

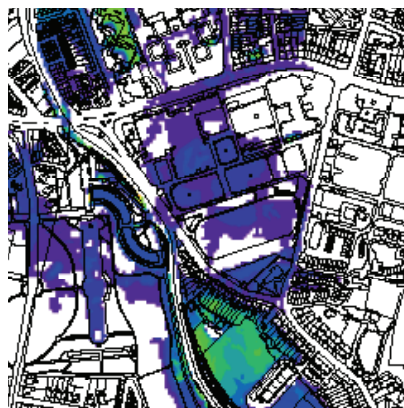
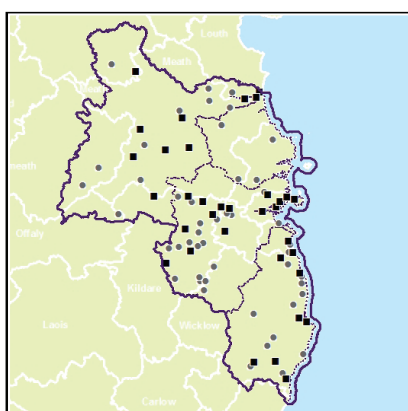
RPS



Eastern CFRAM Study

HA10 Inception Report

IBE0600Rp0005_F02/July12



Eastern CFRAM Study

HA10 Inception Report

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1 INTRODUCTION

The Office of Public Works (OPW) commissioned RPS to undertake the Eastern Catchment Flood Risk Assessment and Management Study (Eastern CFRAM Study) in June 2011. The Eastern CFRAM Study was the second catchment flood risk management study to be commissioned in Ireland under the EC Directive on the Assessment and Management of Flood Risks (Reference 1) as implemented in Ireland by SI 122 of 2010 European Communities (Assessment and Management of Flood Risks) Regulations 2010 (Reference 2).

The Eastern CFRAM Study covers an area of approximately 6,250 km² and includes four Units of Management, Hydrometric Area (HA)07 (Boyne), HA08 (Nanny–Delvin), HA09 (Liffey-Dublin Bay) and HA10 (Avoca-Vartry). There is a high level of flood risk within the Eastern CFRAM Study area with significant coastal and fluvial flooding events having occurred in the past.

HA10 covers an area of approximately 1,248 km² and includes parts of counties Wicklow, Wexford, and Dublin. The Avonmore/Avoca system, which rises in the Wicklow Mountains and flows southwards discharging to the Irish Sea at Arklow, is HA10's principal river, there are also numerous smaller river systems in HA10, including the Carrickmines/Shanganagh and Dargle rivers, flowing generally eastwards to discharge at the coast.

HA10 has mixed catchment land use, with major urbanised areas, including Loughlinstown, Old Connaught/Wilford, Bray, Greystones/Charlesland, Kilcoole, Newcastle, Ashford/Rathnew and Wicklow, generally located along the coastline (Aughrim and Avoca are located inland in the Avoca catchment) while the upland hinterland of HA10 is more rural in nature.

Within HA10 there are 10 Areas for Further Assessment (AFA) under the Eastern CFRAM study as shown in Figure 1.1. The principal sources of flood risk are combined fluvial and tidal flooding in the four coastal AFAs with fluvial flood mechanisms acting in the six inland AFAs. Three High Priority Watercourses (HPWs) were specified by OPW; the Deansgrange, Carrickmines/Shanganagh and Carysfort Maretime Rivers.



Figure 1.1: HA10 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 HA10 as part of the 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, Stephen Neill, 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 Eastern CFRAM Study and HA10 in particular started with a review of the lists of data sources and relevant reports identified in the “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 3), hereinafter referred to as the 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 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 start of June 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: North East coast
- 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-Eastern RBD)
- OSi Maps
- LiDAR
- Aerial photography
- OPW Channels
- OPW Embankments
- OPW Benefiting Lands
- Lakes (Lakes/HA_10)
- 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
- Greater Dublin Strategic Drainage Study

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 June 2011 and February 2012 is provided below.

Immediately upon confirmation of appointment in June 2011, RPS requested hydrometric data, levels and flows for all Environmental Protection Agency (EPA) gauging stations and all Electricity Supply Board (ESB) gauging stations within the study area. Details of rating equations and calibration measurements for these stations were also sought from EPA and ESB.

