blackwater (Enfield)	Castlerickard	51	181.51	809.22	0.649	1.000	A1 & B
07004	Blackwater (Kells)	Stramatt	53	245.74	1007.88	0.619	0.772	A2
07005	Boyne	Trim	52	1332.17	879.71	0.721	0.983	A1
07006	Moynalty	Fyanstown	49	177.45	936.67	0.552	0.990	A2
07007	Boyne	Boyne Aqueduct	50	441.18	870.98	0.663	1.000	A1 & B
07009	Boyne	Navan Weir	34	1658.19	868.55	0.713	0.911	A1
07010	Blackwater (Kells)	Liscartan	51	699.75	948.29	0.658	0.798	A1 & A2

Station No.	Waterbody	Location	Record Length (Years)	Area (Km ²)	SAAR (Mm)	BFI	FARL	Gauge Rating Classification
07011	Blackwater (Kells)	O'Daly's br.	49	281.74	1003.32	0.678	0.965	A2 & B
07012	Boyne	Slane Castle	70	2460.27	890.06	0.678	0.893	A1
07017	Moynalty	Rosehill	11	70.64	991.74	0.516	0.993	Not Classified
07023	Athboy	Athboy	9	100.10	950.81	0.717	0.995	Not Classified
07033	Blackwater (Kells)	Virginia Hatchery	30	124.94	1032.22	0.439	0.893	A2
08002	Delvin	Naul	24	33.43	791.12	0.597	1.000	A1
08003	Broadmeadow	Fieldstown	18	83.59	826.00	0.466	0.880	B
08005	Sluice	Kinsaley Hall	23	9.17	710.76	0.523	1.000	A2
08007	Broadmeadow	Ashbourne	21	37.94	845.02	0.399	1.000	B
08008	Broadmeadow	Broadmeadow	28	107.92	810.61	0.487	0.999	A2
08009	Ward	Balheary	15	61.64	767.09	0.545	0.999	A1
08010	Garristown St.	Garristown S.W.	13	1.13	818.92	0.682	1.000	Not Classified
08011	Nanny	Duleek D/S	28	181.77	819.49	0.520	0.999	B
08012	Stream	Ballyboghill	17	25.95	798.70	0.524	0.999	B
09001	Ryewater	Leixlip	54	209.63	783.26	0.507	1.000	A1
09002	Griffeen	Lucan	25	34.95	754.75	0.674	0.958	A1
09010	Dodder	Waldron's Bridge	57	94.26	955.04	0.561	0.993	A1
09011	Slang	Frankfort	19	5.46	772.95	0.563	0.986	B
09024	Morell	Morell Bridge	9	98.75	851.99	0.705	0.987	Not Classified
09035	Camac	Killeen Road	15	37.14	794.21	0.673	0.932	B
09048	Ryewater	Anne's Bridge	10	59.35	805.54	0.474	1.000	Not Classified
09049	Lyreen	Maynooth	10	87.52	768.17	0.473	1.000	Not Classified
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	Not Classified
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

Station No.	Waterbody	Location	Record Length (Years)	Area (Km ²)	SAAR (Mm)	BFI	FARL	Gauge Rating Classification
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	Not Classified
11001	Owenavorrage	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	Not Classified
12013	Slaney	Rathvilly	35	204.39	1383.48	0.743	0.999	B
13002	Corock	Foulk's Mill	25	62.96	1043.79	0.733	1.000	Not Classified
14003	Barrow	Borness	27	206.73	1160.51	0.532	1.000	Not Classified
14004	Figile	Clonbulloge	53	268.85	838.67	0.537	1.000	Not Classified
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	Not Classified
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	Not Classified
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	Not Classified
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

Station No.	Waterbody	Location	Record Length (Years)	Area (Km ²)	SAAR (Mm)	BFI	FARL	Gauge Rating Classification
15004	Nore	Mcmahons Br.	56	491.38	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	Not Classified
15007	Nore	Kilbricken	35	339.76	1123.04	0.594	1.000	A2
15008	Nore	Borris In Ossory	35	116.22	943.75	0.533	0.993	Not Classified
15009	Kings	Callan	54	203.14	940.19	0.540	1.000	Not Classified
15010	Goul	Ballyboodin	31	159.06	886.97	0.657	0.997	Not Classified
15011	Nore	Mount Juliet	57	2225.79	938.02	0.618	0.999	Not Classified
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	Not Classified
15041	Goul	Ballinfrase	9	135.39	889.60	0.634	0.996	Not Classified
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	Not Classified
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	Rossetown	Clobanna	13	34.19	895.27	0.676	1.000	B

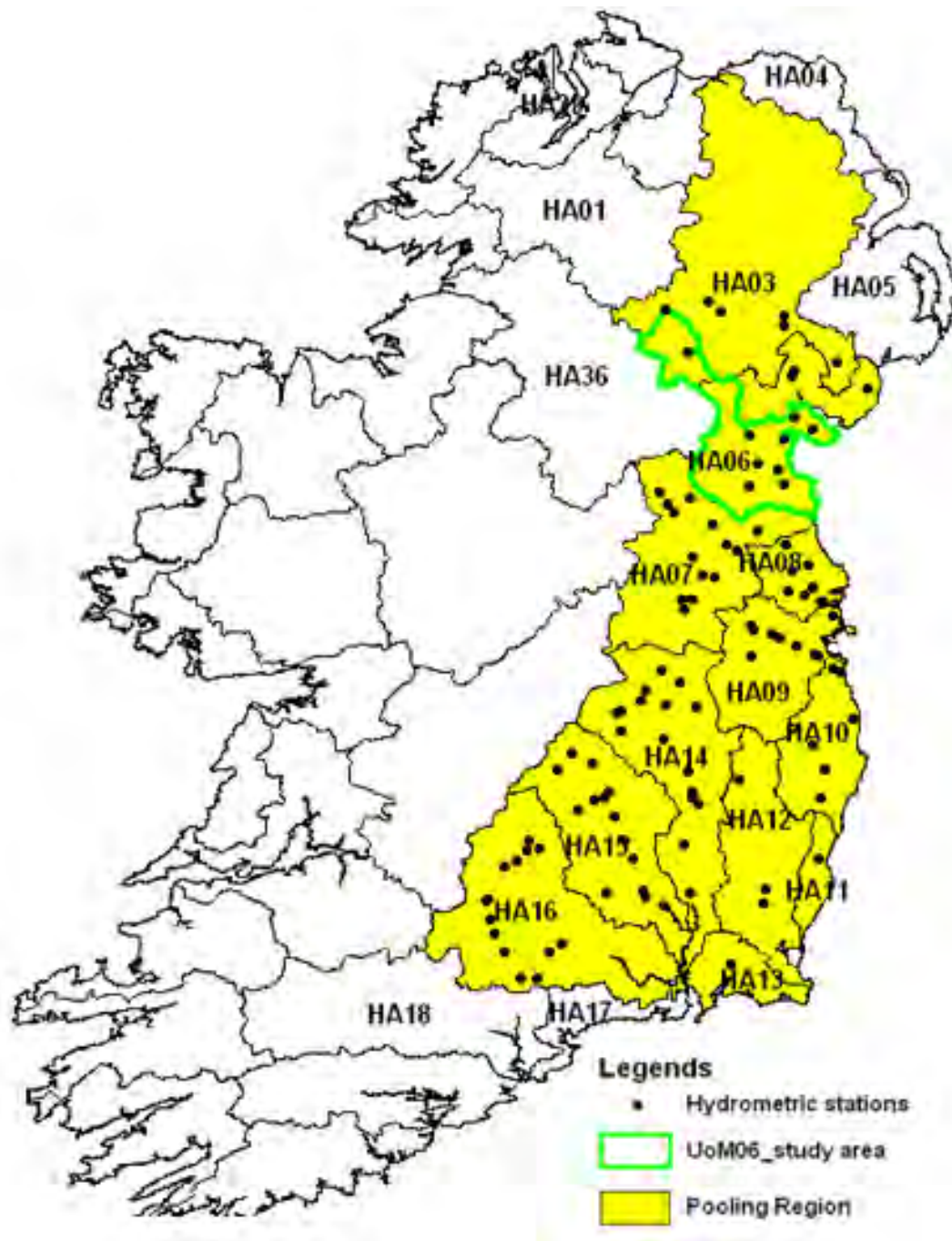


Figure 5.1: Locations of 104 Gauging Stations in Pooling Region

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 104 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 176.72 km², SAAR values range from 711 to 1700 mm with a median value of 933 mm. The BFI values vary from 0.365 to 0.788, while the FARL values range from 0.730 to 1.00.

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

Characteristics	Minimum	Maximum	Average	Median
AREA (km ²)	1.13	2778.15	452.85	176.72
SAAR (mm)	710.76	1700.39	974.96	933.01
BFI	0.365	0.788	0.59	0.62
FARL	0.730	1.000	0.980	0.999

The relative frequencies of the AREA, SAAR and BFI values within the 104 stations are also presented in Figures 5.2, 5.3 and 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 majority of the stations range from 700 to 1200 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 104 catchments. It can be seen from this figure that the BFI values in the majority of the 104 catchment areas range from 0.45 to 0.75.

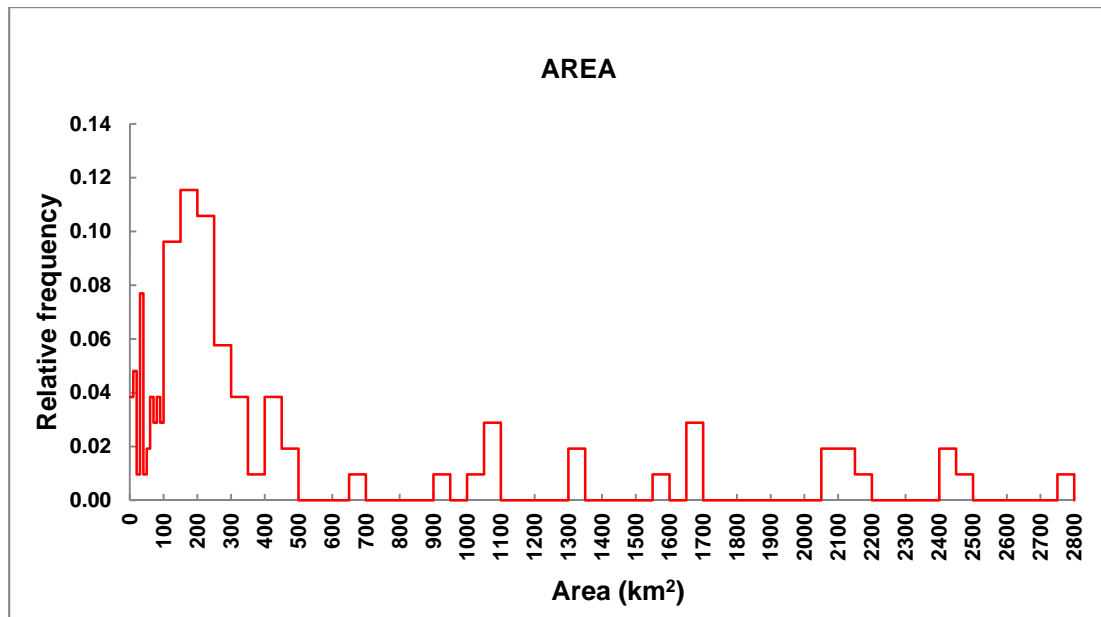


Figure 5.2: Relative frequencies of catchments sizes (AREA) within the Pooling Region (104 stations)

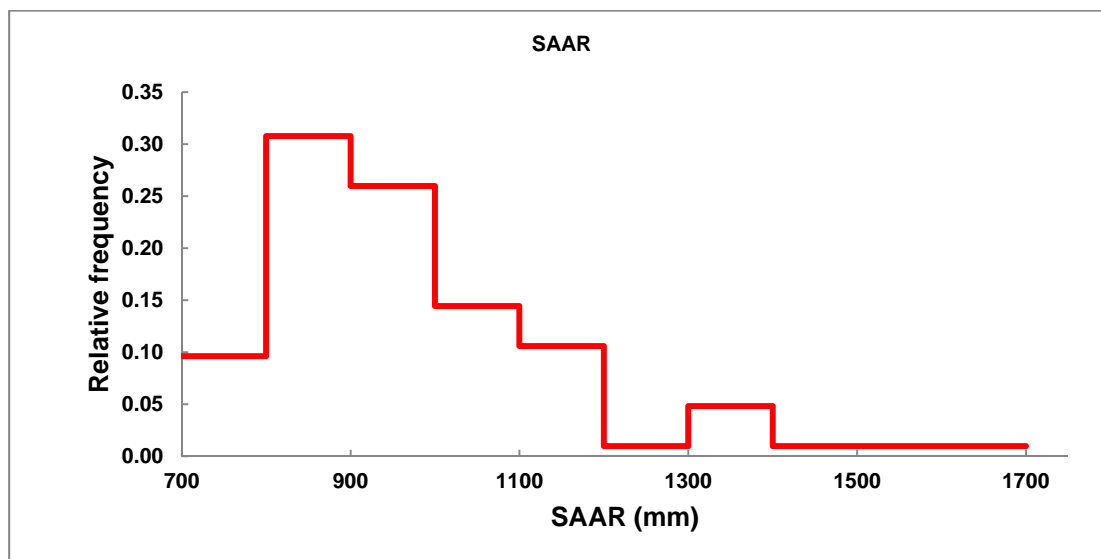


Figure 5.3: Relative frequencies of the SAAR values within the Pooling Region (104 stations)

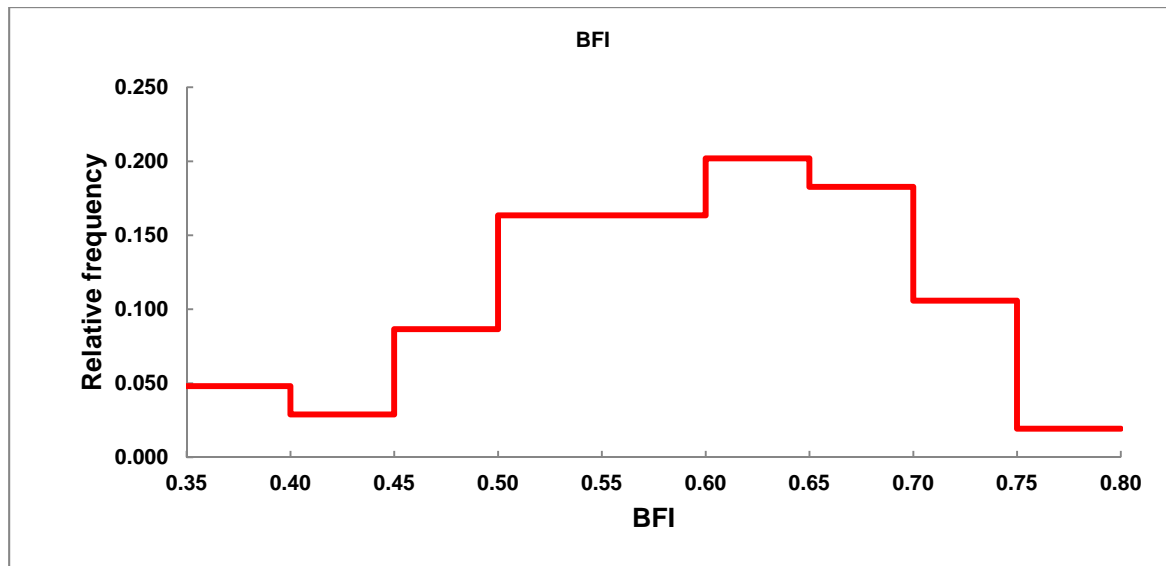


Figure 5.4: Relative frequencies of the BFI values within the Pooling Region (104 stations)

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 104 gauging sites. The median AMAX flows (Q_{med}) range from 0.47 to 299.32 m³/s with an average value of 52.21 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 0.160 which is approximately equal to the theoretical L-Skewness of EV1 distribution.

Table 5.3: Statistical properties of 104 AMAX Series in Pooling Region

Parameters	Minimum	Maximum	Average	Median
Record Lengths (years)	9	71	36	35
Mean Flow (m ³ /s)	0.49	303.45	54.67	27.49
Median Flow (m ³ /s)	0.47	299.32	52.21	26.21
L-CV	0.052	0.415	0.198	0.181
L-skewness	-0.181	0.488	0.160	0.149
L-Kurtosis	-0.127	0.426	0.151	0.135

Figure 5.5 shows the L-CV versus L-Skewness diagram for the 104 AMAX series with the values associated with UoM 06 highlighted.

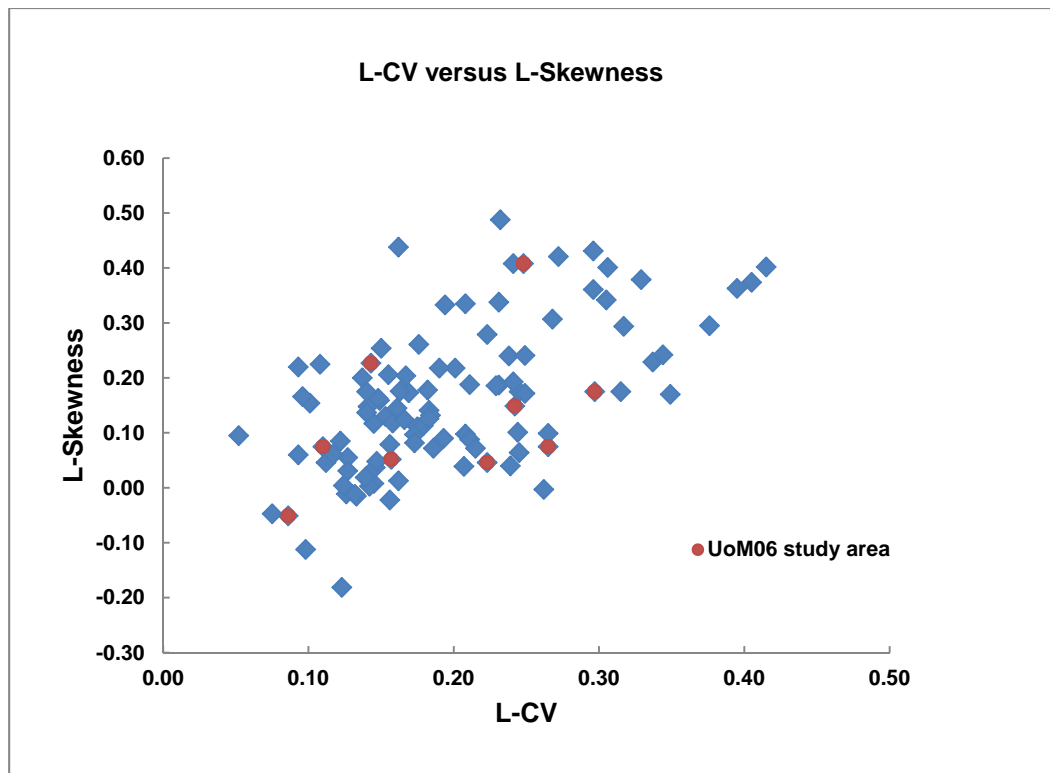


Figure 5.5: L-Moment Ratio Diagram (L-CV versus L-Skewness) for 104 AMAX series in the Pooling Region

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 playing 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 104 AMAX series, it was found that the three-parameter distributions provide better fits to the majority of the 104 AMAX series. Between the GEV and GLO distributions, the GLO distribution was found to be the most appropriate distribution for design purposes when considered against individual sites (see Section 5.7.4). For the GLO distribution, 92 out of 104 frequency curves showed concave upward shape, 4 concave downward and 8 straight lines. For the GEV distribution, 38 showed concave upward shape, 49 showed concave downward and 17 are of straight line type. In the UoM 06 catchments, the GLO distribution was found to be best suited to five AMAX series out of 10 (all concave upward). In the GEV distribution, 3 frequency curves showed concave upward shape, 6 concave downward and one straight line.

Table 5.4 presents the summary results of the visual assessments of the probability plots for all 104 AMAX series. It should be noted here that one reason for the change of concavity (upward and downward) 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 104 AMAX series

Distribution	No. distribution in each quality ranks (1, 2 & 3)			Fitted line type
	Rank 1 (very good)	Rank 2 (good)	Rank 3 (fair)	
EV1	19	15	70	All straight line
LN2	22	36	46	All concave upward (At Log n scale)
GEV	21	62	21	17 – straight line (GEV type I) 38 – concave upward (GEV Type II) 49 – concave downward (GEV Type III)
GLO	58	30	16	8 – straight line, 92 – concave upward & 4 – concave downward

5.5 GROWTH CURVE ESTIMATION POINTS

In order to estimate the peak design flows for each of the 157 HEPs located on the modelled watercourses 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 UoM 06. 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 UoM 06 Inception Report (Section 5.3). Table 5.6 presents a summary of the catchment characteristics associated with the 157 HEPs in UoM 06. The catchment areas vary from close to zero (at the top of modelled tributaries) to 750 km². The SAAR values range from 762 to 1229 mm while the BFI values vary from 0.416 to 0.809.

Table 5.5: Summary of the catchment characteristics associated with the 157 HEPs

Catchment descriptors	Minimum	Maximum	Average	Median
AREA (km ²)	0.03	749.54	61.13	5.62
SAAR (mm)	762	1229	912	905
BFI	0.416	0.809	0.631	0.627

Based on the similarity of the catchment characteristics of 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 pooling 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 so the errors in the estimated growth curves would be larger. Based on these considerations, 80 HEPs (out of 157) were initially selected as points for the estimation of growth curves within UoM 06. However as will be discussed in Section 5.8.2 this was extended to 337 with the addition of a further 257 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 UoM 06.

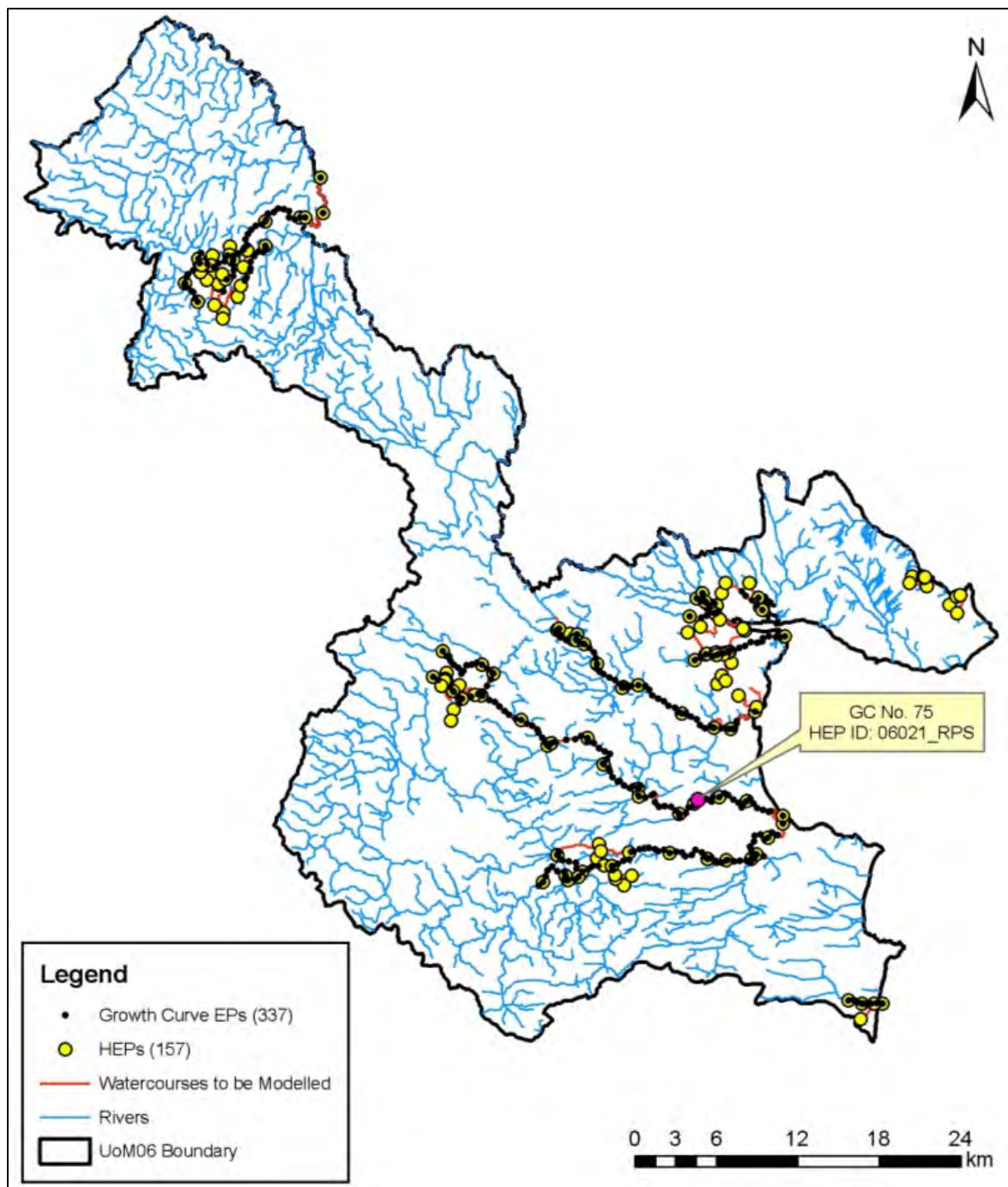


Figure 5.6: Spatial distribution of the HEPs and GC_EPs on modelled watercourses in UoM 06

Note: GC No. 75 (River Glyde at Mansfieldstown is used as an example in Section 5.7.3

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; hydrometric areas HA06 (HA06 – Newry, Fane, Glyde and Dee); and HA03 (Bann) will be pooled to form a pooling group for growth curve estimation for UoM 06. The pooling region for this study area therefore covers the eastern, south-eastern and north-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. Table 5.3 provides a summary of the statistical properties of the AMAX series for all 104 gauging sites. The median AMAX flows (Q_{med}) range from 0.47 to 299.32m³/s with an average value of 52.21m³/s. As discussed 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 0.160.

The values of AREA, SAAR and BFI encountered in the 157 HEPs are summarised by their minimum, maximum, average and median values in Table 5.5. Comparison of these with the histograms of AREA, SAAR and BFI for the 104 stations selected for pooling purposes (Figure 5.2 to Figure 5.4) previously discussed in Section 5.3 show a good overlap, which indicates that the 104 stations provide good coverage for the range of catchments encountered in the HEPs in UoM 06.

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 (ROI) approach of the type proposed by Burn (1990). The ROI 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 are selected based on the lowest distance measures

among the available gauging sites in the pooling region. Individual pooling groups have been developed and growth curves have been estimated for every HEP. However, the estimated pooled growth factors/curves have been generalised further based on a range of catchment sizes as discussed later in Section 5.8.2.

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 the better suited distribution for most of the 104 AMAX series than the two-parameter distributions. Furthermore, it can be seen from the L-moment ratio diagram for these 104 AMAX series as shown in Figure 5.7, that the GEV distribution is providing the line of best fit to the L-moment ratios of AMAX series from the pooling group, since the theoretical values of the GEV distribution's L-Skewness and L-Kurtosis pass centrally through the observed L-moments ratios of the 104 AMAX series.

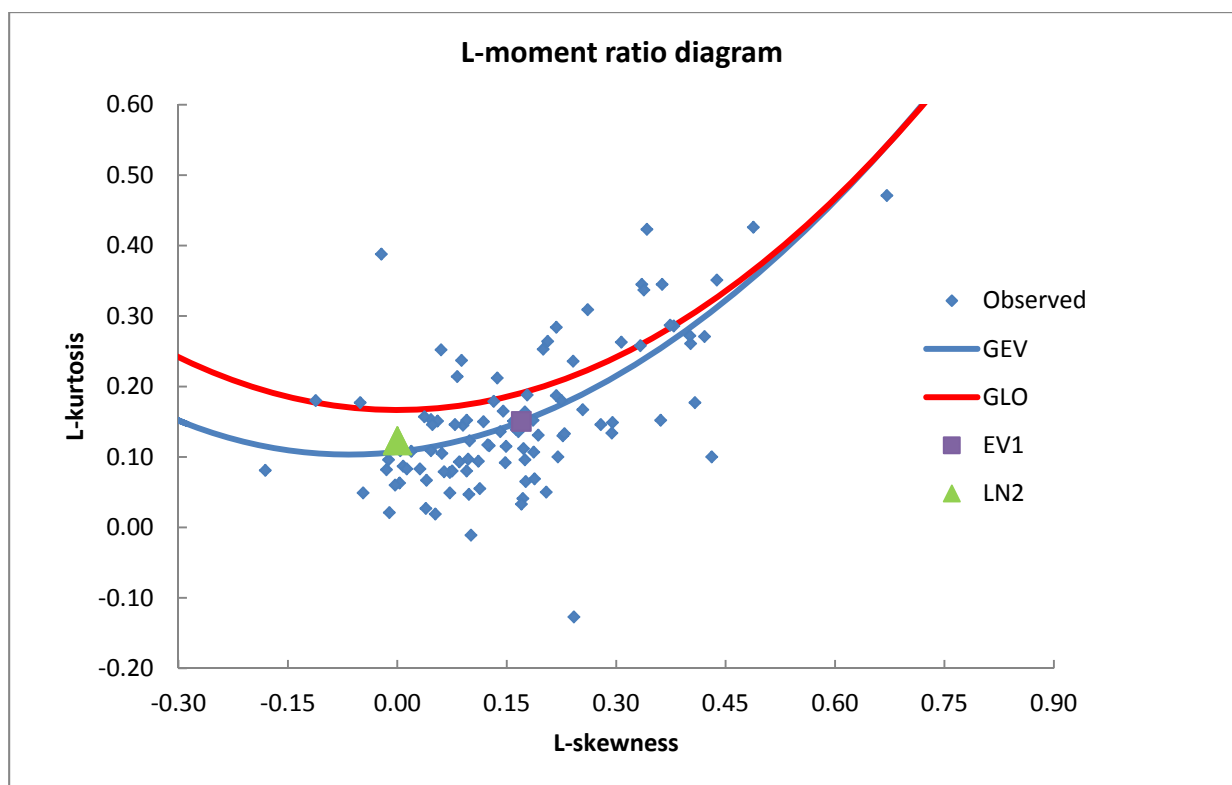


Figure 5.7: L-moment ratio diagram (L-skewness versus L-Kurtosis)

Based on the above, the GEV distribution can be adopted as the best candidate distribution for the regional growth curve for UoM 06. 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 concave downward in order to avoid potential underestimation of extreme event growth factors.

It can also be seen from Figure 5.7 that there are two large outliers at -0.05 (L-Skewness) 0.39 (L-Kurtosis) and 0.25 (L-Skewness) -0.13 (L-Kurtosis). Investigation of these outliers shows that they relate to stations with short records and unclassified ratings and as such are more likely to have more extreme shape parameters. Such stations were included within the analysis to maximise the range of types of catchments within the pooling group despite there being some uncertainty with the data.

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:

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

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)]

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

$$\beta = \frac{k t_3}{t_2 (\Gamma(1+k) - (\ln 2)^k) + \Gamma(1+k) (1 - 2^{-k})} \quad (5.6)$$

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)]:

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

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 80 HEPs for a range of 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 80 HEPs, while in the GEV and GLO distribution cases growth curves take either the concave upwards (upward bend) or concave downwards (downward bend) shapes based on the skewness of the pooled group. In the GEV distribution case, 27 out of 80 curves, showed concave downward shape, 46 showed concave upward shape and 7 showed almost a straight line; while in the GLO distribution case, all 80 curves showed the concave upward shape (see Table 5.6).

Table 5.6: Growth curves shape summary

Distribution	Growth Curve Shape
EV1	All straight lines
GEV	27 - concave downward 46 – concave upward 7 – straight line
GLO	All concave upward

An assessment of the suitability of the three growth curve distributions was undertaken by examining the suitability of these distributions in fitting the AMAX series in the pooling groups associated with all

80 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 for each of the 80 HEPs selected for growth curve analysis was made and recorded. As an example, HEP No. 75 (River Glyde at Mansfieldstown) was selected to illustrate the composition of one pooling group (refer to Figure 5.6).

In estimating the pooled growth curve for HEP No.75, 514 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 GC EP No. 75

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
06021	53	346.01	893.79	0.621	21.58	0.062	0.145	0.117	0.085	0.006
06013	35	309.15	873.08	0.617	27.16	0.088	0.157	0.052	0.019	0.171
06014	35	270.38	927.45	0.634	22.30	0.082	0.143	0.227	0.13	0.315
07007	50	441.18	870.98	0.663	36.91	0.084	0.183	0.141	0.136	0.336
16002	56	485.70	932.15	0.634	55.70	0.115	0.161	0.145	0.165	0.397
15005	55	379.37	884.96	0.712	29.00	0.076	0.182	0.178	0.188	0.454
16004	55	228.74	941.36	0.579	21.84	0.095	0.122	0.085	0.093	0.514
06025	36	175.98	908.31	0.615	18.62	0.106	0.086	-0.051	0.177	0.595
14004	53	268.85	838.67	0.537	21.33	0.079	0.163	0.176	0.065	0.595
15001	48	444.35	935.24	0.514	90.02	0.203	0.162	0.013	0.083	0.619
16010	38	437.10	985.24	0.624	44.76	0.102	0.117	0.061	0.105	0.622
Subject site (Growth Curve EP-75)	-	344.81	893.79	0.620	-	-	0.150*	0.109*	-	-

*Pooled regional values

It can be seen from the above table 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 344.81km², SAAR and BFI values of 894 mm and 0.620 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 0.15 and 0.109 respectively. This suggests that the pooled growth curve would follow a distribution which has L-Skewness slightly less than that of the EV1 distribution (0.167).

Figure 5.8 shows the estimated EV1, GEV and GLO growth curves for the GC EP No. 75. The GEV growth curve is a convex upward shaped curve while the GLO one is a concave upward shaped curve.

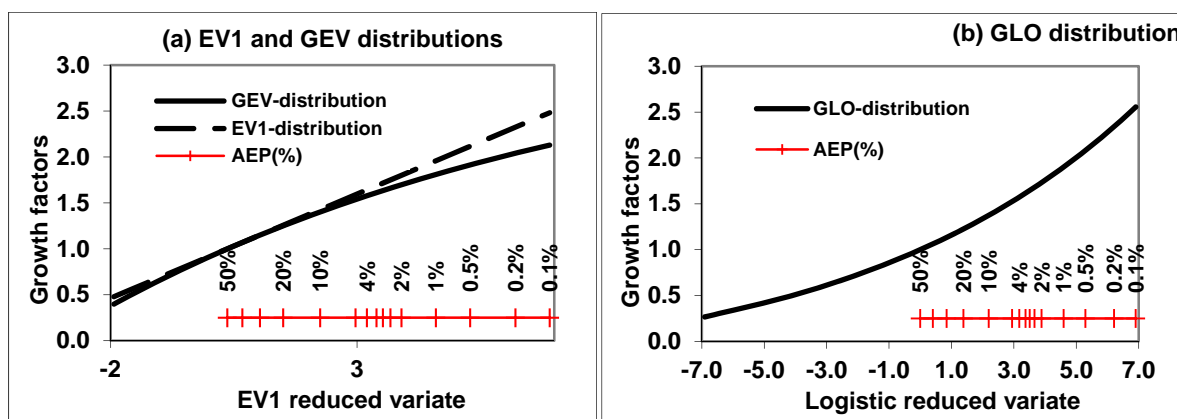


Figure 5.8: Pooled Growth Curve EP 75- (a) EV1 and GEV distributions; (b) GLO distributions

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 in Table 5.8.

Table 5.8: Frequency curve shapes of the individual site's AMAX series associated with the pooled group No. 75

Hydrometric stations	Individual at-site growth curves		
	GEV (EV1y Plot)	GLO (Loy Plot)	Comparison of performances (visual)
06021	Mild concave downward	Mild concave upward	Both fit equally well to the observed records
06013	Mild concave downward	Mild concave upward	GEV fits slightly better
06014	Mild concave upward	Mild concave upward	GEV fits slightly better

Hydrometric stations	Individual at-site growth curves		
	GEV (EV1y Plot)	GLO (Loy Plot)	Comparison of performances (visual)
07007	Mild concave downward	Mild concave upward	Both fit equally well to the observed records
16002	Mild concave upward	Mild concave upward	GLO fits slightly better
15005	Straight line	Mild concave upward	Both fit equally well to the observed records
16004	Mild concave downward	Moderate concave upward	GLO fits slightly better
06025	Mild concave downward	Mild concave downward	Both fit equally well to the observed records
14004	Straight line	Mild concave upward	Both fit equally well to the observed records
15001	Mild concave downward	Straight line	GLO fits slightly better
16010	Mild concave downward	Mild concave upward	Both fit equally well to the observed records

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 concave downward shaped curves (mild to moderate), two concave upward and two sites showed straight line. While in the GLO distribution case, nine sites showed concave upward, one concave downward and one straight line. This suggests that, the shape of the pooled growth curves in the case of GEV distribution can be expected as concave downward while for the GLO distribution case it would be concave upward. In this example the GLO

Table 5.9 shows the estimated growth factors for a range of AEPs for Growth Curve No. 75. The estimated 1% AEP growth factors for the EV1, GEV and GLO distributions are 1.959, 1.810 and 1.901 respectively.

Table 5.9: Estimated growth factors for Growth Curve No. 75

AEP (%)	EV1	GEV	GLO
50	1.000	1.000	1.000
20	1.257	1.251	1.226
10	1.427	1.402	1.375
5	1.590	1.537	1.524
2	1.801	1.698	1.732
1	1.959	1.810	1.901
0.5	2.117	1.914	2.081
0.1	2.482	2.129	2.556

5.7.4 Recommended Growth Curve Distribution for UoM 06

The following factors were considered to select an appropriate growth curve distribution for the UoM 06 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 104 gauging sites when considered individually 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 UoM 06.

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 concave downward shape. A significant number of the GEV growth curves showed concave downward shape (27 out 80). In contrast, all 80 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 80 growth curves by an amount of 0.1 to 5% (see Table 5.9 for growth curve No.75). 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.75, all plotted in the EV1 probability plot.

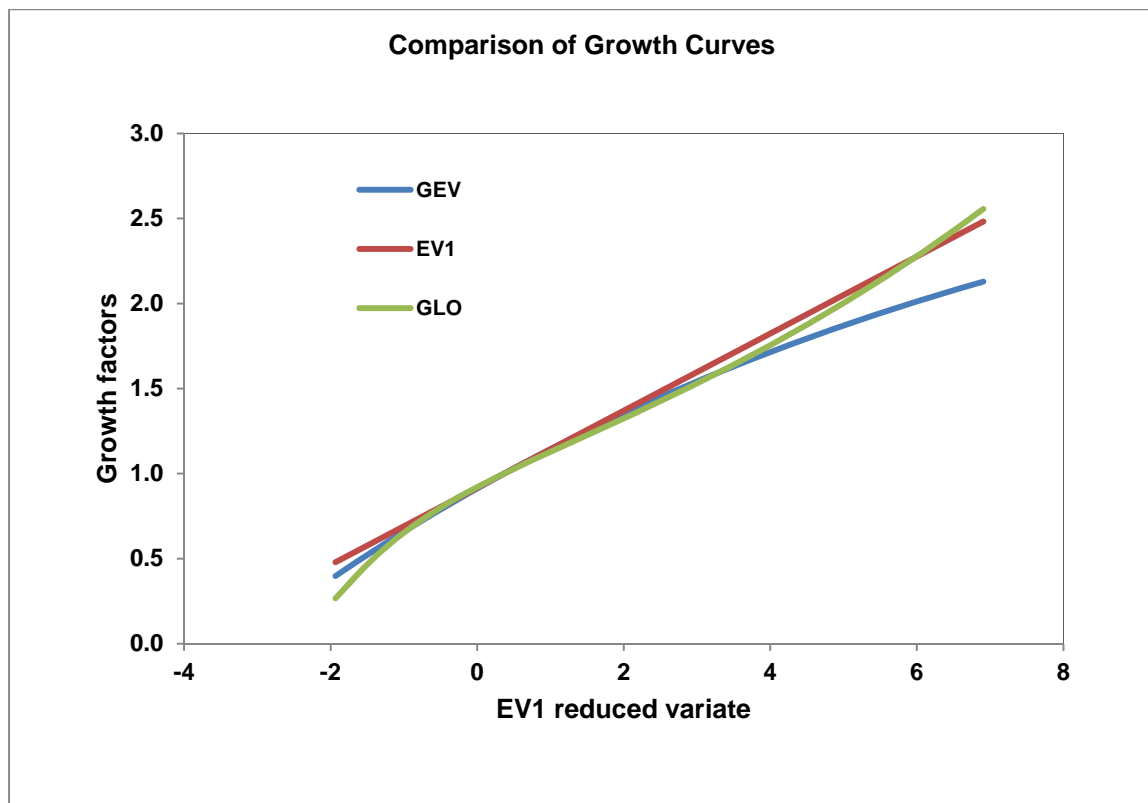


Figure 5.9: Comparison of EV1, GEV and GLO growth curves on the EV1-y probability plot (Growth Curve EP No. 75)

Based on the above, it is recommended to adopt the GLO distribution derived concave upward shape growth curve for the subject rivers catchments in UoM 06.

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 practicable number, the relationship between the estimated growth factors for a range of AEPs and the relevant catchment descriptors were examined. The catchment descriptors used were the AREA, SAAR and BFI. Figures 5.10, 5.11 and 5.12 show the variations of growth factors with AREA, SAAR and BFI respectively for all 80 HEPs.

