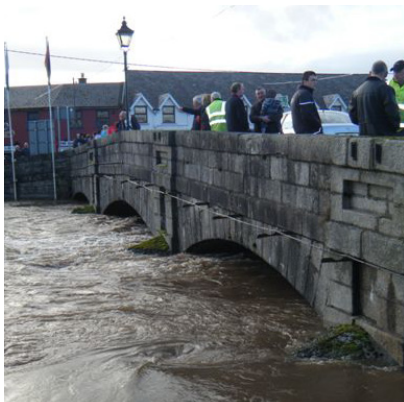
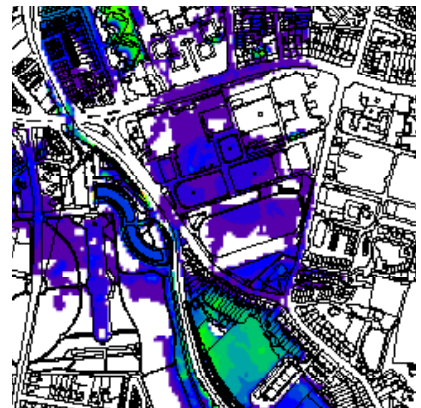
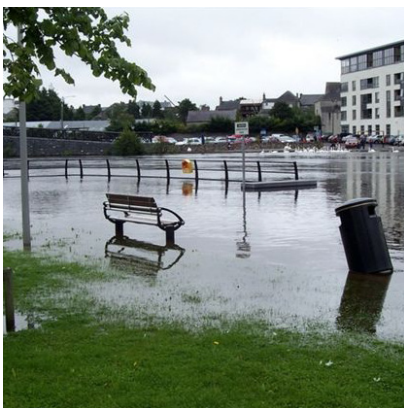
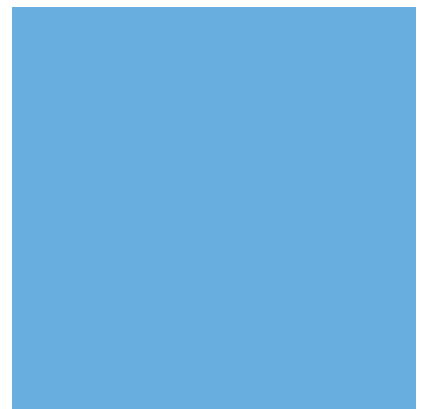




South Eastern CFRAM Study

HA15 Inception Report - Final

IBE0601Rp0008/F02



South Eastern CFRAM Study

HA15 Inception Report

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ABBREVIATIONS

AA	Appropriate Assessment
AEP	Annual Exceedance Probability
AFA	Area for Further Assessment
AMAX	Annual Maximum flood series
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
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 Assessment and 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
HPW	High Priority Watercourse
LA	Local Authority
LAP	Local Area Plan
LN2	2 Parameter Log Normal (distribution)
MAF	Mean Annual Flow
MPW	Medium Priority Watercourse
NDTM	National Digital Terrain Model
NHA	Natural Heritage Area
NIAH	National Inventory of Architectural Heritage
NPWS	National Parks and Wildlife Service
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
RBD	River Basin District
RBMP	River Basin Management Plan

RMSE	Root Mean Square Error
SAAR	Standard Average Annual Rainfall (mm)
SEA	Strategic Environmental Assessment
SERBD	South Eastern River Basin District
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 South Eastern Catchment Flood Risk Assessment and Management Study (South Eastern CFRAM Study) in July 2011. The South Eastern CFRAM Study was the third catchment flood risk management study to be commissioned in Ireland under the EC Directive on the Assessment and Management of Flood Risks 2007 (Reference 1) as implemented in Ireland by SI 122 of 2010 European Communities (Assessment and Management of Flood Risks) Regulations 2010 (Reference 2).

The South Eastern CFRAM Study covers an area of 9,315 km² and includes six Units of Management, Hydrometric Area (HA) 11 (Owenavorrigh), HA12 (Slaney and Wexford Harbour), HA13 (Ballyteigue-Bannow), HA14 (Barrow), HA15 (Nore) and HA17 (Colligan-Mahon). HA16 (Suir) is covered by the Suir pilot CFRAM Study and covers an area of approximately 3,542 km². There is a high level of flood risk within the South Eastern CFRAM study area, with significant coastal and fluvial flooding events having occurred in the past. Table 1.1 lists the local authorities that intersect each unit of management.

Table 1.1: Local Authorities

Unit of Management	Local Authorities
HA11 Owenavorrigh	Wexford, Wicklow
HA12 Slaney and Wexford Harbour	Carlow, Kildare, Wexford, Wicklow
HA13 Ballyteigue-Bannow	Wexford
HA14 Barrow	Carlow, Kildare, Kilkenny, Laois, Offaly, Wexford, Wicklow
HA15 Nore	Carlow, Kilkenny, Laois, Offaly, North Tipperary, South Tipperary
HA16 Suir	Cork, Kilkenny, Laois, Limerick, North Tipperary, South Tipperary, Waterford City, Waterford County
HA17 Colligan-Mahon	Waterford City, Waterford County

Although it has been agreed that some units of management will be grouped where appropriate to facilitate technical reporting, for example HAs 11, 12 and 13, a separate Flood Risk Management Plan (FRMP) will be prepared for each unit of management in the South Eastern CFRAM Study area.

HA15 covers an area of 2,595 km² and includes much of County Kilkenny, a significant portion of County Laois, as well as smaller portions of South Tipperary, North Tipperary, Offaly and Carlow. The principal river in HA15 is the River Nore which rises in a hilly area approximately ten kilometres southwest of Roscrea in North Tipperary. It flows in a north easterly direction through Borris-in-Ossory to Castletown in County Laois and then flows in a south easterly direction through Ballyragget, Kilkenny, Bennettsbridge and Thomastown in county Kilkenny to its confluence with the River Barrow

approximately four kilometres upstream of New Ross. The total length of the Nore from its source to the confluence with the Barrow is 141 kilometres. The lower part of the river, downstream of Inistioge, is tidal. The principal tributaries are the Delour, Mountrath, Owveg, Kilfane and Dinin rivers which join the Nore on its left hand bank and the Gully, Erkina, Nuenna, King's, Breaghagh, Little Arrigle and Arrigle rivers which join the Nore on its right hand bank.

HA15 is predominantly rural with the largest urban area being Kilkenny. Smaller towns and villages include Thomastown, Callan and Castlecomer in county Kilkenny and Durrow, Rathdowney and Mountrath in county Laois. The rich soils are particularly suitable for agriculture and much of the land area is given over to tillage and grassland. The Nore and many of its tributaries support fishing activities.

Within HA15 there are 11 Areas for Further Assessment (AFA) under the South Eastern CFRAM Study as shown in Figure 1.1. All of these AFAs have experienced fluvial flooding: Mountrath; Ballyroan; Rathdowney; Ballyragget; Freshford; Kilkenny–Nore; Kilkenny–Breaghagh; Callan; Thomastown; Ballyhale and Inistioge. The River Nore as it runs through Borris-in-Ossory is a Medium Priority Watercourse; the town itself is not an AFA.

Some AFAs have already benefited from flood relief schemes, for example, the River Nore in Kilkenny. Consequently in accordance with the National Flood Risk Assessment and Management Programme, South Eastern River Basin District Catchment-based Flood Risk Assessment and Management (CFRAM) Study, Stage II Project Brief (Reference 3) (hereinafter referred to as the South Eastern CFRAM Study Brief) only those areas not afforded protection by the existing scheme will be considered in full under the South Eastern CFRAM Study. For other areas within AFAs benefiting from existing flood relief schemes assessment under the South Eastern 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.

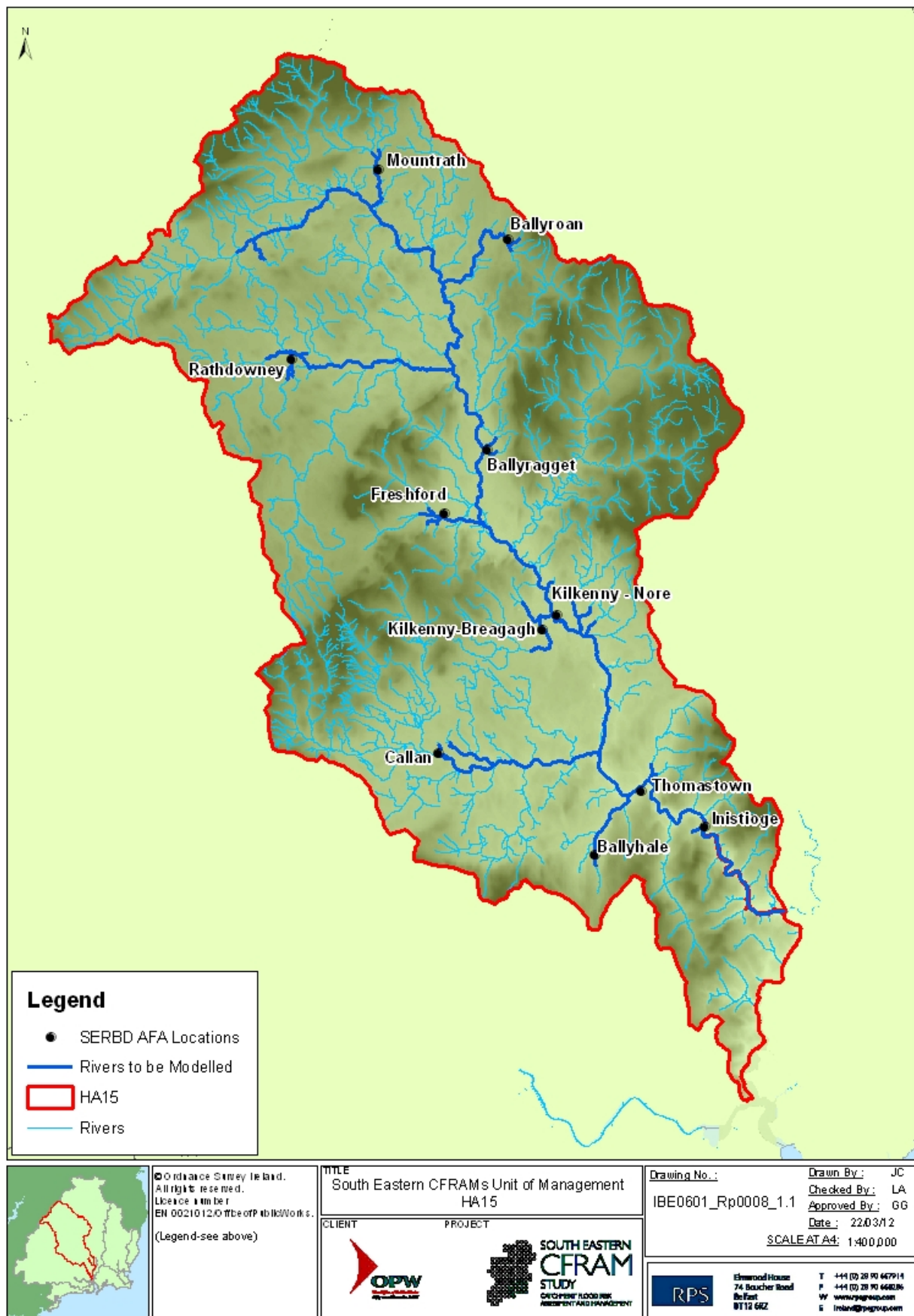


Figure 1.1: HA15 Extents and AFA Locations

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 HA15 as part of the South Eastern 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, Dr Alan Barr, assisted by the Project Manager, Grace Glasgow, and two Assistant Project Managers, Dr Malcolm Brian and Andrew Jackson. 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 as are many of the supporting technical staff, although the overall team includes staff from RPS offices in 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 South Eastern CFRAM Study and HA15 in particular started with a review of the lists of data sources and relevant reports identified in the South Eastern 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 South Eastern 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 end of July 2011. The datasets provided by OPW included:-

Social

- Primary Schools, Post Primary Schools, Third Level
- Fire Stations
- Garda Stations
- Civil Defence
- OPW Buildings
- Nursing Homes, Hospitals, Health Centres

Economic

- Geo-Directory (GeoDirectory Oct 2010)
- Infrastructure: ESB Power Stations, ESB HV Substations, Bord Gais Assets, Eircom Assets
- Road
- Rail
- Ports
- Airports

Environmental

- Architectural Heritage
- National Monuments
- National Heritage Area
- Proposed National Heritage Area
- Special Area of Conservation
- Special Protected Area
- Groundwater Drinking Water (EPA data)
- Pollution Sources (EPA data)

Hydrology

- Irish Coastal Protection Strategy Study: South East coast
- FSU data
- OPW Hydrometrics: Annual Maxima, Gaugings, Q 15min Data, Rating Equations, Staff Gauges Zero, WL 15min Data, Photographs
- EPA Water levels

Meteorology

- Rainfall logger (24hr storage). Daily gauges. (Met Éireann/Data files/Rainfall/Daily Rainfall)
- Rainfall logger (hourly). Synoptic Stations. (Met Éireann/Data files/Rainfall/Hourly Rainfall)
- Evaporation Data. Synoptic Stations (Met Éireann/Data files/Evaporation)
- Pot Evapotranspiration. Synoptic Stations (Met Éireann/Data files/Pot Evapotranspiration)
- Soil Moisture Defective. Synoptic Stations (Met Éireann/Data files/SMD)
- Air Pressure
- Temperature
- Wind Speed and Direction
- Soil temperature
- Rainfall Radar
- Met Éireann Spatial files

Geo-referenced Data

- Development and Local Area Plans
- Historical Flood data
- NDHM (5m resolution IfSAR)
- hDTM (20m resolution hydrologically corrected DTM) (EPA-20m hDTM/Disc 2-South Eastern RBD)
- OSi Maps
- LiDAR
- Aerial photography
- OPW Channels
- OPW Embankments
- OPW Benefiting Lands
- Lakes (Lakes/HA_15)
- River Centrelines

Other

- PFRA Access Database (110310_Final Database)
- floodmaps.ie Registered User log in details
- Contact list of Data Owners
- National Pluvial Screening Project for Ireland report
- PFRA Groundwater Flooding report
- PFRA Tables
- Defence Asset Database
- Operation Instructions for Flood Defences, Hydraulic Structures
- Existing Survey Data from existing studies
- Existing Studies Models and Reports
- Existing Low Flow/ Water Quality Studies Models and Reports

Following an initial review of the received data, further requests were made to the appropriate Local Authorities and other organisations via email and also at meetings, either at their offices or at the various project meetings. A summary of the range of data requests made by RPS between July 2011 and January 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 obtain additional data in specific areas.

Immediately upon confirmation of appointment in July 2011, RPS received hydrometric data, levels and flows for all Environmental Protection Agency (EPA) gauging stations within the study area. Details of current rating equations and calibration measurements for these stations were also sought from EPA. No data was available for the two Electricity Supply Board (ESB) stations in South Eastern study area.

At the beginning of August 2011, RPS issued a request to Local Authorities seeking details of all culverted watercourses, storm sewer systems and discharges and any flood defence schemes in GIS or AutoCAD format. Data was received from Offaly and Laois.

At the beginning of August 2011, a request was also submitted to OPW to obtain missing OSI vector mapping tiles. These were received in the same month.

In mid August, requests were made to GSI for soil and groundwater datasets to inform the MIKE-NAM model parameters decision trees and derive model input parameters. These were received in the same month. The actual datasets requested were:

- Groundwater Vulnerability;
- Soil Permeability;
- Well Drained / Poorly Drained Soils;
- Aquifer Type.

At the start of September, a request was submitted to OPW seeking:

- Re-supply of the National Digital Height Model data as some of the original information was for the wrong area. These were received in the same month. ;
- Details of the Gauging stations, this information was received;
- Feasibility study reports or design reports / drawings that OPW held for any of the schemes listed in the tender documents.

At the beginning of October RPS made a number of data requests to OPW in relation to orthophotography. The data was received in the same month.

Further requests were made to EPA and Met Éireann during September in relation to data gaps within gauging station data previously received. The data was received.

In the middle of October, RPS issued requests to EPS Ireland (consultants managing rain gauges on behalf of some Local Authorities) and Teagasc for any rainfall data they held. The data was received from Teagasc.

At the end of October a request was submitted, and data received, from JBA Consulting for GIS layers relating to the survey contract for Hydrometric areas 12, 14 and 15. Also at this time RPS requested and received 2,500, 5,000 and 1,000 OSi vector mapping datasets and additional missing Orthophotography data from OPW.

In early November, RPS requested, and received, information on the electrical infrastructure data across Ireland from ESB. RPS also made a further request to OPW for missing OSi Vector mapping tiles that had been omitted from the previous resupply at the end of October, these were received. RPS also issued a request to all of the Local Authorities asking them to review the list of previously supplied rainfall gauging stations within their administrative areas and advise RPS regarding:

1. Whether they were aware of additional stations to those listed; and
2. If so, to provide:
 - a. Station name;
 - b. Location (coordinates);
 - c. Type – daily / hourly;
 - d. All available data.

Data was received from Laois County Council, South Tipperary County Council, Waterford City Council and Wexford County Council.

During November a request was issued to Met Éireann for missing rainfall data for the meteorological stations in the study area that had been identified through a review of the previously supplied data. This data was received.

Finally, at the beginning of December, RPS sent a final data request to each Local Authority seeking any out-standing information on the following topics that they were aware of or held:

Flood Relief/Risk Management Measures

- Previous reports or studies concerning flood hazard or risk or possible flood relief measures;
- Information on current flood risk and water management measures or practices;
- Information on other flood-related matters undertaken under other national programmes or other EU directives.

Historic Flood Data

- Information on historic flooding;
- Maps of flood extents;
- Flood levels;
- Flood depths;
- Causes or mechanisms of flooding;
- Resulting damage.

Hydrometric Data

- Information on recorded water levels and tidal data, flows, flow gaugings and ratings (stage-discharge relationships).

Meteorological Data

- Information on rainfall, air pressure, wind speed and direction, temperature and evapo-transpiration.

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

- Information concerning existing development and possible future development;
- Local area plans, town plans, master plans.

Defence and Coastal Protection Asset Data

- Information in relation to the location, type, ownership, design and/or actual performance standard, and condition of these assets.

Existing Survey / Geotechnical Data

- Topographical, channel, structural or geotechnical survey data collected for previous flood relief studies or other construction projects e.g. main drainage or sewer projects.

Environmental Data

- Information, reports, studies, zoning or assessments of environmental and archaeological status, issues, constraints and impacts.

Other Receptor Data

- Data on flood risk receptors, including types and locations such as property types, utility and transport infrastructure, national monuments and protected structures, hospitals, schools etc.

Urban Drainage

- Culverted Watercourse - extents / locations / inlets and outlets;
- Diverted Watercourses;
- Outfalls;
- Storm Water Infrastructure Records.

Other

- Aerial photography of flooding.

This request was implemented by forwarding to each Local Authority a tailored document which stated the study data requirements and also the data currently held by RPS for their area. In this request, Local Authorities were asked to either forward any other relevant data they held in relation to each of the data requirement headings or confirm that they had no further information. This was classified as being the final data collection cut-off date for Local Authority data, however as RPS go through the various stages of the South Eastern CFRAM study, further data needs may be identified and therefore the information will be requested and obtained.

Finally at the beginning of January a request was made to the National Roads Authority for their most recent version of their Road Network dataset. This data was received. A request was also made to OPW to obtain the WFD Gauged Catchment Outlines for Hydrological Areas HA11, 12, 13, 14, 15, and 17. This data was received.

In all cases every request for information was logged into the Data Request Register and followed up with further emails and phone calls as appropriate.

2.2 DATA MANAGEMENT AND REGISTRATION

When 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 a piece of Safe Software called FME (Feature Manipulation Engine). 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, dataset name, date received) e.g. Kilkenny_Zoning_110801, 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 '6.0 Spatial data', 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

2.3.1 Flood Relief / Risk Management Measures

Following a number of data requests as outlined in Section 2.1, RPS has received details of flood relief and management measures within HA15 from Laois County Council.