At the beginning of July, RPS issued a request to all relevant Local Authorities seeking details of culverted watercourses, storm sewer systems and discharges and any flood defence schemes in GIS or AutoCAD format. A request was also submitted to OPW seeking:

- Re-supply of the National Digital Height Model data as the original information was for the wrong area;
- Details of the number of affected properties per Area for Further Assessment (AFA) for each AEP as identified through the Preliminary Flood Risk Assessment (PFRA) process;

In mid August, requests were made to GSI for soil and groundwater datasets to inform the MIKE-NAM hydrological model parameters decision trees and derive model input parameters (refer to Chapter 5). The actual datasets requested were:

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

Also in mid August a request was submitted to Wicklow County Council for information on the culverted routes of rivers and minor watercourses in Bray and Arklow.

RPS also made a request to Dún Laoghaire-Rathdown County Council for permission to use information in relation to the following held in the RPS Dublin offices:-

- Deansgrange River – Culvert routes, manhole locations and InfoWorks CS model, Greater Dublin Strategic Drainage Study (GDSDS) report Phase1, 2 and 3;
- Carrickmines River – Culvert routes, manhole locations, River Centrelines, InfoWorks CS model, digital drawings and reports;
- Racecourse Stream River – Culvert routes, manhole locations, and River Centrelines;
- Commons Road - Gauging Station rating review and data from 2002;
- Shanganagh Flood Walls – construction drawings completed by RPS.

Towards the end of August, RPS requested supply of copies of any feasibility study reports or design reports / drawings that OPW held for all of the schemes listed in the tender documents.

At the start of October, RPS requested and received information on the route of the Swan and Kilruddery watercourses from Bray Town Council.

RPS also issued a request to all of the Local Authorities asking them to review the list of 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.

Any aerial photography of flooding held by the Local Authorities was also requested at this time.

A request was also issued to Met Éireann for some missing rainfall data from the meteorological stations in the study area that had been identified through a review of the previously supplied data.

In the middle of October, RPS issued a request to Teagasc for any rainfall data they hold while at the end of October, RPS requested missing Ordnance Survey Ireland (OSi) vector mapping data from OPW.

Details of the locations of all ground based electrical infrastructure was requested from ESB at the beginning of November 2011.

At the beginning of December, RPS sent a request to each Local Authority for the following information:

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 evapotranspiration.

Land-use Data

- Information on current and past land use.

Soil and Geological Data

- Data on soil classifications, sub-soils, geology and aquifers.

Planning and Development Information

- 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 document which stated the study data requirements and also the data currently obtained 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 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 further to a request by the Eastern CFRAM Study progress group, this request was re-issued on 3rd February 2012.

In response to this final request, Dún Laoghaire-Rathdown County Council provided available rainfall data and a copy of their Coast Defence Strategy with photographs and confirmed that they have no further information to provide.

As RPS go through the various stages of the CFRAM study, further data needs may be identified and therefore the information will be requested and obtained.

In all cases every request for information was logged in 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, Spatial Type, Date received) e.g. OPW_HA10_Rivers_pl_110602, 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 a number of existing flood relief and management measures within HA10. No relevant data has been obtained from Wexford County Council as only a very small part of HA10 lies within the boundaries of County Wexford and no Areas for Further Assessments have been identified within this part of County Wexford.

Dún Laoghaire Rathdown County Council:

- CommonsRdWalls_ShanganaghRiver - Proposed Surface / Foul Sewers
- SEM_Racecourse_BallinteerToShankill_Drainage
- 2001 SEM Reports\Carrickmines-Shanganagh Catchment Report
- 2008 Flood mapping\MDW0298DG0000 - 2008 Flood mapping\100 Year Cherrywood Only Estimate
- CARRICKMINES & SHANGANAGH RIVER CATCHMENT STUDY UPDATE 2007
- 2008 Tributary Update Reports\MDW0298Rp0003F01 Stage1 Catchment.pdf
- GDSDS model
- GDSDS - S1008 – Carrickmines
- GDSDS - S1007 – Deansgrange

Wicklow County Council:

- OPW minor works allocation list 2011;
- OPW coastal and non-coastal approved projects list 2010;
- OPW list of funding allocations coastal and non-coastal 2009;
- OPW drainage channels and drainage channel schemes;
- OPW drainage districts.
- S25C-211100716540 - BrayTC_Swan_KilrudderyStreamLocations_FloodExtents2008