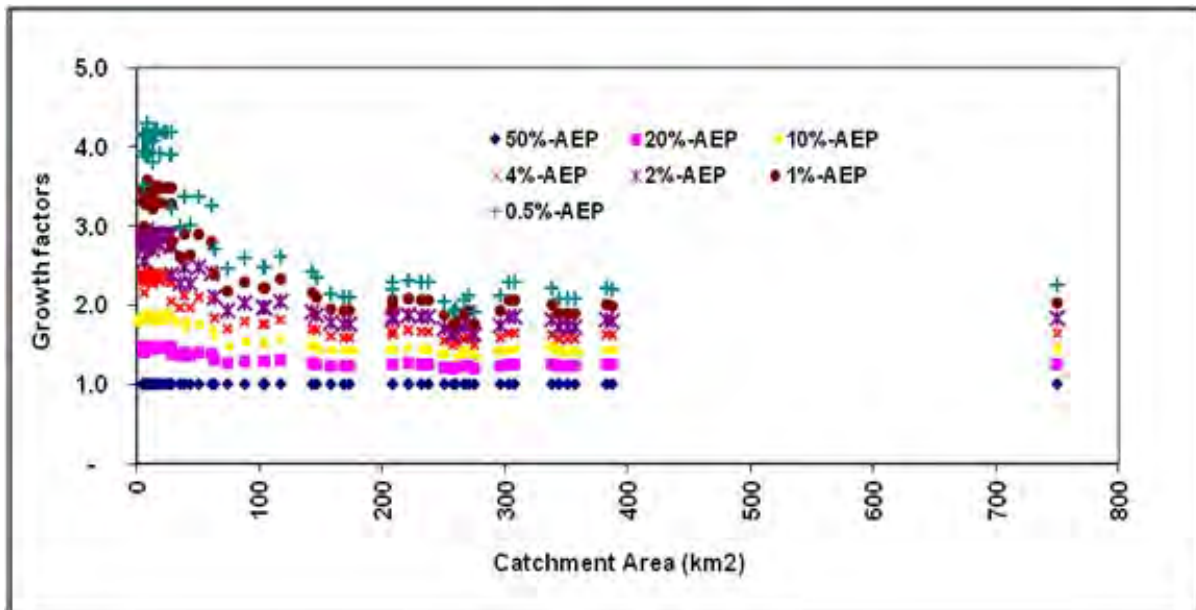


Figure 5.10: Relationship of growth factors with catchment areas for 80 HEPs

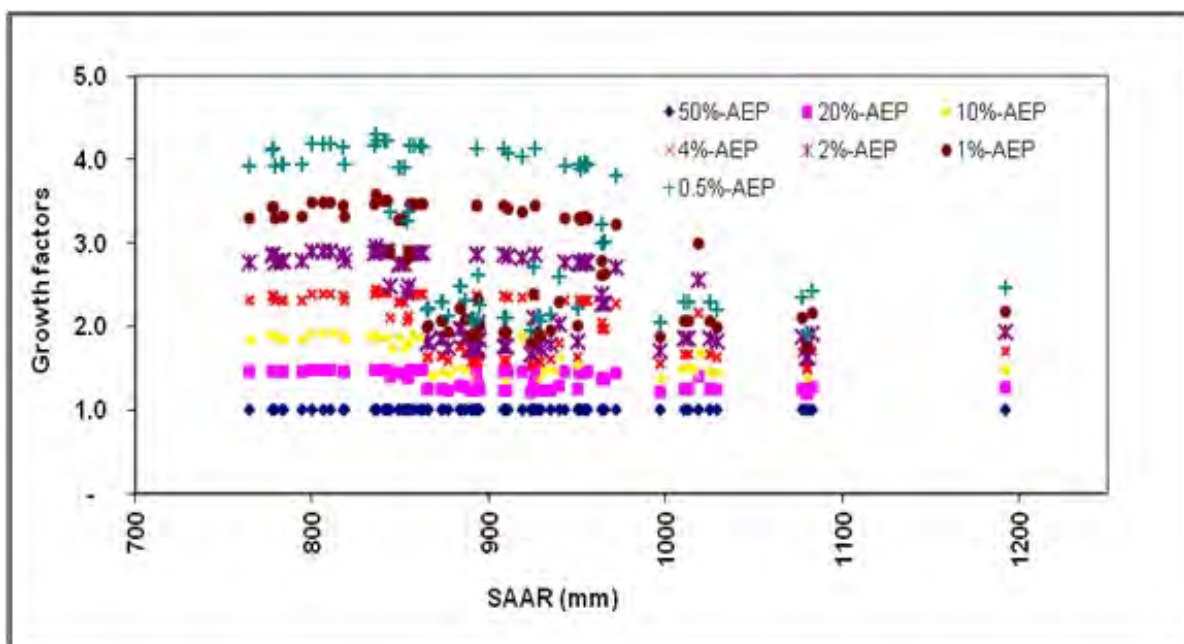


Figure 5.11: Relationship of growth factors with SAAR for 80 HEPs

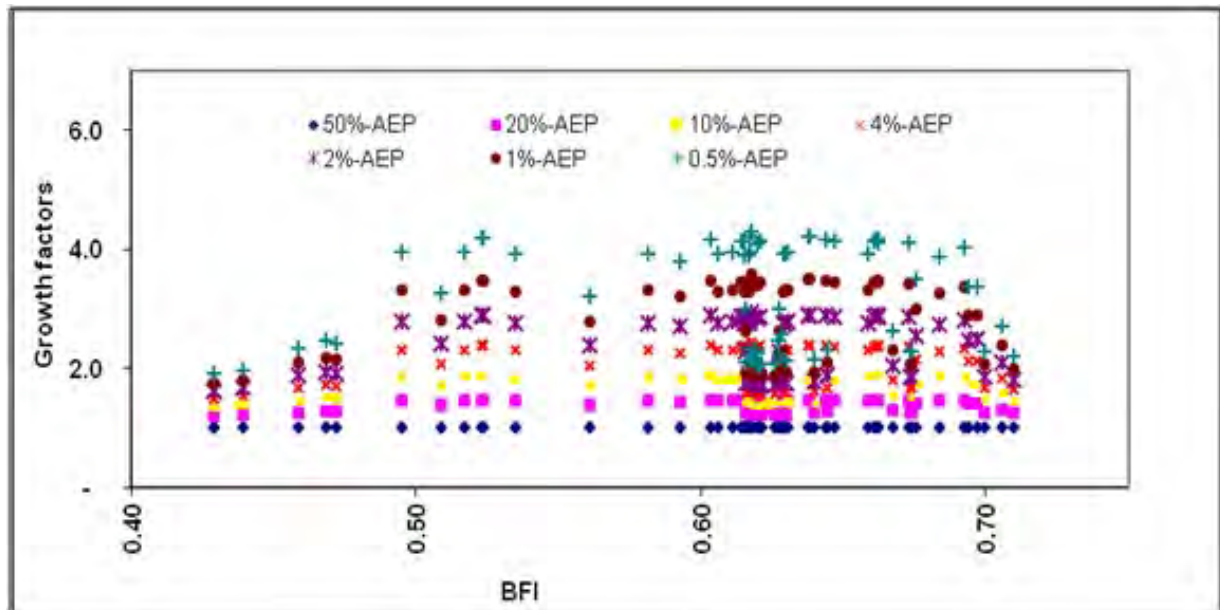


Figure 5.12: Relationship of growth factors with BFI for 80 HEPs

It can be seen from Figure 5.10 that the growth factors generally increase with decrease in catchment sizes. However this rate of increase is larger for the catchment areas less than 100 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 300 km² the growth factors do not change noticeably with the further increase in catchment area. No such clear patterns in the relationships of the growth factors with the SAAR and BFI values were found (Figures 5.11 and 5.12) although the HEPs located on the main channel of the Rivers Glyde and Dee have the effect of clustering a lot of the shallower growth curves within the SAAR range of 870 to 950mm.

5.8.2 Generalised Growth Curves

Based on the findings as discussed in Section 5.8.1, growth curves for UoM 06 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 257 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 5.13 shows the variation of the estimated growth factors for a range of AEPs and catchment sizes for all 337 HEPs (80 HEPs plus 257 additional points). Similar catchment size-growth factor relationships were found in this case as were found in the 80 HEPs case. It can be seen from this figure that the growth factors for catchment areas greater than 300 km² do not change appreciably with

the increase in catchment sizes. However, the variations in growth factors for the smaller catchment sizes are significant.

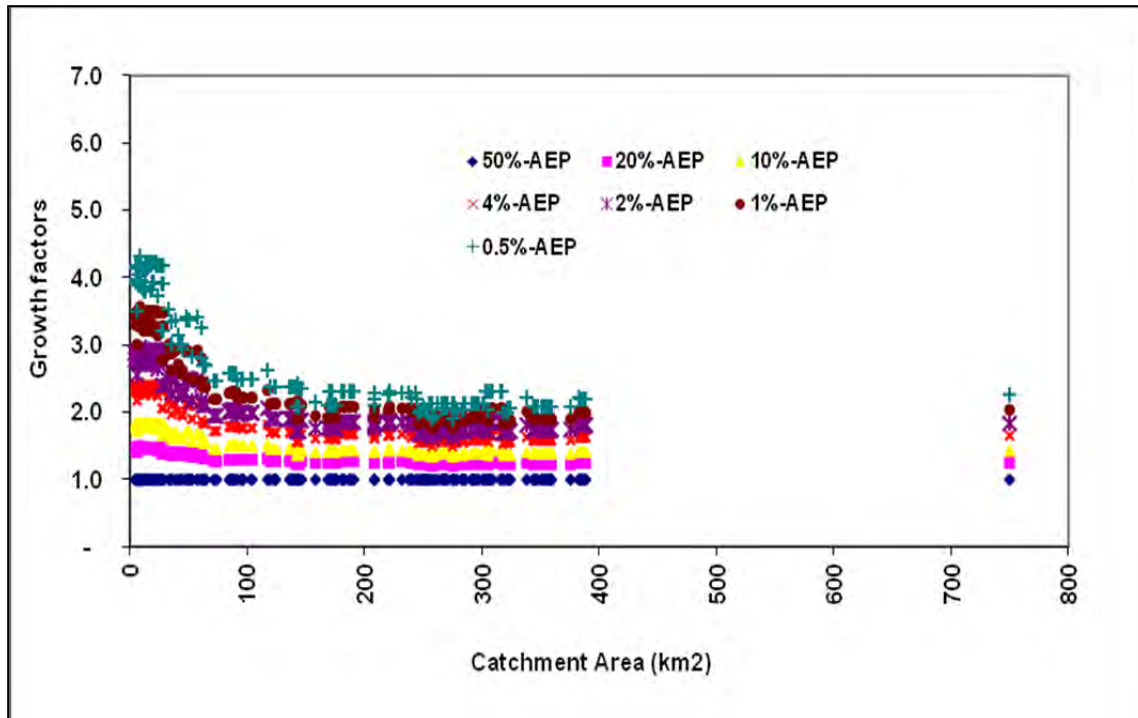


Figure 5.13: Relationship of growth factors with catchment areas (for 337 growth curve estimation points)

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 ≤ 150 km²
6. 150 < AREA ≤ 200 km²
7. 200 < AREA ≤ 300 km²
8. 300 < AREA ≤ 400 km²
9. AREA > 400 km²

Table 5.10 shows the estimated average and median growth factors for the above nine 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 0% to 30.7%. The highest variations

were found in the catchment size categories of 1, 2, 3, 4, 5 & 6. It is recommended that the growth factors for all HEPs with catchment sizes falling in the catchment area categories of 2 to 6 (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 the range of 10 to 200 km². However for all HEPs with catchment areas less than 10km², it is recommended to use the estimated median growth factors associated with catchment area category No 1. Despite the large standard deviation within this group it is not considered appropriate to use the individual growth curves. This would lead to a large amount of variance within a group where the appropriateness of the available pooling data is less certain due to the difference in catchment sizes between subject and pooled sites (lack of pooled data under 10km²). Furthermore the use of a more generalised curve will result in better rationalisation of design flow estimates moving down through the upper / tributary catchments. For the remaining categories the median growth curves will 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%	4%	2%	1%	0.50%	0.10%	
		Return Period (years)	2	5	10	20	25	50	100	200	1000	
AREA < 10 km ²	58	Average	1.000	1.457	1.805	2.193	2.329	2.798	3.347	3.993	5.983	
		Median	1.000	1.453	1.797	2.181	2.316	2.778	3.316	3.946	5.871	
		St. dev	0.000	0.010	0.020	0.034	0.039	0.060	0.087	0.123	0.251	
10 < AREA <= 25 km ²	47	Average	1.000	1.462	1.816	2.212	2.353	2.834	3.400	4.070	6.146	
		Median	1.000	1.471	1.835	2.245	2.389	2.888	3.476	4.174	6.349	
		St. dev	0.000	0.012	0.026	0.045	0.053	0.082	0.120	0.170	0.355	
25 < AREA <= 50 km ²	20	Average	1.000	1.406	1.705	2.032	2.145	2.528	2.968	3.476	4.991	
		Median	1.000	1.398	1.689	2.004	2.113	2.480	2.898	3.377	4.769	
		St. dev	0.000	0.041	0.080	0.130	0.149	0.218	0.307	0.420	0.813	
50 < AREA <= 100 km ²	28	Average	1.000	1.320	1.545	1.781	1.862	2.128	2.424	2.756	3.696	
		Median	1.000	1.299	1.507	1.722	1.795	2.034	2.296	2.587	3.391	
		St. dev	0.000	0.043	0.079	0.122	0.138	0.193	0.261	0.343	0.610	
100 < AREA <= 150 km ²	27	Average	1.000	1.255	1.431	1.611	1.672	1.871	2.088	2.327	2.982	
		Median	1.000	1.260	1.441	1.628	1.691	1.899	2.128	2.381	3.082	

Catchment size range	No of HEPs in size range	Growth factors									
		AEP (%)	50%	20%	10%	5%	4%	2%	1%	0.50%	0.10%
		Return Period (years)	2	5	10	20	25	50	100	200	1000
		St. dev	0.000	0.022	0.040	0.059	0.066	0.089	0.117	0.149	0.247
150 < AREA <= 200 km ²	24	Average	1.000	1.250	1.416	1.583	1.638	1.817	2.007	2.213	2.756
		Median	1.000	1.259	1.434	1.612	1.671	1.864	2.072	2.298	2.905
		St. dev	0.000	0.010	0.020	0.032	0.037	0.053	0.072	0.095	0.166
200 < AREA <= 300 km ²	70	Average	1.000	1.230	1.382	1.534	1.585	1.747	1.920	2.105	2.594
		Median	1.000	1.228	1.379	1.533	1.584	1.748	1.925	2.115	2.622
		St. dev	0.000	0.013	0.023	0.035	0.039	0.053	0.070	0.089	0.147
300 < AREA <= 400 km ²	62	Average	1.000	1.230	1.381	1.532	1.582	1.743	1.915	2.098	2.580
		Median	1.000	1.226	1.375	1.524	1.573	1.732	1.901	2.081	2.556
		St. dev	0.000	0.010	0.018	0.026	0.029	0.038	0.049	0.061	0.096
AREA > 400 km ²	1	Average	1.000	1.251	1.420	1.592	1.649	1.835	2.036	2.253	2.838
		Median	1.000	1.251	1.420	1.592	1.649	1.835	2.036	2.253	2.838
		St. dev	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Thus for UoM 06 the aforementioned nine categories of catchment size have been reduced to five categories (hereafter called Growth Curve Groups) as presented in Table 5.11. The estimated growth curve types in each category are also presented in Table 5.11.

Table 5.11: 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 <= 300 km ²	Use median growth curve
4	300 < AREA <= 400 km ²	Use median growth curve
5	AREA > 400 km ²	Use individual growth curve

Table 5.12 presents the estimated growth factors for a range of AEPs for each of the above growth curve groups. Figure 5.14 shows the estimated growth curves (GLO) for all growth curve groups.

Table 5.12: 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	1.453	1.797	2.181	2.316	2.778	3.316	3.946	4.951	5.8705
2	10 < AREA ≤ 200 km ²	1.000	1.221 to 1.838	1.367 to 1.838	1.515 to 2.251	1.564 to 2.398	1.721 to 2.904	1.890 to 3.504	2.071 to 4.219	2.333 to 5.381	2.550 to 6.462
3	200 < AREA ≤ 300 km ²	1.000	1.228	1.379	1.533	1.584	1.748	1.925	2.115	2.392	2.622
4	300 < AREA ≤ 400 km ²	1.000	1.226	1.375	1.524	1.573	1.732	1.901	2.081	2.341	2.556
5	AREA = 750 km ²	1.000	1.251	1.420	1.592	1.649	1.835	2.036	2.253	2.571	2.838

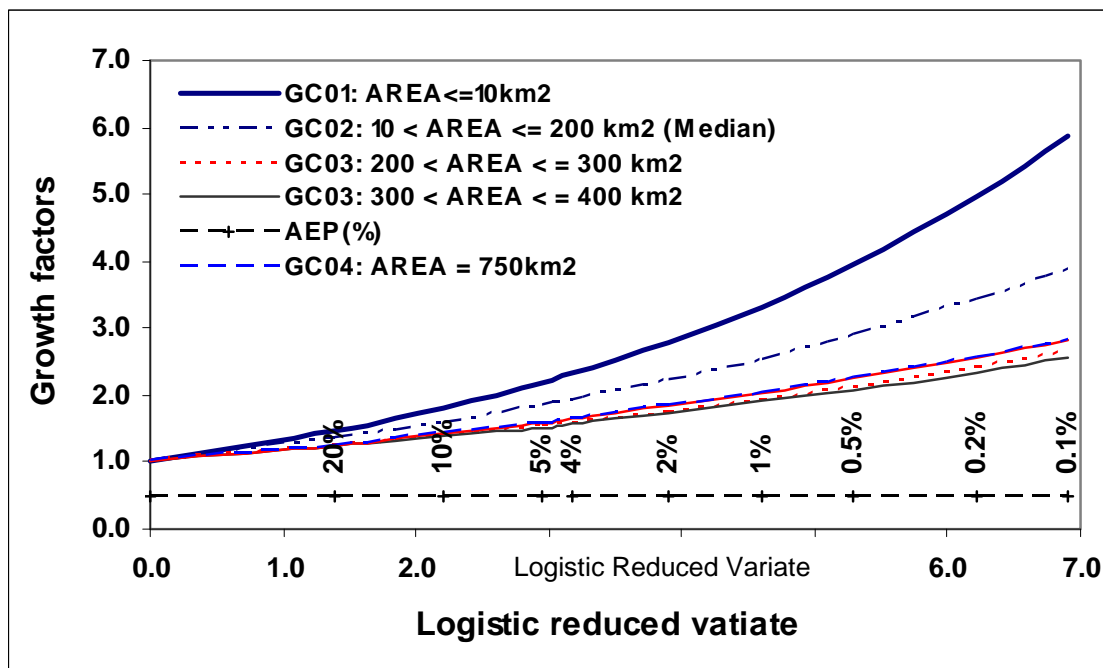


Figure 5.14: GLO growth curves for all Growth Curve Groups (5 No.)

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 5.13 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 1.901 and the associated 95% upper and lower confidence limits are 2.088 and 1.715 respectively. Figure 5.15 shows the estimated growth curve along with the 95% upper and lower confidence limits for GC Group No. 4.

Table 5.13: 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 (XT) %
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

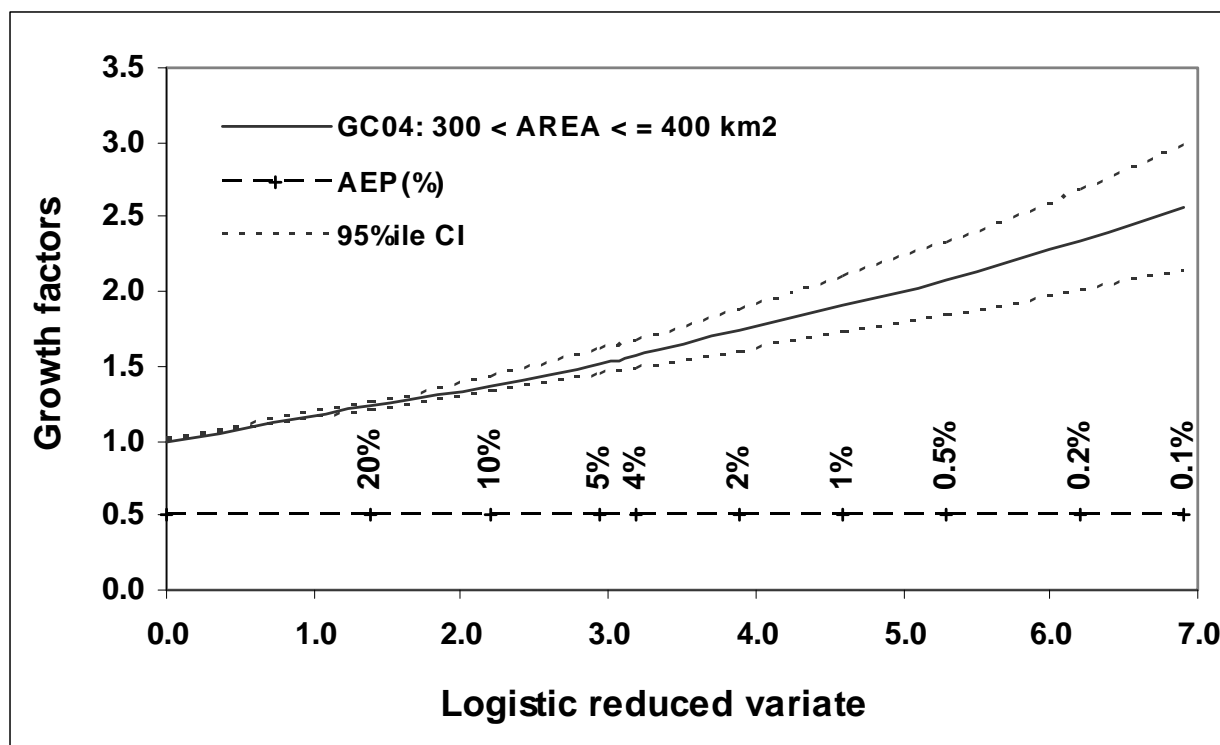


Figure 5.15: Growth Curve for GC Group No. 4 with 95% confidence limits

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 on the modelled watercourses (7 No. gauging sites) in UoM 06 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 concave downward then a two parameter distribution should be fitted to the pooled growth curve so as to avoid the upper bound.

Furthermore 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 5.14 shows the hydrometric gauges (seven gauging sites) located on the UoM 06 modelled watercourses. The estimated pooled growth curve group numbers associated with these gauges are also included therein.

Table 5.14: Hydrometric gauging stations located on the modelled watercourses in UoM 06 hydrometric area

Stations	WATERBODY	LOCATION	Growth Curve Group No.
03051	Fourmile Burn	Flume 1	GC02
06011	Fane	Moyles Mill	GC03
06013	Dee	Charleville	GC04
06014	Glyde	Tallanstown	GC03
06021	Glyde	Mansfieldstown	GC04
06025	Dee	Burley	GC02
06036	Castletown	Ladyswell	GC02

Figure 5.16 shows the comparisons of the At-site and Regional Flood Frequency (AFF and 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 were different considerably, in some cases, 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”.

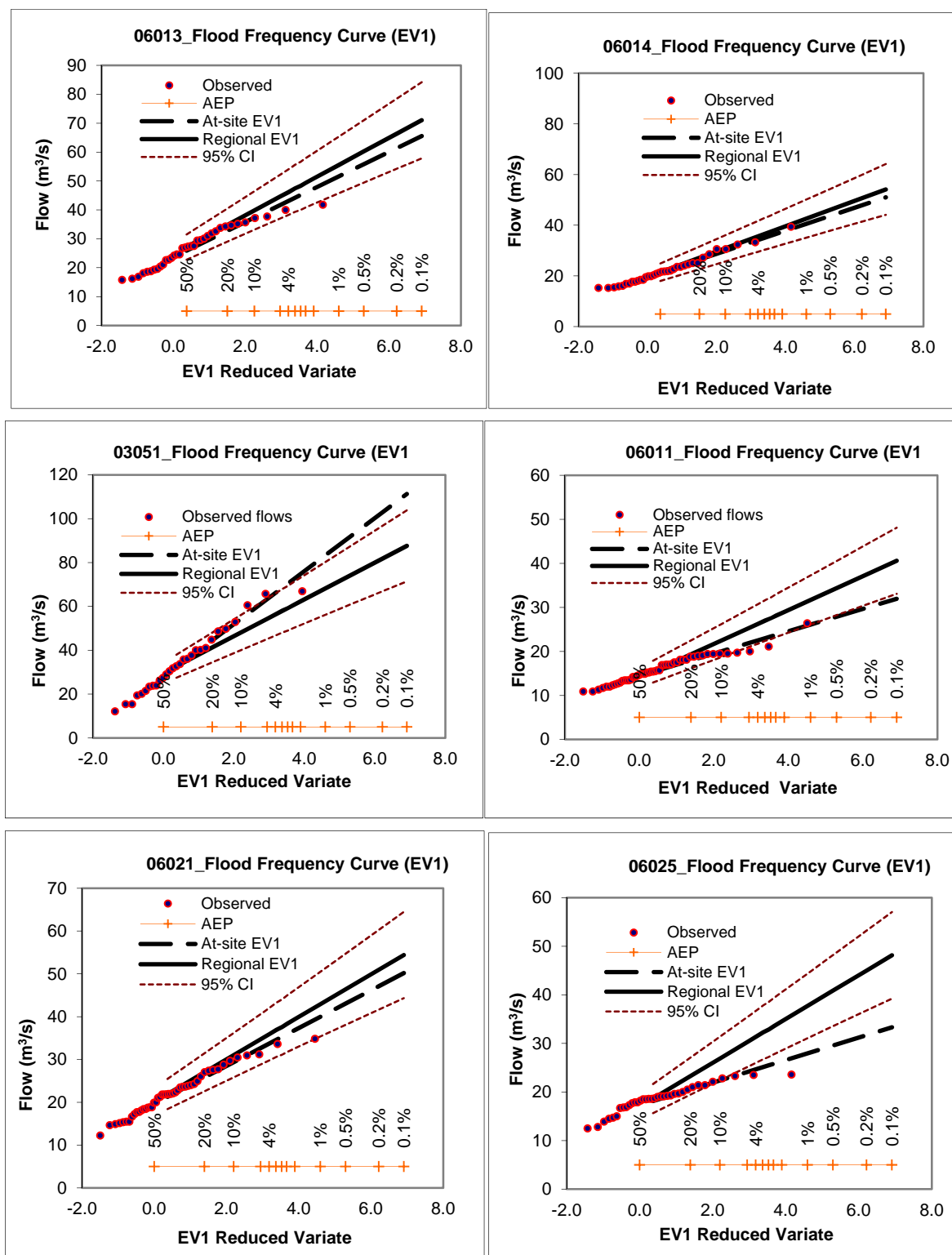


Figure 5.16: The at-site and pooled frequency curves along with the 95% confidence intervals

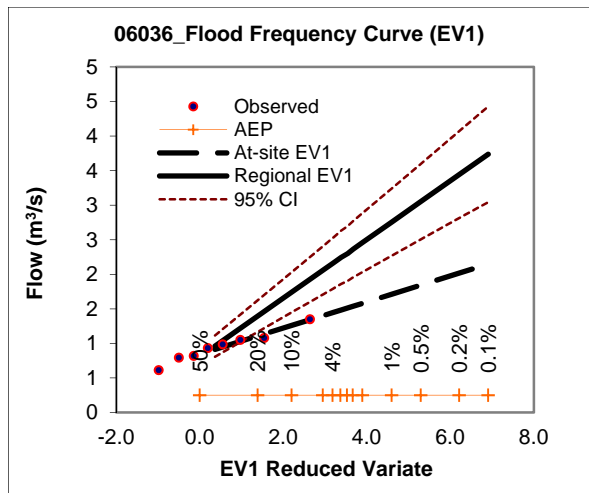


Figure 5.16 (cont'd): The at-site and pooled frequency curves along with the 95% confidence intervals

It can be seen from the above frequency curves that at one site out of seven (03051), the AFF curve is significantly steeper than the RFF curve, suggesting that the regional curve underestimates when compared with a number of observed floods at these stations. The difference is particularly marked above the 2% AEP where the AFF curve exceeds the upper 95th percentile confidence limit of the RFF curve. For the remainder of the sites the at-site growth curves fall within the 95%ile confidence limits of the estimated associated regional growth curves and as such it is not considered that adjustment is appropriate.

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.

In the Fourmile Burn River catchment at Faulkland (Hydrometric Strn.03051) more than 50% of the observed flood values plot above the RFF curve. The at-site curve has a strong case for defining the design growth curve for this station; or, this at-site growth curve might be combined with the RFF growth curve with a large weight for the at-site curve (say 0.70 for at-site + 0.3 for regional curve). However this station was only given a B classification under FSU and as such there may be significant

uncertainty in the rating at flood flows above Q_{med} and hence could result in a skewed AFF curve. It was considered prudent to include this station within the pooling groups to maximise the quantity of geographically close data while any skew in the data would likely be balanced out by the quantity of other stations. However allowing this potentially skewed series to dictate the growth curve is not considered prudent. In light of this only stations which have high confidence in the flood flow values, rated under FSU as A1 or A2, were taken forward for adjustment of the growth curve by allowing the AFF behaviour to dominate. In light of this no adjustments were applied to the UoM06 growth curves to favour at-site behaviour.

5.8.4 Growth factors for all HEPs in the UoM 06

Based on the catchment sizes associated with each of the 157 HEPs, the relevant estimated growth factors for a range of AEPs are presented in Table 5.15 overleaf.

Table 5.15: Growth factors for all 157 HEPs for a range of AEPs for UoM 06

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	06_97_2_RA	63.51	2.153	2.387	2.621	2.735	3.192	3.649	3.024	3.611	4.198
2	06_538_2_RA	12.94	3.074	3.408	3.742	4.421	5.159	5.897	5.154	6.155	7.156
3	06_911_12_RA	35.18	2.360	2.616	2.872	3.063	3.575	4.087	3.414	4.077	4.740
4	06_896_8_RA	7.18	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
5	06_893_5_RA	7.50	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
6	06_892_U_RARPS	0.65	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
7	06_892_3_RARPS	1.13	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
8	06_892_1_RA	1.15	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
9	06_892_2_RPS	0.02	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
10	06_235_3_RA	5.04	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
11	06_205_U	1.00	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
12	06_630_1_RA	2.09	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
13	06_630_U_RARPS	1.26	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
14	06_845_U_RARPS	0.51	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
15	06_845_3_RA	1.58	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
16	06_602_4_RA	158.15	1.759	1.950	2.141	2.062	2.406	2.750	2.200	2.627	3.054
17	06_76_2_RA	5.62	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
18	06_73_2_RA	19.52	2.976	3.299	3.622	4.219	4.924	5.629	4.887	5.837	6.787

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
19	06_70_3_RA	10.19	3.097	3.434	3.771	4.477	5.225	5.973	5.232	6.248	7.264
20	06_276_13_RA	18.97	2.976	3.299	3.622	4.219	4.924	5.629	4.887	5.837	6.787
21	06_603_Inter_1_RA	344.37	1.715	1.901	2.087	2.006	2.341	2.676	2.140	2.556	2.972
22	06_1100_1_RA	387.96	1.715	1.901	2.087	2.006	2.341	2.676	2.140	2.556	2.972
23	06_848_D_RARPS	749.54	1.836	2.036	2.236	2.203	2.571	2.939	2.376	2.838	3.300
24	06_745_U_RARPS	0.32	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
25	06_586_2_RA	39.51	2.621	2.906	3.191	3.518	4.105	4.692	3.976	4.749	5.522
26	06_566_5_RA	50.41	2.614	2.898	3.182	3.533	4.123	4.713	4.009	4.788	5.567
27	06_970_6_RA	168.59	1.740	1.929	2.118	2.027	2.365	2.703	2.155	2.574	2.993
28	06_8_3_RA	26.91	2.962	3.284	3.606	4.196	4.897	5.598	4.860	5.804	6.748
29	06_553_2_RA	15.70	3.117	3.456	3.795	4.523	5.278	6.033	5.294	6.322	7.350
30	06_1016_U_RA	1.43	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
31	06_DeerTrib_RARPS	0.33	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
32	06_782_6_RA	4.06	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
33	06_262_3_RA	1.24	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
34	06_262_U_RARPS	0.66	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
35	06_234_1_RARPS	0.35	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
36	06_135_3_RA	7.19	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
37	06_661_U_RARPS	0.15	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
38	06_565_3_RA	4.33	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
39	06_550_5_RA	61.42	2.531	2.806	3.081	3.389	3.955	4.521	3.830	4.574	5.318
40	06_1050_3_RA	7.98	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
41	06_175_3_RA	208.62	1.736	1.925	2.114	2.050	2.392	2.734	2.195	2.622	3.049
42	06_905_17_RA	13.42	2.898	3.213	3.528	4.064	4.743	5.422	4.686	5.596	6.506
43	06_345_U_RARPS	0.27	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
44	06_345_1_RARPS	0.41	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
45	06_997_2_RA	6.95	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
46	06_92_1_RA	6.95	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
47	06_997_3_RA	7.02	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
48	06_856_1_RA	231.50	1.736	1.925	2.114	2.050	2.392	2.734	2.195	2.622	3.049
49	06_229_4_RA	29.20	2.962	3.284	3.606	4.196	4.897	5.598	4.860	5.804	6.748

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
50	06_870_8_RA	15.76	3.121	3.460	3.799	4.515	5.269	6.023	5.278	6.303	7.328
51	06_376_5_RA	11.75	3.102	3.439	3.776	4.477	5.224	5.971	5.227	6.243	7.259
52	06_979_2_RA	9.83	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
53	06_1093_D_RARPS	338.46	1.715	1.901	2.087	2.006	2.341	2.676	2.140	2.556	2.972
54	06_315_U_RA	1.13	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
55	06_315_5_RA	2.79	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
56	06_913_U	8.21	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
57	06_913_4_RPS	9.38	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
58	06_242_4_RPS	2.78	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
59	06_242_U	0.72	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
60	06_Trib_Ddalk_U	0.07	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
61	06_Trib_Ddalk_1	0.63	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
62	06_918_U	0.22	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
63	06_1038_D	5.38	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
64	06_318_Inter	17.46	3.161	3.504	3.847	4.611	5.381	6.151	5.411	6.462	7.513
65	06_318_D	0.96	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
66	06_1089_U	0.04	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
67	06_1087_U_RA	6.04	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
68	06_600_2_RA	103.28	2.001	2.218	2.435	2.453	2.863	3.273	2.668	3.186	3.704
69	06_991_2_RA	117.17	2.094	2.322	2.550	2.617	3.054	3.491	2.869	3.427	3.985
70	06_1084_1_RA	222.04	1.736	1.925	2.114	2.050	2.392	2.734	2.195	2.622	3.049
71	06_1055_U	0.10	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
72	06_1055_2_RA	2.31	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
73	06_1087_13_RA	7.43	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
74	06_1089_4_RA	2.70	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
75	06_DDalk_D_RARPS	239.30	1.736	1.925	2.114	2.050	2.392	2.734	2.195	2.622	3.049
76	06_1058_2_RA	2.08	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
77	06_1081_D_RA	10.43	3.047	3.378	3.709	4.365	5.094	5.823	5.080	6.067	7.054
78	06_1054_1_RA	1.36	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
79	06_1078_3_RA	5.50	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
80	06_311_U	0.34	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826

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
81	06_311_D	0.91	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
82	06_446_U	0.36	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
83	06_515_U	0.89	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
84	06_847_2	1.16	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
85	06_908_2	2.65	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
86	06_227_U	1.37	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
87	06_227_D	1.69	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
88	06_290_1_RPS	2.15	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
89	06_1075_2_RPS	3.04	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
90	03_296_1_U	1.00	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
91	03_341_1_RA	1.96	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
92	03_341_Trib_RA	3.20	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
93	03_297_7_RA	7.02	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
94	03_235_U_RARPS	0.23	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
95	03_450_1_RA	3.52	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
96	03_451_4_RA	2.13	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
97	03_451_1_RARPS	0.10	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
98	03_315_U_RARPS	0.07	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
99	03_315_Trb_RARPS	0.54	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
100	03_479_5_RA	9.87	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
101	03_113_3_RA	1.88	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
102	03_113_5_RA	2.13	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
103	03_474_4_RA	2.59	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
104	03_474_6_RA	3.00	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
105	03_344_U_RARPS	0.33	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
106	03_184_4_RA	7.14	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
107	03_373_5_RA	29.07	2.505	2.777	3.049	3.341	3.899	4.457	3.770	4.503	5.236
108	03_179_2_RA	44.03	2.369	2.626	2.883	3.083	3.598	4.113	3.440	4.108	4.776
109	03_114_3_RA	74.50	1.968	2.182	2.396	2.465	2.876	3.287	2.712	3.239	3.766
110	03_344_Int_RARPS	1.01	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
111	03_344_Trib_RARPS	0.13	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826

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
112	03_344_1_RA	1.62	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
113	03_235_2_RA	1.17	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
114	03_399_D_RA	275.11	1.736	1.925	2.114	2.050	2.392	2.734	2.195	2.622	3.049
115	06_305_D_RARPS	28.48	3.143	3.484	3.825	4.568	5.331	6.094	5.351	6.391	7.431
116	06_1048_1_RA	23.27	3.143	3.484	3.825	4.568	5.331	6.094	5.351	6.391	7.431
117	03054_RA	9.84	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
118	06016_RA	259.88	1.736	1.925	2.114	2.050	2.392	2.734	2.195	2.622	3.049
119	06021_RA	344.81	1.715	1.901	2.087	2.006	2.341	2.676	2.140	2.556	2.972
120	06023_RA	302.77	1.715	1.901	2.087	2.006	2.341	2.676	2.140	2.556	2.972
121	06032_RA	221.73	1.736	1.925	2.114	2.050	2.392	2.734	2.195	2.622	3.049
122	06035_RA	301.64	1.715	1.901	2.087	2.006	2.341	2.676	2.140	2.556	2.972
123	06036_RPS	17.39	3.161	3.504	3.847	4.611	5.381	6.151	5.411	6.462	7.513
124	06037_RA	25.56	3.143	3.484	3.825	4.568	5.331	6.094	5.351	6.391	7.431
125	06038_RA	10.17	2.973	3.296	3.619	4.212	4.915	5.618	4.877	5.824	6.771
126	06052_RA	357.04	1.715	1.901	2.087	2.006	2.341	2.676	2.140	2.556	2.972
127	06057_RA	29.13	2.962	3.284	3.606	4.196	4.897	5.598	4.860	5.804	6.748
128	03051_RA	142.97	1.947	2.159	2.371	2.420	2.824	3.228	2.653	3.168	3.683
129	06025_RA	173.28	1.740	1.929	2.118	2.027	2.365	2.703	2.155	2.574	2.993
130	06014_RA	270.70	1.736	1.925	2.114	2.050	2.392	2.734	2.195	2.622	3.049
131	06013_RA	307.98	1.715	1.901	2.087	2.006	2.341	2.676	2.140	2.556	2.972
132	06011_RA	208.62	1.736	1.925	2.114	2.050	2.392	2.734	2.195	2.622	3.049
133	03_425b_Inter_RA	257.31	1.736	1.925	2.114	2.050	2.392	2.734	2.195	2.622	3.049
134	03_334_12_RA	146.78	1.895	2.101	2.307	2.319	2.706	3.093	2.524	3.014	3.504
135	06_856_5_RA	237.48	1.736	1.925	2.114	2.050	2.392	2.734	2.195	2.622	3.049
136	06_100_2_RA	88.54	2.071	2.296	2.521	2.588	3.020	3.452	2.839	3.391	3.943
137	06_571_4_RA	267.60	1.736	1.925	2.114	2.050	2.392	2.734	2.195	2.622	3.049
138	06_1097_2_RA	350.88	1.715	1.901	2.087	2.006	2.341	2.676	2.140	2.556	2.972
139	06_1099_8_RA	383.38	1.715	1.901	2.087	2.006	2.341	2.676	2.140	2.556	2.972
140	06_65_3_RA	296.19	1.736	1.925	2.114	2.050	2.392	2.734	2.195	2.622	3.049
141	06_918_1	0.53	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
142	06_147_U	0.03	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826

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
143	06_147_4_RPS	2.15	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
149	06_439_Inter1	15.10	3.117	3.456	3.795	4.523	5.278	6.033	5.294	6.322	7.350
150	06_439_Inter2	14.47	3.161	3.504	3.847	4.611	5.381	6.151	5.411	6.462	7.513
151	06_147_Inter6	5.50	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
152	06_438_Inter1	14.13	3.161	3.504	3.847	4.611	5.381	6.151	5.411	6.462	7.513
153	06_600_4_RA	104.08	2.001	2.218	2.435	2.453	2.863	3.273	2.668	3.186	3.704
154	06_302_5_RARPS	0.82	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
155	06_302_2_RARPS	0.23	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
156	03_469_Trib_RARPS	0.58	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826
157	03_469_U_RARPS	0.32	2.991	3.316	3.641	4.243	4.951	5.659	4.915	5.871	6.826

The design flood flows for any required AEP will 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 will be 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} will be estimated from the FSU and IH 124 recommended catchment descriptors based methodologies 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 mis-specification 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 climate change on the growth curves are expected to be covered within this factor as growth curves when applied to the factored median event will result in scaled design events. Inclusion of a climate change factor within growth curves also could lead to a double application of a climate change factor and lead to a squaring of the climate change effect.

5.9 COMPARISON WITH FSR AND FEM FRAM GROWTH FACTORS

A comparison of the estimated growth factors within UoM 06 was carried out with the FSR and Fingal East Meath Flood Risk Assessment and Management Study (FEM-FRAM) as can be seen in Table 5.17. All growth curves were indexed to the median annual maximum flows (Q_{med}).

Table 5.17: Study growth factors compared with FSR and FEM FRAM growth factors

AEP (%)	50%	20%	10%	4%	2%	1%	0.5%	0.2%	0.1%
UoM 06	1.000	1226 to 1.472	1.375 to 1.838	1.573 to 2.398	1.732 to 2.904	1.901 to 3.504	2.081 to 4.219	2.341 to 5.381	2.556 to 6.462
Average of UoM 06	1.000	1.405	1.707	2.157	2.553	3.012	3.546	4.391	5.160
FSR	1.000	1.260	1.450	1.630	1.870	2.060	2.250	2.620	2.750
FEM-FRAMS	1.000	1.520	1.890	2.380	2.760	3.160	3.570	-	4.600

Table 5.17 indicates that the study area growth factors (average values) are higher than the FSR growth factors and slightly lower than the FEM-FRAM growth factors at most AEPs. These differences in growth factors for the UoM 06 watercourses can be attributed to the Region of Influence Approach to pooling and the development of growth curves for individual catchments including a high number representing small upland and tributary catchments affecting the AFAs. In relation to FEM-FRAM growth factors the small tributary catchments in UoM 06 can be show to have similar growth factors reflecting the similar nature of the small eastern catchments common to both studies. However the presence of much larger catchments in UoM 06 leads to the presence of much flatter growth curves which are not present within the FEM-FRAM Study catchment, i.e. there would be no catchments within the FEM-FRAM Study area that would fall within the final UoM 06 Growth Curve group numbers of 3 – 5. The approach taken in developing individual growth curves to capture differing frequency conditions across the Unit of Management can be considered to be a more refined approach to growth curve development than the application of one growth curve across the study as per FSR.

5.10 GROWTH CURVE DEVELOPMENT SUMMARY

Growth curves for all HEPs were calculated 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 104 hydrometric stations located in the Eastern, South Eastern and North Eastern Regions of Ireland were pooled for estimating the pooled growth curves for 157 HEPs. The selection of the 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 when compared to UoM 06 data and therefore was chosen as the growth curve distribution for all HEPs in UoM 06.

Initially, growth curves for each of the 157 HEPs in UoM 06 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 in rate is larger for the catchment areas less than 100 km² and also for the larger AEP growth factors. For any catchment areas greater than 200 km² growth factors do not change appreciably with the increase in catchment sizes. Based on this the following 5 generalised growth curve groups were recommended for the subject rivers catchments in UoM 06:

1. GC group No. 1: AREA < 10 km²
2. GC group No. 2: 10 < AREA ≤ 200 km²
3. GC group No. 3: 200 < AREA ≤ 300 km²
4. GC group No. 4: 300 < AREA ≤ 400 km²
5. GC group No. 5: AREA = 750 km²

It was recommended 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 individual growth curve estimation process. For the remaining categories the median growth curves will be used. For all HEPs with catchment areas less than 10km², it is recommended to use the estimated median growth factors associated with Growth Curve Group No. 1.