All scheme and feasibility reports received by RPS were reviewed to identify relevant information for the purposes of the South Eastern CFRAM Study. A summary of the various reports reviewed is provided in Table 2.1, 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 2.1: Summary of reviewed reports

Flood Relief Study	River Name	Report Name	Author	Date	Recommendations
Mountrath	Mountrath River	Photographs of area	Laois CC	18 January 2008	Photographs of flooding in the area as well as a short video
Mountrath	Mountrath River / River Barrow / River Nore SAC	Ecological Impact Assessment of proposed maintenance works on a stretch of the Mountrath River at Mountrath, Co. Laois	ecofact environmental engineers	25 August 2008	Broadly recommends to cut back overgrown trees, remove fallen trees and other obstructions from the river and create a compound channel in a number of discrete areas to increase the conveyance capacity of the channel. It is also recommended that two ornamental weirs be removed from the river as these are affecting runoff and also potentially acting as barriers to movements of brook lampreys in the river.
Mountrath		Extract from Laois County Council Draft County Development Plan (2012 – 2018)	Laois CC		Extract from the Draft Development Plan outlining flood area surrounding Mountrath
Thomastown	Nore	Thomastown Weir Amenity Restoration. Final Options Report	JBA Consulting	October 2010	The preferred option is a development of Option 3d, which uses a rock ramp construction to repair the breach section, instead of a traditional weir construction, and will include restoration of the rest of the weir. The rock ramp would be modified from a typical form of construction (as at Lacken Weir) and would consist of a staged channel, constructed as a series of pools with linking constrictions, or throats. The design would include: A moderate flow passage (to take approximately the 95 percentile flows, in this case 5.7 m ³ /s) which would be 5-7m wide and approximately 250-300mm deep; Within the moderate flow passage, a low flow channel with a width of approximately 2-3m; Pools, which would provide

Flood Relief Study	River Name	Report Name	Author	Date	Recommendations
					resting places for migratory fish, of 10-15m width and depths of up to 1m; During high flows water would be passed over the full width of the weir crest. A water management system will also be included in the design, which will allow a head of water suitable for swimming to be maintained in the pool area, whilst providing for a reduction in crest height, making it more suitable for the passage of migratory species. Having demonstrated the feasibility of the preferred option, further analysis will be required before entering the planning process to meet the requirements of NPWS and SRFB. This will include the refinement of the hydraulic model developed by JBA, and the potential construction of a physical model.

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, 20 historical events were identified that had led to flooding within AFAs situated in HA15 during the period 1763 to 1997 as detailed in Table 4.8. 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 South Eastern CFRAM study area. The mapping which has been supplied by OPW includes the following datasets:

- SERBD Digicity10000 Raster;
- SERBD Digitowns 10000 Raster;
- SERBD OS MAP 5000 Raster;
- SERBD OS MAP 5000 Vector;
- SERBD OS MAPS 1000 Vector;
- SERBD OS MAPS 1000Raster;
- SERBD OS MAPS 50000 Raster;
- SERBD Six Inch Tiles;
- Orthophotography (Raster);
- SERBD OS Map 2500 Vector.

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. During the conversion process it was discovered that complete spatial coverage had not been included in the original OPW data supply. Consequently, additional 2500 vector mapping was requested. Again this information was also provided in AutoCAD format which had to be converted into ArcMap shapefile format for use within this study.

2.3.4 Hydrometric Data

Details of the hydrometric data available for HA15, and the analysis of this data are presented in Section 4.1. In summary, 65 hydrometric stations (14 OPW and 51 EPA) were identified as being, or

having been, operational within HA15. However, of these only 21 have data available for use and only 15 are located along watercourses to be modelled as part of the South Eastern CFRAM Study and will consequently be the primary stations used to inform the hydrological analysis and derivation of flows for standard Annual Exceedance Probabilities. The six stations not on modelled watercourses will be used within pooled flood frequency analysis for the derivation of growth curves and may be used in adjusting flow estimations from ungauged catchment descriptors.

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.

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 2.3.9.

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;

Laois County Council

- Development Boundaries
- Zoning Areas 2006
- Zoning Areas 2011-2017
- Map 2.3 Mountrath (map of zoning categories in Mountrath from draft County Development Plan 2012 – 2018)

The current Laois County Council Development Plan covers the period 2011 to 2017 and so the above development zoning information will not be updated during the lifetime of the study.

Kilkenny County Council

- Zonings

The current Kilkenny County Council Development Plan covers the period 2008 to 2014 so the above development zoning information may be updated for the next County Development Plan for the period 2015 - 2021.

No planning or development information is required from Carlow, Offaly, Laois, North Tipperary or South Tipperary as there are no AFAs within the parts of the HA15 catchment lying within these Local Authority districts.

2.3.8 Environmental Data

RPS has identified a preliminary list of datasets and sources as indicated in Table 2.2 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 2.2: 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).	www.npws.ie RPS has access
Biodiversity, Flora and Fauna	Relevant Freshwater Pearl Mussel Sub-basin management plans (if relevant).	www.npws.ie RPS has access
Biodiversity / Flora and Fauna	Invasive species, threatened species, protected species.	www.biodiversity.ie Free to download
Biodiversity / Flora and Fauna	Waterways Ireland ecological, invertebrate, kingfisher, Japanese Knotweed, otter and lamprey surveys	RPS has received relevant WWI data

SEA Issue Area	Data	Availability
Water/Biodiversity/Flora and Fauna	Inland Fisheries Ireland - South Eastern Area Species present, counts etc., Fisheries assessments if available.	www.fisheriesireland.ie On request
Water / Material Assets	Waterways Ireland databases;	www.waterwaysireland.ie 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	www.heritagecouncil.ie Free to download
Cultural Heritage	Record of Monuments and Places;	www.archaeology.ie RPS has access
Cultural Heritage	National Inventory of Architectural Heritage (NIAH)	www.buildingsofireland.ie Free to download
Cultural Heritage	Waterways Ireland heritage information (including Barrow Line and Barrow navigation)	RPS has received relevant WWI data
Material Assets	Coillte forestry database (FIPS)	www.coillte.ie Will request
Soils / Geology	Geological Survey of Ireland (GSI) mapping, including groundwater maps; groundwater vulnerability, protection schemes; soils classification.	www.gsi.ie RPS has access
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 but full dataset expected in March 2012	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

SEA Issue Area	Data	Availability
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	3 Rivers Data: DTM, historical mapping etc.	RPS has access
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, rather such data is much better requested only when it is required. Consequently, RPS will maintain contact with the relevant data owners as the project develops 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 have obtained the following datasets:

- Bedrock and SG Aquifers Union;
- Soils – Wet and Dry;
- Sub soil 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 information held on existing flood defence and coastal protection assets has provided very limited information for assets within HA15. The limited information obtained to date will be supplemented as further assets are identified and relevant geometric data collected through the Nore 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 has made one final request for missing information / data from each of the Local Authorities. The requests were made at the beginning of December 2011 via email and each Local Authority was forwarded a tailored document outlining study data requirements and also the information / data that has been received to date from them or from OPW which covers their administrative areas. Within the document under each of the requirement headings, Local Authorities have been requested to either provide any additional information they feel appropriate for the South Eastern CFRAM Study or confirm that they have no further information. Also detailed in this document is information that has previously been requested but not yet provided. The cut-off point for data collection activities was 1st February 2012, i.e. the date of preparation of the first draft of this report. A breakdown of requirements where no information has been received from each local authority is detailed below:

Kilkenny County Council

- Flood Relief/Risk Management Measures;
- Historic Flood Data;
- Hydrometric Data;
- Meteorological Data
- Planning & Development Information;
- Flood Protection Asset Data;
- Existing Survey / Geotechnical Data
- Aerial Photography of flooding

2.5 DATA GAPS

At present RPS has not confirmed any significant data gaps that will impact on the completion of the South Eastern CFRAM Study. However this statement is made without having received any survey information or having fully established how much of the remaining data requested from the Local Authorities, outlined in the preceding section, is not available. 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. Thus it is not possible at this point in

time to categorically state that there are no data gaps which will impact in some way on the completion of the South Eastern CFRAM Study.

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 2.3 below.

Table 2.3: 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 2.3.2 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 HA15 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	Some of the Planning and Development datasets received where not the latest revision of the County's Development Plans and therefore a

	Information	request was made to obtain their most recent datasets, which depict the zoning areas required by RPS. This is further detailed in 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 Flood Defence Assets.

2.6 CONCLUSION

In conclusion RPS has made every attempt to identify and obtain data that is valid and of good quality for use within the South Eastern CFRAM Study. Requests have been issued and tracked in order to try and obtain as much relevant information as possible. The complete process of requesting and obtaining information has been recorded and logged within the various Request and Incoming Data registers. Reports and spatial data have been reviewed to ensure they relate to the South Eastern CFRAM study area and that they provide beneficial information for the project. During this process RPS identified a few datasets which were not fit for purpose for the project as they were out of date consequently RPS sourced and acquired the most up-to-date versions of such datasets.

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 South Eastern 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 has prepared documentation to procure a survey contract for HA15. This pre-contract survey contract (known nationally as SC4) encompasses the full channel cross-sections, details of hydraulic structures and geometric survey of defences for HA12, 14 and 15. The contract was advertised through e-tenders and OJEU on 4 November 2011 with tenders returned in December. JBA completed tender evaluation and a preferred bidder was identified. The OPW issued a letter of intent on 15 February 2012 with surveys expected to start on site in April/May 2012.

Following completion of the Flood Risk Review and subsequent delineation of all watercourses within AFAs to optimise the quantity of rivers to be surveyed, RPS proposed a substantial reduction in the length of the rivers specified in SC4. Further to this, RPS identified that the quantity of cross sections removed from SC4 was equivalent to that proposed for the survey contract covering HAs 11, 13 & 17. RPS therefore proposed to OPW that these two contracts could be merged, thus offering a time and cost saving and additionally providing CCS with a contract of the magnitude of which they originally tendered. This proposal was accepted by OPW and subsequently CCS were awarded a contract covering the whole of the South Eastern CFRAM Study area.

3.2 FLOOD DEFENCE ASSETS

The identification of flood defence assets is a requirement of the HA15 survey contract and thus at present RPS have not established a definitive list of flood defence assets. However the locations of the flood defence assets identified by JBA Consulting during the survey scoping site visits are indicated in Figure 3.1 and listed in Table 3.1.

Table 3.1: Flood Defence Assets Identified in HA15 Survey Spec.

Name	River Reach	Flood Defence Type	Total Length (m)
Kilkenny	Breaghagh River	Wall	190
Kilkenny	Breaghagh River	Embankment	150
Kilkenny	Nore River	Wall	540
Kilkenny	Nore River	Embankment	1530
Kilkenny	Located along tributary of Nore River. Approx. 4.2km downstream of Kilkenny	Wall	80

3.3 FLOODPLAIN SURVEY

The tender documents indicated that OPW would supply the results of a flood plain survey based on LiDAR techniques by December 2011. RPS has provided input in to the required coverage of this survey based on our initial assessment of AFA locations and extents however delivery of this

information has been delayed and therefore it is not possible to make any comment on the adequacy of the information received for use in later stages of the South Eastern 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.

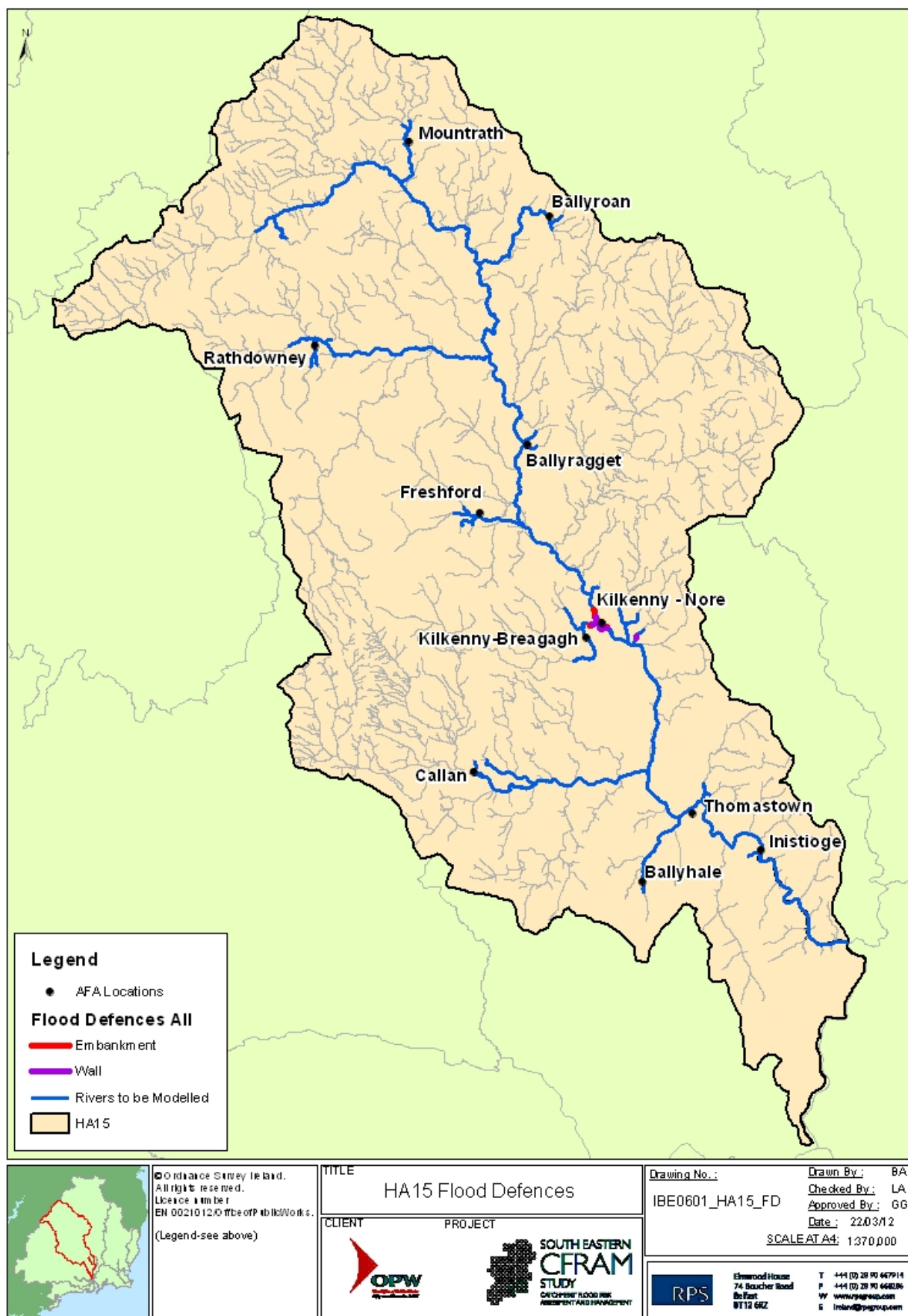


Figure 3.1: Locations of Flood Defence Assets in HA15

4 PRELIMINARY HYDROLOGICAL ASSESSMENT AND METHOD STATEMENT

4.1 HYDROMETRIC DATA

4.1.1 Hydrometric data – HA15

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 South Eastern RBD including Annual Maximum (AMAX) Series data for those stations included in the OPW's Flood Studies Update (FSU). The OPW operate 14 river hydrometric stations within HA15. There are no inactive stations and all stations have data available. Therefore 14 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 HA15

Station Number	Station Name	River/Lake	Records Length
15001	Annamult	Kings	Jan 1972 - Mar 2011
15002	John's Br.	Nore	Nov 1953 - Mar 2011
15003	Dinin Br.	Dinin	Jan 1972 - Mar 2011
15004	McMahons Br.	Nore	Jan 1972 - Mar 2011
15005	Durrow Ft. Br.	Erkina	Jan 1972 - Mar 2011
15006	Brownsbarn	Nore	Jan 1972 - Mar 2011
15007	Kilbricken	Nore	Jan 1972 - Mar 2011
15008	Borris in Ossory	Nore	Oct 1972 - Mar 2011
15009	Callan	Kings	Oct 1972 - Oct 2010
15010	Ballyboodin	Goul	Jan 1972 - Mar 2011
15011	Mount Juliet	Nore	Sept 1945 - Mar 2011
15050	Blackfriar's Br.	Breagagh	Oct 1995 - Dec 2003
15104	Sycamores	Nore	July 2006 – Jan 2011
15105	Archers Grove	Nore	July 2006 – Jan 2011

An additional 51 hydrometric stations are located within HA15 that are owned by Local Authorities (operated by EPA). Hydrometric data is available for 7 of these and has been acquired by RPS. These are listed in Table 4.2. The data provided consisted of flow and level data and rating curves where available.

Table 4.2: Local Authority (EPA) Hydrometric Stations with Available Data in HA15

Station Number	Station Name	River/Lake	Data Available	Records Length
15012	Ballyragget	Nore	Water Level & Flow	Nov 1988 - Sept 2011
15013	Castlecomer	Dinin	Water Level & Flow	Dec 1989 - Oct 2011
15021	Annagh	Delour	Water Level & Flow	Sept 1976 - Sept 2011
15027	Mountrath	Mountrath	Water Level & Flow	Mar 2010 - Aug 2011
15041	Ballinfrase	Goul	Water Level & Flow	July 2001 - Sept 2001
15051	Foulks court Castle	Goul	Flow Measurements	Oct 1972 – Feb 2011
15053	Derryduff	Nore	Water Level & Flow	Feb 2002 - Sept 2011

The remaining 44 Local Authority (EPA) hydrometric stations have no continuous monitoring data available. Thirty eight of these stations are staff gauge only sites, and therefore only spot measurements were taken at these sites in the past and usually for one-off projects related to control of water pollution. Therefore in total, 21 hydrometric stations (14 OPW / 7 Local Authority (EPA)) located in HA15 have data available for use within this Study.

Each of the 21 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. Nineteen of the 21 hydrometric gauges have flow data available that has been derived from continuous water level data using this methodology. The other two 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 21 stations listed in Table 4.1 and 4.2, 12

were included in the FSU review and had a classification assigned as shown in Table 4.3. A definition of the rating quality classification is provided below the table.

Table 4.3: Final Station Rating Quality Classification

Station Number	Station Name	Final Station Rating Quality Classification
15001	ANNAMULT	A2
15002	JOHN'S BR.	A2
15003	DININ BR.	A2
15004	MCPAHONS BR.	A2
15005	DURROW FT. BR.	A1
15006	BROWNSBARN	A2
15007	KILBRICKEN	A2
15009	CALLAN	B
15011	MOUNT JULIET	C
15012	BALLYRAGGET	B
15021	ANNAGH	C
15050	BLACKFRIAR'S BR.	C

- **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

Figure 4.1 shows all 65 hydrometric stations within HA15. The 21 for which data is available are coloured green (water level and flow data), yellow (water level data only) or purple (flow measurements). Those which have additional data from the FSU work, including AMAX series are also highlighted. All 21 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 are also useful in calibration exercises. Recorded water levels are useful in comparing hydraulic model outputs with observed flood events. AMAX series of water levels and derived AEPs can also be useful in hydraulic model calibration of water levels for various design AEPs.
- Stations with water level and flow data within the wider HA15 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.

In addition to the 65 stations within HA15, additional stations outside of the catchment will be used where appropriate to supplement the data from within the catchment. Stations from outside the catchment will be used for the following purposes:

- Stations within the Eastern and South Eastern CFRAM Study areas with a sufficient quality of data will be used to form a study specific pooling group from which additional gauge years will be used to provide a sufficient amount of gauge years for pooled flood frequency analysis and growth curve development.
- Where small to medium sized catchments ($<100\text{km}^2$) are ungauged, Pivotal Sites from outside HA15 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.
- Gauge review data share with Suir CFRAM Study.



Figure 4.1: Hydrometric Stations in HA15

4.1.1.1 Hydrometric Stations along modelled watercourses

There are 15 hydrometric stations along the rivers to be modelled as Medium or High Priority Watercourses (MPW or HPW). These are shown on Figure 4.2. Thirteen of these stations have water level and flow data, whilst two have level data only. Ten of these stations were included in the FSU which is also indicated on Figure 4.2.



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

4.1.1.2 Rating Reviews – South Eastern 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 South Eastern CFRAM Study brief to undertake further rating review of a subset of hydrometric stations. This entails using hydraulic modelling techniques to extrapolate rating curves where high flow gaugings are lacking to construct a theoretical rating curve that provides a relationship between stage and discharge for flood flows. Two hydrometric stations have been specified for this analysis within HA15 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 4.4.