- 071012 – Avoca_modelling_BERP01_v2 Flood Relief Scheme Impact of Bridgewater Development on Flood Risk along the Avoca River Summary of Initial Hydraulic Modelling October 2007
- 071211 - Avoca_modelling_BERP01_v2.pdf Flood Relief Scheme Impact of Bridgewater Development on Flood Risk along the Avoca River Summary of Initial Hydraulic Modelling October 2007
- 071211 - Avoca_modelling_BERP02_v2.pdf Flood Relief Scheme Impact of Bridgewater Development on Flood Risk along the Avoca River Addendum to Initial Hydraulic Modelling Report December 2007
- 74601-FIGURE2_1_BIND_0 "OPW_Arklow_Fig2_Mapping_pg_110922,
- OPW_Arklow_Fig2_Mapping_pl_110922,
- OPW_Arklow_Fig2_Mapping_pt_110922,
- OPW_Arklow_Fig2_Mapping_ptText_110922" Flood Relief Scheme
- 74601-FIGURE2_1_BIND_5yr-flood OPW_Arklow_Fig2_5yr_Flood_pl_110922 Flood Relief Scheme
- 74601-FIGURE2_1_BIND_100yr-flood "OPW_Arklow_Fig2_100yr_Flood_pg_110922,
- OPW_Arklow_Fig2_100yr_Flood_pl_110922" Flood Relief Scheme
- 74601-FIGURE2_1_BIND_1000yr-flood "OPW_Arklow_Fig2_1000yr_Flood_pg_110922,
- OPW_Arklow_Fig2_1000yr_Flood_pl_110922" Flood Relief Scheme
- 74601-FIGURE2_1_BIND_AREA OPW_Arklow_Fig2_Area_pg_110922 Flood Relief Scheme
- 74601-FIGURE2_1_BIND_SITEOPT1 OPW_Arklow_Fig2_SiteOpt1_pg_110922 Flood Relief Scheme
- 74601-FIGURE2_1_BIND_SITEOPT2 OPW_Arklow_Fig2_SiteOpt2_pg_110922 Flood Relief Scheme
- 74601-FIGURE2_1_BIND_SITEOPT3 OPW_Arklow_Fig2_SiteOpt3_pg_110922 Flood Relief Scheme
- Map1 with Area Flood Relief Scheme
- Map1 without Area Flood Relief Scheme
- Map 1 (A3 Landscape) Flood Relief Scheme
- Map 1 (A3 Portrait) Flood Relief Scheme
- Map 1 via map info Flood Relief Scheme
- Map 1 via map info zoomed in Flood Relief Scheme
- CD1 - Arklow LiDAR 2004 - AutoCAD - ESRI Grid - Shape File\ESRI Grid - ARKLOW~1 Flood Relief Scheme
- CD1 - Arklow LiDAR 2004 - AutoCAD - ESRI Grid - Shape File\ESRI Grid - ARKLOW~2 Flood Relief Scheme
- CD1 - Arklow LiDAR 2004 - AutoCAD - ESRI Grid - Shape File\ESRI Grid - ARKLOW~3 Flood Relief Scheme
- Arklow OPW_Arklow_Lidar2004_pl_110927 Flood Relief Scheme
- Bear Earth - arklow.shp OPW_Arklow_Lidar2004_BareEarth_pt_110922 Flood Relief Scheme
- Arklow_Bare_Earth Flood Relief Scheme
- CD4 - DCMNR LiDAR and Photogrammetry (1999 - 2006)\DCMNR_to_OPW\1999\LIDAR~1.shp OPW_Arklow_DCMNR_Lidar1999_pg_110922 Flood Relief Scheme
- CD4 - DCMNR LiDAR and Photogrammetry (1999 - 2006)\DCMNR_to_OPW\2005\Arklow\ARKLOW~1.shp OPW_Arklow_DCMNR_Lidar2005_pg_110922 Flood Relief Scheme
- CD4 - DCMNR LiDAR and Photogrammetry (1999 - 2006)\DCMNR_to_OPW\Bndary 2004\ARKLOW~1.shp OPW_Arklow_DCMNR_LidarBoundary2004_pg_110922 Flood Relief Scheme
- CD4 - DCMNR LiDAR and Photogrammetry (1999 - 2006)\DCMNR_to_OPW\Shapefile\ARKLOW~1.shp OPW_Arklow_DCMNR_pt_110922 Flood Relief Scheme
- T10008151 to T10008367 Flood Relief Scheme
- Arklow Coastal Image References.xls Flood Relief Scheme
- Arklow Lidar OPW_Arklow_Lidar_pt_110922 Flood Relief Scheme
- Photos of Flooding Aug 2008 - Flooding Photographs
- River Dargle at Bray Flood Defence Scheme Physical Model Study Report and Environmental Impact Statement (July 2007)