The estimated 1% AEP growth factors for UoM 06 vary from 1.901 to 3.504 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

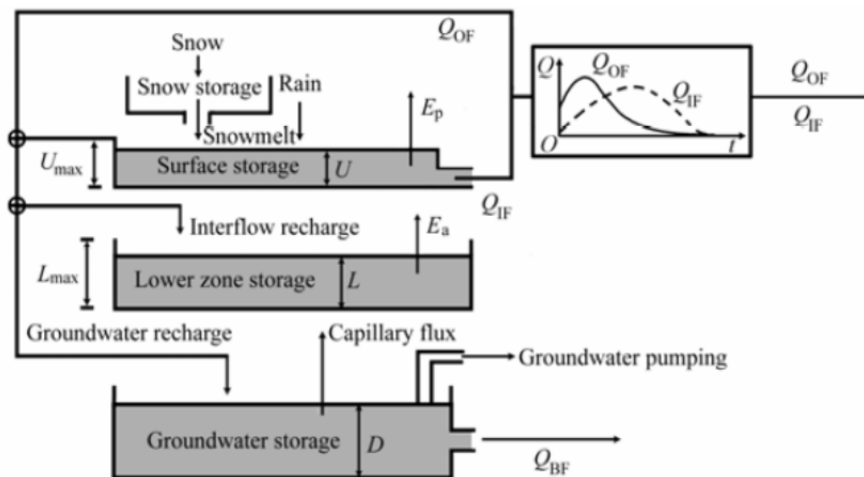
Following estimation of the Index Flood Flow (Q_{med}) and growth factors for each HEP it is possible to estimate the peak design flows for a range of Annual Exceedance Probabilities (AEPs). In addition to the total design flows estimated for each HEP, lateral inflows must be generated to represent the flow from the lateral catchment between HEPs. Catchment descriptors do not exist for the lateral inflow catchments within FSU and these have not been derived as part of this Study. The RPS methodology involves using the catchment descriptors of the total catchment at the downstream HEP with the area replaced by the difference in area between the upstream and downstream nodes / HEPs to derive an estimate of the lateral inflow Q_{med} based on FSU WP 2.3. In some instances where it is obvious that the catchment descriptors of the total catchment are not representative of the lateral / top-up catchment (particularly URBEXT and FARL) these have been adjusted based on orthophotography / Corine datasets. These will be reviewed as required during the hydraulic analysis stage as part of a hierarchical approach to ensuring the correct frequency conditions are achieved (i.e. the total flow in the model at each intermediate / gauging station / downstream limit HEP is correct) as we move down through the modelled catchment.

All of the design flows which will be used for hydraulic modelling input are detailed in Appendix C. 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 for UoM 06 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 one rainfall run-off modelling point based on guidance within FSU WP 3.1 'Hydrograph Width Analysis'.
2. FSU Hydrograph Shape generation tool (developed from FSU WP 3.1) for all HEPs representing catchments more than 10 km².
3. FSSR 16 Unit Hydrograph method for catchment less than 10 km² where no suitable pivotal site is available.

6.1.1 Rainfall Run-off (NAM) Modelling and HWA

This method was undertaken in one instance in UoM 06 – at hydrometric station 03051 (Faulkland) on the Monaghan Blackwater within Model 1 (Monaghan) (refer to Section 4.1). The hydrograph output was then used as a pivotal shape for appropriate inflow HEPs within the model. There are two processes involved in this 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 was 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 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 HEP node (03051) for the Monaghan model (model no. 1) is shown in Figure 6.2.

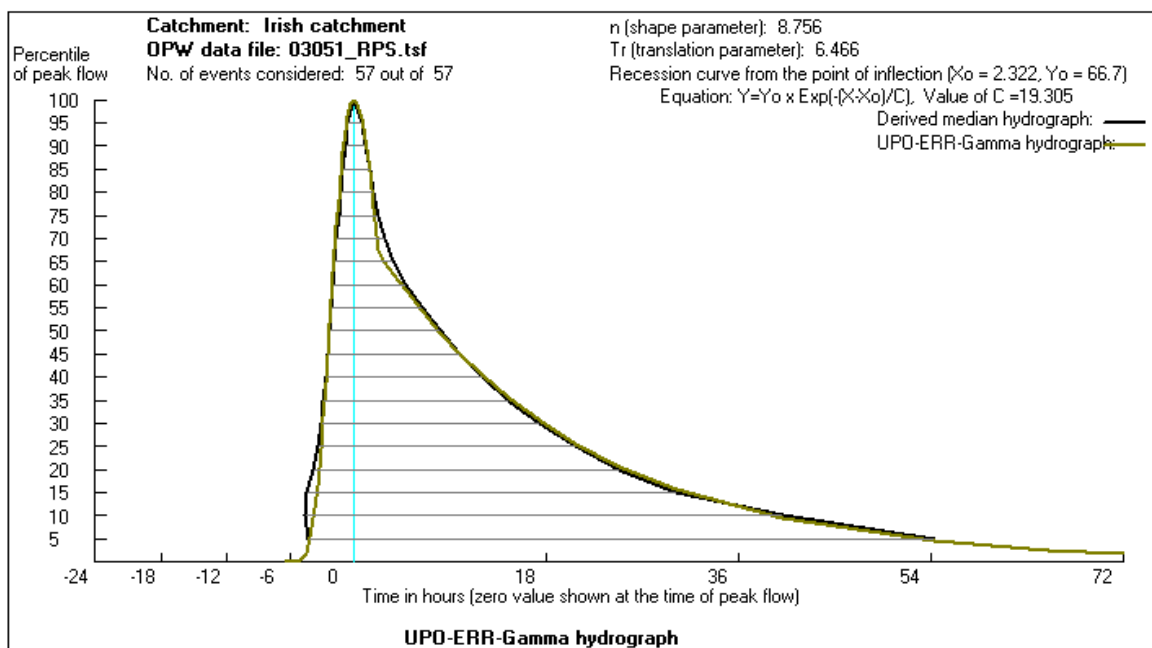


Figure 6.2: Median Semi-dimensionless Hydrograph with Fitted Gamma Curve

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 baseflow 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.

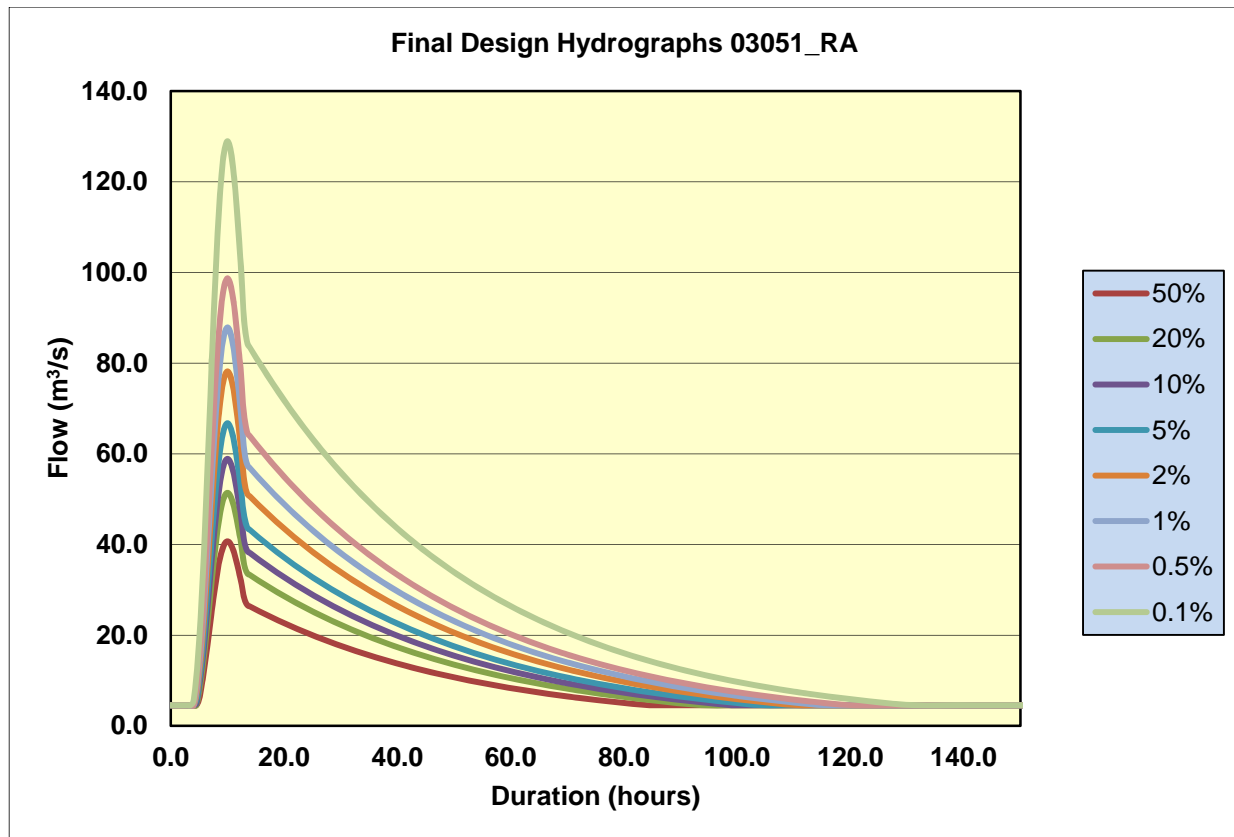


Figure 6.3: Design Flow Hydrographs for Faulkland Hydrometric Station HEP Node 03051_RA

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 represent catchments larger than 10 km² 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.

An example is shown in Figure 6.1 for the HEP 06_970_6_RA upstream of Ardee on the Dee River and representing a catchment of 169 km². The hydrograph shape parameters have been adjusted based on the most hydrologically similar (and geographically closest) pivotal site, Burley on the Swilly (06025) which is located almost 3km downstream with a catchment area of 176 km².

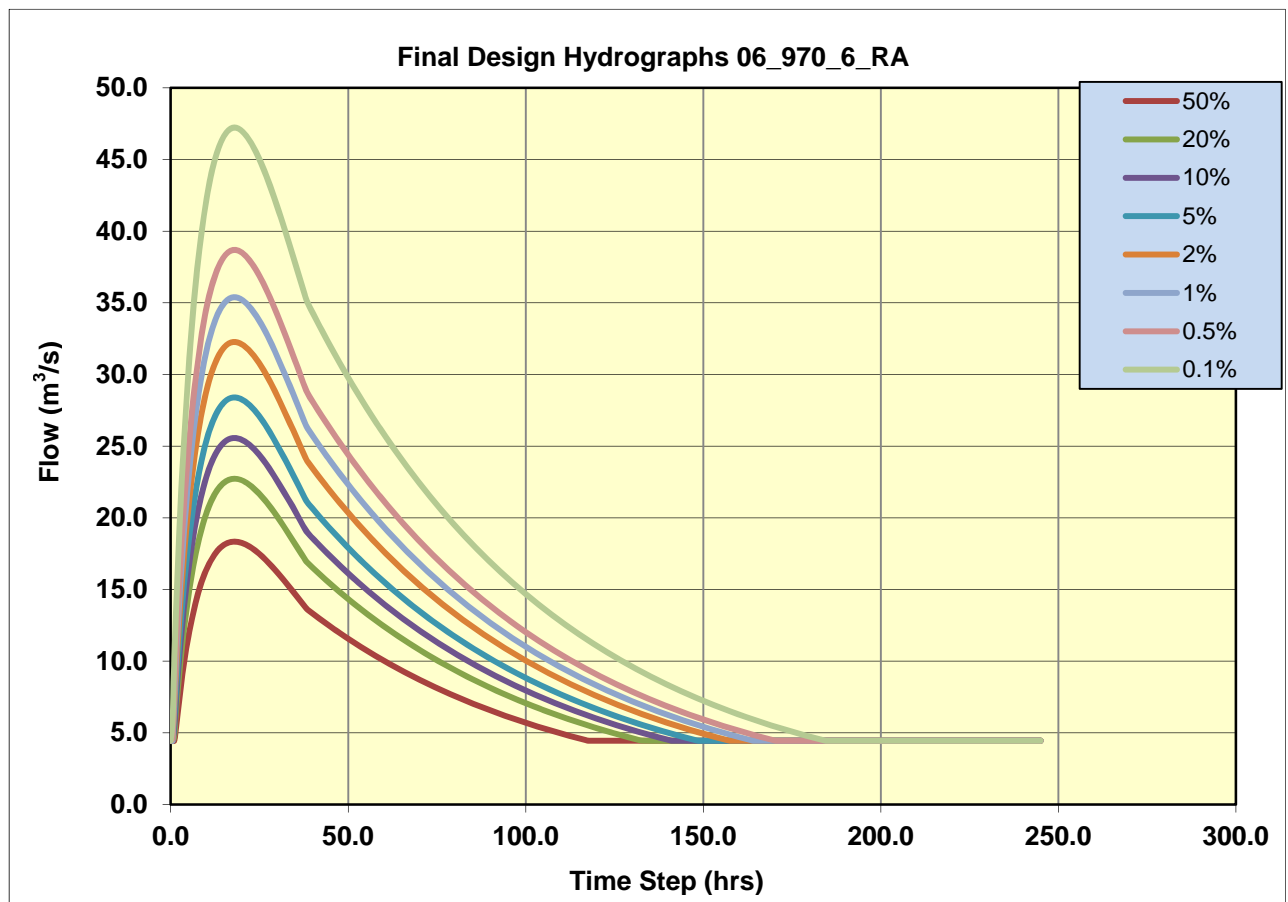


Figure 6.4: Various AEP Hydrographs for Upstream HEP on Dee River (06_970_6_RA)

6.1.3 FSSR 16 Unit Hydrograph Method

Early testing of the FSU Hydrograph Shape Generator tool found that for smaller catchments the shape that was derived appeared to be unrealistically long for some of the smaller catchments when compared to the available observed / simulated flow data for small sites. It is thought that this is as a result of a lack of pivotal sites within the library representing small catchments with only two pivotal sites representing a catchment area of less than 25 km² included (with shape parameters identified). Based on this experience it was found that below 10km² it was difficult to obtain a suitable pivotal site such that the duration of the hydrograph was not significantly overestimated and therefore for catchments less than 10km² (but not limited to) an alternative but tried and tested methodology is used to derive the

hydrograph. 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. The methodology followed to derive the FSSR 16 semi dimensionless hydrograph for a subject catchment is summarised below:

1. Time to Peak of the 1 hour unit hydrograph estimated from FSU PCDs (area, MSL, S1085, SAAR & URBEXT) and adjusted for time step
2. The design storm duration is estimated as a function of SAAR and the estimated time to peak
3. An areal reduction factor is calculated as a function of design storm duration and catchment area.
4. Catchment Wetness Index is calculated as a function of SAAR.
5. A soil index is calculated using on FSR Winter Rain Acceptance Potential soil mapping
6. The Standard Percentage Runoff (SPR) is calculated as a function of the soil types within the subject catchment
7. Rainfall characteristics for the subject catchment are derived from FSU DDF gridded outputs (M5-2D & M5-25D) and FSR maps (Jenkinson's Ratio r)

The outputs from steps 2 to 7 are input to the ISIS FSSR 16 boundary unit module to produce a semi dimensionless hydrograph (fitted to a peak of 1) based on Unit Hydrograph principles which can then be scaled to the various design peak flows

6.2 COASTAL HYDROLOGY

Analysis of the hydrological elements which contribute to coastal flood risk has been undertaken at a national level through the Irish Coastal Protection Strategy Study (ICPSS) and the Irish Coastal Wave and Water level Study (ICWWS). This study does not seek to re-analyse these elements of coastal flood risk but rather seeks to combine them, along with the fluvial elements where applicable, such that the total combined fluvial and coastal flood risk is assessed on an AFA by AFA basis. None of the AFAs / HPWs identified as at coastal flood risk in UoM 06 experience only coastal flood risk, i.e. they all experience combined coastal / fluvial flood risk.

6.2.1 ICPSS Levels

Outputs from the Irish Coastal Protection Strategy Study have resulted in extreme tidal and storm surge water levels being made available around the Irish Coast for a range of Annual Exceedance Probabilities (AEPs). The location of ICPSS nodes are shown in Figure 6.5. There are a number of coastal AFAs and a number of additional High Priority Watercourses (HPWs) which are to be considered for the full range of coastal flood risk scenarios.

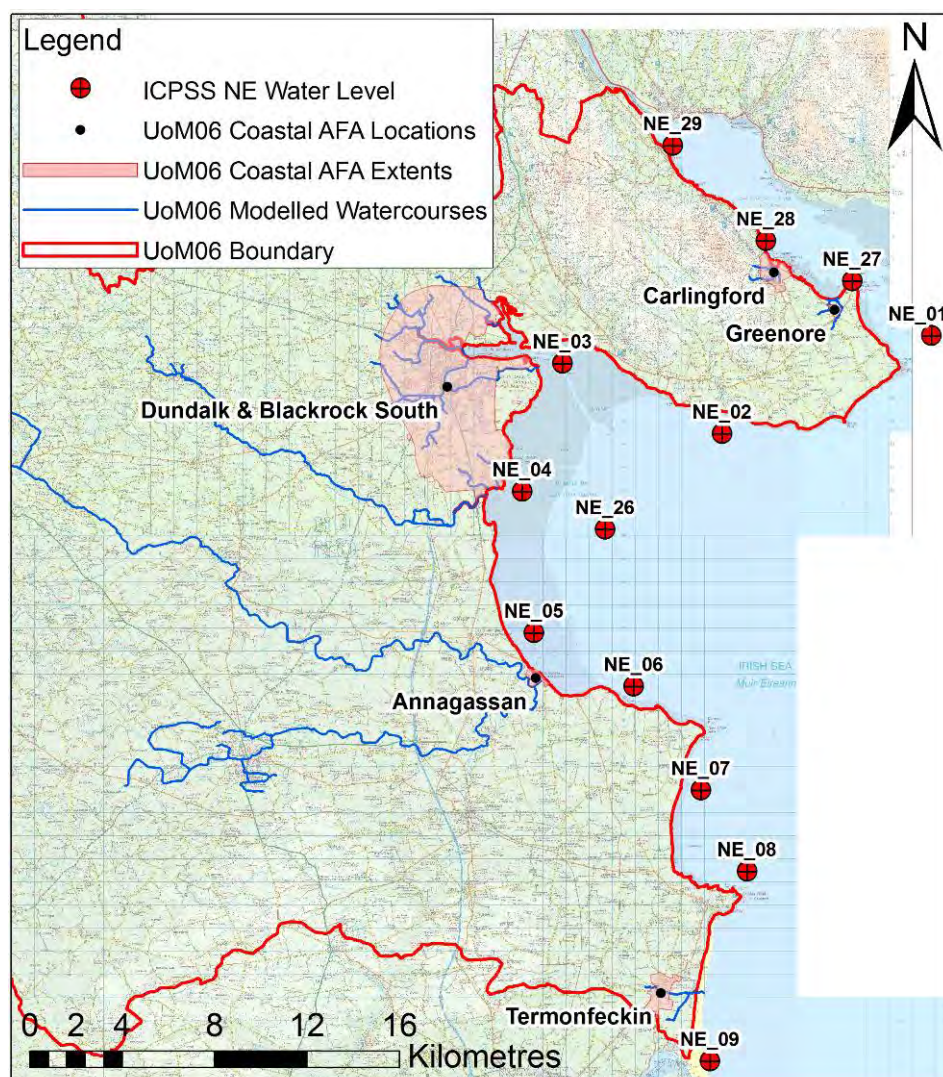


Figure 6.5: Location of ICPSS Nodes in Relation to Coastal AFAs

Levels for a range of AEPs have been extracted from the ICPSS and are shown in Table 6.1.

Table 6.1: ICPSS Level in Close Proximity to UoM 06 AFAs

ICPSS Node	AFA / HPW	Annual Exceedance Probability (AEP) %							
		2	5	10	20	50	100	200	1000
		Highest Tidal Water Level to OD Malin (m)							
NE03	Dundalk	3.08	3.21	3.31	3.40	3.53	3.62	3.72	3.94
NE04	Blackrock South	3.04	3.17	3.27	3.37	3.50	3.60	3.70	3.93
NE05	Annagassan	3.01	3.14	3.25	3.35	3.48	3.58	3.69	3.92

ICPSS Node	AFA / HPW	Annual Exceedance Probability (AEP) %							
		2	5	10	20	50	100	200	1000
		Highest Tidal Water Level to OD Malin (m)							
NE09	Termonfeckin	2.88	3.00	3.09	3.18	3.30	3.39	3.48	3.69
NE27	Greenore	3.10	3.23	3.33	3.42	3.55	3.65	3.75	3.97
NE28	Carlingford	3.14	3.26	3.36	3.45	3.58	3.68	3.77	3.99

(Extract from: Irish Coastal Protection Strategy Study, Phase 5 – North West Coast, Work Packages 2, 3 & 4A)

6.2.2 ICWWS Levels

The Irish Coastal Wave and Water level Study (ICWWS) is being progressed by OPW in order to consider the potential risk associated with wave overtopping at exposed coastal locations. The study is currently ongoing but preliminary analysis has been made available for the NW-NB CFRAM Study to identify the areas within UoM 06 which have been identified as potentially vulnerable to this flood mechanism. The length of vulnerable coastline and the affected AFAs are shown in Figure 6.6.

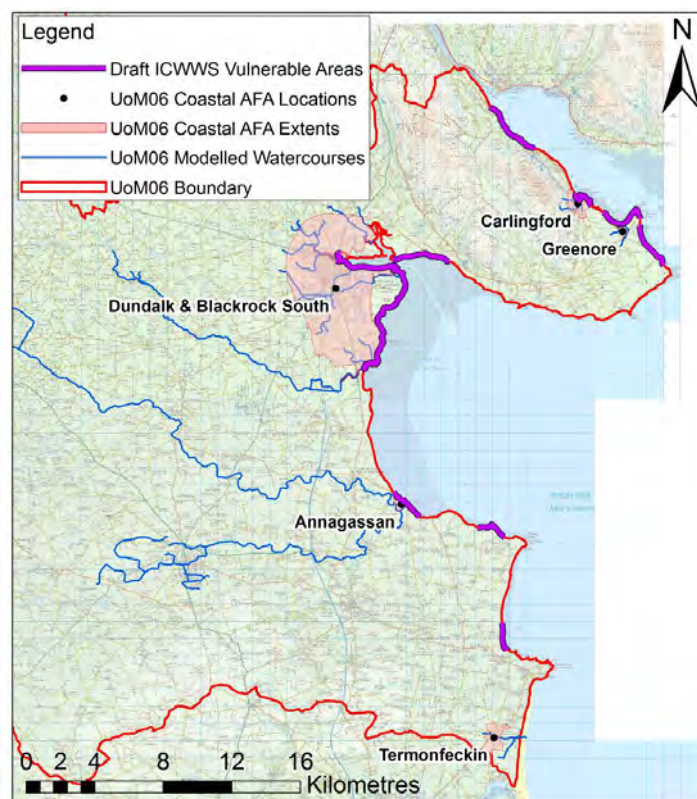


Figure 6.6: Draft ICWWS potential areas of vulnerable coastline

As shown in Figure 6.6, four AFAs are potentially vulnerable to flooding due to wave overtopping. These are Carlingford, Greenore, Dundalk & Blackrock South and Annagassan. The study outputs will be in the form of a range of combinations of water level and wave characteristics (wave height, period, frequency and the joint probability assessed extreme water level) for each annual exceedance probability (AEP %).

6.2.3 Consideration of ICPSS and ICWWS Outputs

It is important to note that the outputs from both the ICPSS and the ICWWS are to be considered separately. Tidal boundaries will be applied within the 2D models at a scale and distance necessary to capture the complete effects of a dynamic tide and the propagation effects e.g. at Dundalk Bay and up the Castletown River. At all AFAs where coastal and fluvial flooding has been identified as a consideration within the model the ICPSS levels will be applied considering a range of joint probability scenarios (as detailed in 6.3.2) in order to determine the most onerous flood outline for any AEP. The levels which have been derived from the ICPSS will be applied within the 2D portion of the hydraulic (hydrodynamic) models. All ICPSS levels will be applied as the maximum level on the oscillating average tidal cycle observed at the nearest tidal gauge with the surge applied over 48 hours. A typical 1% AEP surge on tidal cycle to staff gauge zero is shown in Figure 6.7 below. Bathymetric and cross sectional survey has been undertaken within the tidal reaches of coastal models in order to accurately capture the effects of tidal propagation within the estuaries and into the tidal reaches of the watercourses where relevant. Details on the model specific application of the ICPSS levels at the coastal boundaries will be contained within the subsequent Hydraulic Modelling report.

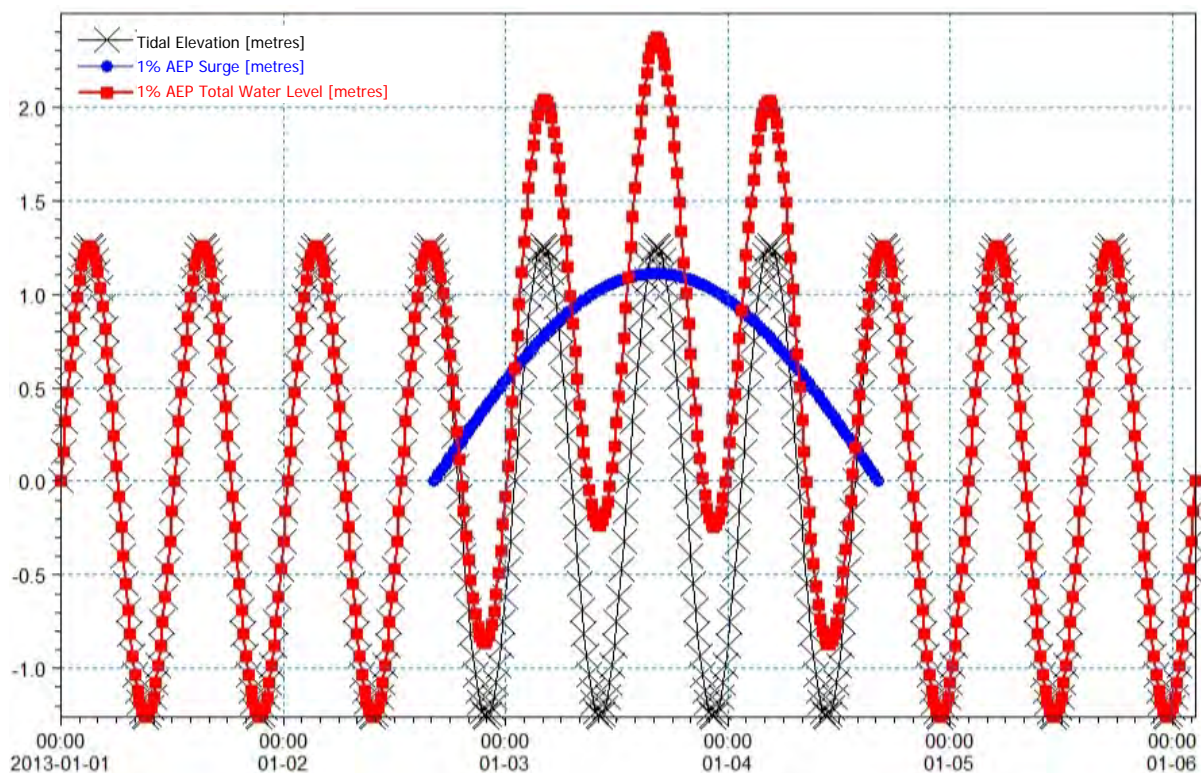


Figure 6.7: Typical 1% AEP Coastal Boundary Makeup (to Staff Gauge Zero)

It is important to note that the outputs from the ICWWS are not directly applicable through the standard 2D hydraulic modelling packages used for coastal flood modelling. The assessment of the volume of flood water from wave overtopping is a function of the outputs from the ICWWS (wave height, period, frequency and the joint probability assessed extreme water level), the duration of the event and the dimensions and hydraulic performance of the sea defence and foreshore. At each of the AFAs that have been identified as vulnerable to wave overtopping, preliminary analysis will identify the location and length of sea defence / frontage which is vulnerable to wave overtopping. This section will then be assessed against the range of wave / extreme water level combinations for each annual exceedance probability (AEP %) to determine the most onerous scenario. The total overtopping volume from the most onerous scenario for each AEP will then be assessed against the digital terrain model (LiDAR based) to ascertain the mapped flood extents, depth and hazard behind the sea defence / frontage within the AFA. Further details of the methodology for assessment and modelling of the wave overtopping flood risk will be contained within the Hydraulic modelling report.

6.3 JOINT PROBABILITY

Joint probability is a consideration within UoM 06 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 the modelled watercourses where tidal – fluvial events become a consideration such as within Dundalk Bay and the tidal reaches of the River Glyde.

6.3.1 Fluvial – Fluvial

There are some significant watercourse confluence points on the major rivers to be modelled within UoM 06, namely where the River Glyde meets the River Dee, where the Lagan River meets the River Glyde and where the White River meets the River Dee. At these confluence points consideration must be given to the probability of coincidence of flood flows within the model. This is less of a concern on models representing smaller catchments such as those around Dundalk where the critical storm in the confluent sub-catchments is likely to be similar. Where fluvial to fluvial joint probability is likely to be a significant consideration is at confluence points where two catchments with remote catchment centroids meet or where it is apparent that two catchments may have very different response times. Where a small tributary enters a much larger river system such that the increase in flow in the main channel is small the consideration of joint probability is unlikely to be significant.

The only model where fluvial to fluvial joint probability is likely to be a significant consideration is at Annagassan where the major confluence between the Glyde and the Dee lies just upstream. The combined effect and likelihood of flood flows in both Rivers has not been directly observed as the only gauge stations are located upstream of the confluence point. A review of the AMAX series records for both the FSU A1 rated gauges on the Glyde River (06014 – OPW) and the Dee River (06013 – OPW) shows that the maximum flow in each year was the same event for 17 out of the 30 years of concurrent

data and in each series the event which caused the maximum flow on record (approximate AEP of 2%) caused the 2nd highest on record (approximate AEP of 5%) in the other catchment. In all of the 17 events which caused the peak event in each year in both catchments the catchment response was quicker in the Dee by approximately 1.5 days. The data suggests that the level of dependence between both catchments is high as would be expected in two neighbouring, similar sized catchments. If we consider the guidance provided in Table 13-1 of WP 3.4 'Guidance for River Basin Modelling' which considers dependence between two catchments based on catchment descriptors, both of the catchments would fall within the highest dependence bracket, having centroids within 25km, ratio of area of approximately 1.15, difference of FARL values of 0.03 and a difference in BFI gauged soil values of less than 0.02. Both data and catchment descriptors point to a high level of dependence between both catchments and as such it is considered appropriate to apply the same frequency conditions in both branches of the model.

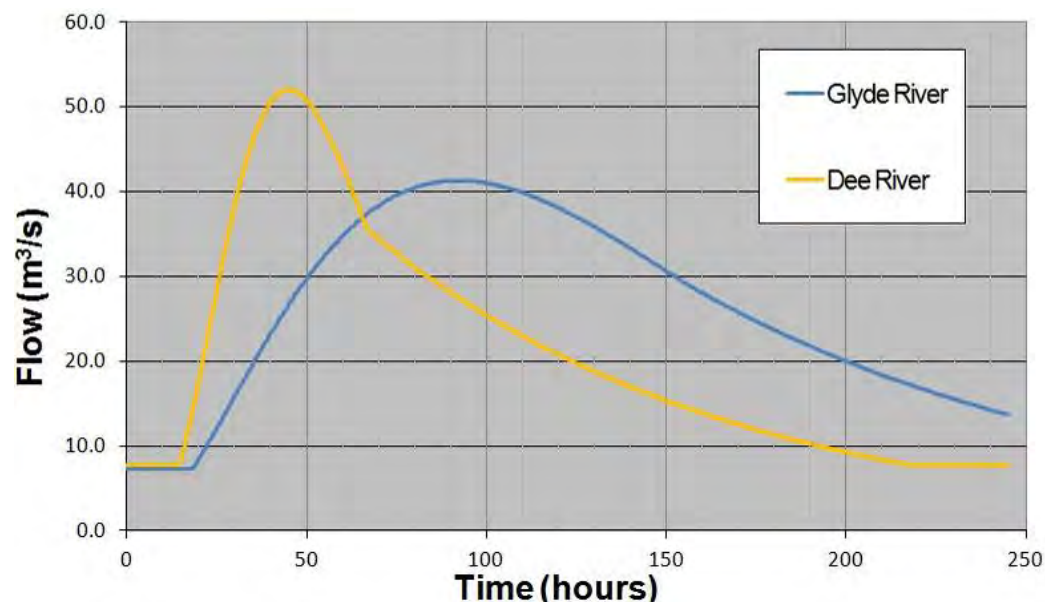


Figure 6.8: 1% AEP Hydrographs on River's Glyde and Dee for Model 8 (Annagassan)

As shown in Figure 6.8, due to the timing of both hydrographs which are derived from FSU Hydrograph Width Analysis on the observed data at the aforementioned gauging stations, the peaks of the design hydrographs in both catchments occur approximately 2 days apart and as such will not meet at Annagassan peak on peak. It is difficult to say why this is the case but it may be due to small variances in the catchment characteristics which particularly impact hydrograph time to peak (such as alluvium or arterial drainage). It may also be affected by the prevailing weather conditions in relation to the geographical placement of each catchment.

To account for fluvial joint probability in the remainder of less significant confluence points RPS has specified a high number of HEPs such 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.

6.3.2 Fluvial – Coastal

In terms of UoM 06, this category of joint probability may be relevant to all the AFAs which have significant areas at risk from fluvial flooding which are also within tidally influenced river reaches i.e. Dundalk & Blackrock South, Carlingford, Greenore, Annagassan and Termonfeckin. The RPS methodology for assessing joint probability for coastal and fluvial flooding is outlined in the CFRAM Study technical note '*NTCG GN20 Joint Probability Guidance (RPS, June 2013)*'. It advocates a stepped approach to the consideration of fluvial coastal joint probability whereby the relevance is assessed to ascertain at which sites dependence may exist and further analysis is needed:

The first stage in any Joint Probability analysis should be to ascertain whether the flooding mechanisms in any particular area, either AFA or MPW, actually warrant the consideration of the joint probability of occurrence. This screening stage should involve a review of all existing information on flooding within the area of interest, such as records of historic events or previous studies including the output from the CFRAM PFRA and the complementary ICPSS data. Where this review identifies either a significant overlap in the areas of fluvial and tidal flood risk or a proven history of significant flooding from both sources, joint probability should be considered. Where the flooding mechanism is heavily dominated by one particular source it is questionable whether joint probability analysis is justified.

An initial screening process has been undertaken on all of the coastal / fluvial models within UoM 06 where joint probability could potentially be a significant consideration (excluding previous studies). The results of this screening are shown in Table 6.2.

Table 6.2: Initial Screening for Relevance of Joint Probability

Model No.	AFA Name	Evidence / History of Joint Occurrence	Comments	Further JP Analysis
2	Carlingford	Yes	Village generally on higher ground and watercourses relatively steep. Nevertheless significant overlap within AFA extents	Yes

Model No.	AFA Name	Evidence / History of Joint Occurrence	Comments	Further JP Analysis
3	Greenore	No	Village on relatively low lying land and some overlap of flood extents.	Yes
4	Dundalk & Blackrock South	Yes	Large overlap between PFRA and ICPSS flood extents within the AFA extents.	Yes
8	Annagassan	Yes	Large overlap between PFRA and ICPSS flood extents within the AFA extents.	Yes
9	Termonfeckin	No	AFA extents are inland and above the 0.1% ICPSS flood level. Golf course floods but outside AFA extents.	No

Following initial screening one model (Termonfeckin) was removed from the consideration of joint probability of fluvial and coastal flood events. This is not to say there is no evidence of a tidal influence at this location but rather that there is no known evidence of joint fluvial and coastal flood occurrence and that there are no low lying areas on the lower reaches that would be particularly sensitive to such a joint occurrence, over and above a fluvially or tidally dominant event in isolation. For each of these models suitable conservative tidal downstream boundary conditions will be applied which are relatively conservative such as the highest astronomical tide, oscillating such that there is coincidence between peak tide and hydrograph. It is not thought this will lead to unrealistic downstream flood extents as there is no overlap of the most extreme 0.1% AEP events, when considering the PFRA and ICPSS outlines, within the AFA extents. Nevertheless this will be reviewed following initial model runs to check that this assumption is valid.

The Carlingford, Greenore, Dundalk & Blackrock South and Annagassan models however must consider the occurrence of joint probability further. The result of a joint occurrence of both fluvial and coastal flood conditions would have a significant impact on the flat, low lying river reaches and estuaries.

The next stage in assessing the joint probability is to review the available data to ascertain if there is a dependence relationship between extreme coastal and fluvial events. The nearest long term gauge record available for comparison is at Dublin which is between 60km and 80km to the south of the AFAs to be considered. There are however shorter term gauge records available at Port Oriel and Dundalk. In terms of fluvial hydrometric gauge records the Charleville (06013 – OPW) and Tallanstown (06014 –

OPW) gauging stations on the Rivers Dee and Glyde respectively both have long term high quality fluvial flow data upstream of Annagassan. Although not located directly on the modelled watercourses the Ballygoly (06030 – EPA) is located in close proximity to Carlingford, Greenore and Dundalk & Blackrock South AFAs and is typical of the smaller catchments which make up these models generally. All three station records have been compared against the Dublin total water level tidal gauge data and residual storm surge (tide removed) for 2000 to 2007 as shown in Figure 6.9.

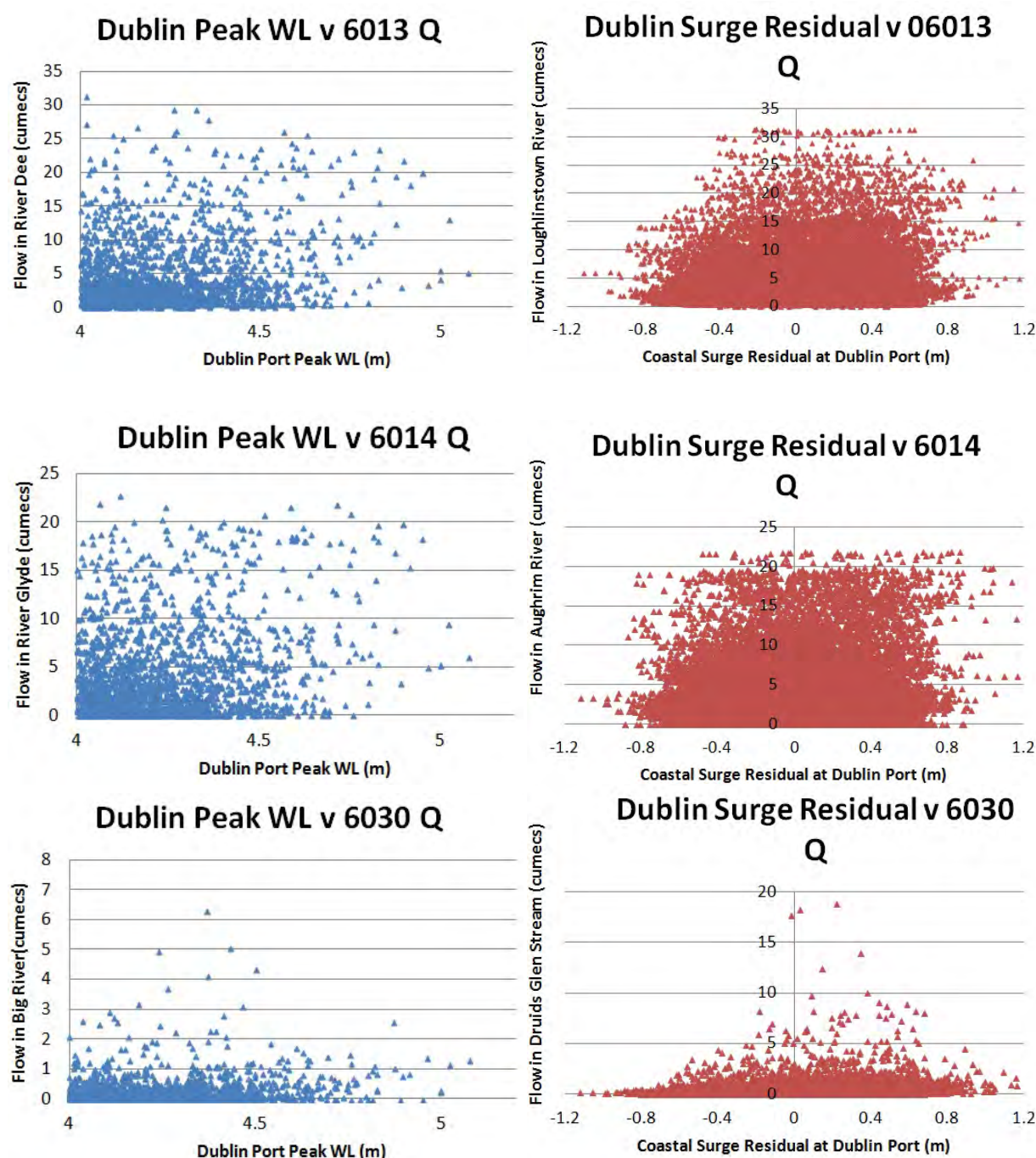
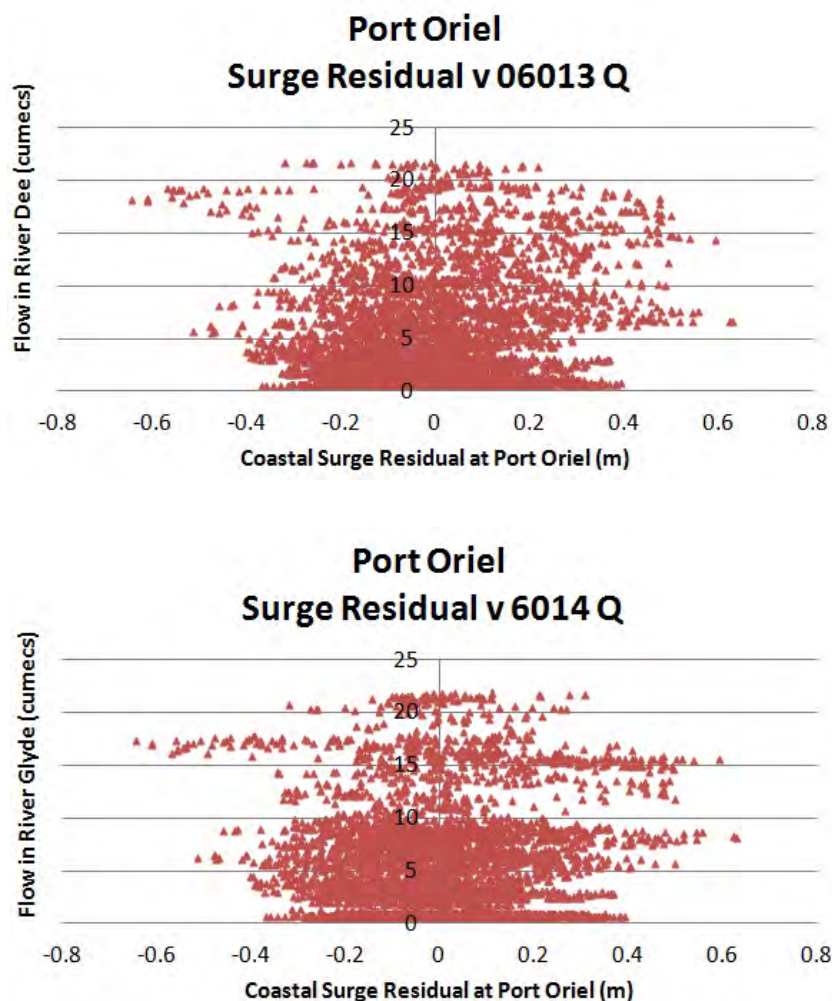


Figure 6.9: Coastal WL Peak & surge residual @ Dublin Port versus River Flow in UoM 06

The scatter diagrams shown in Figure 6.9 indicate no obvious correlation between peak total water levels at Dublin Port and fluvial water levels in the UoM 06 Rivers (left hand side diagrams). When the effect of tide is removed from the tidal gauge data and the effect of storm surge against fluvial flow is considered (right hand side diagrams) and some mild positive correlation is evident, particularly at the smaller Big River catchment gauging station (06030). However in relation to coastal flooding the effect of surge appears to be dwarfed by the oscillation of the tides which are driven by astronomical factors and can be considered totally independent from meteorological factors. When we consider total peak water levels the correlation is so diluted as to be negligible. It is this total water level dataset which is most relevant in terms of the joint probability relationship as this represents the real world scenario. The stations have also been compared to the shorter but geographically closer Port Oriel surge residual data from 2007 to 2008 and the results are shown in Figure 6.10.