Table 4.4: Existing Rating Quality Classification for Rating Review Stations in HA15

Station Number	Station Name	Final Station Rating Quality Classification
15006	BROWNSBARN	A2
15011	MOUNT JULIET	C

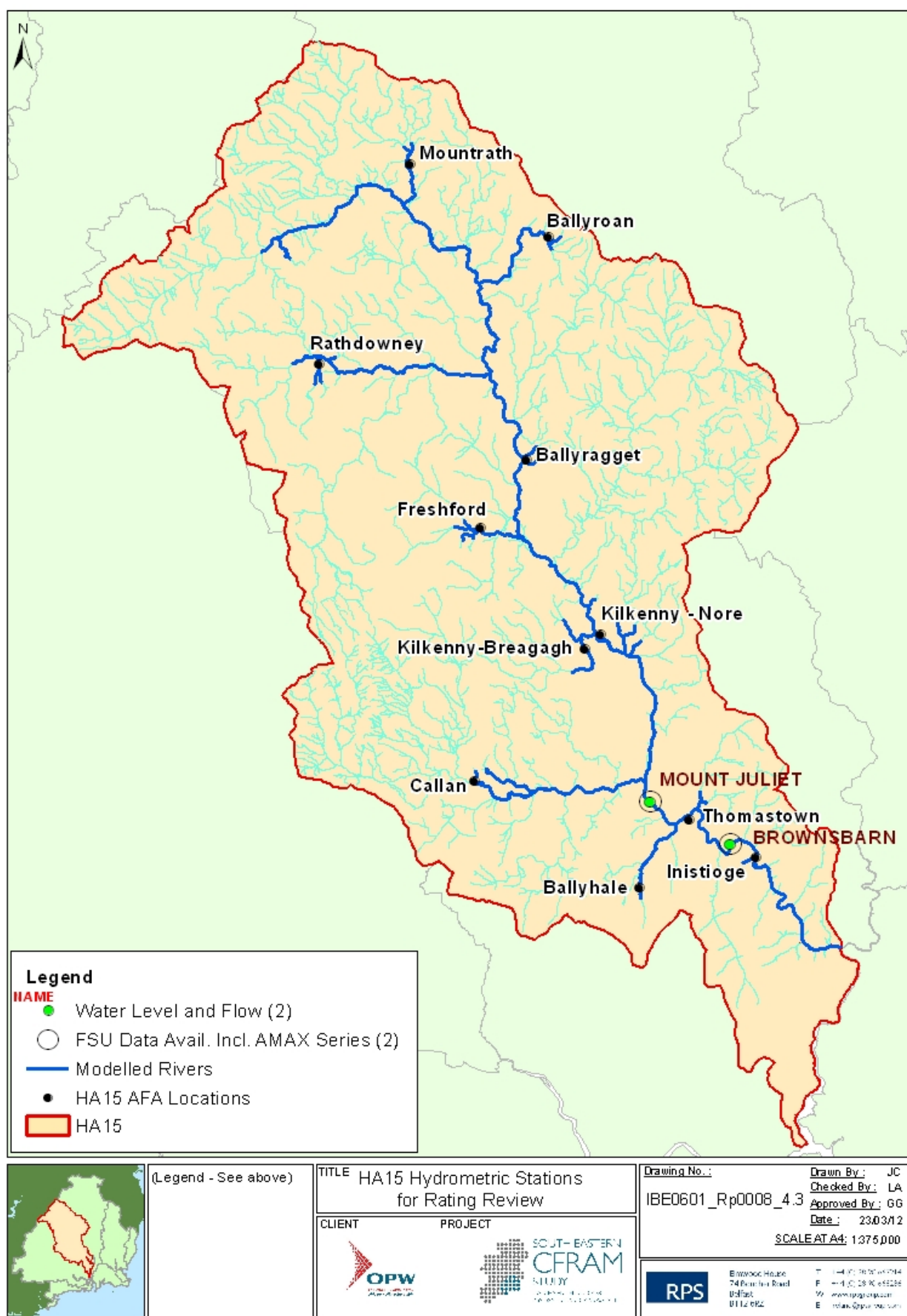


Figure 4.3: Hydrometric Stations used for rating review in HA15

4.1.1.3 Summary of Hydrometric Data

Table 4.5 summaries the number of hydrometric stations with data available within HA15 overall, and those located on modelled watercourses only. Two of these stations require CFRAMS rating review, all of which have water level and flow data available.

Table 4.5: Number Summary – HA15 Stations with Data Available

Data Available	HA15	HPW/MPWs	CFRAM Rating Review
Water Level and Flow	18	13	2
Water Level Only	2	2	0
Total	21	15	2

Table 4.6 provides a more detailed summary of the type of data for each of the 21 usable Hydrometric Stations within HA15 that has been collected for the South Eastern CFRAM Study. The 15 stations that are located on the watercourses to be modelled are highlighted in blue.

Hydrometric Station Data Status Tables for HA15 are provided in Appendix A.

Table 4.6: Summary of Hydrometric Data Provision within HA15

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/MP W	CFRAMS RATING REVIEW
15001	Annamult	Office of Public Works	Active	Water Level and Flow	Jan 1972 - Mar 2011	N	Y	Y	Y	Y	N
15002	John's Br.	Office of Public Works	Active	Water Level and Flow	Nov 1953 - Mar 2011	N	Y	Y	Y	Y	N
15003	Dinin Br.	Office of Public Works	Active	Water Level and Flow	Jan 1972 - Mar 2011	N	Y	Y	Y	N	N
15004	McMahons Br.	Office of Public Works	Active	Water Level and Flow	Jan 1972 - Mar 2011	N	Y	Y	Y	Y	N
15005	Durrow Ft. Br	Office of Public Works	Active	Water Level and Flow	Jan 1972 - Mar 2011	N	Y	Y	Y	Y	N
15006	Brownsbarn	Office of Public Works	Active	Water Level and Flow	Jan 1972 - Mar 2011	N	Y	Y	Y	Y	Y
15007	Kilbricken	Office of Public Works	Active	Water Level and Flow	Jan 1972 - Mar 2011	N	Y	Y	Y	Y	N
15008	Borris in Ossory	Office of Public Works	Active	Water Level and Flow	Oct 1972 - Mar 2011	N	Y	Y	N	Y	N
15009	Callan	Office of Public Works	Active	Water Level and Flow	Oct 1972 - Oct 2010	N	Y	Y	Y	Y	N
15010	Ballyboodin	Office of Public Works	Active	Water Level and Flow	Jan 1972 - Mar 2011	N	Y	Y	N	N	N
15011	Mount Juliet	Office of Public Works	Active	Water Level and Flow	Sept 1945 - Mar 2011	N	Y	Y	Y	Y	Y

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/MP W	CFRAMS RATING REVIEW
15012	Ballyragget	Kilkenny County Council	Active	Water Level and Flow	Nov 1988 - Sept 2011	Y	Y	Y	Y	Y	N
15013	Castlecomer	Kilkenny County Council	Active	Water Level and Flow	Dec 1989 - Oct 2011	Y	Y	N	N	N	N
15021	Annagh	Laois County Council	Active	Water Level and Flow	Sept 1976 - Sept 2011	Y	Y	N	Y	N	N
15027	Mountrath	Laois County Council	Active	Water Level and Flow	Mar 2010 - Aug 2011	N	N	N	N	Y	N
15041	Ballinfrase	Laois County Council	Active	Water Level and Flow	July 2001 - Sept 2001	Y	Y	N	N	N	N
15050	Blackfriar's Br.	Office of Public Works	Active	Water Level and Flow	Oct 1995 - Mar 2011	N	Y	Y	Y	Y	N
15051	Foulkscourt Castle	Kilkenny County Council	Inactive	Flow Only	Oct 1972 - Dec 2003	N	N	N	N	N	N
15053	Derryduff	Laois County Council	Active	Water Level and Flow	Feb 2002 - Sept 2011	Y	Y	N	N	Y	N
15104	Sycamores	Office of Public Works	Active	Water Level Only	July 2006 - Jan 2011	N	N	N	N	Y	N
15105	Archers Grove	Office of Public Works	Active	Water Level Only	July 2006 - Jan 2011	N	N	N	N	Y	N

4.2 METEOROLOGICAL DATA

Meteorological data was provided by Met Éireann through the OPW at the project outset. A gap analysis was undertaken and additional data acquired from Met Éireann directly by RPS. Additional rainfall data was also requested from Local Authorities if available. Further development of the hydrological analysis method required rainfall radar data at Dublin Airport (refer to Section 5.1.3 for detail). Radar data was requested and received from Met Éireann.

4.2.1 Daily Rainfall Data

Daily rainfall data was received from Met Éireann for a total 837 rainfall gauges both within and beyond the South Eastern CFRAM Study Area. Additional information was also provided by Wexford County Council for one further station (Mayglass) giving a total of 838 daily rainfall gauges that are available for the Study. Table 4.7 summarises the number of available daily rainfall stations for the Study.

Table 4.7: Number of Available Daily Rainfall Stations

	Provided By:		Total
Station Location	Met Éireann	Local Authorities	
Within South Eastern CFRAM Study Area Only	323	1	324
Within South Eastern CFRAM Buffer Area Only	514	0	514
Within South Eastern CFRAM Study Area plus Buffer	837	1	838

A total of 324 of the daily rainfall stations are located within the South Eastern CFRAM Study Area. An additional 514 are located beyond the Study area boundary as shown in Table 4.7 and Figure 4.4. These additional stations 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).

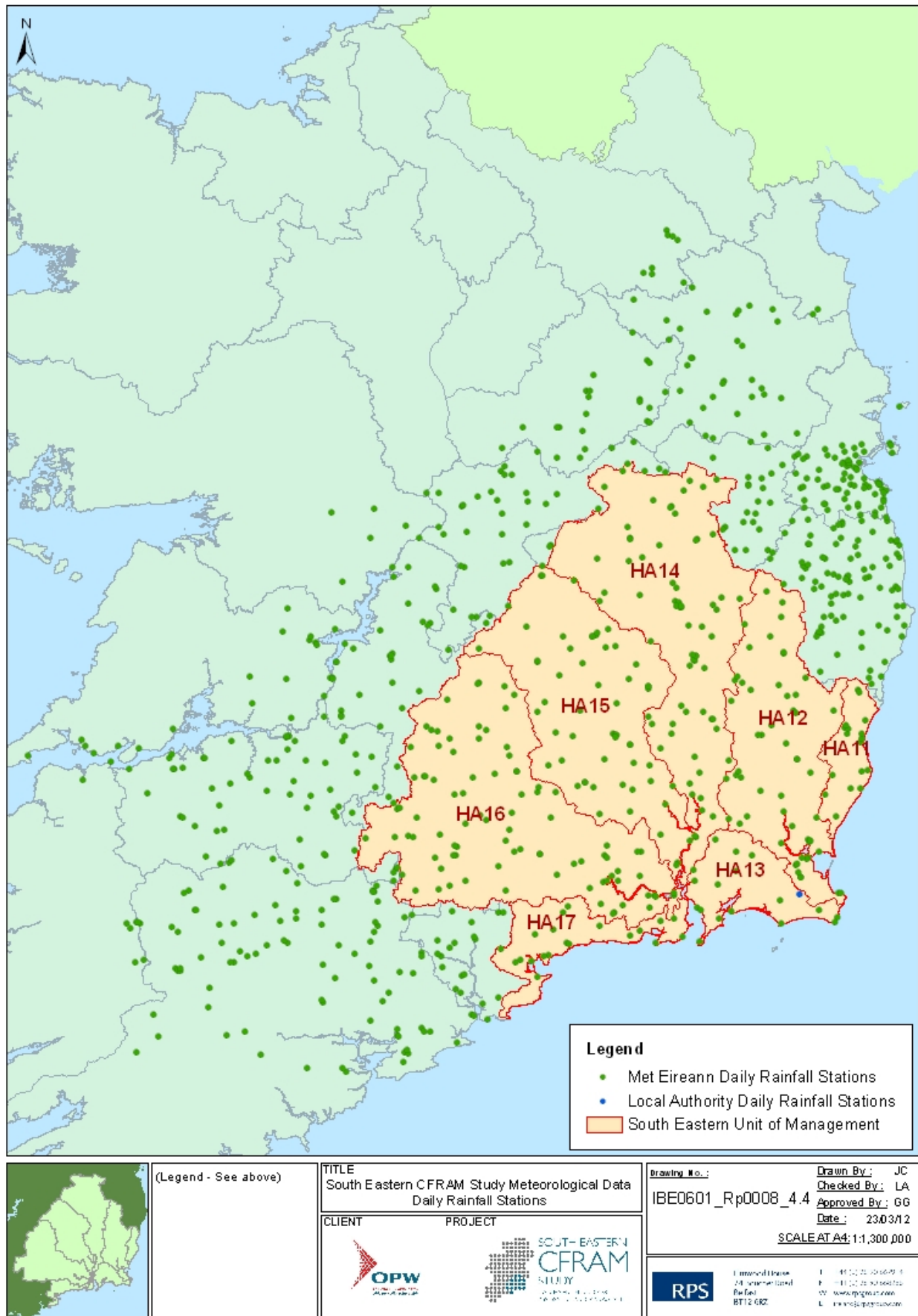


Figure 4.4: Location of Daily Rainfall Gauges

Within HA15 there are 55 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 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 provided for each station.

4.2.2 Hourly Rainfall Data

Data for hourly rainfall stations was also provided by Met Éireann. A total of 15 hourly rainfall gauges were provided. Their location is shown in Figure 4.5. Kilkenny rainfall station is located within HA15. 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. Pending the outcome of trials within the Eastern CFRAM Study area this analysis approach may be rolled out to the South Eastern CFRAM Study area in which case additional rainfall radar data will be requested including:

- Hourly precipitation accumulation (PAC) data of the Dublin and Shannon radar on a 1 x 1 km grid (from 1997)
- 15 minute Pseudo-CAPPI (PCR) data of the Dublin and Shannon radar (from 1997)
- Plan Position Indicator (PPI) data of the Dublin and Shannon radar (from 1997)

If following the trials on the use of the rainfall radar data it is decided not to use it then hydrological input data for rainfall run-off modelling will be taken from the rainfall gauge stations only.

4.3 HISTORICAL FLOOD EVENTS – SOURCES OF INFORMATION

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

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 HA15. 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 HA15, there is only one catchment – the Nore catchment. The search within the Nore catchment was sub-divided into 33 separate searches, one for each river or stream within the catchment.

Internet Search Engines

In some instances, it was felt it may be useful to supplement the information gathered from the OPW National Flood Hazard Mapping website. This was especially the case for more recent flood events such as the August 2008 event. There were some reports available for these events on the OPW website (primarily from Local Authorities); however there was a lack of press reports when compared to floods which had occurred pre-2005.

A wider search for information on the more recent flood events was carried out for each Area for Further Assessment (AFA) in HA15 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, annual exceedance probabilities (AEPs), etc.

4.3.1 Hydrometric Data

In conjunction with historical data researched as described above, hydrometric data from the EPA Hydronet website (<http://hydronet.epa.ie>) and the OPW Hydro-Data website (<http://www.opw.ie/hydro>) was consulted, where available. These websites include data such as recorded water levels and corresponding flow rates, quoted in some instances as mean daily flows, while in other instances, the peak flow for the flood event is available. This data was used to verify and supplement the historical data, such as dates of floods, river levels and flows.

Active hydrometric stations with recorders are located in/near Mountrath, Ballyragget, Kilkenny, Thomastown Callan and Inistioge AFAs and Borris In Ossory (not at AFA but the River Nore running through this town is a medium priority watercourse. It should be noted that flood relief works were carried out in the vicinity of John's Bridge Hydrometric Station, in Kilkenny, between 2001 and 2005. Therefore hydrometric data from this station, and also from downstream stations near Thomastown and Inistioge, from before and after the dates of the flood relief works may not necessarily be consistent, and care should be taken where comparing data from different flood events.

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 HA15 are summarised in Table 4.8.

Table 4.8: Summary of Historical Flood Events for each AFA

Event	Mountrath	Ballyroan	Ballyragget	Freshford	Kilkenny	Callan	Thomastown	Inistioge	Ballyhale	Borris in Ossory (MPW)	Rathdowney
Nov-2009							✓	✓			
Aug-2008	✓				✓		✓				
Mar-2008	✓										
Jan-2008							✓	✓			
Nov-2006					✓						
Oct-2006					✓						
Nov-2005					✓						

Event	Mountrath	Ballyroan	Ballyragget	Freshford	Kilkenny	Callan	Thomastown	Inistioge	Ballyhale	Borris in Ossory (MPW)	Rathdowney
Oct-2004						✓					
Nov-2002					✓						
Nov-2000			✓		✓		✓	✓	✓		
Nov-1997					✓						
Jan-1996					✓	✓	✓	✓			
Jan-1995			✓		✓	✓	✓				
Feb-1990			✓	✓	✓	✓					
Aug-1986			✓	✓	✓	✓					
Jan-1984					✓						
Dec-1979					✓						
Dec-1978					✓						
Jan-1974					✓						
Jan-1969							✓				
Dec-1968	✓				✓						✓
Nov-1965							✓				
Dec-1960					✓	✓	✓	✓			
Oct-1954					✓	✓	✓				
Mar-1947				✓	✓	✓	✓	✓			
Aug-1946					✓						
Mar-1933					✓						
Nov-1931					✓						
Jan-1926					✓		✓				
Oct-1763					✓		✓	✓			

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.

It should be noted that for Borris in Ossory and Ballyroan, the only details of flooding that were found during the historical review process (on www.floodmaps.ie) related to recurring floods. In Borris in Ossory, low lying lands at Townparks and at Moneymore are regularly affected after heavy rainfall, while in Ballyroan, roads regularly get flooded due to overflowing streams.

4.3.2.2 Flood Event of November 2009

The review indicated that flooding occurred in Thomastown and Inistioge on 19th November 2009. It was reported in a Seanad Éireann Debate (Vol. 198 No. 7) on 25th November 2009 (<http://debates.oireachtas.ie>) to be the worst flooding in Thomastown for 41 years. Photos found on

www.flickr.com indicate flooding of low lying lands and roads in Thomastown while the Kilkenny People reported that all of the properties on the Green in Inistioge suffered water damage. At Brownsbarn hydrometric station between these two AFAs, the peak flow measured during this event was $396\text{m}^3/\text{s}$.

While a peak flow of $352\text{m}^3/\text{s}$ was measured at John's Bridge hydrometric station in Kilkenny (as per <http://www.opw.ie/hydro>), press reports state that the recently constructed flood relief scheme defended the city against flooding.

4.3.2.3 Flood Event of August 2008

Aerial photographs were found on www.floodmaps.ie during the review process, which indicated that flooding occurred in Mountrath, Kilkenny, and Thomastown on 16th August 2008. At the Kilbricken hydrometric station downstream of Mountrath, a peak level of 87.62mOD (Malin Head) was recorded with an estimated peak flow of $365\text{m}^3/\text{s}$ (<http://www.opw.ie/hydro>). This was the 5th highest flood level since the station's establishment in 1953. An aerial photo was taken to show the flooding in the Mountrath area; however as the flood level had dropped by 1.11m when the photo was taken, the extents of the flooding are not clear.

Aerial photos were taken to show the extents of the flooding in Kilkenny City. However, as the flood level at John's Bridge hydrometric station had dropped by approximately 0.7m from its peak level before the photos were taken, and by approximately 0.5m at Blackfriar's Bridge hydrometric station, the extents of the flood are not clear. A peak flood level of 43.252mOD (Malin Head) was recorded at John's Bridge hydrometric station, where the estimated peak flow was $350\text{m}^3/\text{s}$ as per <http://www.opw.ie/hydro>.

Aerial photos of Thomastown were also found depicting flooding of low lying land adjacent to the river. It is not clear if roads or houses were flooded as the flood level had dropped by approximately 1.27m from its peak prior to the photo being taken. The peak flood level recorded at the Brownsbarn hydrometric station downstream of Thomastown was 7.94mOD (Malin Head), as per <http://www.opw.ie/hydro>.

4.3.2.4 Flood Event of March 2008

Review of the historical data on www.floodmaps.ie indicated that flooding occurred in Mountrath on 31st March 2008 when the White Horse river overflowed. A report on this event (Reference 6) estimates that the AEP for this flood event is between 12.5% and 33.3%. Localised flooding occurred at areas on the right bank of the Whitehorse River and between Patrick Street and the GAA grounds, while it was indicated that 6 houses were flooded on Patrick Street up to a depth of 600mm.

4.3.2.5 Flood Event of January 2008

Review of the historical data indicated that a flood event occurred on 10th January 2008 in Thomastown and Inistioge. A letter written by Kilkenny County Council dated 3rd March 2008, found on the www.floodmaps.ie website reported that at the Met Eireann weather station in Kilkenny, 33.6mm of heavy rain fell mainly during a 12 hour period on 9th-10th January and caused the Nore to burst its banks.

In Thomastown, photos found on www.floodmaps.ie indicate flooding near the Quay, the Castle, the library and nearby areas. The Kilkenny County Council letter reported that three private houses, two commercial premises and a local library were flooded. Marshes Street and a section of the R700 had to be closed. Marshes Street car park was flooded resulting in a number of cars being flooded. A sewage pumping station was flooded for 24 hours resulting in sewage overflowing to the river. A weir on the river upstream of Thomastown was also damaged where it appears that a section of it was washed away, causing the water level to drop upstream of the weir. No information on flows or levels was available.

In Inistioge, the R700 was flooded. Flood gates saved several houses from flooding except one house, where the gate was not put in place on time. The quay area was flooded to a depth of 300mm.

4.3.2.6 Flood Event of November 2006

The historical data on www.floodmaps.ie indicated that flooding occurred in Kilkenny on 15th November when the Breaghagh River overflowed, following a rainfall of 40mm in a 24 hour period. Approximately a dozen houses near the Circular Road, with floor levels of 53.846mOD or greater, were flooded for a period of approximately 4 hours (Reference 7). Water was 750mm above road level at the White Bridge. A mean daily flood level of 44.6mOD (Malin) was recorded at Blackfriars Bridge Hydrometric Station on 16th November (as per <http://www.opw.ie/hydro>) – the peak flood level was not available on the website for this event.