All scheme and feasibility reports received by RPS were reviewed to identify relevant information for the purposes of this project. A summary of the various reports reviewed is provided in Table 2.1. The headings provide further information on; the area the report covers, the river associated with the report, the name of the report, who compiled the report, when it was produced as well as providing 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 of report
Arklow	Avoca River	Arklow Flood Study Revised Preliminary Report	P.H. McCarthy & Partners	12/06/2002	Recommend Method 3 includes: Levee embankment, flood defence walls, Arklow Bridge modifications and Flood Warning System. Full details are provided in part 10.4 of the Arklow Flood Study Revised Preliminary Report.
Arklow	Avoca River	Impact of Bridgewater Development on Flood Risk along the Avoca River. Summary of Initial Hydraulic Modelling	RPS	October 2007	Overall the increase in flood elevation and flow velocities are relatively small and mostly confined to the immediate vicinity of the new pier. However there is still a slight increase in flood level upstream of the bridge. Deepening the arches to provide a larger cross sectional area seems a feasible and favourable approach.
Arklow	Avoca River	Impact of Bridgewater Development on Flood Risk along the Avoca River. Addendum to Initial Hydraulic Modelling Report	RPS	December 2007	The particulars of the model for option 1 show significant improvements compared to the originally proposed layout. This option would have the least impact in terms of changes in water levels in relation to the required construction works. The option of a cantilevered footpath with dredging is very close to the existing situation, with minor localised changes confined to the immediate vicinity of the new pier and therefore would be the recommendation option for the development.
Bray	Swan river & Kilruddery Stream noted in drawing				Bray Town flood map

Flood Relief Study	River Name	Report Name	Author	Date	Recommendations of report
Bray	River Dargle	Environmental Impact Statement for River Dargle (Bray) Flood Defence Scheme	Compiled by McGill Planning	July 2007	<p>Area 1 – Harbour Bridge to Bray Bridge The river in this stretch will be deepened and widened where possible with defences being constructed along each side of the river.</p> <p>Area 2 – Bray Bridge The riverbed at Bray Bridge will be lowered to increase its cross sectional area. A culverted by-pass channel will be constructed under Castle Street on the northern side of the river to provide greater flow capacity at the bridge. Area 3 – Bray Bridge to the western end of People's Park. The river channel in this section will be widened and deepened where possible to increase the flow capacity. The existing river walls will be replaced with new defences to the required flood defence level. Area 4 – Western end of People's Park through The Slang/Rehills Land to La Vallee. An extensive amount of river re-grading and excavation will be undertaken in this area. The existing defences will be enhanced and additional defences will be provided where necessary. A debris trap will be located in this river reach to prevent trees and other large objects from travelling down the river. Area 5 - La Vallee to N11 bridge. The river channel will be deepened and widened where possible along this reach to increase the flow capacity.</p> <p>River Dargle, Typical Cross Sections, Realignment of Harbour Bridge and by-pass culvert noted</p>
Bray	Dargle	River Dargle Flood Defence (Drawings Only)	O'Connor Sutton Cronin	Oct-07	

Flood Relief Study	River Name	Report Name	Author	Date	Recommendations of report
Bray	Dargle	Physical Model Study	HR Wallingford	March 2009	These recommendations are based on the EIS. A number of recommendations are made in the report, including but not limited to; protection is used to prevent erosion of the berms, banks and bed of the channel at this location, protection to prevent erosion. The following should be taken into account which act on the structure; hydrodynamic forces, collision and impact forces and scour and foundation failure. Guide walls with freeboard are constructed, Swan Stream bed is protected, rehabilitation measures should be implemented concurrently with the re-grading/re-alignment of the river channel. An upstream weir is constructed, the bed should be protected against high flow velocities, a concave weir is constructed, the screen should be regularly maintained, flap gates are regularly inspected and maintained. It is recommended that model observed scour depths should be interpreted accordingly. The risk of scour during construction should be addressed, and that transported bed material is not allowed to build up in the channel adjacent to the exit from the bypass culvert.
Deansgrange	Deansgrange River	Deansgrange River Catchment. Phase 1 - Initial Planning Study Report.	Dublin Drainage Consultancy	May 2006	Recommendations to be taken into account for the Phase 2 & 3 reports. Indicates to use SUS database for storm model. Additional recommendations located in section 8.
Deansgrange	Deansgrange River	Deansgrange Catchment. Phase 2 - Model Preparation, Verification & System performance Assessment Report	Dublin Drainage Consultancy	May 2006	The Phase 2 model is considered suitable for use in Phase 3 study. As there are likely to be limited future development in the catchment the majority of changes to flows are likely to be as a result of climate change issues rather than developments. Unless improvements to the system are made to address the effects of climate change the existing flooding particularly in the lower parts of the catchment, will be exacerbated.