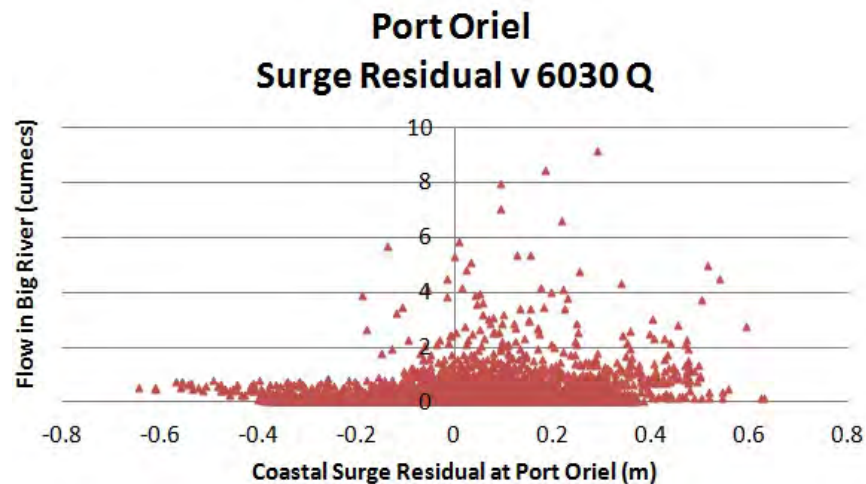


Figure 6.10: Storm surge residual @ Port Oriel versus River Flow in UoM 06

A review of the shorter but possibly more relevant Port Oriel storm surge residual record provides a similar picture. The two gauges which represent the larger Dee and Glyde catchments show that some of largest surge residuals (both positive and negative) occurred during times of high flow in both rivers. The bands within the scatter plots are reflective of the small number of fluvial events within the short record and appear to show only that the duration of the fluvial events is such that positive and negative surge are both equally likely to occur within the timeframe of the fluvial event. The only positive correlation within the data appears to be on the smaller Big River catchment. This correlation is relatively weak and will be diluted further when the affect of tide is considered.

As such correlation between total water levels and fluvial flood flow within UoM 06 can be considered to be negligible and it is proposed to follow a simplified conservative approach whereby the 50% AEP design event is maintained for one mechanism while the whole range of probabilities for the other mechanism are tested and vice versa, subject to sensitivity testing against average winter conditions to ensure the approach does not yield results which could lead to unrealistic flood extents or over design of measures.

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 such that the outputs can accommodate as much as practically possible these changes. This chapter outlines potential environmental changes such as climate change and changes to the catchment such as afforestation and changing land uses. UoM 06 represents catchments which are mostly entirely rural but it has been shown (Chapter 4) that many of them feature high degrees of forest coverage which is known to have an effect on catchment run-off. Despite the rural nature of the catchments there are some highly urbanised catchments such as the Acarreagh watercourse flowing through Dundalk and the effect of further urbanisation on the watercourses flowing through AFAs must be considered. These issues, along with potential management and policy changes are considered in this chapter.

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 higher¹.

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 rises 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 UOM 06 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

¹ <http://www.theguardian.com/environment/2013/may/10/carbon-dioxide-highest-level-greenhouse-gas>

quantify the impact of climate change on Irish hydrology and considers the impacts of nine Irish catchments all of which were outside UoM 06 with the nearest being the Moy catchment in Mayo / Sligo. The ensemble scenario modelling from the regional climate change model predicts that between the two periods of 1961 – 2000 and 2021 – 2060 that 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 Moy catchment (HA34) was calibrated using historical meteorological data against the hydrometric gauge record at the Rahans gauging station (34001). The Moy model was found to be the best calibrated of the nine catchment run-off models when considered in terms of the R^2 error measurement. Validation of the model against observed data at the gauging station found that the Moy model was moderately well calibrated when it came to simulating the annual maximum daily mean flow but that the model appeared to be underestimating mean winter flow. Following simulation of the meteorological climate change ensembles within the run-off models the following observations were made in the Moy and other 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% are the general pattern across all nine study catchments. In the Moy catchment this increase in mean winter flow was found to occur in February and March as opposed to January which was typical in the other catchments.
- Mixed results were obtained in terms of increased risk of extremely high winter flows in the Moy catchment although some other catchments such as the Feale and Suir showed risk doubling. It is thought that increased risk is more likely on catchments with a quicker response time.
- No change in annual maximum daily mean flow is apparent in the Moy catchment for all return periods but a moderate increase in risk is apparent on two of the other eight.

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 more modest in the Irish Sea with a 'net trend' (allowing for isostatic adjustment of the earth's crust) of 2.3 – 2.7mm per year. On top of this the report notes that storm surges are likely to increase in frequency.

The latest UK Climate Projections are covered in UKCP09 and put the central estimate of relative sea level rise at Belfast (to the east of UoM 06), based on a medium emissions scenario for the year 2095

at 31.6cm. The central estimate of a high emissions scenario for 2095 is 40.3cm but the predictions range from approximately 10cm to 70cm. The relative sea level rise detailed in UKCP09 allows for vertical land movement (isostatic adjustment) based on estimates taken from Bradley *et al* (2009). Storm surge models using the operational Storm Tide Forecasting Service (STFS) also show some increase in extreme storm surge although these rises are much less than was predicted in UKCIP02. It is not projected that the surge which could be expected to be exceeded for the 2, 10, 20 or 50 year return periods will increase by any more than 9cm by 2100 anywhere along the UK coast. It is noted however that other international climate models predict the rises to be much greater and these cannot be completely ruled out. In particular one high end surge scenario H++ combined with sea level rise infers increases in the 50 year return period extreme water level of as much as 3m by 2100 in some places around the UK.

7.2 AFFORESTATION

7.2.1 Afforestation in UoM 06

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 UoM 06 the current forest coverage as recorded in the 2006 CORINE land maps is shown in Figure 7.1.

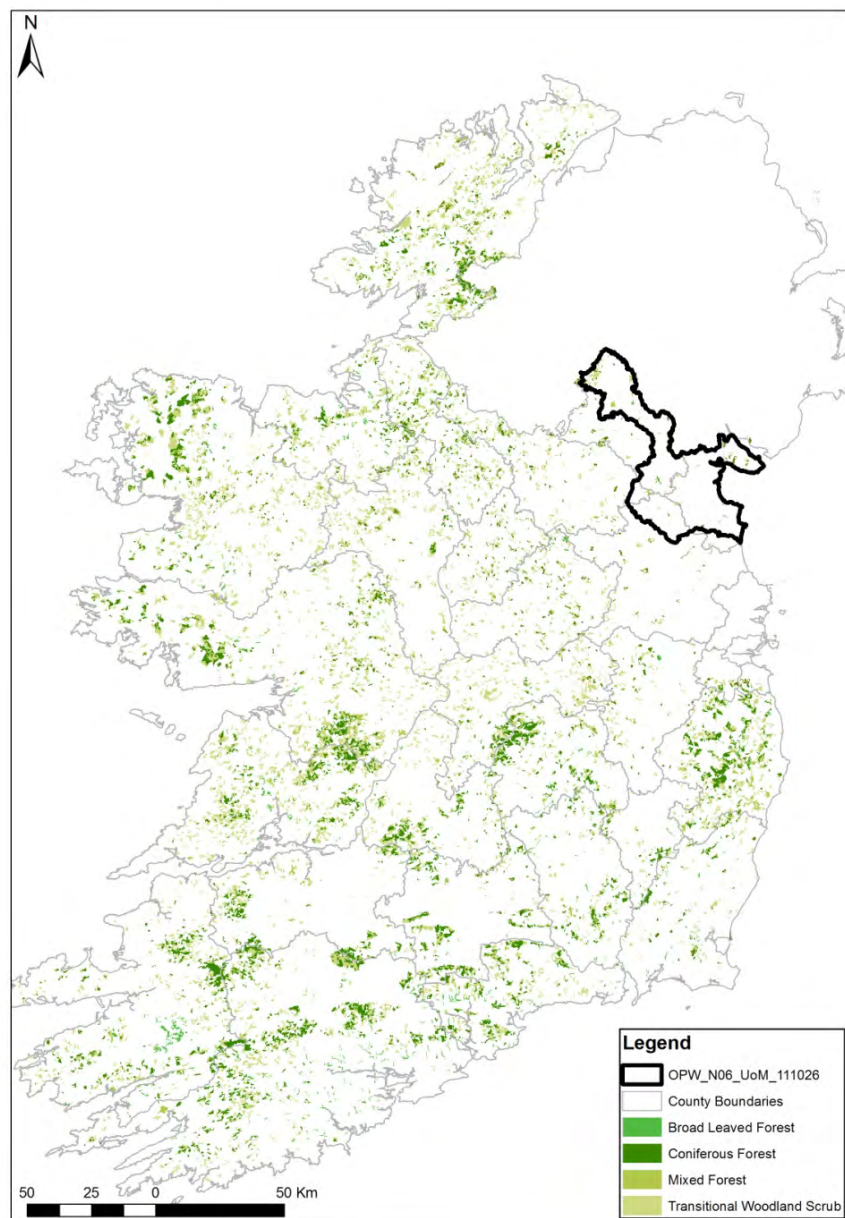


Figure 7.1: CORINE 2006 Forest Coverage in UoM 06 Compared to the rest of Ireland

The total forested area, including transitional woodland scrub, within UoM 06 is 62km² which is approximately 3.5% of the total area. This is well below the average for the country which is approximately 10%. Forest cover is generally sparse across UoM 06 with the densest pocket located in the north west in the foothills of Slieve Beagh located just across the border in County Tyrone. When we compare the CORINE 2006 database to the 2000 database there appears to have been a small amount of increase in the forested area at this location only as shown in Figure 7.2

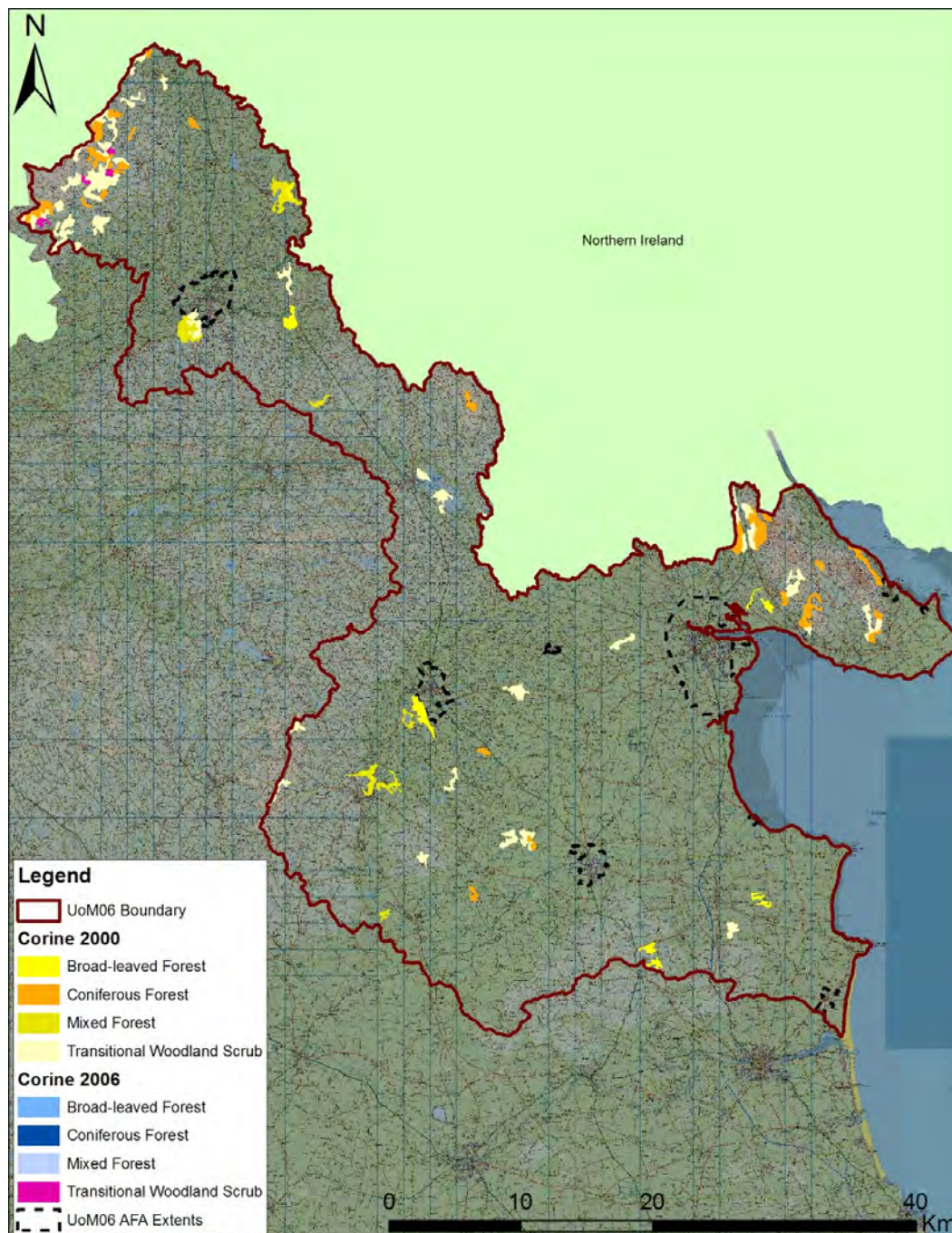


Figure 7.2: Forest Coverage Changes in UoM 06

As can be seen from Figure 7.2 there appears to be a small increase in the amount of forested area overall generally within the area to the north west of Monaghan but the increase has been in transitional woodland scrub as opposed to actual forest. However the total forestry coverage has slightly decreased as indicated on Table 7.1.

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	33	1.9	28	1.6	-5.0	-0.3	-0.68	-0.04
Transitional Woodland Scrub	30	1.7	34	1.9	+4	+0.2	0.5	0.03
Total	63	3.6	62	3.5	-1	-0.1	-0.18	-0.01
Total Countrywide	6,631	9.4	7,087	10.1	456	+ 0.65	76	+0.11

From Table 7.1 it can be shown that total forest / woodland scrub has slightly increased in UoM 06 between 2000 and 2006 but the actual forest coverage has slightly decreased. When considered together the total area of forest / woodland scrub as a proportion of the catchment is considerably lower than the national average of approximately 10%. Forestry in UoM 06 has experienced an annual decrease of -0.01% compared to a national annual increase of +0.11%. If the annualised decrease in afforestation were to continue for the next 100 years there would be almost one third less forest coverage in UoM 06 from 62.3 km² (3.5%) to 44 km² (2.5%).

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 in comparison 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 the North Western Neagh Bann CFRAM Study but given the sparse forestry coverage and the lack of change in UoM 06 its relevance is limited. The densest pocket of forestry in County Monaghan is within the catchment of the River Blackwater which is included in Model 1. It accounts for 13% of the catchment area at the upstream limit of Model 1 on the Blackwater. The overall impact of afforestation is likely to be negligible given the small proportion of upland forested area against the catchment area. No AFAs within UoM 06 have been identified as potentially susceptible to significant future afforestation within the upstream catchment and as such it is not considered appropriate to apply changes to run-off behaviour to the future scenario events at any of the AFAs within UoM 06.

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 the counties located within UoM 06 has increased by varying degrees since 1991 as demonstrated by Table 7.2.

Table 7.2: Population Growth in UoM 06 (Source: Central Statistics Office of Ireland (CSO))

		1986	1991	1996	2002	2006	2011
Monaghan* (58% in UoM 06)	Population (Number)	52,379	51,293	51,313	52,772	55,997	60,495
	Actual Change Since Previous Census (Number)		-1,086	20	1,459	3,225	4,498
	Population Change Since Previous Census (%)		-2.1	0.04	2.8	6.1	8.0
Louth* (90% in UoM 06)	Population (Number)	91,810	90,724	92,166	101,802	111,267	122,808
	Actual Change Since Previous Census (Number)		-1,086	1,442	9,636	9,465	11,541
	Population Change Since Previous Census (%)		-1.2	1.6	10.5	9.3	10.4
Meath (10% in UoM 06)	Population (Number)	102,881	105,370	109,732	133,936	162,831	184,034
	Actual Change Since Previous Census (Number)		2,489	4,362	24,204	28,895	21,203
	Population Change Since Previous Census (%)		2.4	4.1	22.1	21.6	13.0
Cavan (3% on UoM 06)	Population (Number)	53,965	52,796	52,944	56,416	64,003	72,874
	Actual Change Since Previous Census (Number)		-1,169	148	3,472	7,587	8,871
	Population Change Since Previous Census (%)		-2.2	0.3	6.6	13.4	13.9

*Counties containing AFAs are highlighted

As indicated by Table 7.2, UoM 06 has seen significant population rise since 1991. It is evident that the percentage of population change has been steadily increasing with an average annual growth rate of 2.4% within the counties containing AFAs since the 1991 census.

Further analysis of the census data from 2006 & 2011 shows that none of the counties have experienced an increase in the share of the rural population since 2006. This period has seen population growth within the towns of 28,574 versus rural population growth 8,846 and as such it can be inferred that the population growth within UoM 06 has been mostly within the urban centres.

Table 7.3 confirms that urban population growth within the urban AFAs (population > 1500) for the period 2006 – 2011 has been quite significant ranging from 5% in Ardee to 12.3% in Carrickmacross over the five year census period.

Table 7.3: Population Growth within Urban AFAs (Source: Central Statistics Office of Ireland (CSO))

Urban Area	Population 2011	Increase Since 2006 (%)
Dundalk	37816	7.8
Ardee	4927	5
Carrickmacross	4925	12.3
Monaghan	7452	11.1

The total percentage population growth in these AFAs however is 9.1% for the period 2006 – 2011 which equates to an average annual growth rate of approximately 1.8%.

To determine if these changes translate into equivalent increases in urbanised areas we must examine the CORINE database within UoM 06 and the changes from 2000 to 2006. A simple comparison of the datasets within UoM 06 appears to show that there has been a modest increase in artificial surfaces within UoM 06 from 52 km² in 2000 to 61 km² in 2006 which represents an increase of just over 17% in six years (see Figure 7.3).

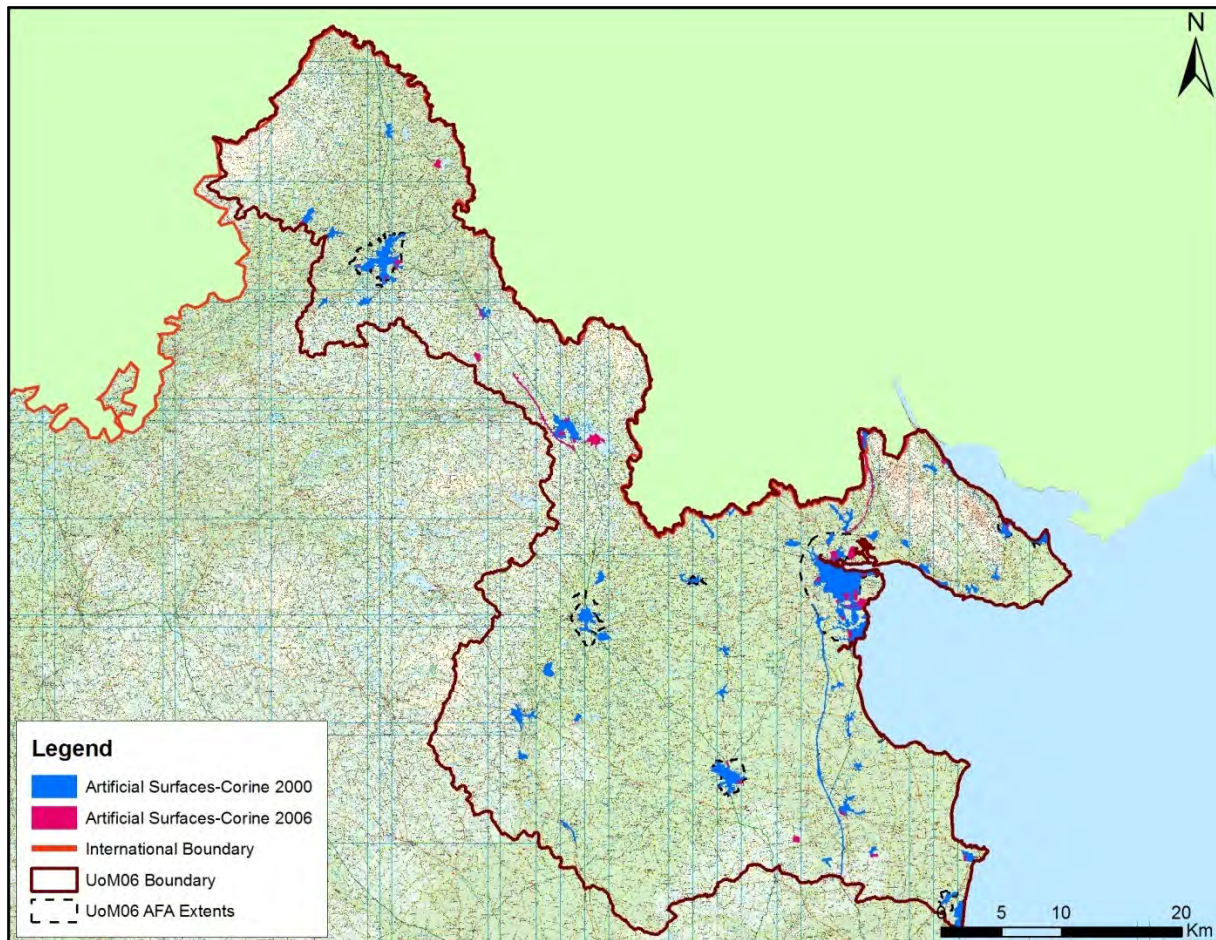


Figure 7.3: UOM 06 CORINE Artificial Surfaces (2000 / 2006)

Closer inspection of the CORINE datasets shows that a notable proportion of this growth in artificial surfaces is due to changes outside the AFAs. 66% of artificial growth between 2000 and 2006 occurred outside the AFAs however a large proportion of this growth consists of the addition of sports facilities such as the golf course at Lough Muckno and road upgrades including the Castleblayney bypass and the M2 upgrade north of Dundalk. Golf courses, however, are generally permeable surfaces and it is assumed that Sustainable Urban Drainage Systems have maintained as closely as possible Greenfield run-off rates in terms of the road upgrade, as such neither directly affect the AFAs. The AFAs with an increase in the extent of artificial surfaces are:

- Monaghan: 8.7% increase (1.4% annually)
- Ardee: 8.7% increase (1.4% annually)
- Dundalk & Blackrock South: 17.1% increase (2.7% annually)
- Carlingford: 10.5% increase (1.7% annually)

No change in terms of artificial surface land cover was experienced between 2000 and 2006 for Iniskeen, Termonfeckin, Annagassan and Greenore AFAs.

The average annual growth rate in the artificial surfaces within all UoM 06 AFA extents is 1.8%.

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 Border 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 6.3% equating to an average annual growth rate of 0.4%. Under the M2F1 Recent model, which tends to reflect more recent growth rates, the projected rise in population is 25% equating to an annual average growth rate of 1.5%. 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 CSO for the region. These are summarised in Table 7.4 below.

Table 7.4: Urbanisation Growth Indicators

	Population in UoM 06 Counties 1991 - 2011	Population in UoM 06 Urban AFAs 2006 - 2011	Artificial Surfaces (CORINE) within UoM 06 AFA Extent 2000 - 2006	CSO M0F1 Population Projection 2011 - 2016	CSO M2F1 Population Projection 2011 - 2016
Average Annual Growth Rate (%)	2.4%	1.8%	1.8%	0.4%	1.5%

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 for example we consider the FSU 'URBEXT' catchment descriptor at an FSU node on the River Longfield just downstream of Carrickmacross AFA (part of the Glyde catchment) currently at 8.58% the URBEXT could potentially rise to between 12.8% urbanised (based on growth of 0.4% per annum) and 91.9% urbanised (based on growth of 2.4% per annum) in the 100 year span which must be considered under the future scenarios.

Based on the FSU equation (WP 2.3) for index flow estimation (Q_{med}) based on catchment descriptors the Urban Adjustment Factor (UAF) for the Longfield catchment just downstream of Carrickmacross would vary as shown in Table 7.5 if we consider growth of 1% and 2.5% as representative for the 100 year mid range (MRFS) and high end (HEFS) future scenarios respectively.

Table 7.5: Potential Effect of Urbanisation on Q_{med} Flow on River Longfield just downstream of Carrickmacross

	Growth Rate	URBEXT ²	UAFS ¹	Total Catchment Q_{med} Flow m^3/s
Present Day	n.a.	23.21	1.13	1.92
100 Year MRFS	1% p.a.	11.36	1.36	2.32
100 Year HEFS	2.5% p.a.	100.00	2.79	4.75

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

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

Table 7.5 represents one of the more urbanised catchments within UoM 06 and as such can be considered a more onerous example of the potential effect of urbanisation within UoM 06. At the less onerous end catchments with no existing urbanisation could remain totally rural. There are also examples of catchments representing small watercourses on the edges of AFAs which are currently totally rural but which could become totally urbanised in 100 years time if the spatial growth of the urban fabric of the AFA occurs in the direction of that small catchment. In this scenario the application of growth rates to a URBEXT value of zero will have no effect and as such the effect could be missed using a methodology that applies factors to the URBEXT values. It must also be considered that any attempts to predict the spatial growth of AFAs on a 100 year time frame would be highly uncertain as growth rates and growth direction are dictated by complex social, economic and cultural factors which cannot be predicted far into the future.

In light of these large uncertainties it is not considered prudent to attempt to predict the varying effects of urbanisation on a HEP by HEP basis and as such it is considered prudent to apply a factor based on the average URBEXT values within the Unit of Management and the growth rates considered above of 1% and 2.5% respectively for the medium and high end future scenarios. It is still considered prudent though that small urban watercourses with catchments that emanate around the periphery of AFA extents are considered to become much more urbanised and as such will be considered as having URBEXTs of 50% for the mid range and 85% for the high end future scenarios (85% is considered the urban saturation level as some green spaces will always remain).

The effect of recent developments in sustainable drainage policy and guidance must also be considered. The move away from conventional drainage systems is likely to gather pace with the aim of these policies and systems to provide drainage for urban areas which recreates the run-off behaviour of the rural catchment in an attempt to mitigate flood risk. Sustainable drainage policy is already being implemented in Dublin through the Greater Dublin Strategic Drainage Strategy (GDSDS) but is largely in its infancy outside the capital but it would be expected to develop greatly throughout time span of the

future scenarios. Therefore the current effect of urbanisation on catchment run-off could be expected to reduce over time as sustainable drainage policy and systems develop.

There is no directly applicable data / research into the likely effectiveness of SuDS policies at reducing the impact of future urbanisation on catchment run-off in an Irish context. The paper titled 'Performance and Design Detail of SUDS' (Macdonald & Jefferies, 2003) outlines research undertaken in Scotland on the effectiveness of a range of different systems implemented and found that the effectiveness is dependent on the type of system implemented (source control or site / regional) but that all systems considered delivered at least a 50% reduction in peak run-off rate rising to over 80% for source control systems.

Given the development of SuDS policies in recent years it is appropriate that some allowance is made for the effectiveness of SuDS at mitigating the impact of urbanisation on peak run-off rates. It is therefore assumed that SuDS policies and systems will mitigate the impact of future urbanisation by half (50% effective) within the tributary watercourses affecting the AFAs where SuDS implementation is most likely to be focussed. The urban adjustment factors which will therefore be applied to the design flow estimates for the mid range and high end future scenarios for a typical catchment (shown here as a catchment average HEP) and for a small tributary catchment which may be susceptible to full urbanisation are shown for HA06 in Table 7.6 and for HA03 in Table 7.7.

Table 7.6: Potential Effect of Urbanisation on Q_{med} Flow in HA06

	Growth Rate	URBEXT ²	UAF ¹	UAF (adjusted for SuDS)
HEP Average		4.0	1.026	n.a.
100 Year MRFS	1% p.a.	10.8	1.16	n.a.
100 Year HEFS	2.5% p.a.	47.3	1.77	n.a.
Tributary Catchments susceptible to full urbanisation	n.a.	varies	varies	varies
100 Year MRFS		50	1.824	1.412
100 Year HEFS		85	2.488	1.744

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

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

Table 7.7: Potential Effect of Urbanisation on Q_{med} Flow in HA03

	Growth Rate	URBEXT ²	UAF ¹	UAF (adjusted for SuDS)
HEP Average		3.67	1.05	n.a.
100 Year MRFS	1% p.a.	9.9	1.15	n.a.
100 Year HEFS	2.5% p.a.	43.1	1.7	n.a.
Tributary Catchments susceptible to full urbanisation	n.a.	varies	varies	varies
100 Year MRFS		50	1.824	1.412
100 Year HEFS		85	2.488	1.744

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

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

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. An approach has been developed that considers an average adjustment factor for the majority of HEPs across UoM 06. These adjustment factors will translate into increases in flow of approximately 3% and 22% for the mid range and high end future scenarios respectively. Small catchments emanating from just outside AFAs which would be susceptible to full urbanisation are to be considered separately and will see their flows increase by up to 41% and 74% for the mid range and high end future scenarios respectively.

There is high uncertainty in all of these allowances as discussed above and it is recommended that they are reviewed at each cycle of the CFRAM Studies.

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 Soil Type

Figure 7.4 overleaf illustrates the soil types that characterise UoM 06. The predominantly flat landscape across the south eastern portion of UoM 06 is reflected by the predominance of deep well drained mineral podzols with interspersed deep well drained lithosols. The higher land to the north west above Monaghan AFA is characterised by peat and peaty podzols where the eastern foothills of Slieve Beagh are located. Peaty podzols and scree are also located on Carlingford Mountain. The south eastern seaboard between Annagassan and Termonfeckin is characterised by deep gleys. The upper catchment of the River Lagan is also characterised by deep gleys, which is a tributary of the Glyde, joining the system between Carrickmacross and Annagassan.

There is currently ongoing research in Ireland and the UK involving modelling the risk of diffuse pollution in river catchments, including sediment transport. Recent research has focussed attention on assessing risk based on erodibility and hydrological connectivity to the river network, with land use/land cover the most common measure of erodibility. While soil type clearly has an influence on erodibility, Reaney et al. (2011) argue that an emphasis upon land cover is warranted as land cover is typically correlated with soil type (refer to Section 7.4.3).

The predominance of well drained mineral soils to the south east is conducive to its predominance of agricultural land use (refer to Section 7.4.3). To the north west of UoM 06 above Monaghan, the peaty soils would indicate relatively high susceptibility to soil erosion and can be considered a source of sediment which if accelerated due to anthropogenic pressures and given the right pathway (channel typology) can make its way to the watercourse network which drains towards Monaghan AFA. The deep gleys along the south eastern seaboard in the vicinity of Annagassan and Termonfeckin indicate poorly drained soils and higher potential for surface water runoff.

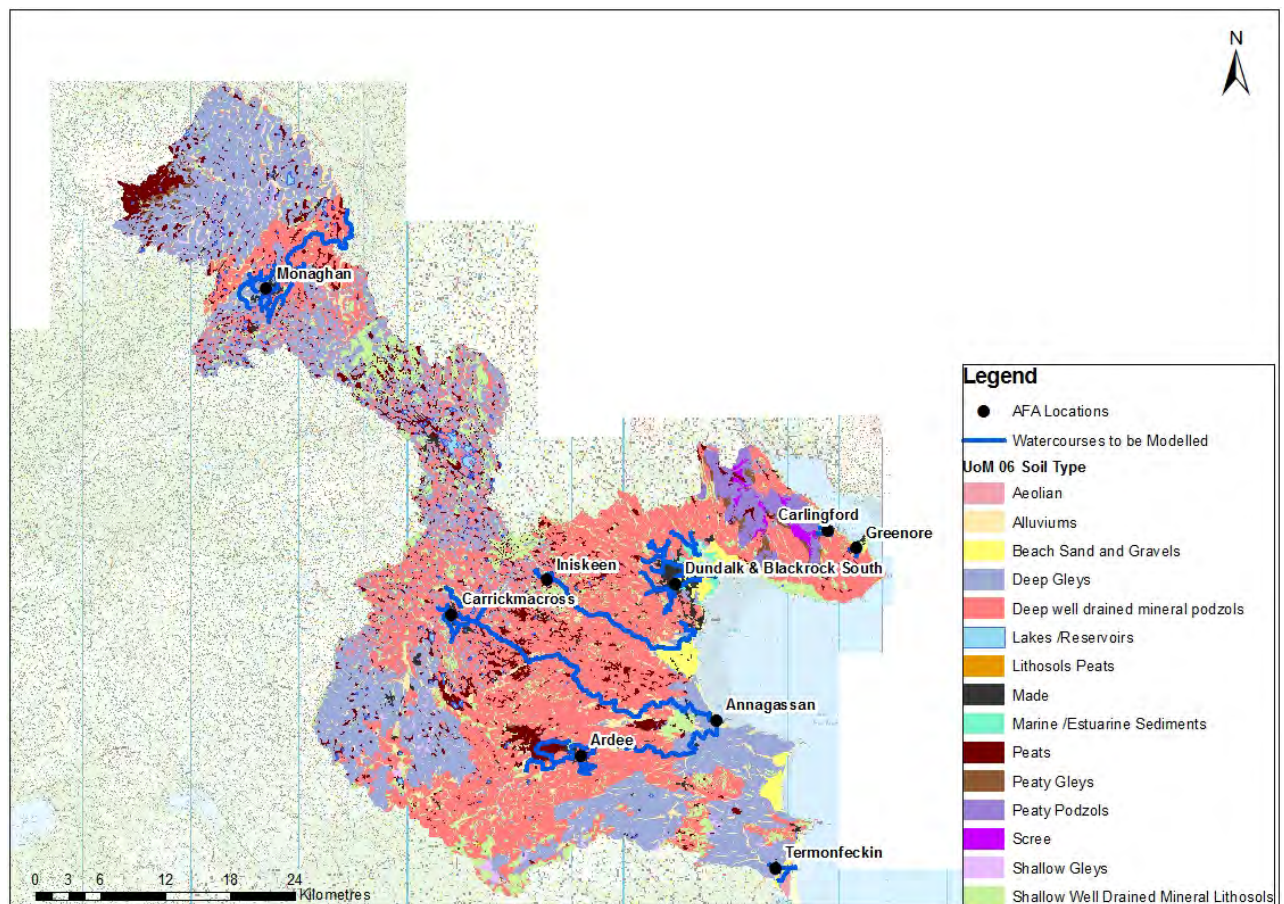


Figure 7.4: UoM 06 Soil Types (Source: Irish Forest Soils Project, FIPS – IFS, Teagasc, 2002)

7.4.2 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 rivers². It classified river channels into channel type at 100m node points along each reach. Table 7.8 below outlines the four main channel types and how these relate to the four catchment descriptors used to define them; valley confinement, sinuosity, channel slope and geology.

² (http://www.wfdireland.ie/docs/20_FreshwaterMorphology/CompassInformatics_MorphologyReport)

Table 7.8: Channel Types and Associated Descriptors

Channel Type	Confinement	Sinuosity	Slope	Geology
Step Pool / 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.

Lowland Meandering:

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

Figures 7.5 and 7.6 illustrate the channel typology and channel slope of UoM 06 in a national context.

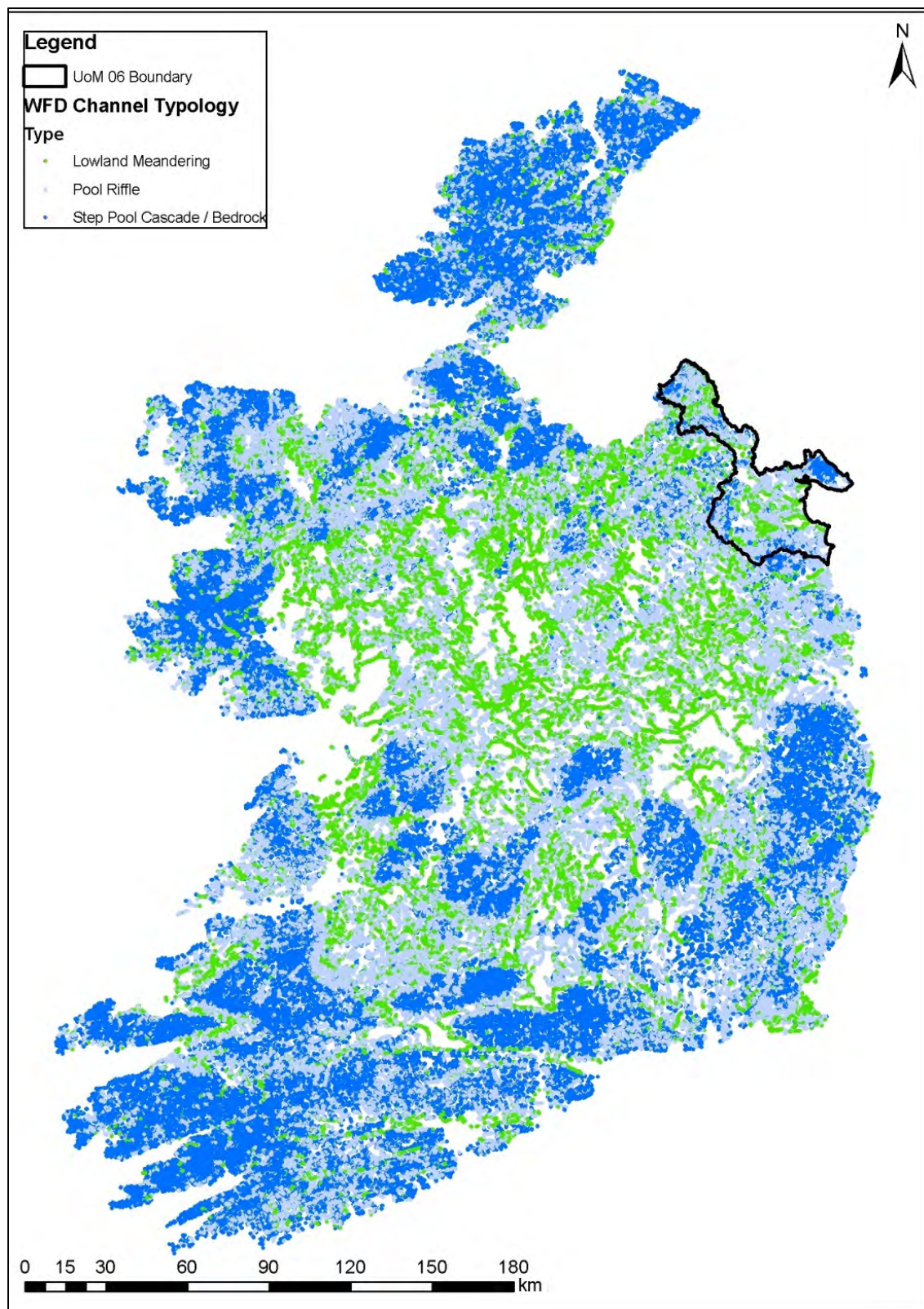


Figure 7.5: Channel Types within UoM 06 in National Context (Source: WFD Channel Typology dataset)

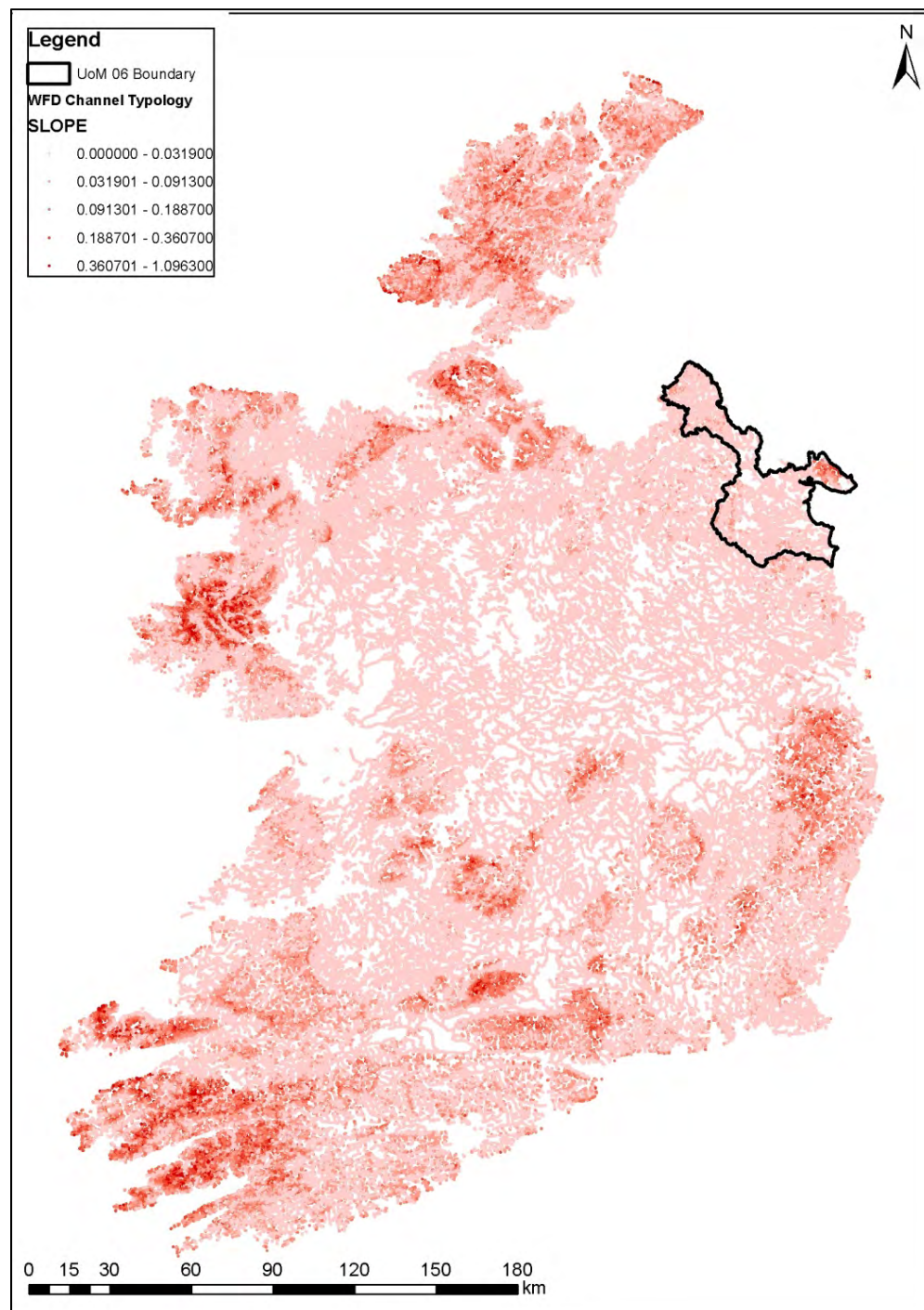


Figure 7.6: Channel Slopes within UoM 06 in National Context (Source: WFD Channel Typology dataset)

UoM 06 is a relatively low slope, low energy system with a predominance of inland low slope lowland meandering channels, flanked by steeper pool riffle channels to the west and north east where lands of higher altitude progress towards low lying flatter lands both to the north in County Armagh and at the Louth coast. Figures 7.7 and 7.8 provide a closer look at channel types and slope within UoM 06.

