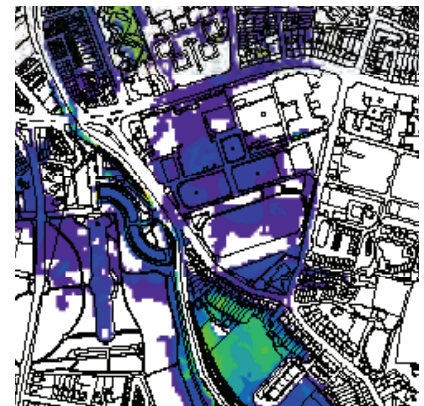


# North Western - Neagh Bann CFRAM Study

## UoM 06 Inception Report

IBE0700Rp0003







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## ABBREVIATIONS

AA	Appropriate Assessment
AEP	Annual Exceedance Probability
AFA	Area for Further Assessment
AMAX	Annual Maximum flood series
APSR	Area of Potentially Significant Risk
CFRAM	Catchment Flood Risk Assessment and Management
CC	Coefficient of Correlation
COD	Coefficient of Determination
COV	Coefficient of Variance
cSAC	Candidate Special Area of Conservation
DAHG	Department of Arts, Heritage and the Gaeltacht
DARD	Department of Agriculture and Rural Development
DOE	Department of the Environment
DTM	Digital Terrain Model
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
ESB	Electricity Supply Board
EU	European Union
EV1	Extreme Value Type 1 (distribution) (=Gumbel distribution)
FRA	Flood Risk Assessment
FRMP	Flood Risk Management Plan
FRR	Flood Risk Review

FSU	Flood Studies Update
FSSR	Flood Studies Supplementary Report
GEV	Generalised Extreme Value (distribution)
GLO	General Logistic (distribution)
GIS	Geographical Information Systems
GSI	Geological Survey of Ireland
HA	Hydrometric Area
HEP	Hydrological Estimation Point
HGF	Highest Gauged Flow
HPW	High Priority Watercourse
ICPSS	Irish Coastal Protection Strategy Study
IFSAR	Interferometric Synthetic Aperture Radar
IRBD	International River Basin District
LA	Local Authority
LAP	Local Area Plan
LN2	2 Parameter Log Normal (distribution)
MAF	Mean Annual Flow
MPW	Medium Priority Watercourse
NDHM	National Digital Height Model
NDTM	National Digital Terrain Model
NHA	Natural Heritage Area
NIAH	National Inventory of Architectural Heritage
NBIRBD	Neagh Bann International River Basin District
NPWS	National Parks and Wildlife Service

NWIRBD	North Western International River Basin District
OD	Ordnance Datum
OPW	Office of Public Works
OSi	Ordnance Survey Ireland
PEE	Proportional Error Estimate
PFRA	Preliminary Flood Risk Assessment
$Q_{med}$	median of AMAX flood series
$Q_{bar}$	mean average of AMAX flood series
RA	Rivers Agency
RBD	River Basin District
RBMP	River Basin Management Plan
RMSE	Root Mean Square Error
SAAR	Standard Average Annual Rainfall (mm)
SEA	Strategic Environmental Assessment
SAC	Special Area of Conservation
SC	Survey Contract
SI	Statutory Instrument
SPA	Special Protection Area
SuDS	Sustainable Urban Drainage System
UoM	Unit of Management
WFD	Water Framework Directive
WP	Work Package
WWI	Waterways Ireland

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# 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 (Reference 1) as implemented in Ireland by SI 122 of 2010 European Communities (Assessment and Management of Flood Risks) Regulations, 2010 (Reference 2).

The North Western – Neagh Bann CFRAM Study incorporates two River Basin Districts (RBDs), both of which are transboundary and are therefore classified as International River Basin Districts (IRBDs). This report deals only with the portions of the district that are within Ireland.

The Office of Public Works (OPW) is the national competent authority for the implementation of the Directive in Ireland. Rivers Agency (RA), part of the Department of Agriculture and Rural Development (DARD), is undertaking a similar role in Northern Ireland.

To ensure that a coordinated approach is adopted for the IRBDs, and building upon a long-standing history of cooperation between the two organisations, a cross-border coordination group on the implementation of the Directive has been established between the OPW and RA. This group has taken into account the catchment areas, their flood history, topography and the significant flood risk areas within them, in order to assign and plan work between the two jurisdictions.

RA and the OPW will undertake the necessary work separately within their own jurisdictions but will closely coordinate on all technical matters and proposed measures. The OPW and RA will combine their work to produce single, over-arching Flood Risk Management Plans (FRMPs) for each IRBD.

The North Western IRBD covers an area of 12,320 km<sup>2</sup> with approximately 7,400 km<sup>2</sup> of that area in 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 km<sup>2</sup> with approximately 2,010 km<sup>2</sup> of that area in Ireland. It represents one single Unit of Management, UoM 06 (Neagh Bann). It includes parts of counties Monaghan, Louth, Meath and Cavan. The district is also affected by both coastal and fluvial flooding.

Table 1.1 lists the local authorities that intersect each unit of management.

**Table 1.1: Local Authorities**

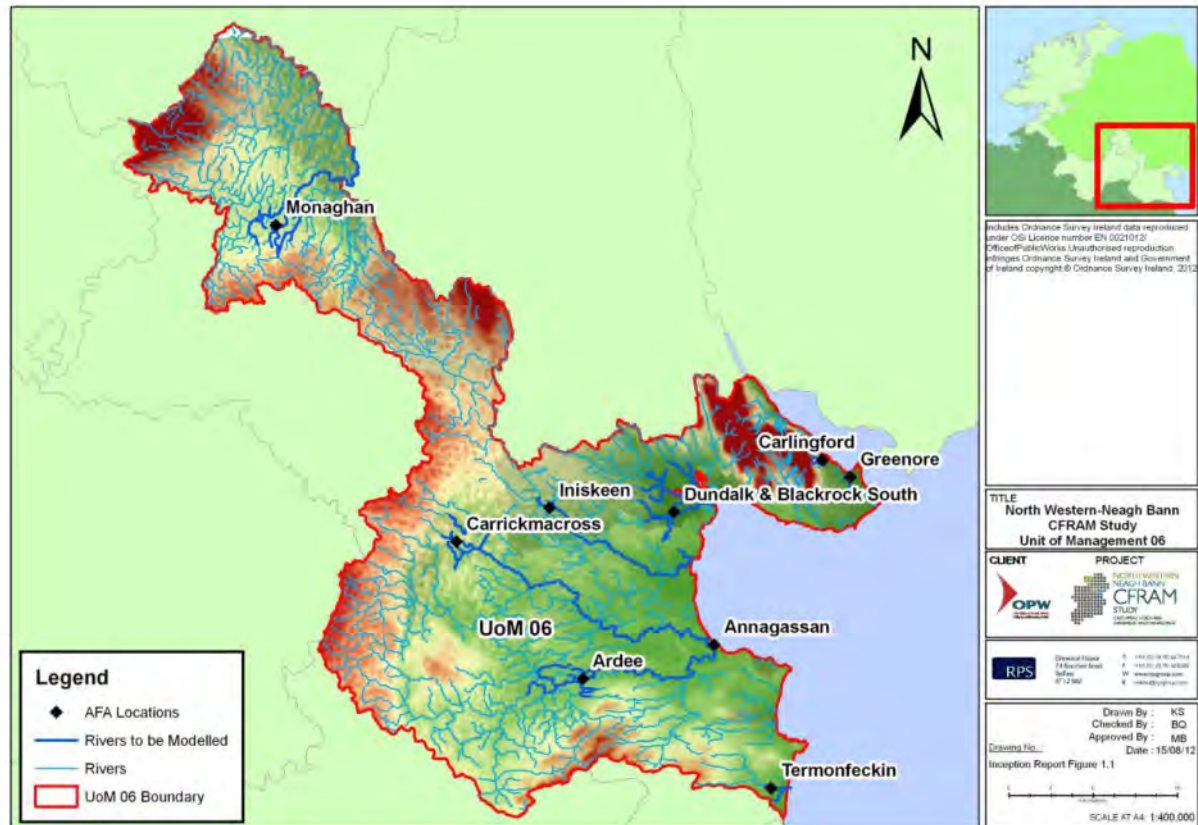
Unit of Management	Local Authorities
UoM 01 Donegal	Donegal
UoM 06 Neagh Bann	Cavan, Louth, Meath, Monaghan
UoM 36 Erne	Monaghan, Cavan, Donegal, Leitrim, Longford, Sligo

This document is the inception report for UoM 06. UoM 06 includes hydrometric areas 03 and 06. It covers an area of 1,779 km<sup>2</sup> and includes the majority of County Louth, much of County Monaghan and significant areas of Meath and Cavan (Figure 1.1). 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 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 (Figure 1.1).

In accordance with the National Flood Risk Assessment and Management Programme, North Western – Neagh Bann River Basin District Catchment-based Flood Risk Assessment and Management (CFRAM) Study, Stage II Project Brief (Reference 3) (hereinafter referred to as the North Western – Neagh Bann CFRAM Study Brief) only those areas not afforded protection by existing or planned schemes will be considered in full under the North Western – Neagh Bann CFRAM Study. For areas within AFAs that are 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.



**Figure 1.1: UoM 06 Extents and Study AFA Locations**

## 1.1 OBJECTIVE OF THIS INCEPTION REPORT

The principal objective of this Inception Report is to provide detail on the relevant datasets identified for use in UoM 06 as part of the North Western – Neagh Bann CFRAM Study, and provide an update on the collection and interpretation process to date for that data.

This document will also identify any issues that have been encountered in sourcing data and flag any that may affect the proposed methodologies or programme going forward.

The data requested, received or outstanding is detailed in the following section of this document, and progress with analysis of this data in current work packages is presented in Section 4.

## 1.2 APPROACH TO PROJECT DELIVERY

RPS has established a project specific team which includes a Project Management Board consisting of our nominated Project Director, Grace Glasgow, assisted by the Project Manager, Dr Alan Barr, and two Assistant Project Managers, Adrian Bell and Mark Magee. This senior management team are closely involved in all aspects of the study and will have responsibility for specific technical and geographic areas. All members of the RPS Project Board are based in the Belfast office of RPS with

the exception of Mark Magee who is based in the Letterkenny office. Most of the supporting technical staff is based in Belfast, although the overall team includes staff from RPS offices in Letterkenny, Dublin, Limerick, Cork and Galway as well as support from sub-consultants Compass Informatics and Hydrologic BV.

Within the overall RPS project team are a core group of staff who will remain involved in the project throughout its duration from initial data collection to reporting to ensure coherence and consistency in approach. Within this group we have identified a dedicated data manager, Richard Bingham, who is responsible for ensuring that all received data is logged and for maintaining a project specific inventory of datasets available to the project.



## **2 DATA COLLECTION**

### **2.1 DATA COLLECTION PROCESS**

RPS places a high importance on data collection throughout the lifetime of a project and considers sourcing, acquisition, quality checking and updating of information to be critical to the successful implementation of the CFRAM Studies.

The data collection process for the North Western – Neagh Bann CFRAM Study started with a review of the lists of data sources and relevant reports identified in the North Western - Neagh Bann CFRAM Study Brief and the “National Flood Risk Assessment and Management Programme, Catchment-based Flood Risk Assessment and Management (CFRAM) Studies, Stage I Tender Documents: Project Brief” (Reference 4), hereinafter referred to as the Generic CFRAM Study Brief, followed by tailored requests to probable data holders including all steering and progress group members.

The formal data collection process for the North Western - Neagh Bann CFRAM Study was initiated by OPW providing RPS with a range of datasets in various formats, including data from various Local Authorities and other organisations at the start of April 2012. The datasets provided by OPW are listed in Sections 2.1.1.1 to 2.1.1.7.

#### **2.1.1 Initial Data Received**

##### **2.1.1.1 Social**

- Civil Defence Headquarters (Dept of Defence);
- Fire Stations (Dept of Environment, Heritage and Local Government);
- Garda Stations (Dept of Defence);
- Nursing Homes, Hospitals, Health Centres, Public residential Care for the elderly centres (HSA);
- OPW Buildings;
- Primary Schools, Post Primary Schools (Dept of Education);
- Third Level School (Higher Education Authority);

##### **2.1.1.2 Economic**

- Geo-Directory (July 2011);
- Transport Infrastructure: Airports, Ports, Rail, Roads (NRA);

- Airports/Airport Regions (Irish Aviation Authority);
- Eircom Exchange Assets (Eircom);
- Water and Waste Water Treatment Plant Locations (EPA); and
- Power Stations, HV Substations and Infrastructure Vulnerability (ESB).

#### **2.1.1.3 Environmental**

- WFD Groundwater bodies, Licensed IPPC Facilities, Licence Water Facilities, Risk Data, WTP and WWTP Locations (EPA);
- Monument Data: UNESCO Sites, National Monuments (Dept of Environment, Heritage and Local Government);
- National Inventory of Architectural Heritage: Listed Buildings;
- National Heritage Areas (NPWS);
- Proposed Natural Heritage Areas (NPWS);
- Special Areas of Conservation (NPWS); and
- Special Protected Areas (NPWS).

#### **2.1.1.4 Hydrology**

- Register of Hydrometric Stations in Ireland (Jan 2011);
- FSU report;
- Outline and Description for gauged and ungauged catchments within the NWNB; and
- OPW Hydrometrics for NWNB: Annual Maxima, Gaugings, Q 15min Data, Q Day Data, Rating Equations, Staff Gauges Zero, WL 15min Data, WL Day Data, Station Photographs.

#### **2.1.1.5 Meteorology**

- Met Éireann Daily/Hourly Rainfall;
- Evaporation Data;
- Evapotranspiration Data;
- Soil Moisture Deficit Synoptic Stations; and

- Met Éireann Spatial Data files: Climate Stations, Rainstations, Daily Rain recorder stations, Weekly rain recorder stations, Monthly rainfall stations, Rain gauges, Evaporation stations synoptic stations.

#### **2.1.1.6 Geo-referenced Data**

- Aerial Photos for NWNB;
- Lakes within HAs 01, 03, 06, 35-40;
- Existing LIDAR for NWNB – Ballybofey;
- Development and Local Area Plans;
- Historical Flood data/Flood Extent Data/Surge Point Data;
- NDHM (5m DTM);
- OPW Benefiting Lands;
- OPW Channels;
- OPW Embankments;
- OSi Maps within NWNB:
  - 5000, 2500 vector maps;
  - 5000 raster map;
  - 6inch maps;
  - Digitown Maps.
- River Centreline (Blue Line network).

#### **2.1.1.7 Other**

- Data received from the Central Statistics Office (CSO): Ireland Gaeltacht Regions;
- Data received from ESRI included: Building in Ireland 2011;
- PFRA Tables: Monument Vulnerability, SAC/SPA Vulnerability;
- National Pluvial Screening Project for Ireland report;

- Historical Flood Data: Flood Hazard Mapping Database, Photographs from October 2011 floods (Monaghan), SERTIT Flyover data, Images from floods.ie;
- Coastal Flood Extents for NWNB area, and
- Development Boundaries (Cavan, Donegal, Leitrim, Longford, Louth, Meath, Monaghan, Sligo).
- Section 50 database;
- Defence asset database; and
- LiDAR data capture extents.
- Reports:
  - Preliminary Flood Risk Assessments - Groundwater Flooding Report (June 2010);
  - Irish Coastal Protection Strategy for the NE Coast (June 2010);
  - Flood Risk Assessment and Management Programme- National Pluvial Screening Project for Ireland (November 2010); and
  - NWNB Flood Risk Review (March 2012): (Site Assessment Reports/Site Maps/AFA Boundaries/ Extreme Flood Outlines).
  - SEA Guidance Documents: SEA of the Lee CFRAM, OPW CFRAM SEA Screening Report, EPA comments on the SEA of the FEM FRAM and the SEA of the Suir CFRAM.
  - North-South Issue papers 1 - Coordination Structures, 2 – Joint Action, 3 – Units of Management, and 4 – FRMPs.

### **2.1.2 Data Requested**

Following an initial review of the data received, further requests were made to the appropriate Local Authorities and relevant organisations, via email, telephone and also at meetings. A summary of the range of data requests made by RPS between February 2012 and August 2012 is provided below. In addition to requesting data from Progress and Steering Group members and other stakeholder organisations, RPS also undertook internet searches to try and obtain additional data in specific areas.

- On 5<sup>th</sup> April 2012, RPS requested Q1/Q15 gauge data from the EPA, this information was received on the same day.

- On the 5<sup>th</sup> April 2012, RPS requested buildings layer from the OSI Prime 1 Database from the OPW. This data was received on the 17<sup>th</sup> July 2012.
- On the 5<sup>th</sup> April 2012, RPS requested Bedrock and Sand/Gravel Aquifer data from GSI. The following layers were received from GSI on the same day: soil type, soil permeability, soil vulnerability and aquifers.
- On the 5<sup>th</sup> April 2012, RPS issued a request for gauging data from the Marine Institute Ireland. Gauge Information for Sligo, Malin Head and Killybegs was received on the same day.
- On the 28<sup>th</sup> May and the 1<sup>st</sup> June 2012 requests were made by RPS to all Local Authorities within the NWNB area, shown in Table 2.1, seeking available information on the following:
  - Flood Relief / Risk Management Measures: Fluvial Flood defences, Flood risk assessments, current flood risk and water management measures or practices;
  - Historic Flood Data: Maps of Flood extents, Flood levels and depths, causes or mechanisms of previous flood events and the resulting damage;
  - Hydrometric Data: Recorded water levels, flow gauging and ratings;
  - Meteorological Data: Information on rainfall, air pressure, wind speed and direction, temperature and evapotranspiration;
  - Land use Data: information on current and past land use;
  - Soil and Geological Data: Data on soil classifications, sub-soils, geology and aquifers;
  - Planning and development Information : Development limits of AFAs, Zoning within development limits, Information concerning existing development, Local area plans, town plans and master plans;
  - Defence and Coastal Protection Asset Data;
  - Existing Survey/Geotechnical Data;
  - Environmental Data;
  - Cultural Heritage Data;
  - Receptor Data; and
  - Urban Drainage Data: Culverts, Diverted Water Courses, Outfalls, Storm Water Discharges.
- On the 26<sup>th</sup> June 2012 a request was made by RPS to the OPW office in Trim to resend the FSU Data for the NWNB. This information was received the same month.
- On the 4<sup>th</sup> July 2012, RPS made a second data request to all the Local Authorities within the NWNB area following up on the information that was requested in May-June 2012. The data received from the UoM 06 Local Authorities is listed in Table 2.1.

- On the 19<sup>th</sup> July 2012, requests were issued to the OPW seeking EPA hydrometric data. This data request was completely closed on the 17<sup>th</sup> August 2012 following receipt of information.
- On the 14<sup>th</sup> August 2012 RPS made a third data request to all the Local Authorities within the NWNB area. The data received from the UoM 06 Local Authorities is listed in Table 2.1.
- On the 27<sup>th</sup> July RPS made a request for information to the Met Office. However the number of stations where data was needed was not defined at that time. On the 30<sup>th</sup> July the Met Office responded with a generic quote (based on the provision of rainfall data over a 30 year period for 10 weather stations; five of which offer hourly data (a potential of 1,314,000 data points) and five of which offer daily rainfall totals (a potential of 54,750 data points)). An estimate of the overall cost would be approximately £15,951.60 + VAT. This request was discussed at a number of levels and it was suggested that Rivers Agency would be best placed to pursue this data as a public body. No further information has yet been received.

**Table 2.1: Local Authorities**

County Council	Request	Data Request Date	Data Received
Cavan CoCo	1	28 <sup>th</sup> May 2012	<ul style="list-style-type: none"> <li>Existing Wastewater collection system.</li> <li>Existing foul and combined collection network (Town Centre)</li> <li>Existing Storm Water Collection Network.</li> <li>Flood Locations/Descriptions</li> <li>Recorded Monuments</li> <li>Recorded Protected Structures</li> <li>Town Council Record of Protected Structures</li> </ul>
	2	4 <sup>th</sup> July 2012	<ul style="list-style-type: none"> <li>Ballyconnell Zoning Data</li> <li>Cavan Zoning Data</li> <li>Cavan Land use Layers</li> <li>Cavan Town Zoning Data</li> <li>Cavan Flood Locations</li> </ul>
Louth CoCo	1	9 <sup>th</sup> May 2012	<ul style="list-style-type: none"> <li>Zoning Data for: Ardee, Blackrock South, Dundalk and Louth Town.</li> <li>Local Area Plans for Ardee, Baltry, Carlingford and Termofeekin</li> <li>Louth County Development Plan</li> </ul>
	2	28 <sup>th</sup> May 2012	
	3	4 <sup>th</sup> July 2012	
Monaghan CoCo	1	28 <sup>th</sup> May 2012	<ul style="list-style-type: none"> <li>Zoning Data for Ballybay, Carrickmacross, Inniskeen, Monaghan, Monaghan County, Monaghan Town</li> <li>Natural Heritage Survey Information</li> <li>Cultural Heritage Survey Information</li> <li>Roads Section Information</li> <li>Landscape Character Information</li> <li>Flooding Aerial photography</li> <li>Draft Flood Risk Assessment Mapping</li> </ul>
	2	4 <sup>th</sup> July 2012	
Meath CoCo	1	4 <sup>th</sup> July 2012	<ul style="list-style-type: none"> <li>Meath County Zoning</li> </ul>

As RPS go through the various stages of the North Western - Neagh Bann CFRAM Study, further data needs may be identified and therefore the data collection process will be ongoing throughout the project duration.

## **2.2 DATA MANAGEMENT AND REGISTRATION**

When spatial data is received by RPS, it is transferred from the medium supplied into a temporary Incoming Data Folder. Any spatial data that is not provided in ESRI ArcMap format is converted using Feature Manipulation Engine (FME) software. A shapefile or a file Geodatabase is then created and the translated feature classes are imported into it, where they are named appropriately using the convention of (owner, study initial, unit of management, dataset name, date received) e.g. DCC\_N1\_LetterkennyZoning\_120801, and the correct spatial reference is attached. These datasets are then imported to ArcMap to verify the positional accuracy against OSi background mapping.

All spatial and non-spatial information details are recorded into the Incoming Data Register. This register records the date of receipt, issuing organisation, supplier contact, data owner, filename as received, renamed filename, category, work package, description, original data format, new data format, type, medium, metadata, hyperlink, hydrological area, data requirement. Once receipt has been recorded and the data has been re-processed as necessary, the spatial and non-spatial datasets are moved to the appropriate folder location on our dedicated data server i.e. spatial data is moved to the folder 'NWNBCFRAMS\_SpatialData', non-spatial is moved to the folder '8.2 Data Collection'. Data which is specific to a particular work package is moved into the relevant work package folder, for example, hydrometric data is moved to the '8.5 Hydrology WP' folder.

## **2.3 DATA REVIEW**

The purpose of the data review was to assess the quality and fitness-for-purpose of the data. Where data gaps or issues were found it has been attempted to source more adequate information that is suitable for the required modelling and assessments.

### **2.3.1 Flood Relief / Risk Management Measures**

Following a number of data requests as outlined in Section 2, RPS has received details of flood relief and management measures within Unit of Management 06 (UoM06) from Louth County Council and OPW.

All scheme and feasibility reports received by RPS were reviewed to identify relevant information for the purposes of the North Western – Neagh Bann CFRAM Study. A summary of the various reports reviewed is provided in Table 2.2, which summarises; the area the report covers, the river associated with the report, the name of the report, who compiled the report, when it was produced and a brief summary of any recommendations contained within each report.

**Table 2.2: Summary of reviewed reports**

<b>Flood Relief Study</b>	<b>River Name</b>	<b>Report Name</b>	<b>Author</b>	<b>Date</b>	<b>Recommendations</b>
Dundalk Bay	Tidal/River Fane	Study of Blackrock Beach	Aquafact	November 2009	It is recommended that the best option for returning the beach to its former condition would be to either prevent waves reflecting onto the beach or alter their reflective angle away from the beach by constructing a wave barrier.
Drumconrath Flood Relief	Neagh River	DRAFT Drumconrath Flood Relief Feasibility Study East Region Minor Works	Not specified	Not specified (report produced following flooding of 24 October 2011)	The preferred Option 4 involves underpinning the centre arch and the right arch of the bridge by 1000mm, regrading of the channel from upstream of Meath Co Co. Bridge at the treatment plant to approximately 300m upstream of the Village Bridge and some localised raising of the banks.



### **2.3.2 Historical Flood Data**

Information on historical flood events was sought from a variety of sources including OPW and Local Authority records, internet searches and other general enquiries. In total, 30 historical events were identified that had led to flooding within AFAs situated in UoM 06 during the period 1954 to 2011 as detailed in Table 4.9. A summary of the information available for each of these events is presented in Section 4.3.2.

### **2.3.3 Baseline Mapping**

RPS has obtained complete baseline mapping coverage of the entire North Western – Neagh Bann CFRAM study area. The mapping which has been supplied by OPW includes the following datasets:

- NWNB RBD Six Inch Tiles;
- NWNB RBD OS MAPS 1000 Vector;
- NWNB RBD OS MAPS 2500 Vector
- NWNB RBD OS MAP 5000 Raster\_bw;
- NWNB RBD OS MAP 5000 Vector;
- NWNB RBD Digitowns 10560 Raster;
- NWNB RBD OS MAPS 50000 Raster;
- Orthophotography (Raster);
- NWNB RBD LIDAR.

Due to the limited quality of the 5000 and 1000 raster mapping when printed at the scales required for this study, the equivalent vector mapping had to be processed using Feature Manipulation Engine Software to convert it from AutoCAD to ArcMap format.

RPS are in discussion with OPW with regards to acquiring additional bathymetry or LiDAR data for AFAs which have a coastal modelling requirement. A proposed methodology for re-using LiDAR data from the OPW Irish Coastal Protection Strategy Study (ICPSS) in combination with some additional survey data has been submitted for approval.

### **2.3.4 Hydrometric Data**

Details of the hydrometric data available for UoM 06, and the analysis of this data are presented in Section 4.1. The OPW operate 12 river hydrometric stations within UoM 06. Three stations are inactive and have no continuous recorded data available (these are staff gauge only stations). Therefore nine

OPW hydrometric stations are available for use within the study. An additional 41 hydrometric stations are located within UoM 06 and are owned by one of the Local Authorities (Cavan, Louth, Meath or Monaghan County Council) and are operated by EPA. Hydrometric data is available for 11 of these and has been acquired by RPS. In addition to the hydrometric gauge stations identified within UoM 06, three additional gauge stations were identified which may have information relevant for hydrological analysis within UoM 06, which are located just within Northern Ireland (operated by Rivers Agency). Therefore in total, 23 hydrometric stations (nine OPW / 11 Local Authority (EPA) and three RA) have data directly relevant to UoM 06 and available for use within this Study.