Flood Relief Study	River Name	Report Name	Author	Date	Recommendations of report
Deansgrange	Deansgrange River	Deansgrange Catchment. Phase 3 - Needs, options and Strategy Report	Dublin Drainage Consultancy	May 2006	Addition of a second culvert where currently capacity is inadequate, enlarging river cross-sections, increase flow capacities at bridges, provision of a new bypass culvert, construction of a river bund, construct a new culvert / outfall system under the DART line.
		Drawings only	RPS	February 2000	Drainage drawings for the South Eastern Motorway (Ballinteer to Shankill)
Carrickmines / Shanganagh	Carrickmines River & Shanganagh River	South Eastern Motorway - River Catchment Study Volume 1	MCOS / HR Wallingford	February 2001	Option C for Kilgobbin Area. This option provides a route via the road network bypassing houses. It then travels across fields and rejoins downstream of the properties involved (Section 6.2). N11 Loughlinstown, insert a trash screen and re-grade the river bed. Construction of a flood protection wall (Section 6.3). Commons Road, Flood walls upstream of bridge, river channel improvement, improvements to Shanganagh Bridge, provide flood wall on the River Lane and provide new drainage along Commons Road and River Lane's area (Section 6.4). Some planning constraints also identified. Some additional proposals in relation to SEM Storm drainage management proposals, Water Quality Improvements & cost estimates.
Carrickmines / Shanganagh	Carrickmines River & Shanganagh River	South Eastern Motorway - River Catchment Study Volume 1	HR Wallingford	May 2001	This report is a summary of the modelling activity carried out by HR Wallingford for the South Eastern Motorway Project. HR Wallingford was a sub-consultant to MCO Sullivan's in Dublin. The recommendations etc were taken into account in the MCOS report.
	Shanganagh River	Drawings only	RPS / MCOS	August 2003	Detailed drawings showing the construction of the Commons Road wall

Flood Relief Study	River Name	Report Name	Author	Date	Recommendations of report
Carrickmines	Carrickmines River & Shanganagh River	Carrickmines River Catchment. Phase 1 - Initial Planning Study Report	Dublin Drainage Consultancy	May 2006	No new modelling for this catchment - results from SEM study are to be used for development impacts/floodplain predictions and for assessing improvements strategies/options. Re-calibration of existing model, to determine runoff parameters for other GSDS models. Update existing model, to include all the previously surveyed river sections in the new InfoWorks format, along with a brief review of the quality of the modelled pipe data.
Carrickmines	Carrickmines River & Shanganagh River	Carrickmines Catchment. Phase 2 - Model Preparation, Verification and System Performance Assessment Report	Dublin Drainage Consultancy	May 2006	Although there are some limitations in the model - particularly in the modelled pipe network - it is considered suitable for use in a Phase 3 study. There are likely to be significant changes in the runoff in the catchment, as a result of the construction of the SEM motorway, proposed new residential and commercial developments and the effects of Climate Change. Unless suitable drainage standards are adopted for the new developments, etc. and appropriate improvements are made to address the effects of Climate Change, then the existing flooding, particularly in the lower parts of the catchment, will be exacerbated.
Carrickmines	Carrickmines River & Shanganagh River	Carrickmines River Catchment. Phase 3 - Needs, options and Strategy Report	Dublin Drainage Consultancy	May 2006	The recommendations made in the SEM Catchment Study report are still valid. The improvements proposed include the provision of a bypass culvert in the Kilgobbin Road area and a range of improvements near the downstream end of the catchment from the N11 to Commons Road. Proposals are currently being developed for the N11 crossing / Commons Road work, as part of the Shanganagh River Management Plan. This work is likely to include provision of a screen upstream of the N11 and the construction of a reinforced concrete flood wall in the Commons Road / Shanganagh Bridge area. If changes are to be made, additional modelling is required and a list of items has been listed to be updated. These can be