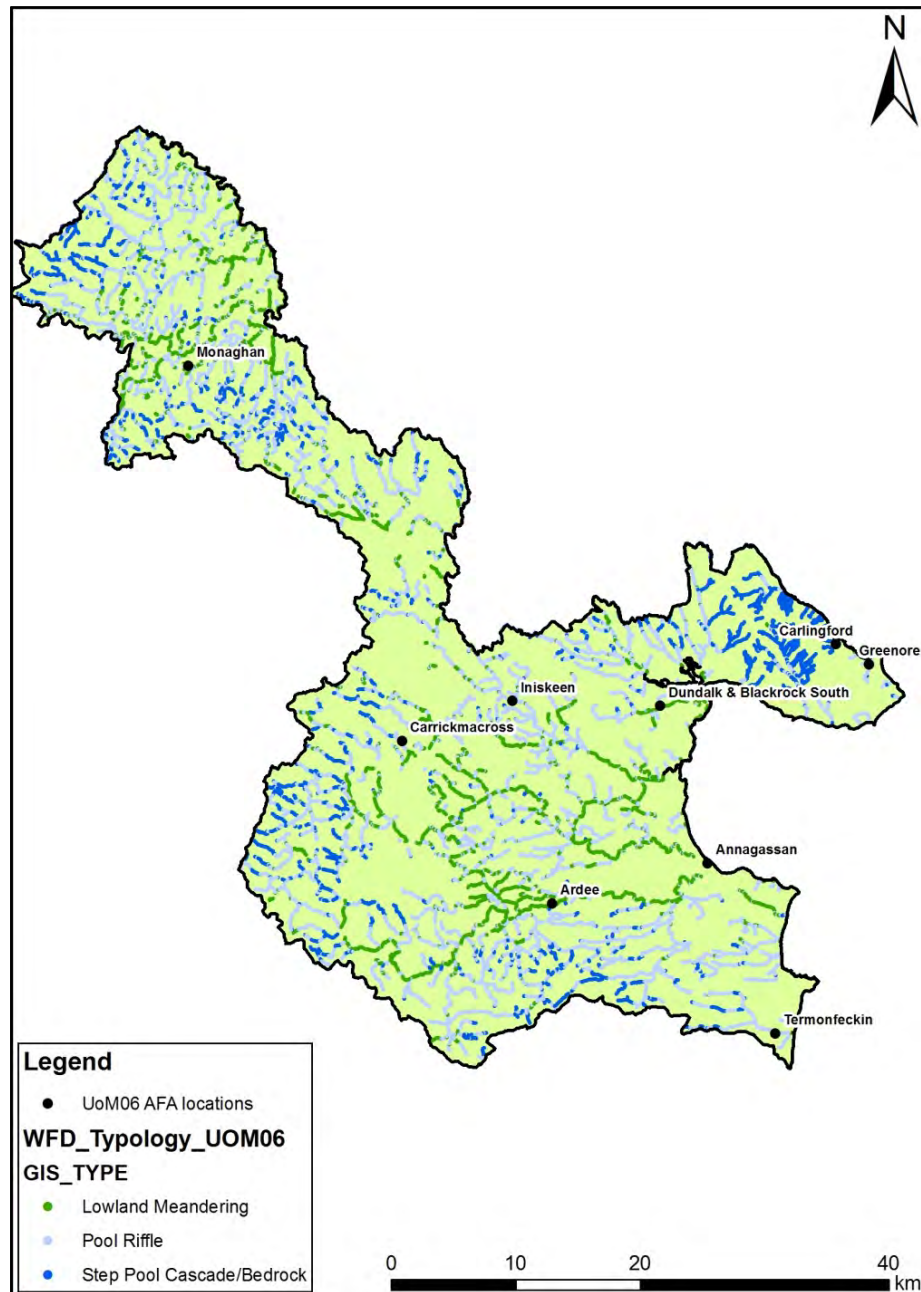


Figure 7.7: WFD Channel Typology UoM 06

As illustrated by Figure 7.7 Monaghan AFA is located amongst pool riffle and lowland meandering watercourses which are sourced from the surrounding hills. Carlingford AFA is at the receiving end of a steep, high energy step pool cascade watercourses from Carlingford Mountain. The remaining AFAs are located within the lower flatter lands to the east of UoM 06 which are generally characterised by low energy lowland meandering rivers. Figure 7.8 shows the channel type of all modelled watercourses and the associated AFA. Most of the AFAs are affected by a lowland meandering main channel that is fed by smaller steeper pool riffle watercourses. Annagassan however is at the downstream end of the larger lowland meandering Glyde and Dee systems and is therefore particularly prone to sediment deposition and consequent accumulation within the river channel.

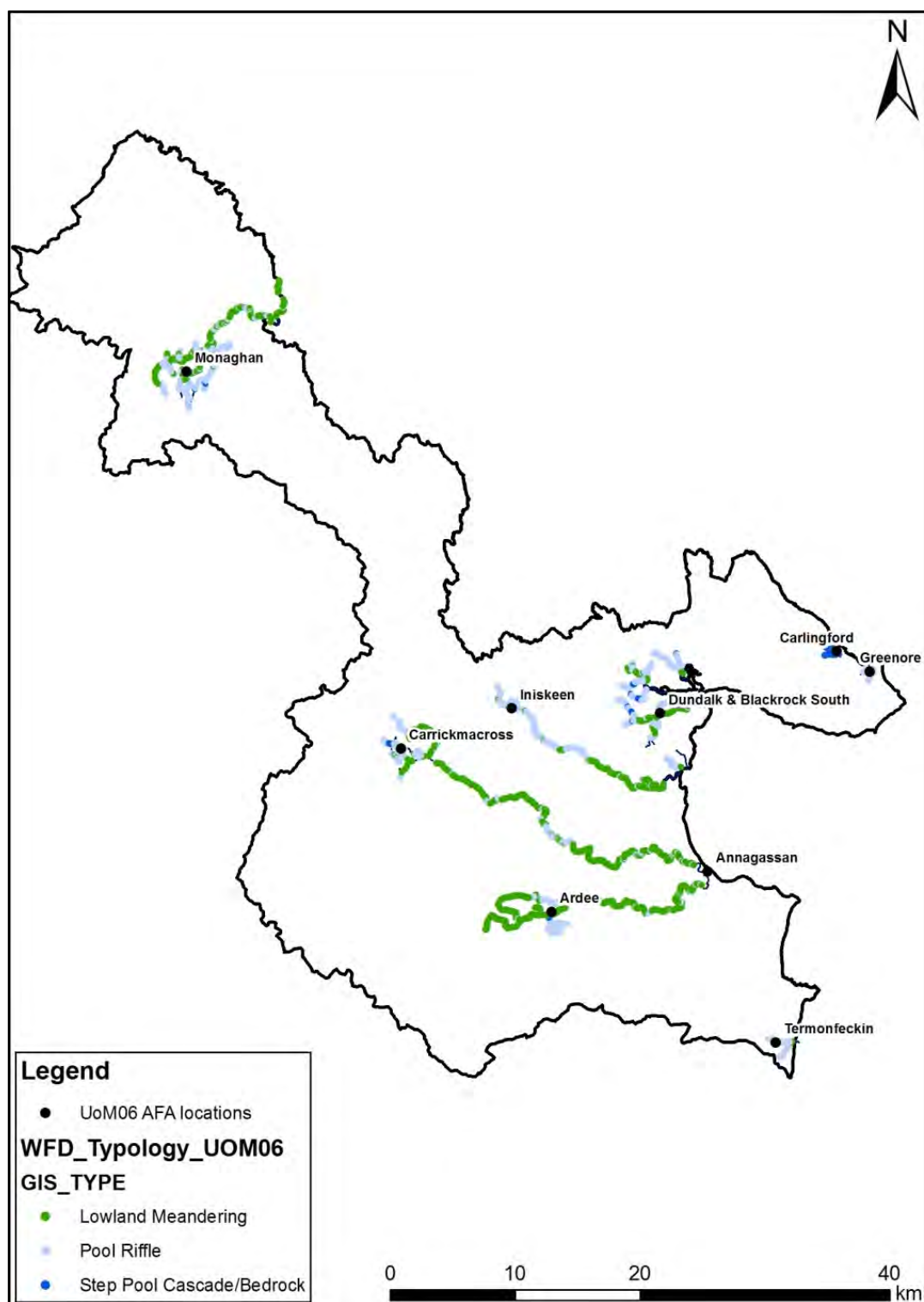


Figure 7.8: Modelled Watercourses – Channel Type

These channel types also represent the change in channel slope from relatively steep in upland areas to relatively shallow moving downstream. Figure 7.9 indicates the change in channel steepness across the UoM 06.

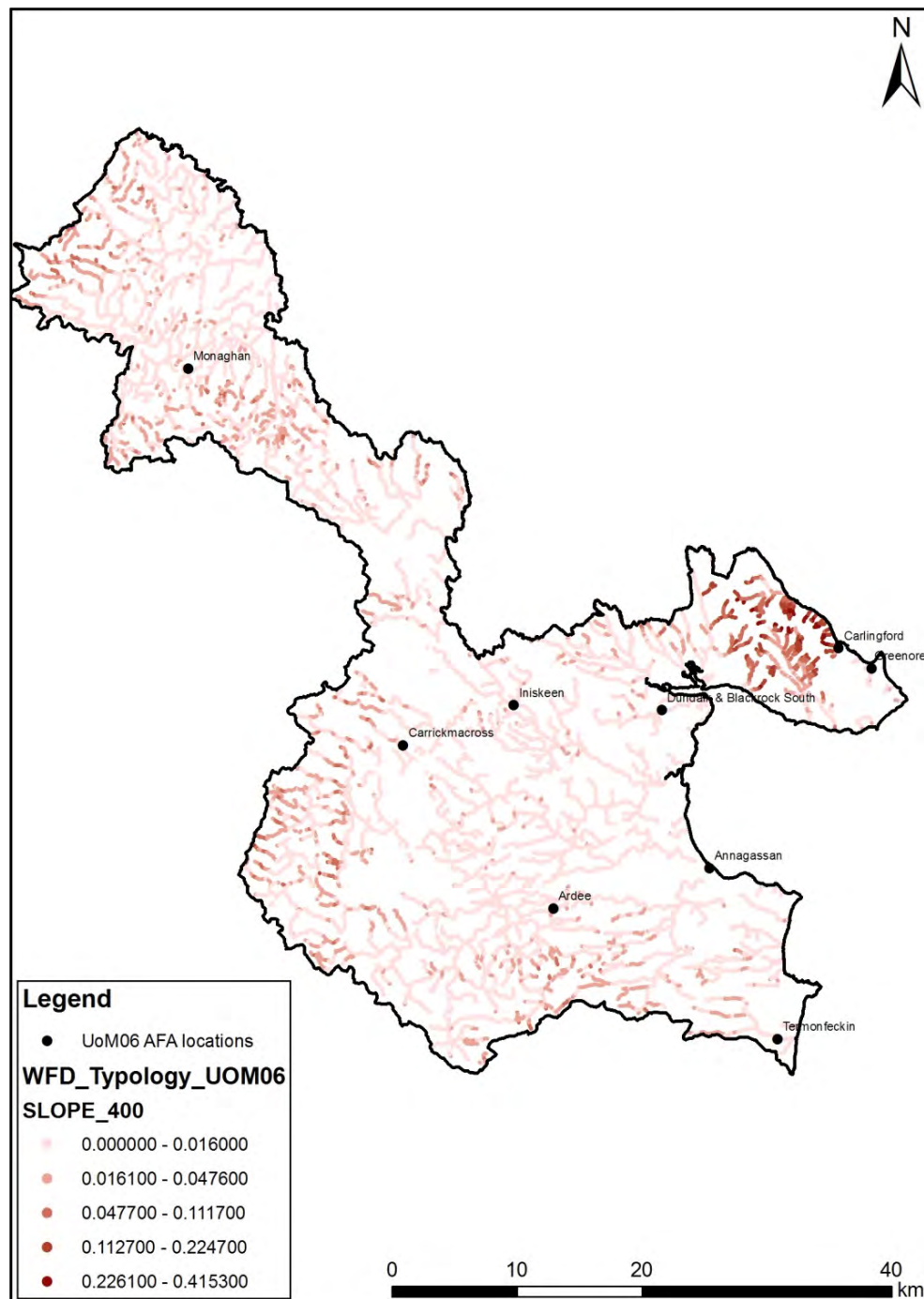


Figure 7.9: Changes in Channel Slope UoM 06

The steepest channels are located at the mountainous areas west of Carlingford ranging from 0.415 to 0.226 (in other words 1 in 2.5 to 1 in 4). The southern boundary of UoM 06 is flanked by channels of slope generally ranging from 0.224 to 0.047 (1 in 4 to 1 in 20). These watercourses progress to lower slopes moving north and east ranging from 0.047 to 0.00 (1 in 20 to almost flat).

These channel types are typical of Irish catchments. Sediment transport, erosion and deposition are natural morphological processes. In larger catchments it is expected that the upper reaches will be more dynamic with erosion taking place 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 the aforementioned figures, the AFAs that could be affected by sediment deposition are:

- Annagassan
- Monaghan
- Carrickmacross
- Ardee
- Iniskeen
- Dundalk

7.4.3 Morphological Pressures - Land Use

As discussed in Section 7.4.1 land use/land cover is becoming the most common measure of soil erodibility in national research. Figure 7.10 illustrates the land use types within UoM 06. It is essentially rural dominated by pasture (67% of catchment area) and arable land (14%). There are pockets of peat bogs in the uplands to the north west and north east (2%) and areas of forest make up 3% of the catchment area (refer to Section 7.1). Drainage of bog lands and peat extraction activities potentially lead to large quantities of peat silt being discharged to the receiving waters. However peat bogs and associated drainage of the land are restricted in area and location within UoM 06 such that they do not have significant impact on the modelled watercourse catchments. The peat bogs located within the upper catchment of the Monaghan Blackwater are relatively small in area and is not expected to be a significant sediment source.

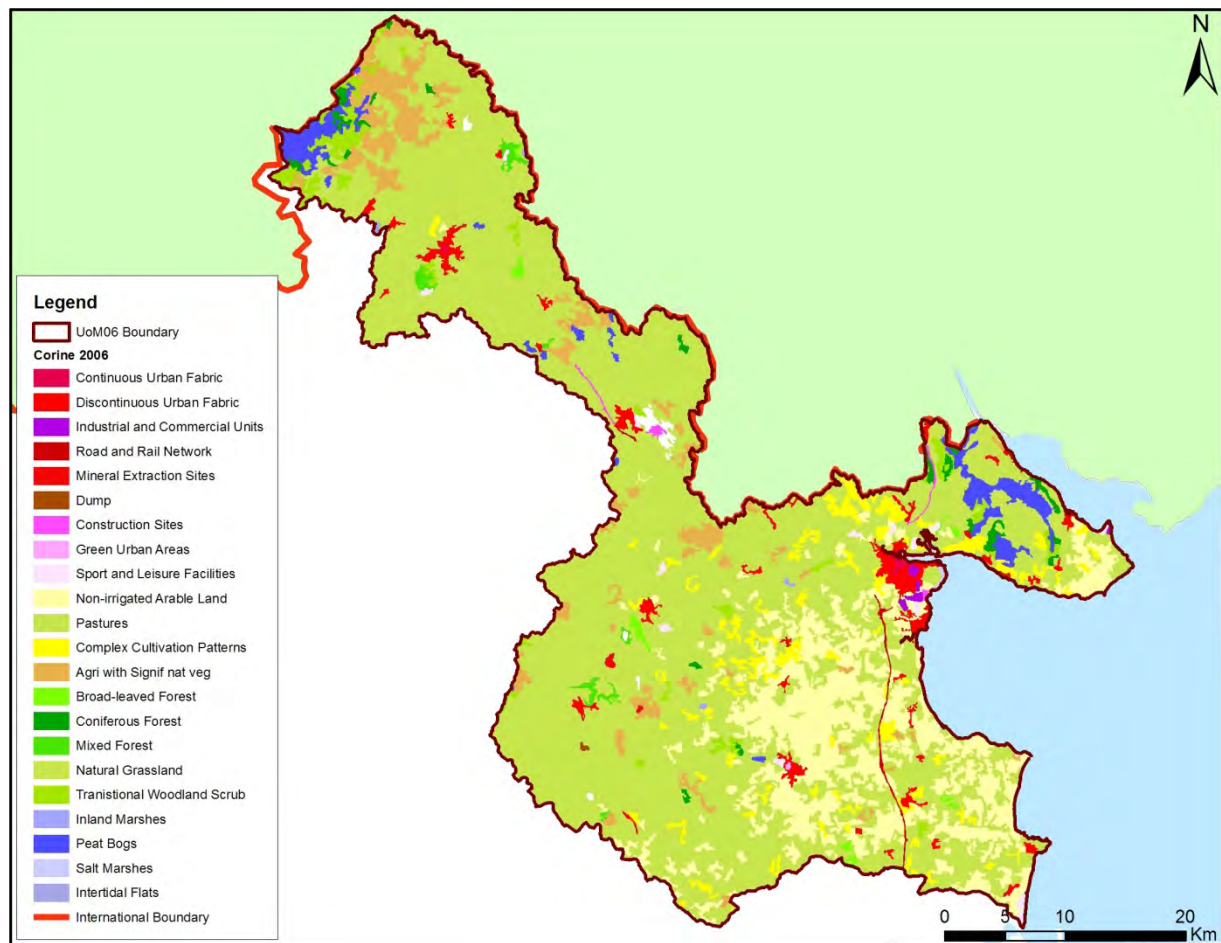


Figure 7.10: UoM 06 Land Use (CORINE 2006)

Pasture is the predominant land use in UoM 06. Overgrazing of soils in areas of commonage is also a source of increased geo-morphological impact due to exposed soils washing into headwaters, increasing flashiness through more rapid run-off and increased sediment load in rivers resulting in increased deposition downstream. Under the Water Framework Directive this pressure was identified as a potential risk to river morphological status in the national context but not within UoM 06, indicating that overgrazing is not an issue, certainly not from a flood risk management perspective.

Arable land coverage is significant in UoM 06 at 14%. As indicated by Figure 7.10 it is predominantly within the low lying flat lands to the south east. Depending on agricultural practices, farming of arable land can lead to increased soil loss to receiving watercourses through ploughing and presence of exposed soils, which will be exacerbated if environmental measures such as buffer strips along river banks are not employed. The models affected are Annagassan and Ardee.

The impact of hydro-geomorphological changes on UoM 06 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.

The issue of sediment transportation and subsequent deposition is identified for further consideration within the hydraulic analysis at the following AFAs:

- Monaghan
- Ardee
- Annagassan
- Dundalk

7.4.4 Arterial Drainage (Channelisation)

A further consideration in UoM 06 is the potential effect of arterial drainage on watercourse channel and floodplain geomorphology. 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 modelled watercourses and their contributing catchments that are affected by arterial drainage within UoM 06 is conveyed by the Arterial Drainage Scheme and Drainage District GIS shapefiles provided by OPW. Rivers within modelled catchments that have been subject to arterial drainage schemes and subsequent channel maintenance are shown in Figure 7.11.

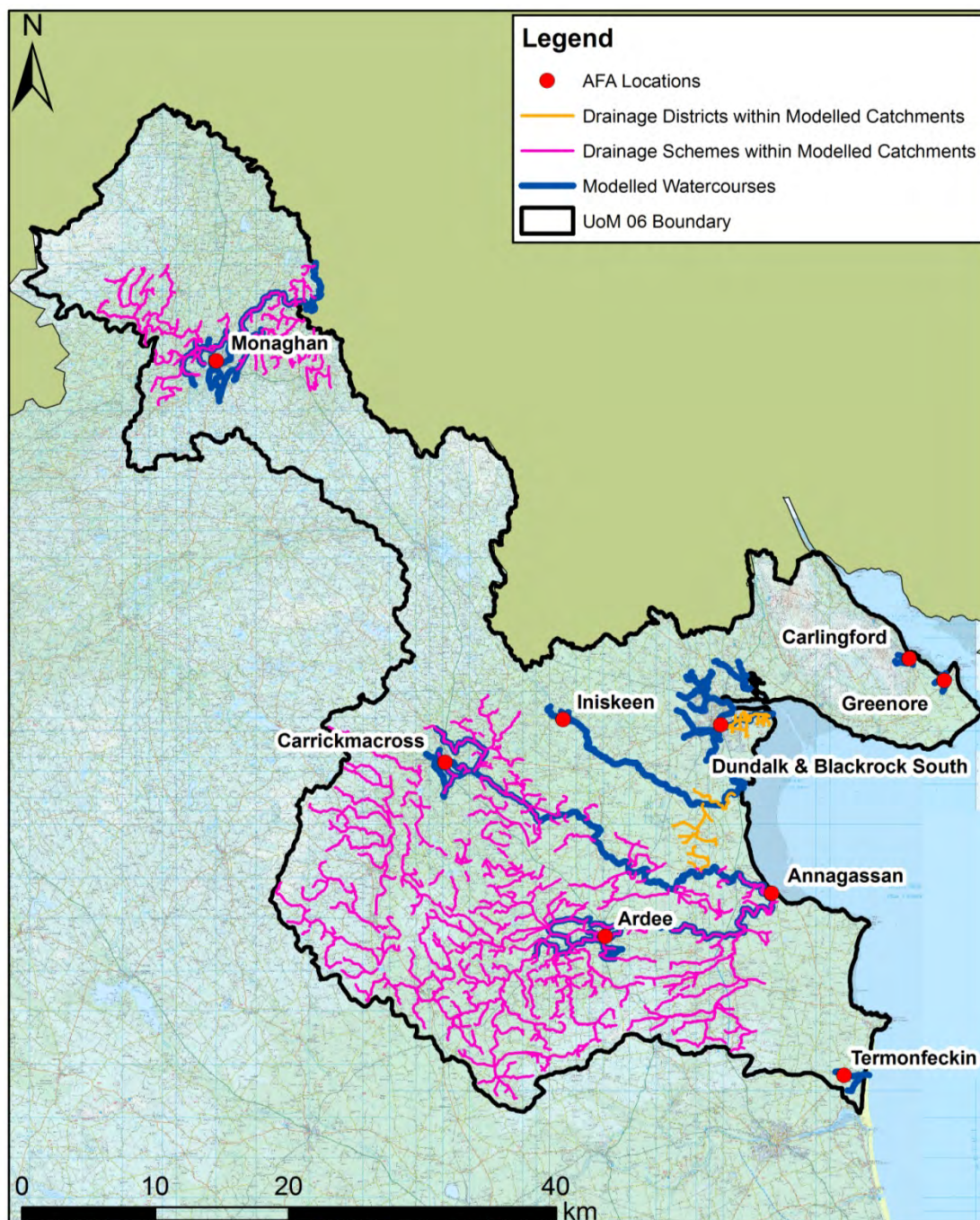


Figure 7.11: Arterial Drainage Schemes within UoM 06 Modelled Catchments

As indicated by Figure 7.11, Monaghan, Carrickmacross, Annagassan and Ardee are located within modelled catchments that have been extensively arterially drained in the past. The Glyde and Dee Arterial Drainage Scheme took place between 1950 and 1957 and was a pilot drainage scheme implemented shortly after the 1945 Arterial Drainage Act. It benefited 10643 hectares of land in terms of drainage for agricultural use. The Monaghan Blackwater Scheme was a smaller more recent scheme that took place between 1984 and 1992 benefitting 2367 hectares of land. Historical drainage has also been undertaken within Dundalk.

In terms of sedimentation of rivers, the initial schemes have had the long term effect of making river courses more susceptible to bed and bank erosion in high flow conditions and resulting siltation. This was due to the removal of natural gravels and bank vegetation. However this impact is more of a consideration in the Glyde and Dee Scheme since it was one of the first to be carried out. Environmental practices evolved over time such that the Monaghan Blackwater Scheme is likely to have had less impact in this regard.

Whilst the initial works took place historically, maintenance activities have since been required to maintain channel capacity by removing silt and debris build up, typically every six years. Maintenance works in itself can be a source of sediment loss if bank vegetation and river buffer zones are not protected. However OPW now employ comprehensive environmental drainage maintenance practices which minimise the risk of sediment loss in light of the Water Framework Directive and other related legislation whilst still fulfilling their statutory duties under the Arterial Drainage Act to maintain channel conveyance capacity from a flood risk perspective.

In terms of the modelled watercourses, the recently acquired channel cross section survey data will reflect the current status of the watercourses in terms of siltation based on the measurements taken for modelling purposes. Therefore the models will reflect present day conditions as closely as possible. During the options analysis stage, the potential for sediment loss from drainage maintenance works and subsequent impact on channel conveyance will be looked at by examining forthcoming drainage maintenance programmes as this in itself is likely to be a flood risk management option that will be considered. However it will be assumed that such maintenance works minimise sediment loss and resulting transport downstream due to the employment of environmental drainage maintenance measures.

7.4.4.1 The Impact of Arterial Drainage Scheme on UoM 06 Hydrology (Q_{med})

The effect of arterial drainage within UoM 06 relates to the River Blackwater system in Monaghan; the River Glyde system in Carrickmacross and Annagassan and the River Dee system in Ardee. These extensive schemes involved river widening and deepening and construction of flood embankments. 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%³. 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).

³ Extracted from Table 13 of FSU Work Package 2.3

In the case of the Glyde and Dee scheme hydrometric data is not available to compare pre and post drainage Q_{med} values as data records for all stations located on these rivers begin in 1975. In the case of the Monaghan Blackwater Scheme, Station 03051 is an FSU rated B station located on the Blackwater River. The FSU AMAX series begins in 1990 stating that arterial drainage took place at this location between 1985 and 1989. Whilst FSU does not include pre-arterial drainage data for this station, EPA did provide flow data at 1 hour intervals from 1975 to 2000. RPS has extracted an AMAX series (running from October to October) for this dataset which is shown graphically on Figure 7.12.

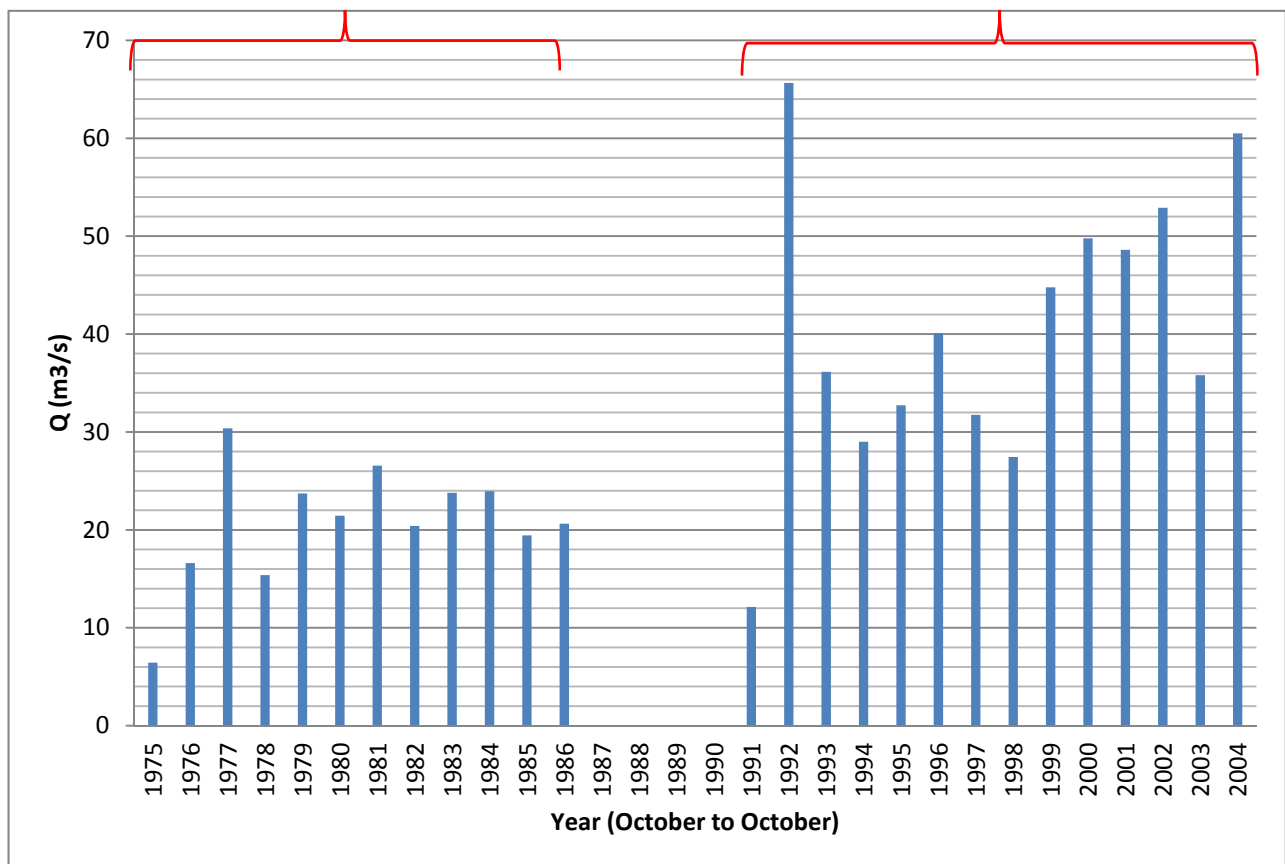


Figure 7.12: AMAX Series at Station 03051 pre and post Arterial Drainage Scheme (Monaghan Blackwater).

Figure 7.12 demonstrates a general increase in AMAX values post drainage scheme at station 03051. The Pre-drainage Q_{med} value is $21\text{m}^3/\text{s}$ whilst the post-drainage Q_{med} value is $40\text{m}^3/\text{s}$ representing an increase of 90%. The post drainage Q_{med} value is the one that has been taken forward for hydrological analysis within this Study as detailed in Section 4.1. The Q_{med} estimated from catchment descriptors using the FSU regression equation includes arterial drainage. The estimate for Station 03051 is in keeping with the post-drainage Q_{med} value as outlined in Section 4.1.

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. The catchment rainfall run-off model at Station 03051 has been generated using the CORINE 2006 database and GSI datasets and have been calibrated against post scheme continuous flow data. As

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. During option development, the importance of channel scheme maintenance in ensuring the channel capacity that can deliver Q_{med} values that are significantly higher than the natural condition will be considered.

7.4.5 River Continuity

River continuity is primarily an environmental concept relating to the linear nature of the river ecosystem and its disruption due to manmade 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.

The risk of impassability may also be an indication of significant hydraulic control and as such is useful in hydraulic modelling. The channel and structure survey undertaken specifically for the North-West Neagh-Bann CFRAM Study includes full geometric survey of these structures and as such ensure their inclusion in the hydraulic modelling phase

7.4.6 Localised Pressures

As well as the catchment based pressures discussed in this report, localised morphological changes can have an impact on channel capacity and the structural integrity of flood defences due to the effects of scour from high sediment loads within rivers. For example known areas of bank erosion within AFAs can undermine existing channel structures. At this stage of the study, data relating to such localised effects within AFAs has not been received for inclusion in this analysis. It is recommended that Progress Group members confirm if such data is available within their organisations that could be of use in the options development process.

7.6 FUTURE SCENARIOS FOR FLOOD RISK MANAGEMENT

The 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 for the design flow adjustment for the mid range (MRFS) and high end (HEFS) future scenarios.

Table 7.9: UoM 06 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	URBEXT multiplied by 2.7 ¹ Susceptible sub-catchments URBEXT = 50% ²	URBEXT multiplied by 11.8 ¹ Susceptible sub-catchments URBEXT = 85% ²
Afforestation	-	-

Note 1: Reflects growth rates of 1% and 2.5% p.a. for mid range and high end future scenarios. To be applied to FSU URBEXT Physical Catchment Descriptor (PCD) up to a maximum of 85%.

Note 2: Applied to areas of sub-catchment or tributary catchment within the AFA which are susceptible to rapid urbanisation but which at present are predominantly undeveloped (i.e. growth rates applied to existing low FSU URBEXT PCD would result in an unrealistically low future scenario URBEXT).

The peak flows for each of the future scenario design events for every HEP can be found in Appendix D.

7.7 POLICY TO AID FLOOD REDUCTION

Considering the projected growth in population predicted within UoM 06 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 some catchments 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.

SuDS policy at a national level is outlined in the OPW document “The Planning System and Flood Risk Management” (November 2009) where guidance on its design and implementation is also provided. 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. The use of retrofitting SuDS in areas of flood risk will be considered as a flood risk management option in the options development phase of this CFRAM Study where appropriate.

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-based, 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 North Western – Neagh Bann CFRAM Study varies greatly due to the quality and availability of observed data. The following 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, sedimentation 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 North Western – Neagh Bann CFRAM Study is subject to further 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 potential 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	Catchment Data ²	Ungauged Flow Estimates ³	Forest-ation ⁴	Urban-isation ⁵	Climate Change ⁶	Sediment-ation ⁷	
1	Monaghan	Low	Medium	Medium / Low	Low	Medium	Medium	Medium	B gauging station downstream of catchment but may not be reflective of many small tribs affecting AFA. Some of the smaller catchments in AFA not defined in FSU. Some potential afforestation in upland catchments not considered a risk but potential for urbanisation in smaller tribs affecting AFA. Peat extraction in upper catchment increases potential for sedimentation. Modelled reaches lowland / meandering but lakes may intercept sediment.
2	Carlingford	n.a.	Medium	Medium / High	Low	Medium	Medium	Low	No gauge data available within catchment. Some catchments not defined in FSU and a high adjustment applied based on nearby station 06030. Urbanisation could impact flows of middle / lower catchment.
3	Greenore	n.a.	Medium	Medium / High	Low	Low	Medium	Low	No gauge data available within catchment. Some catchments not defined in FSU and a high adjustment applied based on nearby station 06030.
4	Dundalk and Blackrock South	n.a.	Medium	Medium / High	Low	Medium / High	Medium	Medium	No gauge data available and Kilcurry River catchment emanates from NI which is not considered in PCDs. High potential for urban growth within small to medium sized catchments. Very flat watercourses within AFA increase potential for sediment deposition.

Model No.	Model Name	Uncertainty / Sensitivity – Present Day Scenario			Uncertainty / Sensitivity – Future Scenarios				Notes
		Observed Flow Data ¹	Catchment Data ²	Ungauged Flow Estimates ³	Forest-ation ⁴	Urban-isation ⁵	Climate Change ⁶	Sediment-ation ⁷	
5	Iniskeen	Low	Low	Medium Low / Low	Low	Low	Medium	Medium Low /	A1 gauge data and all catchments generally well defined. Adjustment based on pivotal site within catchment not applicable due to difference in scale. Unlikely to be much impact on catchment due to land use changes. Fairly flat (Fane River) catchment but consistent slope throughout so negligible risk of sediment deposition
6	Carrickmacross	Low	Medium	Medium High /	Low	Medium	Medium	Medium Low /	A1 gauge data at downstream boundary of catchment but risk from many small ungauged sub-catchments to which pivotal site adjustment is not applicable, a few of which are poorly defined. Urbanisation could impact on these smaller catchments. Catchment flattens out through AFA somewhat but no significant upstream land use that would lead to sedimentation.
7	Ardee	Low	Low	Medium Low /	Low	Medium	Medium	Medium	A1 gauges upstream and downstream of AFA. All catchments generally well defined but pivotal site adjustment not applicable to the smaller catchments within AFA extents. Urbanisation could impact on these smaller catchments. Catchment fairly flat through AFA and potential sediment erosion upstream.
8	Annagassan	Low	Low	Low	Low	Low	Medium	Medium High /	A1 gauges on both rivers upstream of AFA. No small ungauged tribs and large catchments unlikely to be impacted by urbanisation or afforestation. Lowland / meandering reaches and significant confluence point within AFA indicates potential significant risk of sediment deposition.

Model No.	Model Name	Uncertainty / Sensitivity – Present Day Scenario			Uncertainty / Sensitivity – Future Scenarios				Notes
		Observed Flow Data ¹	Catchment Data ²	Ungauged Flow Estimates ³	Forest-ation ⁴	Urban-isation ⁵	Climate Change ⁶	Sediment-ation ⁷	
9	Termonfeckin	n.a.	Low	Medium / Low	Low	Low	Medium	Low	No gauge data from within catchment but catchments well defined. Adjustment based on hydrologically similar A1 catchment gauging station 20km to south on coast. Unlikely to be much impact on catchment due to land use changes.

¹ Observed flow data marked n.a. where there is no gauged data within the modelled catchment to inform the flood flow estimation for the model. Low to high reflects uncertainty in the gauged data at Q_{med} if available.

² Catchment data refers to delineated catchment extents or catchment descriptors. Low to high reflects uncertainty in physical catchment descriptors or catchment delineation.

³ Ungauged flow estimates based on FSU WP 2.3. Dependent on 1 & 2. 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.

⁴ See Section 7.2 Considered to be low risk of uncertainty to hydrological analysis in most of UoM 06. High risk where there is significant risk of forestation of small catchment just upstream of AFA which is the dominant source of flood risk to the catchment.

⁵ See Section 7.3 Considered generally to be a medium to high risk of uncertainty to hydrological analysis in urban areas where potential significant, dense urbanisation is possible which would make up a significant proportion of the catchment. High risk where small catchments largely contained within the AFA extents and potentially subject to high risk of urbanisation.

⁶ See Section 7.1 Considered a medium risk of uncertainty to hydrological analysis in all cases due to the range of projections.

⁷ Sedimentation of channels causing capacity issues or localised impacts on channel structures are to be considered in options development phase of CFRAM Study where relevant. Degree of uncertainty indicated here is based on qualitative assessment of accelerated soil erosion risk due to land use pressures and pathways to watercourses. Considered under future scenarios only as present day sediment conditions are reflected by recently captured channel survey data.

8.2 CONCLUSIONS OF SENSITIVITY ANALYSIS

The assessment of uncertainty and sensitivity in each category is relative within UoM 06. The assessment of uncertainty as being medium or high does not suggest that the analysis is poor but rather in the context of the design flow estimation techniques being employed in the North Western – Neagh Bann CFRAM Study that uncertainty in that category is towards the higher end of the range. For example the modelled watercourse which affects the Termonfeckin AFA is fairly small, ungauged and mainly rural but is well defined in terms of catchment data. However the flow estimation methods used are based on catchment descriptors only. Other sites which are either nearby or hydrologically similar were considered for the transfer of data and an appropriate A1 site was used to increase the robustness of the Q_{med} estimate. However the smaller tributaries within the e.g. Carrickmacross model have not had their initial Q_{med} estimates adjusted using a pivotal site since the options review did not indicate a clear trend towards upwards or downwards adjustment. The use of a pivotal site was therefore not considered to reduce uncertainty associated with the initial Q_{med} estimate and so was not applied. 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. This is common within smaller catchments within UoM 06 due to the lack of gauge data and the disparate nature and small scale of the catchments.

In UoM 06 the largest degree of uncertainty for the present day scenarios is attributed to the ungauged models, Carlingford, Greenore, Dundalk and Blackrock South and also in Carrickmacross due to the dense network of small ungauged tributaries directly affecting the AFA.

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. Within UoM 06 it is considered that urbanisation is not generally a source of high uncertainty in the prediction of future flood flows with the exception of Dundalk and Blackrock South. This AFA is of a size and growing such that large swathes of dense development drained through conventional drainage systems could in the future make up a large proportion of the catchment or sub-catchments. The factors which affect urbanisation are difficult to predict for a 100 year time horizon due to the complex social, cultural and economic factors which affect it. At the upper limit of the predictions large swathes of the smaller catchments on the periphery of towns could become fully urbanised which could more than double some of the index flood flows. There is also the affect of sustainable drainage to consider which adds a further degree of uncertainty depending on the extent to which it is successfully implemented.

Afforestation has not been identified as a potential source of future uncertainty the AFAs in UoM 06 given the sparse coverage in the catchment and the fact that it is unlikely to increase significantly. The impact of hydro-geomorphological changes has been assessed and is considered a source of uncertainty in Monaghan, Carrickmacross, Ardee and particularly Annagassan. This is ultimately a

consideration for flood risk management options and it will be considered through the modelling of options at the hydraulic modelling stage.

9 CONCLUSIONS

Good hydrometric data exists within the larger channels of UoM 06 which is of sufficient quality to be of use for design flow estimation and as such there is generally a high degree of certainty in design flow estimates along main watercourses such as the Monaghan Blackwater, Glyde, Dee, and Fane. The smaller modelled tributaries which enter these watercourses are ungauged and as such there is less confidence in these flow estimates. There are also four models which are completely ungauged. These are located along the coast, Dundalk and Blackrock South, Carlingford, Greenore, and Termonfeckin.

The FSU $Q_{med\ pod}$ equation (WP 2.3) generally tends to overestimate when compared with $Q_{med\ gauged}$ at hydrometric stations. This has had the effect of reducing $Q_{med\ pod}$ estimates at HEPs where these stations are used as pivotal sites. However, in the case of smaller tributaries where downward adjustment was not deemed appropriate, alternative pivotal site options have been reviewed and adjustment factors applied where relevant.

There is good availability of meteorological data, both daily and hourly within and in close proximity to UoM 06. These provide the high temporal resolution data needed for driving the rainfall run-off model that has been undertaken at station 03051. This is the only hydrometric station located on modelled watercourses that has an FSU classification lower than A2 and as such it was considered that NAM modelling would be of benefit. Elsewhere, the good availability of A1 stations already provides high confidence in flow data such that there is no need for additional hydrological modelling.

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 UoM 06 changes that have a high degree of certainty in the projections from those changes which are less certain. Future changes which have a high 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 to which mapped flood extents are to be treated.

9.1 SUMMARY OF THE RESULTS AND GENERAL PATTERNS

The catchment can be characterised hydrologically as follows:

- The catchment has a wide range of climatic and physiographic characteristics. The drier, lowland areas in the Glyde and Dee floodplain have SAAR values as low as 762mm while catchments in the upland areas of Carlingford Mountain have SAAR values in excess of 1200mm.
- Hydrometric data is of good quality and availability for larger channels but is not available for smaller modelled tributaries.
- Meteorological data is of good availability in the catchment.
- Flood behaviour when defined in terms of the growth curve, i.e. in orders of magnitude greater than the median event, is relatively more extreme in the upper catchment than would have been thought based on older methodologies (FSR). This is in line with other more recent, catchment specific studies.
- The 1% AEP flood event ranges from approximately 1.9 to 3.5 times larger than the median flood flow. This compares to approximately 2 under FSR.

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 quality assessed observed data and the latest Irish catchment flood hydrology 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 the use of best practice statistical methods that 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 UoM 06 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 the lack of hydrometric gauge data in the majority of smaller catchments.

Following this cycle of the North Western – Neagh Bann CFRAM Study the main potential adverse impact on the hydrological performance of the catchments is the effect of future changes and in particular the scope for rapid urbanisation of towns. Further rapid urbanisation of the tributary catchments around towns such as Dundalk could significantly increase flood risk if this leads to development which is unsustainable from a drainage perspective.

9.3 OPPORTUNITIES / RECOMMENDATIONS

The lack of available hydrometric data on smaller catchments for use in the study highlights potential opportunities to improve the hydrological analysis further in the next cycle of the North Western – Neagh Bann CFRAM Study:

1. There are seven stations with flow data available located on the modelled reaches within UoM 06. Of these stations five were classified as having a good enough rating such that they were taken forward for use within the Flood Studies Update and four were deemed to have a rating classification of A1 suggesting high confidence at flood flows. If all the stations with flow data are considered which are on or directly upstream or downstream of the rivers to be modelled there are still four out of nine AFAs which can be considered ungauged. Any of these ungauged AFAs would obviously benefit from the addition of a hydrometric gauge.