4.3.2.7 Flood Event of October 2006

The historical review indicated that a flood event occurred in Kilkenny on 26th October following 25mm of rainfall over a twenty-four hour period. Prior to this rainfall event the ground was already saturated due to previous rainfall. The Breaghagh River burst its banks and lands were flooded at Water Barrack Road Sports Pitch and at Circular Road in the Robertshill area. The water level came to within 290mm of houses at Circular Road which have floor levels of 53.846mOD or greater (Reference 7). A daily average flood level of 44.53mOD (Malin) was recorded at Blackfriar Bridge Hydrometric Station on 26th October as per <http://www.opw.ie/hydro> – the peak flood level was not available on the website for this event.

4.3.2.8 Flood Event of November 2005

The historical review indicated that a flood event occurred in Kilkenny on 2nd November 2005. Although details on the rainfall are not available, increased flows in the Breaghagh River led it to overflow in the Water Barrack Road Sports Pitch area and flood these lands (Reference 7).

4.3.2.9 Flood Event of October 2004

In Callan on 27th October, flooding occurred following a period of heavy rainfall. Photos were found on www.floodmaps.ie depicting extensive flooding of roads, streets, farmland, and property in the area. A peak flood level of 24.97mOD (Malin) and a corresponding peak flow of 129m³/s were recorded at Annamult Hydrometric Station (on King's River, upstream of its confluence with the Nore) on 29th October as per <http://www.opw.ie/hydro>. A peak level of 62.86mOD (Malin) was recorded at Callan Hydrometric Station as per the same website; however there is no corresponding flow rate available.

4.3.2.10 Flood Event of November 2002

Photos were found on www.floodmaps.ie indicating localised flooding outside Kilkenny town on 27th November 2002. The photos show flooding of roads, fields and at least one property in areas such as Brownstown/Castleinch, Cuffesgrange, Circular Road, Kells Road, Bennetsbridge Road, Newpark Lower and Ballynalina. A peak flood level of 45.07mOD (Malin) was recorded at Blackfriar Bridge Hydrometric Station on 27th November as per <http://www.opw.ie/hydro>.

4.3.2.11 Flood Event of November 2000

A press article in the Kilkenny People and a letter from the County Engineer of Kilkenny County Council to the County Secretary, dated 9th November 2000, were found on www.floodmaps.ie during the historical review which indicated that a flood event occurred in Ballyragget, Kilkenny, Thomastown, Inistioge, and Ballyhale on November 2000. The flooding was caused by heavy rainfall causing the River Nore to overflow.

In Ballyragget the flooding occurred when the Nore broke its banks. The N77 near the town was flooded. A daily mean flow of 92.4m³/s was recorded on 7th November at an EPA Hydrometric station in Ballyragget (see <http://hydronet.epa.ie>). This level was noted as being above the upper limit of the gauge on the EPA website.

In Kilkenny, Irishtown, Green Street, Johns Quay, Bateman Quay, St. Canice's Place and Waterbarracks were flooded. Approximately 100 premises were flooded and 24 properties were evacuated by their owners or occupiers during the flood. A peak flood level of 44.9mOD (Malin) was recorded at Blackfriar's Bridge Hydrometric Station on 6th November as per <http://www.opw.ie/hydro>.

References to flooding in Thomastown, Inistioge and Ballyhale on this date were also found. The N9 at Ballyhale was closed. A peak flood level of 8.0mOD (Malin) and a corresponding peak flow of

376m³/s were recorded at Brownsbarn Hydrometric Station on 6th November, as per <http://www.opw.ie/hydro>. No further information was found on the damage caused in these towns.

4.3.2.12 Flood Event of November 1997

A memo dated 3rd December 1997 was found on www.floodmaps.ie during the historical review process, from a Senior Executive Engineer of Kilkenny Corporation to the County Engineer of Kilkenny County Council, which indicated that flooding occurred in Kilkenny following heavy rainfall on 17th November 1997. Houses were flooded at Green Street, Irishtown and Vicar Street. A peak flood level of 45.38mOD (Malin) was recorded at Blackfriar's Bridge Hydrometric Station on 18th November, while a peak flood level of 44.21mOD (Malin) and a corresponding peak flow of 281m³/s were recorded at John's Bridge Hydrometric Station on 18th November, as per <http://www.opw.ie/hydro>.

4.3.2.13 Flood Event of January 1996

Kilkenny, Callan, Thomastown and Inistioge endured floods on 6th January 1996 following heavy rainfall. Press articles from the Kilkenny People and the Munster Express were found on www.floodmaps.ie containing information on this event.

In Kilkenny flooding occurred when the Breaghagh and Nore Rivers burst their banks. A peak flood level of 45.04mOD (Malin) was recorded at Blackfriar's Bridge Hydrometric Station on 7th January, while a peak flood level of 44.09mOD (Malin) and a corresponding peak flow of 263m³/s were recorded at John's Bridge Hydrometric Station, as per <http://www.opw.ie/hydro>.

In Callan, floodwater flowed through houses at Lower Bridge Street when the King's River broke its banks. A peak flood level of 62.68mOD (Malin) was recorded at Callan hydrometric station (as per <http://www.opw.ie/hydro>) while downstream of Callan, at Annamult hydrometric station, the peak flow on the King's River was 113m³/s, upstream of its confluence with the Nore.

References to flooding in Inistioge, where the Green and GAA pitch were flooded, and Thomastown on this date were also found. A pub and a number of houses on the Quay in Thomastown were under approximately 1 metre of water, while the library and Concert Hall on Marshes Street were also flooded. Parts of Market Street was also flooded. At the Brownsbarn Hydrometric Station (between Thomastown and Inistioge) on 7th January, the peak flood level reached 8.06mOD (Malin) with a corresponding peak flow of 388m³/s, as per <http://www.opw.ie/hydro>.

4.3.2.14 Flood Event of January 1995

A Kilkenny People press article, a Kilkenny Corporation memo to the County Manager (dated 31st January 1995) and OPW notes found in www.floodmaps.ie indicated that a flood event occurred in Ballyragget, Kilkenny, Callan and Thomastown at the end of January 1995. The flooding was caused by heavy rainfall.

In Ballyragget, flooding occurred when the Nore broke its banks and flooded farmland. A daily mean flow of $99.3\text{m}^3/\text{s}$ was recorded on 29th January at an EPA Hydrometric station in Ballyragget (as per <http://hydronet.epa.ie>).

In Kilkenny, the Nore River burst its banks flooding 10 properties on John Street, 20 properties on John's Quay, one property on Bateman's Quay, 12 properties on Green Street, 20 properties in Irishtown and six properties on Vicar Street. Most of these were private dwellings. The minimum cost of the damage was estimated at IR£28,000 in a memo from a Senior Executive Engineer of Kilkenny Corporation to the County Manager, dated 31st January 1995. This was based on an allowance of IR£400 per property; however it was estimated that in some cases the costs involved could be up to IR£2,500 per property. A peak flood level of 44.3mOD (Malin) and a corresponding peak flow of $297\text{m}^3/\text{s}$ were recorded at John's Bridge Hydrometric Station, as per <http://www.opw.ie/hydro>.

In Callan the King's River broke its bank. A peak flood level of 62.56mOD (Malin) was recorded at Callan hydrometric station (as per <http://www.opw.ie/hydro>) while downstream of Callan, the hydrometric station at Annamult recorded a peak flow of $109\text{m}^3/\text{s}$ on the King's River, upstream of its confluence with the Nore.

In Thomastown, shops and private houses in Marsh Street, Market Street and the Quay were flooded with 75-100mm of water, and the GAA pitch at Grennan was also flooded. A peak flood level of 7.98mOD (Malin) and a corresponding peak flow of $368\text{m}^3/\text{s}$ were recorded at Brownsbarn Hydrometric Station on 28th January, as per <http://www.opw.ie/hydro>.

4.3.2.15 Flood Event of February 1990

The historical data indicated that flooding occurred in Ballyragget, Freshford, Kilkenny, and Callan on 6th February 1990. Press articles from the Irish Independent, Kilkenny People, Munster Express and the Cork Examiner were found on www.floodmaps.ie containing information on the event.

In Ballyragget, heavy rain caused the Nore to break its banks. Tractors were used to ferry people through flooded areas. Several cars became stranded on the Ballyragget-Freshford road. A daily average flow of $120\text{m}^3/\text{s}$ was recorded on 8th February at an EPA Hydrometric station in Ballyragget (see <http://hydronet.epa.ie>). However it should be noted that the data from 3rd to 6th February is missing.

In Freshford, the Nuenna broke its banks. Tractors were also used in this area to ferry people through flooded areas. The Bridge St., Church St., and Buncrusha St. area was under 300mm of water.

In Kilkenny, there was over 600mm of water on Green Street houses. John's Quay was under approximately 1m of water (reported as several feet). Houses and shops in Irishtown and Vicar Street were inundated to a depth of several centimetres. A peak flood level of 44.31mOD (Malin) and a corresponding peak flow of $299\text{m}^3/\text{s}$ were recorded at John's Bridge Hydrometric Station, as per <http://www.opw.ie/hydro>.

In Callan the King's River broke its banks. The hydrometric station at Callan recorded a peak level of 62.64mOD (Malin), while the hydrometric station at Annamult recorded a peak level of 24.79mOD (Malin) and a corresponding flow of 111m³/s on 6th February on the King's River, upstream of its confluence with the Nore, as per <http://www.opw.ie/hydro>.

4.3.2.16 Flood Event of August 1986

The review of information indicated that a flood event occurred in Ballyragget, Freshford, Kilkenny and Callan on 25th August 1986 due to heavy rainfall. Press articles from the Kilkenny People and the Cork Examiner were found on www.floodmaps.ie containing information on the event.

In Ballyragget, the Nore River burst its banks inundating many houses. No information on flows or levels was available.

Houses were also flooded in Freshford when the Nuenna River burst its banks. No information on flows or levels was available.

In Kilkenny the Nore and Breagagh rivers burst their banks causing flooding on John's Quay, John Street and Irishtown. Vicars Street was flooded to a depth of 0.3m while Green Street was flooded to a depth of 0.1-0.15m. Flood levels for Kilkenny at different locations as recorded in a letter from M. C. O'Sullivan Consulting Engineers to Kilkenny Corporation (dated 4th September 1986) can be seen below and give an indication of flooded areas.

Table 4.9: Kilkenny Flood Levels – August 1986

Location	Flood Level (mOD Malin)	Street Level (mOD Malin)	Lowest floor level of house (mOD Malin)
<u>River Nore</u>			
Upstream of Green's Bridge.	45.30	44.80 (land level)	-
Green's Street	44.95	44.73	44.83
Upstream of Green's Bridge weir	44.70	45.00	44.93
Adjacent to OPW Gauging station	44.20	43.80	-
At Library	44.15	43.50	43.77
Upstream of weir no. 2	43.45	43.25	-
Downstream of weir no. 2	43.00	43.10	-
Lacken walk	42.15	41.60	-
<u>River Breagagh</u>			
Waterbarracks	46.00	46.00	45.8-45.3
Watergate	44.76	44.60	44.62

A peak flood level of 44.2mOD (Malin) and a corresponding peak flow of 281m³/s were recorded at John's Bridge Hydrometric Station, as per <http://www.opw.ie/hydro>.

In Callan the King's river overflowed flooding houses. The hydrometric station at Callan recorded a peak level of 62.68mOD (Malin), while the hydrometric station at Annamult recorded a peak level of 24.92mOD (Malin) and a corresponding flow of 124m³/s on 26th August on the King's River, upstream of its confluence with the Nore, as per <http://www.opw.ie/hydro>.

4.3.2.17 Flood Event of January 1984

The historical review indicated that a flood event occurred in Kilkenny on 16th January. According to a consultant's report (Reference 8), the flood had an AEP of approximately 10%. A peak level of 44.26mOD (Malin) and a corresponding flow of 285.9m³/s were recorded at John's Bridge Hydrometric Station, as per the same report. No information on damage caused by the flood was found.

4.3.2.18 Flood Event of December 1979

A flood event was found to have occurred in Kilkenny on the 27th December 1979. The Nore and Breaghagh Rivers broke their banks and an Irish Independent article described how floodwater rose to approximately 900mm deep in parts of John Street, Irishtown and John's Quay. A consultant's report (Reference 8) estimated that the flood had an AEP of approximately 10%. A peak level of 44.31mOD (Malin) and a corresponding flow of 289m³/s were recorded at John's Bridge Hydrometric Station.

4.3.2.19 Flood Event of December 1978

A flood event was found to have occurred on 27th December in Kilkenny due to heavy rainfall. An Irish Times article described how John's Quay and Blackmill Street were flooded. According to a consultant's report (Reference 8), the flood had an AEP of approximately 20%. A peak level of 44.12mOD (Malin) and a corresponding flow of 259m³/s were recorded at John's Bridge Hydrometric Station as outlined in the same consultant's report.

4.3.2.20 Flood Event of January 1974

A flood event was found to have occurred on 8th January in Kilkenny due to heavy rainfall. A consultant's report (Reference 8) estimated that, the flood had an AEP of approximately 20%. A peak level of 44.09mOD (Malin) and a corresponding flow of 255m³/s were recorded at John's Bridge Hydrometric Station. No information on damage caused by the flood was found.

4.3.2.21 Flood Event of January 1969

Press articles in the Kilkenny People and Munster Express downloaded from www.floodmaps.ie during the historical review indicated that a flood event occurred in Thomastown on 24th January due to heavy rainfall causing the Nore to overflow. Private houses were flooded to a depth of up to three metres.

4.3.2.22 Flood Event of December 1968

The review of the data indicated that a flood event occurred in Mountrath, Kilkenny and Rathdowney on 25th December 1968. Details were contained in an Irish Independent press article downloaded from www.floodmaps.ie.

In Kilkenny 48 hours of continuous rainfall caused the Nore and Breagagh rivers to break their banks. This was the largest flood since 1947 with an approximate AEP of 4% (Reference 8). Flooding occurred at Blackmill St, Green St., Greens Bridge and John St. A peak level of 44.83mOD (Malin) and a corresponding flow of 378m³/s were recorded at John's Bridge Hydrometric Station as outlined in a consultant's report (Reference 8).

Homes and streets were flooded in Mountrath following heavy rainfall and there was also extensive flooding in Rathdowney.

4.3.2.23 Flood Event of November 1965

Flooding occurred in Thomastown on 27th November due to heavy rainfall. An article in the Kilkenny People described that water entered houses in Marshes St. and the Quay. There is no information on levels or flows available for this date.

4.3.2.24 Flood Event of December 1960

Review of the historical data indicated that flooding occurred in Kilkenny, Callan, Thomastown and Inistioge on 1st December caused by heavy rainfall and snowmelt. Information on the event was found on www.floodmaps.ie in the form of photos and as press articles from the Kilkenny Journal, Kilkenny People, Munster Express, Irish Independent, Irish Times, Cork Examiner and Evening Press (Dublin).

In Kilkenny, the Nore and Breagagh Rivers broke their banks flooding Blackmill Bridge, John's Quay and the Dominican Black Abbey. Houses were flooded in the low lying areas of the town. The event had an AEP of approximately 10% (Reference 8) and, at the time, it was the largest flood since 1947. A peak level of 44.29mOD (Malin) and a corresponding flow of 309.8m³/s were recorded at John's Bridge Hydrometric Station (Reference 8).

In Callan, shops and houses were flooded to a depth of 600mm. The hydrometric station at Callan recorded a peak level of 62.99mOD (Malin), while the hydrometric station at Annamult recorded a peak level of 24.82mOD (Malin) and a corresponding flow of 110m³/s on 26th August on the King's River, upstream of its confluence with the Nore, as per <http://www.opw.ie/hydro>.

In Thomastown, streets and surrounding countryside were inundated with up to 1.6m of water. Areas worst affected were Marshes St., Low St. and the Quay. House owners in the town were forced to retreat to their upper storeys. Portions of the old town wall collapsed. The concert hall was flooded to a depth of 1m.

In Inistioge, houses were flooded to a depth of 1 to 1.2m. At Brownsbarn Hydrometric Station, between Thomastown and Inistioge, a peak flood level of 8.24mOD (Malin) and a corresponding peak flow of 411m³/s were recorded on 4th December, as per <http://www.opw.ie/hydro>.

4.3.2.25 Flood Event of October 1954

The historical review indicated that a flood event occurred in Kilkenny, Callan and Thomastown on 29th October caused by heavy rainfall. An Irish Independent press article and Kilkenny Corporation correspondence (dated 9th November 1954) were found on www.floodmaps.ie containing details of the event.

In Kilkenny, John Street was flooded to a depth of 400mm, the Dominican Black Abbey was flooded and Waterbarrack road was also flooded. The flood had an estimated AEP of 10%, while a peak level of 44.153mOD (Malin) and a corresponding flow of 287.9m³/s were recorded at John's Bridge Hydrometric Station (Reference 8).

Flooding occurred in Callan when the King's River broke its banks. The hydrometric station at Annamult recorded a peak level of 24.81mOD (Malin) and a corresponding flow of 107m³/s on 29th October on the King's River, upstream of its confluence with the Nore, as per <http://www.opw.ie/hydro>.

In Thomastown, the Nore burst its banks flooding shops and private premises to a depth of 150mm. No information on flows or levels was found.

4.3.2.26 Flood Event of March 1947

A major flood event was found to have occurred on 14th March in Freshford, Kilkenny, Callan, Thomastown and Inistioge. Information on the event was contained in press articles from the Kilkenny Journal, Kilkenny People and the Irish Independent, downloaded from www.floodmaps.ie.

In Freshford, the Nuenna River broke its banks. Serious damage was done to property especially in Bohercrussia Street and Bridge Street and the lower end of Kilkenny Street. Water was over 300mm deep in some shops.

Kilkenny suffered the second worst known flood in the history of the area, second only to the flood of October 1763. The flood had an AEP of less than 0.5% (Reference 8). There was severe flooding in the town, particularly in John Street, Irishtown, Vicar Street and Green Street. A peak level of 45.81mOD (Malin) and a corresponding flow of 520m³/s were recorded at Smithwick's Brewery (Reference 9). A report by Kilkenny County Council (Reference 10) stated that a local committee investigation found that 235 houses were rendered temporarily unfit for habitation and some houses were rendered permanently unfit, while damage to furniture and goods was estimated at IR£14,000.

In Callan, the King's River broke its banks flooding 40 shops and houses on Upper and Lower Bridge Street. No information on flows or levels was found.

In Thomastown, shops and private premises were flooded to a depth of 1.2m. In Marshes Street, where water rose to a depth of almost 2m, a boat was used to convey food to people marooned in their homes. 115 houses were affected. No information on flows or levels was found.

In Inistioge, the lower part of the village was flooded to a depth of 1.6m. Ten houses were affected. No information on flows or levels was found.

4.3.2.27 Flood Event of August 1946

A flood event was found to have occurred in Kilkenny on 12th August when heavy rainfall caused the Nore and Breaghagh River to burst their banks. A peak level of 44.67mOD (Malin) and a corresponding flow of 302m³/s were recorded at Smithwick's Brewery (Reference 9).

4.3.2.28 Flood Event of March 1933

A flood event was found to have occurred in Kilkenny on 1st March 1933 when heavy rainfall caused the Nore and Breaghagh River to burst their banks. The flood had an approximate AEP of 4% (Reference 8). A peak level of 44.75 mOD (Malin) and a corresponding flow of 314m³/s were recorded at Smithwick's Brewery (Reference 9).

4.3.2.29 Flood Event of November 1931

A flood event was found to have occurred in Kilkenny on 23rd November 1931 following heavy rainfall. The flood had an approximate AEP of 2% (Reference 8). A peak level of 45.17mOD (Malin) and a corresponding flow of 390m³/s were recorded at Smithwick's Brewery (Reference 9).

4.3.2.30 Flood Event of January 1926

Review of the historical data on www.floodmaps.ie indicated that flooding occurred in Kilkenny and Thomastown on 29th January following a period of heavy rainfall.

In Kilkenny, a peak level of 44.99mOD (Malin) and a corresponding flow of 359m³/s were recorded at Smithwick's Brewery (Reference 9). The flood had an approximate AEP of 2% (Reference 8). No information on damage caused by the flood was found.

Flooding was also found to have occurred in Thomastown. No information on flood levels, flows or damage caused by the flood was found.

4.3.2.31 Flood Event of October 1763

Review of the historical data indicated that flooding occurred in Kilkenny, Thomastown and Inistioge on 2nd October caused by 24 hours of incessant rain. It was reported that every bridge on the Nore was washed away except for one in Ballyragget and one in Inistioge, which was badly damaged (Reference 9, 11). This is the worst known flood in the history of the area.