Flood Relief Study	River Name	Report Name	Author	Date	Recommendations of report
Carrickmines / Shanganagh	Carrickmines River & Shanganagh River	Fluvial Flooding Report for Carrickmines / Shanganagh River Catchment (Stage 1 report)	RPS	June 2008	found at the end of the report. Table 5.1 provides a summary of the outline solutions. Includes proposing by-pass pipes, ensuring fluvial flooding is maintained, removing/up sizing culverts or route diversions.
	Sea	Coastal Defence Strategy Study	Malachy Walsh & Partners	September 2010	Undertake whole coast measures to reduce risk to coastal defence measures. Undertake coastal defence measures for specific areas identified during the study and outlined in order of priority in Table 10.1 of the report. Further investigation and / or assessment may be required to confirm the preferred coastal defence option. Areas may require planning and foreshore lease permissions. Discuss this report with OPW to gain funding and adopt the findings of this report into the County Development Plan.
	Avoca (Arklow, Aughrim)				Deeping Bridge Arches to provide larger cross sectional Area, Alleviate impact of new pier. Reduce flood risk upstream of bridge. Decrease sedimentation. Reduce flow velocity through bridge. Predicted 100 year return level 21.48m OD
Wicklow		Wentworth Place Culvert Replacement as-built drawings	Barry & Partners Consulting Engineers	July 2009	Culvert Replacement drawings (As-built drawings)

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 led to flooding within AFAs situated in HA10 during the period 1905 to 2011 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 Eastern CFRAM study area. The mapping which has been supplied by OPW includes the following datasets:

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

Due to the poor 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 HA10, and the analysis of this data are presented in Sections 4.1 and 4.4. In summary, 44 hydrometric stations (1 OPW and 43 other) were identified as being, or having been, operational within HA10. However, of these only 16 had data available for use and only 7 are located along watercourses to be modelled as part of the Eastern CFRAM Study although all 16 will be used to inform the hydrological analysis and derivation of return period flows.

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 RPS have the following development zoning datasets:

Dún Laoghaire Rathdown County Council:

- 6_Year_Motorway_Proposal(in_tunnel).MAP - Motorway6YrProposal_InTunnel_pl_100702
- 6_Year_Motorway_Proposal.MAP - Motorway6YrProposal_pl_100702
- 6_Year_Road_Proposal.MAP - Road6YrProposal_pl_100702
- Architectural_Conservation_Area.MAP - ArchitecturalConservationArea_pg_100702
- BOUNDA~1.MAP -Boundary_StrategicDev_pg_100702
- BURIAL_GROUND.MAP - BurialGround_pg_100702
- CANDID~1.MAP - CandidateArchitecturalConservationArea_pg_100702
- COUNCIL_HOUSING.MAP - CountyCouncilHousing_pt_100702
- INSTITUTIONAL_LANDS.MAP - InstitutionLands_pt_100702
- Local_Area_Plan.MAP - LA_Plan_pg_100702
- Long_Term_Motorway_Proposals.MAP - LongTerm_MotorwayProposals_pl_100702
- Long_Term_Road_Proposals.MAP - LongTerm_RoadProposals_pl_100702
- MEWS_DEVELOPMENT.MAP - MewsDevelopment_pl_100702
- NO_INC~1.MAP - NoIncreaseNumBuildingsPermissable_pg_100702
- Objective_A.MAP - ObjA1_ProvideNewResidentialCommunities_pg_100702
- Objective_A1.MAP - ObjA_ProtectOrImproveResidentialAmenity_pg_100702
- Objective_B.MAP - ObjB_ProtectImproveRuralAmenity_pg_100702
- Objective_DC.MAP - ObjDC_ProtectProvideImproveMixedUseDistricts_pg_100702
- Objective_E.MAP - ObjE_ProvideEconomicDevAndEmployment_pg_100702
- Objective_F.MAP -ObjF_ProvideOpenSpace_pg_100702
- Objective_G.MAP -ObjG_ProtectImproveHighAmenityAreas_pg_100702
- Objective_GB.MAP -ObjGB_ProtectEnhanceOpenNatureofLands_pg_100702
- Objective_MTC.MAP -ObjMTC_ProtectImproveMajorTownCentreFacilities_pg_100702
- Objective_NC.MAP -ObjNC_ProtectProvideMixedUseNeighbourhoodCentreFacilities_pg_100702
- Objective_TLI.MAP -ObjTLI_SupportEnhance3rdLevelEducationInstitues_pg_100702
- Objective_W.MAP -ObjW_ProvideWaterfrontDevAndHarbourUses_pg_100702
- Proposed_Luas_Line_Extension.MAP -Proposed_LuasLine_Ext_pl_100702
- PROPOSED_NATURAL_HERITAGE_AREAS.MAP - Proposed_NaturalHeritageAreas_pg_100702
- PROPOSED_SPECIAL_PROTECTION_AREA.MAP - Proposed_SPA_pg_100702
- Proposed_Walkway_Cycleway.MAP - Proposed_WalkwayCycleway_pl_100702
- PROPOS~1.MAP - ProposedLuasLineUnderConstruction_pl_100702
- PROPOS~4.MAP - ProposedBusPriorityRoutes_pl_100702
- Public_Rights_of_Way.MAP - PublicRightsOfWay_pl_100702
- RECORD_OF_MONUMENTS_AND_PLACE.MAP - Record_MonumentsAndPlace_pg_100702
- RECORD_OF_PROTECTED_STRUCTURES_LINE.MAP - Record_ProtectedStructures_pl_100702
- RECORD_OF_PROTECTED_STRUCTURES_POLY.MAP - Record_ProtectedStructures_pg_100702
- Recreation_Access_Route.MAP - RecreationAccessRoute_pl_100702
- SPECIFIC_OBJECTIVES_POINT.MAP - Specific_Objectives_pt_100702
- SPECIFIC_OBJECTIVES_POLY.MAP - Specific_Objectives_pl_100702
- To_Preserve_Prospects.MAP - PreserveProspects_pt_100702
- To_Preserve_Views.MAP - PreserveViews_pt_100702
- To_provide_for_a_Primary_School.MAP - ProvideFoPrimarySchool_pt_100702