### **2.3.5 Meteorological Data**

Meteorological data provided by Met Éireann through OPW at the project outset was subject to a gap analysis and additional data was acquired directly by RPS as required. Requests were also issued to Local Authorities for any additional rainfall data they might possess over and above that available from the Met Éireann gauges. Further discussion of the actual rainfall data obtained is presented in Section 4.2.

Meteorological data is also being sought from the UK Met Office to help fill information gaps in the areas along the border with Northern Ireland. RPS requested a quotation from the Met Office in July 2012, to which the Met Office responded with a generic quote, based on the provision of rainfall data over a 30 year period from 10 weather stations; five of which offer hourly data (a potential of 1,314,000 data points) and five of which offer daily rainfall totals (a potential of 54,750 data points). Rivers Agency are assisting in the procurement of this data, however no information has yet been received.

### **2.3.6 Land Use Data**

Following various data requests, land use data obtained includes CORINE land cover data, GSI data and development data. The development plan and GSI datasets received are outlined in Sections 2.3.7 and 2.3.10.

The CORINE datasets obtained are as follows:

- EPA\_Corine\_2000rev;
- EPA\_CorineChangesOnly\_2006;
- EPA\_Corine\_2006\_complete.

Having viewed the European Environment Agency (EEA) website (<http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-clc2000-seamless-vector-database-3>) it was identified that the current European version is 'CORINE 15' which was updated in August 2011. A query was issued to EPA Ireland to ascertain if the updated European CORINE 15 dataset had any impact on the Irish CORINE dataset, to which they responded that they were not aware of any updates made to the Irish

CORINE data and that the CORINE 2006 dataset supplied is the latest version of the dataset available for Ireland.

### **2.3.7 Planning and Development Information**

Accurate and current development zoning information is essential to the correct delineation of AFA extents and will also be important when considering options and developing future scenarios. At present we have the following development zoning datasets:

#### **2.3.7.1 Cavan County Council**

- Cavan Town Limits;
- Cavan Town Zoning Data;
- Ballyconnell Zoning Data;
- County Cavan – Amenity Recreation Areas, Industry-Enterprise-Employment Areas, Low Density Residential Areas, Mixed Use Areas, Public Community Areas, Residential Areas, Town Core Areas.

#### **2.3.7.2 Louth County Council**

- Zoning Data for Ardee, Blackrock South, Dundalk and Louth Town;
- Local Area Plans for Ardee, Baltry, Carlingford and Termofeckin;
- Louth County Development Plan.

#### **2.3.7.3 Monaghan County Council**

- Ballybay – Zoning;
- Carrickmacross – Zoning;
- Inniskeen – Zoning;
- Monaghan Town Limits;
- Monaghan County – Zoning, protected structures, national monuments, areas of amenity, pNHAs, SPAs, SACs.

#### **2.3.7.4 Meath County Council**

- Meath County Zoning

Following receipt of these planning and development datasets Local Authority staff were consulted with regards to AFA delineation with this information.

### 2.3.8 Environmental Data

RPS has identified a preliminary list of datasets and sources as indicated in Table 2.3 which are relevant to the Strategic Environmental Assessment and Appropriate Assessment. However this list is subject to revision pending the outcome of the scoping exercise which is ongoing.

**Table 2.3: Preliminary List of Environmental Datasets**

SEA Issue Area	Data	Availability
Biodiversity, Flora and Fauna	National Parks and Wildlife database (e.g. protected habitats and species including SAC/SPA/NHA).	<a href="http://www.npws.ie">www.npws.ie</a> RPS has access
Biodiversity, Flora and Fauna	Relevant Freshwater Pearl Mussel Sub-basin management plans (if relevant).	<a href="http://www.npws.ie">www.npws.ie</a> RPS has access
Biodiversity / Flora and Fauna	Invasive species, threatened species, protected species.	<a href="http://www.biodiversity.ie">www.biodiversity.ie</a> Free to download
Biodiversity / Flora and Fauna	Waterways Ireland ecological, invertebrate, kingfisher, Japanese Knotweed, otter and lamprey surveys	RPS has received relevant WWI data
Water/Biodiversity/Flora and Fauna	Inland Fisheries Ireland - North Western - Neagh Bann Area Species present, counts etc., Fisheries assessments if available.	<a href="http://www.fisheriesireland.ie">www.fisheriesireland.ie</a> On request
Water / Material Assets	Waterways Ireland databases;	<a href="http://www.waterwaysireland.ie">www.waterwaysireland.ie</a> Free to download but not as GIS
Cultural Heritage/ Biodiversity / Flora and Fauna	Cultural Heritage e.g. Brú na Bóinne UNESCO World Heritage Site Natural Heritage e.g. local biodiversity action plans	<a href="http://www.heritagecouncil.ie">www.heritagecouncil.ie</a> Free to download
Cultural Heritage	Record of Monuments and Places;	<a href="http://www.archaeology.ie">www.archaeology.ie</a> RPS has access
Cultural Heritage	National Inventory of Architectural Heritage (NIAH)	<a href="http://www.buildingsofireland.ie">www.buildingsofireland.ie</a> Free to download
Cultural Heritage	Waterways Ireland heritage information (including Ulster Canal navigation)	RPS has received relevant WWI data
Material Assets	Coillte forestry database (FIPS)	<a href="http://www.coillte.ie">www.coillte.ie</a> Will request
Soils / Geology	Geological Survey of Ireland (GSI) mapping, including groundwater maps; groundwater vulnerability, protection schemes; soils classification.	<a href="http://www.gsi.ie">www.gsi.ie</a> RPS has access

SEA Issue Area	Data	Availability
Soils	Teagasc soil information;	www.teagasc.ie RPS has access
Material Assets / Land Use	Corine and Landcover Land Use Databases;	RPS has access
Water	Information gathered during the implementation of the Water Framework Directive;	RPS has access
Population	Central Statistics Office database, including census data. Prelim 2011 data available.	www.cso.ie RPS has access to 2006. Will request 2011 when it becomes available.
Material Assets / Landuse	Department of Agriculture, Food and the Marine databases e.g. fertilizer usage.	Will request.
All aspects	Relevant County Development Plans Detailed flora and fauna field surveys, habitat mapping, water quality measurements, tree protection orders, landscape character areas, seascapes, protected views, areas of high amenity, development plan boundaries and zonings digitally;	Will be requested from environmental, heritage officers during scoping consultation
All aspects	Other Local Authority datasets;	Will be requested from environmental, heritage officers during scoping consultation
All aspects	Regional Authority datasets;	Will be requested during scoping consultation
All environmental aspects	EPA databases (e.g. groundwater and surface water quality, air quality, etc.); EPA 2008 State of Environment Report and updated report, if available; and EPA ENVision (Environmental Mapping / Geographical Information System).	www.epa.ie Free to download
All environmental aspects	EPA Additional datasets e.g. contaminated land, brownfield sites etc	www.epa.ie Not available for download but will request.
General / mapping	Aerial photography OSI vector mapping	RPS has access

It is also important to note that many of the environmental dataset are not static over time and thus early acquisition of all data is not necessarily desirable. Such data is much better requested only when it is required. Consequently, RPS will maintain contact with the relevant data owners as the project progresses to ensure that data requests are appropriately timed to ensure that the most up to date information is used to inform the study.

### **2.3.9 Soil and Geological Data**

Following requests to GSI for soil and sub-soil information to inform the selection of appropriate parameters for the MIKE-NAM modelling activities, RPS obtained the following datasets:

- Bedrock and SG Aquifers Union;
- Soils – Wet and Dry;
- Subsoil Permeability;
- Vulnerability.

Initial review of this data indicates that it will be sufficient for the intended purpose. However this data will be reviewed in detail in the hydrology report, in particular to assess its suitability for identifying karst features.

### **2.3.10 Defence and Coastal Protection Asset Data**

Requests to Local Authorities and OPW for details of any additional information held on existing flood defence and coastal protection assets has provided no additional information for assets within UoM 06, beyond that originally received from OPW in October 2011 and delivered by RPS. The limited information obtained to date will be supplemented as further assets are identified and relevant geometric data collected through the North Western – Neagh Bann survey contract. Information on the current condition of all assets will be obtained during the follow up asset condition survey.

## **2.4 DATA OUTSTANDING**

RPS made one final request for missing information / data from each of the Local Authorities. These final requests were made in mid August 2012 via email and each Local Authority was forwarded the tailored document outlining study data requirements with the information / data received to date for their administrative areas. Within the document under each of the requirement headings, Local Authorities were requested to either provide any additional information they feel appropriate for the North Western - Neagh Bann CFRAM Study or confirm that they have no further information. Also detailed in the documents was information that had previously been requested but had not yet been provided. The cut-off point for data collection activities was the end of August 2012. All Local Authorities have responded to date with data available or have responded that they have no more information to offer.

## **2.5 DATA GAPS**

At present RPS has not confirmed any significant data gaps, that cannot be mitigated for, that will impact on the completion of the North Western - Neagh Bann CFRAM Study. However this statement

is made without having received any survey information. RPS expect that as the final scope of the study is refined as the study progresses through the next phases, additional data needs will be identified, which will be addressed in so far as is possible through on-going data collection exercises in a similar manner to the initial data collection phase reported here. Therefore it is not possible at this point in time to categorically state that there are no data gaps which will impact on the completion of the North Western - Neagh Bann CFRAM Study.

RPS are in discussion with OPW with regards to acquiring additional bathymetry or LiDAR data for AFAs which have a coastal modelling requirement. A proposed methodology for re-using LiDAR data from the OPW Irish Coastal Protection Strategy Study (ICPSS) in combination with some additional survey data has been submitted for approval. Meteorological data is currently being sought from the UK Met Office to help fill information gaps in the areas along the border with Northern Ireland. DARD Rivers Agency are assisting in the procurement of this data, however no information has yet been received.

RPS has been implementing data quality and validity checks on information that has been obtained throughout the data collection process. The findings of these checks have been briefly detailed in Table 2.4.

**Table 2.4: Summary of Data Quality and Validity Checks**

Section Reference	Section Heading	Comment
2.3.1	Flood Relief / Risk Management Measures	Historical Flood data has been reviewed by a member of RPS staff to ascertain its fitness for purpose. The outcome of the review has been detailed in Section 2.3.1 of this report.
2.3.2	Historical Flood Data	Historical Flood data has been reviewed by a member of RPS staff to ascertain its fitness for purpose. The outcome of the review has been detailed in Section 4.3.2 of this report.
2.3.3	Baseline Mapping	Originally only Raster mapping was provided which was not fit for purpose as it was not of sufficient clarity for the production of detailed maps, therefore Vector mapping was requested and received which is adequate for printing detailed maps. Also complete coverage of UoM 06 was not supplied initially however full coverage has now been obtained following further data requests as described in Section 2.3.3.
2.3.4	Hydrometric Data	Hydrometric Data has been reviewed by a member of RPS staff to ascertain its fitness for purpose. The outcome of the review has been detailed in Section 4. Preliminary Hydrological Assessment and Method Statement of this report.
2.3.5	Meteorological Data	Meteorological Data has been reviewed by a member of RPS staff to ascertain its fitness for purpose. The outcome of the review has been detailed in Section 5. Detailed Methodology Review of this report.
2.3.6	Land Use Data	RPS originally received old versions of Land Use datasets which were not fit for purpose. RPS therefore requested and obtained the most recent version of the Land Use datasets as outlined in Section 2.3.6 of this report.

2.3.7	Planning and Development Information	Some of the Planning and Development datasets received were not the latest revision of the County's Development Plans and therefore a request was made to obtain their most recent datasets, which depict the zoning areas required by RPS. This is further detailed in Section 2.3.7.
2.3.8	Environmental Data	This information has not been fully assessed for fitness for purpose, as the information is not required at this early stage of the project.
2.3.9	Soil and Geological Data	Initial review of this data indicates that it will be sufficient for the intended purpose.
2.3.10	Defence and Coastal Protection Asset Data	RPS have obtained a very limited amount of information on defence data, however, further analysis of defence information shall be undertaken during the asset condition surveys. Further information on Defence Surveys is outlined in Section 3.2.

## 2.6 CONCLUSION

In conclusion RPS has identified and obtained data that is valid and of good quality for use within the North Western - Neagh Bann CFRAM Study. Requests have been issued and tracked in order to obtain as much relevant information as possible. The complete process of requesting and obtaining information has been recorded and logged within the various Data Request and Incoming Data registers. Reports and spatial data have been reviewed to ensure they relate to the North Western - Neagh Bann CFRAM study area and that they provide beneficial information for the project. During this process RPS identified certain datasets that were not fit for purpose as they were out of date and subsequently RPS sourced the most up-to-date versions of the relevant datasets.

There are currently outstanding data issues and data gaps with regards to the LiDAR coverage for AFAs that require coastal modelling and meteorological data from the Met Office. All of these issues are currently being dealt with between the relevant bodies.

RPS has received a very limited amount of information in relation to defence assets from the Local Authorities, however, this should not have a significant impact on the North Western - Neagh Bann CFRAM Study as this information shall be collected and recorded during subsequent planned on-site surveys.



### 3 SURVEYS

#### 3.1 CHANNEL & CROSS-SECTION SURVEYS

On behalf of OPW, JBA Consulting commenced the preparation of documentation to procure a channel and cross-section survey contract for most of the area within UoM 01 as part of a pre-contract national survey management programme. Subsequently RPS were tasked with procuring a survey contractor to complete UoM 01 and also to provide the required channel and cross-section surveys within UoM 06 and 36. Due to the emerging timescales and proximity of the works the contracts were merged in mid 2012 under one contract prepared by RPS providing the full survey requirements on the three units of management within the North Western and Neagh Bann CFRAM Study area. This survey contract (known nationally as SC7) encompasses the full channel cross-sections, details of hydraulic structures and geometric survey of defences for UoM 01, 06 and 36. The contract was advertised through e-tenders and OJEU on 25 July 2012 with tenders returned in August. RPS completed the tender evaluation and a preferred bidder was identified. The OPW issued a letter of intent on 6 November 2012 with surveys expected to start on site in late 2012.

#### 3.2 FLOOD DEFENCE ASSETS

The identification of non-APSR and APSR flood defence assets is a requirement of the SC7 survey contract and thus at present RPS have not established a definitive list of flood defence assets. However the locations of some of the study area's flood defence assets that lie within the non-APSRs were identified within the North Western – Neagh Bann CFRAM Study Brief by OPW, these include some lengths of defences that are within expected APSRs. Additional locations flood defence assets were suggested by RPS and confirmed by the Local Authorities on the study progress group and the OPW. These assets are indicated in Figure 3.1 and listed in Table 3.1. In the North Western – Neagh Bann CFRAM Study Brief, OPW indicated that no other flood defence assets within APSRs are known to them. Nonetheless, a condition survey should be undertaken for any flood defence assets within APSRs.

**Table 3.1: Non-APSR Flood Defence Assets Identified in UoM 06 Survey Specification**

Name	River Reach	Flood Defence Type	Total Length (m)
<b>Non-APSR Groups of Flood Defences for Channel and Structure Survey</b>			
Annagassan	River Glyde / River Dee	Embankment	9910 + 2220 (identified by RPS)
Belurgan	Dundalk Harbour	Embankment	1340 + 8460 (identified by RPS)

### **3.3 FLOODPLAIN SURVEY**

The tender documents indicated that OPW would supply the results of a floodplain survey based on LiDAR techniques by May 2012. RPS provided input to the required coverage of this survey based on initial assessment of AFA locations and extents. Delivery of the processed floodplain survey information was delayed until September 2012 due to weather issues during the fieldwork period. Whilst the survey coverage appears to be complete, checking will be ongoing throughout the building of the hydraulic computational models during 2013. Therefore it is not possible to make further comment at present on the adequacy of the information received for use in later stages of the North Western - Neagh Bann CFRAM Study.

### **3.4 PROPERTY SURVEY**

The Generic CFRAM Study Brief requires property surveys to be undertaken to confirm locations, type, use, floor area etc of properties identified as potentially being at risk. Consequently, we will not be undertaking this work until draft flood hazard maps are available.



**Figure 3.1: Locations of Flood Defence Assets in UoM 06**

## 4 PRELIMINARY HYDROLOGICAL ASSESSMENT AND METHOD STATEMENT

### 4.1 HYDROMETRIC DATA

UoM 06 is made up of two hydrometric areas, HA03 (Bann) and HA06 (Newry, Fane, Glyde and Dee).

#### 4.1.1 Hydrometric data – UoM 06

The OPW provided RPS with hydrometric station data from the OPW Hydrometric Section database. This consisted of all available data for all OPW stations within the North Western and Neagh Bann IRBDs including Annual Maximum (AMAX) Series data for those stations included in the OPW's Flood Studies Update (FSU). The OPW operate 12 river hydrometric stations within UoM 06. Three stations are inactive and have no continuous recorded data available (these are staff gauge only stations). Therefore nine OPW hydrometric stations are available for use within the study. These are listed in Table 4.1.

**Table 4.1: OPW Hydrometric Stations with available data within UoM 06**

Station Number	Station Name	River/Lake	Records Length
03055	Glaslough	Mountain Water	Jun 1980 – Feb 2011
03058	Cappog Bridge	Blackwater	Sep 1995 – Oct 2011
06011	Moyles Mill	Fane	Oct 1972 – Mar 2011
06012	Clarebane	Clarebane	Oct 1972 – Jul 2011
06013	Charleville	Dee	Oct 1975 – Oct 2011
06014	Tallanstown	Glyde	Oct 1975 – Oct 2011
06021	Mansfieldstown	Glyde	Aug 1955 – Oct 2011
06025	Burley	Dee	Jan 1972 – Oct 2011
06026	Aclint	Lagan (Glyde)	Jan 1972 – Oct 2011

An additional 41 hydrometric stations are located within UoM 06 and are owned by one of the Local Authorities (Cavan, Louth, Meath or Monaghan County Council) and are operated by EPA. Hydrometric data is available for 11 of these and has been acquired by RPS. These are listed in Table 4.2. The data provided consisted of flow and / or level data and rating curves where available.

**Table 4.2: Local Authority (EPA) Hydrometric Stations with Available Data in UoM 06**

Station Number	Station Name	River/Lake	Data Available	Records Length
03051	Faulkland	Blackwater	Water Level and Flow	Jan 2000 – Feb 2012
03056	Killycooly	Emy Lough	Water Level Only	Sep 2003 – May 2010
03057	Emyvale Weir	Mountain Water	Water Level Only	Feb 2000 – Feb 2012
03070	Emy Lough	Emy Lough	Water Level Only	Jan 2000 – Jul 2012
06030	Ballygoly	Big River	Water Level and Flow	Mar 2000 – Feb 2012
06031	Curralhir	Flurry River	Water Level and Flow	Sep 2000 – July 2010
06033	Coneyburrow Br.	White River	Water Level and Flow	Dec 1999 – August 2011
06036	Ladyswell	Ramparts	Water Level Only	Dec 2000 – Feb 2012
06056	Drumleek	Drumleek Stream	Water Level and Flow	Oct 2005 – Jan 2012
06070	Muckno	Mucknoo Lough	Water Level and Flow	Jan 2000 – Jan 2012
06072	Whitewood	Whitewood Lough	Water Level Only	August 1983 – Sep 1995

The remaining 30 EPA operated hydrometric stations have no continuous monitoring data available. These stations are either staff gauge only sites where only spot measurements were taken at these sites in the past and usually for one-off projects related to control of water pollution or sites where despite there being evidence of a recorder, no data appeared to be available.

In addition to the hydrometric gauge stations identified within UoM 06, three additional gauge stations were identified which may have information relevant for hydrological analysis within UoM 06, which are located just within Northern Ireland (operated by Rivers Agency).

**Table 4.3: Relevant Rivers Agency Hydrometric Stations with Available Data**

Station Number	Station Name	River/Lake	Data Available	Records Length
03022	Derrymeen Bridge	Blackwater	Water Level & Flow	Jan 1983 – Sep 2009
06001	Mountmill Bridge	Newry - Dee	Water Level & Flow	Dec 1974 – Sep 2009

Station Number	Station Name	River/Lake	Data Available	Records Length
06004	Carnbane	Newry -Dee	Water Level & Flow	Dec 1983 – Sep 2009

Therefore in total, 23 hydrometric stations (nine OPW / 11 Local Authority (EPA) and three RA) have data directly relevant to UoM 06 and available for use within this Study. Each of the 23 stations with data available has a monitoring station fitted with a staff gauge and an automatic water level recorder. The automatic water level recorder can either be an autographic recorder or a digital datalogger. An autographic recorder is a simple float operated device that records water level onto a paper chart. These charts are then digitised to convert the data to a digital format. In recent years data loggers have replaced the recorder technology and are now installed at almost all stations where continuous water levels are recorded. The digital data from these loggers can be entered directly into a computer, overcoming the need to digitise water level records. The production of continuous flow data for a gauging station is derived from the water level data and it requires: continuous recording of water levels and; development of a station calibration. The station calibration is developed by plotting the results of flow measurements (spot gaugings) which have been carried out at various water levels and developing a stage-discharge relationship (also known as a rating curve) between water level and river flow. 18 of the 23 hydrometric gauges have flow data available that has been derived from continuous water level data using this methodology. The other five hydrometric sites have only water level data available.

As part of the FSU, selected hydrometric stations throughout the country were reviewed and analysed to generate a database of hydrometric data (using data up to 2004). Where applicable, OPW have provided a summary of this FSU generated station data, which includes any changes in rating classification, Highest Gauged Flow (HGF),  $Q_{med}$  and MAF (Mean Annual Flow) estimates and the period of AMAX record analysed under FSU (including AMAX 2009). An FSU generated rating classification was also assigned to these stations. Of the 23 stations listed in Table 4.1, 4.2 and 4.3, thirteen were included in the FSU review and had a classification assigned as shown in Table 4.4. A definition of the rating quality classification is provided below the table.

**Table 4.4: Final Station Rating Quality Classification**

Station Number	Station Name	Final Station Rating Quality Classification
03051	Faulkland	B
03055	Glaslough	U
03058	Cappog Bridge	U

Station Number	Station Name	Final Station Rating Quality Classification
06011	Moyles Mill old bridge	A1
06012	Clarebane	A1
06013	Charleville Weir	A1
06014	Tallanstown Weir	A1
06025	Burley	A1
06026	Aclint	A1 (Pre 01/05/1988) A2 (Post 01/05/1988)
06030	Ballygoly	B
06031	Curralhir	A2
06033	Coneyburrow Br	B
06070	Muckno	A1

- **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  $Q_{med}$ , bankfull 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.

#### **4.1.2 Application of Hydrometric Data within UoM 06**

Figure 4.1 shows all 56 hydrometric stations within UoM 06, and the three Rivers Agency gauges which may be directly relevant to UoM 06. The 23 for which data is available are coloured green (water level and flow data) or yellow (water level data only). Those which have additional data from the FSU work, including AMAX series are also highlighted. All 23 stations with data available will be used in the hydrological analysis as appropriate:

- Stations along modelled watercourses with water level and flow data, gaugings and ratings will be used for hydrological and hydraulic model calibration, historical flood analysis and growth curve derivation.
- Stations along modelled watercourses with water level data only which are located on watercourses to be modelled may be useful in calibration exercises. Recorded water levels may be useful in comparing hydraulic model outputs with observed flood events. AMAX series of water levels and derived AEPs may also be useful in hydraulic model calibration of water levels for various design AEPs.
- Stations with water level and flow data within the wider UoM 06 area are used in historical flood analysis and growth curve derivation.
- Stations which have already been included in the FSU are of benefit to the Study since AMAX series of flows have previously been derived, and quality ratings have been assigned. A range of hydrometric data analyses would have been undertaken at these stations (up until 2004). These stations will also be used in the Study with care taken to ensure all available data, including post 2004 is used.

Over and above the 23 stations within UoM 06 (including the Rivers Agency stations), additional stations outside of the catchments will be used where appropriate to supplement the data from within the catchments. Stations from outside the catchments will be used for the following purposes:

- FSU Pivotal Sites may be used in a pooled flood frequency analysis. Gauge years taken from pivotal sites outside the catchment may be used (where they are found to be sufficiently hydrologically similar) to provide additional gauge years for pooled flood frequency analysis and growth curve development within the catchment.
- Where catchments are ungauged, Pivotal Sites from outside UoM 06 may be used to transfer data in order to modify regression estimates of the index flood ( $Q_{med}$ ) where the Pivotal Site is found to be sufficiently hydrologically similar as per FSU Work Package 2.3.





Figure 4.1: Hydrometric Stations in UoM 06

### **4.1.3 Hydrometric Stations along modelled watercourses**

There are seven hydrometric stations with data along the rivers to be modelled as Medium or High Priority Watercourses (MPW or HPW). These are shown on Figure 4.2. Six of these stations have water level and flow data with the other station having water level data only. Five out of seven of these stations were classed as having data useable for the FSU which is also indicated on Figure 4.2.



Figure 4.2: Hydrometric Stations along Modelled Watercourses (HPW / MPW)

#### 4.1.4 Rating Reviews – North Western – Neagh Bann CFRAM Study

As a follow on from the recommendations of Work Package 2.1 of the FSU (Reference 5), a task was included in the North Western – Neagh Bann CFRAM Study brief to undertake further rating review of a subset of hydrometric stations. Following the completion of the risk review stage and finalisation of the AFA locations three hydrometric stations were specified for rating review. These stations were chosen for rating review by OPW as they had available continuous flow data, were located on (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).

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.
3. Spot gauged flows are replicated within the model and the model calibrated in order to achieve the observed measured water levels at the gauge station location.
4. When calibration 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 Figure 4.3. The current rating quality classification assigned under the FSU for each station (if available) is stated in Table 4.5.

**Table 4.5: Existing Rating Quality Classification for Rating Review Stations in UoM 06**

Station Number	Station Name	Final Station Rating Quality Classification
06011	Moyles Mill old bridge	A1
06021	Mansfieldstown	Not rated
06025	Burley	A1

Following completion of a rating review either certainty will be brought to the rating relationship beyond the highest gauged flow or a new relationship will be defined which can be used to re-process flow information to a higher degree of certainty.