Recommending that new gauging stations are installed on the ungauged watercourses affecting the AFAs is unrealistic within the timeframe of this or even the next CFRAM Study cycle. Multiplied up nationally this would lead to a long list of gauging stations which would likely remain unrealised at a time when many organisations are rationalising their existing networks and may even obscure the case for those gauging stations which are more acutely needed. A more focussed exercise to identify the most acutely needed gauging stations would be more effectively undertaken following hydraulic modelling and consultation such that the AFAs which are at greatest risk, are most affected by uncertainty in the design flow estimates and which would significantly benefit from additional calibration data are identified as priorities. As such it is recommended that this exercise is undertaken following the hydraulic modelling stage.

In the interim improvements to the existing hydrometric gauge network should focus on improving the ratings through the collection of additional spot flow gaugings at flood flows at the existing stations on, directly upstream or downstream of AFAs:

- 03051 Faulkland (EPA)
- 03058 Cappog Bridge (OPW)
- 06021 Mansfieldstown (OPW)
- 06036 Ladyswell (EPA)

It is assumed that the four gauging stations which currently have a rating of A1 will be maintained to that standard into the foreseeable future.

Furthermore there is a shortage nationally of very small and / or heavily urbanised catchment gauge data and as such new gauging stations on this type of catchment, ideally within a CFRAM Study AFA, could be progressed immediately.

2. Observed rainfall data is generally of limited use for fluvial and coastal flood risk analysis. Its primary usage in this study is in developing catchment runoff models. The main rivers in UoM 06 are generally well gauged and as such any catchment runoff models would only be of benefit in relation to the smaller tributary watercourses affecting the AFAs. In order to achieve the accuracy required this data must be of high temporal resolution (hourly) but must also be accompanied by some calibration (flow) data which is not readily available for these smaller watercourses. Rainfall data may also be useful in relation to hydraulic model calibration for estimating rainfall event return period which can be linked to flood return period. Rainfall data may also be integral to the operation of any flood forecasting system but a recommendation to provide additional infrastructure on that basis would come as a result of risk assessment and optioneering process.

High quality, high temporal resolution rainfall data is currently not being collected directly within UoM 06. There are however a number of hourly rainfall gauges with data available in close proximity to the northern portion of the Unit of Management such that they are useable for rainfall run-off modelling. There are however no hourly rainfall gauges in close proximity to many of the southern catchment. High resolution rainfall data is being collected by Met Éireann at Dublin Airport and if it were to be processed (spatial and temporal adjustment to the daily rain gauge network) this could be used to provide high resolution data across all of the southern catchments within UoM 06. It is therefore recommended that this data is processed and made available for future cycles of the Study.

3. The delineation of cross-border catchments and derivation of associated FSU physical catchment descriptors should be reviewed to ensure potential errors in the data for catchments emanating from Northern Ireland is amended for future cycles.

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APPENDIX A

UOM 06 HYDROMETRIC DATA STATUS TABLE

APPENDIX B

RATING REVIEWS

MOYLES MILL (06011)

The gauging station at Moyles Mill (06011) is located on the River Fane. North West of Inniskeen, County Monaghan approximately 2km upstream of the Lannat River Tributary confluence. The staff gauge is located on the upstream face of a bridge. The channel is approximately 12m wide with a minimum bed level of 53.37 OD Malin and bank levels of 55.2m OD Malin (Right bank) and 55.3m OD Malin (Left bank). The rating review is modelled 1D/2D and has been conducted on MIKE 11, MIKE 21 and MIKE FLOOD software. Water is able to spill onto the flood plain as water level rise higher than the specified bank markers. The gauge zero ordnance level used by OPW is currently 56.26m OD Poolbeg, this converts to 53.56m OD Malin. The staff gauge zero level was surveyed to 53.539m OD Malin. The OPW staff gauge zero level has been used as the basis for this review to ensure consistency with the spot gaugings and existing rating curve.

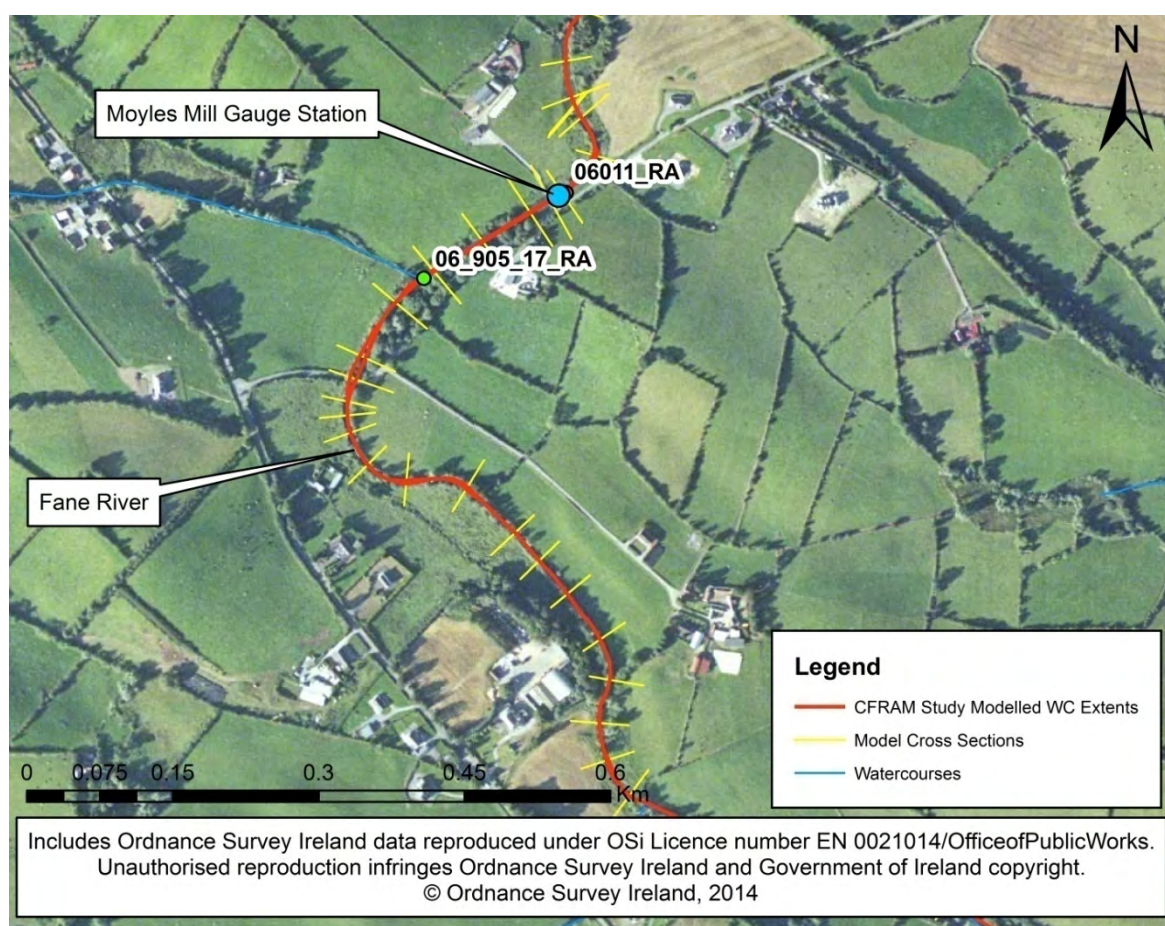


Figure 1: Location of the Moyles Mill Gauging Station

The gauge is operated by the OPW and is currently active. The station has recorded water level information from 01/10/1957. Continuous water level and derived flow records have been provided from 1972 to 2011. The rating review curve and equations have been reviewed / revised by the OPW eight times with the current rating applicable from 01/01/1995. The OPW have provided ratings covering the entire period of data although the rating has significantly changed since 1981, possibly due to the construction of a new bridge at the gauging station. Therefore only the 84 spot gaugings

recorded since 1981 have been used for the rating review. The largest spot gauging during this period is $18.52\text{m}^3/\text{s}$ recorded on 05/01/1982. Q_{med} for this site is estimated to be $15.39\text{m}^3/\text{s}$.

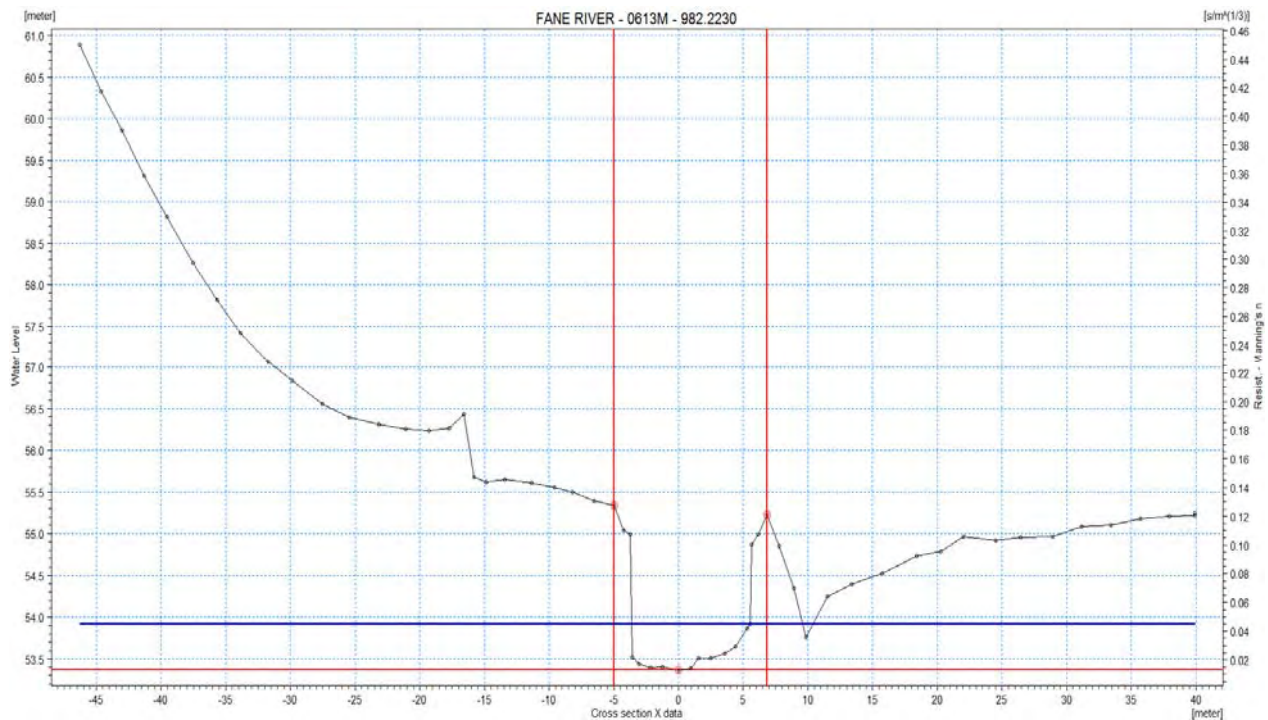


Figure 2: Model Cross-Section at Gauge Location (Top); Photo of Gauge Location (Bottom)

The extent of the River Fane for this model extends approximately 1km upstream from the gauge and approximately 21km downstream through the Inniskeen AFA. There are two tributaries which join the River Fane, the River Lannat (approx 2km downstream of gauge) and the River Inniskeen (approx 2.2km downstream of gauge). There are an additional four millraces modelled. There are sixteen bridge structures in total along this reach of the River Fane. One is located 323m upstream of the gauge, one is at the gauge location and fourteen are downstream of Moyles Mill, the closest of which is approximately 285m away. There are also a number of weirs in the river, one upstream of the gauge and four downstream. The one dimensional hydraulic model uses information from 198 cross sections for the River Fane. The downstream boundary condition applied to this model was calculated as the

critical flow Q-h relationship. The upstream boundary input was set with a hydrograph with a peak flow of $40.35\text{m}^3/\text{s}$ 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 commented on Hydro-data website which states 'Poor quality low flow data - to be used for indicative purposes only'. The National Review under FSU Work Package 2.1 assigned a classification of A1, which means 'confirmed ratings good for flood flows well above Q_{med} with the highest gauged flow greater than $1.3 \times Q_{\text{med}}$ and/or with a good confidence of extrapolation up to 2 times Q_{med} , bankfull or, using suitable survey data, including flows across the flood plain.' There is high confidence in the Q_{med} value from the OPW for the station which is $15.39\text{m}^3/\text{s}$ as the highest flow spot gauging is $18.52\text{m}^3/\text{s}$.

The results of the rating review are shown below in Figure 3. The graph demonstrates the modelled Q-H relationship and shows the comparison with the OPW rating curve and spot gaugings.

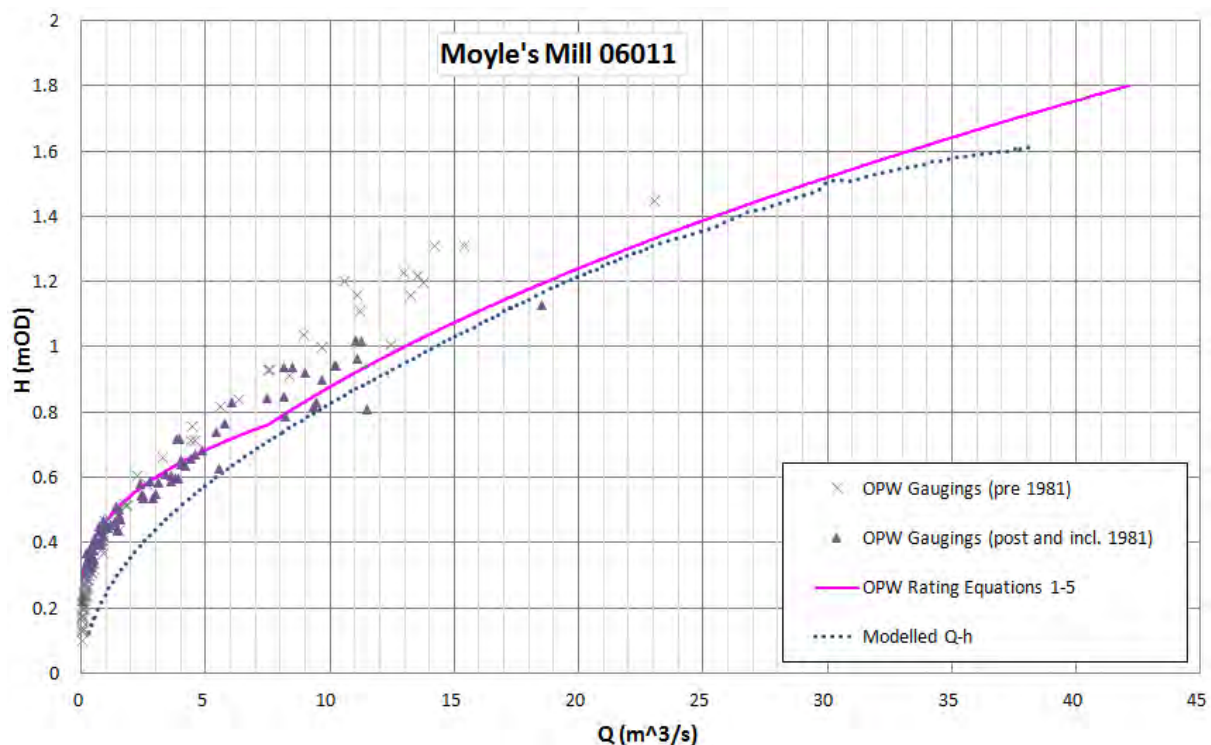


Figure 3: Comparison of Existing OPW Rating Curve and RPS Rating Curve for all flows

Figure 3 shows that the modelled curve does not capture the low flow spot gaugings accurately with the modelled Q-h up to 200mm below the spot gauged flows up to $5\text{m}^3/\text{s}$. An infill survey was commissioned to find a low flow control point and additional cross sections were added to the model but these did not change the shape of the lower curve. The modelled curve is in better agreement with the spot gaugings and second OPW derived equation from approximately 0.8m and up to 1.5m where the modelled curve begins to diverge from the OPW equation once more. The RPS curve is a good match to the highest spot gauge since 1981. Calibration parameters were adjusted including, in-channel roughness, floodplain roughness, bridge inflow and free overflow co-efficients in order to

achieve a match to the low flow spot gaugings yet calibration could not be achieved at low flows and medium to high flows also. Following additional survey the resolution of the 1D model was improved however this did not result in calibration at low flows. All of the spot gaugings were taken at least 15 years ago and it may be the case that there have been changes to the channel and the Q-h relationship in the intervening period. However a new set of rating equations cannot be derived with confidence as calibration to the lower spot gaugings could not be achieved and there is no new data to calibrate a new Q-h relationship to. In light of this it is considered that additional up to date spot gaugings are undertaken to establish if the rating has changed.

The 1D cross sections have a Manning's n value of 0.045 for the channel applied between the left and right bank markers which describes a clean, winding channel with some weeds and stones. This is considered an accurate description of the gauging station reach. The CORINE dataset drives the Manning's n value for the banks as the water levels rise past the markers and spill onto the floodplain which is designated as pastures and has a value of 0.034. These values provide the best fit calibration of the model and have been verified by photographs of the surrounding area.

MANSFIELDSTOWN (06021)

Gauging station 06021 at Mansfieldstown is located on the River Glyde, approximately 10km upstream of its confluence with the River Dee. The gauge is located immediately downstream of a confluence point where a Mill Race of the River Glyde re-joins the main channel. The gauge board and hut are approximately 8m upstream of the skewed L2215 road bridge. The gauge is located in an open channel section approximately 20m wide with a minimum bed level of 5.287m OD Malin and bank levels of 8.735m OD Malin (left bank) and 8.546m OD Malin (right bank). The current ordnance level of the gauge zero is 8.31m OD Poolbeg (as stated by OPW). The location of the gauge and modelled watercourse are shown in Figure 1 below:

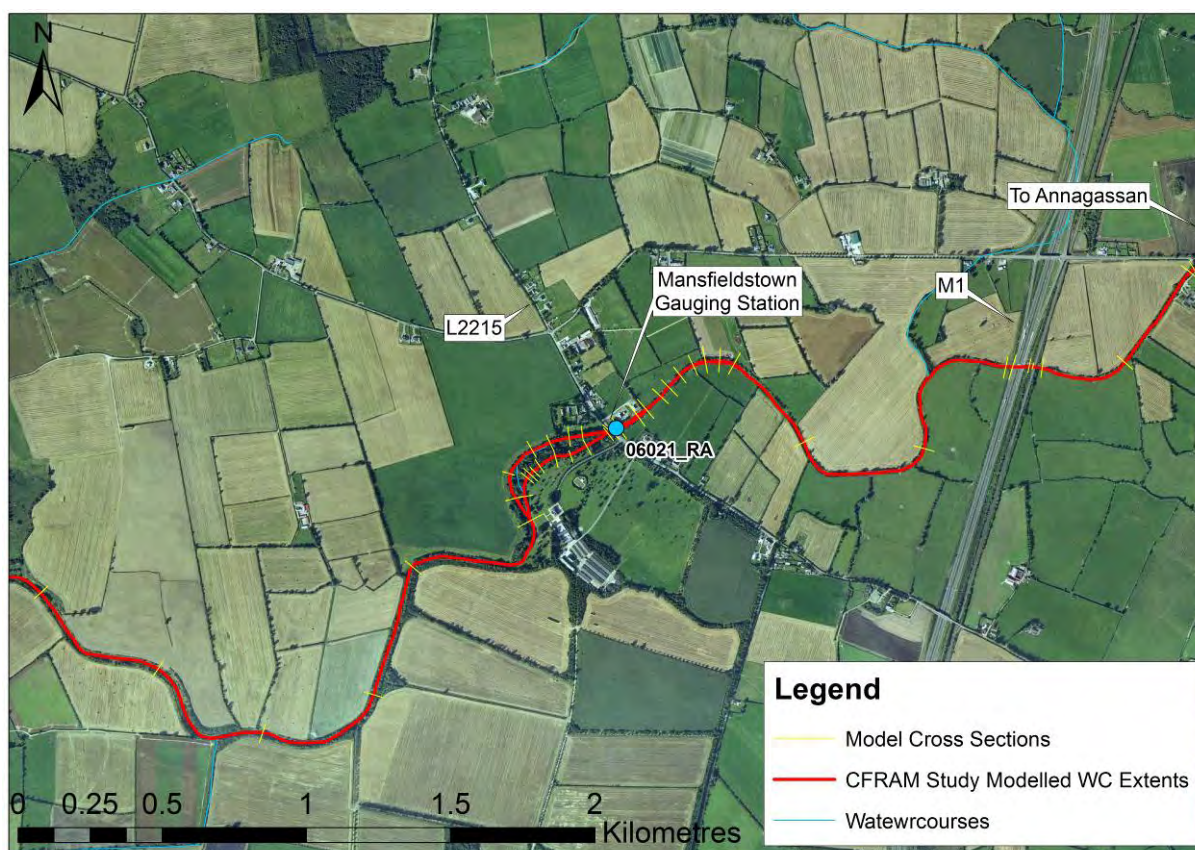


Figure 1: Modelled Watercourse and Gauge Station Location

The gauge is operated by OPW, with continuous water level and derived flow records available from 1955 to 2011.



Figure 2: Model cross-section closest to gauge location (Top); Photo of gauge location (Bottom)

The study reach extends approximately 11km upstream and downstream of the gauge. There are ten bridge structures and two weirs along this reach of the River Glyde. The River Glyde generally meanders but the immediate upstream and downstream approaches to the gauge are relatively straight. The one dimensional hydraulic model uses information from 143 original cross sections. The downstream boundary condition applied to the model was calculated as the critical flow Q-h relationship with the upstream boundary consisting of a hydrograph with a peak flow of $149.0 \text{ m}^3/\text{s}$, equivalent to an estimated 0.1% AEP event.

A review of the spot gaugings reveals an obvious shift in the ratings from 1971 – 1972 onwards and it is noted in the OPW AMAX series that levels up to 1971 are chart levels and post 1971 are staff gauge readings. It is also noted that the rating changed in 1972 with the limit of the rating reduced from $36\text{m}^3/\text{s}$ to $24\text{m}^3/\text{s}$. For these reasons calibration of the rating review model is based on the spot gaugings from 1972 onwards.

OPW have not provided an assessment of the quality of the rating and it was not reviewed under FSU Work Package 2.1. However the highest spot flow gauging post 1972 is $29.11\text{m}^3/\text{s}$ and the reliable limit of the rating is stated as $24\text{m}^3/\text{s}$. Considering that the observed Q_{med} is $21.9\text{m}^3/\text{s}$ it would suggest that there is confidence in the rating up to Q_{med} which would be sufficient to give the rating at least a B classification under FSU Work Package 2.1.

The model was calibrated for low flows by applying a low flow to the start of the hydrograph at the upstream boundary and comparing model outputs with spot gauge data and existing rating curve information. Adjustments were made to the Manning's n values for channel and over bank roughness to reflect vegetation growth and channel roughness in order to develop a realistic model of the channel and flow conditions.

The results of the rating review, including a comparison with the spot gauges since 1995 and the existing rating equation, are shown in Figure C1.2 and Table C1.1. Note that the first two rating equation values are taken from the existing OPW rating curve.

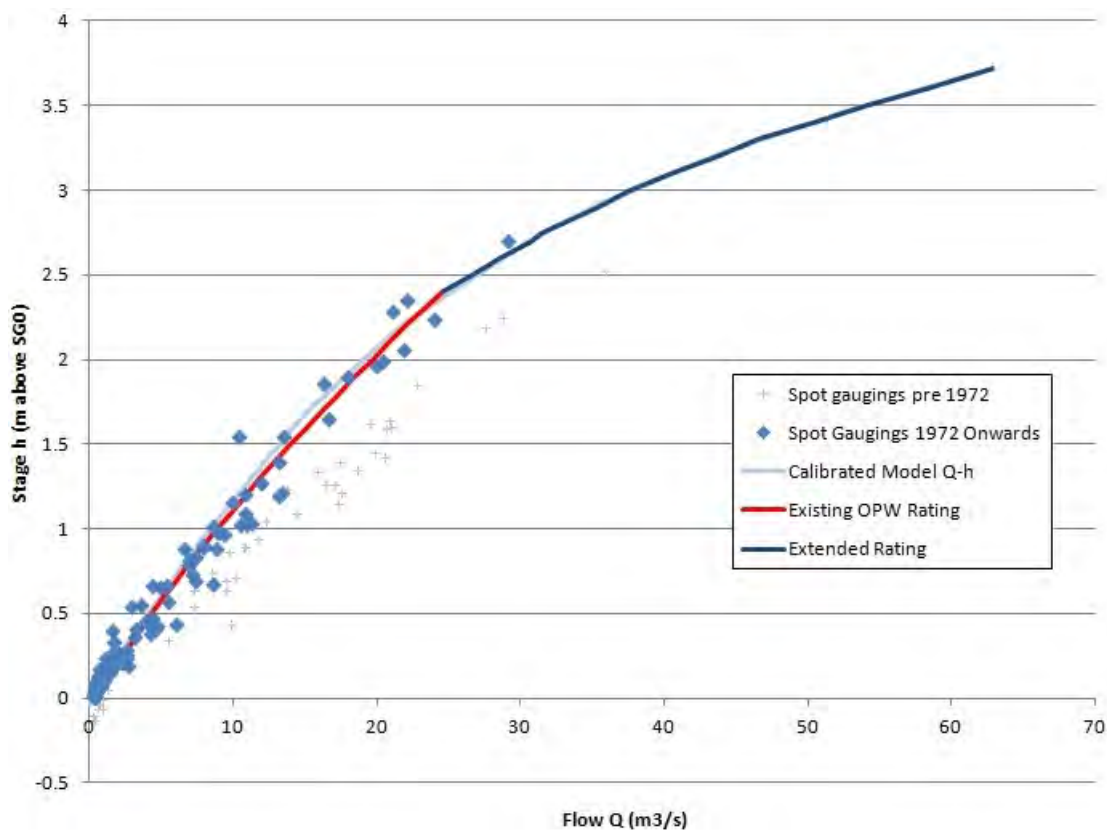


Figure 3: Comparison of Existing OPW Rating Curve and RPS Rating Curve for all flows

Section	Min Stage (m)	Max Stage (m)	C	a	b
1	-0.100	0.270	20	0.2	2.7
2	0.270	2.400	7	0.2	1.31
3	2.400	2.740	15.435	-0.924	1.200
4	2.740	3.000	20	-1.251	1.135
5	3.000	3.300	25	-1.561	1.128
6	3.300	3.717	15	-1.270	1.602

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

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

Table 1: Rating equation values for gauge 06021

Figure 3 shows that the model accurately represents the OPW rating curve based on the lower flow gaugings up to its reliable limit of 24 m³/s. There is some discrepancy in the existing rating and the modelled Q–h relationship in around the range of 10 – 25 m³/s although considering the scatter within the spot gaugings the existing rating and the modelled Q–h can be considered to be a good match. The best fit rating curve was achieved with variable Manning’s n values of 0.03 in-bank and 0.06 out-of-bank. Analysis of the results show that floodwaters remain in bank at the gauged section until water level exceeds approximately 3m on the staff gauge.

BURLEY (06025)

The gauging station at Burley (06025) is located on the River Dee (river reach ID: 0607M) 3.77km west of Ardee, County Louth, approximately 3.8km upstream of the Boharnamoe River. This station is operated by OPW, has 40 years of data and is rated A1 under FSU. The staff gauge and recorder house is located on the left hand bank of an open channel section. The channel is over 30m wide with a minimum bed level of 22.396 OD Malin and bank levels of 26.483mOD Malin (Left bank) and 26.104 OD Malin (Right bank). The current OPW ordnance level of the gauge zero (SG0) level is 24.73m OD Poolbeg (as stated by OPW) which is approximately 100mm lower than the Study surveyed level of 22.128m (OD Malin) however the OPW SG0 level was used for consistency with the existing rating and spot gaugings. The location of the gauge and modelled watercourse are shown in Figure 1 below:

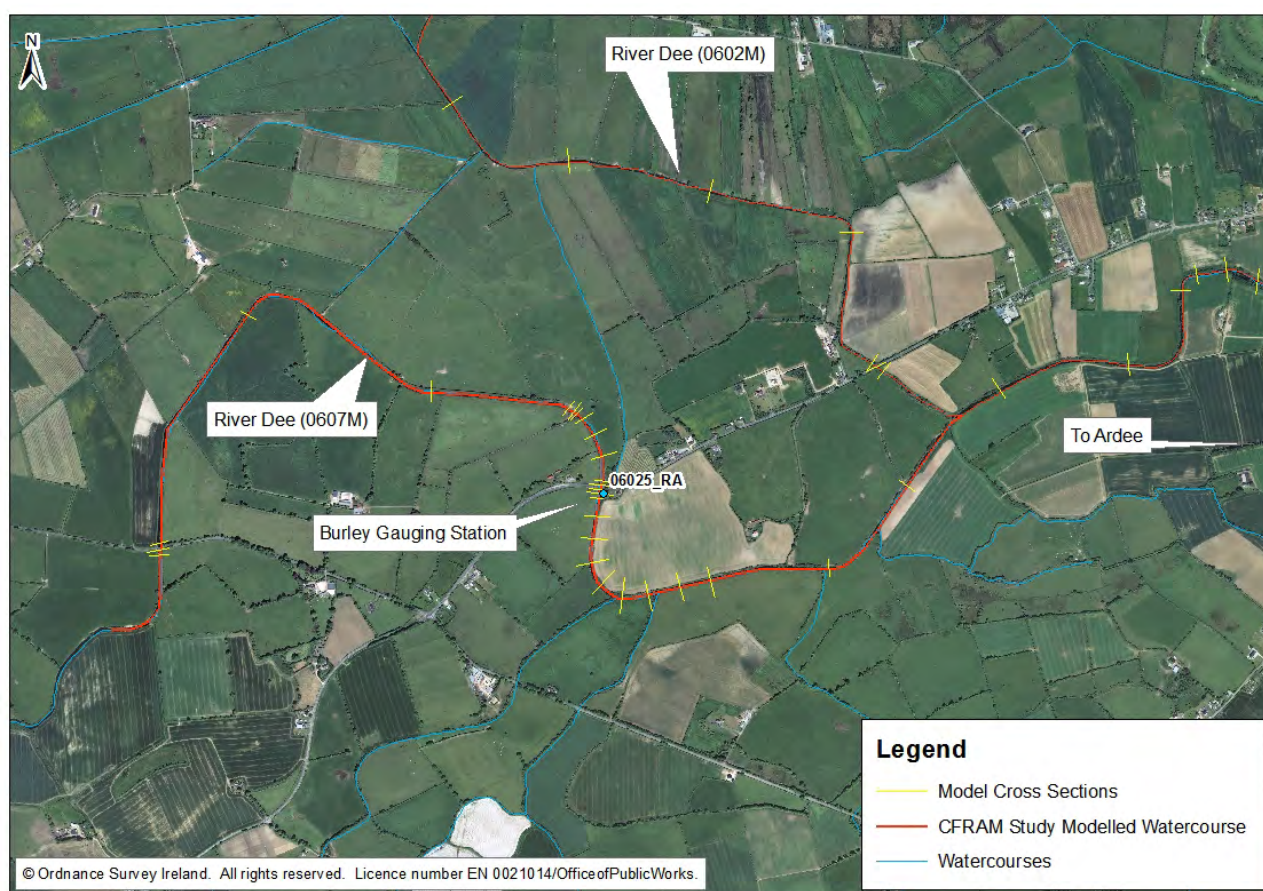


Figure 1: Modelled Watercourse and Gauge Station Location

The gauge is operated by the OPW, with continuous water level and derived flow records from January 1972 to October 2011. A photograph and the surveyed cross section at the gauging station location are shown in Figure 2.

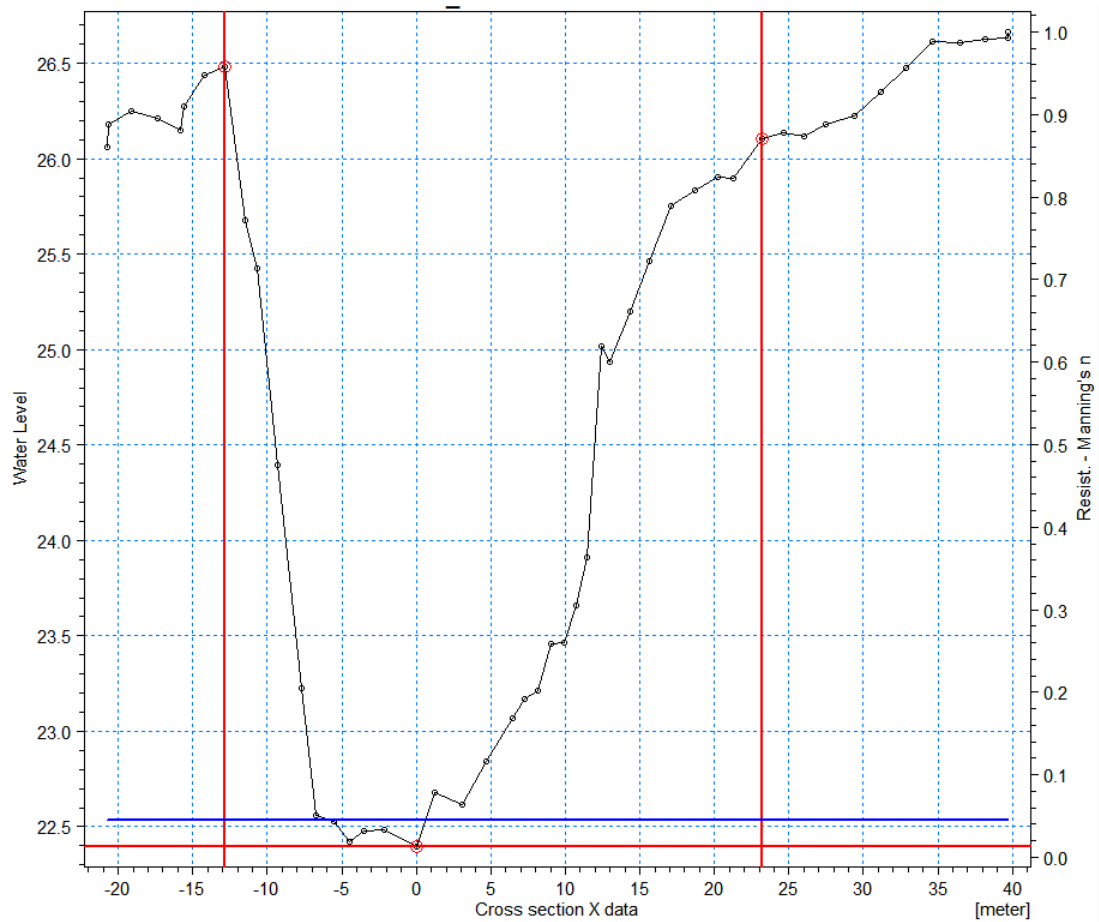


Figure 2: Model cross-section closest to gauge location (Top); Photo of gauge location (Bottom)

The study reach extends approximately 3km in the upstream direction and 15km in the downstream direction of the gauge. There are three bridge structures along this reach, the first is at chainage 388.237, the second is an access bridge approximately 293m upstream of the gauge, the third is a

single span road bridge just upstream of the gauge (shown in Figure 2), the. The one dimensional hydraulic model uses information from 31 cross sections, this includes three bridge structures and one interpolated section. The two dimensional portion of the model extents from the top of bank and was constructed using LiDAR data surveyed as part of the study. The initial upstream boundary input was set with a hydrograph with a peak flow of 47.22 m³/s equivalent to an estimated 0.1% AEP event.

A review of the spot gaugings reveals that the rating was developed in 1972 and the highest spot gauged flow is 26m³/s which is also considered the limit of reliability of the rating. The gauging station was given an A1 classification under FSU Work Package 2.1. this confirms that the rating is good for flood flows well above Q_{med} with the highest gauged flow greater than 1.3 x Q_{med} and/or with a good confidence of extrapolation up to 2 times Q_{med} , bankfull or, using suitable survey data, including flows across the flood plain.

The model was calibrated for low flows by applying a low flow to the start of the hydrograph at the upstream boundary and comparing model outputs with spot gauge data and existing rating curve information. Adjustments were made to the Manning's n values for channel and over bank roughness to reflect vegetation growth and channel roughness in order to develop a realistic model of the channel and flow conditions.

The results of the rating review, including a comparison with the spot gaugings since 1972 and the existing rating equation, are shown in Figure 3 and Table 1.

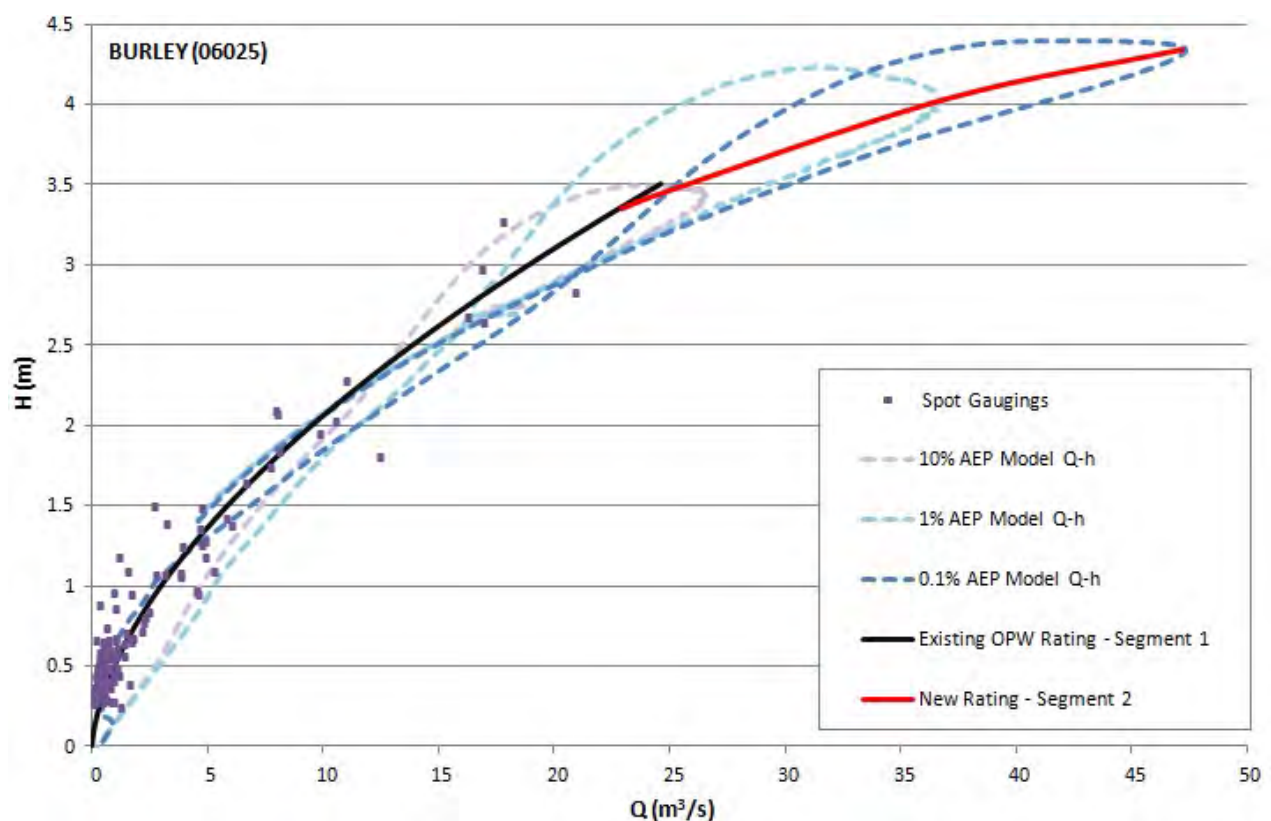


Figure 3: Comparison of Existing OPW Rating Curve and RPS Rating Curve for all flows

Section	Min Stage (m)	Max Stage (m)	C	a	b
1	0.01	3.35	2.76	0.05	1.73
2	3.35	4.031	0.01	2.543	4.362

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

Note: Section 1 is the existing OPW rating curve segment

Table 1: Rating equation values for gauge 06025

Figure 3 plots the results of modelling in 1D only. This is because the results are much more unstable within the 1D/2D model. This is thought to be because of spill points upstream of the bridge with water spilling and returning to the channel at various stage heights within these flat, wide floodplain results. The 1D only results are considered an appropriate representation of the theoretical rating curve as the flow is totally controlled by the bridge orifice upstream and the road embankment prevents 2D flow in the floodplain at the cross section of the gauging station. The 1D only results are smooth and demonstrate the theoretical hydraulic performance clearly. Figure 3 shows that there is some discrepancy in the OPW rating and the modelled Q–h relationship due to a hysteresis effect present within the model and which would not be capable of being reflected within a single rating curve. The hysteresis effect has been displayed on the graph for a number of return periods in order to demonstrate that a wide range of flows may be possible for any particular stage height. The modelled Q-h is in good agreement with the spot gaugings and helps to explain the large amount of scatter within the spot gaugings. The effect demonstrated within the model is considered to be mainly due to the effect of the bridge just upstream. The initial higher velocities for stage heights below 2m are achieved at lower flows as the flood flow rises. At a point in the rising limb the constriction of the bridge forces water levels higher resulting in an 'S' shape to the rising limb. After the flood hydrograph peaks higher velocities, possibly due to the draining out of the head built up at the bridge upstream, and hence higher flows are achieved for flood stage heights above 2.5m.

From the model it can be shown that there are multiple flow values possible for any given stage height, this explains why there is a huge scatter in the spot gaugings. As shown in the graph the 10% AEP modelled Q-h relationship is a good match to many of the spot gaugings above 2.5m on both the rising and receding limb which is considered more likely given that it is closer to flood events which are likely to have occurred within the record length a number of times. The RPS rating curve extension was taken from the intersection point at which the existing rating is considered to have confidence at a stage height of 3.35m, equating to approximately $23\text{m}^3/\text{s}$ in both equations. The extended rating plots through the peak flood flows for a range of events as these can be considered to be the critical flows

for which the gauging station is primarily used and will result in accurate AMAX data. The rating review however demonstrates that the rating must be used with caution, with the flows derived on the rising and the receding limb likely to be inaccurate due to the hysteresis effect discussed.

It is worth noting that a flow above $24 \text{ m}^3/\text{s}$ has never been recorded within the long gauging station record despite being not much larger than Q_{med} . The reason for this became apparent in the 1D/2D modelling where it was found that due to multiple embankment spill points upstream of the gauging station and bridge flows and levels above this are never reached as the wide open floodplain upstream is filled. The 1D only modelled rating is considered appropriate as it represent the theoretical rating above this flow level that would be achieved if the floodplain spilling upstream were to be prevented. It is considered that there is no loss of accuracy within the realistic range up to $24 \text{ m}^3/\text{s}$.

The rating curve extension is a best fit representation of the estimated flow captured within the hysteresis effect curvatures. . The best fit rating curve was achieved with variable Mannings n values of 0.045 in-bank and 0.03 out-of-bank which was considered to be the best representation of the floodplain roughness / vegetation based on photos / survey.

APPENDIX C

NAM OUTPUT

RAINFALL-RUNOFF MODEL AND ITS CALIBRATION

A combined rainfall-runoff model was produced by joining together the NAM and Urban models for the Blackwater (Monaghan) catchment describing both parts, the rural part of the catchment area and the urban part, through various datasets including the Corine landuse and Geological Survey of Ireland spatial datasets. The combined model was calibrated against recorded flow data from the Faulkland hydrometric station and catchment characteristics to simulate appropriate runoff responses.