In Kilkenny, Johns Bridge was washed away. Fourteen men and women on the bridge died when it collapsed. Greens Bridge was also washed away.

A bridge was also washed away in Thomastown while in Inistioge a bridge was badly damaged.

4.4 PRELIMINARY ASSESSMENT OF PAST FLOODS AND FLOODING MECHANISMS

A preliminary assessment of a number of major historical flood events which occurred within HA15 (Nore catchment) 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 HA15 have experienced a number of major flood events in the past, most notably in March 1947, December 1960, December 1968, February 1990, January 1995, January 1996, November 2000, August 2008 and November 2009. The March 1947, December 1968, August 2008 and November 2009 flood events were the worst among these.

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 16 gauging stations located on or upstream of watercourses to be modelled within HA15 as shown below.

Table 4.10: Flow data availability for gauges on watercourses to be modelled in HA15

Station Number	Station Name	Watercourse	Catchment	AMAX Series Provided	Continuous Flow Record Available
15001	Annamult Bridge	Kings River	Nore	Y	Y
15002	John's Bridge	River Nore	Nore	Y	Y
15003	Dinin Bridge	Dinin River	Nore	Y	Y
15004	McMahon's Bridge	River Nore	Nore	Y	Y
15005	Durrow Foot Bridge	Erkina River	Nore	Y	Y
15006	Brownsbarn	River Nore	Nore	Y	Y
15007	Kilbricken Bridge	River Nore	Nore	N	Y
15008	Borris In Ossory	River Nore	Nore	Y	Y
15009	Callan	Kings River	Nore	Y	Y
15010	Ballyboodin	Goul River	Nore	Y	Y
15011	Mount Juliet	River Nore	Nore	Y	Y
15012	Ballyragget	River Nore	Nore	Y	N
15021	Annagh	Delour River	Nore	N	Y
15041	Ballinfrase	Goul River	Nore	N	Y
15050	Blackfriar's Bridge	Breagagh River	Nore	N	Y
15053	Derryduff	River Nore	Nore	N	Y

These have been used to conduct flood event analysis within HA15. Table 4.11 presents the selected events on the affected AFA basis.

4.4.2 Flood Mechanisms in HA15

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. The geology of HA15 is also affected by karst features such as springs, caves and swallow holes particularly to the north of Kilkenny City in the Dunmore area. Karst features can cause unpredictable and rapid groundwater flooding and can complicate the hydrology and modelling of smaller watercourses.

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 HA15, most flooding events are 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 obviously dependent on the

catchment physical and meteorological characteristics and in particular, the catchment area, slope, catchment soil type and the antecedent wet condition, drainage density and the catchment storage behaviour and the rainfall type. 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 a larger catchment like the River Nore, flash floods in the upper steeper tributary catchments can have lesser effects on the downstream part of the catchment, due to the attenuation effect. Flooding at the coastal downstream reach of the River Nore catchment can result from the joint occurrence of fluvial and tidal flood events. The frequency of selected flood events within HA15 have been analysed by fitting the AMAX time series for the associated gauging sites. The AMAX time series were fitted to three flood-like distributions, namely, the GEV, EV1 and 2-parameter Lognormal (LN2) distributions. As an example of flood event analysis within HA15, a hydrograph plot of the November 2009 event on the River Nore as recorded at Hydrometric Station 15004 (McMahon’s Bridge) is shown on Figure 4.6.

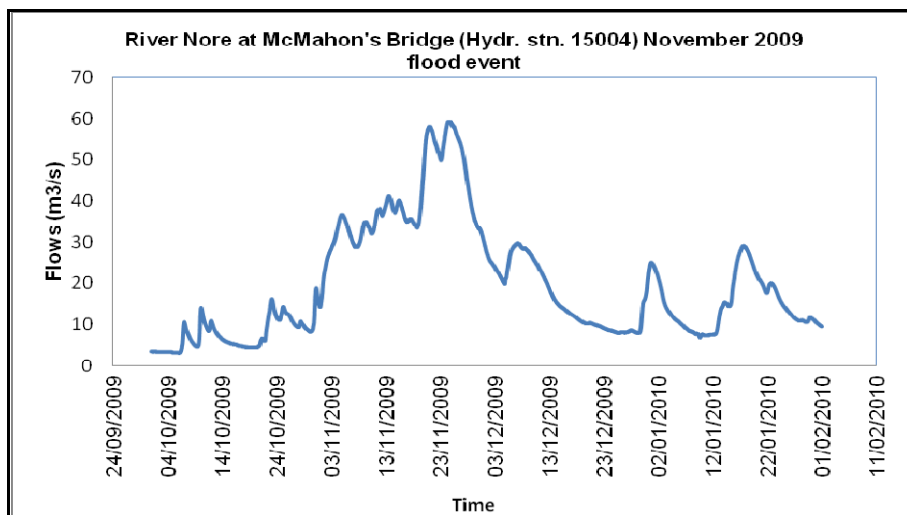


Figure 4.6: Observed flood hydrograph during the November 2009 flood event at MacMahon’s Bridge hydrometric station of River Nore.

The observed annual maximum flow records for the River Nore at McMahon’s Bridge for the period of 1954 to 2009 is illustrated in Figure 4.7.

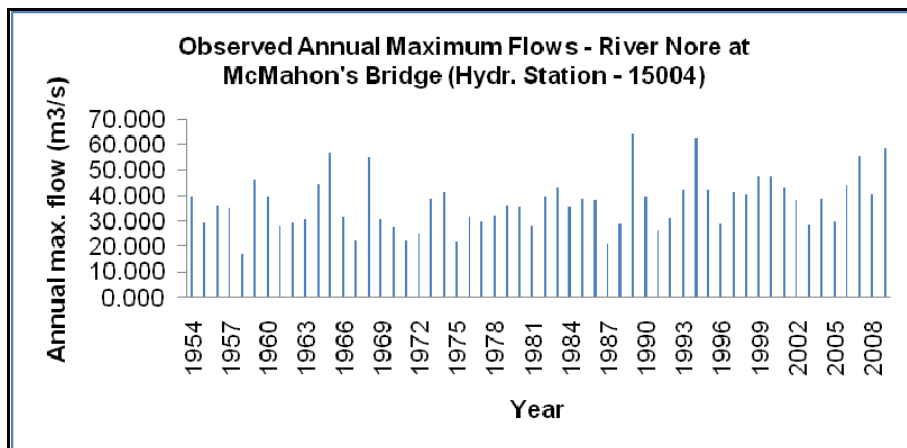


Figure 4.7: Observed Annual Maximum Flows for River Nore at McMahon's Bridge (1954 – 2009).

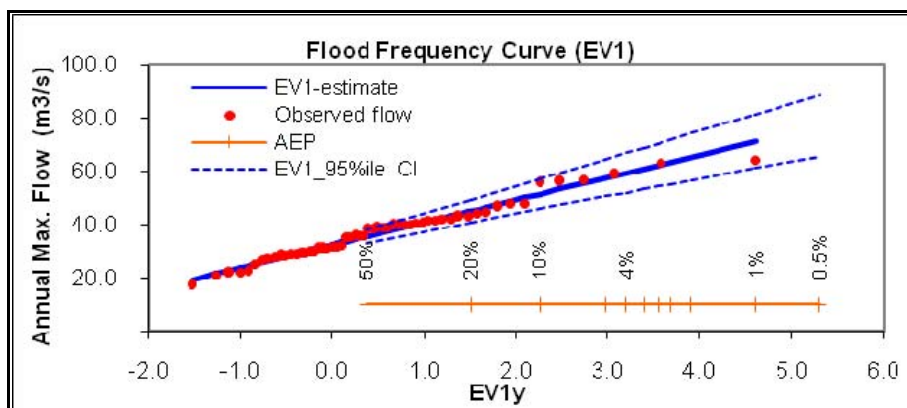


Figure 4.8: Fitted EV1 frequency Curve to the observed annual maximum records River Nore at McMahon's Bridge.

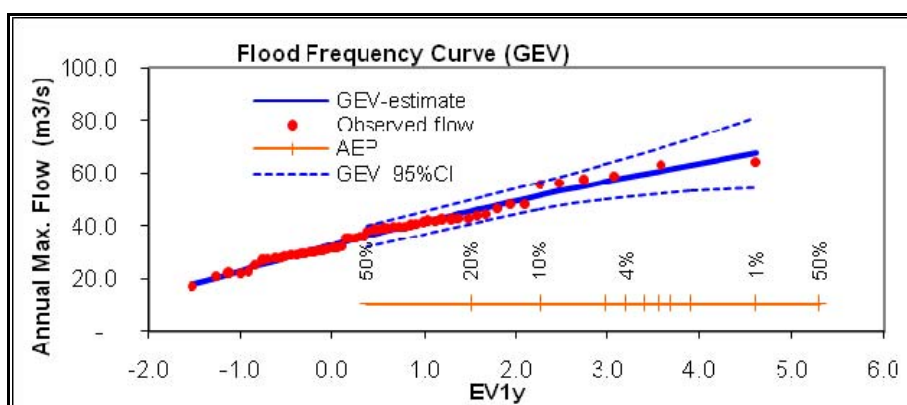


Figure 4.9: Fitted GEV frequency curve to the observed annual maximum records for River Nore at McMahon's Bridge.

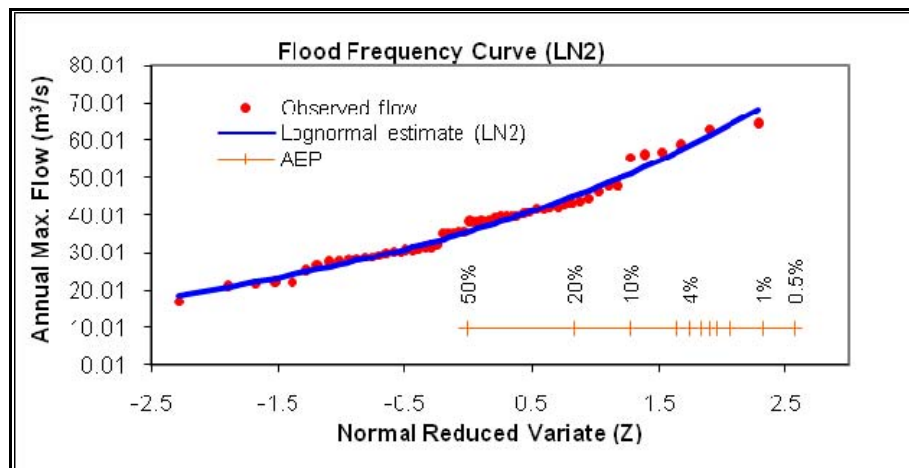


Figure 4.10: Longnormal (2-parameter) frequency curve to the observed annual maximum records for River Nore at McMahon's Bridge.

Figures 4.8, 4.9 and 4.10 show the fitted EV1, GEV and LN2 distributions to these records respectively. It can be seen from these figures that the GEV and LN2 distributions provide slightly better fit to the observed annual maximum records than the EV1 distribution. Based on the GEV distribution, the estimated AEP of the observed flood flow of $64.18 \text{ m}^3/\text{s}$ during the February 1990 flood event (08/02/1990), is approximately 1.11% and the August 2008 event is approximately 2%.

For many of the hydrometric stations in HA15 sufficiently long records were not available to estimate the frequency of the observed events using the associated at-site data. The frequency of the observed flood events for these stations can be approximated from the corresponding estimated frequency of the nearest gauging site on the same river which has longer records. For example, the estimated AEP of the observed flood event in March 1947 at Thomastown would be approximately 1% based on the corresponding estimate for River Nore at Mount Juliet (Hydrometric station No. 15011) which is located approximately 5km upstream of Thomastown.

Table 4.11 summarises the flood mechanism, hydrograph shape and estimated frequency of all selected flood events. It can be seen from this table that the majority of the flood events are of 'fluvial' type. The historical review in Section 4.3 identified most severe flood events (in terms of frequency and damage caused) in the River Nore catchment were the March 1947, December 1968, August 2008 and November 2009 flood events. Most parts of the River Nore catchment area were affected during these events and the causes of flooding were the prolonged intense rainfall (fluvial).

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 5.2.1.1, Hydraulic Model Calibration.

Table 4.11: Significant flood events, their generation mechanisms and frequency in HA15

AFAs	Nearest Gauging Stations		Major flood events				
	Stn. No.	Location	Date	Peak flow (m3/s)	Rank	Approximate AEP (%)	Flood mechanisms
Borris In Ossory (Located on MPW, not an AFA)	15008	River Nore at Borrin In Ossory	Dec 1968	Missing	-	No records	Fluvial: Heavy and prolonged rainfall
			25/01/1975	27.26	35 (highest)	1.25 – 1.11%	Fluvial: Heavy and prolonged rainfall
			16/01/1984	16.80	26	50 – 20%	Fluvial: Heavy and prolonged rainfall
			08/02/1990	18.72	32	20 -10%	Fluvial: Heavy and prolonged rainfall
			27/01/1995	18.27	29	20 -10%	Fluvial: Heavy and prolonged rainfall
			18/08/2008	19.68	33	20 – 10%	Fluvial: Heavy and prolonged rainfall
			19/11/2009	19.22	32	20 – 10%	Fluvial: Heavy and prolonged rainfall
Annagh	15021	Delour River at Annagh	Dec 1968	Missing	-	No records	-
			02/11/2000	30.01	9	20 – 10%	Fluvial: Heavy and prolonged rainfall
			16/08/2008	43.74	11 (highest)	4 – 3.33%	Fluvial: Heavy and prolonged rainfall
Derryduff	15053	River Nore at Derryduff	16/07/2010	30.57	10	20 – 10%	Fluvial: Heavy and prolonged rainfall
			08/01/2005	47.40	6 (highest)	10 – 6.67%	Fluvial: Heavy and prolonged rainfall
			31/03/2008	41.70	5	50 – 20%	Fluvial: Heavy and prolonged rainfall
Mountrath	15007	River Nore at Kilbricken	01/12/1975	51.40	26	50 – 20%	Fluvial: Heavy and prolonged rainfall
			26/08/1986	50.69	14	50 – 20%	Fluvial: Heavy and prolonged rainfall
			28/01/1995	54.21	34	20 – 10%	Fluvial: Heavy and prolonged rainfall
			03/11/1998	58.04	33	5%	Fluvial: Heavy and prolonged rainfall
			06/11/2000	59.07	34	2.86%	Fluvial: Heavy and prolonged rainfall
			08/01/2005	63.21	35 (highest)	≈ 1%	Fluvial: Prolonged intense rainfall
			16/08/2008	54.39	32	20 – 10%	Fluvial: Heavy and prolonged rainfall
Ballyroan	15032	Gloreen River at Ballyroan	Nov 2009	Missing	-	No records	-
Durrow	15005	Erkina River at Durrow Foot Bridge	Dates not known	No records	-	No records	-
			05/12/1960	39.70	50	20 – 10%	Fluvial: Heavy and prolonged rainfall
			26/12/1968	61.80	55 (highest)	2.22 – 2%	Fluvial: Heavy and prolonged rainfall
			17/01/1984	41.80	51	10%	Fluvial: Heavy and prolonged rainfall

AFAs	Nearest Gauging Stations		Major flood events			
	Stn. No.	Location	Date	Peak flow (m ³ /s)	Rank	Approximate AEP (%)
Ballyboodin	15010	Goul River at Ballyboodin	07/02/1990	61.20	54	2.22%
			29/01/1995	34.30	42	50 – 20%
			28/12/1999	34.00	40	50 – 20%
			11/01/2008	38.90	49	20 – 10%
			21/11/2009	47.40	53	5 – 4%
			Dec 1968	Missing	-	No records
Rathdowney	15056	Erkina River at Conyburrow	26/01/1975	52.88	31 (highest)	1.67%
			14/02/1977	50.30	30	2.5 – 2.22%
			07/02/1990	29.46	29	20 – 10%
			07/11/2000	24.85	21	50 – 20%
			21/11/2009	26.05	26	50 – 20%
			Dates not known	No records	-	No records
Castlewood	15004	River Nore at McMahon's Bridge	22/04/1966	56.88	53	5 – 4%
			25/12/1968	55.46	51	6.67 – 5%
			17/10/1984	42.01	43	50 – 20%
			08/02/1990	64.18	56 (highest)	≈ 1.11%
			28/01/1995	62.99	55	1.67%
			18/06/2008	56.03	52	6.67 – 5%
Ballyragget	15012	River Nore at Ballyragget	24/11/2009	58.60	54	4 – 3.33%
			Dec 1968	Missing	-	No records
			08/02/1990	133.00	16 (highest)	3.33 – 2.86%
			29/01/1995	104.00	15	20 – 10%
			26/12/1999	94.31	13	50 – 20%
			31/10/2004	75.82	8	50 – 20%
Freshford	15039	Nuenna River at Fishford	Dates not known	No records	-	No records
Kilkenny - Nore	15002	River Nore at John's Bridge	29/10/1954	383.80	51	4%
			04/12/1960	414.50	53 (highest)	2.22%
			25/12/1968	392.70	52	3.33%
			26/08/1986	280.70	40	50 – 20%

AFAs	Nearest Gauging Stations		Major flood events				
	Stn. No.	Location	Date	Peak flow (m3/s)	Rank	Approximate AEP (%)	Flood mechanisms
Kilkenny - Breagagh			06/02/1990	298.60	46	20 – 10%	Fluvial: Heavy and prolonged rainfall
			27/01/1995	296.90	45	20 – 10%	Fluvial: Heavy and prolonged rainfall
			05/02/2002	376.60	50	5 – 4%	Fluvial: Heavy and prolonged rainfall
			16/08/2008	350.30	48	10 – 6.67%	Fluvial: Heavy and prolonged rainfall
			19/11/2009	352.10	49	10 – 6.67%	Fluvial: Heavy and prolonged rainfall
Callan	15050	Breagagh River at Blackfriar's Bridge	18/11/1997	67.14	8 (highest)	6.67 – 5%	Fluvial: Heavy and prolonged rainfall
			27/11/2002	32.63	6	50 – 20%	Fluvial: Heavy and prolonged rainfall
			03/12/1960	50.06	46	20 – 10%	Fluvial: Heavy and prolonged rainfall
			12/12/1964	47.90	42	50 – 20%	Fluvial: Heavy and prolonged rainfall
			24/12/1968	45.98	36	50 – 20%	Fluvial: Heavy and prolonged rainfall
	15009	Kings River at Callan	26/08/1986	55.54	52	6.67 – 5%	Fluvial: Heavy and prolonged rainfall
			06/02/1990	54.04	50	10 – 6.67%	Fluvial: Heavy and prolonged rainfall
			07/01/1996	52.37	49	20 – 10%	Fluvial: Heavy and prolonged rainfall
			29/10/2004	59.16	53	2%	Fluvial: Heavy and prolonged rainfall
			16/08/2008	60.17	54 (highest)	1.54%	Fluvial: Heavy and prolonged rainfall
Thomastown	15011	River Nore at Mount Juliet	01/11/2009	54.23	51	10 – 6.67%	Fluvial: Heavy and prolonged rainfall
			16/03/1947	444.39	57 (highest)	≈1%	Fluvial: Heavy and prolonged rainfall
			04/12/1960	339.62	50	20 – 10%	Fluvial: Heavy and prolonged rainfall
			25/12/1968	348.55	53	20 – 10%	Fluvial: Heavy and prolonged rainfall
			31/10/1997	346.34	52	20 – 10%	Fluvial: Heavy and prolonged rainfall
			26/08/1986	326.43	48	50 – 20%	Fluvial: Heavy and prolonged rainfall
			07/01/1996	329.61	47	50 – 20%	Fluvial: Heavy and prolonged rainfall
			29/10/2005	341.95	51	20 – 10%	Fluvial: Heavy and prolonged rainfall
			16/08/2008	363.95	55	10 – 6.67%	Fluvial: Heavy and prolonged rainfall
			20/11/2009	403.12	56	2.5 – 2.22%	Fluvial: Heavy and prolonged rainfall
	15001	Kings River at Annamult Bridge	26/12/1968	151.21	48 (highest)	≈1%	Fluvial: Heavy and prolonged rainfall
			26/08/1986	123.91	43	20 – 10%	Fluvial: Heavy and prolonged rainfall

AFAs	Nearest Gauging Stations		Major flood events				
	Stn. No.	Location	Date	Peak flow (m3/s)	Rank	Approximate AEP (%)	Flood mechanisms
Ballyhale			29/10/2004	129.12	46	10 – 6.67%	Fluvial: Heavy and prolonged rainfall
			16/08/2008	127.02	45	10 – 6.67%	Fluvial: Heavy and prolonged rainfall
			20/11/2009	133.16	47	6.67 – 5%	Fluvial: Heavy and prolonged rainfall
Ballyhale	15046	Little Arrigle River at Jerpoint	Dates not known	No records	-	No records	Fluvial: Heavy and prolonged rainfall
Inistioge	15006	River Nore at Brownsbarn	08/12/1954	338.90	37	50 – 20%	Fluvial: Heavy and prolonged rainfall
			04/12/1960	411.00	51	6.67 – 5%	Fluvial: Heavy and prolonged rainfall
			25/12/1968	449.50	54 (highest)	1.33%	Fluvial: Heavy and prolonged rainfall
			17/01/1984	337.10	36	50 – 20%	Fluvial: Heavy and prolonged rainfall
			26/08/1986	415.0	53	6.67 – 5%	Fluvial: Heavy and prolonged rainfall
			28/01/1995	368.50	43	20 – 10%	Fluvial: Heavy and prolonged rainfall
			18/11/1997	377.90	46	20 – 10%	Fluvial: Heavy and prolonged rainfall
			17/08/2008	369.60	44	20 – 10%	Fluvial: Heavy and prolonged rainfall
			20/11/2009	412.00	52	6.67 – 5%	Fluvial: Heavy and prolonged rainfall
			08/12/1953	176.16	55	20 – 10%	Fluvial: Heavy and prolonged rainfall
			04/12/1960	168.98	45	50 – 20%	Fluvial: Heavy and prolonged rainfall
Dinin	15003	Dinin River at Dinin Bridge	17/11/1965	175.35	49	20 – 10%	Fluvial: Heavy and prolonged rainfall
			02/11/1968	184.25	53	5%	Fluvial: Heavy and prolonged rainfall
			26/08/1986	187.52	56 (highest)	2.5%	Fluvial: Heavy and prolonged rainfall
			06/02/1990	160.36	36	50 – 20%	Fluvial: Heavy and prolonged rainfall
			18/11/1997	185.06	55	5 – 4%	Fluvial: Heavy and prolonged rainfall
			16/08/2008	184.25	54	5 – 4%	Fluvial: Heavy and prolonged rainfall
			16/01/2010	172.64	48	20 – 10%	Fluvial: Heavy and prolonged rainfall

5 HYDROLOGICAL ANALYSIS METHOD STATEMENT

5.1 ANALYSIS OF HYDROMETRIC AND METEOROLOGICAL DATA

5.1.1 Gauging Station Rating Review

A rating review of two hydrometric stations in HA15 is being undertaken. The stations were identified in the South Eastern Project Brief document as stations 15006, Brownsbarn and 15011, Mount Juliet. 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

Refer to discussion of preliminary data analysis in Section 4.4.