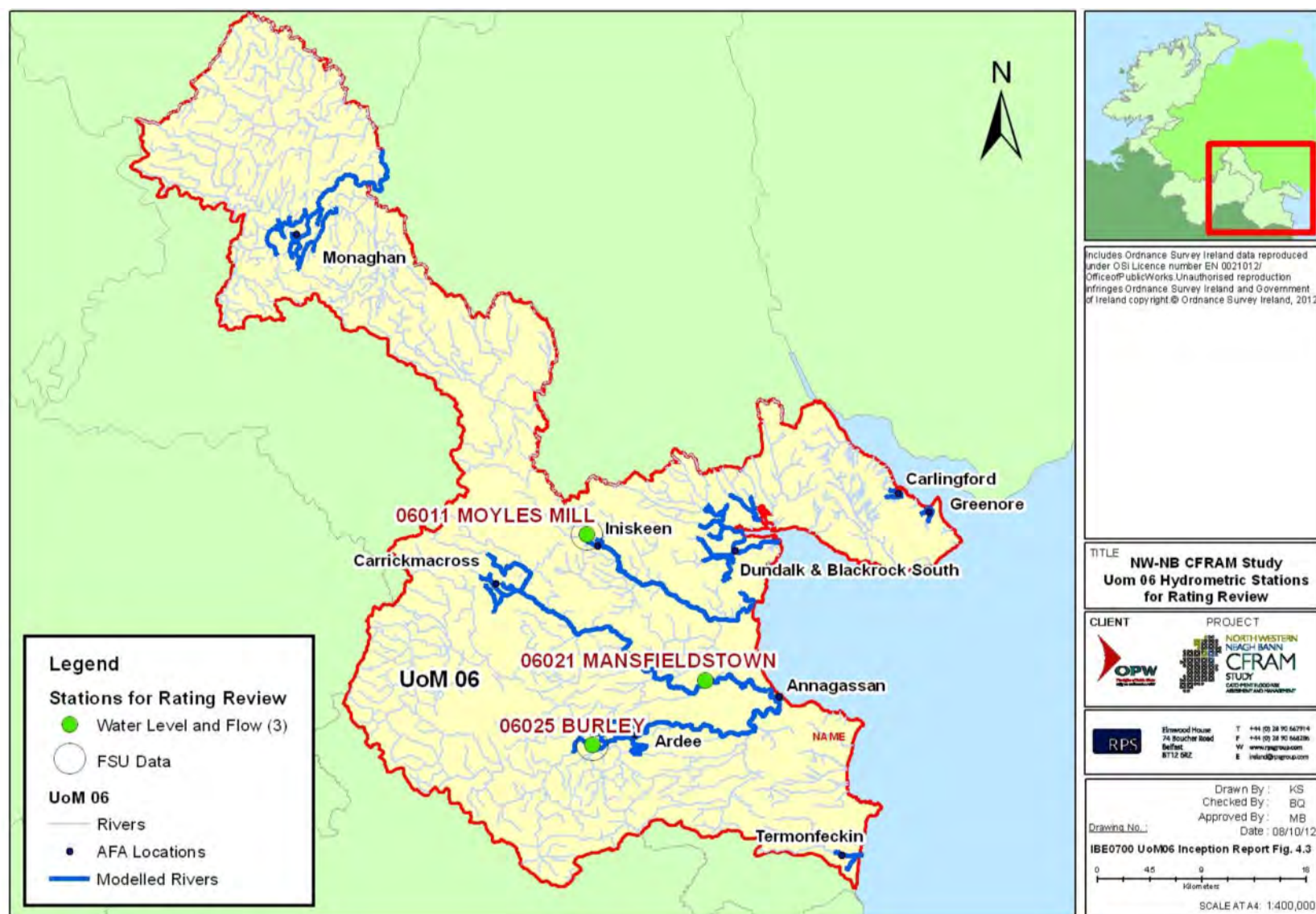


Figure 4.3: Hydrometric Stations used for rating review in UoM 06

#### 4.1.5 Summary of Hydrometric Data

Table 4.6 summarises the number of hydrometric stations with data available within UoM 06 overall. Seven of the UoM 06 stations which have water level and flow data available are located on modelled watercourses and three of these stations require CFRAMS rating review.

**Table 4.6: Number Summary – Stations with Data Available**

Data Available	UoM 06	Rivers Agency	HPW/MPWs	CFRAM Rating Review
Water Level and Flow	15	3	7	3
Water Level Only	5	-		
Total	23			

Table 4.7 provides a more detailed summary of the type of data for each of the 23 usable Hydrometric Stations within UoM 06 that has been collected for the North Western – Neagh Bann CFRAM Study. The seven stations that are located on the watercourses to be modelled are highlighted in blue.

Six hydrometric stations with continuous water level and flow data are available on watercourses to be modelled. As a result of this five out of the nine AFAs affected by fluvial flooding in UoM 06 have a gauging station with water level and flow on the modelled stretch of watercourse which would be suitable for direct hydrological analysis and / or model calibration. As shown in Table 4.5, five out of seven of the gauge stations have 'A' classification ratings and as such can be considered to have a high confidence in the gauging above the index flood flow,  $Q_{med}$ . The gauging station 03051 downstream of Monaghan has a U rating and as such the gauging can be considered to have a high degree of uncertainty at flood flows.

Hydrometric Station Data Status Tables for UoM 06 are provided in Appendix A.

**Table 4.7: Summary of Hydrometric Data Provision within UoM 06**

NUMBER	NAME	BODY RESPONSIBLE	STATUS	DATA AVAILABLE	Record Length (dates)	Rating Info Provided	Gaugings Provided	AMAX Series Provided	FSU Generated Data Provided	Located on HPW/MPW	CFRAMS RATING REVIEW
03022	Derrymeen Bridge	Rivers Agency NI	Active	Water Level and Flow	Jan 1983 – Sep 2009	N	N	Y	N	N	N
03051	Faulkland	Monaghan County Council	Active	Water Level and Flow	Jan 2000 – Feb 2012	Y	N	N	N	Y	N
03055	Glaslough	OPW	Active	Water Level and Flow	Jun 1980 – Nov 2011	Y	Y	Y	N	N	N
03056	Killycooly	Monaghan County Council	Active	Water Level Only	Sep 2003 – May 2010	Y	N	N	N	N	N
03057	Emyvale Weir	Monaghan County Council	Active	Water Level Only	Feb 2000 – Feb 2012	N	N	N	N	N	N
03058	Cappog Bridge	OPW	Active	Water Level and Flow	Sep 1995 – Oct 2011	N	Y	Y	N	N	N
03070	Emy Lough	Monaghan County Council	Active	Water Level Only	Jan 2000 – Jul 2012	N	N	N	N	N	N
06001	Mountmill Bridge	Rivers Agency	Active	Water Level & Flow	Dec 1974 – Sep 2009	N	N	Y	N	N	N
06004	Carnbane	Rivers Agency	Active	Water Level & Flow	Dec 1983 – Sep 2009	N	N	Y	N	N	N
06011	Moyles Mill	OPW	Active	Water Level and Flow	Oct 1972 – Mar 2011	Y	Y	Y	Y	Y	Y
06012	Clarebane	OPW	Active	Water Level and Flow	Oct 1972 – Jul 2011	Y	Y	Y	Y	N	N



NUMBER	NAME	BODY RESPONSIBLE	STATUS	DATA AVAILABLE	Record Length (dates)	Rating Info Provided	Gaugings Provided	AMAX Series Provided	FSU Generated Data Provided	Located on HPW/MPW	CFRAMS RATING REVIEW
06013	Charleville	OPW	Active	Water Level and Flow	Oct 1975 – Oct 2011	Y	Y	Y	Y	Y	N
06014	Tallanstown	OPW	Active	Water Level and Flow	Oct 1975 – Oct 2011	Y	Y	Y	Y	Y	N
06021	Mansfieldstown	OPW	Active	Water Level and Flow	Aug 1955 – Oct 2011	Y	Y	Y	N	Y	Y
06025	Burley	OPW	Active	Water Level and Flow	Jan 1972 – Oct 2011	Y	Y	Y	Y	Y	Y
06026	Aclint	OPW	Active	Water Level and Flow	Jan 1972 – Oct 2011	Y	N	Y	Y	N	N
06030	Ballygoly	LouthCounty Council	Active	Water Level and Flow	Mar 2000 – Feb 2012	Y	N	Y	Y	N	N
06031	Curralhir	LouthCounty Council	Inactive	Water Level and Flow	Sep 2000 – July 2010	Y	N	Y	Y	N	N
06033	Coneyburrow Br.	LouthCounty Council	Active	Water Level and Flow	Dec 1999 – Mar 2012	Y	N	Y	Y	N	N
06036	Ladyswell	LouthCounty Council	Active	Water Level Only	Dec 2000 – Feb 2012	N	N	N	N	Y	N
06056	Drumleek	Monaghan County Council	Active	Water Level and Flow	Oct 2005 – Jan 2012	Y	N	N	N	N	N
06070	Muckno	Monaghan County Council	Active	Water Level and Flow	Jan 2000 – Jan 2012	N	N	Y	Y	N	N
06072	Whitewood	Meath County Council	Inactive	Water Level Only	Aug 1983 – Sep 1995	N	N	N	N	N	N

## 4.2 METEOROLOGICAL DATA

Meteorological data can be statistically analysed to determine the frequency of rainfall events which cause flooding. The data can also be input to rainfall run-off models which can then be used to derive simulated flow records. This can be particularly useful where there is little or poor quality hydrometric data. Meteorological data was provided by Met Éireann through the OPW at the project outset. A gap analysis was undertaken and additional data was acquired from Met Éireann directly by RPS. Additional rainfall data was also requested from Local Authorities if available.

### 4.2.1 Daily Rainfall Data

Daily rainfall data was received from Met Éireann for a total 417 rainfall gauges both within and beyond the North Western – Neagh Bann CFRAM study area. Table 4.8 summarises the number of available daily rainfall gauges for the study.

**Table 4.8: Number of Available Daily Rainfall Gauges**

Station Location	Provided By:		Total
	Met Éireann	Local Authorities	
Within NW-NB CFRAM Study Area Only	231	0	231
Within NW-NB CFRAM Buffer Area Only	186	0	186
Within NW-NB CFRAM Study Area plus Buffer	417	0	<b>417</b>

A total of 231 of the daily rainfall gauges are located within the North Western – Neagh Bann CFRAM study area. An additional 186 are located beyond the Study area boundary as shown in Table 4.8 and Figure 4.4. These additional rainfall gauges have been included to provide a wide enough rainfall station network for determining the rainfall event input at Hydrological Estimation Points (refer to Section 5.3).

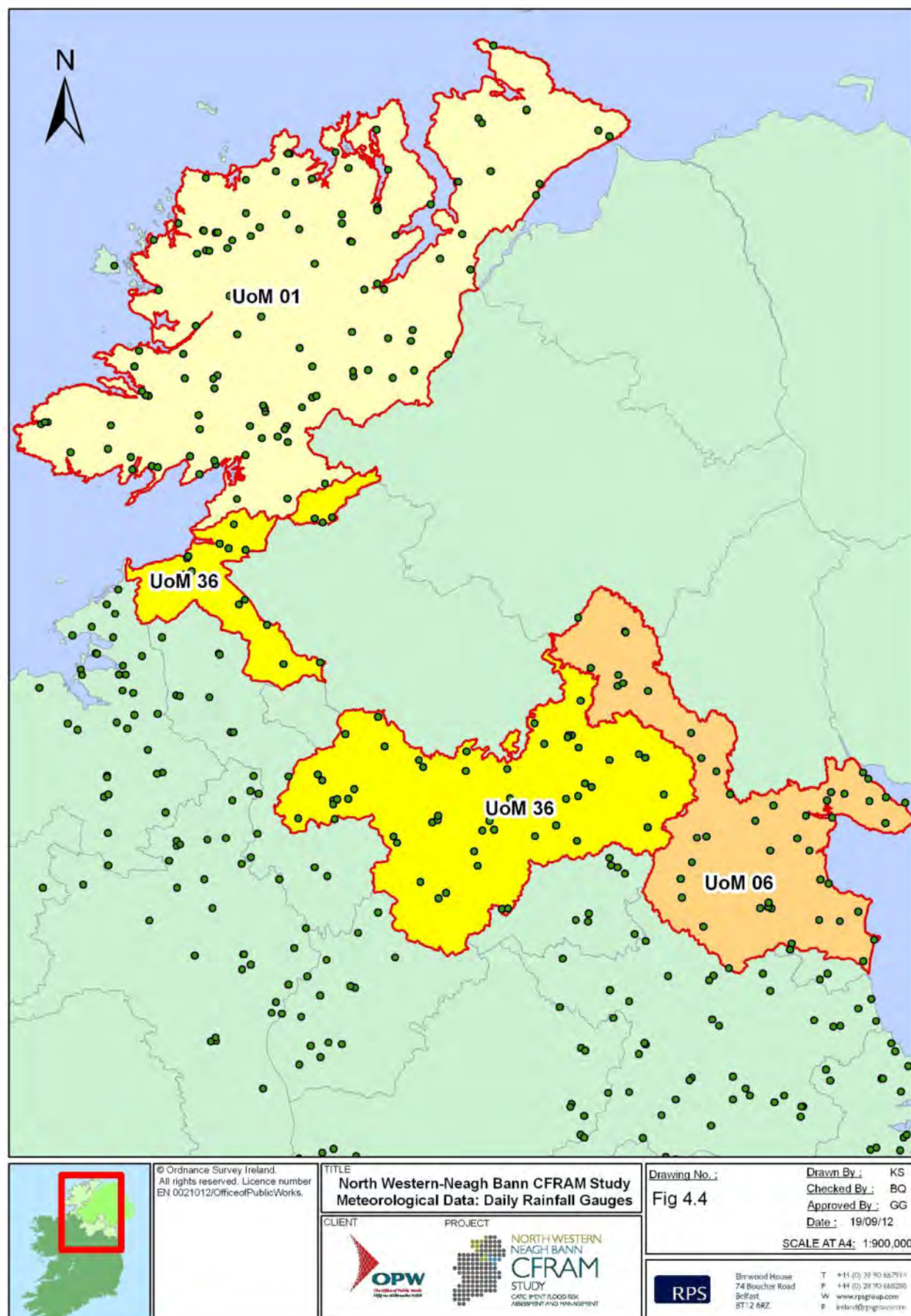


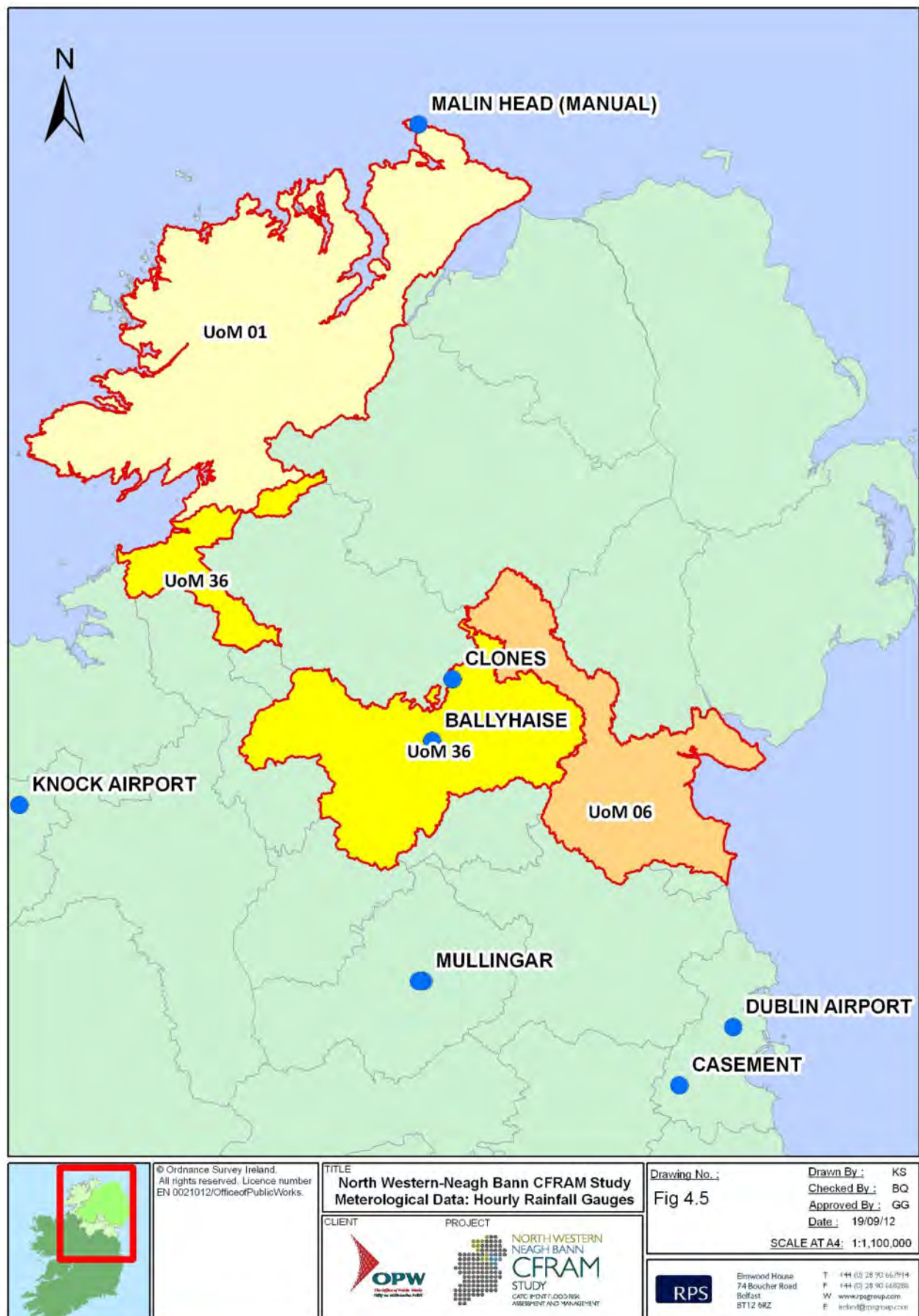
Figure 4.4: Location of Daily Rainfall Gauges

Within UoM 06 there are 48 Met Éireann daily rainfall gauges and no Local Authority gauges. A 20 – 30km buffer will also be applied to this area and the surrounding rainfall gauges within the buffer zone (this may include Met Office UK rainfall gauges within Northern Ireland) will be included in rainfall spatial analysis. This will be decided on a case-by-case basis depending on the spatial analysis requirements towards the boundary of the study area.

A data status table has been compiled for all daily rainfall stations as shown in Appendix B. This table shows the timeline over which daily rainfall data is available for each station.

#### **4.2.2 Hourly Rainfall Data**

Data for hourly rainfall stations was also provided by Met Éireann for the study. A total of seven hourly rainfall gauges were provided. Their location is shown in Figure 4.5. There are no hourly rainfall gauges located within UoM 06 although there are a number of hourly gauges surrounding UoM 06 at distances varying from 10km to 50km from the edge of the unit of management boundary. Information on the length of the records for each hourly rainfall gauge is provided in Appendix B.



**Figure 4.5: Hourly Rainfall Gauges**



### **4.2.3 Rainfall Radar Data**

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

RPS have reviewed the spatial distribution of the Met Éireann radar at Dublin Airport and found that there are potential benefits for some rainfall run-off modelling for sub-catchments within the Neagh Bann IRBD and parts of the Erne catchment. The resolution of the Dublin radar is relatively high within most of UoM 06. The only exception is around the Carlingford and Greenore AFAs where clutter effects due to the Mourne Mountains are likely to present some uncertainty in the measured rainfall accumulations.

### **4.2.4 Summary of Meteorological Data**

The majority of the watercourses to be modelled are relatively small catchments (60% are less than 25km<sup>2</sup> in area) and likely to have a rapid response to rainfall. High resolution temporal data is necessary for accurate rainfall run-off modelling in these types of catchments. A request has been made to the UK Met Office for Northern Ireland hourly data which could be used for catchments close to the border if sufficiently close. Likewise hourly data from the Clones and Ballyhaise hourly gauges may be to varying degrees representative of data in the catchments relating to the Monaghan and Carrickmacross AFAs. There are no hourly gauges within UoM 06 and as such the only high resolution temporal rainfall data observed within the boundary of UoM 06 would need to be derived from the rainfall radar at Dublin Airport. As discussed there are a number of hourly gauges at various distances from the UoM which could be used to derive interpolated rainfall data within the catchment through the use of the Thiessen polygon method. The spatial coverage of daily rainfall gauges is relatively good and could be used to inform the spatial distribution of hourly data.

### 4.3 HISTORICAL FLOOD EVENTS – SOURCES OF INFORMATION

The following sources of information were consulted as part of the historical flood data assessment: -

#### 1. Office of Public Works (OPW) National Flood Hazard Mapping

The OPW National Flood Hazard Mapping website <http://www.floodmaps.ie> contains information on flood events that occurred within Unit of Management (UoM) 06. The information available includes Local Authority flood records, OPW Flood Event Reports, press articles and consultants flood study reports.

The information can be searched for and downloaded in a number of ways (e.g. by location, by date, by catchment name and river name). To ensure all available information was downloaded for review, the website was searched firstly by catchment name, and each catchment was in turn searched according to river name. In the case of UoM 06, there are 16 separate catchments in the unit of management. Searches were carried out for each of the rivers in the catchment as follows:

Catchment	River
• Ballymascanlan	Ballymascanlan Flurry
• Blackwater (Monaghan)	Blackwater [Monaghan] Clontibret (Stream) Conawary Mountain (Water) Scotstown
• Castletown	Castletown Cully (Water) Kilcurry
• Coastal (Baltray)	
• Coastal (Carlingford)	
• Coastal (Clogherhead)	
• Coastal (Dowdallshill)	
• Coastal (Drummeenagh)	
• Coastal (Dundalk)	
• Coastal (Jeninstown)	
• Dee	Dee Killary (Water) White [Louth]
• Fane	Ballykelly County (Water) Fane
• Glyde	Glyde

	Proules
• Piedmont	Big [Louth]
• Stream (Strandfield)	Raskeagh
• Stream (Termonfeckin)	Termonfeckin

Where there were no rivers in the catchment, searches for the catchments themselves were carried out.

## **2. Internet Search Engines**

The results of the search carried out on the OPW National Flood Hazard Mapping website yielded details of floods which occurred up until 2009. To supplement this information, a wider search for information on more recent flood events, such as the October 2011 and September 2010 floods, was carried out for each Area for Further Assessment (AFA) in UoM 06 using internet search engines. While a number of results were yielded, these were generally news reports, photos or press articles which contained details of affected areas and damage done, but contained no details on flows, flood extents, flood annual exceedance probabilities (AEP), etc. Some Development Plans were found also but again, these typically contained only general information on flooding.

## **3. Strategic Flood Map (Northern Ireland)**

For those AFAs close to the Ireland/Northern Ireland border, the Strategic Flood Map for Northern Ireland (available at [www.dardni.gov.uk](http://www.dardni.gov.uk)), which was developed by Rivers Agency (DARD) in co-operation with the Department of Environment (DOE), was consulted to check if any additional information was available on flood events in these areas.

## **4. Local Authorities**

During the North Western – Neagh Bann CFRAM Study Flood Risk Review process, local authorities were asked to provide their views / information on the flood risk to potential AFAs. Where information was provided on historic flooding this has been included in this report also.

### **4.3.1 Hydrometric Data**

In conjunction with historical data researched as described above, hydrometric data from Environmental Protection Agency (EPA) and OPW sources were consulted, where available. This data was used to verify and supplement the historical data, such as dates of floods, river levels and flows.



## 4.3.2 Historical flood Events

### 4.3.2.1 Summary of Historical Flood Events

Based on a review of the information outlined above, the historical flood events which occurred in the various AFAs in UoM 06 are summarised in Table 4.9. If available, information reported on the recorded rainfall depth has been included but in many instances only descriptions of the type of rainfall were available.

**Table 4.9: Summary of Historical Flood Events for each Study AFA**

Event	AFA								
	Annagassan	Ardee	Carlingford	Carrickmacross	Dundalk & Blackrock South	Greenore	Inishkeen	Monaghan	Termonfeckin
Oct-2011					✓	No results found	Recurring	✓	
Sep-2010					✓				
Nov-2009		✓						✓	
Aug-2008		✓	✓					✓	
Oct-2005			✓						
Oct-2004	✓				✓				
Oct-2002									✓
Feb-2002	✓		✓		✓				
Nov-2000		✓	✓		✓				✓
Feb-1990								✓	
Oct-1986		✓							
Dec-1981	✓		✓		✓				
Nov-1980				✓					
Dec-1978		✓		✓					
Feb-1977					✓				
Dec-1954					✓				
Nov-1954					✓				

These flood events are discussed in the following sections, with additional details summarised in Table 4.11, such as dates, flows, AEPs and flood mechanisms.

### 4.3.2.2 Flood Event of October 2011

News sources (Monaghan Life, RTE News) were found during the internet search indicating a flooding event in Monaghan town on 25<sup>th</sup> October 2011. This was caused by the heaviest 24 hour period of rainfall

on record. Photos show major flooding of central streets in Monaghan town and many roads around the town were flooded also. The Irish Times reported that Monaghan town centre was impassable. The website [www.mapalserter.com](http://www.mapalserter.com) also indicated flooding in Monaghan town, Clones and on the Carrickmacross – Shercock road (R178). The Blackwater River also burst its banks at O’Neills Garden Centre, Piper’s Bridge and other local roads were also flooded.

Similarly, [www.argus.ie](http://www.argus.ie) reported that Dundalk suffered some flooding although it escaped severe flooding. The heavy rain led to flooding at the Castletown Road and also flooding on the Ardee Road. As the heavy rains coincided with high tides, the council also had 500 sandbags on standby for distribution if necessary.

#### **4.3.2.3 Flood Event of September 2010**

On 6<sup>th</sup> September 2010, flooding occurred due to heavy rainfall, high tides and strong easterly winds. Anecdotal information reported in the Dundalk Democrat estimated this event to have an Annual Exceedance Probability (AEP) of 2%. St Alphonsus Road was reported to be one of the areas worst affected.

#### **4.3.2.4 Flood Event of November 2009**

Information was found on [www.floodmaps.ie](http://www.floodmaps.ie) which indicated that flooding occurred in the vicinity of Monaghan town and Ardee on 19<sup>th</sup> November 2009.

Photographs show flooding occurred in the Monaghan Creamery area, Crover area, Coolshannagh area and at Ballyalbony Graveyard. Low lying lands, roads and some properties were flooded by the Blackwater. Furthermore, photos also show the New Road area flooded by Shambles River. In addition, photographs were found depicting flooding of farmland and roads in the Ardee Bog area.