The combined model was calibrated by adjusting the various NAM and Urban model parameters to appropriately reflect the catchment characteristics and attempt to match the modelled discharge to the recorded data focusing on the portion of the flow data for which there is confidence which in this case was approximately up to Q_{med} . The objectives of the model calibration were to achieve good match between:

1. Simulated and observed catchment runoff (i.e. a good water balance);
2. Simulated and observed hydrograph shapes;
3. Simulated and observed peak flows with respect to timing, rate and volume;
4. Simulated and observed low flows.

To assess the quality of the NAM hydrological model calibration two specific parameters that compare the modelled discharge data with observed or recorded discharge data were used as follows:

- A. *Overall Water Balance Error*: The difference between the average simulated and observed runoff. This is expressed as a percentage.
- B. *Overall Shape of Hydrograph (R^2)*: A measure of the overall shape of the hydrograph based on the *Nash-Sutcliffe coefficient*. A perfect match corresponds to $R^2 = 1$. Note that square root of the Nash-Sutcliffe coefficient equals to the statistical correlation coefficient between the modelled and observed discharge time series.

$$R^2 = 1 - \frac{\sum_{i=1}^N [Q_{obs,i} - Q_{sim,i}]^2}{\sum_{i=1}^N [Q_{obs,i} - \bar{Q}_{obs}]^2}$$

Where:

$Q_{sim,i}$ = simulated discharge at time i

$Q_{obs,i}$ = corresponding observed discharge

Q_{obs} = average observed discharge

Calibrated Mike NAM Model

Catchment code = 36150_RA

Catchment name = Monaghan

Catchment_Name = '03051_RA_NAM'

Catchment_Model = 'NAM'

Catchment_Area = 135.98

Catchment_Name = '03051_RA_URBAN'

Catchment_Model = 'Urban'

Catchment_Area = 6.9

Catchment_Name = '03051_RA'

Catchment_Model = 'Combined'

Catchment_Area = 142.95

Parameter settings

U_Max = 2.83

L_Max = 1

CQOF = 0.594

CKIF = 197.9

CK1 = 2.89

CK12_DIF = true

CK2 = 13.6

TOF = 0.469

TIF = 0

TG = 0.2647

CKBF = 929.43

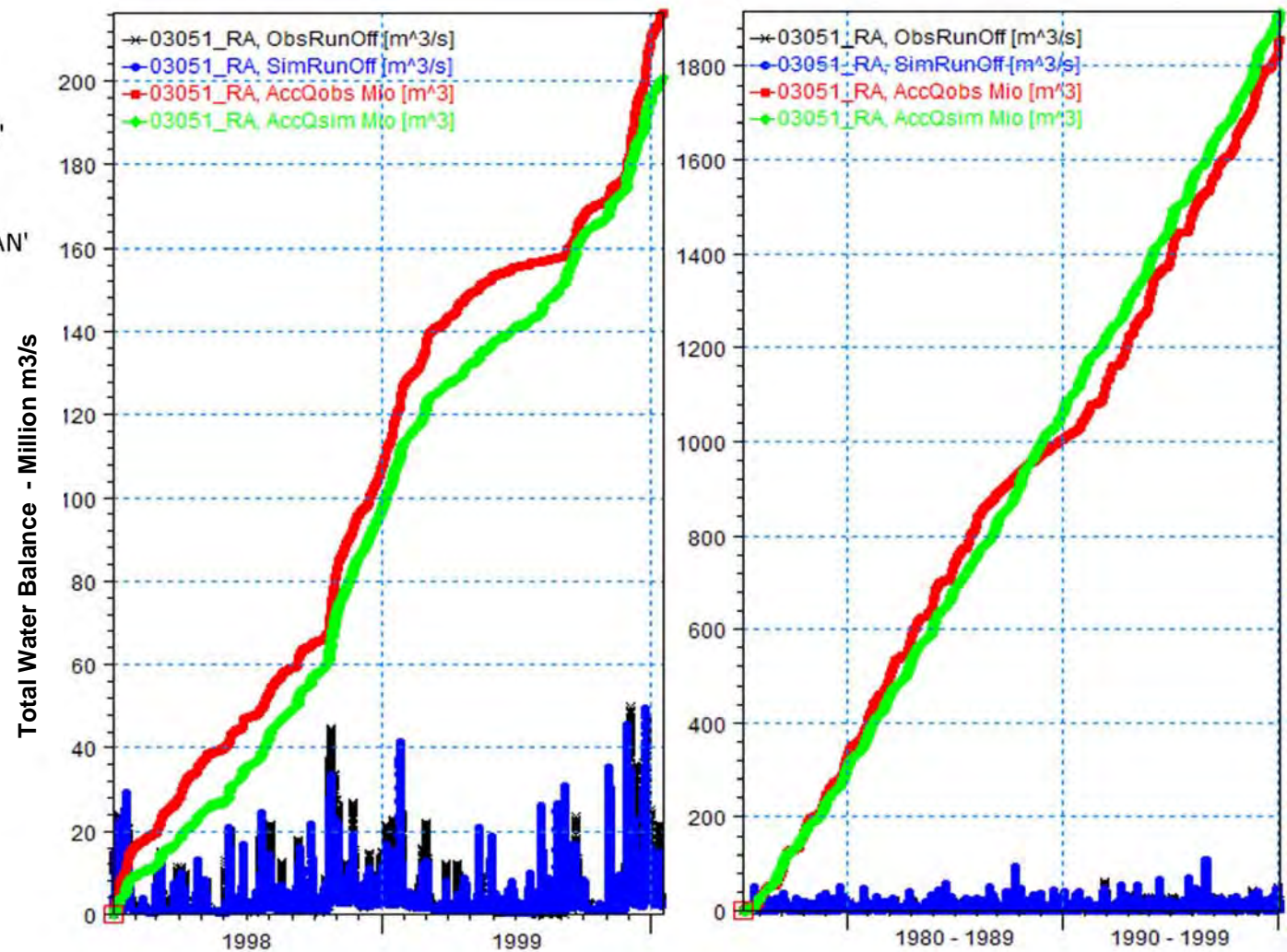
Calibration period

start = 1998, 1, 2, 11, 45, 0

end = 2000, 1, 17, 12, 30, 0

Precipitation data source

station 2437 1



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

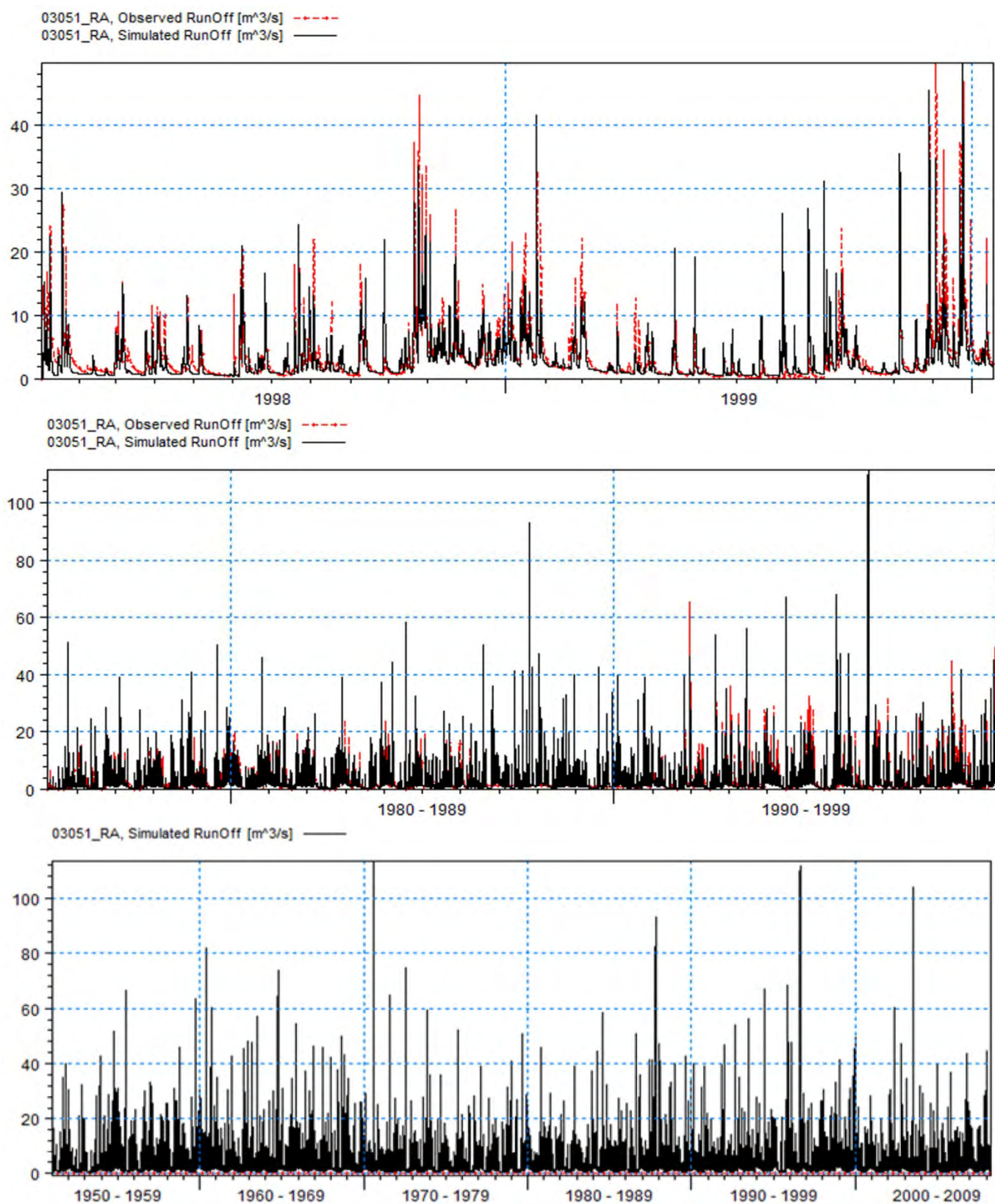
R2 = 0.566

Error measures without missing values

RMSE(Q) = 3.01

Peak-weighted RMSE(Q) = 11.23

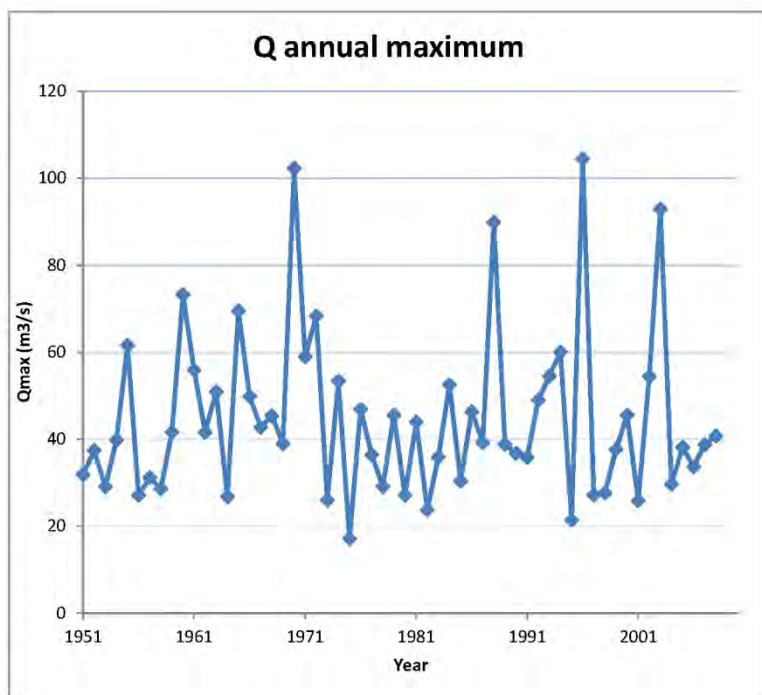
R2 = 0.566



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

Datetime	Qmax	Year
24/08/1951 01:15	31.836	1951
04/11/1951 21:15	37.3999	1952
27/10/1952 07:15	29.0984	1953
03/12/1953 13:15	39.7961	1954
03/07/1955 03:15	61.5944	1955
11/08/1956 03:30	27.0979	1956
23/01/1957 15:15	31.1776	1957
03/06/1958 09:15	28.5571	1958
04/10/1958 10:30	41.6148	1959
05/06/1960 19:30	73.2033	1960
02/10/1960 17:00	55.9252	1961
11/09/1962 20:15	41.5968	1962
18/06/1963 03:15	50.9015	1963
13/06/1964 02:45	26.8205	1964
07-Oct-64	69.5124	1965
25/11/1965 08:15	49.8445	1966
09/12/1966 20:15	42.7017	1967
19/08/1968 16:30	45.3459	1968
31/10/1968 20:15	38.9678	1969
15/08/1970 23:30	102.2798	1970
01/08/1971 22:15	58.9396	1971
31/07/1972 18:00	68.3031	1972
19/08/1973 18:15	25.972	1973
04/11/1973 15:45	53.3699	1974
10/12/1974 23:15	17.1668	1975
02/10/1975 19:15	46.8762	1976
11/02/1977 06:15	36.3858	1977
28/09/1978 11:00	29.1279	1978
01/09/1979 20:15	45.499	1979
26/11/1979 04:15	27.1417	1980
22/10/1980 21:15	43.9606	1981
09/03/1982 19:15	23.7565	1982
23/11/1982 08:15	35.9191	1983
02/08/1984 00:15	52.5006	1984
24/10/1984 20:15	30.3913	1985
06/08/1986 03:15	46.3302	1986
03/06/1987 19:45	39.2417	1987
21/10/1987 18:15	89.8624	1988
13/08/1989 05:00	38.8447	1989
06/02/1990 15:30	36.748	1990
15/10/1990 13:30	35.8157	1991
30/08/1992 06:45	48.9963	1992
11/06/1993 21:00	54.5049	1993
24/06/1994 11:15	60.0631	1994
13/11/1994 09:45	21.429	1995
06/08/1996 07:15	104.4433	1996
25/10/1996 01:30	27.167	1997
18/01/1998 15:30	27.6841	1998
24/01/1999 21:30	37.6419	1999
24/12/1999 19:15	45.5299	2000
08/12/2000 09:15	25.8561	2001
17/05/2002 22:15	54.4246	2002
17/07/2003 23:15	92.8956	2003
29/11/2003 11:45	29.6639	2004
08/01/2005 05:30	38.1216	2005
24/10/2005 05:30	33.6327	2006
11/10/2006 06:30	38.7517	2007
21/01/2008 07:00	40.7583	2008

NAM Qmed 40.70



APPENDIX D

DESIGN FLOWS FOR MODELLING INPUT

Model 1 - Monaghan

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)	
03_114_3_RA	74.50	34.76	34.76	43.93	50.40	57.25	67.26	75.84	85.44	112.58	Model 1
03_184_4_RA	7.14	1.19	1.19	1.73	2.14	2.60	3.31	3.95	4.70	7.00	Model 1
03_373_5_RA	29.07	7.81	7.81	10.76	12.91	15.21	18.67	21.69	25.13	35.17	Model 1
03_179_2_RA	44.03	9.55	9.55	12.98	15.43	18.01	21.82	25.09	28.77	39.25	Model 1
Top-up flow between 03_184_4_RA & 03_179_2_RA	7.82	1.89	1.89	2.57	3.06	3.57	4.32	4.97	5.70	7.77	Model 1
03_344_U_RARPS	0.33	0.19	0.19	0.27	0.34	0.41	0.52	0.62	0.74	1.10	Model 1
03_344_Int_RARPS	1.01	0.54	0.54	0.79	0.97	1.18	1.50	1.79	2.13	3.17	Model 1
Top-up flow between 03_344_U_RA & 03_344_Int_RARPS	0.68	0.37	0.37	0.54	0.67	0.82	1.04	1.24	1.48	2.20	Model 1
03_344_1_RA	1.62	0.84	0.84	1.22	1.52	1.84	2.34	2.80	3.33	4.95	Model 1
Top-up flow between 03_344_Int_RARPS & 03_344_1_RA	0.61	0.34	0.34	0.49	0.61	0.74	0.94	1.12	1.34	1.99	Model 1
03_344_Trib_RARPS	0.13	0.06	0.06	0.08	0.10	0.12	0.16	0.19	0.22	0.33	Model 1
03_474_4_RA	2.59	0.40	0.40	0.58	0.71	0.86	1.10	1.31	1.56	2.33	Model 1
03_474_6_RA	3.00	0.45	0.45	0.65	0.80	0.98	1.24	1.48	1.76	2.62	Model 1
Top-up flow between 03_474_4_RA & 03_474_6_RA	0.40	0.32	0.32	0.47	0.58	0.70	0.89	1.06	1.27	1.88	Model 1
03_113_3_RA	1.88	0.22	0.22	0.33	0.40	0.49	0.62	0.74	0.89	1.32	Model 1
03_113_5_RA	2.13	0.49	0.49	0.71	0.88	1.07	1.37	1.63	1.94	2.89	Model 1
Top-up flow between 03_113_3_RA & 03_113_5_RA	0.25	0.07	0.07	0.10	0.12	0.14	0.18	0.22	0.26	0.39	Model 1
03_450_1_RA	3.52	0.89	0.89	1.29	1.60	1.94	2.47	2.95	3.51	5.23	Model 1
03_451_1_RARPS	0.10	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.06	Model 1
03_451_4_RA	2.13	0.34	0.34	0.50	0.62	0.75	0.95	1.14	1.35	2.02	Model 1
Top-up flow between 03_451_1_RARPS & 03_451_4_RA	2.02	0.33	0.33	0.48	0.59	0.71	0.91	1.09	1.29	1.92	Model 1
03_315_U_RARPS	0.07	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.04	Model 1
03_315_Trib_RARPS	0.54	0.23	0.23	0.33	0.41	0.50	0.64	0.76	0.90	1.35	Model 1
Top-up flow between 03_315_U_RARPS & 03_315_Trib_RARPS	0.47	0.30	0.30	0.44	0.55	0.66	0.84	1.01	1.20	1.78	Model 1
Top-up flow between 03_450_1_RA & 03_315_Trib_RARPS	1.52	0.75	0.75	1.08	1.34	1.63	2.07	2.47	2.94	4.38	Model 1
03_469_U_RARPS	0.32	0.19	0.19	0.28	0.35	0.42	0.54	0.64	0.76	1.13	Model 1
03_469_Trib_RARPS	0.58	0.43	0.43	0.63	0.78	0.94	1.20	1.43	1.71	2.54	Model 1

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)	
Top-up flow between 03_469_U_RARPS & 03_469_Trib_RARPS	0.27	0.24	0.24	0.34	0.42	0.51	0.66	0.78	0.93	1.38	Model 1
03054_RA	9.84	2.97	2.97	4.32	5.34	6.48	8.25	9.85	11.72	17.44	Model 1
Top-up flow between 03_315_Trib_RARPS & 03054_RA	1.55	0.70	0.70	1.02	1.26	1.53	1.94	2.32	2.76	4.11	Model 1
03_479_5_RA	9.87	See 03054									Model 1
03_235_U_RARPS	0.23	0.06	0.06	0.09	0.11	0.13	0.17	0.21	0.24	0.36	Model 1
03_235_2_RA	1.17	0.24	0.24	0.36	0.44	0.53	0.68	0.81	0.97	1.44	Model 1
Top-up flow between 03_235_U_RARPS & 03_235_2_RA	0.94	0.20	0.20	0.29	0.36	0.44	0.55	0.66	0.79	1.17	Model 1
03051_RA	142.97	40.70	40.70	51.40	58.89	66.75	78.18	87.87	98.70	128.94	Model 1
Top-up flow between 03_114_3_RA & 03051_RA	6.52	2.48	2.48	3.13	3.59	4.07	4.76	5.35	6.01	7.85	Model 1
03_334_12_RA	146.78	38.51	38.51	48.64	55.72	63.16	73.98	83.14	93.39	122.00	Model 1
Top-up flow between 03051_RA & 03_334_12_RA	3.81	n.a.	-	-	-	-	-	-	-	-	Model 1
03_425b_Inter_RA	257.31	50.19	50.19	61.63	69.21	76.94	87.73	96.61	106.14	131.59	Model 1
Top-up flow between 03_334_12_RA & 03_425b_Inter_RA	110.54	24.98	24.98	30.68	34.45	38.30	43.67	48.10	52.84	65.51	Model 1
03_399_D_RA	275.11	53.43	53.43	65.61	73.68	81.91	93.40	102.86	113.01	140.10	Model 1
Top-up flow between 03_425b_Inter_RA & 03_399_D_RA	17.80	4.80	4.80	5.89	6.62	7.35	8.39	9.23	10.15	12.58	Model 1
03_296_1_U	1.00	0.37	0.37	0.54	0.67	0.81	1.03	1.23	1.46	2.18	Model 1
03_341_1_RA	1.96	0.62	0.62	0.90	1.11	1.34	1.71	2.04	2.43	3.62	Model 1
03_341_Trib_RA	3.20	0.98	0.98	1.42	1.76	2.13	2.72	3.24	3.86	5.74	Model 1
Top-up flow between 03_341_1_U & 03_341_Trib_RA	1.25	0.38	0.38	0.55	0.67	0.82	1.04	1.25	1.48	2.20	Model 1
03_297_7_RA	7.02	2.04	2.04	2.97	3.67	4.46	5.68	6.78	8.07	12.00	Model 1
Top-up flow between 03_296_1_U & 03_297_7_RA	2.81	0.87	0.87	1.26	1.56	1.89	2.41	2.88	3.42	5.10	Model 1

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)	
03_114_3_RA	74.50	43.32	54.76	62.82	71.35	83.83	94.53	106.49	140.33	82.14	123.61	183.49	Model 1
03_184_4_RA	7.14	1.49	2.16	2.67	3.25	4.13	4.94	5.87	8.74	3.29	6.06	10.73	Model 1
03_373_5_RA	29.07	9.59	13.21	15.85	18.68	22.93	26.63	30.86	43.18	19.32	32.45	52.62	Model 1
03_179_2_RA	44.03	11.78	16.01	19.02	22.20	26.90	30.93	35.46	48.38	23.62	38.40	60.07	Model 1
Top-up flow between 03_184_4_RA & 03_179_2_RA	7.82	4.07	5.54	6.58	7.68	9.31	10.70	12.27	16.74	9.73	15.82	24.74	Model 1
03_344_U_RARPS	0.33	0.36	0.52	0.64	0.78	1.00	1.19	1.42	2.11	0.76	1.41	2.49	Model 1
03_344_Int_RARPS	1.01	1.03	1.50	1.85	2.25	2.86	3.42	4.07	6.05	2.19	4.04	7.16	Model 1
Top-up flow between 03_344_U_RA & 03_344_Int_RARPS	0.68	0.57	0.83	1.03	1.25	1.59	1.89	2.25	3.35	1.52	2.80	4.96	Model 1
03_344_1_RA	1.62	1.61	2.34	2.89	3.51	4.47	5.33	6.35	9.44	3.42	6.31	11.16	Model 1
Top-up flow between 03_344_Int_RARPS & 03_344_1_RA	0.61	0.52	0.75	0.93	1.13	1.44	1.71	2.04	3.03	1.37	2.53	4.49	Model 1
03_344_Trib_RARPS	0.13	0.07	0.10	0.13	0.15	0.20	0.23	0.28	0.41	0.16	0.29	0.51	Model 1
03_474_4_RA	2.59	0.49	0.72	0.89	1.08	1.37	1.64	1.95	2.90	1.09	2.02	3.57	Model 1
03_474_6_RA	3.00	0.56	0.81	1.00	1.22	1.55	1.85	2.20	3.28	1.23	2.27	4.03	Model 1
Top-up flow between 03_474_4_RA & 03_474_6_RA	0.40	0.40	0.58	0.72	0.88	1.12	1.33	1.59	2.36	0.89	1.64	2.90	Model 1
03_113_3_RA	1.88	0.28	0.41	0.50	0.61	0.78	0.93	1.11	1.65	0.62	1.14	2.02	Model 1
03_113_5_RA	2.13	0.61	0.89	1.10	1.34	1.71	2.04	2.42	3.61	1.36	2.50	4.43	Model 1
Top-up flow between 03_113_3_RA & 03_113_5_RA	0.25	0.14	0.21	0.26	0.32	0.40	0.48	0.57	0.85	0.38	0.71	1.26	Model 1
03_450_1_RA	3.52	1.11	1.61	2.00	2.42	3.09	3.69	4.39	6.52	2.45	4.53	8.02	Model 1
03_451_1_RARPS	0.10	0.01	0.02	0.02	0.03	0.03	0.04	0.05	0.07	0.02	0.05	0.08	Model 1
03_451_4_RA	2.13	0.47	0.69	0.85	1.03	1.31	1.57	1.86	2.77	1.63	3.01	5.33	Model 1

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 flow between 03_451_1_RARPS & 03_451_4_RA	2.02	0.66	0.96	1.18	1.43	1.83	2.18	2.59	3.86	1.75	3.22	5.70	Model 1
03_315_U_RARPS	0.07	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.06	0.04	0.07	0.12	Model 1
03_315_Trib_RARPS	0.54	0.42	0.62	0.76	0.93	1.18	1.41	1.68	2.49	0.96	1.77	3.13	Model 1
Top-up flow between 03_315_U_RARPS & 03_315_Trib_RARPS	0.47	0.48	0.69	0.86	1.04	1.33	1.58	1.88	2.80	1.27	2.35	4.16	Model 1
Top-up flow between 03_450_1_RA & 03_315_Trib_RARPS	1.52	1.11	1.61	1.99	2.41	3.07	3.67	4.36	6.49	2.94	5.42	9.60	Model 1
03_469_U_RARPS	0.32	0.32	0.46	0.57	0.69	0.88	1.05	1.25	1.86	0.62	1.14	2.01	Model 1
03_469_Trib_RARPS	0.58	0.56	0.82	1.01	1.23	1.57	1.87	2.22	3.31	1.10	2.02	3.58	Model 1
Top-up flow between 03_469_U_RARPS & 03_469_Trib_RARPS	0.27	0.28	0.41	0.51	0.62	0.79	0.94	1.12	1.66	0.55	1.02	1.80	Model 1
03054_RA	9.84	5.36	7.79	9.63	11.69	14.89	17.78	21.15	31.47	12.72	23.48	41.57	Model 1
Top-up flow between 03_315_Trib_RARPS & 03054_RA	1.55	1.13	1.64	2.03	2.46	3.13	3.74	4.45	6.62	3.00	5.53	9.79	Model 1
03_479_5_RA	9.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Model 1
03_235_U_RARPS	0.23	0.08	0.12	0.14	0.18	0.22	0.27	0.32	0.47	0.23	0.42	0.74	Model 1
03_235_2_RA	1.17	0.32	0.46	0.57	0.69	0.88	1.05	1.24	1.85	0.86	1.58	2.80	Model 1
Top-up flow between 03_235_U_RARPS & 03_235_2_RA	0.94	0.42	0.61	0.75	0.91	1.16	1.39	1.65	2.46	1.11	2.05	3.63	Model 1
03051_RA	142.97	52.82	66.71	76.43	86.62	101.46	114.04	128.08	167.33	118.78	177.23	260.06	Model 1
Top-up flow between 03_114_3_RA & 03051_RA	6.52	3.22	4.06	4.66	5.28	6.18	6.95	7.80	10.19	7.24	10.80	15.84	Model 1
03_334_12_RA	146.78	49.90	63.02	72.20	81.83	95.85	107.73	121.00	158.07	111.52	166.39	244.15	Model 1
Top-up flow between 03051_RA & 03_334_12_RA	3.81	n.a.	-	-	-	-	-	-	-	-	-	-	Model 1
03_425b_Inter_RA	257.31	65.03	79.85	89.67	99.69	113.67	125.18	137.53	170.50	138.50	193.33	263.33	Model 1

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 flow between 03_334_12_RA & 03_425b_Inter_RA	110.54	32.38	39.76	44.65	49.63	56.59	62.32	68.47	84.89	68.95	96.25	131.11	Model 1
03_399_D_RA	275.11	69.23	85.02	95.47	106.13	121.02	133.27	146.43	181.53	147.45	205.83	280.36	Model 1
Top-up flow between 03_425b_Inter_RA & 03_399_D_RA	17.80	6.81	8.36	9.39	10.43	11.90	13.10	14.39	17.84	19.21	26.81	36.52	Model 1
03_296_1_U	1.00	0.55	0.80	0.99	1.20	1.52	1.82	2.16	3.22	1.46	2.69	4.76	Model 1
03_341_1_RA	1.96	0.77	1.12	1.38	1.68	2.14	2.55	3.04	4.52	1.70	3.14	5.55	Model 1
03_341_Trib_RA	3.20	1.22	1.77	2.19	2.66	3.39	4.05	4.82	7.17	2.70	4.97	8.81	Model 1
Top-up flow between 03_341_1_U & 03_341_Trib_RA	1.25	0.50	0.73	0.90	1.09	1.39	1.66	1.97	2.94	2.18	4.03	7.13	Model 1
03_297_7_RA	7.02	2.90	4.21	5.21	6.33	8.06	9.62	11.44	17.03	10.67	19.68	34.85	Model 1
Top-up flow between 03_296_1_U & 03_296_7_RA	2.81	1.70	2.48	3.06	3.72	4.74	5.65	6.73	10.01	4.53	8.36	14.79	Model 1

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 2 - Carlingford

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)	
06_311_U	0.34	0.42	0.42	0.61	0.75	0.91	1.16	1.38	1.65	2.45	Model 2
06_311_D	0.91	1.12	1.12	1.63	2.01	2.45	3.11	3.72	4.42	6.58	Model2
Top-up flow between 06_311_U & 06_311_D	0.57	0.74	0.74	1.08	1.33	1.62	2.06	2.46	2.92	4.35	Model 2
06_446_U	0.36	0.44	0.44	0.64	0.79	0.96	1.22	1.46	1.73	2.58	Model 2
06_823_Trib_RPS	0.73	0.96	0.96	1.39	1.72	2.09	2.66	3.18	3.78	5.62	Model 2
06_446_1_RPS	1.39	1.79	1.79	2.60	3.21	3.90	4.96	5.93	7.05	10.49	Model 2
Top-up flow between 06_446_U & 06_446_1_RPS	0.29	0.51	0.51	0.74	0.92	1.11	1.42	1.69	2.01	2.99	Model 2
06_515_U	0.89	0.37	0.37	0.53	0.66	0.80	1.02	1.21	1.44	2.15	Model 2
06_847_1_RPS	1.09	0.82	0.82	1.19	1.47	1.78	2.27	2.71	3.22	4.79	Model 2
Top-up flow between 06_515_U & 06_847_1_RPS	0.20	0.48	0.48	0.70	0.87	1.05	1.34	1.60	1.91	2.84	Model 2
06_908_2	2.65	3.27	3.27	4.76	5.88	7.14	9.10	10.86	12.92	19.22	Model 2
Top-up flow between 06_446_1_RPS & 06_908_2	0.47	1.16	1.16	1.69	2.08	2.53	3.22	3.85	4.58	6.81	Model 2

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)	
06_311_U	0.34	0.52	0.76	0.94	1.14	1.45	1.73	2.06	3.06	1.01	1.87	3.32	Model 2
06_311_D	0.91	2.28	3.32	4.10	4.98	6.34	7.57	9.01	13.40	4.44	8.20	14.52	Model 2
Top-up flow between 06_311_U & 06_311_D	0.57	2.00	2.91	3.60	4.36	5.56	6.63	7.89	11.74	3.89	7.19	12.72	Model 2
06_446_U	0.36	0.55	0.80	0.99	1.20	1.52	1.82	2.16	3.22	1.07	1.97	3.49	Model 2
06_823_Trib_RPS	0.73	1.39	2.01	2.49	3.02	3.85	4.60	5.47	8.14	2.70	4.98	8.81	Model 2
06_446_1_RPS	1.39	2.65	3.85	4.76	5.78	7.36	8.79	10.46	15.56	5.16	9.52	16.85	Model 2
Top-up flow between 06_446_U & 06_446_1_RPS	0.29	0.95	1.39	1.71	2.08	2.65	3.16	3.76	5.60	1.86	3.43	6.07	Model 2
06_515_U	0.89	0.69	1.00	1.23	1.50	1.91	2.27	2.71	4.03	1.34	2.46	4.36	Model 2

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)	
06_847_1_RPS	1.09	1.56	2.27	2.81	3.41	4.34	5.18	6.16	9.17	3.04	5.61	9.93	Model 2
Top-up flow between 06_515_U & 06_847_1_RPS	0.20	0.63	0.91	1.13	1.37	1.75	2.09	2.48	3.70	1.23	2.26	4.00	Model 2
06_908_2	2.65	6.06	8.81	10.90	13.22	16.84	20.11	23.93	35.60	11.80	21.78	38.56	Model 2
Top-up flow between 06_446_1_RPS & 06_908_2	0.47	1.39	2.02	2.50	3.04	3.87	4.62	5.49	8.17	2.71	5.00	8.85	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 - Greenore

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)	
Mullatee Trib.	0.41	0.16	0.16	0.24	0.30	0.36	0.46	0.55	0.65	0.97	Model 3
06_227_U	1.37	0.40	0.40	0.59	0.72	0.88	1.12	1.34	1.59	2.37	Model 3
06_227_D	1.69	0.49	0.49	0.72	0.89	1.07	1.37	1.63	1.94	2.89	Model 3
Top-up flow between 06_227_U & 06_227_D	0.33	0.11	0.11	0.15	0.19	0.23	0.29	0.35	0.41	0.62	Model 3
06_290_1_RPS	2.15	0.66	0.66	0.96	1.19	1.44	1.84	2.19	2.61	3.88	Model 3
06_1075_2_RPS	3.04	0.94	0.94	1.37	1.69	2.05	2.62	3.12	3.72	5.53	Model 3
Top-up flow between 06_290_1_RPS & 06_1075_2_RPS	0.89	0.30	0.30	0.43	0.53	0.65	0.82	0.98	1.17	1.74	Model 3

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)	
Mullatee Trib.	0.41	0.22	0.32	0.40	0.48	0.62	0.74	0.88	1.30	0.71	1.32	2.33	Model 3
06_227_U	1.37	0.50	0.73	0.90	1.10	1.40	1.67	1.99	2.95	1.11	2.05	3.63	Model 3
06_227_D	1.69	0.61	0.89	1.10	1.34	1.71	2.04	2.43	3.61	1.36	2.50	4.43	Model 3
Top-up flow between 06_227_U & 06_227_D	0.33	0.13	0.19	0.24	0.29	0.36	0.44	0.52	0.77	0.29	0.53	0.95	Model 3
06_290_1_RPS	2.15	0.83	1.20	1.48	1.80	2.29	2.74	3.26	4.84	1.82	3.36	5.95	Model 3
06_1075_2_RPS	3.04	1.17	1.71	2.11	2.56	3.26	3.89	4.63	6.89	2.59	4.78	8.47	Model 3
Top-up flow between 06_290_1_RPS & 06_1075_2_RPS	0.89	0.37	0.54	0.67	0.81	1.03	1.23	1.46	2.17	0.82	1.51	2.67	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.

Model 4 - Dundalk & Blackrock South

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)	
06_1054_1_RA	1.36	0.61	0.61	0.89	1.10	1.33	1.69	2.02	2.41	3.58	Model 4
06_1059_Trib_RPS	3.17	1.02	1.02	1.48	1.83	2.22	2.82	3.37	4.01	5.97	Model 4
06_1078_3_RA	5.50	1.97	1.97	2.86	3.54	4.30	5.48	6.54	7.78	11.57	Model 4
Top-up flow between 06_1054_1 & 06_1078_3	0.96	0.38	0.38	0.56	0.69	0.84	1.07	1.28	1.52	2.26	Model 4
06_1058_2_RA	2.08	0.55	0.55	0.79	0.98	1.19	1.52	1.81	2.15	3.20	Model 4
06_1069_4_RPS	4.31	1.61	1.61	2.36	2.93	3.56	4.55	5.45	6.52	9.80	Model 4
06_1081_D_RA	10.43	2.34	2.34	3.41	4.24	5.15	6.59	7.89	9.43	14.17	Model 4
Top-up flow between 06_1058_2 & 06_1081_D	4.04	0.91	0.91	1.33	1.65	2.00	2.56	3.07	3.66	5.51	Model 4
06_991_2_RA	117.17	17.03	17.03	22.26	25.88	29.62	35.02	39.55	44.56	58.38	Model 4
06_600_2_RA	103.28	13.28	13.28	17.14	19.77	22.45	26.28	29.45	32.91	42.30	Model 4
06_600_4_RA	104.08	13.30	13.30	17.17	19.80	22.49	26.32	29.50	32.97	42.37	Model 4
Top-up flow between 06_600_2_RA & 06_600_4_RA	0.80	0.14	0.14	0.18	0.21	0.23	0.27	0.31	0.34	0.44	Model 4
06032_RA	221.73	27.65	27.65	33.95	38.13	42.38	48.33	53.22	58.47	72.49	Model 4
Top-up flow between 06_991_2 & 06032_RPS	0.48	0.09	0.09	0.11	0.12	0.14	0.15	0.17	0.19	0.23	Model 4
06_1084_1_RA	222.04	27.68	27.68	34.00	38.18	42.44	48.39	53.29	58.55	72.59	Model 4
Top-up flow between 06032_RA & 06_1084_1_RA	0.32	0.06	0.06	0.07	0.08	0.09	0.10	0.11	0.13	0.16	Model 4
06_1055_U	0.10	0.03	0.03	0.04	0.05	0.06	0.07	0.09	0.10	0.15	Model 4
06_1055_2_RA	2.31	0.56	0.56	0.81	1.00	1.21	1.54	1.84	2.19	3.26	Model 4
Top-up flow between 06_1055_U & 06_1055_2	2.22	0.53	0.53	0.77	0.96	1.16	1.48	1.77	2.10	3.13	Model 4
06_1087_U_RA	6.04	1.16	1.16	1.69	2.09	2.53	3.23	3.85	4.58	6.82	Model 4
06_1087_13_RA	7.43	1.51	1.51	2.20	2.72	3.30	4.21	5.02	5.98	8.89	Model 4
Top-up flow between 06_1087_U & 06_1087_13_RA	1.39	0.31	0.31	0.46	0.57	0.69	0.87	1.04	1.24	1.85	Model 4
06_1089_U	0.04	0.02	0.02	0.02	0.03	0.04	0.04	0.05	0.06	0.09	Model 4

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)	
06_1089_4_RA	2.70	1.10	1.10	1.59	1.97	2.39	3.05	3.64	4.33	6.44	Model 4
Top-up flow between 06_1089_U & 06_1089_4_RA	2.67	1.08	1.08	1.57	1.95	2.36	3.01	3.59	4.27	6.36	Model 4
06_DDalk_D_RARPS	239.30	28.46	28.46	34.94	39.24	43.62	49.74	54.78	60.18	74.61	Model 4
Top-up flow between 06_1084_1_RA & 06_Ddalk_D	4.82	0.73	0.73	0.90	1.01	1.12	1.28	1.41	1.55	1.92	Model 4
06_913_U	8.21	1.27	1.27	1.85	2.28	2.77	3.53	4.22	5.02	7.46	Model 4
06_913_4_RPS	9.38	1.50	1.50	2.18	2.70	3.27	4.17	4.97	5.92	8.80	Model 4
Top-up flow between 06_913_U_RA & 06_913_4_RA	1.17	0.21	0.21	0.31	0.38	0.47	0.59	0.71	0.84	1.25	Model 4
06_242_U	0.72	0.22	0.22	0.31	0.39	0.47	0.60	0.72	0.85	1.27	Model 4
06_242_4_RPS	2.78	0.72	0.72	1.05	1.30	1.58	2.01	2.40	2.85	4.24	Model 4
Top-up flow between 06_242_U & 06_242_4_RPS	2.06	0.54	0.54	0.79	0.98	1.19	1.51	1.81	2.15	3.20	Model 4
06_147_U	0.03	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	Model 4
06_Trib_Ddalk_U	0.07	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.03	Model 4
06_Trib_Ddalk_1	0.63	0.04	0.04	0.06	0.08	0.10	0.12	0.15	0.17	0.26	Model 4
Top-up flow between 06_Trib_Ddalk_U & 06_Trib_Ddalk_1	0.56	0.04	0.04	0.06	0.07	0.09	0.11	0.13	0.15	0.23	Model 4
06_147_4_RPS	2.15	0.42	0.42	0.61	0.75	0.91	1.16	1.39	1.65	2.46	Model 4
Top-up flow between 06_147_U & 06_147_4_RPS	1.49	0.30	0.30	0.43	0.53	0.65	0.82	0.98	1.17	1.74	Model 4
06_918_U	0.22	0.05	0.05	0.07	0.09	0.11	0.14	0.16	0.20	0.29	Model 4
06_918_1	0.53	0.11	0.11	0.17	0.21	0.25	0.32	0.38	0.45	0.67	Model 4
Top-up flow between 06_918_U & 06_918_1	0.31	0.07	0.07	0.10	0.13	0.15	0.19	0.23	0.28	0.41	Model 4
06036_RPS	17.39	3.00	3.00	4.42	5.52	6.76	8.73	10.53	12.68	19.42	Model 4
Top-up flow between 06_913_4_RPS & 06036_RPS	2.55	0.65	0.65	0.96	1.20	1.47	1.90	2.29	2.75	4.22	Model 4
06_318_Inter	17.46	3.08	3.08	4.53	5.66	6.93	8.94	10.78	12.98	19.89	Model 4
Top-up flow between 06036_RPS & 06_318_Inter	0.07	0.02	0.02	0.03	0.03	0.04	0.05	0.06	0.08	0.12	Model 4
06_1038_D	5.45	2.09	2.09	3.03	3.75	4.55	5.80	6.92	8.23	12.25	Model 4

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)	
06_318_D	0.96	0.43	0.43	0.62	0.77	0.93	1.19	1.42	1.69	2.51	Model 4
06_315_U_RA	1.13	0.17	0.17	0.25	0.31	0.38	0.48	0.58	0.69	1.02	Model 4
06_315_5_RA	2.79	0.43	0.43	0.62	0.77	0.93	1.19	1.42	1.69	2.51	Model 4
Top-up flow between 06_315_U_RA & 06_315_5_RA	1.67	0.27	0.27	0.39	0.48	0.58	0.74	0.89	1.06	1.57	Model 4
06_0616A_U	1.37	0.34	0.34	0.49	0.60	0.73	0.93	1.11	1.32	1.97	Model 4
06_0616A_D	3.21	0.69	0.69	1.01	1.24	1.51	1.92	2.30	2.73	4.07	Model 4
Top-up flow between 06_0616A_U & 06_0616A_D	1.84	0.43	0.43	0.63	0.77	0.94	1.20	1.43	1.70	2.53	Model 4