5.1.3 Rainfall Data Analysis

Rainfall data analysis is required to provide the necessary rainfall input to hydrological models (refer to Sections 5.4 and 5.6.1) where required. An ongoing trial looking at the potential benefits of using rainfall radar data (calibrated to daily and hourly rainfall gauges described in Section 4.2) to provide

rainfall input to hydrological models is currently ongoing as part of the overall Eastern CFRAM Study. If the trial outcomes conclude that there is a benefit to using rainfall radar data, then its use may be rolled out to the South Eastern Study Area. If this is the case, rainfall radar data analysis will be undertaken to provide rainfall input to rainfall runoff hydrological models as part of the overall hydrology methodology. A detailed description of rainfall radar data analysis is provided in Appendix C.

However if the radar data analysis trial of the Dublin radar data for the Eastern CFRAM Study project area shows significant problems and inconsistencies that are difficult to correct and calibrate in order to generate the hourly data rainfall series for each of the HEPs; 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.

5.2 MODEL CONCEPTUALISATION

5.2.1 HA15 Hydraulic Models

To facilitate hydrological assessment and hydraulic modelling, eight hydraulic models have been conceptualised for HA15 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 separate models and therefore can be used to directly calibrate flow estimations on both models. The large number of HEP's will allow good variation in the rarity / frequency conditions up and down the catchments and at each HEP comparison 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). 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'

In selecting the eight 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 used *'because there is no direct link between design peak flow and event duration'* (FSU WP 3.4, paragraph 4.3.1).

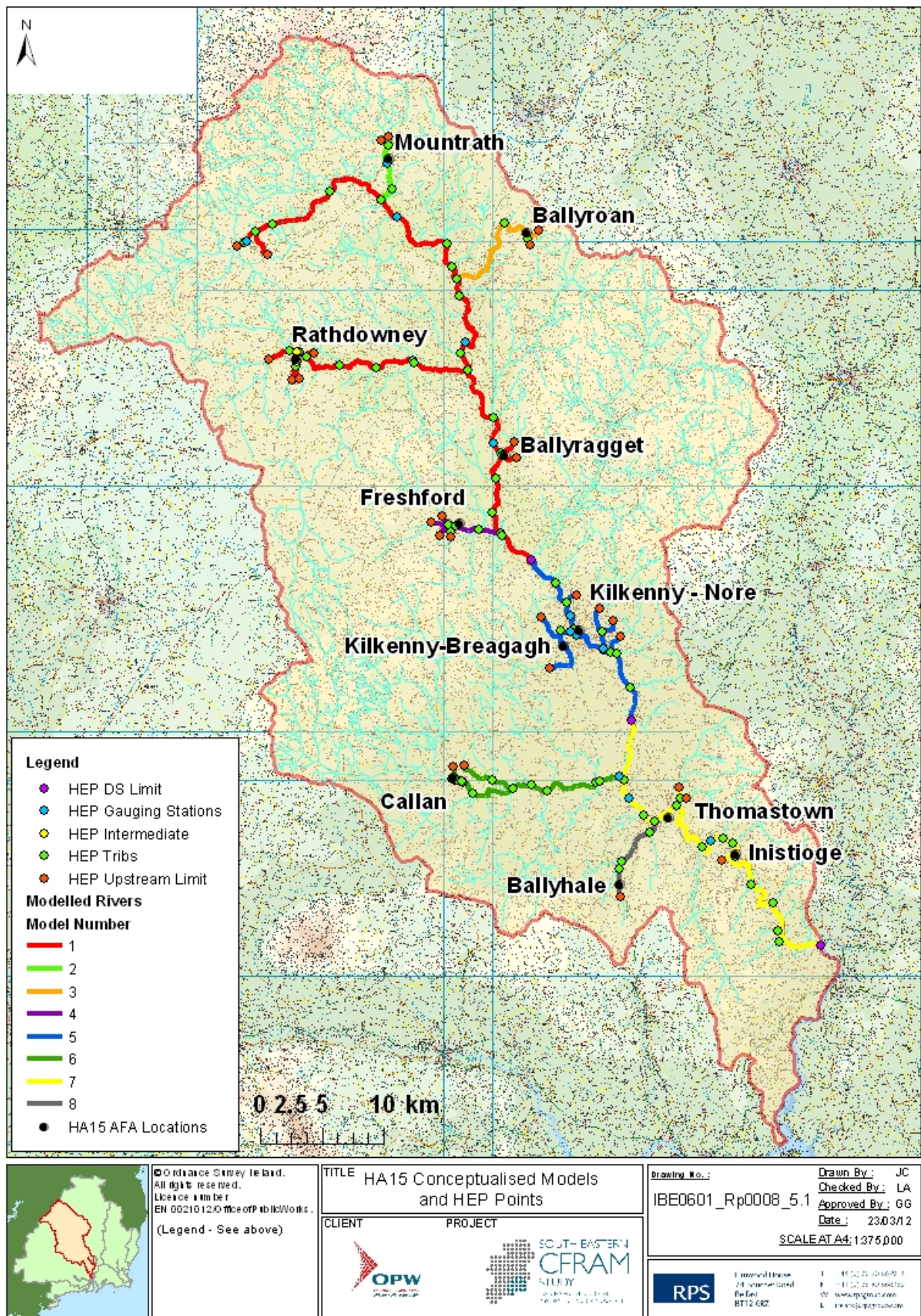


Figure 5.1: HA15 Conceptualised Models

5.2.1.1 Modelling of Karst Features

Where karst features are found to have a contributing affect on flood risk to AFA's, the particular karst feature may need to be modelled. Where this is identified as being required the feature will be modelled as a closed or piped system.

5.2.2 Catchment Boundary Review

Catchment boundaries for each HEP have been derived from the OPW national dataset containing the ungauged catchment outlines produced as part of the FSU for points every 500m along watercourses. Each catchment boundary will be reviewed against orthophotography and the NDHM (National Digital Height Model) using GIS based tools. Any amendments to catchment boundaries will be reported at the hydrology reporting stage.

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)
15001	6	26/12/1968	151.21
		26/08/1986	123.91
		06/02/1990	110.94
		29/10/2004	129.12
		16/08/2008	127.02
		20/11/2009	133.16
15002	5	25/12/1968	392.70
		26/08/1986	280.70
		06/02/1990	298.60
		05/02/2002	376.60
		16/08/2008	350.30
		19/11/2009	352.10
15004	1	25/12/1968	55.46
		08/02/1990	64.18
		28/01/1995	62.99
		06/11/2000	47.99
		18/08/2008	56.03
		24/11/2009	58.60
15005	1	26/12/1968	61.80
		07/02/1990	61.20

Hydrometric Stations	Hydraulic Model Number	Selected Flood events for hydraulic model calibration and verifications	
		Date	Peak flow (m3/s)
		29/01/1995	34.30
		28/12/1999	34.00
		11/01/2008	38.90
		21/11/2008	47.40
15006	7	25/12/1968	449.50
		26/08/1986	415.00
		28/01/1995	368.50
		06/11/2000	376.00
		17/08/2008	369.60
		20/11/2009	412.00
15007	1	26/08/1986	50.69
		06/02/1990	50.09
		28/01/1995	54.21
		08/01/2005	63.21
		16/08/2008	54.39
15008	1	16/01/1984	16.80
		08/02/1990	18.72
		27/01/1995	18.27
		18/08/2008	19.68
		19/11/2009	19.22
15009	6	24/12/1968	45.98
		26/08/1986	55.54
		06/02/1990	54.04
		07/01/1996	52.37
		16/08/2008	60.17
		01/11/2009	54.23
15011	7	25/12/1968	348.55
		26/08/1986	326.43
		07/01/1996	329.61
		29/10/2005	341.95
		16/08/2008	363.95
		20/11/2009	403.12
15012	1	-	No flow records available
15023	6	-	No flow records available
15027	2	-	No flow records available
15028	3	-	No flow records available
15030	1	-	No flow records available
15032	3	-	No flow records available
15035	1	-	No flow records available
15039	4	-	No flow records available
15040	5	-	No flow records available
15043	1	-	No flow records available

Hydrometric Stations	Hydraulic Model Number	Selected Flood events for hydraulic model calibration and verifications	
		Date	Peak flow (m ³ /s)
15046	8	-	No flow records available
15050	5	18/11/1997	67.14
		29/12/1998	52.53
		27/11/2002	32.63
15053	1	29/10/2002	35.40
		08/01/2005	47.10
		31/03/2008	41.70
15054	3	-	No flow records available
15056	1	-	No flow records available
15104	5	-	No flow records available
15105	5	-	No flow records available

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. 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 hydrologic 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).

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.

5.3 HYDROLOGICAL ESTIMATION POINTS

Hydrological Estimation Points (HEPs) are located along each modelled watercourse to denote points where hydrological analysis is required for the estimation of design flows that will be used as hydraulic model input. They also serve as check points at gauging station locations, so that the design AEP event is properly derived, particularly in AFAs.

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 HA15. 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 an HEP at which design flows and hydrographs will be derived primarily from a rainfall runoff model; or flow estimation methods as appropriate (for example IH124 method in small catchments).

5.3.1.2 HEP where Tributaries enter Modelled Channel

Moving downstream along the modelled reach, an HEP is located where tributaries with catchment areas greater than 5km² 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 Suir CFRAM Study team (who were identifying HEPs in the Suir Catchment at the same time) and it was considered that including all tributaries with catchments greater than 5km² 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 5km² 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:

- Hydrology estimations at 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 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 an 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 a FSU NODE_ID (particularly those at the upstream limit of models) 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.

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. These routes are:

- Rainfall run off modelling using NAM to provide peak flow and design hydrograph input to the hydraulic model or;
- Peak flow estimation providing point / lateral flow inputs to the hydraulic model.

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 until calibration with the HEP gauging station check points is achieved.

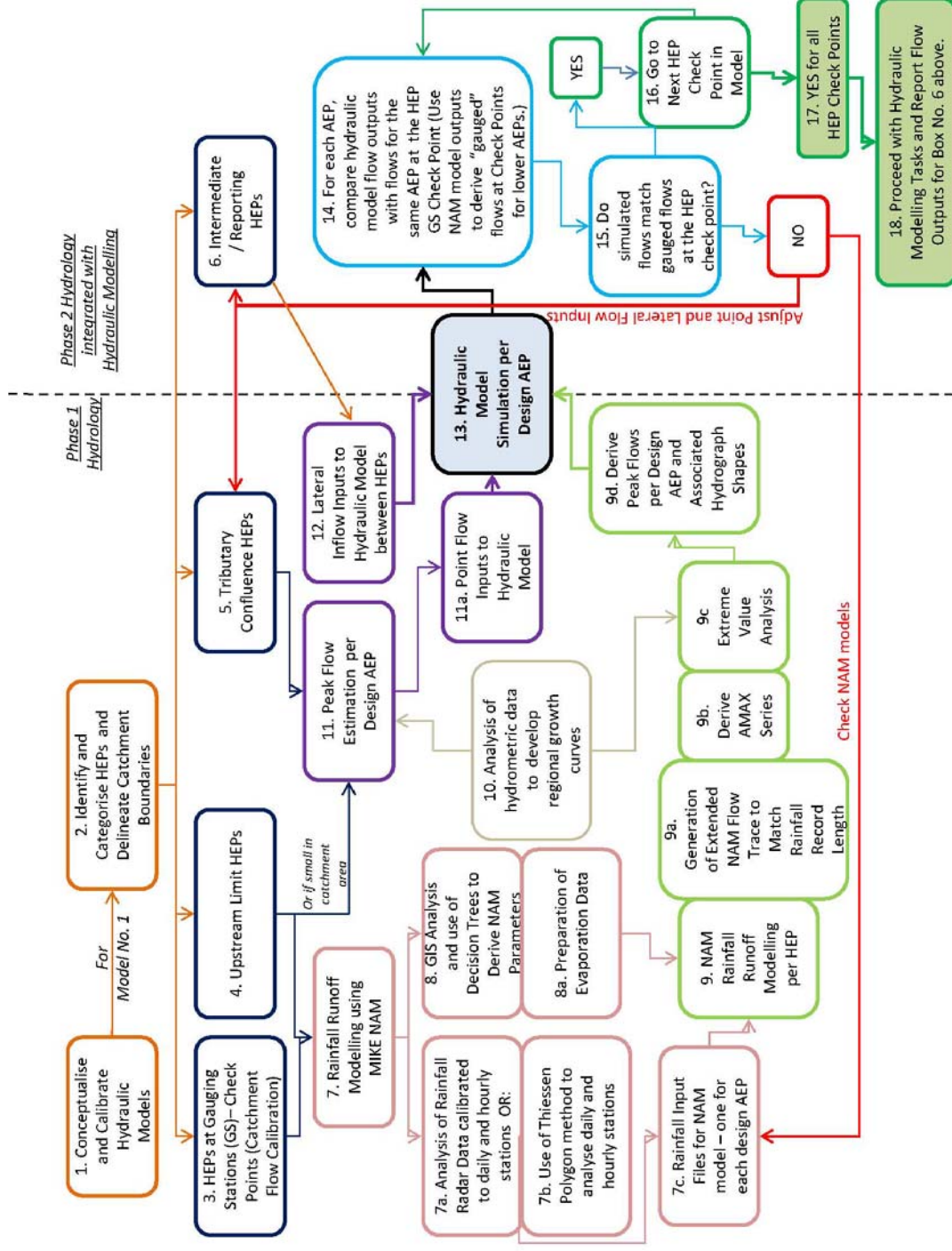


Figure 5.2: Two Phased Hydrology Analysis Process Chart

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 D 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 HA15 – (Box 10)

In accordance with the FSU method, each of the HEPs should have a separate growth curve. Or as a minimum, a growth curve should be developed at each of the hydrometric stations (gauged or ungauged) on a river network. However this is likely to result in an abundance of growth curves with unrealistic changes to growth factors along modelled reaches. 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 would be developed on a more regional basis. Alternatively the estimated growth curves at each of the nodes will be grouped into a lesser number of representative growth curves on a zoned basis. Growth curves will be developed using the FSU proposed 'Region-of-Influence' approach. Suitability of a suite of flood like distributions will be examined such as GEV, EV1, GLO and LN2. 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 10).

A review of the available records within the Eastern and South Eastern CFRAM areas showed that there are sufficient records (AMAX) to form a recommended pooling group size of 450 station-years from these records. However, a region can be formed by pooling records from all across Ireland. For HA15 there are 580 station-year of AMAX records are available which are sufficient to form a pooling group for estimating a regional growth curve for this hydrometric area. However, for estimation of growth curve at each of the HEP or hydrometric gauging locations, pooling of AMAX records from other gauged catchments with similar physiographic and climatological characteristics located in the neighbouring hydrometric areas would be required.

In addition, hydrometric station review outputs from the Suir CFRAM Study will be incorporated to pooling group analysis as deemed appropriate based on the confidence associated with any revised stage discharge relationships and AMAX series.

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. In addition, incoming flow between tributaries will be accounted for in the catchment flow calibration process whereby tributary flow inputs are iteratively adjusted to achieve a match with observed flow at hydrometric stations. 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, volume and spatiotemporal distribution (if radar data is used). 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 11) 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 25km²; 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 Institute of Hydrology Report (IH) No. 124 method (Reference 12) would be more appropriate (**Box 11**). IH 124 (refer to Section 5.6.2) remains the recommended estimation method over FSU for small catchments, as advised by OPW. The factorial standard error associated with the QBAR estimation will also be used to calculate 68% and 95%ile confidence intervals. Gauging station data within HA15 will be analysed to determine a

relationship between QBAR and Q_{med} so that a conversion can be undertaken before the relevant growth factor is applied.

Where hydrograph shapes are required for upstream limit model input, the Flood Studies Supplementary Report (FSSR) (Reference 13) Unit Hydrograph Technique or FSU Hydrograph Shape Generator will be explored in an effort to derive the most appropriate hydrograph shapes. These methods are outlined in Sections 5.6.2, 5.6.3 and 5.6.4.

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

5.4.3.2.1 Tributary catchments < 25km²

Similar to small Upstream Limit HEPs, these will be assessed using the IH 124 method for small ungauged catchments; coupled with the relevant derived growth curve. However if such catchments are gauged, a single site analysis may be more appropriate.

5.4.3.2.2 Tributary catchments >25km²

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_{medpdc}) 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_{medpdc} . The Q_{medpdc} 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. Seven pivotal site options are listed. 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 listed.

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, DRAIN, S₁₀₈₅ 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 ± 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 for example, the Dinin River which is a large tributary of the River Nore. Flow contributions from tributaries $5\text{km}^2 \sim 100\text{km}^2$ will be estimated using 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 calibration. At these points, a NAM model will be constructed for the entire upstream catchment, calibrated to available flow data. The generated AMAX series (and growth curve as needed) will be used to derive peak flows for each design AEP at the gauging station HEP. This will be used in Catchment Flow Calibration

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 5.2.1.1)).

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 15 hydrometric stations located on modelled watercourses in HA15, 13 have water level and flow data available for catchment flow calibration (refer to Table 4.6), and are therefore viable has HEP Check Points. The remaining two stations have only water level data available (refer to Table 4.6). However this level data could be used to compare observed water levels at the check point with the hydraulic model level outputs for higher AEP (lower return period) events i.e. 50% (2 year return period); 20% (5 year return period).

Design rainfall input to the NAM models will be estimated using probabilistic analysis based on radar derived rainfall data series (if approved for use) 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.

FSU Work Package 3.4 (Reference 14) provides river basin modelling guidance; on how to use catchment descriptors to estimate peak flow inputs from tributaries to ensure that the design AEP flow is simulated in the modelled channel (section 13.5.3). Where gauging stations are available, the guidance is followed in that the observed data will be used to adjust flow inputs as required as described above. 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 <5km² 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 HA15 AND ASSOCIATED ANALYSIS

Appendix E contains a map showing the layout of HEPs in HA15, and their category. A map showing the contributing catchments to each HEP is also contained in Appendix E.