#### **4.3.2.5 Flood Event of August 2008**

Information was found on a website ([www.dundalkdemocrat.ie](http://www.dundalkdemocrat.ie)) during the internet search which indicated that roads were flooded in the Carlingford area on 16<sup>th</sup> August 2008.

Similarly, information was found on [www.floodmaps.ie](http://www.floodmaps.ie) which indicated that flooding occurred in some areas near Monaghan town, adjacent to the Shambles and Blackwater rivers. However no reports were found of flooding in the town itself.

In addition, photographs were found on [www.floodmaps.ie](http://www.floodmaps.ie) indicating flooding of farmland and roads in the Ardee Bog area.

#### **4.3.2.6 Flood Event of October 2005**

Information was found on [www.floodmaps.ie](http://www.floodmaps.ie) which indicated that flooding occurred in Carlingford on 24<sup>th</sup> October 2005. Landscaping works and realignment of the channel of the mountain river was taking place

at the time of this particular rainfall event. Heavy rainfall washed material from landscaping works downstream which blocked grills on the river channel, causing the river to spill onto the public roads and flood adjacent buildings. In addition, photos indicate that the flood waters washed silt/gravels onto roads.

#### **4.3.2.7 Flood Event of October 2004**

Details were found on [www.floodmaps.ie](http://www.floodmaps.ie) which indicated that flooding occurred in Annagassan and Dundalk in October 2004.

In Dundalk, flooding was caused by heavy rainfall (20.5mm on October 27<sup>th</sup> and 16.5mm on October 28<sup>th</sup>). High tides impeded drainage although gullies had been cleaned prior to this event. However, no details of flood extents or damage caused are available.

In Annagassan, high tides and wave action caused flooding coastal flooding. Strand Road was flooded. However no further details were available.

#### **4.3.2.8 Flood Event of October 2002**

A flooding event was found to have occurred in Termonfeckin on 21<sup>st</sup> October 2002. A letter was downloaded from [www.floodmaps.ie](http://www.floodmaps.ie) from the resident of a house on Strand Road describing flooding in the property and house to a depth of 1.2m. However, no details on the full extents of the flood were available.

#### **4.3.2.9 Flood Event of February 2002**

Information was found on [www.floodmaps.ie](http://www.floodmaps.ie) indicating that flooding occurred on 2<sup>nd</sup> February 2002 in Annagassan, Carlingford and Dundalk & Blackrock South due to heavy rain, high tides and strong easterly winds.

Photographs of flooded farmland in Annagassan were found dated 2<sup>nd</sup> February 2002, following breaching of an embankment at two locations.

An Irish Times article contained reports of houses being flooded in Carlingford. However no further details were available.

Correspondence from the Dundalk Area Senior Executive Engineer described a flooding event in Blackrock, caused by a high tide and easterly gales. The sea wall was undermined, an old lifeboat house was flooded and houses along Main Street were damaged. Also Village Green/new Golf Links Road and Wallis Road/Rock Road junction were badly affected.

In Dundalk, an unprecedented high tide was recorded (3.65mOD) along with gale force easterly winds. Fairgreen was flooded. The Dundalk to Blackrock Road, Racecourse Road and Moorland Road were flooded. An old sand embankment on Marsh Road was breached in four locations resulting in up to half a meter of water in gardens and the flooding of one house and a construction site on the R172.

#### **4.3.2.10 Flood Event of November 2000**

The review indicated that a flood event occurred in Ardee, Carlingford, Dundalk and Termonfeckin in November 2000.

In Ardee, photographs were found on [www.floodmaps.ie](http://www.floodmaps.ie) depicting flooding of farmland near the Ardee Bog area.

Correspondence from the Louth County Secretary to the Department of Environment and Local Government, dated 10<sup>th</sup> November 2000, indicated that on 2<sup>nd</sup> November in Carlingford, heavy rainfall and run-off from the Cooley Mountains caused flooding which damaged roads including the N1.

The same document indicated that flooding occurred in Dundalk from blocked or overwhelmed culverts and from the Ramparts River. Flooded areas included Fatima (North West Dundalk) and Dundalk brewery was also flooded.

The letter estimated that, in the Dundalk/Carlingford engineering area, approximately IR£100,000 worth of damage was done when the edge of c. 20 miles of road was washed away. In addition, a further IR£100,000 would be required to repair culverts. Within the Dundalk UDC area, repairs to damaged roads, upgrading of culverts and drains was estimated to cost an additional IR£100,000.

In Termonfeckin, heavy rain and high winds caused flooding. An Irish Times article reported that houses along the coast had to be evacuated and roads were closed, while an article from the Drogheda Independent indicated that the bridge at the entrance to the Seapoint golf course was completely submerged and residents were trapped.

#### **4.3.2.11 Flood Event of February 1990**

A press article from the Northern Standard, dated 22<sup>nd</sup> February 1990, was found on [www.floodmaps.ie](http://www.floodmaps.ie) which mentions recent flooding in Monaghan town following a spell of heavy rain. The exact date of the flood is unknown. The article describes that the New Road area was flooded by the Shambles River. However no further details are available.

#### **4.3.2.12 Flood Event of October 1986**

An article in the Dundalk Democrat, downloaded from [www.floodmaps.ie](http://www.floodmaps.ie), indicated that on 14<sup>th</sup> October 1986 extensive flooding of farmland took place in the Ardee Bog area. Houses in the area were flooded “to a height of three or four feet”.

#### **4.3.2.13 Flood Event of December 1981**

Flooding occurred in Annagassan, Carlingford and Dundalk & Blackrock South on 3<sup>rd</sup> December 1981 due to heavy rainfall, high tides and strong winds.

In Annagassan, the sea came up over the road, flooding houses and business premises. The Dundalk Democrat stated that “it was the highest flood level in living memory”. This newspaper also reported that waves came over the wall at Carlingford; however only minor damage was caused.

The same article indicated that in Blackrock flood water entered most houses and business premises along the exposed length of village for several hundred yards. Damage was caused to the sea wall fronting the village. Walls to the swimming pool were also damaged.

Articles in the Dundalk Democrat were downloaded from [www.floodmaps.ie](http://www.floodmaps.ie), which indicated a flooding event in Dundalk on the same date when the tide rose above the quay wall. The Town Engineer reported that the tide was 450mm higher than any previously recorded tide.

The worst affected areas were at Seatown and Quay Street, where basements of houses were “flooded to depths of several feet and in some cases, almost to their ceilings”. Flooding also occurred at Fair Green, St. Marys Road, Broughton Street, Castle Road, St. Patrick’s Terrace and St. Brigid’s Terrace. Offices of C.C.O. coal firm, a local shop, PMPA offices, the Harbour Offices and a number of houses were flooded. The Newry Road, from Lisdoon corner to the Racecourse Road, was also flooded when floodwater entered over the sloblands. Some houses at Lisdoon corner flooded.

The Dundalk Democrat reported one fatality from the floods when a man drowned at Race Course Road. Gardaí suspect he was caught unexpectedly by a tidal surge, which is reported “to have reached a height of several feet after it crossed the sea banks along the estuary of the Ballymascanlon River”.

Other people had to be evacuated from their homes in this area also and sheep, pigs and domestic animals were drowned.

#### **4.3.2.14 Flood Event of November 1980**

Information was found on [www.floodmaps.ie](http://www.floodmaps.ie) which indicated that, on 17<sup>th</sup> November 1980, extensive flooding occurred in Carrickmacross following heavy rain. The Irish Times reported that several houses and business premises were flooded, while roads to Castleblaney and Kingscourt were closed. No further details were available.

#### **4.3.2.15 Flood Event of December 1978**

An Irish Times report indicated that flooding occurred in Carrickmacross on 29<sup>th</sup> December 1978 following heavy rainfall. The Ballybay, Shercock and Castleblaney roads from Carrickmacross were flooded, with reports of 1.2m of water on the Ballybay road.

Similarly, it was reported in the Evening Press (Dublin) that the Ardee-Drogheda road was unpassable. However the precise location of the flooding was not known.

#### **4.3.2.16 Flood Event of February 1977**

Information contained in a Consultant's report (Reference 6) indicates that in early February 1977, prolonged rainfall caused the Rampart River to burst its banks inundating considerable areas of land in the Dundalk urban district. The flooding caused extensive disruption to traffic flow and to business in the low lying areas adjacent to the Ardee Road, as well as causing damage to stocks and domestic dwellings in the area.

This report also notes that flood relief works were carried out within two years of this event.

#### **4.3.2.17 Flood Event of December 1954**

Archive articles from the Dundalk Democrat indicate that flooding occurred on 8<sup>th</sup> December 1954 in Dundalk. Flooding was caused by prolonged rainfall, high tides and strong easterly winds. This was exacerbated when stream flow was impeded by debris in a culvert near the Fatima housing estate. Some speculated that an open sluice valve was to blame for some of the flooding. Houses were flooded to a depth of over 200mm on Quay Street with houses also flooded in Ladywell Terrace. Gardens were flooded at Thomastown while “there was up to three feet of water at the Castletown Bridge”. There was also flooding at O'Hanlon Park, Castleblaney Road, Ardee Road, Fatima Park and Mill Road.

#### **4.3.2.18 Flood Event of November 1954**

The historical data from [www.floodmaps.ie](http://www.floodmaps.ie) indicated that flooding occurred in Dundalk on 8<sup>th</sup> November 1954 due to high tides, strong winds and heavy rainfall. It was reported that the worst flood spot around the town was at Castletown, under the railway bridge, where there was “over 5 feet of water lying under the bridge”. In addition flooding occurred at Long Avenue up to the doorsteps of houses at the pork factory, at Fair Green and the basement and playground of the Convent New Schools. It was also reported that three warehouses on Quay Street were flooded with water “at least 12 inches high”.

## 4.4 PRELIMINARY ASSESSMENT OF PAST FLOODS AND FLOODING MECHANISMS

A preliminary assessment of a number of major historical flood events which occurred within UoM 06 has been carried out. The assessment mainly focused on the examination of flood generation mechanism for each event and estimation of its frequency of occurrence.

### 4.4.1 Past flooding history and selection of flood events

River catchments within UoM 06 have experienced many major flood events in the past with different hydrometric areas (UoM 06 encompasses 2 different hydrometric areas – HA03 (partly) and HA06 being affected in varying degrees by different events. As such it is not possible to identify specific events which are relevant throughout UoM 06 and therefore events will be selected on a case by case basis within each AFA.

The historic flood data collected from various sources were reviewed and reported in Section 4.3. Based on the historical review of the severity of all flood events and subject to the availability of continuous and AMAX records, a number of major flood events were selected to examine further their causes/mechanisms, behaviour and their frequency of occurrences. AMAX time series and/or continuous flow records are available for 7 gauging stations located on watercourses to be modelled within UoM 06 as shown below.

**Table 4.10: Flow data availability for gauges on watercourses to be modelled in UoM 06**

Station Number	Station Name	Watercourse	Catchment	AMAX Series Provided	Continuous Flow Record Available
03051	Faulkland	Blackwater (Monaghan)	River Blackwater	Yes	Yes
06011	Moyles Mill	Fane	Fane River	Yes	Yes
06013	Charleville	Dee	River Dee	Yes	Yes
06014	Tallanstown	Glyde	River Glyde	Yes	Yes
06021	Mansfieldstown	Glyde	River Glyde	Yes	Yes
06025	Burley	Dee	River Dee	Yes	Yes
06036	Ladyswell	Ramparts	Castletown River	No	No

These have been used to conduct flood event analysis within UoM 06. Table 4.11 presents the selected events on the affected AFA basis.

#### **4.4.2 Flood Mechanisms in UoM 06**

Flooding is a natural process and can happen at any time in a wide variety of locations. Flooding can come from rivers and the sea, directly from rainfall on the ground surface and from rising groundwater, surcharging sewers and drainage systems.

The various types of flooding can be categorised as follows:

**Fluvial flooding:** This type of flooding occurs when the capacity of the river channel is exceeded or the channel is blocked or restricted, and excess water spills out from the channel onto adjacent low-lying areas. Fluvial flooding is generally caused by short duration high-intensity or prolonged rainfall in the catchment.

**Pluvial flooding:** This type of flooding is defined as flooding from rainfall-generated overland flow, before the runoff enters any watercourse or sewer. This mainly occurs when intense rainfall, often of short duration, that is unable to soak into the ground or enter drainage systems, can run quickly off land and result in local flooding. It can also result when the drainage system is overwhelmed by heavy rainfall, becomes blocked or is of inadequate capacity.

**Groundwater flooding:** Groundwater flooding occurs when water levels in the ground rise above surface elevation following prolonged and heavy rainfall. It is most likely to occur in low-lying areas underlain by permeable rocks. Groundwater flooding may take weeks or months to dissipate because groundwater flow is much slower than surface flow and water levels thus take much longer to fall.

**Tidal and coastal flooding:** This type of flooding occurs during exceptionally high tides or during storm events when low pressure systems result in storm surges on the coast lines and estuaries. Wind action causes increased wave heights which also contribute to coastal flooding.

**Combined fluvial and tidal flooding:** This type of flooding occurs from the joint effect of both fluvial and tidal flood events.

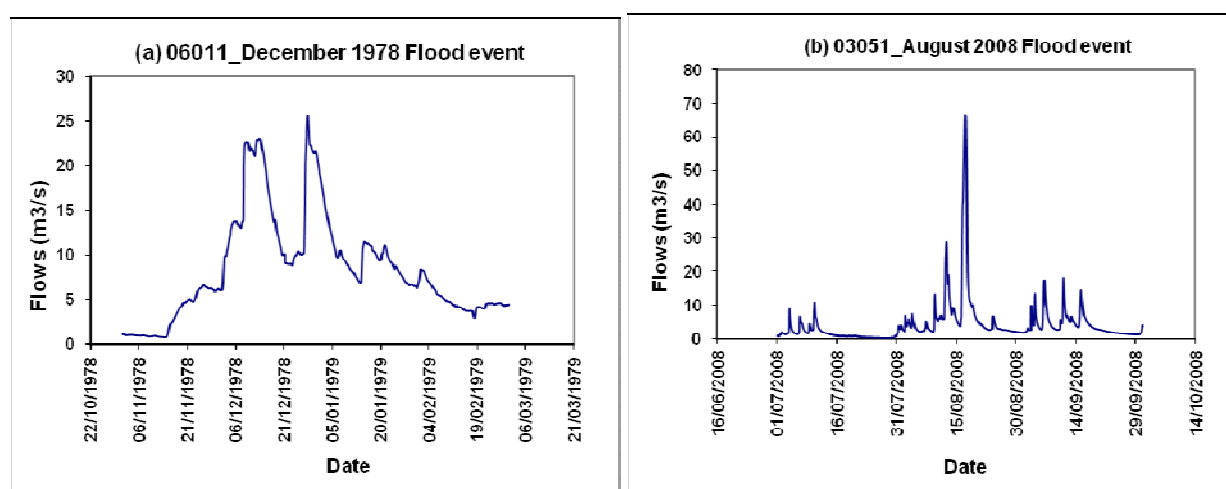
In UoM 06 flooding events are generally of the 'Fluvial' category.

#### **4.4.3 Flood event behaviour and their frequency**

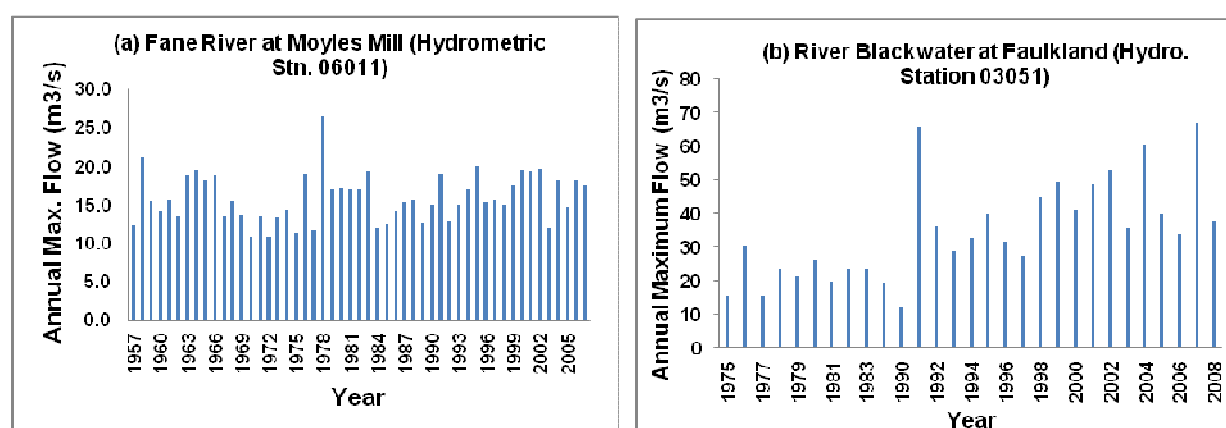
The behaviour of the selected flood events were examined by plotting their associated flow hydrographs. The shape of the hydrograph, its response time and flood duration have been examined for each of the selected events. The shape of the hydrograph is dependent on the catchment's physical and meteorological characteristics and in particular the catchment area, slope, soil type, antecedent wet condition, drainage density, storage behaviour and average rainfall characteristics. In small, steep catchments, local intense rainfall can result in the rapid onset of deep and fast-flowing flooding with little warning. Such 'flash' flooding, which may last a few hours can give a very peaky shape hydrograph. In larger catchments like the Rivers Blackwater, Fane, Glyde and Dee, more intense run-off in the upper steeper tributary catchments can have lesser effects on the downstream part of the catchments, due to



the attenuation effect. Flooding at the coastal downstream reach of these larger river catchments can also be caused by the joint occurrence of fluvial and tidal flood events. The frequency of selected flood events within UoM06 have been analysed by fitting the AMAX time series for the associated gauging sites. The AMAX time series were fitted to four flood-like distributions, namely, the GEV, GLO, EV1 and 2-parameter Lognormal (LN2) distributions. These distributions were considered due to their suitability in fitting the range of pooled frequency relationships witnessed in the Neagh Bann RBD pooling groups. As an example of flood event analysis within UoM06, hydrograph plots of the December 1978 flood event on the Fane River as recorded at Hydrometric Station 06011 (Moyles Mill) and of the August 2008 flood event on the River Blackwater at Faulkland (Hydrometric Station. 03051) are shown in Figure 4.6.



**Figure 4.6: Observed flood hydrographs during the (a) December 1978 flood event at Moyles Mill of Fane River (Hydr. Stn. 06011) and (b) August 2008 flood event at Faulkland of River Blackwater (Hydr. Stn. 03051).**



**Figure 4.7: Observed Annual Maximum Flows at (a) Fane River at Moyles Mill (1957 – 2007); (b) River Blackwater at Faulkland (1975–2008).**

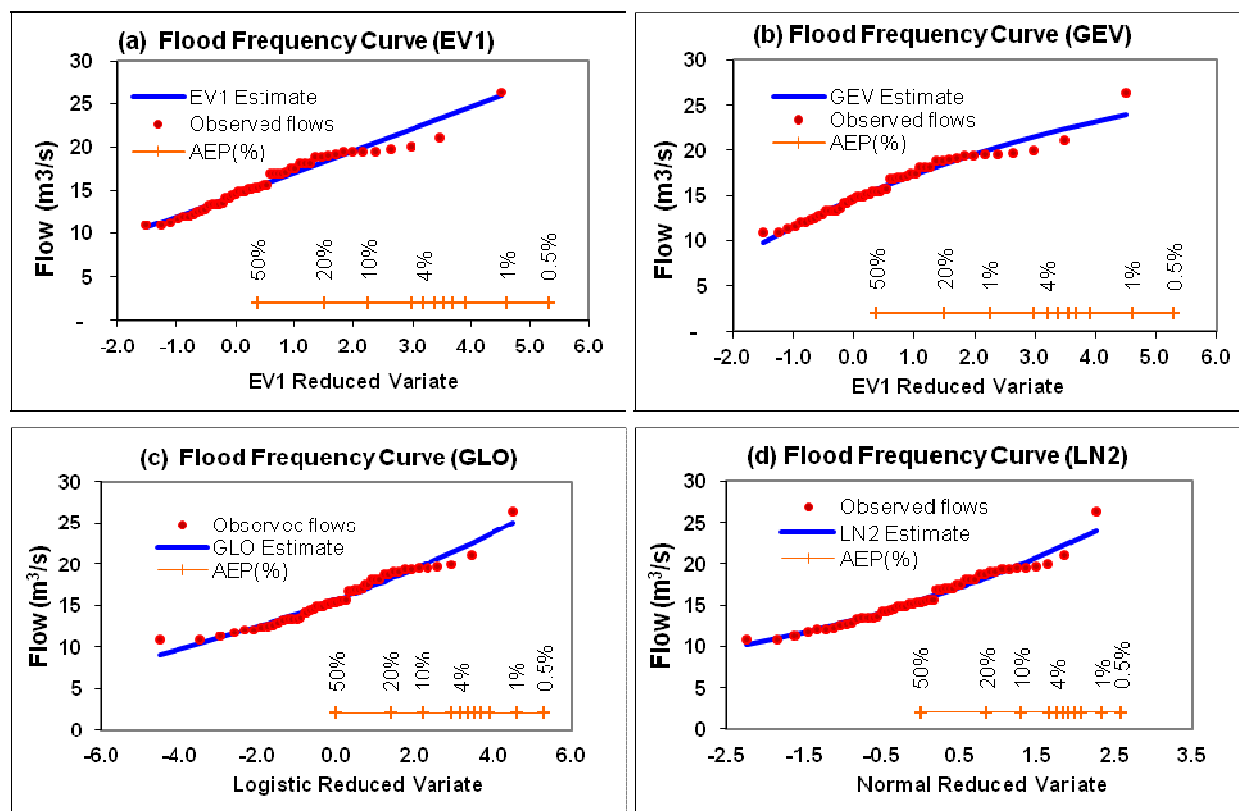


Figure 4.8: Fitted Flood Frequency Curves to the observed annual maximum records for Fane River at Moyles Mill (Hydro.Stn. 06011): (a) EV1 distribution, (b) GEV distribution, (c) GLO distribution and (d) LN2 distribution.

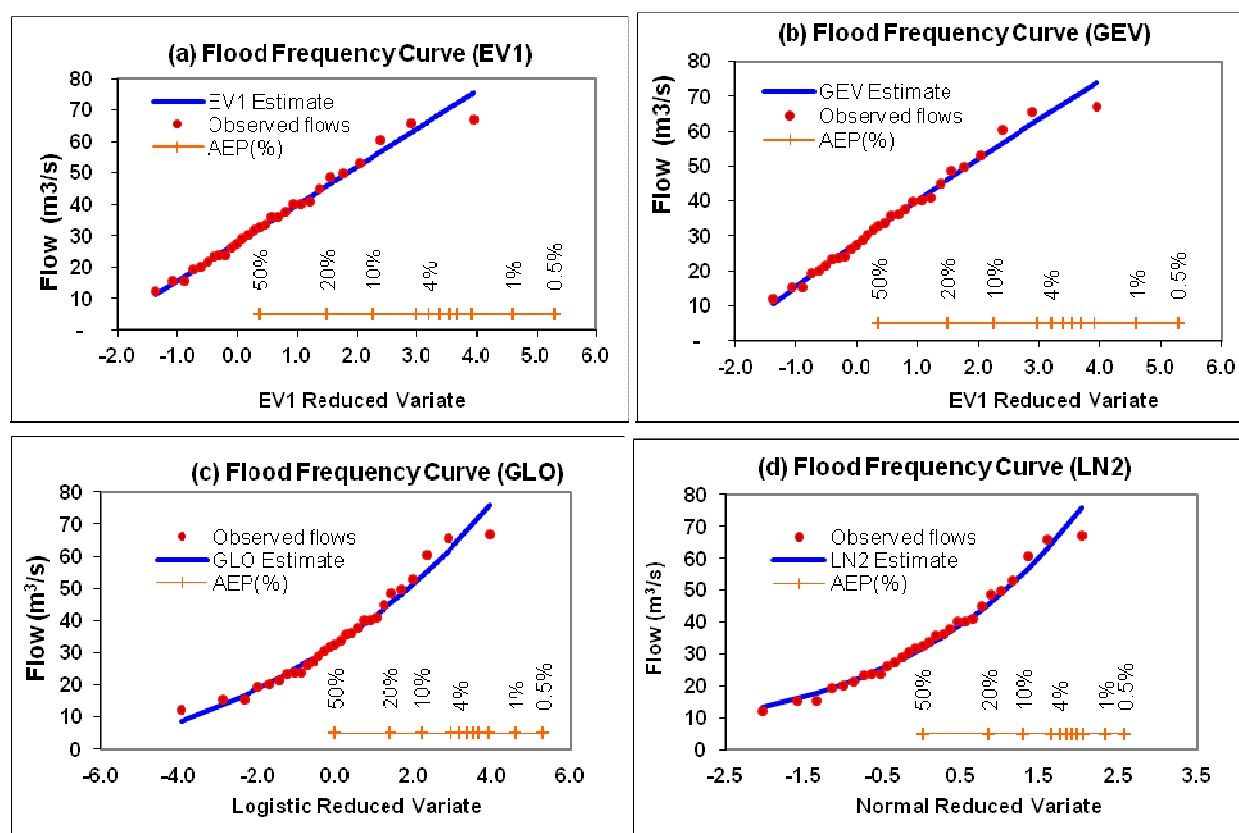


Figure 4.9: Fitted Flood Frequency Curves to the observed annual maximum records for River Blackwater at Faulkland (Hydro.Stn. 03051): (a) EV1 distribution, (b) GEV distribution, (c) GLO distribution and (d) LN2 distribution.

Figure 4.7(a) shows the observed AMAX flow records for Fane River at Moyles Mill for the period of 1957 to 2007, while Figure 4.7(b) shows the corresponding records for River Blackwater at Faulkland. Figures 4.8 and 4.9 show the fitted EV1, GEV, GLO and LN2 distributions to these records for the hydrometric stations 06011 and 03051 respectively. It can be seen from these figures that GLO and LN2 distribution provide slightly better fits to the observed annual maximum records for both stations. Based on this, the estimated AEP of the observed flood flow of  $26.40 \text{ m}^3/\text{s}$  during the December 1978 flood event (28/12/1978) at Moyles Mill of Fane River is approximately 0.66%% (1 in 150 years return period).