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)	
06_1054_1_RA	1.36	1.14	1.67	2.06	2.49	3.17	3.79	4.52	6.72	2.24	4.10	7.27	Model 4
06_1059_Trib_RPS	3.17	1.28	1.85	2.29	2.78	3.53	4.22	5.02	7.47	3.36	6.20	10.98	Model 4
06_1078_3_RA	5.50	3.11	4.52	5.59	6.79	8.65	10.32	12.28	18.27	9.49	17.54	31.03	Model 4
Top-up flow between 06_1054_1 & 06_1078_3	0.96	0.70	1.03	1.27	1.54	1.96	2.35	2.79	4.15	1.87	3.47	6.13	Model 4
06_1058_2_RA	2.08	0.68	0.98	1.21	1.47	1.88	2.24	2.66	3.96	1.49	2.75	4.87	Model 4
06_1069_4_RPS	4.31	2.41	3.54	4.39	5.33	6.82	8.16	9.77	14.68	8.22	15.29	27.49	Model 4
06_1081_D_RA	10.43	3.08	4.48	5.57	6.77	8.66	10.37	12.39	18.62	9.15	17.03	30.58	Model 4
Top-up flow between 06_1058_2 & 06_1081_D	4.04	1.99	2.90	3.60	4.37	5.59	6.70	7.99	12.03	5.32	9.91	17.78	Model 4
06_991_2_RA	117.17	21.26	27.79	32.31	36.98	43.73	49.38	55.64	72.90	39.70	60.67	89.56	Model 4
06_600_2_RA	103.28	16.92	21.83	25.19	28.60	33.48	37.52	41.92	53.89	36.29	54.06	77.65	Model 4
06_600_4_RA	104.08	16.91	21.83	25.17	28.59	33.46	37.51	41.92	53.87	35.96	53.57	76.95	Model 4
Top-up flow between 06_600_2_RA & 06_600_4_RA	0.80	0.18	0.23	0.26	0.29	0.34	0.39	0.43	0.55	0.38	0.56	0.79	Model 4
06032_RA	221.73	34.58	42.46	47.69	53.01	60.45	66.57	73.13	90.67	63.39	88.47	120.50	Model 4
Top-up flow between 06_991_2 & 06032_RPS	0.48	0.11	0.13	0.15	0.17	0.18	0.21	0.23	0.28	0.20	0.28	0.38	Model 4

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)	
06_1084_1_RA	222.04	34.63	42.54	47.77	53.10	60.54	66.67	73.25	90.82	63.48	88.61	120.70	Model 4
Top-up flow between 06032_RA & 06_1084_1_RA	0.32	0.13	0.15	0.17	0.19	0.21	0.23	0.28	0.34	0.25	0.34	0.50	Model 4
06_1055_U	0.10	0.03	0.04	0.05	0.07	0.08	0.10	0.11	0.16	0.07	0.12	0.20	Model 4
06_1055_2_RA	2.31	0.69	1.00	1.24	1.50	1.91	2.28	2.71	4.03	1.52	2.80	4.96	Model 4
Top-up flow between 06_1055_U & 06_1055_2	2.22	1.17	1.69	2.11	2.55	3.26	3.90	4.62	6.89	3.12	5.76	10.18	Model 4
06_1087_U_RA	6.04	1.45	2.11	2.61	3.16	4.04	4.81	5.73	8.53	3.21	5.91	10.47	Model 4
06_1087_13_RA	7.43	1.90	2.78	3.43	4.16	5.31	6.33	7.54	11.21	4.68	8.63	15.29	Model 4
Top-up flow between 06_1087_U & 06_1087_13_RA	1.39	0.67	0.99	1.23	1.49	1.88	2.25	2.68	4.00	1.82	3.32	5.91	Model 4
06_1089_U	0.04	0.02	0.02	0.03	0.05	0.05	0.06	0.07	0.10	0.07	0.12	0.21	Model 4
06_1089_4_RA	2.70	2.20	3.17	3.93	4.77	6.09	7.27	8.65	12.86	4.26	7.87	13.93	Model 4
Top-up flow between 06_1089_U & 06_1089_4_RA	2.67	2.17	3.15	3.91	4.74	6.04	7.20	8.57	12.76	4.24	7.81	13.83	Model 4
06_DDalk_D_RARPS	239.30	36.06	44.27	49.71	55.26	63.02	69.40	76.24	94.52	69.96	97.66	133.01	Model 4
Top-up flow between 06_1084_1_RA & 06_Ddalk_D	4.82	1.55	1.91	2.15	2.38	2.72	3.00	3.29	4.08	3.17	4.43	6.03	Model 4
06_913_U	8.21	1.59	2.31	2.85	3.46	4.41	5.27	6.27	9.32	3.50	6.48	11.45	Model 4
06_913_4_RPS	9.38	1.87	2.71	3.36	4.07	5.19	6.18	7.37	10.95	4.13	7.60	13.45	Model 4
Top-up flow between 06_913_U_RA & 06_913_4_RA	1.17	0.27	0.39	0.48	0.59	0.75	0.90	1.06	1.58	0.59	1.10	1.94	Model 4
06_242_U	0.72	0.27	0.38	0.48	0.58	0.74	0.88	1.04	1.56	0.59	1.09	1.91	Model 4
06_242_4_RPS	2.78	0.89	1.30	1.61	1.96	2.49	2.98	3.54	5.26	2.03	3.75	6.63	Model 4
Top-up flow between 06_242_U & 06_242_4_RPS	2.06	1.17	1.71	2.12	2.58	3.27	3.92	4.66	6.93	3.14	5.80	10.25	Model 4
06_147_U	0.03	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	Model 4
06_Trib_Ddalk_U	0.07	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	Model 4
06_Trib_Ddalk_1	0.63	0.06	0.09	0.13	0.16	0.19	0.24	0.27	0.41	0.25	0.48	0.82	Model 4
Top-up flow between 06_Trib_Ddalk_U & 06_Trib_Ddalk_1	0.56	0.08	0.11	0.13	0.17	0.21	0.25	0.29	0.44	0.20	0.37	0.65	Model 4

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)	
06_147_4_RPS	2.15	0.55	0.80	0.98	1.19	1.51	1.81	2.15	3.21	1.58	2.93	5.18	Model 4
Top-up flow between 06_147_U & 06_147_4_RPS	1.49	0.62	0.88	1.09	1.33	1.68	2.01	2.40	3.57	1.61	2.97	5.28	Model 4
06_918_U	0.22	0.07	0.10	0.12	0.15	0.19	0.22	0.28	0.40	0.26	0.47	0.85	Model 4
06_918_1	0.53	0.16	0.25	0.30	0.36	0.46	0.55	0.65	0.97	0.64	1.16	2.05	Model 4
Top-up flow between 06_918_U & 06_918_1	0.31	0.14	0.20	0.26	0.30	0.38	0.46	0.56	0.81	0.38	0.67	1.20	Model 4
06036_RPS	17.39	4.01	5.91	7.38	9.04	11.67	14.08	16.95	25.96	12.76	24.34	44.89	Model 4
Top-up flow between 06_913_4_RPS & 06036_RPS	2.55	1.02	1.50	1.88	2.30	2.98	3.59	4.31	6.61	2.78	5.30	9.77	Model 4
06_318_Inter	17.46	4.23	6.22	7.78	9.52	12.28	14.81	17.83	27.33	16.78	31.96	58.98	Model 4
Top-up flow between 06036_RPS & 06_318_Inter	0.07	0.02	0.04	0.04	0.05	0.06	0.07	0.10	0.15	0.08	0.16	0.32	Model 4
06_1038_D	5.45	2.99	4.34	5.37	6.52	8.31	9.91	11.79	17.55	5.82	10.74	19.01	Model 4
06_318_D	0.96	0.56	0.80	1.00	1.20	1.54	1.84	2.19	3.25	1.08	1.99	3.52	Model 4
06_315_U_RA	1.13	0.26	0.39	0.48	0.59	0.74	0.90	1.07	1.58	0.88	1.65	2.90	Model 4
06_315_5_RA	2.79	0.72	1.06	1.31	1.60	2.04	2.42	2.88	4.29	2.01	3.72	6.58	Model 4
Top-up flow between 06_315_U_RA & 06_315_5_RA	1.67	0.46	0.67	0.82	0.99	1.27	1.53	1.82	2.69	1.22	2.26	3.98	Model 4
06_0616A_U	1.37	0.54	0.77	0.95	1.15	1.47	1.75	2.08	3.11	1.02	1.90	3.36	Model 4
06_0616A_D	3.21	1.17	1.71	2.10	2.55	3.25	3.89	4.61	6.88	2.27	4.21	7.45	Model 4
Top-up flow between 06_0616A_U & 06_0616A_D	1.84	0.71	1.03	1.26	1.54	1.97	2.35	2.79	4.15	1.37	2.54	4.50	Model 4

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 5 - Inniskeen

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)	
06011_RA	208.622	15.39	15.39	18.90	21.22	23.59	26.90	29.63	32.55	40.35	Model 5
06_905_17_RA	13.421	1.97	1.97	2.84	3.50	4.22	5.33	6.33	7.50	11.03	Model 5
06_345_U_RARPS	0.27	0.07	0.07	0.10	0.13	0.15	0.20	0.23	0.28	0.42	Model 5
06_345_1_RARPS	0.409	0.10	0.10	0.15	0.19	0.23	0.29	0.35	0.41	0.61	Model 5
Top-up flow between 0_345_U_RARPS & 06_345_1_RARPS	0.139	0.04	0.04	0.06	0.07	0.08	0.11	0.13	0.15	0.22	Model 5
06_92_1_RA	224.017	17.37	17.37	21.33	23.95	26.62	30.36	33.43	36.73	45.54	Model 5
Top-up flow between 06011_RA & 06_92_1_RA	1.565	0.27	0.27	0.33	0.37	0.41	0.46	0.51	0.56	0.70	Model 5
06_997_2_RA	6.953	0.98	0.98	1.43	1.77	2.15	2.73	3.26	3.88	5.78	Model 5
06_997_3_RA	7.02	1.04	1.04	1.51	1.87	2.26	2.88	3.44	4.10	6.10	Model 5
Top-up flow between 06_997_2_RA & 06_997_3_RA	0.067	0.01	0.01	0.02	0.02	0.03	0.04	0.04	0.05	0.08	Model 5
06_856_1_RA	231.497	18.02	18.02	22.13	24.85	27.63	31.51	34.70	38.12	47.26	Model 5
Top-up flow between 06_92_1_RA & 06_856_1_RA	7.48	1.14	1.14	1.40	1.57	1.75	2.00	2.20	2.41	2.99	Model 5
06_856_5_RA	237.478	18.33	18.33	22.51	25.28	28.10	32.04	35.29	38.77	48.06	Model 5
Top-up flow between 06_856_1_RA & 06_856_5_RA	5.981	0.91	0.91	1.12	1.26	1.40	1.59	1.76	1.93	2.39	Model 5
06057_RA	29.128	3.97	3.97	5.76	7.11	8.62	10.95	13.05	15.52	23.07	Model 5
06_229_4_RA	29.195	3.98	3.98	5.77	7.13	8.63	10.97	13.08	15.55	23.11	Model 5
Top-up flow between 06057_RA & 06_229_4_RA	0.067	0.01	0.01	0.02	0.02	0.03	0.04	0.04	0.05	0.08	Model 5
06_870_8_RA	15.759	1.80	1.80	2.64	3.30	4.03	5.18	6.23	7.47	11.34	Model 5
06035_RA	301.639	25.81	25.81	31.69	35.59	39.56	45.11	49.68	54.58	67.66	Model 5
Top-up flow between 06_856_5_RA & 06035_RA	19.207	2.80	2.80	3.44	3.86	4.29	4.89	5.39	5.92	7.34	Model 5
06_376_5_RA	11.75	1.14	1.14	1.68	2.08	2.54	3.27	3.92	4.70	7.12	Model 5
06_979_2_RA	9.826	1.54	1.54	2.24	2.77	3.36	4.28	5.11	6.08	9.05	Model 5
06_1093_D_RARPS	338.456	28.93	28.93	35.53	39.90	44.35	50.57	55.69	61.19	75.86	Model 5
Top-up flow between 06035_RA &	15.241	2.21	2.21	3.20	3.95	4.78	6.08	7.24	8.61	12.80	Model 5

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)	
06_1093_D_RA											

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)	
06011_RA	208.622	19.06	23.40	26.28	29.21	33.31	36.68	40.30	49.96	33.38	46.60	63.47	Model 5
06_905_17_RA	13.421	2.49	3.59	4.42	5.33	6.74	8.00	9.47	13.93	5.63	10.19	17.75	Model 5
06_345_U_RARPS	0.27	0.09	0.13	0.16	0.19	0.25	0.30	0.35	0.52	0.20	0.38	0.67	Model 5
06_345_1_RARPS	0.409	0.13	0.19	0.24	0.29	0.37	0.44	0.52	0.77	0.30	0.56	0.99	Model 5
Top-up flow between 0_345_U_RARPS & 06_345_1_RARPS	0.139	0.05	0.07	0.09	0.10	0.13	0.16	0.19	0.28	0.11	0.20	0.36	Model 5
06_92_1_RA	224.017	21.55	26.46	29.72	33.04	37.67	41.48	45.58	56.51	38.14	53.24	72.51	Model 5
Top-up flow between 06011_RA & 06_92_1_RA	1.565	0.33	0.40	0.45	0.51	0.58	0.63	0.70	0.86	0.58	0.81	1.11	Model 5
06_997_2_RA	6.953	1.23	1.79	2.21	2.68	3.41	4.07	4.85	7.21	2.71	5.01	8.86	Model 5
06_997_3_RA	7.02	1.28	1.86	2.31	2.80	3.56	4.25	5.06	7.53	2.83	5.23	9.25	Model 5
Top-up flow between 06_997_2_RA & 06_997_3_RA	0.067	0.03	0.04	0.05	0.06	0.08	0.10	0.11	0.17	0.08	0.14	0.25	Model 5
06_856_1_RA	231.497	22.39	27.49	30.87	34.32	39.13	43.09	47.35	58.70	39.79	55.55	75.66	Model 5
Top-up flow between 06_92_1_RA & 06_856_1_RA	7.48	1.42	1.74	1.96	2.17	2.48	2.73	3.00	3.72	2.52	3.52	4.80	Model 5
06_856_5_RA	237.478	22.76	27.94	31.38	34.88	39.78	43.80	48.13	59.66	40.36	56.34	76.74	Model 5
Top-up flow between 06_856_1_RA & 06_856_5_RA	5.981	1.13	1.39	1.56	1.74	1.98	2.18	2.40	2.97	2.01	2.80	3.82	Model 5
06057_RA	29.128	4.91	7.12	8.79	10.65	13.53	16.13	19.18	28.51	11.06	20.28	35.85	Model 5
06_229_4_RA	29.195	4.92	7.14	8.81	10.67	13.56	16.17	19.22	28.57	11.08	20.33	35.92	Model 5
Top-up flow between 06057_RA & 06_229_4_RA	0.067	0.02	0.02	0.03	0.04	0.05	0.05	0.06	0.10	0.04	0.07	0.12	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)	
06_870_8_RA	15.759	2.25	3.30	4.11	5.03	6.46	7.77	9.32	14.16	5.06	9.55	17.39	Model 5
06035_RA	301.639	31.86	39.12	43.93	48.84	55.69	61.33	67.38	83.54	55.05	76.85	104.68	Model 5
Top-up flow between 06_856_5_RA & 06035_RA	19.207	3.46	4.24	4.77	5.30	6.04	6.65	7.31	9.06	5.97	8.34	11.36	Model 5
06_376_5_RA	11.75	1.42	2.09	2.60	3.17	4.07	4.89	5.86	8.88	3.41	6.41	11.64	Model 5
06_979_2_RA	9.826	2.17	3.16	3.90	4.74	6.03	7.20	8.57	12.75	8.09	14.93	26.42	Model 5
06_1093_D_RARPS	338.456	35.91	44.10	49.52	55.05	62.77	69.12	75.95	94.15	63.62	88.80	120.96	Model 5
Top-up flow between 06035_RA & 06_1093_D_RA	15.241	2.74	3.97	4.90	5.94	7.55	8.99	10.70	15.90	6.30	11.56	20.42	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 6 - Carrickmacross

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)	
06_893_5_RA	7.501	0.82	0.82	1.19	1.48	1.79	2.28	2.73	3.24	4.83	Model 6
06_892_U_RARPS	0.646	0.10	0.10	0.15	0.18	0.22	0.28	0.33	0.40	0.59	Model 6
06_892_3_RARPS	1.131	0.23	0.23	0.34	0.42	0.50	0.64	0.77	0.91	1.36	Model 6
Top-up flow between 06_892_U_RARPS & 06_892_3_RARPS	0.485	0.12	0.12	0.18	0.22	0.27	0.34	0.41	0.48	0.72	Model 6
06_892_1_RA	1.146	0.23	0.23	0.34	0.42	0.51	0.65	0.78	0.92	1.37	Model 6
Top-up flow between 06_892_3_RARPS & 06_892_1_RA	0.015	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.03	Model 6
06_892_2_RPS	0.024	0.02	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.13	Model 6
Top-up flow between 06_892_3_RARPS & 06_892_2_RARPS	0.024	0.02	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.13	Model 6
06038_RA	10.167	1.40	1.40	2.04	2.51	3.05	3.87	4.62	5.49	8.16	Model 6
Top-up flow between 06_893_5_RA & 06038_RA	1.496	0.44	0.44	0.64	0.79	0.96	1.22	1.46	1.74	2.58	Model 6
06_205_U	0.5	0.07	0.07	0.11	0.13	0.16	0.20	0.24	0.29	0.43	Model 6
06_630_U_RARPS	1.263	0.22	0.22	0.32	0.40	0.49	0.62	0.74	0.88	1.31	Model 6
06_630_1_RA	2.085	0.36	0.36	0.52	0.64	0.78	0.99	1.19	1.41	2.10	Model 6
Top-up flow between 06_630_U_RARPS & 06_630_1_RA	0.822	0.15	0.15	0.22	0.27	0.33	0.42	0.50	0.59	0.88	Model 6
06_235_3_RA	5.042	0.71	0.71	1.03	1.28	1.55	1.98	2.36	2.81	4.18	Model 6
Top-up flow between 06_205_U & 06_630_1_RA	1.824	0.27	0.27	0.39	0.48	0.59	0.75	0.89	1.06	1.58	Model 6
Top-up flow between 06_630_1_RA & 06_235_3_RA	0.633	0.09	0.09	0.14	0.17	0.20	0.26	0.31	0.37	0.55	Model 6
06_845_U_RARPS	0.507	0.18	0.18	0.26	0.32	0.39	0.49	0.59	0.70	1.04	Model 6
06_845_3_RA	1.584	0.43	0.43	0.63	0.78	0.94	1.20	1.43	1.70	2.54	Model 6
Top-up flow between 06_845_U_RA & 06_845_3_RA	1.077	0.38	0.38	0.56	0.69	0.84	1.07	1.28	1.52	2.26	Model 6
06_896_8_RA	7.178	1.75	1.75	2.54	3.14	3.81	4.85	5.79	6.89	10.26	Model 6
06_911_12_RA	35.183	2.98	2.98	4.05	4.80	5.61	6.78	7.79	8.93	12.14	Model 6
06_538_2_RA	12.944	1.97	1.97	2.88	3.58	4.36	5.59	6.70	8.02	12.10	Model 6

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)	
06_97_2_RA	63.505	5.10	5.10	6.69	7.81	8.98	10.70	12.17	13.81	18.41	Model 6
Top-up flow between 06_896_8_RA & 06_97_2_RA	8.2	1.15	1.15	1.52	1.77	2.03	2.42	2.76	3.13	4.17	Model 6
06_100_2_RA	88.543	7.94	7.94	10.32	11.97	13.68	16.16	18.24	20.55	26.94	Model 6
Top-up flow between 06038_RA & 06_100_2_RA	8.245	1.32	1.32	1.72	2.00	2.28	2.69	3.04	3.43	4.49	Model 6
06_602_4_RA	158.152	12.59	12.59	15.63	17.62	19.59	22.34	24.56	26.92	33.08	Model 6
06016_RA	259.876	21.46	21.46	26.35	29.59	32.90	37.51	41.31	45.39	56.27	Model 6
Top-up flow between 06_100_2_RA & 06016_RA	13.181	2.10	2.10	2.58	2.90	3.23	3.68	4.05	4.45	5.52	Model 6
06_571_4_RA	267.601	21.46	21.46	26.35	29.59	32.90	37.51	41.31	45.39	56.27	Model 6
Top-up flow between 06016_RA & 06_571_4_RA	7.725	1.25	1.25	1.54	1.73	1.92	2.19	2.41	2.65	3.29	Model 6
06014_RA	270.697	21.46	21.46	26.35	29.59	32.90	37.51	41.31	45.39	56.27	Model 6
Top-up flow between 06_571_4_RA & 06014_RA	3.096	0.50	0.50	0.62	0.69	0.77	0.88	0.97	1.06	1.32	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)	
06_893_5_RA	7.501	1.03	1.49	1.85	2.24	2.85	3.40	4.05	6.03	2.27	4.18	7.41	Model 6
06_892_U_RARPS	0.646	0.15	0.22	0.27	0.33	0.42	0.50	0.59	0.88	0.51	0.94	1.66	Model 6
06_892_3_RARPS	1.131	0.44	0.64	0.79	0.96	1.23	1.47	1.75	2.60	0.86	1.59	2.81	Model 6
Top-up flow between 06_892_U_RARPS & 06_892_3_RARPS	0.485	0.20	0.29	0.36	0.44	0.56	0.66	0.79	1.17	0.39	0.72	1.27	Model 6
06_892_1_RA	1.146	0.28	0.41	0.50	0.61	0.78	0.93	1.11	1.65	0.87	1.61	2.85	Model 6
Top-up flow between 06_892_3_RARPS & 06_892_1_RA	0.015	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.05	0.01	0.03	0.05	Model 6
06_892_2_RPS	0.024	0.03	0.04	0.05	0.06	0.08	0.10	0.11	0.17	0.09	0.17	0.30	Model 6
Top-up flow between 06_892_3_RARPS & 06_892_2_RARPS	0.024	0.03	0.04	0.05	0.06	0.08	0.10	0.11	0.17	0.09	0.17	0.30	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)	
06038_RA	10.167	2.02	2.94	3.63	4.40	5.59	6.66	7.92	11.77	7.22	13.25	23.42	Model 6
Top-up flow between 06_893_5_RA & 06038_RA	1.496	0.95	1.38	1.71	2.07	2.63	3.13	3.72	5.53	1.85	3.39	5.99	Model 6
06_205_U	0.5	0.13	0.18	0.23	0.28	0.35	0.42	0.50	0.75	0.32	0.60	1.06	Model 6
06_630_U_RARPS	1.263	0.28	0.41	0.50	0.61	0.77	0.92	1.10	1.64	0.62	1.14	2.01	Model 6
06_630_1_RA	2.085	0.45	0.65	0.80	0.97	1.24	1.48	1.76	2.62	0.98	1.82	3.22	Model 6
Top-up flow between 06_630_U_RARPS & 06_630_1_RA	0.822	0.19	0.27	0.34	0.41	0.52	0.62	0.74	1.09	0.41	0.76	1.35	Model 6
06_235_3_RA	5.042	0.90	1.31	1.62	1.97	2.51	3.00	3.57	5.31	2.30	4.25	7.53	Model 6
Top-up flow between 06_205_U & 06_630_1_RA	1.824	0.46	0.67	0.83	1.01	1.28	1.53	1.82	2.71	2.04	3.77	6.67	Model 6
Top-up flow between 06_630_1_RA & 06_235_3_RA	0.633	0.46	0.67	0.83	1.01	1.28	1.53	1.82	2.71	2.04	3.77	6.67	Model 6
06_845_U_RARPS	0.507	0.28	0.41	0.51	0.62	0.79	0.94	1.12	1.67	0.55	1.02	1.81	Model 6
06_845_3_RA	1.584	0.83	1.20	1.49	1.80	2.30	2.74	3.27	4.86	1.61	2.97	5.26	Model 6
Top-up flow between 06_845_U_RA & 06_845_3_RA	1.077	0.74	1.07	1.32	1.61	2.05	2.44	2.91	4.33	1.44	2.65	4.69	Model 6
06_896_8_RA	7.178	2.18	3.17	3.92	4.76	6.06	7.23	8.61	12.80	4.81	8.88	15.73	Model 6
06_911_12_RA	35.183	3.72	5.05	6.00	7.00	8.47	9.73	11.15	15.16	7.37	11.95	18.63	Model 6
06_538_2_RA	12.944	2.46	3.59	4.47	5.45	6.97	8.37	10.01	15.11	5.49	10.28	18.57	Model 6
06_97_2_RA	63.505	7.36	9.66	11.28	12.98	15.46	17.58	19.94	26.59	22.39	34.89	52.79	Model 6
Top-up flow between 06_896_8_RA & 06_97_2_RA	8.2	1.67	2.19	2.56	2.94	3.50	3.98	4.52	6.02	5.07	7.90	11.96	Model 6
06_100_2_RA	88.543	9.99	12.98	15.05	17.20	20.32	22.93	25.84	33.87	20.46	31.17	46.03	Model 6
Top-up flow between 06038_RA & 06_100_2_RA	8.245	1.67	2.16	2.51	2.87	3.39	3.82	4.31	5.65	3.41	5.20	7.67	Model 6
06_602_4_RA	158.152	15.52	19.27	21.72	24.16	27.54	30.27	33.19	40.78	26.68	37.19	50.10	Model 6
06016_RA	259.876	27.57	33.86	38.02	42.27	48.20	53.08	58.32	72.30	47.81	66.74	90.91	Model 6
Top-up flow between	13.181	2.60	3.20	3.59	3.99	4.55	5.01	5.50	6.82	4.51	6.30	8.58	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)	
06_100_2_RA & 06016_RA													
06_571_4_RA	267.601	27.84	34.19	38.39	42.68	48.66	53.59	58.88	72.99	48.04	67.07	91.35	Model 6
Top-up flow between 06016_RA & 06_571_4_RA	7.725	1.55	1.90	2.14	2.37	2.71	2.98	3.28	4.06	2.67	3.73	5.08	Model 6
06014_RA	270.697	26.51	32.55	36.55	40.63	46.33	51.03	56.06	69.50	45.75	63.87	86.99	Model 6
Top-up flow between 06_571_4_RA & 06014_RA	3.096	0.62	0.76	0.85	0.95	1.08	1.19	1.31	1.62	1.07	1.49	2.03	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 - Ardee

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)	
06_970_6_RA	168.591	18.34	18.34	22.73	25.57	28.40	32.27	35.39	38.69	47.22	Model 7
06025_RA	173.282	18.64	18.64	23.09	25.98	28.85	32.79	35.96	39.31	47.98	Model 7
Top-up flow between 06_970_6_RA & 06025_RA	4.691	0.63	0.63	0.78	0.88	0.98	1.11	1.22	1.34	1.63	Model 7
06_8_3_RA	26.908	4.29	4.29	6.22	7.68	9.31	11.83	14.10	16.76	24.92	Model 7
06_553_2_RA	15.7	2.51	2.51	3.68	4.59	5.60	7.21	8.68	10.42	15.87	Model 7
06_745_U_RARPS	0.321	0.03	0.03	0.05	0.06	0.07	0.09	0.11	0.13	0.19	Model 7
06_586_2_RA	39.514	4.55	4.55	6.40	7.74	9.18	11.34	13.22	15.36	21.60	Model 7
06_566_5_RA	50.413	5.54	5.54	7.74	9.35	11.09	13.73	16.04	18.69	26.50	Model 7
Top-up flow between 06_745_U_RARPS & 06_566_5_RA	10.578	1.28	1.28	1.79	2.16	2.57	3.18	3.71	4.33	6.14	Model 7
06_1016_U_RA	1.434	0.18	0.18	0.27	0.33	0.40	0.51	0.61	0.73	1.08	Model 7
06_DeerTrib_RARPS	1.76	0.22	0.22	0.33	0.40	0.49	0.62	0.74	0.88	1.31	Model 7
Top-up flow between 06_1016_U_RARPS & 06_DeerTrib_RARPS	0.326	0.05	0.05	0.07	0.08	0.10	0.13	0.15	0.18	0.27	Model 7
06_782_6_RA	4.061	0.84	0.84	1.22	1.50	1.82	2.32	2.77	3.30	4.91	Model 7
06_262_U_RARPS	0.659	0.14	0.14	0.21	0.26	0.31	0.40	0.47	0.57	0.84	Model 7
06_262_3_RA	1.24	0.26	0.26	0.38	0.48	0.58	0.74	0.88	1.04	1.55	Model 7
Top-up flow between 06_262_U_RARPS & 06_262_3_RA	0.581	0.13	0.13	0.19	0.23	0.28	0.36	0.43	0.51	0.76	Model 7
06_234_1_RARPS	0.346	0.10	0.10	0.14	0.18	0.21	0.27	0.33	0.39	0.58	Model 7
06_135_3_RA	7.194	1.60	1.60	2.32	2.87	3.48	4.44	5.30	6.30	9.37	Model 7
Top-up flow between 06_782_6_U_RARPS & 06_135_3_RA	1.547	0.41	0.41	0.60	0.74	0.90	1.15	1.37	1.63	2.43	Model 7
06_661_U_RARPS	0.149	0.02	0.02	0.04	0.04	0.05	0.07	0.08	0.10	0.14	Model 7
06_565_3_RA	4.331	0.86	0.86	1.25	1.55	1.88	2.39	2.85	3.39	5.05	Model 7
Top-up flow between 06_661_U_RARPS & 06_565_3_RA	4.182	0.83	0.83	1.21	1.50	1.81	2.31	2.76	3.28	4.89	Model 7
06_65_3_RA	296.193	26.60	26.60	32.66	36.68	40.77	46.49	51.20	56.25	69.74	Model 7
Top-up flow between 06025_RA & 06_65_3_RA	16.605	1.79	1.79	2.20	2.47	2.74	3.13	3.44	3.78	4.69	Model 7

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)	
06023_RA	302.773	26.85	26.85	32.92	36.93	40.93	46.51	51.05	55.89	68.64	Model 7
Top-up flow between 06_65_3_RA & 06023_RA	6.58	0.74	0.74	0.91	1.02	1.13	1.29	1.41	1.55	1.90	Model 7
06013_RA	307.975	27.37	27.37	33.56	37.63	41.71	47.40	52.03	56.96	69.96	Model 7
Top-up flow between 06023_RA & 06013_RA	5.202	0.60	0.60	0.73	0.82	0.91	1.04	1.14	1.24	1.53	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)	
06_970_6_RA	168.591	22.82	28.28	31.81	35.33	40.14	44.02	48.13	58.74	39.08	54.08	72.17	Model 7
06025_RA	173.282	23.19	28.73	32.32	35.90	40.79	44.73	48.90	59.69	39.71	54.96	73.33	Model 7
Top-up flow between 06_970_6_RA & 06025_RA	4.691	0.79	0.98	1.10	1.22	1.39	1.52	1.66	2.03	1.35	1.87	2.49	Model 7
06_8_3_RA	26.908	5.36	7.77	9.59	11.62	14.76	17.60	20.92	31.10	11.78	21.62	38.21	Model 7
06_553_2_RA	15.7	3.13	4.60	5.72	6.99	8.99	10.83	13.00	19.81	7.03	13.30	24.33	Model 7
06_745_U_RARPS	0.321	0.04	0.06	0.07	0.09	0.11	0.13	0.16	0.23	0.09	0.16	0.29	Model 7
06_586_2_RA	39.514	5.68	7.99	9.66	11.46	14.15	16.50	19.17	26.96	11.86	20.27	33.12	Model 7
06_566_5_RA	50.413	6.91	9.66	11.67	13.84	17.13	20.02	23.33	33.08	14.34	24.60	40.64	Model 7
Top-up flow between 06_745_U_RARPS & 06_566_5_RA	10.578	1.60	2.24	2.70	3.21	3.97	4.64	5.40	7.66	3.32	5.69	9.41	Model 7
06_1016_U_RA	1.434	0.23	0.34	0.41	0.50	0.64	0.76	0.91	1.35	0.51	0.94	1.66	Model 7
06_DeerTrib_RARPS	1.76	0.28	0.41	0.50	0.61	0.78	0.93	1.10	1.64	0.62	1.14	2.02	Model 7
Top-up flow between 06_1016_U_RARPS & 06_DeerTrib_RARPS	0.326	0.06	0.08	0.10	0.13	0.16	0.19	0.23	0.34	0.13	0.23	0.42	Model 7
06_782_6_RA	4.061	1.04	1.52	1.88	2.28	2.90	3.46	4.12	6.13	2.31	4.25	7.53	Model 7
06_262_U_RARPS	0.659	0.18	0.26	0.32	0.39	0.50	0.59	0.71	1.05	0.39	0.73	1.29	Model 7
06_262_3_RA	1.24	0.44	0.64	0.79	0.96	1.23	1.46	1.74	2.59	1.54	2.84	5.03	Model 7
Top-up flow between 06_262_U_RARPS &	0.581	0.28	0.41	0.51	0.62	0.79	0.94	1.12	1.67	0.76	1.40	2.47	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)	
06_262_3_RA													
06_234_1_RARPS	0.346	0.16	0.23	0.29	0.35	0.44	0.53	0.63	0.93	0.47	0.86	1.52	Model 7
06_135_3_RA	7.194	2.25	3.27	4.05	4.91	6.25	7.47	8.88	13.22	8.37	15.44	27.34	Model 7
Top-up flow between 06_782_6_U_RARPS & 06_135_3_RA	1.547	0.58	0.85	1.05	1.27	1.62	1.93	2.30	3.42	1.99	3.66	6.49	Model 7
06_661_U_RARPS	0.149	0.03	0.05	0.06	0.07	0.09	0.11	0.13	0.19	0.10	0.19	0.34	Model 7
06_565_3_RA	4.331	1.55	2.25	2.79	3.38	4.31	5.15	6.12	9.11	4.12	7.61	13.47	Model 7
Top-up flow between 06_661_U_RARPS & 06_565_3_RA	4.182	1.50	2.18	2.70	3.28	4.17	4.98	5.93	8.82	3.99	7.36	13.03	Model 7
06_65_3_RA	296.193	32.81	40.29	45.24	50.29	57.35	63.16	69.39	86.02	55.58	77.59	105.69	Model 7
Top-up flow between 06025_RA & 06_65_3_RA	16.605	2.21	2.71	3.04	3.38	3.85	4.25	4.66	5.78	3.74	5.22	7.10	Model 7
06023_RA	302.773	33.14	40.63	45.56	50.50	57.39	62.99	68.96	84.70	55.98	77.39	104.06	Model 7
Top-up flow between 06_65_3_RA & 06023_RA	6.58	0.92	1.12	1.26	1.40	1.59	1.74	1.91	2.34	1.55	2.14	2.88	Model 7
06013_RA	307.975	33.72	41.34	46.36	51.39	58.40	64.10	70.17	86.18	56.96	78.75	105.88	Model 7
Top-up flow between 06023_RA & 06013_RA	5.202	0.74	0.90	1.01	1.12	1.28	1.40	1.53	1.88	1.24	1.72	2.31	Model 7

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 8 - Annagassan

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)	
06014_RA	270.70	21.46	21.46	26.35	29.59	32.90	37.51	41.31	45.39	56.27	Model 8
06_76_2_RA	5.62	0.68	0.68	0.98	1.21	1.47	1.88	2.24	2.66	3.96	Model 8
06_73_2_RA	19.52	1.43	1.43	2.08	2.57	3.12	3.96	4.73	5.62	8.37	Model 8
06_70_3_RA	10.19	1.07	1.07	1.56	1.94	2.37	3.04	3.66	4.39	6.66	Model 8
06_276_13_RA	18.97	1.34	1.34	1.94	2.40	2.91	3.70	4.41	5.25	7.80	Model 8
06_603_Inter_1_RA	344.37	21.86	21.86	26.81	30.06	33.32	37.87	41.56	45.50	55.89	Model 8
Top-up flow between 06014_RA & 06_603_Inter_1_RA	19.38	1.47	1.47	1.81	2.03	2.25	2.55	2.80	3.07	3.77	Model 8
06021_RA	344.81	21.87	21.87	26.81	30.07	33.33	37.88	41.57	45.51	55.90	Model 8
Top-up flow between 06_603_Inter_1_RA & 06021_RA	0.44	0.04	0.04	0.05	0.06	0.06	0.07	0.08	0.09	0.11	Model 8
06_1097_2_RA	350.88	21.88	21.88	26.83	30.09	33.35	37.90	41.60	45.54	55.93	Model 8
Top-up flow between 06021_RA & 06_1097_2_RA	6.07	0.49	0.49	0.60	0.67	0.74	0.85	0.93	1.02	1.25	Model 8
06052_RA	357.04	21.88	21.88	26.82	30.09	33.35	37.90	41.59	45.53	55.93	Model 8
Top-up flow between 06_1097_2_RA & 06052_RA	6.17	0.47	0.47	0.57	0.64	0.71	0.81	0.89	0.98	1.20	Model 8
06013_RA	307.98	27.37	27.37	33.56	37.63	41.71	47.40	52.03	56.96	69.96	Model 8
06_550_5_RA	61.42	22.36	22.36	27.41	30.74	34.07	38.72	42.50	46.52	57.14	Model 8
06_1050_3_RA	7.98	1.58	1.58	2.30	2.84	3.45	4.40	5.25	6.24	9.29	Model 8
06_1099_8_RA	383.38	32.43	32.43	39.76	44.59	49.43	56.17	61.65	67.49	82.89	Model 8
Top-up flow between 06013_RA & 06_1099_8_RA	6.00	0.66	0.66	0.81	0.91	1.00	1.14	1.25	1.37	1.69	Model 8
06_1100_1_RA	387.96	32.70	32.70	40.09	44.97	49.84	56.64	62.17	68.06	83.59	Model 8
Top-up flow between 06_1099_8_RA & 06_1100_1_RA	4.58	0.51	0.51	0.63	0.70	0.78	0.88	0.97	1.06	1.31	Model 8
06_848_D_RARPS	749.54	49.56	49.56	62.00	70.37	78.89	90.94	100.90	111.65	140.64	Model 8
Top-up flow between 06052_RA & 06_848_D_RARPS	4.55	0.35	0.35	0.44	0.50	0.56	0.64	0.71	0.79	0.99	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)	
06014_RA	270.70	21.46	21.46	26.35	29.59	32.90	37.51	41.31	45.39	56.27	63.87	86.99	Model 8
06_76_2_RA	5.62	0.68	0.68	0.98	1.21	1.47	1.88	2.24	2.66	3.96	3.37	5.97	Model 8
06_73_2_RA	19.52	1.43	1.43	2.08	2.57	3.12	3.96	4.73	5.62	8.37	7.25	12.83	Model 8
06_70_3_RA	10.19	1.07	1.07	1.56	1.94	2.37	3.04	3.66	4.39	6.66	6.16	11.20	Model 8
06_276_13_RA	18.97	1.34	1.34	1.94	2.40	2.91	3.70	4.41	5.25	7.80	6.61	11.69	Model 8
06_603_Inter_1_RA	344.37	21.86	21.86	26.81	30.06	33.32	37.87	41.56	45.50	55.89	69.04	92.83	Model 8
Top-up flow between 06014_RA & 06_603_Inter_1_RA	19.38	1.47	1.47	1.81	2.03	2.25	2.55	2.80	3.07	3.77	4.30	5.78	Model 8
06021_RA	344.81	21.87	21.87	26.81	30.07	33.33	37.88	41.57	45.51	55.90	63.39	85.23	Model 8
Top-up flow between 06_603_Inter_1_RA & 06021_RA	0.44	0.04	0.04	0.05	0.06	0.06	0.07	0.08	0.09	0.11	0.13	0.17	Model 8
06_1097_2_RA	350.88	21.88	21.88	26.83	30.09	33.35	37.90	41.60	45.54	55.93	64.38	86.57	Model 8
Top-up flow between 06021_RA & 06_1097_2_RA	6.07	0.49	0.49	0.60	0.67	0.74	0.85	0.93	1.02	1.25	1.45	1.95	Model 8
06052_RA	357.04	21.88	21.88	26.82	30.09	33.35	37.90	41.59	45.53	55.93	68.88	92.61	Model 8
Top-up flow between 06_1097_2_RA & 06052_RA	6.17	0.47	0.47	0.57	0.64	0.71	0.81	0.89	0.98	1.20	1.54	2.07	Model 8
06013_RA	307.98	27.37	27.37	33.56	37.63	41.71	47.40	52.03	56.96	69.96	78.75	105.88	Model 8
06_550_5_RA	61.42	22.36	22.36	27.41	30.74	34.07	38.72	42.50	46.52	57.14	79.72	107.19	Model 8
06_1050_3_RA	7.98	1.58	1.58	2.30	2.84	3.45	4.40	5.25	6.24	9.29	8.05	14.25	Model 8
06_1099_8_RA	383.38	32.43	32.43	39.76	44.59	49.43	56.17	61.65	67.49	82.89	95.43	128.31	Model 8
Top-up flow between 06013_RA & 06_1099_8_RA	6.00	0.66	0.66	0.81	0.91	1.00	1.14	1.25	1.37	1.69	1.94	2.61	Model 8
06_1100_1_RA	387.96	32.70	32.70	40.09	44.97	49.84	56.64	62.17	68.06	83.59	96.08	129.18	Model 8
Top-up flow between 06_1099_8_RA & 06_1100_1_RA	4.58	0.51	0.51	0.63	0.70	0.78	0.88	0.97	1.06	1.31	1.50	2.02	Model 8
06_848_D_RARPS	749.54	49.56	49.56	62.00	70.37	78.89	90.94	100.90	111.65	140.64	156.60	218.28	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)	
Top-up flow between 06052_RA & 06_848_D_RARPS	4.55	0.35	0.35	0.44	0.50	0.56	0.64	0.71	0.79	0.99	1.10	1.54	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 9 - Termonfeckin

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)	
06_1048_1_RA	23.27	5.87	5.87	8.63	10.77	13.18	16.97	20.45	24.58	37.51	Model 9
06037_RA	25.56	6.31	6.31	9.28	11.58	14.17	18.25	21.99	26.43	40.33	Model 9
Top-up flow between 06_1048_1_RA & 06037_RA	2.29	0.66	0.66	0.97	1.21	1.48	1.90	2.29	2.75	4.20	Model 9
06_302_2_RARPS	0.23	0.05	0.05	0.07	0.09	0.11	0.13	0.16	0.19	0.28	Model 9
06_302_5_RARPS	0.82	0.10	0.10	0.14	0.17	0.21	0.26	0.32	0.38	0.56	Model 9
Top-up flow between 06_302_2_RARPS & 06_302_5_RARPS	0.59	0.07	0.07	0.10	0.13	0.15	0.19	0.23	0.28	0.41	Model 9
06_305_D_RARPS	28.48	6.82	6.82	10.03	12.51	15.31	19.72	23.76	28.56	43.59	Model 9
Top-up flow between 06013_RA & 06_305_D_RARPS	2.10	0.59	0.59	0.87	1.09	1.33	1.71	2.06	2.48	3.78	Model 9

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)	
06_1048_1_RA	23.27	7.33	10.78	13.44	16.45	21.19	25.52	30.68	46.82	16.52	31.36	57.52	Model 9
06037_RA	25.56	8.22	12.10	15.09	18.46	23.78	28.65	34.44	52.56	19.00	36.07	66.17	Model 9
Top-up flow between 06_1048_1_RA & 06037_RA	2.29	1.41	2.08	2.59	3.17	4.09	4.93	5.92	9.04	3.84	7.28	13.36	Model 9
06_302_2_RARPS	0.23	0.06	0.09	0.11	0.13	0.17	0.20	0.24	0.35	0.13	0.25	0.44	Model 9
06_302_5_RARPS	0.82	0.18	0.26	0.32	0.39	0.50	0.60	0.71	1.06	0.46	0.85	1.50	Model 9
Top-up flow between 06_302_2_RARPS & 06_302_5_RARPS	0.59	0.15	0.22	0.27	0.33	0.42	0.50	0.60	0.89	0.40	0.74	1.31	Model 9
06_305_D_RARPS	28.48	9.37	13.79	17.20	21.04	27.11	32.65	39.25	59.90	22.12	42.00	77.04	Model 9
Top-up flow between 06013_RA & 06_305_D_RARPS	2.10	1.27	1.87	2.33	2.86	3.68	4.43	5.33	8.13	3.45	6.55	12.02	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.