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
15_198_10	Model 1	HEP Tributary	Rainfall Runoff Modelling
15_946_2	Model 1	HEP Tributary	Peak Flow Estimation
15_1938_5	Model 1	HEP Tributary	Peak Flow Estimation
15004	Model 1	HEP Gauging Stations	Catchment Flow Calibration
15007	Model 1	HEP Gauging Stations	Catchment Flow Calibration
15012	Model 1	HEP Gauging Stations	Catchment Flow Calibration
15_1003_4	Model 1	HEP Tributary	Peak Flow Estimation
15_1965_5	Model 1	HEP Tributary	Peak Flow Estimation

NODE_ID_CFRAM	MODEL NUMBER	HEP CATEGORY	HYDROLOGY
15_420_6	Model 1	HEP Tributary	Peak Flow Estimation
15_994_1	Model 1	HEP Upstream Limit	Rainfall Runoff Modelling
15_306_2	Model 1	HEP Upstream Limit	Peak Flow Estimation
15_306_8	Model 1	HEP Tributary	Peak Flow Estimation
TBC	Model 1	HEP Upstream Limit	Rainfall Runoff Modelling
TBC	Model 1	HEP Upstream Limit	Rainfall Runoff Modelling
TBC	Model 1	HEP Upstream Limit	Peak Flow Estimation
15_1318_3	Model 1	HEP Tributary	Peak Flow Estimation
15_1880_7	Model 1	HEP Tributary	Peak Flow Estimation
15_420_3	Model 1	HEP Upstream Limit	Peak Flow Estimation
15_1965_2	Model 1	HEP Upstream Limit	Peak Flow Estimation
15_1461_8	Model 1	HEP Tributary	Peak Flow Estimation
15_1455_7	Model 1	HEP Tributary	Peak Flow Estimation
15_911_5	Model 1	HEP Tributary	Rainfall Runoff Modelling
15_923_2	Model 1	HEP Tributary	Rainfall Runoff Modelling
15_1060_5	Model 1	HEP Tributary	Peak Flow Estimation
15_1813_11	Model 1	HEP Tributary	Peak Flow Estimation
15_1749_11	Model 1	HEP Tributary	Rainfall Runoff Modelling
15_338_5	Model 1	HEP Tributary	Peak Flow Estimation
15_359_2	Model 1	HEP Tributary	Peak Flow Estimation
15_1880_5	Model 1	HEP Upstream Limit	Peak Flow Estimation
15_1770_2	Model 1	HEP Tributary	Peak Flow Estimation
15_1858_10	Model 1	HEP Tributary	Peak Flow Estimation
15_200_2	Model 1	HEP Tributary	Peak Flow Estimation
15_196_2	Model 1	HEP Tributary	Rainfall Runoff Modelling
15_479_6	Model 1	HEP Tributary	Peak Flow Estimation
15_1824_6	Model 1	HEP Tributary	Peak Flow Estimation
15_944_2	Model 1	HEP Tributary	Peak Flow Estimation
15027	Model 2	HEP Gauging Stations	Catchment Flow Calibration
TBC	Model 2	HEP Tributary	TBC
15_289_1	Model 2	HEP Upstream Limit	Rainfall Runoff Modelling
15_1000_1	Model 2	HEP Upstream Limit	Rainfall Runoff Modelling
TBC	Model 2	HEP Upstream Limit	Peak Flow Estimation
15_289_3	Model 2	HEP Tributary	Peak Flow Estimation
15_1360_8	Model 2	HEP Tributary	Peak Flow Estimation
TBC	Model 3	HEP Tributary	Peak Flow Estimation
15_12_1	Model 3	HEP Upstream Limit	Rainfall Runoff Modelling
15_467_2	Model 3	HEP Upstream Limit	Peak Flow Estimation
15_418_4	Model 3	HEP Tributary	Peak Flow Estimation
15_1390_3	Model 4	HEP Tributary	Peak Flow Estimation
15_75_9	Model 4	HEP Tributary	Peak Flow Estimation
TBC	Model 4	HEP Tributary	Peak Flow Estimation
15_75_7	Model 4	HEP Upstream Limit	Rainfall Runoff Modelling
15_1029_1	Model 4	HEP Upstream Limit	Rainfall Runoff Modelling

NODE_ID_CFRAM	MODEL NUMBER	HEP CATEGORY	HYDROLOGY
15_1423_14	Model 4	HEP Tributary	Peak Flow Estimation
TBC	Model 4	HEP Tributary	TBC
15_1323_5	Model 5	HEP Tributary	Peak Flow Estimation
15_1257_7	Model 5	HEP Tributary	Peak Flow Estimation
15_1269_4	Model 5	HEP Tributary	Peak Flow Estimation
15_1332_4	Model 5	HEP Tributary	Peak Flow Estimation
15_671_2	Model 5	HEP Tributary	Peak Flow Estimation
15002	Model 5	HEP Gauging Stations	Catchment Flow Calibration
15050	Model 5	HEP Gauging Stations	Catchment Flow Calibration
15104	Model 5	HEP Gauging Stations	Catchment Flow Calibration
15105	Model 5	HEP Gauging Stations	Catchment Flow Calibration
15_1323_1	Model 5	HEP Upstream Limit	Rainfall Runoff Modelling
15_1922_1	Model 5	HEP Upstream Limit	Peak Flow Estimation
15_1257_3	Model 5	HEP Upstream Limit	Rainfall Runoff Modelling
15_1515_3	Model 5	HEP Upstream Limit	Rainfall Runoff Modelling
15_1955_6	Model 5	HEP Tributary	Rainfall Runoff Modelling
15_1078_3	Model 5	HEP Tributary	Peak Flow Estimation
15_671_1	Model 5	HEP Upstream Limit	Peak Flow Estimation
15_1150_1	Model 5	HEP Upstream Limit	Rainfall Runoff Modelling
15_368_5	Model 5	HEP Tributary	Peak Flow Estimation
15_159_4	Model 5	HEP Tributary	Peak Flow Estimation
15009	Model 6	HEP Gauging Stations	Catchment Flow Calibration
15_1786_4_RPS	Model 6	HEP Tributary	Peak Flow Estimation
15_593_1	Model 6	HEP Upstream Limit	Peak Flow Estimation
15_1786_1	Model 6	HEP Upstream Limit	Peak Flow Estimation
15_1733_4	Model 6	HEP Upstream Limit	Rainfall Runoff Modelling
TBC	Model 6	HEP Tributary	TBC
TBC	Model 6	HEP Tributary	Peak Flow Estimation
TBC	Model 6	HEP Tributary	TBC
15_501_2	Model 6	HEP Tributary	Peak Flow Estimation
15_157_3	Model 6	HEP Tributary	Peak Flow Estimation
15_686_5	Model 6	HEP Tributary	Peak Flow Estimation
15_458_8	Model 6	HEP Tributary	Peak Flow Estimation
15_1991_3	Model 6	HEP Tributary	Peak Flow Estimation
15_1762_5	Model 6	HEP Tributary	Peak Flow Estimation
15_1106_5	Model 7	HEP Tributary	Peak Flow Estimation
15_1814_4	Model 7	HEP Tributary	Peak Flow Estimation
15_1819_6	Model 7	HEP Tributary	Rainfall Runoff Modelling
15_1848_3	Model 7	HEP Tributary	Peak Flow Estimation
15006	Model 7	HEP Gauging Stations	Catchment Flow Calibration
15011	Model 7	HEP Gauging Stations	Catchment Flow Calibration
15_1106_3	Model 7	HEP Upstream Limit	Rainfall Runoff Modelling
15_482_4	Model 7	HEP Upstream Limit	Rainfall Runoff Modelling
15_520_4	Model 7	HEP Tributary	Peak Flow Estimation

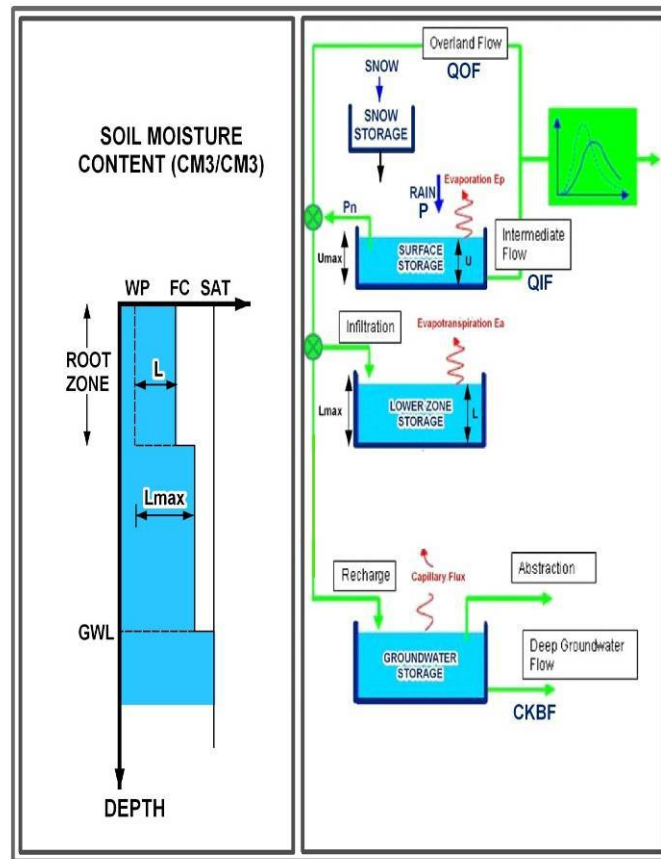
NODE_ID_CFRAM	MODEL NUMBER	HEP CATEGORY	HYDROLOGY
15_707_3	Model 7	HEP Tributary	Peak Flow Estimation
15_93_7	Model 7	HEP Tributary	Peak Flow Estimation
15_1511_8	Model 7	HEP Tributary	Peak Flow Estimation
15_650_7	Model 7	HEP Tributary	Peak Flow Estimation
15_2002_9	Model 7	HEP Tributary	Peak Flow Estimation
15_2008_6	Model 7	HEP Tributary	Peak Flow Estimation
15_2016_2	Model 7	HEP Tributary	Peak Flow Estimation
15_2014_4	Model 7	HEP Tributary	Peak Flow Estimation
15_1358_3	Model 8	HEP Upstream Limit	Rainfall Runoff Modelling
15_1337_12	Model 8	HEP Tributary	Peak Flow Estimation
15_1212_7	Model 8	HEP Tributary	Peak Flow Estimation
15_1358_8	Model 8	HEP Tributary	Peak Flow Estimation

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 interrelated 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 15)

MIKE NAM utilises all available rainfall data as hydrological model input, together with parameters to describe catchment response. 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.

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;
- CK₁₂ - 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 Eastern CFRAM Study area. The following parameters will be estimated based on a decision tree methodology:

- The **surface storage U_{max}** [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 15), a series of decision tables were developed to determine four 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_{max}), (SWRBD, RPS, 2008)

NAM Parameter	Corine	Range of NAM parameter value	Slope	Lakes	Poorly drained soils	Urban	GIS estimation for sub-catchment
U_{max} (mm)	>5% Forestry & Semi-natural areas	15 - 25	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%	10 – 20					1B, 2C
	Forestry 0%, Pastures <40% and Bare rock >20%	8 - 15	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_{max} (*surface storage zone*) for each catchment. U_{max} 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_{max} 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_{max} values given in the adjacent column.

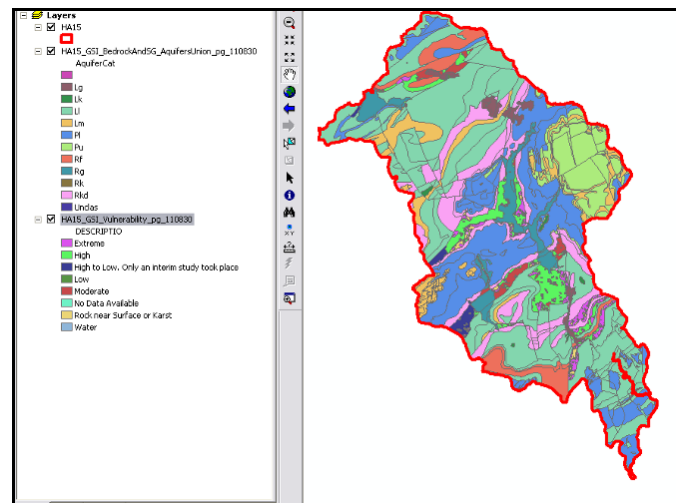
The selected value of U_{max} for a catchment can be further refined dependent upon the average slope, coverage by lakes, coverage by wet soils and the amount of urban area. For example, the U_{max} value would be expected to be at the lower end of the land cover ranges if the average slope of a catchment is relatively steep (>5%). Also, a high percentage of lakes will act as storage resulting value of U_{max} 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_{max}.

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.

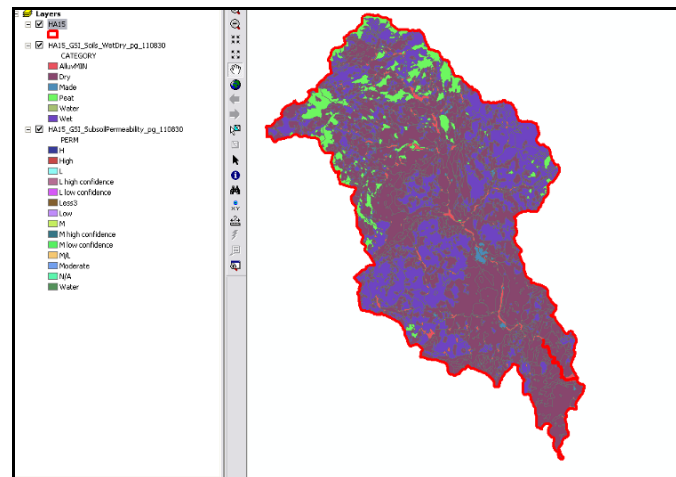
The initial estimation of the four parameters (Umax, CQOF, CKIF and CKBF) driving the rainfall-runoff process will be done using the available GIS datasets, namely:

- 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

Bedrock Aquifer Type and Groundwater Vulnerability



Sub Soil Permeability & Soil Drainage



Land Use

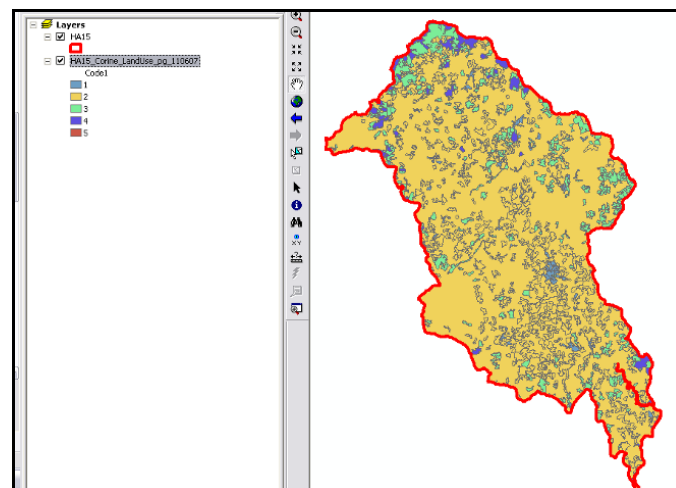


Figure 5.4: Available GIS datasets for deriving the NAM model parameters in HA15

The parameters for the NAM modelling that have not been estimated 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 16) 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.

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 1 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 4 parameters: U_{max} ,
- 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 data is available (water levels / flows) at HEPs Gauging Station 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 data is available, i.e. at the 15 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. Additional tools for analysis of the calibrated NAM models will be also provided, see Figure 5.5.

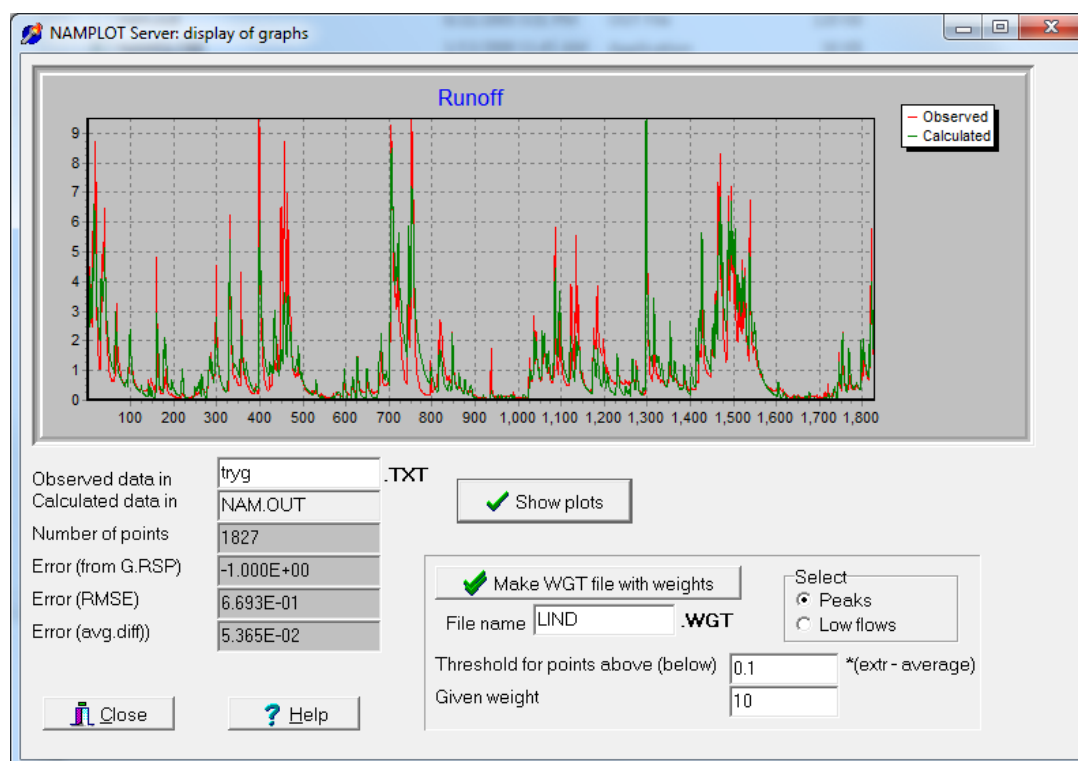


Figure 5.5: Visualization tools for the NAM model calibration component.

It may be necessary in urban areas such as Kilkenny 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 2 at Mountrath has two upstream limit NAM models with a HEP Gauging Station Check Point further downstream within the town. In this case, three NAM models will be set up - two NAM models at the HEP upstream limits and one joint 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 HEPs catchments analysis, it is estimated that approximately 30% 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.

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} . If the rainfall radar trials are successful and this method of analysis is rolled out to the entire South Eastern CFRAM area the rainfall inputs used in the NAM modelling process will be generated from a combination of rain gauge data and radar data using the methodology outlined in Appendix C. In the event that the rainfall radar approach is not adopted the rainfall profiles will be derived from gauge data alone and distributed using Thiessen 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 Institute of Hydrology Report No. 124

This statistical method was developed by the Institute of Hydrology (IH) in the UK for small catchments (<25km²). It was developed in 1994 and does not contain any Irish catchment data. However, it is the preferred method for smaller catchments in Ireland and it is still recommended by OPW.

There are two applications within the IoH 124 report:

1. Replacement of Time to Peak Equation in FSSR Unit Hydrograph method (refer to Section 5.6.4) for small catchments so that a hydrograph can be generated
2. Use of QBAR estimation equation by catchment characteristics and a growth curve to estimate Q_t where peak flows only are required. The Factorial Standard Error associated with this method for QBAR estimation is 1.651. The relationship between QBAR and Q_{med} must then be derived from relevant gauging data so that Q_{med} can be calculated.

5.6.3 Flood Studies Update (FSU) Qmed Estimation

As referred to in Section 5.4 the OPW have 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 17). It has been in development since 2004 and is in the final stages of completion.

A software application in 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, but the number of stations across the country deemed suitable for this purpose is smaller than for Q_{med} estimation.

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

The recommended method for flood estimation in small catchments (approx $<25\text{km}^2$) is still IH 124 as there is not enough gauged data from small catchments to serve as pivotal sites in the FSU as of yet.. OPW are working on augmenting the gauged data with smaller catchments at present.

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 18) 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.

5.6.4 FSSR Unit Hydrograph Method

The FSSR Unit Hydrograph method is a deterministic method for estimating design hydrographs (Reference 13). It is a rainfall runoff method based on estimating a unit hydrograph using catchment descriptors and estimating critical rainfall for design storm duration i.e. rainfall and catchment response to develop the storm hydrograph.

The Flood Studies Report undertook a comprehensive analysis of rainfall and discharge data in UK and Ireland up to 1970 and contains a series of maps of various quantities derived for rainfall data. Regional analysis was undertaken in the UK, but Ireland was taken as a single region which is widely accepted as an inaccurate representation of the east-west differences on the Island. In cases where this method is applied to Upstream Limit or Tributary HEPs in this Study, appropriate rainfall profiles will be used based on the rainfall data analysis described in Section 5.1.3.

A spreadsheet calculation will be used to input relevant catchment descriptors to calculate Time to peak, data intervals, storm duration, rainfall amount for the required AEP, standard percentage run off

and base flow. ISIS software then facilitates an automated convolution process to draw the hydrograph shape and provide the Q and time data necessary for hydraulic model input.