Table 4.11 summarises the flood mechanism, hydrograph shape and estimated frequency of a selection of recorded flood events in UoM06. The selection of these flood events is based on the magnitude of the observed flow records (mainly flood events with smaller exceedence probability) and also the severity of damage caused to properties and people. It can be seen from this table that the majority of the flood events are of 'fluvial' type. From the historical review in Section 4.3 the most severe flood events (in terms of frequency and damage caused) within the Blackwater, Fane, Glyde and Dee River catchments were the December 1978, December 1995, November 2002, January 2005 and August 2008 flood events. Most parts of these catchment areas were affected during these events and the cause of flooding was the prolonged intense rainfall (fluvial). The estimated approximate AEP of the August 2008 flood event recorded at Faulkland of River Blackwater (Hydrometric Station - 03051) is approximately 3.33%.

The historical review of flood information and hydrometric data has been used to select flood events that will be used in calibration of the hydraulic models of MPWs and HPWs. This is discussed in Section 5.2.3, Hydraulic Model Calibration.

**Table 4.11: Significant flood events, their generation mechanisms and frequency in UoM 06**

AFAs	Nearest Gauging Stations		Major flood events				
	Stn. No.	Location	Date	Peak flow (m3/s)	Rank <sup>1</sup>	Approximate AEP (%)	Flood mechanisms
Annagassan	06013	River Blackwater at Faulkland	29/12/1978	40.0	2	5%	Fluvial: Prolonged and heavy rainfall coupled with snow melt. Flood duration was approximately 15 days and the time of concentration was approx. 2.5 – 3 days.
			22/01/1980	37.7	3	8.33%	Fluvial: Prolonged and heavy rainfall. Flood duration was approximately 8 days and the time of concentration was approx. 2 days.
			07/10/1993	35.70	4	12.5%	Fluvial: Prolonged intense rainfall. Flood duration was approximately 14 days and the time of concentration was approx. 2 days.
			01/12/1995	41.8	1 (largest among 36 AMAX records)	3.33%	Fluvial: Prolonged and heavy rainfall. Flood duration was approximately 14 days and the time of concentration was approx. 3.5 - 4 days.
			07/11/2000	34.7	7	14%	Fluvial: Prolonged intense rainfall. Flood duration was approximately 13 days and the time of concentration was approx. 4.5-5 days. Slow response to rainfall.
	06021	River Glyde at Mansfieldstown	20/12/1958	33.63	2	3.33%	Fluvial & tidal: Prolonged intense rainfall. Flood duration was approximately 15 days and the time of concentration was approx. 3 days.
			11/01/1968	34.85	1 (largest among 48 AMAX records)	2.5%	Fluvial & tidal: Prolonged and heavy rainfall. Flood duration was approximately 16 days and the time of concentration was approx. 3 days.
			01/01/1979	30.46	5	7.5%	Fluvial & tidal: Prolonged and heavy rainfall. Flood duration was approximately 13 days and the time of concentration was approx. 7 days. Slow response to rainfall.
			03/12/1995	29.70	6	10%	Fluvial & tidal: Prolonged and heavy rainfall. Flood duration was approximately 20 days and the time of concentration was approx. 8 days. Slow response to rainfall.
			25/11/2009	27.74	8	14%	Fluvial & tidal: Prolonged and heavy rainfall. Flood duration was approximately 25 days. Time of

AFAs	Nearest Gauging Stations		Major flood events				
	Stn. No.	Location	Date	Peak flow (m3/s)	Rank <sup>1</sup>	Approximate AEP (%)	Flood mechanisms
							concentration was approx. 15 days. Slow response to rainfall.
Ardee	06025	River Dee at Burley	29/12/1978	20.0	9	35 – 30%	Fluvial: Intense rainfall followed by prolonged antecedent wet condition. Flood duration was 7 days. Time to peak was approximately 2 days.
			30/11/1995	23.50	2	2.85%	Fluvial: Prolonged and heavy rainfall. Flood duration was approximately 17 days. Time of concentration was approx. 5 days. Slow response to rainfall.
			06/11/2000	23.60	1 (largest among 36 AMAX records)	2.5%	Fluvial: Prolonged intense rainfall. Flood duration was approximately 13 days. Time of concentration was approx. 4 days. Slow response to rainfall.
			14/11/2002	22.80	4	6.25%	Fluvial: Prolonged intense rainfall followed by prolonged antecedent wet condition. Flood duration was 7 days. Time to peak was approximately 24 hours.
			06/09/2008	23.30	3	4%	Fluvial: Prolonged intense rainfall followed by prolonged antecedent wet condition. Flood duration was 10 days. Time to peak was approximately 24 hours.
			20/11/2009	22.10	5	10%	Fluvial: Prolonged and heavy rainfall. Flood duration was approximately 25 days. Time of concentration was approx. 10 days.
Carlingford	No gauges	No gauges	03/12/1981	No records	-	-	Fluvial & coastal: Heavy rainfall, high tides and strong winds.
			02/11/2000	No records	-	-	Fluvial: Prolonged and heavy rainfall
			21/10/2002	No records	-	-	Fluvial: Prolonged and heavy rainfall heavy rainfall
			24/10/2005	No records	-	-	Fluvial: Prolonged and heavy rainfall heavy rainfall
			16/08/2008	No records	-	-	Fluvial: Prolonged and heavy rainfall heavy rainfall
Carrickmacross	06014	River Glyde at Tallanstown	30/12/1978	39.40	1 (largest among 36 AMAX records)	1.81%	Fluvial: Prolonged and heavy rainfall. Flood duration was approximately 10 days. Time of concentration was approx. 3 days.
			05/01/1982	32.40	3	6.66 – 5%	Fluvial: Prolonged and heavy rainfall. Flood duration was approximately 17 days and time to peak was

AFAs	Nearest Gauging Stations		Major flood events				
	Stn. No.	Location	Date	Peak flow (m3/s)	Rank <sup>1</sup>	Approximate AEP (%)	Flood mechanisms
							approx. 8 days. Slow response to rainfall.
			18/01/1984	30.60	4	10 – 8%	Fluvial: Prolonged and heavy rainfall. Flood duration was approximately 18 days. Time of concentration was approx. 7 days.
			02/12/1995	33.30	2	5%	Fluvial: Prolonged and heavy rainfall. Flood duration was approximately 20 days and time of concentration was approx. 8 days. Slow response to rainfall.
			22/11/2009	27.20	7	20 – 15%	Fluvial: Prolonged and heavy rainfall. Flood duration was approximately 25 days and time to peak was approx. 13 days. Slow response to rainfall.
Dundalk & Blackrock South	06036	Castletown River at Ladyswell	06/01/1982	1.35	1(largest among 8 AMAX records)	No long AMAX records	Fluvial: Prolonged intense rainfall.
			21/03/1991	1.08	2	No long AMAX records	Fluvial: Prolonged and heavy rainfall.
			25/11/1992	0.987	4	No long AMAX records	Fluvial: Prolonged and heavy rainfall.
			Nov. 2000	No records	-	-	Fluvial: Prolonged and heavy rainfall.
			Oct. 2011	No records	-	-	Fluvial: Prolonged and heavy rainfall.
Inishkeen	06011	Fane River at Moyles	21/12/1958	21.10	2	6.66%	Fluvial: Prolonged and heavy rainfall.
			28/12/1978	26.40	1 (largest among 51 AMAX records)	0.66%	Fluvial: Prolonged intense rainfall followed by prolonged antecedent wet condition. Flood duration was 12 days. Time to peak was approximately 1.5 -2 days.
			30/11/1995	20.0	3	10%	Fluvial: Prolonged and heavy rainfall. Flood duration was approximately 35 days and time to peak was approx. 5 days.
			08/11/2000	19.50	5	12 – 10%	Fluvial: Prolonged and heavy rainfall. Flood duration was approximately 18 days. Time of concentration was approx. 7 days.
			14/11/2002	19.70	4	10%	Fluvial: Prolonged and heavy rainfall. Flood duration was approximately 35 days and time to peak was approx. 5 days.
			19/11/2009	No records	-	-	Fluvial: Prolonged and heavy rainfall.

AFAs	Nearest Gauging Stations		Major flood events				
	Stn. No.	Location	Date	Peak flow (m3/s)	Rank <sup>1</sup>	Approximate AEP (%)	Flood mechanisms
Monaghan	03051	River Blackwater at Faulkland	21/12/1991	65.70	2	4%	Fluvial: Prolonged and heavy rainfall.
			03/12/1999	49.80	5	15 – 12%	Fluvial: Prolonged and heavy rainfall.
			22/10/2002	52.90	4	10%	Fluvial: Intense rainfall. Flood duration was 4 days with the time-to-peak of approximately 1.5 days. Fast response catchment.
			08/01/2005	60.50	3	6 – 5%	Fluvial: Intense rainfall followed by prolonged antecedent wet condition. Flood duration was 5 days. Time to peak was approximately 2 days.
			17/08/2008	66.90	1 (largest among 29 AMAX records)	4 – 3%	Fluvial: Intense rainfall followed by prolonged antecedent wet condition. Flood duration was 5 days. Time to peak was approximately 1.5 days.
	03058	River Blackwater at Cappog Bridge	16/08/2008	110.95	1 (largest among 13 AMAX records)	7 – 6%	Fluvial: Intense rainfall followed by prolonged antecedent wet condition. Flood duration was 2 days. Time to peak was approximately 20 hours. Fast response catchment.
			20/08/2009	64.72	5	35 – 30%	Fluvial: Intense rainfall. Flood duration was 3 days. Time to peak was approximately 20 hours.
			07/09/2010	94.01	3	12 – 10%	Fluvial: Intense rainfall. Flood duration was 3 days and time of concentration was approximately 20 hours.
			22/06/2011	74.86	4	25%	Fluvial: Intense rainfall. Flood duration was 2 days. Time to peak was approximately 8 hours. Fast response to rainfall.
			24/10/2011	103.82	2	9 – 8%	Fluvial: Intense rainfall followed by prolonged antecedent wet condition. Flood duration was 2 days. Time to peak was approximately 8-10 hours.

Note 1: For each hydrometric station, the observed AMAX time series was ranked in descending order i.e. the largest peak flow has rank 1 and the smallest peak flow has the highest rank. For example, at the hydrometric station 06014 (River Glyde at Tallanstown), the peak flow recorded on 30/12/1978 (39.40m3/s) is the largest in 36 years of AMAX records and was therefore given a rank of 1.

## **5 HYDROLOGICAL ANALYSIS METHOD STATEMENT**

This chapter outlines the methodology for undertaking hydrological analysis of both hydrometric and meteorological data, the process for deriving estimations of design flows and identifies where these will be coupled to conceptualised hydraulic models. The methodology involves the use of the full range of statistical based techniques for estimating river flows outlined in the FSU (and departures from FSU where appropriate) and supplemented with catchment rainfall run-off modelling techniques (where the rainfall data allows) to give a higher degree of confidence.

### **5.1 ANALYSIS OF HYDROMETRIC AND METEOROLOGICAL DATA**

#### **5.1.1 Gauging Station Rating Review**

A rating review of three hydrometric stations in UoM 06 is being undertaken. The rating review task involves:

- visiting the site (at high flows where practical);
- liaising with OPW or EPA (as appropriate) to request available information on each station. This included the staff gauge zero datum history, the history of the station, annual maximum series data, spot gaugings and a rating report;
- procuring a channel and floodplain survey for an adequate reach of the river upstream and downstream of the gauging station location;
- constructing a hydraulic model based on the surveyed sections, using MIKE FLOOD software;
- calibrating the model (by adjusting weir / bridge coefficients and Manning's roughness values) using the existing station rating up to the reliable limit (usually the highest gauged flow or  $Q_{med}$ );
- using the calibrated model to simulate fluvial discharges up to and exceeding the estimated 1 in 1000 year flow for the site.

The above process results in a modelled stage-discharge relationship for upper range of the hydrometric gauging station ratings. It reduces the uncertainty associated with previous rating equations which were based on simple extrapolation beyond the maximum gauged flow over the period of record for the station.

Past experience has shown that this is a critical exercise in terms of improving confidence and providing a site specific understanding of limitations at certain stations due to, for example, changes in the rating curve with time at “soft” engineered stations, bypass flow, blockages or over levée flood situations.



### **5.1.2 Hydrometric Data**

As previously discussed, six hydrometric stations with continuous water level and flow data are available on watercourses to be modelled. As a result of this five out of the nine AFAs affected by fluvial flooding in UoM 06 have a gauging station with water level and flow on the modelled stretch of watercourse which would be suitable for direct hydrological analysis and / or model calibration. As shown in Table 4.5, five of these gauge stations have 'A' classification ratings and as such can be considered to have a high confidence in the gauging above the index flood flow,  $Q_{med}$ .

### **5.1.3 Rainfall Data Analysis**

Rainfall data analysis is required to provide the rainfall input to hydrological models (refer to Sections 5.4 and 5.6.1) where required. As discussed in Section 4.2.3 the rainfall radar located at Dublin Airport has a high resolution within UoM 06 and as such radar data could be included within the input data for run-off modelling otherwise rainfall data analysis will be undertaken using data from daily and hourly rainfall gauges to provide the necessary rainfall input to hydrological models. GIS elevation-based spatial-temporal interpolation techniques will be used to enhance the standard Thiessen polygons methodology to generate spatially-weighted rainfall time series as inputs to the hydrological models, refer to Sections 5.4 and 5.6.1.

### **5.1.4 Data Availability and Hydrological Analysis**

Analysis of the available hydrometric data has shown that four of the models do not have hydrometric flow data (Dundalk & Blackrock South, Termonfeckin, Carlingford and Greenore) or data of sufficient quality (Monaghan) and as such can be considered to be 'ungauged' for the purposes of flow estimation. Where this is the case tried and tested statistical regression techniques will be applied to estimate the design flood flows in line with best practice guidance as outlined in the Flood Studies Update (Work Package 2.3, Flood Estimation in Ungauged Catchments). Where sufficient meteorological data is available rainfall run-off modelling will be carried out to provide simulated flow data upon which statistical analysis can be carried out in order to add further robustness to the hydrological analysis. The Carlingford and Greenore models are unsuitable for radar based rainfall run-off modelling due to their size and position within the radar cluttering effect of the Mourne Mountains and topography around Carlingford Lough. This methodology would therefore only bring significant benefit to two of the models within UoM 06 and could pose an adverse significant risk to the tight timeframes of the North Western – Neagh Bann CFRAMS programme (due to the time required to process the radar data). Furthermore, the ongoing trials in the Eastern and South Eastern CFRAM Study areas have not yet been finalised and these will inform the decisions regarding adoption of such methodologies in Irish catchments on a more widespread basis. It is therefore advised that for the small number of rainfall run-off models for UoM 06 input data is based on rainfall data derived from the network of Met Éireann rainfall gauges and supplemented with UK Met Office gauges where these are found to be sufficiently close and that the use of radar based inputs is discounted due to the limited benefit and potential impacts on programme.

## **5.2 MODEL CONCEPTUALISATION**

### **5.2.1 UoM 06 Hydraulic Models**

To facilitate hydrological assessment and hydraulic modelling, nine models have been conceptualised for UoM 06 as shown in Figure 5.1. Hydrological estimation will be undertaken to provide inputs for each hydraulic model. The number and boundaries of the models have been largely chosen due to modelling practicalities such as having one 2D mesh per model and therefore one AFA per model and such that gauge stations can be used to directly calibrate flow estimations within modelled extents.

### **5.2.2 Model Interdependence**

In selecting the nine models the degree of interdependence has been a secondary consideration. This is acknowledged within WP 3.4 as being less important where an FSU approach is being considered *‘because there is no direct link between design peak flow and event duration’* (FSU WP 3.4, paragraph 4.3.1). Where appropriate the guidance within FSU WP 3.4, paragraph 4.3.3 will be followed:

*‘One way to meet the aspiration for treating large river models in small units is to carry out multiple runs with different inflow conditions, each run being intended to simulate the required design conditions in a different part of the model’*

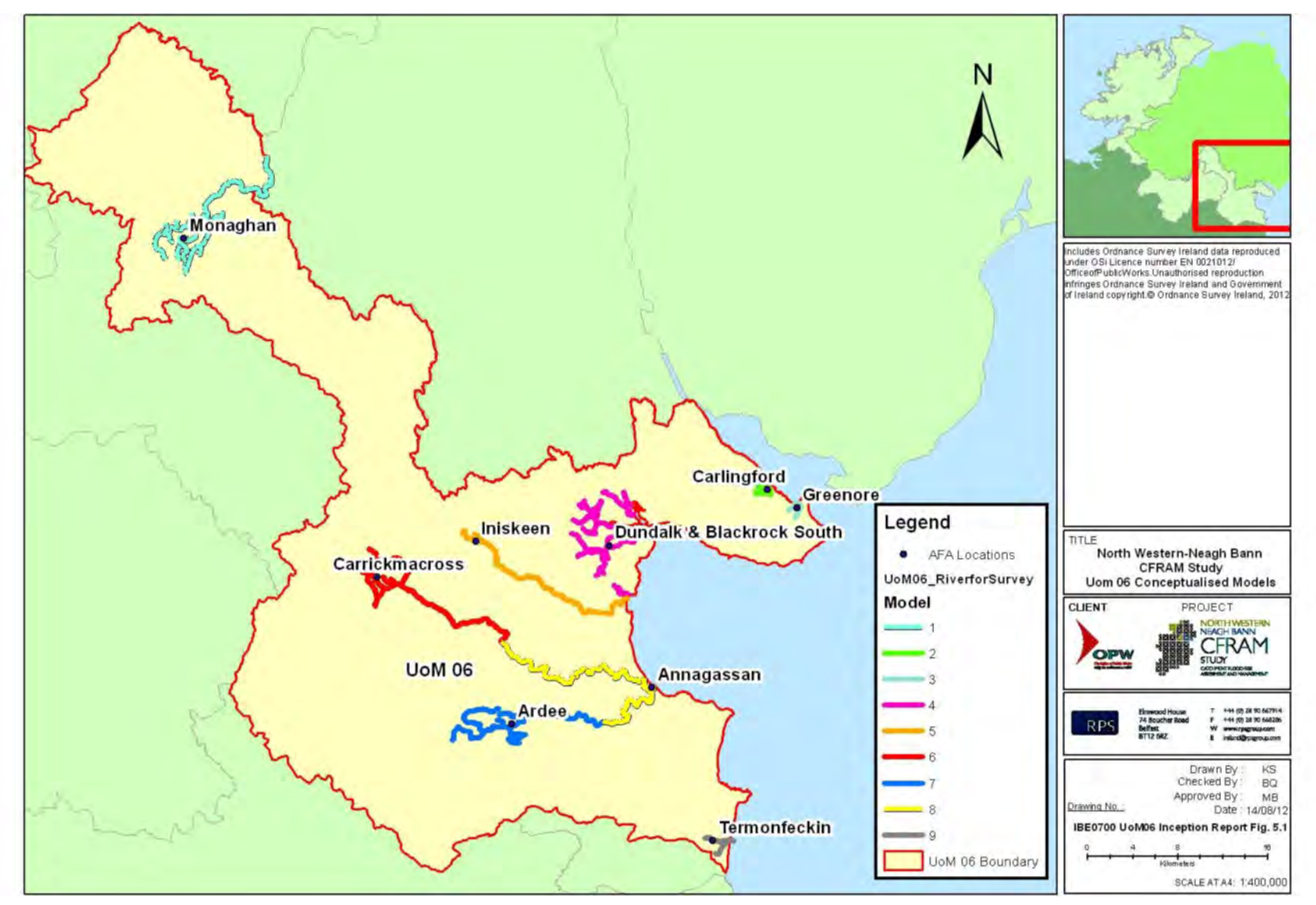


Figure 5.1: UoM 06 Conceptualised Models

### 5.2.3 Hydraulic Model Calibration

Based on the review of historical flood events (Section 4.3) and preliminary assessment of flood mechanisms using available hydrometric data to determine AEPs (Section 4.4), the following flood events have been selected for model calibration and verification purposes (refer to Table 5.1).

**Table 5.1: Selected Flood Events for Hydraulic Model Calibration and Verification**

Hydrometric Stations	Hydraulic Model Number	Selected Flood events for hydraulic model calibration and verifications	
		Date	Peak flow (m3/s)
03051	1	20/02/2002	48.60
		22/10/2002	52.90
		08/01/2005	60.50
		17/08/2008	66.90
		20/08/2009	37.60
06011	5	28/12/1979	26.40
		30/11/1995	20.00
		08/11/2000	19.50
		14/11/2002	19.70
		10/01/2005	18.10
06013	7 8	29/12/1978	40.00
		22/01/1980	37.70
		07/10/1993	35.70
		01/12/1995	41.80
		07/11/2000	34.70
06014	6 8	30/12/1978	39.40
		05/01/1982	32.40
		18/01/1984	30.60
		02/12/1995	33.30
		22/11/2009	27.20
06021	8	20/12/1958	33.60
		11/01/1968	34.85
		01/01/1979	30.46
		03/12/1995	29.70
		25/11/2009	27.74
06025	7	29/12/1978	20.00
		30/11/1995	23.50
		06/11/2000	23.60
		14/11/2002	22.80
		06/09/2008	23.30
06036	4	06/01/1982	WL Only – 4.647m (mOD)

Hydrometric Stations	Hydraulic Model Number	Selected Flood events for hydraulic model calibration and verifications	
		Date	Peak flow (m3/s)
		21/03/1991	WL Only – 4.420m (mOD)
		25/11/1992	n.a.
		Nov. 2000	n.a.
		Oct. 2011	n.a.

The fluvial hydraulic models will be calibrated and verified against these past flood events. The models will be verified to vertical accuracies of not less than 0.2m and 0.4m for HPWs and MPWs respectively. Calibration and verification of the models will involve adjusting a number of parameters in various combinations during a series of additional simulations, in an attempt to achieve modelled levels closer to the recorded levels at gauging stations. The parameters investigated included channel and structure roughness coefficients, link weir roughness coefficients, tidal boundaries and floodplain resistance.

Rating curve analysis, including hydraulic modelling of the hydrometric stations to reduce uncertainty in extrapolated values will also be used where appropriate to verify the magnitude of observed events.

The results of this historical flood analysis will also be compared with design flood levels and extents to ensure that there is consistency between observed and design events, particularly with reference to the events' estimated AEPs. This desk-based historical data analysis along with the information gathered during our site visits will help the modellers to understand the hydrological and hydraulic behaviour of the river catchment including flood generation mechanism, causes of flooding and constraints (i.e. to establish the source pathway-receptor model). It is anticipated that the flow estimated for a particular AEP from historic 'single site' analysis will sometimes vary from the equivalent AEP event derived from design flow estimation (involving a pooled analysis) due to the difference in the analysed data sets. In these instances calibration will be undertaken using the recorded level and flow (rather than design AEP flow compared to recorded water levels). In most cases (where design AEP equivalent return period is more than twice the record length) pooled analysis will be given precedence over the single site analysis for design flow estimation due to the statistical robustness provided by the additional gauge years added to the analysis through pooling techniques.

A review of all previous studies and reports relating to the study area will also be undertaken with relevant data again being used to support the calibration and verification process.

As discussed five of the nine watercourse models are gauged and of the six hydrometric gauges located on these watercourses four have A1 ratings, one has a B rating and the other was not given an FSU rating classification. Therefore at most stations the recorded water level and flow data upon which calibration is undertaken can be considered to have a good degree of certainty. Nevertheless

calibration against the peak recorded flood flows will be verified against other calibration information such as flood outlines. Following the completion of rating reviews, either certainty of the existing rating will be confirmed or a new relationship will be defined such that peak flood level information can be re-processed into flow data and a higher degree of certainty achieved.

For ungauged models calibration will only be possible through comparison of flood extents, recorded water levels and indirect flow estimates for the particular flood event. In general though, UoM 06 can be considered to have good hydrometric data available for calibration.

### **5.3 HYDROLOGICAL ESTIMATION POINTS**

Hydrological Estimation Points (HEPs) are defined as the points on the modelled watercourses for which hydrological analysis and design flow estimation are undertaken. The design flow estimates are entered into the model at the HEP locations effectively coupling the hydrology to the hydraulic models at these nodes. HEPs also serve as check points at gauging station locations, so that the design AEP event is properly derived, particularly in AFAs.

A large number of HEPs have been defined which will allow good variation in the rarity / frequency conditions up and down the catchments and at each HEP comparisons of different hydrology estimations will be undertaken for robustness (from rainfall run-off methods to statistical analysis methods such as outlined in FSU WP 2.2 & 2.3).

Based on model conceptualisation, and following finalisation of the AFA designations (post PFRA consultation and Flood Risk Review), a GIS exercise is being undertaken to identify HEPs in UoM 06. These are identified according to the following categories.

#### **5.3.1 HEP Categories**

##### **5.3.1.1 HEP at Upstream Limit of Model**

The upstream extent of each model requires a HEP at which design flows and hydrographs will be derived primarily from a rainfall runoff model; or flow estimation methods as appropriate (for example FSU WP 2.3 'Flood Estimation in Ungauged Catchments').

##### **5.3.1.2 HEP where Tributaries enter Modelled Channel**

Moving downstream along the modelled reach, a HEP is located where tributaries with catchment areas greater than 5km<sup>2</sup> enter the channel. The Generic CFRAM Study Brief required these HEPs at tributaries where it was considered that more than 10% of the main channel flow was contributed. However, this application led to an abundance of HEPs at tributary confluences in the upper reaches of catchments, and under representation in the lower reaches. This was discussed with the OPW following pilot studies and it was considered that including all tributaries with catchments greater than 5km<sup>2</sup> would ensure a more appropriate distribution of HEPs at tributary confluences throughout the

catchment. On High Priority Watercourses (HPWs) it will often be appropriate to include flows from catchments which are much smaller than 5km<sup>2</sup> and where this is the case the inclusion of tributaries will be considered on an individual basis.

#### **5.3.1.3 HEP at Gauging Stations on Modelled Channel**

At gauging stations along the modelled reaches (for which data is available), a HEP is located. These HEPs serve as check points throughout the modelled catchment, so that flow estimates can be calibrated on a catchment basis ensuring appropriate discharges are modelled for each design event.

#### **5.3.1.4 Intermediate/Reporting HEPs**

Intermediate/Reporting HEPs have both hydraulic input (top-up) and reporting functions as described below:

- Hydrological analysis and design flow estimation at intermediate HEPs will be undertaken to ensure that the total contributing catchment at that point in the model can be checked to ensure that the sum of the model inputs are consistent with the total catchment up to that point in the model. Where necessary the models may need to be ‘topped up’ at these HEPs to ensure all of the contributing catchment is considered.
- HEPs along main channel ensuring there are no reaches greater than 5km without a HEP –this is a requirement of the Generic CFRAM Study Brief. HEPs will serve as reporting points where calibrated peak flows and levels for each design event at the end of the hydraulic analysis task will be reported as a CFRAM Study deliverable.
- HEPs immediately upstream and downstream of AFAs and in the centre of each AFA. This is a requirement of the Generic CFRAM Study Brief. At these HEPs, calibrated peak flows for each design event will be reported at the end of the hydraulic analysis task as a CFRAM Study deliverable.