6 DETAILED METHODOLOGY REVIEW

The discussion regarding data collection, gaps and outstanding information, presented in Section 2 of this South Eastern CFRAM Study Inception Report - HA15 (Nore), 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 National Flood Risk Assessment and Management Programme, South Eastern River Basin District Catchment-based Flood Risk Assessment and Management (CFRAM) Study Stage II Tender Documents: Instructions to Tenderers – used to add or remove specified contract items.

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 the HA15 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 and health and safety requirements. These activities are all either complete or currently in place and ongoing during the study. Technical training and National Technical Coordination Group participation have not yet commenced awaiting delivery/procurement of other CFRAM Study partners however these are not currently critical path and no associated methodology changes are proposed at present. There is a requirement under the South Eastern CFRAM Study brief to liaise with the Suir CFRAM Pilot Study, reporting and technical activities in this regard are summarised in Section 6.2.
- Data Collection – section 2 of this report details the collection of relevant datasets and the initial phase has concluded 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 is complete and the final report with RPS recommendations to OPW has been issued. The methodology for this task was updated as detailed in a Technical Note (Section 6.1).
- 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 – section 4 of this inception report expands on the tendered hydrological methodology as applied to HA15. In addition a proposal to improve the rainfall inputs to the hydrological and hydraulic models by using RADAR rainfall data is being implemented on a staged basis as detailed in a Technical Note (Section 6.2).
- Hydraulic Analysis – there is no tendered methodology change proposed in HA15 to date.
- Flood Risk Assessment – there is no tendered methodology change proposed in HA15 to date.
- Environmental Assessment – there is no tendered methodology change proposed in HA15 to date.
- Consultation And Engagement – there is no tendered methodology change proposed in HA15 to date.
- Development Of Flood Risk Management Options – there is no tendered methodology change proposed in HA15 to date.
- Preparation Of Flood Risk Management Plans – there is no tendered methodology change proposed in HA15 to date.
- Reporting And Deliverables – there is no tendered methodology change proposed in HA15 to date.

RPS maintains a live project risk and opportunities register to consider implications for programme, quality and budget for the South Eastern 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

Flood Risk Review – the methodology applied in the South Eastern CFRAM study followed that developed for the Eastern CFRAM Study detailed in Technical Note 1 (IBE0601 TN0001). This details an updated methodology for flood risk review (FRR) in the South Eastern study area based on the progress with the Preliminary Flood Risk Assessment (PFRA) between time of generic specification and tender and the Eastern CFRAM Study FRR. Updated consultation, scoring and modelling approaches were set out in the document in order to progress the task in the absence of some data sets (such as flood defence databases) which were not available at the time of the FRR due to the delayed start date of the overall project.

Surveys – the Generic CFRAM Study brief requires the following surveys:

- Defence asset condition survey – project specific specification applies to HA15, these surveys are not yet scheduled to commence (programmed for June 2012 – September 2012 these surveys are subject to locations being identified by structure and cross section survey contracts), no methodology change is proposed at this stage.
- Property survey – project specific specification applies to HA15, these surveys are not yet scheduled to commence, no methodology change is proposed at this stage.
- Floodplain survey – project specific specification applies to HA15, the LiDAR survey is progressing at national level, due to programme slippage RPS have not yet been able to undertake any data quality assessment, RPS have undertaken additional work to review the survey extents so that complete coverage of revised Areas of Further Assessment (AFAs) is obtained and RPS are also considering prioritisation of LiDAR survey deliverables to accommodate programming constraints.
- Channel and structure survey – the project specific specification excludes HA15 from the scope of the RPS procured surveys. Pre-contracted surveys are progressing in the field, however, due to concerns regarding survey resourcing across several simultaneous CFRAM Studies, RPS proposed the following methodology amendments.

Following completion of the Flood Risk Review and subsequent delineation of all watercourses within AFAs to optimise the quantity of rivers to be surveyed, RPS proposed a substantial reduction in the length of the rivers specified in SC4. Further to this, RPS identified that the quantity of cross sections removed from SC4 was equivalent to that proposed for the survey contract covering HAs 11, 13 & 17. RPS therefore proposed to OPW that these two contracts could be merged, thus offering a time and cost saving and additionally providing CCS with a contract of the magnitude of which they originally tendered. This was proposal was accepted by OPW and subsequently CCS were awarded a contract covering the whole of the South Eastern CFRAM Study area.

There are no further additional risks and associated methodology amendments identified at present in the HA15 Unit of Management.

6.2 OPPORTUNITIES AND PROPOSED METHODOLOGY AMMENDMENTS

Data Collection – South Eastern CFRAM Study Technical Note 1 (IBE0601 TN0001) details RPS's proposed Flood Event Response Plan so that the response team members are appraised of requirements before an event occurs.

Hydrological Analysis – Eastern CFRAM Study Technical Note 3 (IBE0600 TN0003) details a potential opportunity to utilise RADAR rainfall data to provide a more accurate representation of the spatial and temporal hydrological inputs to the hydraulic models made possible by the availability of Met Éireann's RADAR datasets. A demonstration of the method was provided to OPW 26/10/11 and a staged basis of service delivery accepted by OPW in their letter of 14 December 2011. The staged trial initially applies to the Dodder catchment and subject to the success of stage 1 a fourth stage would apply to the whole South Eastern study area and therefore HA15.

Study Integration - The involvement of RPS in providing modelling support to the OPW team undertaking the Suir CFRAM study and in the preparation of the SEA for this catchment provides an opportunity to ensure harmonisation between the two projects particularly in terms of downstream boundary conditions. In order to facilitate integration of the Suir and South Eastern CFRAM Studies there are a number of formal reporting and technical actions in place:

- An update on the Suir CFRAM is included in the South Eastern CFRAM progress meeting agenda;
- RPS are provided with regular Suir CFRAM progress reports; and
- Information sharing is ongoing, particularly at this stage focussing on ongoing technical activities including hydrological analysis methodologies and joint probability analysis of the downstream modelled watercourse boundary where the Barrow and Suir meet at Cheekpoint.

There are no further additional opportunities and associated methodology amendments identified at present in the HA15 Unit of Management.

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, Eastern River Basin District 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:** Office of Public Works, December 2009: “Flooding at Newacre, Athy Road, Co. Carlow on 23rd November 2009”
- Reference 7:** John Creed & Associates Consulting Civil Engineers, August 2005: “New Ross Town – October 2004 Flood Levels”
- Reference 8:** T.J. O'Connor & Associates Consulting Engineers, July 1998: “Report on flooding of the Lower Rosbercon Area, New Ross, Co. Wexford”
- Reference 9:** M. C. O'Sullivan Consulting Engineers, April 1996: “Preliminary Report on Carlow/Graigue-Cullen Flood Relief Scheme”
- Reference 10:** Office of Public Works, 2009: “Flood Studies Update - Work Package 2.2 - Frequency Analysis”
- Reference 11:** Met Éireann, 2004: “Flood Studies Update - Work Package 1.2 – Estimation of Point Rainfall Frequencies”
- Reference 12:** Institute of Hydrology, 1994: “Report No. 124, Flood Estimation for Small Catchments”
- Reference 13:** 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 14:** Office of Public Works, JBA, 2010: “Flood Studies Update - Work Package 3.4, Guidance for River Basin Modelling”
- Reference 15:** RPS, SWRBD, 2008, “Further Characterisation Study: An Integrated Approach to Quantifying Groundwater and Surface Water Contributions of Stream Flow”
- Reference 16:** 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 17: Office of Public Works, 2011: “Flood Studies Update, Alpha Testing Users Guide”

Reference 18: 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

HA15 - Hydromteric Stations

Key

	Annual Max Data
	Daily Data
	15 Min Data

APPENDIX B

DAILY AND HOURLY RAINFALL

DATA STATUS TABLES

Daily Rain - Data Status Table

[illegible]

Daily Rain - Data Status Table

[illegible]

Daily Rain - Data Status Table

Station No.	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Station No.
ASHTOWN																																1507	
BELLEMEAD (TESTN.)																																707	
DUNGARVAN (RES. STN.)																																807	
DUNGARVAN (CROSSLCA)																																1407	
DUNGARVAN (CLODCA)																																2007	
DUNGARVAN (CLODCA)																																307	
DUNGARVAN (CLODCA)																																1607	
DUNGARVAN (CLODCA)																																307	
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Daily Rain - Data Status Table

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Daily Rain - Data Status Table

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Daily Rain - Data Status Table

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Daily Rain - Data Status Table

[illegible]

Daily Rain - Data Status Table

[illegible]

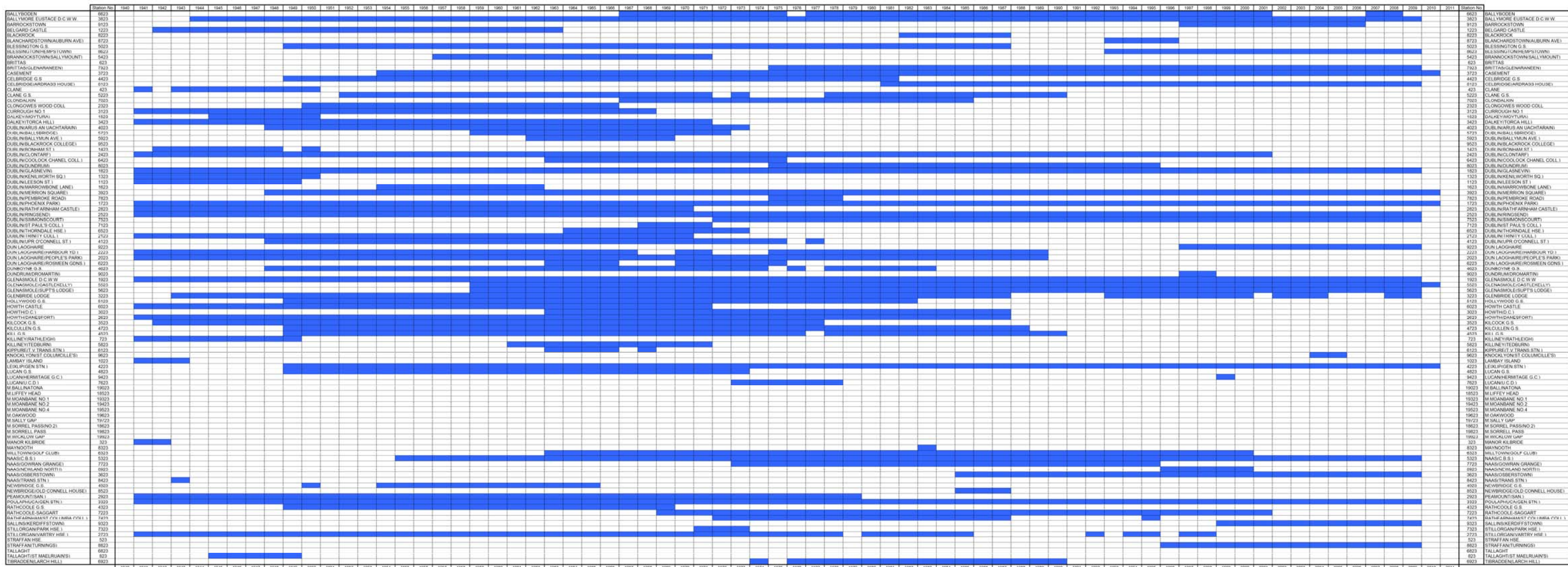
Daily Rain - Data Status Table

Station No	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Station No
ANAMORGLUGLONDUGH HOUSE)																																	2220 ANAMORGLUGLONDUGH HOUSE)
ARLOWCOOLADANGAN HOUSE)																																	2720 ARLOWCOOLADANGAN HOUSE)
ARLOWWHELETON ABBEY)																																	1220 ARLOWWHELETON ABBEY)
ARLOWFERREBAN)																																	1820 ARLOWFERREBAN)
ARLOW W.W.																																	1920 ARLOW W.W.
AUGHAVANNAGHFOR STN.)																																	120 AUGHAVANNAGHFOR STN.)
AUGHIMBALLYTEGE)																																	1320 AUGHIMBALLYTEGE)
AUCFIRM G.S.																																	260 AUCFIRM G.S.
AVOCA/COPPER MINES)																																	1720 AVOCA/COPPER MINES)
BALLINASTOE																																	720 BALLINASTOE
GLENDALOUGH FOR LARAIGH)																																	400 GLENDALOUGH FOR LARAIGH)
GLENDALOUGH FOR STN.)																																	320 GLENDALOUGH FOR STN.)
GLENDALOUGH																																	2320 GLENDALOUGH
GLENNACROSS)																																	1420 GLENNACROSS)
GLENNALURE FOR STN.)																																	200 GLENNALURE FOR STN.)
GLENNALURE FOR KIRKREE)																																	1120 GLENNALURE FOR KIRKREE)
LARAIGHTTPOOFCRISTOWN)																																	2620 LARAIGHTTPOOFCRISTOWN)
LOUGH DANOL(BRIDGEE)																																	1820 LOUGH DANOL(BRIDGEE)
LOUGH DAN																																	620 LOUGH DAN
LOUGH NANAGHAN																																	1620 LOUGH NANAGHAN
LUGGALA GATE LODGE																																	2020 LUGGALA GATE LODGE
M.GLENNALURE(UGHERNAGH FOR.)																																	8420 M.GLENNALURE(UGHERNAGH FOR.)
M.LOUGH DANCAS MTN.)																																	2120 M.LOUGH DANCAS MTN.)
M.LOUGH DULER																																	860 M.LOUGH DULER
M.MULLAGHCLEEVAN																																	8720 M.MULLAGHCLEEVAN
M.RATHOYIMALLINTOMBAY FOR.)																																	950 M.RATHOYIMALLINTOMBAY FOR.)
M.AUGHAVANNAGH(SLEVEAN FOR.)																																	9620 M.AUGHAVANNAGH(SLEVEAN FOR.)
M.AUGHRENCARRICKAHANE)																																	8820 M.AUGHRENCARRICKAHANE)
M.AUCFIRM(COLASH FOR.)																																	890 M.AUCFIRM(COLASH FOR.)
M.DUJUCE MTN																																	9020 M.DUJUCE MTN
M.DUFF HILL																																	9220 M.DUFF HILL
M.GLENDALOUGH(SUDDIFT FOR.)																																	9320 M.GLENDALOUGH(SUDDIFT FOR.)
MONEY TOWN																																	620 MONEY TOWN
OLDBRIDGEE(DAIVEW)																																	2420 OLDBRIDGEE(DAIVEW)
PETTIGO																																	440 PETTIGO
RATHOYIMALLINTOMBAY)																																	520 RATHOYIMALLINTOMBAY)
TIMAHELYMULLAGH)																																	2520 TIMAHELYMULLAGH)
TURLLOGH HILL																																	1520 TURLLOGH HILL

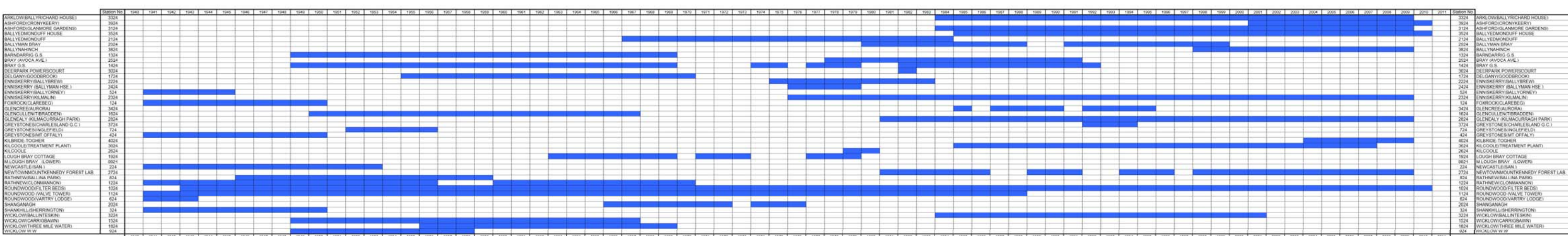
Daily Rain - Data Status Table

[illegible]

Daily Rain - Data Status Table



Daily Rain - Data Status Table



RevF02

Hourly Rain
Data Status Table

[illegible]

APPENDIX C

RAINFALL RADAR DATA ANALYSIS TO PROVIDE INPUT TO HYDROLOGICAL MODELS

If the use of radar data for hydrological input is rolled out to the entire South Eastern CFRAM Study area, rainfall radar data for Dublin and Shannon Airport for the period 1997-2011 will be processed by HydroLogic. Preliminary calibration of radar data on a monthly basis using ground observation data from rain gauges will be undertaken. Rainfall input for hydrological models will be generated using weighted averaging of the radar pixels above each HEP catchment area.

Daily and hourly rainfall data provided by Met Éireann and Local Authorities will be used to calibrate rainfall radar data as applied to HA15. The number of rain gauges used for calibration of radar is variable; the results calibration depends on the number of high quality rain gauges. Rain gauge data quality assessment and labelling includes several data checks including:

- detection of gaps,
- detection of physically impossible data,
- detection of constant intensities,
- values above set thresholds,
- detection of too high or too low daily sums compared to neighbouring stations.

Only periods of plausible data are taken for calibration and verification procedures.

The combination of spatial distributed rainfall intensities from radar and accurate rainfall amounts from rain gauges will result in an improved dataset for use in hydrological modelling, both in terms of spatial resolution (1 x 1 kilometre grid) and temporal resolution (hourly data). The result of the preliminary radar calibration will be verified using independent stations (not used for calibration of radar).

Improved calibration of radar data will consist of several consecutive calibration steps on an hourly or 15 minute basis, similar to the steps described by Holleman (2007)¹:

1. Calculate the parameter (RG) describing the relation between the amount of precipitation from rain gauges (G) and the corresponding radar pixels (R) for each pair of G and R:

$$RG = 10^{10} \log\left(\frac{R}{G}\right)$$

2. Bias correction: the average of all available RG values is used to correct for any bias, for example calibration errors. Moreover, the calculated standard deviation is used to perform a quality control on the RG values, and thus the radar and rain gauge observations.

3. Distance correction: correction for the height of the radar beam above earth surface and related underestimation of the precipitation intensity at that location. This correction is described as a function of the distance from the radar (r); RG and r are then fitted to a parabola.
4. Spatial correction: an inverse-distance method of the RG values is used to correct for local effects in the radar composite. This analysis yields a smooth field fitted to the data points.

Existing HydroNET tools will be used together with the SCOUT software by hydro&meteo (www.hydrometeo.de). These tools are already widely used in the Netherlands and internationally. The result is a self describing dataset in the NetCDF format; a format which is well-known and widely used in meteorology.

A phased approach to the use of radar rainfall data will be applied within the overall Eastern CFRAM Study hydrology methodology. The phasing is based on determining the accuracy and applicability by trialling it on a pilot area, then rolling it out to the entire Eastern and South Eastern CFRAM area if proven beneficial.

Stage 1 of the Dublin radar data analysis for the Dodder catchment indicated that the usage of the Dublin radar data, although with variable quality, can bring a significant improvement in the estimation of the rainfall inputs when compared to the area weighted rainfall estimation (traditionally used) for the hydrologic and hydrodynamic modelling for each HEPs. For hydrological modelling and estimation of the designed flows in the Study area, radar-based NAM inputs will be generated (subject to the results of the first phase of trialling, using polygon shape files describing catchment areas for each individual HEP (refer to Section 5.3 and 5.4)

Since radar data is available only for the period 1997- 2011, the spatio-temporal distribution for the periods before 1997 will be estimated using the daily and sub-daily time series of the additionally available rainfall data from the rain gauges (provided by Met Éireann and the Local Authorities). From the processed and calibrated radar data (period 1997-2011) typical rainfall parameters (daily and monthly sums) will be generated for each month for the HEP catchment areas. Those sums will be scaled to relative weights using grid-based weighing techniques (inverse-distance, radial basis functions or others). The daily and the sub-daily precipitation patterns for the HEP catchment areas will then be generated by multiplying the radar patterns (relative weights) with the time recorded series for the periods before 1997 for the length of the available time series. In cases where it is impossible to generate averaged radar-based patterns, we will use standard Thiessen polygons or other interpolation techniques (such as IDW) to generate spatially-weighted time series rainfall inputs for the hydrological models. This will result in the production of rainfall input files for each NAM HEP for the entire length of rainfall time series data provided.

¹ I. Holleman. (2007) Bias adjustment and long-term verification of radar-based precipitation estimates. *Meteorological Applications* 14:2, pp.195-203.

APPENDIX D

Hydrology Method Process Chart – Used Datasets Table

Box Number (Figure 2.2)	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	Rainfall Radar Data (if approved)	Daily and Hourly Rainfall Station Data	Met Eireann 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 E

HEP and Catchment Diagrams