#### **5.3.1.5 HEP at Downstream Limit of the Model**

The downstream extent of each model requires a HEP such that the total contributing catchment can be estimated in order to check that the sum of the model inputs are consistent with hydrology estimations for the whole catchment. These will act as upstream limit HEPs where a further model is connected downstream. Where a gauging station HEP forms the boundary between two models this will act as the upstream and downstream HEP for the respective models.

### **5.3.2 Catchment Boundaries**

As part of the OPW FSU programme, physical catchment descriptors and catchment boundaries were delineated at 500m node points along all watercourses in Ireland (based on 50k mapping), with associated GIS point and polygon shapefiles produced. Each node point has a corresponding NODE

ID. This dataset has been used as the basis for HEP and catchment boundary identification, with adjustments made as necessary.

Where HEPs have corresponding FSU NODE\_IDs, the catchment is extracted from the FSU Ungauged Catchment Boundary GIS polygon dataset. This is reviewed by checking mapping, DTM; and LiDAR data where available. Where local knowledge or site walkover information indicates a deviation from the boundary shown, it will be revised accordingly.

Several HEPs do not have equivalent FSU nodes (particularly those at the upstream limit of models) and hence do not have catchments delineated and as such will require catchment delineation. This will be done on GIS using mapping, DTM and LiDAR when available. Again, local knowledge and information gained from site walkover will feed into the process. Urban catchments are particularly relevant in this respect, as catchment boundaries can be affected by drainage infrastructure and engineering interventions such as pumping from one catchment to another in high flows.

Where catchment boundaries extend into Northern Ireland a further check will be carried out to ensure the extents are consistent and that the catchment is properly delineated across the border (some of the mapping used to derive the FSU boundaries may not be complete across the border) with those delineated within the FEH CD ROM (Version 3). In addition Rivers Agency have provided manually delineated catchment boundaries which extend from Northern Ireland into the Republic of Ireland which will be used for further detailed checking.

## **5.4 ESTIMATION OF DESIGN FLOW PARAMETERS**

### **5.4.1 Design Flow Estimation**

Design flow estimation will be undertaken using the process illustrated by the schematic Figure 5.2. It indicates a two-phased hydrology process. Phase 1 involves initial design flow estimation by two main routes depending on the type of HEP being analysed (for further detail on methodologies see 5.6). These routes are:

- Design flow estimation using appropriate statistical based techniques (FSU Work Packages 2.2, 2.3 and 3.1) and / or
- Rainfall runoff modelling using MIKE NAM<sup>1</sup> to provide peak flow and design hydrograph input to the hydraulic model where sufficient rainfall data is available

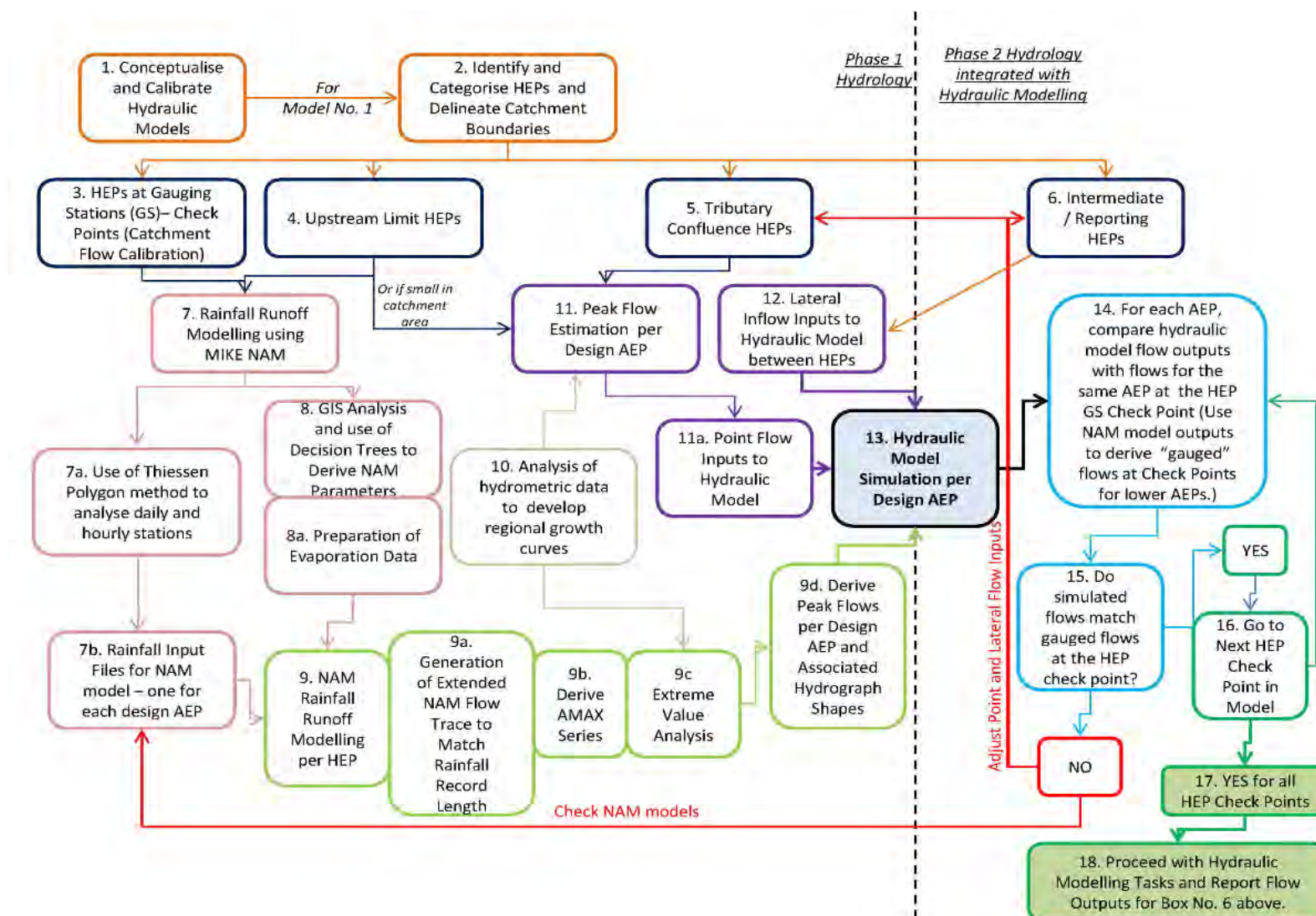
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<sup>1</sup> MIKE NAM (by DHI) is a module of MIKE 11 and is used for hydrological catchment rainfall run-off modelling. MIKE NAM is an established rainfall run-off modelling tool and is the preferred software of RPS / HydroLogic for CFRAMS as outputs from NAM can be input directly into MIKE 11 / 21, one of the hydraulic modelling software packages stipulated for CFRAMS.



Due to the difference in the preferred method of design flow estimation at different HEP points it is possible that where the methodology changes there could be a difference (a jump or a drop) in flows. Generally the adjustment based on pivotal sites will help to smooth the estimates in  $Q_{med}$ . Where this is not appropriate, and design flows remain unadjusted and there is a sudden change in flow estimate, inflows upstream of the NAM point will be adjusted to smooth out any sudden changes. In most cases flows derived from rainfall run-off modelling are preferable to catchment descriptor based estimates as they are derived directly from observed data.

When these hydrographs and flows are derived, they will be simulated in the hydraulic model and the outputs compared with observed flows at HEP gauging station check points for the AEP being considered. This brings the process into Phase 2 which is an integrated process between hydrology and hydraulics, iteratively adjusting hydrological inputs (from methodologies detailed in 5.6) until calibration with the HEP gauging station check points is achieved.



**Figure 5.2: Two Phased Hydrology Analysis Process Chart**

Boxes 1 and 2 shown in Figure 5.2 relate to Hydraulic Model Conceptualisation/Calibration and defining HEP/Catchment Boundaries as previously described in Sections 5.2 and 5.3. Boxes 3, 4, 5 and 6 relate to the HEP categories as described in Section 5.3.1. The remaining boxes outline the hydrology estimation tasks according to HEP type as undertaken for each hydraulic model, and for each design AEP. The subsequent sections of this chapter describe these tasks and refer back to the box numbers in Figure 5.2 for clarity. Appendix C contains a table indicating the datasets that will be used in completing each task on the process chart according to Box Number.

#### **5.4.2 Phase 1: Derivation of Growth Curves for UoM 06 – (Box 10)**

There is a balance to be found between developing a growth curve at each HEP or as a minimum, developing a growth curve at each of the hydrometric gauge stations on a river network. However the first approach likely to result in an abundance of growth curves if each HEP is considered with unrealistic changes to growth factors along modelled reaches. Within UoM 06 there are six gauge stations with flow data available along modelled watercourses while nine models have been conceptualised in UoM 06. Growth curves developed at gauge stations only would not produce enough growth curves to represent all of the catchments. In these circumstances, by examining the catchment characteristics associated with each of the HEP nodes/gauging stations a number of strategic locations or nodes will be identified/selected for which growth curves will be developed on each model. At least one growth curve will be developed for each model in UoM 06. Following development of growth curves it may be appropriate to rationalise the number per catchment based on catchment characteristics to provide smooth transition in design flow estimation as we move down the catchment. Growth curves will be developed using the FSU pooled analysis approach. Suitability of a suite of flood like distributions will be examined such as GEV, EV1, GLO, LO, LN2 and LN3. All relevant calculations will be carried out using a FORTRAN language based Program which was developed by NUI Galway as part of the FSU Work Package 2.2 “Frequency Analysis” (Reference 7).

It is not possible using gauge years only from within UoM 06 to create a study specific pooling group which has homogeneous physiographic and climatological characteristics and has the required number of station years to form a pooling group with confidence for low AEP (%) events. As such growth curves will be developed using station years taken from the FSU pivotal sites database.

#### **5.4.3 Phase 1: Calculation of Design Flows at HEPs**

In general, Figure 5.2 outlines the hydrology estimation methods depending on the type of HEP. Derived peak flows and hydrographs at these HEPs will then be input to the hydraulic model for the design event AEP being considered. Upstream limit inflows will generally be input to the model as hydrographs or as point flows for small catchments. Flows from tributary confluences will generally be input as point flows, unless the tributary is of a significant catchment area, in which case a hydrograph will be derived for model input. Lateral inflows will also be used to facilitate inclusion of flow inputs between tributaries where necessary. The subsequent sections describe the hydrology estimation methods per HEP type.

#### 5.4.3.1 Upstream Limit HEPs (Box 4, 7, 8, 9,11)

The choice of hydrology estimation method for Upstream Limit HEPs largely depends on the contributing catchment area. Rainfall runoff modelling using all available rainfall data and GIS catchment parameters is the preferred method for providing design peak flow and hydrograph input to the upstream limit of each model. This is as outlined in **Boxes, 7, 8 and 9**. Rainfall runoff modelling will be undertaken using MIKE NAM software and is described in detail in Section 5.6.1.

NAM model outputs will provide a flow trace time series equal to that of the rainfall record available. From this an extreme value analysis can be undertaken to derive peak flows for design AEPs. For lower AEPs (higher return periods) relevant growth factors as described in Section 5.4.2 will be applied.

Typical hydrograph shape (storm profiles) will be extracted from the NAM flow trace output regarding the shape of the hydrographs (and hence the response of the HEPs catchments) and the hydrograph shape parameters such as: time of the rising part of hydrographs, time of the recession part of the hydrograph, their ratios, the volume of water, the concentration and the response time of the catchment; as well as the antecedent conditions of the catchment that can be inferred from the NAM model parameters. In addition, the up-scaling of hydrographs to represent the lower AEP design flow events that have not been historically recorded will be undertaken. The corresponding rainfall events that generate the design peak flow for each AEP will be further analysed in terms of their characteristics: intensity, duration, and volume. These rainfall events that cause the design peak flows will be also further compared to the Depth Duration Frequency (FSU Work Package 1.2 – Reference 8) growth curves to infer correlation characteristics.

Each Upstream Limit HEP will be individually reviewed to determine suitability of MIKE NAM modelling. If it is the case that the contributing area to the upstream limit HEP is very small, i.e. less than 25km<sup>2</sup>; ungauged and fairly homogenous, for example small urban streams, it is generally considered that rainfall runoff modelling would not be applicable and index flow estimation methods (coupled by the relevant growth factor (Section 5.4.2)) such as the method detailed in the FSU Work Package 2.3 'Flood Estimation in Ungauged Catchments' (Reference 9) would be more appropriate (**Box 11**). The factorial standard error associated with the  $Q_{med}$  estimation will also be used to calculate 68% and 95%ile confidence intervals. At the time of project inception the Institute of Hydrology Report 124 'Flood Estimation for Small Catchments' was considered the most appropriate methodology for estimating the index flood for small catchments due to the specific, small catchment data (<25km<sup>2</sup>) used to develop the 3 variable regression equation. Recent research undertaken by the OPW has shown that the FSU 7 variable equation (FSU WP 2.3), although not developed specifically for small catchments, outperformed the IH124 equation when tested across a number of small Irish catchment gauge sites (*National Hydrology Conference 2012, Paper 09 'Flood Estimation in Small and Urbanised Catchments in Ireland' Gebre & Nicholson*). In light of this RPS has altered the methodology being used such that FSU is the only (except for where specific cases require otherwise) index flood flow estimation to be used within the UoM 36.

Where hydrograph shapes are required for upstream limit model input but where rainfall run-off modelling is not carried out, the FSU Hydrograph Shape Generator version 5 will be used to provide the most appropriate shapes for these, generally smaller flows. These methods are outlined in Sections **Error! Reference source not found.** and 5.6.2.

#### 5.4.3.2 HEPs at Tributary Confluences (Box 5, 11, 12)

These will be analysed using FSU  $Q_{med}$  estimation coupled with the relevant derived growth curve. Care will be taken to ensure appropriate pivotal sites are selected, drawing first on those upstream or downstream or at least within the hydrometric area. The FSU  $Q_{med}$  estimation spreadsheet will be used to calculate  $Q_{med}$  using physical catchment descriptors ( $Q_{medpcd}$ ) associated with the HEP being considered. Pivotal site(s) are then used to adjust the  $Q_{med}$  estimation based on catchment descriptors by donating gauging data from a suitable station. This donation is achieved through the use of an adjustment factor which is the ratio of the Pivotal Site's  $Q_{medgauged}$  and  $Q_{medpcd}$ . The  $Q_{medpcd}$  calculated at the HEP is then multiplied by the adjustment factor to arrive at a final  $Q_{med}$  estimation. This can be further adjusted for urbanisation if required.

Selection of pivotal sites is therefore important to ensure that the optimum adjustment factor is applied. The order of preference for pivotal site selection is:

1. A gauging station downstream of the subject site;
2. A gauging station upstream of the subject site;
3. A gauging station in geographical proximity to the subject site (see below);
4. A gauging station identified by the hydrological similarity measure (see below).

Geographical closeness is calculated automatically by the FSU  $Q_{med}$  estimation spreadsheet based on distance from the HEP. Hydrological Similarity (dij) is calculated automatically by the FSU  $Q_{med}$  estimation spreadsheet using AREA, BFIsoil and SAAR physical catchment descriptors. Seven pivotal site options are then listed in order of similarity.

If relying on options 3 or 4 due to lack of gauging stations on the watercourse, the wider range of physical catchment descriptors will also be compared for each Pivotal Site option such as FARL, DRAIN2,  $S_{1085}$  and ARTDRAIN2. It is important to check similarity of these characteristics (attenuation from rivers and lakes, drainage density, catchment slope and whether or not the pivotal site has been arterially drained), as these will affect how appropriate the gauged data will be for donation to the HEP. To compare these descriptors, charts will be plotted showing the relevant values with respect to the HEP value for the same descriptor. The pivotal site which compares best will be chosen. If two pivotal sites are prominent, both can be used in the adjustment, by applying a weighting to each. This weighting will be based on the user's judgement after having looked closely at the catchment descriptors.

Sensitivity analysis on the choice of pivotal site will also be undertaken by plotting the resulting  $Q_{med}$  values from each to identify trends and outliers. This will also be done in the context of the 68% and 95% confidence limits associated with the  $Q_{medpcd}$  estimation for the HEP, using the FSU factorial standard error of  $\pm 1.37$ . This will ensure that the selected pivotal site results in an adjusted  $Q_{med}$  estimation that is within the confidence limits. The latest FSU  $Q_{med}$  estimation spreadsheet provided by OPW facilitates this sensitivity analysis by automatically populating a scatter chart with the resulting adjusted  $Q_{med}$  values per pivotal site option.

For stations where a CFRAM rating review is undertaken, consideration will be given to updating adjustment factors depending on RPS's recommendation on the robustness of the revised rating. The factorial standard error associated with the  $Q_{med}$  estimation will also be used to calculate 68% and 95%ile confidence intervals to assist in pivotal site selection and to inform any adjustments to derived flows in catchment flow calibration.

However, if a larger tributary catchment is gauged (say  $>100\text{km}^2$  decided on a case-by-case basis), it is likely to be more appropriate to construct a rainfall runoff model, calibrated to the gauged data, so that a calibrated inflow hydrograph is derived. This will be undertaken where applicable. Flow contributions from tributaries  $5\text{km}^2 \sim 100\text{km}^2$  will be estimated using FSU index design flood and growth curve derivation methods.

#### **5.4.3.3 HEPs at Gauging Stations – Check Points - (Box 3, 7, 8, 9)**

At gauging station locations along the modelled reach (where flow data is available), HEPs are located as check points for catchment flow verification and adjustment. At these points and where rainfall data of sufficient quality is available, a NAM model will be constructed for the entire upstream catchment, calibrated to available flow data. The AMAX series (extended through rainfall run-off modelling where suitable) will be used to derive the index flood flow  $Q_{med}$ . Where this estimate is deemed to be of a high degree of certainty (pivotal site, improved through NAM modelling and rating review) the  $Q_{medgauged}$  and  $Q_{medpcd}$  relationship will be used (see 5.4.3.2) within the catchment to adjust and improve ungauged estimates of  $Q_{med}$ .

#### **5.4.4 Phase 2: Catchment Flow Calibration (Box 13 to 18)**

The estimated design event flows at Upstream Limit, Tributary (and Intermediate where top-up is required) HEPs will be simulated in the hydraulic model (which will have been calibrated in terms of model parameters e.g. channel and floodplain roughness; structure coefficients to selected flood events, (refer to Section 5.2.3)).

The peak flow output from the design event hydraulic model will be compared with that of the combined NAM Check model output at the HEP Gauging Station Check Point (**Box 14, 15**). Where differences in discharge occur, the NAM models will be checked in terms of model parameters (**Box 7,8,9**) and point and lateral flow inputs will be iteratively adjusted (**Box 11, 12**) within relevant

confidence intervals until calibration to the gauged data is achieved for each design event (**Box 16**). This will be undertaken at each HEP gauging station check point moving downstream, to ensure the appropriate peak flow for the design AEP is simulated throughout the catchment (**Box 17**). Therefore, final design flow estimation will very much be integrated with the hydraulic modelling process.

Of the seven hydrometric stations located on modelled watercourses in UoM 06, all have water level and flow data available for catchment flow calibration (refer to Table 4.7), and are therefore viable as HEP Check Points.

Design rainfall input to the NAM models will be estimated using probabilistic analysis based on rainfall gauge derived rainfall data series and treated as a “truth” input. Hydrological NAM models will be calibrated by adjusting physical model parameters to achieve mass balance, not rainfall input. However if the calibration exercise exhibits significant differences between simulated and observed flows at the NAM check points, rainfall input files and the associated analysis to derive them will be checked. This phase of calibration cannot be directly applied at upstream input HEPs where no gauge data is available, however if the rainfall input files are found to require adjustment within the catchment through calibration applied at a gauge station HEP downstream, then the same calibration of the rainfall data may be applied, with caution, at the upstream HEP. The calibration tolerances (mass balance) will be dependent on the gauge station quality classification and where a gauge station rating is found to have a high degree of uncertainty at flood flows it may be more appropriate to calibrate the NAM model against the low to mid range flow trace from the continuous flow record.

FSU Work Package 3.4 (Reference 11) provides river basin modelling guidance; on estimating dependency between main channel and tributary AEP (section 13.5.3). Where gauging stations are available on both the main channel and tributary then the observed data will be used to derive a dependence relationship which can be applied for design flows. Where a tributary joins the modelled channel that is ungauged, Table 13.1 in FSU 3.4 report will be used to estimate the AEP (and therefore growth factor) to apply to the index flows calculated for tributary input that will result in the design AEP in the main channel. The provided regression equation in 13.5.4 will be used to estimate the time difference between peaks so that the peak flow can be input to the model at the correct time. Where two modelled channels meet, dependence analysis will also be undertaken following FSU WP 3.4 if HEP Check Points are not available.

#### **5.4.4.1 Intermediate / Reporting HEPs (Box 6)**

As discussed previously the models may need to be topped up at Intermediate HEPs to ensure all of the contributing catchment is considered (e.g. in a long, narrow catchment with many tributaries <5km<sup>2</sup> entering). Where this is considered necessary the additional contributing catchment will be added via lateral inflows upstream of the Intermediate HEP. Intermediate HEPs will also be continuously identified throughout the hydrological analysis when flow checks are required to verify estimations. For example, flow estimations for a tributary entering a modelled reach will be compared with the difference between flow estimates at intermediate HEPs immediately upstream and downstream of the

confluence point. These points will be derived from the FSU un-gauged catchment descriptors dataset as required.

Since Intermediate HEPs are located along the modelled reaches they will be used as flow check points and to denote further points in the model for which flow data will be reported for each design AEP. This will facilitate the completion of tables of peak flood levels for all design event probabilities at key points – upstream and downstream of AFAs; in the centre of AFAs and along MPWs with no distance between nodes greater than 5km. In addition, model points will be assigned at every cross section location and flows will be reported for these in accordance with the specification. Note that reporting points based on AFA extent will not be identified until the hydraulic modelling tasks have been completed and AFA extents fully defined.

## 5.5 SUMMARY OF HEPs IN UOM 06 AND ASSOCIATED ANALYSIS

Appendix D contains maps showing the layout of HEPs in UoM 06, and their category. There are approximately 150 HEPs in UoM 06

Table 5.2 provides a summary of the hydrology analysis that will be undertaken at each HEP according to model number and the HEP category. NODE\_ID\_CFRAMS denotes the unique identification number assigned to each HEP. This hydrology analysis is based on the overall methodology and checking each HEP in terms of catchment area, location and its contribution to the hydraulic models.

**Table 5.2: Summary of Hydrology Analysis per HEP and Model Number**

NODE_ID_CFRAM	MODEL NUMBER	HEP CATEGORY	HYDROLOGY
03_399_D_RA	1	HEP Downstream Limit	Dynamic Tidal Boundary
03_297_7_RA	1	HEP Downstream Limit	Dynamic Tidal Boundary
03051_RA	1	HEP Gauging Stations	NAM CHECK
03_425b_Inter_RA	1	HEP Intermediate	FSU
03_334_12_RA	1	HEP Intermediate	FSU
03_344_Int_RARPS	1	HEP Intermediate	FSU
03054_RA	1	HEP Intermediate	T.B.C.
03_373_5_RA	1	HEP Tribs	FSU
03_179_2_RA	1	HEP Tribs	FSU
03_341_Trib_RA	1	HEP Tribs	FSU
03_451_4_RA	1	HEP Tribs	FSU
03_315_Trb_RARPS	1	HEP Tribs	FSU



<b>NODE_ID_CFRAM</b>	<b>MODEL NUMBER</b>	<b>HEP CATEGORY</b>	<b>HYDROLOGY</b>
03_479_5_RA	1	HEP Tribs	FSU
03_113_5_RA	1	HEP Tribs	FSU
03_474_6_RA	1	HEP Tribs	FSU
03_344_Trib_RARPS	1	HEP Tribs	FSU
03_344_1_RA	1	HEP Tribs	FSU
03_235_2_RA	1	HEP Tribs	FSU
03_469_Trib_RARPS	1	HEP Tribs	FSU
03_296_1_U	1	HEP Upstream Limit	FSU
03_341_1_RA	1	HEP Upstream Limit	FSU
03_235_U_RARPS	1	HEP Upstream Limit	FSU
03_450_1_RA	1	HEP Upstream Limit	FSU
03_451_1_RARPS	1	HEP Upstream Limit	FSU
03_315_U_RARPS	1	HEP Upstream Limit	FSU
03_113_3_RA	1	HEP Upstream Limit	FSU
03_474_4_RA	1	HEP Upstream Limit	FSU
03_344_U_RARPS	1	HEP Upstream Limit	FSU
03_184_4_RA	1	HEP Upstream Limit	FSU
03_469_U_RARPS	1	HEP Upstream Limit	FSU
03_114_3_RA	1	HEP Upstream Limit	NAM
06_311_D	2	HEP Downstream Limit	Dynamic Tidal Boundary
06_908_2	2	HEP Downstream Limit	Dynamic Tidal Boundary
06_847_2	2	HEP Tribs	FSU
06_311_U	2	HEP Upstream Limit	FSU
06_446_U	2	HEP Upstream Limit	FSU
06_515_U	2	HEP Upstream Limit	FSU
06_227_D	3	HEP Downstream Limit	Dynamic Tidal Boundary
06_1075_2_RPS	3	HEP Downstream Limit	Dynamic Tidal Boundary
06_227_U	3	HEP Upstream Limit	FSU
06_290_1_RPS	3	HEP Upstream Limit	FSU
06_1093_D_RARPS	4	HEP Downstream Limit	Dynamic Tidal Boundary
06_DDalk_D_RARPS	4	HEP Downstream Limit	Dynamic Tidal Boundary

<b>NODE_ID_CFRAM</b>	<b>MODEL NUMBER</b>	<b>HEP CATEGORY</b>	<b>HYDROLOGY</b>
06_315_5_RA	4	HEP Downstream Limit	Dynamic Tidal Boundary
06_1038_D	4	HEP Downstream Limit	Dynamic Tidal Boundary
06_318_D	4	HEP Downstream Limit	Dynamic Tidal Boundary
06_1081_D_RA	4	HEP Downstream Limit	Dynamic Tidal Boundary
06_1078_3_RA	4	HEP Downstream Limit	Dynamic Tidal Boundary
06_1084_1_RA	4	HEP Intermediate	FSU
06032_RA	4	HEP Intermediate	FSU
06_913_4_RPS	4	HEP Intermediate	FSU
06_318_Inter	4	HEP Intermediate	FSU
06036_RPS	4	HEP Intermediate	FSU
06_147_Inter1	4	HEP Intermediate	FSU
06_147_Inter2	4	HEP Intermediate	FSU
06_147_Inter3	4	HEP Intermediate	FSU
06_147_Inter4	4	HEP Intermediate	FSU
06_147_Inter5	4	HEP Intermediate	FSU
06_439_Inter1	4	HEP Intermediate	FSU
06_439_Inter2	4	HEP Intermediate	FSU
06_147_Inter6	4	HEP Intermediate	FSU
06_438_Inter1	4	HEP Intermediate	FSU
06_242_4_RPS	4	HEP Tribs	FSU
06_Trib_Ddalk_1	4	HEP Tribs	FSU
06_1055_2_RA	4	HEP Tribs	FSU
06_1087_13_RA	4	HEP Tribs	FSU
06_1089_4_RA	4	HEP Tribs	FSU
06_918_1	4	HEP Tribs	FSU
06_147_4_RPS	4	HEP Tribs	FSU
06_600_4_RA	4	HEP Tribs	FSU
06_315_U_RA	4	HEP Upstream Limit	FSU
06_913_U	4	HEP Upstream Limit	FSU
06_242_U	4	HEP Upstream Limit	FSU
06_Trib_Ddalk_U	4	HEP Upstream Limit	FSU

<b>NODE_ID_CFRAM</b>	<b>MODEL NUMBER</b>	<b>HEP CATEGORY</b>	<b>HYDROLOGY</b>
06_918_U	4	HEP Upstream Limit	FSU
06_1089_U	4	HEP Upstream Limit	FSU
06_1087_U_RA	4	HEP Upstream Limit	FSU
06_1055_U	4	HEP Upstream Limit	FSU
06_600_2_RA	4	HEP Upstream Limit	NAM
06_991_2_RA	4	HEP Upstream Limit	NAM
06_1058_2_RA	4	HEP Upstream Limit	NAM
06_1054_1_RA	4	HEP Upstream Limit	NAM
06_147_U	4	HEP Upstream Limit	NAM
06011_RA	5	HEP Gauging Stations	NAM CHECK
06_92_1_RA	5	HEP Intermediate	FSU
06_856_1_RA	5	HEP Intermediate	FSU
06035_RA	5	HEP Intermediate	FSU
06057_RA	5	HEP Intermediate	FSU
06_229_4_RA	5	HEP Tribs	FSU
06_905_17_RA	5	HEP Tribs	FSU
06_345_1_RARPS	5	HEP Tribs	FSU
06_997_3_RA	5	HEP Tribs	FSU
06_870_8_RA	5	HEP Tribs	FSU
06_376_5_RA	5	HEP Tribs	FSU
06_979_2_RA	5	HEP Tribs	FSU
06_856_5_RA	5	HEP Tribs	FSU
06_175_3_RA	5	HEP Upstream Limit	FSU
06_345_U_RARPS	5	HEP Upstream Limit	FSU
06_997_2_RA	5	HEP Upstream Limit	FSU
06016_RA	6	HEP Intermediate	FSU
06_100_2_RA	6	HEP Intermediate	FSU
06_571_4_RA	6	HEP Intermediate	FSU
06_892_3_RARPS	6	HEP Intermediate	FSU
06038_RA	6	HEP Intermediate	FSU
06_97_2_RA	6	HEP Tribs	FSU

<b>NODE_ID_CFRAM</b>	<b>MODEL NUMBER</b>	<b>HEP CATEGORY</b>	<b>HYDROLOGY</b>
06_538_2_RA	6	HEP Tribs	FSU
06_911_12_RA	6	HEP Tribs	FSU
06_892_1_RA	6	HEP Tribs	FSU
06_892_2_RPS	6	HEP Tribs	FSU
06_235_3_RA	6	HEP Tribs	FSU
06_630_1_RA	6	HEP Tribs	FSU
06_845_3_RA	6	HEP Tribs	FSU
06_602_4_RA	6	HEP Tribs	FSU
06_896_8_RA	6	HEP Upstream Limit	FSU
06_893_5_RA	6	HEP Upstream Limit	FSU
06_892_U_RARPS	6	HEP Upstream Limit	FSU
06_205_U	6	HEP Upstream Limit	FSU
06_630_U_RARPS	6	HEP Upstream Limit	FSU
06_845_U_RARPS	6	HEP Upstream Limit	FSU
06025_RA	7	HEP Gauging Stations	NAM CHECK
06023_RA	7	HEP Intermediate	FSU
06_65_3_RA	7	HEP Intermediate	FSU
06_566_5_RA	7	HEP Tribs	FSU
06_8_3_RA	7	HEP Tribs	FSU
06_586_2_RA	7	HEP Tribs	FSU
06_553_2_RA	7	HEP Tribs	FSU
06_DeerTrib_RARPS	7	HEP Tribs	FSU
06_262_3_RA	7	HEP Tribs	FSU
06_234_1_RARPS	7	HEP Tribs	FSU
06_135_3_RA	7	HEP Tribs	FSU
06_565_3_RA	7	HEP Tribs	FSU
06_745_U_RARPS	7	HEP Upstream Limit	FSU
06_1016_U_RA	7	HEP Upstream Limit	FSU
06_782_6_RA	7	HEP Upstream Limit	FSU
06_262_U_RARPS	7	HEP Upstream Limit	FSU
06_661_U_RARPS	7	HEP Upstream Limit	FSU

<b>NODE_ID_CFRAM</b>	<b>MODEL NUMBER</b>	<b>HEP CATEGORY</b>	<b>HYDROLOGY</b>
06_970_6_RA	7	HEP Upstream Limit	NAM
06_848_D_RARPS	8	HEP Downstream Limit	Dynamic Tidal Boundary
06021_RA	8	HEP Gauging Stations	NAM CHECK
06014_RA	8	HEP Gauging Stations	NAM CHECK
06013_RA	8	HEP Gauging Stations	NAM CHECK
06_603_Inter_1_RA	8	HEP Intermediate	FSU
06052_RA	8	HEP Intermediate	FSU
06_1097_2_RA	8	HEP Intermediate	FSU
06_1099_8_RA	8	HEP Intermediate	FSU
06_1100_1_RA	8	HEP Tribs	FSU
06_550_5_RA	8	HEP Tribs	FSU
06_76_2_RA	8	HEP Tribs	FSU
06_73_2_RA	8	HEP Tribs	FSU
06_70_3_RA	8	HEP Tribs	FSU
06_276_13_RA	8	HEP Tribs	FSU
06_1050_3_RA	8	HEP Tribs	FSU
06_305_D_RARPS	9	HEP Downstream Limit	Dynamic Tidal Boundary
06037_RA	9	HEP Intermediate	T.B.C.
06_302_5_RARPS	9	HEP Tribs	FSU
06_1048_1_RA	9	HEP Upstream Limit	FSU
06_302_2_RARPS	9	HEP Upstream Limit	FSU

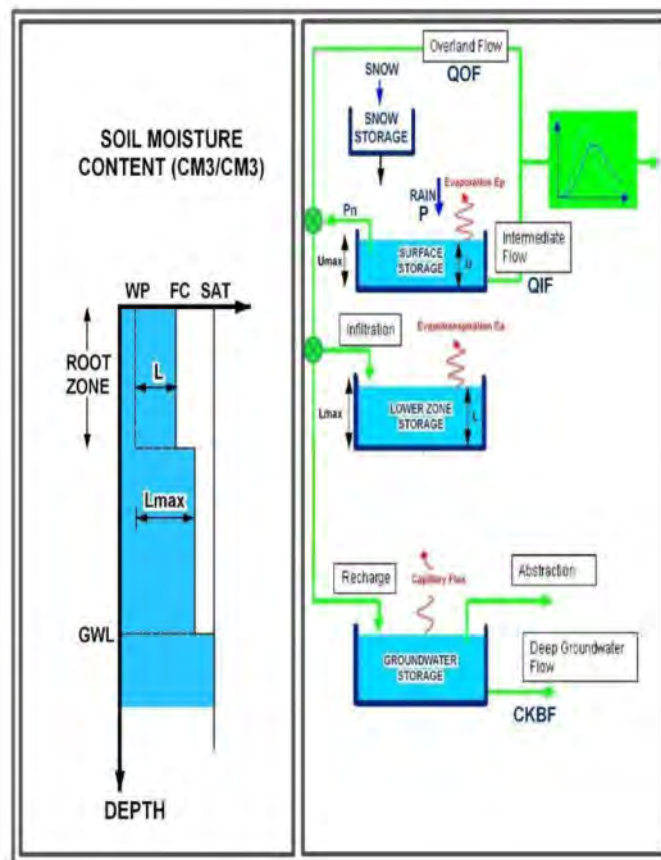
Note: Downstream Limit and additional Intermediate HEPs will be added during the analysis to enable catchment flow checks as required.

## **5.6 DETAILS ON DIFFERENT HYDROLOGICAL MODELLING METHODS**

### **5.6.1 Rainfall Runoff Catchment Modelling – MIKE NAM**

Hydrological modelling for the GIS-delineated catchments of the identified HEPs will be carried out using NAM rainfall-runoff simulator of the MIKE 11 modelling software. MIKE NAM is a deterministic lumped hydrological rainfall-runoff model that operates by continuously accounting for the runoff and soil moisture content in three different and mutually inter-related storages (nonlinear reservoirs), which represent physical elements of a catchment (surface storage, root zone and ground water storages) as illustrated by Figure 5.3 below. Being a lumped model, it treats each sub-catchment as one unit;

therefore the parameters and variables considered represent average values for the catchment areas and are very sensitive as calibration parameters.



- ( $U_{MAX}$ ) - maximum water content in the surface storage– affects overland flow, recharge, amounts of evapotranspiration and intermediate flow;
- ( $L_{MAX}$ ) - maximum water in the lower zone/root zone storage– affects overland flow, recharge, amounts of evapotranspiration and intermediate flow;
- ( $CQ_{OF}$ ) - overland flow coefficient– affects the volume of overland flow and recharge;
- ( $CK_{IF}$ ) - intermediate flow drainage constant– affects the amount of drainage from the surface storage zone as intermediate flow;
- (TOF) - overland flow threshold– affects the soil moisture content that must be satisfied for quick flow to occur;
- intermediate flow threshold (TIF) - affects the soil moisture content that must be satisfied for intermediate flow to occur;
- ( $CK_{1,2}$ ) - time constant for overland flow– affects the routing of overland flow along catchment slopes and channels;
- (TG) - deep groundwater recharge threshold - affects the soil moisture content that must be satisfied for groundwater recharge to occur;
- ( $CKBF_1$  - time constant for deep groundwater flow) - affects the routing of groundwater recharge in the regional aquifers.
- $Q_{OF}$  - Overland flow
- $Q_{IF}$  - Intermediate flow

**Figure 5.3: NAM model structure (SWRBD/RPS, Reference 12)**

MIKE NAM utilises all available rainfall data as hydrological model input, together with parameters to describe catchment response. Available rainfall data is discussed in 4.2 and the data gaps identified in the data status tables in Appendix B. Further analysis of data for reconstructing flows will be done on a case by case basis through the construction and calibration of each NAM model. The Thiessen polygons method as detailed in 5.1.3 which will be used to derive the rainfall input files from surrounding gauges will be consistent throughout. Where it is possible to apply patterns in the hourly

rainfall measured at Ballyhaise, Clones, Mullingar and Dublin Airport to surrounding daily rainfall gauge data with confidence this will be carried out.

In addition to rainfall data, evaporation and potential evapotranspiration data is required as meteorological input to the NAM models. Daily data is available for both parameters recorded at the Ballyhaise / Clones (1951 – 2010) and Dublin Airport (1941 – 2010) weather stations.

The post calibration output is a flow trace matching the time series of available rainfall data. This will provide hydrograph shape, and an extended AMAX series from which peak flows can be derived using growth curves as required (refer to Section 5.4.2). The benefit of this approach is that a discharge file will be generated for the entire length of rainfall record available, as opposed to limiting the AMAX series to the length of the hydrometric record. This maximises the length of AMAX series from which to calculate peak flows per AEP (using derived growth curves where required). Furthermore, using the NAM hydrological models, simulation of the typical shape of the hydrograph as a response of the catchment area for the peak flows for each AEP will be undertaken. This will provide the key parameters describing the shape of the hydrograph per event, such as the time of concentration –  $T_c$ , rising time of the hydrograph –  $T_p$ , recession time of the hydrograph –  $T_r$  and their ratios. The main limitation of using NAM rainfall run-off models is that quality is restricted by the available input data and in the case of UoM 06 this appears to be poor in some areas. Within UoM 06 this technique will only be used to supplement the full suite of statistical techniques.

#### **5.6.1.1 NAM Parameters**

The NAM model includes 5 state variables and 9 model parameters. The state variables are: SS - initial snow storage; U - upper zone storage ( $U/U_{max}$ ); L - lower zone storage ( $L/L_{max}$ ); QR1 - Initial runoff from routing reservoir #1; QR2 - Initial runoff from routing reservoir #2.

The model parameters are:

- $U_{max}$  (mm) – the maximum water content in the surface storage;
- $L_{max}$  (mm) the maximum water content in the root zone storage;
- CQOF - is the overland flow runoff coefficient;
- CKIF (hrs) – the interflow time constant routing parameter;
- CKBF - is the time constant for deep groundwater flow;
- $CK_{12}$  - is the time constant for overland flow routing, this is an important parameter and it depends on the size of the catchment and how fast it responds to rainfall;
- TOF - time transfer factor for the overland storage;

- TIF - time transfer factor for the interflow storage;
- TG - time transfer factor for the groundwater storage.

Based on previous NAM hydrological modelling studies (including parameters sensitivity analysis), RPS and HydroLogic will use a physically-based approach to estimate the values of some of the key NAM model parameters using a decision tree and utilising the available GIS data sets for the North Western – Neagh Bann CFRAM Study area. The following parameters will be estimated based on a decision tree methodology:

- The **surface storage Umax** [mm] is defined as the volume of water stored on foliage and generally on the surface following rainfall, but also in dips and puddles and subsurface non groundwater storage, which can feed the interflow discharge component. It is usually in the order of 5-25 mm, is available for immediate evaporation and excludes moisture stored in soil and subsoil. Steep ground tends to have less surface storage compared to for example drumlin landscapes, also for large vegetation types i.e. trees or shrub the storage is greater compared to grass or rocky surfaces. Calibration of this parameter is often achieved through assessment of the overall water balance; this requires good evaporation information ideally varying on a weekly or monthly interval. Once the surface storage is depleted interflow ceases to exist in the model and evaporation takes place from the lower or soil moisture storage at a slower rate. Overland flow is only present while the surface storage is fully replenished in the model.
- The maximum amount of overland flow is given by the **overland flow runoff coefficient CQOF** [/], which is often higher compared to other deterministic models, as the actual runoff is also proportioned in relation to the soil moisture at each time step.
- The time constant for **interflow CKIF** [hour] controls how fast water can be discharged from the surface storage into the stream, though as with the overland flow this is proportioned by the ratio of available soil moisture to the total soil moisture storage.
- The **discharge from the ground water** reservoir is simulated through a recession relationship defined by a time constant **CKBF** [hour]. As the constant already suggests the flow simulated is baseflow, i.e. a very slowly varying stream flow component, often attributed to the groundwater reservoir, though in some instances this might also be due to large peat layers in the catchments. Attempts have been made to simulate this behaviour through splitting the baseflow into two components with varying discharge time constants often found in peat catchments in wet and dry seasons.

As part of the Water Framework Directive further characterisation study 'An Integrated Approach to Quantifying Groundwater and Surface Water Contributions of Stream Flow' (Reference 12), a series of decision tables were developed to determine the following NAM parameters - the coefficient for overland flow (CQOF), the time constant for overland flow (CK1,2), the surface storage zone (Umax),



the time constant for interflow (CKIF) and the time constant for baseflow (CKBF). The decision tables were based on the assessment of GIS datasets, as well as expert judgement (e.g. gravels scenario).`

An example decision tree for determination of the NAM model parameters is presented in Table 5.3 below. Similar decision trees (lookup tables) are available for the rest of the NAM model parameters.

**Table 5.3: Example decision table for the determination of the NAM surface storage zone (U<sub>max</sub>), (SWRBD, RPS, 2008)**

NAM Parameter	Corine	Range of NAM parameter value	Slope	Lakes	Poorly drained soils	Urban	GIS estimation for sub-catchment
<b>U<sub>max</sub> (mm)</b>	>5% Forestry & Semi-natural areas	<b>15 -25</b>	Steep slope (>5%): lower end of limit	Lakes > 1%: 15 – 20	High percentage of poorly drained soils (>50%): upper end of limit	If >2% urban areas: upper end of limit	1A, 2B, 3C
	Forestry 0 – 5% & Pastures > 40%	<b>10 – 20</b>					1B, 2C
	Forestry 0%, Pastures <40% and Bare rock >20%	<b>8 - 15</b>	Relatively flat slope (<5%): upper end of limit		Low percentage of poorly drained soils (<20%): lower end of limit		4A, 4B

The example decision table presented in Table 5.3 is to determine the value of U<sub>max</sub> (*surface storage zone*) for each catchment. U<sub>max</sub> is controlled by vegetation - which can intercept moisture - and depressions in a catchment. The amount of water that is stored in the surface storage zone is also controlled by evaporation and drainage to the subsurface. The range of U<sub>max</sub> values are controlled by the proportion of forestry, agricultural land and outcropping rock. Forestry has a higher potential to intercept the moisture from rainfall compared to agricultural land and bare rock. The 'Corine' column in Table 5.3 gives upper and lower limits of percentage cover of forestry, agricultural land and outcropping rock. The catchment under investigation is assigned to one of the three categories (depending on its land cover), with a broad range of U<sub>max</sub> values given in the adjacent column.

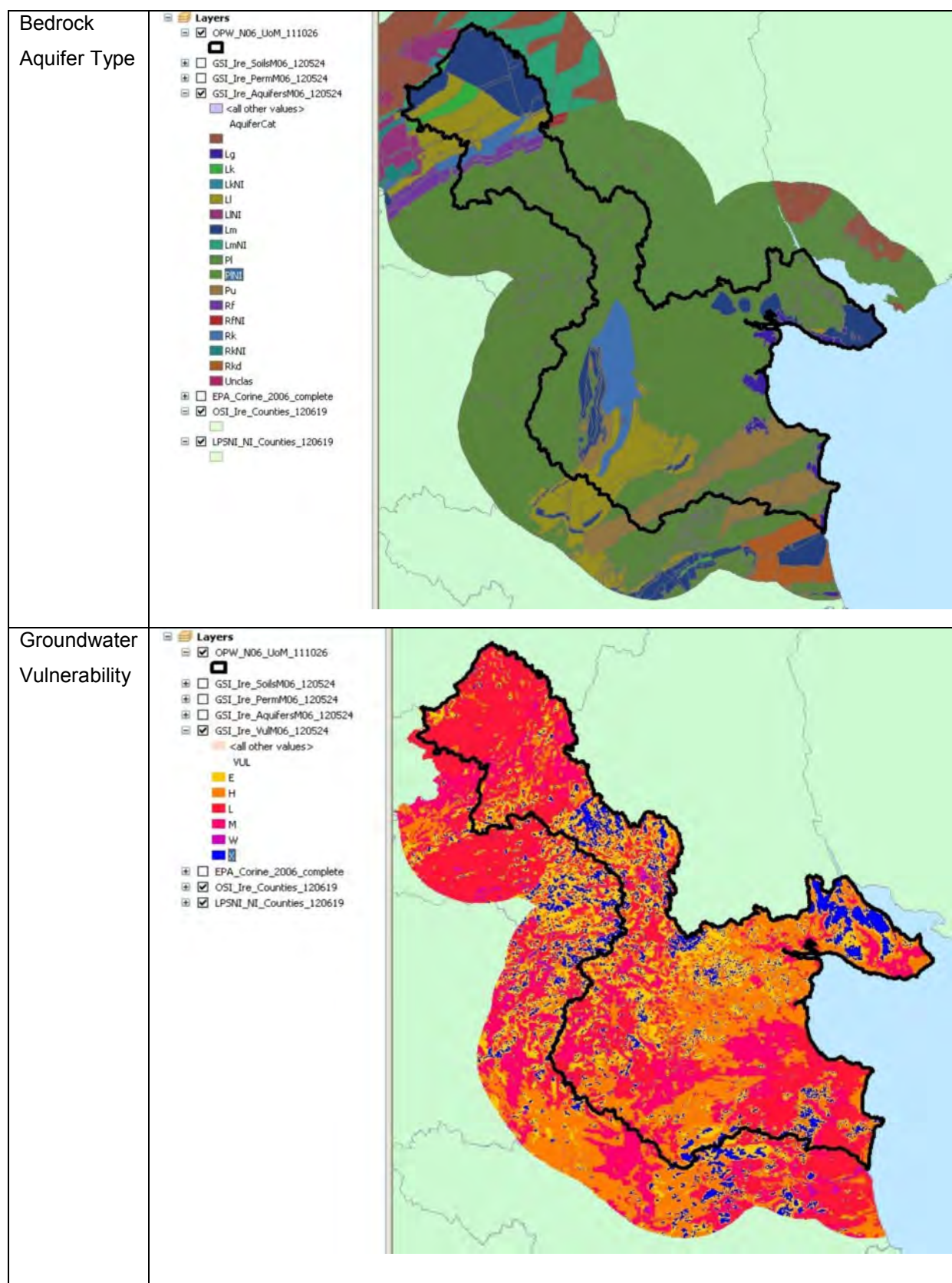
The selected value of U<sub>max</sub> for a catchment can be further refined dependent upon the average slope, coverage by lakes, coverage by wet soils and the amount of urban area. For example, the U<sub>max</sub> value would be expected to be at the lower end of the land cover ranges if the average slope of a catchment is relatively steep (>5%). Also, a high percentage of lakes will act as storage resulting value of U<sub>max</sub> at the upper end of the land cover ranges. Similarly, a high proportion of wet soils and urban areas will intercept rainfall and affect U<sub>max</sub>.

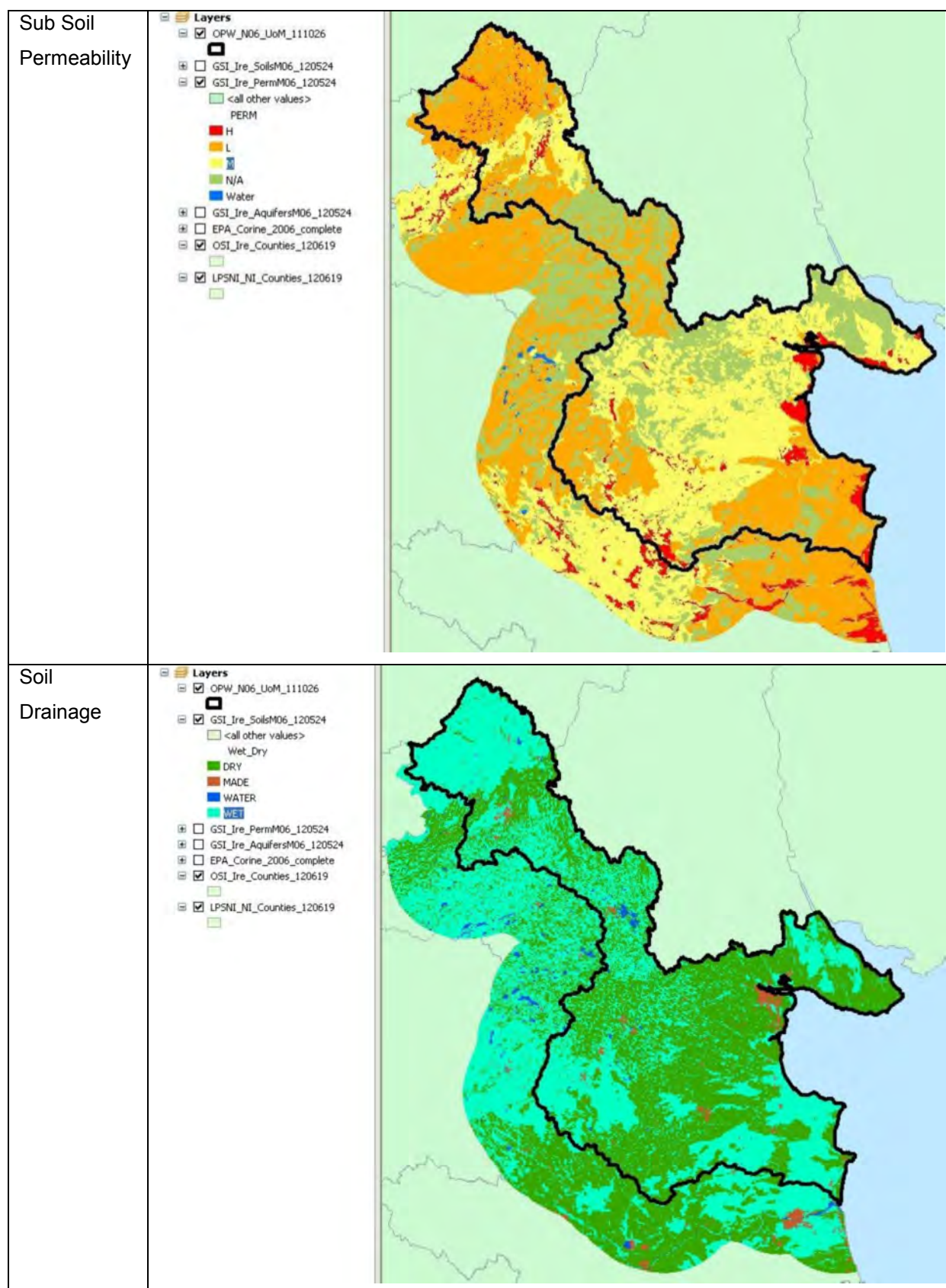
River catchments are not necessarily composed of one aquifer type and more often than not contain mixed aquifers. The method for estimating the NAM parameters CQOF, CKIF and CKBF is based on single aquifer types. For the mixed aquifer scenarios an *area percentage of each aquifer type in the catchment* approach will be used to estimate these NAM parameters.

The initial estimation of the four parameters (Umax, CQOF, CKIF and CKBF) driving the rainfall-runoff process will be done using the available GIS datasets, namely:

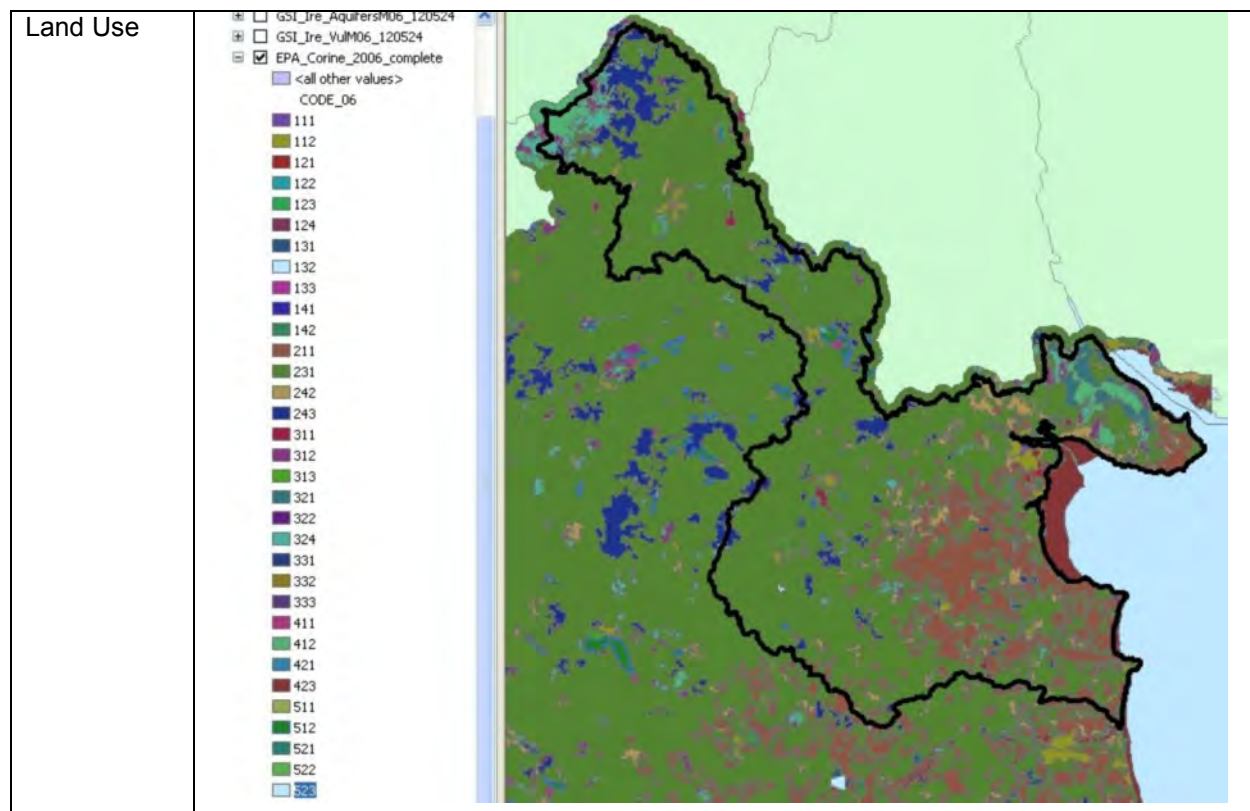
- GSI\_BedrockAndSG\_AquifersUnion\_pg\_110830 - *aquifer type*;
- GSI\_Soils\_WetDry\_pg\_110830 - *poorly drained soils*;
- GSI\_SubsoilPermeability\_pg\_110830 – *permeability*;
- GSI\_Vulnerability\_pg\_110830 – *ground water vulnerability*;
- DTM;
- Corine Land Use GIS layer.

The auto-calibration process can arrive at several good models with different variations of parameter sets (equifinality). In the NAM model calibration, the optimal parameter sets are searched in 10-dimensional hyperspace. Taking a particular objective function, the error landscape can be rough; however the model equifinality may still exist since two models with different parameter sets which are placed at quite some distance in hyperspace both have good performance. The control method for equifinality is to find the nearest distance between the equifinal model parameter sets to the parameters set which is defined by the decision (tree) rules previously discussed. This decision rule generates a set of NAM parameters that are formulated based on the physical characteristics of the catchment (i.e. Corine land cover land use map, soil type and drainage, permeability and DTM characteristics such as slope and (sub)catchment area). One method for finding the nearest distance between the optimal (robust) NAM calibrated parameters and the parameter set derived by the decision tree rules in hyperspace is to define a k-parameter measure of the nearest neighbour. This methodology provides a unique NAM model parameter set that is physically-based and solves the potential issue of model equifinality.









**Figure 5.4: Available GIS datasets for deriving the NAM model parameters in UoM 06**

The parameters for the NAM modelling that a decision tree has not been derived for based on the aforementioned WFD Study are the maximum soil moisture content in the root zone, storage available for vegetative transpiration ( $L_{max}$ , measured in mm) and the threshold values for overland flow, intermediate flow and deep groundwater flow (the  $L/L_{max}$  value at which that component of flow occurs).

Based on NAM modelling undertaken for the Neagh Bann catchment study in Northern Ireland (Reference 13) it is suggested to use the following default values for the initial modelling of further catchments:

- Maximum soil moisture content in the root zone storage  $L_{max}$ : 120mm;
- Threshold value for overland flow: 0.6;
- Threshold value for interflow: 0.5;
- Threshold value for groundwater flow: 0.4.

These parameters will serve as a starting point and will not affect the final NAM parameters. Use of these parameters in the first instance should shorten the calibration time due to their likely hydrological similarity (starting from nearby defined Irish catchment parameters rather than starting from scratch). The value of these parameters should be altered during the modelling to improve the correlation and

water balance. There are certain circumstances within catchments that will indicate the threshold values. If a catchment has mainly dry soils or high permeability subsoils then the threshold value for overland flow will tend towards one i.e. the root zone storage must be saturated before overland flow will occur. If a catchment contains mainly exposed karst aquifers or gravel aquifers then the threshold value for overland flow will tend towards one and the threshold value for intermediate flow will tend towards zero i.e. flow will be routed to the intermediate component almost as soon as precipitation occurs.

HydroLogic is currently looking at developing ArcGIS scripts that will automate the estimation of the NAM model parameters:

- Based on the defined HEP and delineated catchment area using the national DTM provided by OPW;
- Overlay the catchment boundary (polygon) with the available GIS layers;
- Use the look-up decision trees (see tables) to initially estimate the four parameters:
- Write / update the NAM model input files.

This methodology will provide a more realistic narrowed range of values for the most sensitive NAM model parameters. For example, if using the decision tree one estimates from the GIS data for a given HEP catchment area  $U_{max} = 15-25$  [mm], initially the mid value will be used to instantiate the NAM model ( $U_{max} = 20$  [mm], in this case). If measured flow data is available at Gauging Station HEP check points further autocalibration procedures will be used to fine-tune the model parameters and generate a better fit between the measured and simulated flows, as described below. Note that during the autocalibration process the allowable values for the model parameters ( $U_{max}$  in this example) will be set within the estimated narrowed bands,  $U_{max} = 15-25$  [mm] in this case. For HEPs without gauged hydrometric data, NAM model autocalibration procedure will not be carried out and the values of the model parameters estimated by the decision tree approach will be used for hydrological modelling. These will then be revisited if hydraulic model simulation at NAM check points identifies differences between hydraulic model flow and observed flow at the hydrometric station. (Refer to Figure 5.2: Two Phased Hydrology Analysis Process **Chart**).

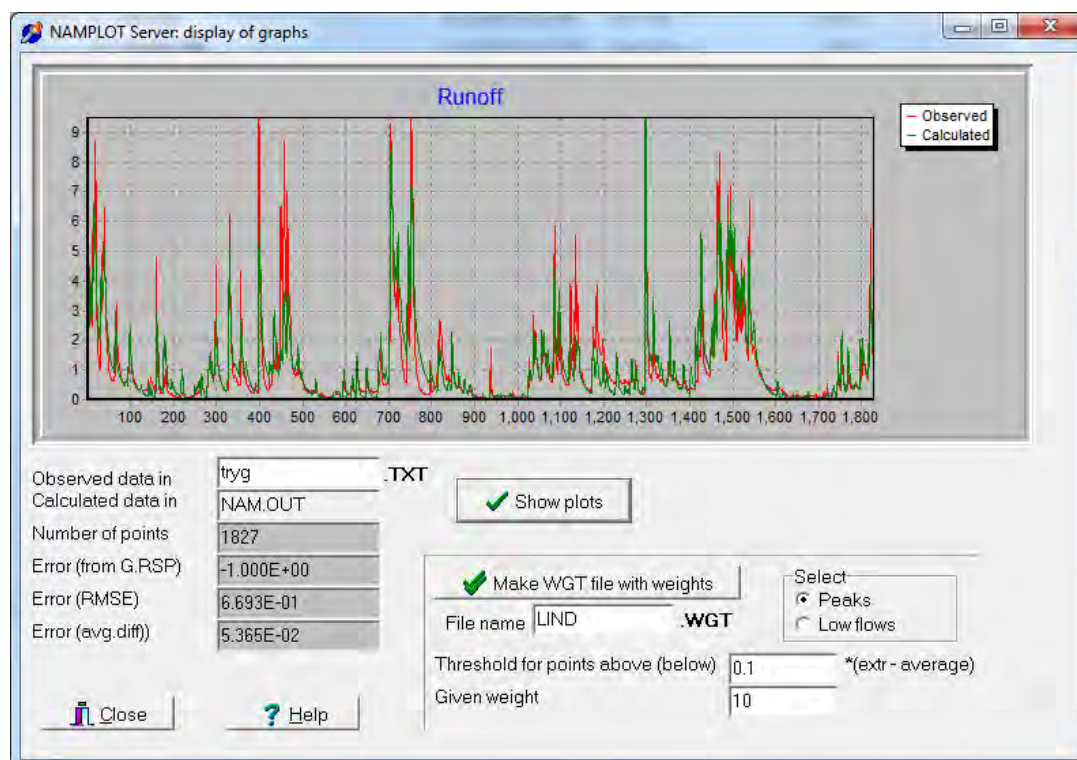
#### **5.6.1.2 MIKE NAM Calibration**

Where gauged flow data is available, i.e. at the locations along modelled watercourses as shown in Figure 4.2, MIKE NAM models will be calibrated to produce a discharge file as similar as possible to the actual gauged data. The NAM model software has an autocalibration function which will be utilised for each of the gauged catchment rainfall-runoff models. Recorded discharge data from the appropriate gauge will be entered into the model as part of the autocalibration process. The models will then be run in autocalibration mode where the software allocates appropriate values to the NAM parameters and uses the rainfall and evaporation data (as provided by Met Éireann) to produce a

discharge file as similar as possible to the actual gauged data. This autocalibration exercise will result in a roughly calibrated model. Calibration plots will be produced to compare the discharge file with gauged data, after which a second phase of calibration will be undertaken by adjusting NAM parameter values until satisfactory calibration is achieved.

- Optimisation Stage 1: optimising the water balance using multi-objective genetic algorithm.
- Optimisation Stage 2: optimising the hydrograph shape using multi-objective genetic algorithm.

The objective function can be a combination from different error measures (goodness of fit) between the measured flow and the computed flow, such as Root Mean Square Error (RMSE); Coefficient of correlation (CC) and determination (COD); Coefficient of variance (CV); Second momentum (MM); Proportional error estimate (PEE) specialising on both, peak and base flows. The acceptable values depend on the error measures used and the catchment characteristics. An error measure, like CoD/CoE (Nash-Sutcliffe) has a value range of  $[-\infty, 1]$  and the value above 0.8 is considered to be good, as demonstrated in numerous case studies. Other error measures, such as RMSE and peak weighted-RMSE have acceptable values depending on the catchment properties. Nevertheless, the relative / normalisation of these error measures could provide the general acceptable values. For instance, the model with relative pw-RMSE between 0-10% is considered to be very good. Additional tools for analysis of the calibrated NAM models will be also provided, see Figure 5.5.



**Figure 5.5: Visualization tools for the NAM model calibration component.**



It may be necessary in urban areas such as Letterkenny to utilise the Urban function of MIKE NAM to more accurately simulate runoff in highly impervious areas. Where Urban models are created, they will be joined with the NAM models in combined hydrological models.

As outlined in Sections 5.4.3.3 and 5.4.4, for catchment flow calibration, where NAM models are used at upstream limits HEPs (upstream boundary conditions), the calibration of the models for a hydrometric station which is further downstream will be undertaken by setting-up an integral NAM model at the hydrometric station which will have the sub-catchments of the upstream models included. For example, Hydraulic Model 22 at Ballybofey and Stranorlar has an upstream limit NAM model (River Finn) with one HEP Gauging Station Check Point further downstream within Ballybofey. In this case, two NAM models will be set up - one NAM model at the main HEP upstream limit on the Finn (there are also a number of smaller tributaries which will be calculated using statistical flow estimation techniques) and one NAM model at the HEP gauging station in order to undertake the catchment based NAM model calibration.

For NAM models at HEP tributaries which have significant contributing flows to the main stream as hydrodynamic model (MIKE 11), a joint hydrological and hydrodynamic calibration will be carried out.

Based on the initial HEP catchments analysis, it is estimated that approximately one third of the NAM models will have gauging stations that will enable full NAM model calibration. Typically for these models our experience is that 70% of the available data is used for model calibration with the remainder held for validation along with any new flow data that may become available during the modelling period. However in the case of UoM 06 and considering the scarcity of hydrometric data it is proposed that all available data up to the end of 2010 is used for calibration with only 2011 data and beyond data used for validation.

The RPS hydrology methodology is not dependent on simulated rainfall profiles being identified as the complete rainfall record will be input to the NAM models and following calibration against hydrometric gauge records, the NAM modelling will determine the rainfall events which will dictate the size of the index flood,  $Q_{med}$ . Within UoM 06 the rainfall inputs used in the NAM modelling process will be generated from rain gauge data. Rainfall profiles will be derived from gauge data and distributed using Thessian polygons or similar approaches, with reference to the FSU Depth Duration Frequency (FSU Work Package 1.2 – Reference 11) recommendations where appropriate.

## **5.6.2 Flood Studies Update (FSU)**

As referred to in Section 5.4 the OPW have been preparing an extensive update of the Flood Study Report for Ireland. This is referred to as the FSU Programme and is to provide improved methods of extreme rainfall and flood estimation at both gauged and ungauged locations in Ireland (FSU, Alpha Testing Users Guide, 2011 – Reference 14). It has been in development since 2004 and is in the final stages of completion.

A software application is under development however pending its completion the OPW provided excel automated spreadsheets for the following calculations:

1.  $Q_{med}$  estimation for ungauged sites based on catchment descriptors and factored based on gauging information at suitable pivotal sites.
2. Pooled Frequency Analysis to estimate the appropriate growth curve and associated factor for obtaining Q values for required AEPs. This process also uses pivotal stations to compile pooling groups of data.
3. Generation of Hydrograph Shape using the parametric method based on catchment descriptors and the Q value obtained in Step 2. This process also uses pivotal site data recently updated to include data from all 216 pivotal sites. This design methodology is captured in the recently released Hydrograph Shape Generator (version 5).

The factorial standard error value associated with this method is 1.37 for  $Q_{med}$  estimation.

If hydrographs are required as model input at HEP tributary locations consideration will be given to applying the FSU derived flood peak to a hydrograph shape derived from the FSSR Unit Hydrograph method. Whilst FSU hydrograph shape generation is relatively new, FSU derived flows may be better applied using a bridging method between the FSU and the Flood Studies Supplementary Report (FSSR) rainfall runoff Unit Hydrograph Method. The report on Work Package 3.5 of the FSU (Reference 15) discusses such an approach calling it an Interactive Bridge Invoking the Design Event Method (IBIDEM) and aims at providing a bridge between the FSU method of estimating a design flood hydrograph and the FSSR design method that it replaces. If it is found that the FSU Hydrograph Shape generator does not yield usable hydrographs e.g. infinite receding limb; inaccurate representation of water volume, this option will be considered. It may also be the case that nearby NAM model outputs provide an indication of catchment response and a typical hydrograph shape. This will also be considered when deriving appropriate hydrograph shapes to inform the overall process.

## 6 DETAILED METHODOLOGY REVIEW

The discussion regarding data collection, gaps and outstanding information, presented in Section 2 of this report informs the methodology risks and opportunities review.

The following general mechanisms are available for methodology amendments:

- Technical notes – used to expand or update methodology at appropriate project planning stages;
- Inception report (this report) – used to expand or update methodology in response to formal data review six months into the contract; and
- Agreed changes to scope of services (under Clause 2.6.2 of the North Western - Neagh Bann CFRAM Study Brief) – used to add or remove specified contract items (for example additional AFAs, changes of sources of flooding or alterations to the gauge review network).

Given the tightly prescribed work scope and tender specification and the fact that most of the datasets are as expected in terms of quality and availability, there have been a small number of methodology amendments in UoM 06 to date.

A brief summary of the status with regard to tendered methodology for each of the individual project tasks is as follows:

- General Requirements – there has been no methodology change with regard to level of detail, management arrangements, project inception, web-based work platform, project website, use of digital media and GIS, technical training, National Technical Coordination Group and health and safety requirements. These activities are all either complete or currently in place and ongoing during the study. Given the international status of the North Western District there is a requirement under the North Western – Neagh Bann CFRAM Study brief to liaise with the authorities in Northern Ireland in relation to Floods Directive implementation. Reporting and technical activities in this regard are progressing under the auspices of the Cross Border Coordination Group.
- Data Collection – section 2 of this report details the collection of relevant datasets and the initial phase has been completed in accordance with the tendered methodology. Further data or updates will be pursued on an ‘as needed’ basis or as they emerge. Flood event response activities will remain ongoing in accordance with the Generic CFRAM Study Brief and a project specific flood event response plan is detailed in a Technical Note (Section 6.2).
- Flood Risk Review – this task was completed by the Western CFRAM Study as it had to be undertaken before the North Western – Neagh Bann CFRAM Study commenced, the final report is available via the project website.

- Surveys – there are a number of issues regarding survey contract award and subsequent delivery timescales which pose potential project time constraints for the follow-on tasks of hydraulic modelling and flood mapping and may jeopardise delivery and consultation milestones in 2013. These risks and possible mitigation measures are discussed in more detail in Section 6.1.
- Hydrological Analysis – sections 4 and 5 of this inception report expands on the tendered hydrological methodology as applied to UoM 06.
- Hydraulic Analysis – there is no tendered methodology change proposed in UoM 06 to date.
- Flood Risk Assessment – there is no tendered methodology change proposed in UoM 06 to date.
- Environmental Assessment – there is no tendered methodology change proposed in UoM 06 to date.
- Consultation and Engagement – there is no tendered methodology change proposed in UoM 06 to date.
- Development of Flood Risk Management Options – there is no tendered methodology change proposed in UoM 06 to date.
- Preparation of Flood Risk Management Plans – there is no tendered methodology change proposed in UoM 06 to date.
- Reporting and Deliverables – there is no tendered methodology change proposed in UoM 06 to date.

RPS maintains a live project risk and opportunities register to consider implications for programme, quality and budget for the North Western – Neagh Bann CFRAM Study, which is reviewed at regular project working group meetings. This process has identified a small number of risks and opportunities that have a direct bearing on task methodology which are discussed in the following report sections.

## **6.1 RISKS AND PROPOSED METHODOLOGY AMMENDMENTS**

**Surveys** – the Generic CFRAM Study Brief requires the following surveys:

- Defence asset condition survey – project specific specification applies to UoM 06, surveys were scheduled to have commenced (programmed for September 2012 – March 2013) however these surveys are subject to locations being identified by structure and cross section survey contracts which have not yet commenced due to national procurement delays. Whilst no methodology change is formally proposed at this stage, it is hoped that a database capture

tool to increase the efficiency of the works can be progressed as a shared service across the CFRAM Study programme.

- Property survey – project specific specification applies to UoM 06, these surveys are not yet scheduled to commence - no methodology change is proposed at this stage.
- Floodplain survey – project specific specification applies to UoM 06, the LiDAR survey is progressing at national level, due to programme slippage RPS have not yet completed data quality assessment, RPS undertook additional work to review the survey extents in October 2012 so that complete coverage of revised AFAs was obtained and provided prioritisation of LiDAR survey deliverables to accommodate programming constraints.
- Channel and structure survey – after merging the pre-contracted and RPS procured survey scope, which afforded the opportunity to procure the survey contract as quickly as possible, the surveys are progressing. Due to concerns regarding survey resourcing across several simultaneous CFRAM Studies and subsequent slippage in the procurement programme at national level, RPS and the OPW have been considering the following methodology amendments to further mitigate survey delays.
  - RPS has applied guidance notes provided by the OPW in order to rationalise the AFAs, HPWs and MPWs and, in particular, to de-prioritise certain watercourses where flood risk receptors are not present within the flood extents of the watercourses. In addition the overall project programme has been reviewed to target delivery dates at key consultation periods in late 2013 and early 2014. Within this process the de-prioritisation of certain deliverables and the phased production of flood mapping are still currently under consideration between RPS and the OPW.
- There is a risk associated with the dispersion of alien species and the survey methodologies will take account of best practice in transferring survey equipment between catchments to ensure the spread of alien species is prevented. This environmental risk also poses survey programme risks which must be managed during the fieldwork phase of the project.

**Hydrology** – RADAR rainfall analysis methods are being trialled in the Eastern CFRAM and South Eastern CFRAM Studies as a methodology change to the generic specification however this method change is not proposed in the North Western – Neagh Bann CFRAM Study as it would be very limited in application and would bring programme risks to this final CFRAM Study.

There are no further additional risks and associated methodology amendments identified at present in UoM 06.

## 7 REFERENCES

- Reference 1:** EC Directive on the Assessment and Management of Flood Risks (2007/60/EC) (2007)
- Reference 2:** SI 122 of 2010 European Communities (Assessment and Management of Flood Risks) Regulations, 2010
- Reference 3:** Office of Public Works, 2011: “National Flood Risk Assessment and Management Programme, North West – Neagh Bann River Basin Districts Catchment-based Flood Risk Assessment and Management (CFRAM) Study, Stage II Tender Documents: Project Brief”
- Reference 4:** Office of Public Works, 2010: “National Flood Risk Assessment and Management Programme, Catchment-based Flood Risk Assessment and Management (CFRAM) Studies, Stage I Tender Documents: Project Brief”
- Reference 5:** Office of Public Works, 2006: “Flood Studies Update - Work Package 2.1, Review of Flood Flow Ratings for Flood Studies Update, Final Report J2194”
- Reference 6:** Patrick J. Tobin & Co. Consulting, Civil and Structural Engineers, 1979: "Rampart River Flooding Relief – A Feasibility Study"
- Reference 7:** Office of Public Works, 2009: “Flood Studies Update - Work Package 2.2 - Frequency Analysis”
- Reference 8:** Met Éireann, 2004: “Flood Studies Update - Work Package 1.2 – Estimation of Point Rainfall Frequencies”
- Reference 9:** Office of Public Works / NUI Maynooth 2009: “Flood Studies Update – Work Package 2.3 - Flood Estimation in Ungauged Catchments”
- Reference 10:** Natural Environmental Research Council (NERC), 1985 “The FSR rainfall-runoff model parameter estimation equations updated”, Flood Studies Supplementary Report (FSSR) No. 16 December 1985.
- Reference 11:** Office of Public Works, JBA, 2010: “Flood Studies Update - Work Package 3.4, Guidance for River Basin Modelling”
- Reference 12:** RPS, SWRBD, 2008, “Further Characterisation Study: An Integrated Approach to Quantifying Groundwater and Surface Water Contributions of Stream Flow”
- Reference 13:** Bell, A. K., Higginson, N., Dawson, S., Glasgow, G., and Elsaesser, B. 2005. Understanding and managing hydrological extremes in the Lough Neagh Basin, Tullamore National Hydrology Seminar, Proceedings, 1-10.
- Reference 14:** Office of Public Works, 2011: “Flood Studies Update, Alpha Testing Users Guide”
- Reference 15:** Office of Public Works, JBA, 2009: “Flood Studies Update - Work Package 3.5 – IBIDEM (Interactive Bridge Invoking the Design Event Method)”

## **APPENDIX A**

### **HYDROMETRIC DATA STATUS TABLE**





KEY

	Annual Max Data
	WL 15 Min Data
	WL & Flow 15 Min Data
	Flow 15 Min Data



## **APPENDIX B**

### **DAILY AND HOURLY RAINFALL**

### **DATA STATUS TABLES<sup>2</sup>**

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<sup>2</sup> Tables represent records of years of available data and not useable data. Individual gauge data QA processing will be carried out prior to rainfall run-off modelling using NIKLAS software.





### Hourly Rain - Data Status Table

[illegible]

Daily Rain - Data Status Table

[illegible]

Daily Rain - Data Status Table

[illegible]



Daily Rain - Data Status Table

[illegible]

### Daily Rain - Data Status Table

[illegible]



Daily Rain - Data Status Table

[illegible]

Daily Rain - Data Status Table

[illegible]

Daily Rain - Data Status Table

[illegible]



Catchment 41  
Daily Rain - Data Status Table

[illegible]

Catchment 42  
Daily Rain - Data Status Table

[illegible]

Catchment 43  
Daily Rain - Data Status Table

[illegible]



[illegible]



## **APPENDIX C**

### **Hydrology Method Process Chart – Used Datasets Table**



Box Number (Figure 5.2)	GIS Shapefile of River Network	DTM, Mapping, Aerial Imagery	FSU Ungauged Catchment Descriptors GIS Point File	FSU Gauged Catchment Descriptors GIS Point File	FSU Ungauged and Gauged Catchment Outlines GIS Polygon Layer	Daily and Hourly Rainfall Station Data	Met Éireann Evaporation Data	GSI Soil and Bedrock /Aquifer GIS Layers	Corine 2006 Landuse GIS Layer	Hydrometric Data
1	✓	✓								
2	✓	✓	✓	✓	✓					
3	✓		✓	✓	✓					✓
4	✓		✓	✓	✓					
5	✓		✓	✓	✓					
6	✓		✓	✓	✓					
7						✓				
8							✓	✓	✓	
9	✓		✓	✓	✓	✓	✓	✓	✓	✓
10	✓	✓								✓
11	✓	✓	✓	✓	✓					✓
12	✓	✓	✓	✓	✓					
13										
14										✓
15										✓
16										✓
17										
18										



## **APPENDIX D**

### **HEP and Catchment Diagrams**