- TO_PRO~1.MAP - ProvideForPostPrimary_pt_100702
- TO__PR~1.MAP - ProtectPreserveTreesWoodland_pt_100702
- TRAVELLER_ACCOMODATION.MAP - TravellerAccommodation_pt_100702
- Urban_Framework_Plan.MAP - UrbanFrameworkPlan_pg_100702
- Wicklow_Way.MAP - WicklowWay_pl_100702

Dún Laoghaire Rathdown also have their County Development Plan 2010-2016, all up to date variations to the CDP and all current Local Area Plans (including any environmental reports) available on the council website: www.dlrco.ie under planning department.

Wicklow County Council:

- CDP2010-2016 - Employment-Tourism-Health;
- Wicklow CoCo Land Zoning;
- Wicklow CoCo LAP-TP Boundaries.

No Planning or Development information has been requested from Wexford County Council as there are no AFA's for consideration under the Eastern CFRAM Study located in County Wexford.

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
Water/Biodiversity/Flora and Fauna	Inland Fisheries Ireland - 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

SEA Issue Area	Data	Availability
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
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 / Landuse	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
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

SEA Issue Area	Data	Availability
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.

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 HA10. Principally we

have received the Dún Laoghaire - Rathdown Coastal Defence Strategy which includes their final report and also numerous photographs. RPS has also obtained details of the Bray Flood Relief Scheme for the River Dargle.

The limited information obtained to date will be supplemented as further assets are identified and relevant geometric data collected through the HA10 survey contract. Information on the current condition of all assets will be obtained during the follow up asset condition survey.

2.3.11 Greater Dublin Strategic Drainage Study (GDSDS) Data

Within HA10, two HPWs (including all tributaries) within the Dún Laoghaire Rathdown Local Authority Area were previously included in the Greater Dublin Strategic Drainage Study (GDSDS):

- Deansgrange River
- Carrickmines River /Shanganagh River

As such a range of GIS datasets were made available by Dún Laoghaire Rathdown County Council with respect to these watercourses. The associated GDSDS codes assigned to the HPWs and associated catchments are as follows:

- Deansgrange River – S1007
- Shanganagh and Carrickmines River – S1008

These codes were used to extract relevant GIS information from the GDSDS database held by Dún Laoghaire Rathdown County Council.

Figure 2.1 shows the river polylines, river labels and catchment boundary lines collected for S1007 (Deansgrange) and S1008 (Carrickmines/Shanganagh).

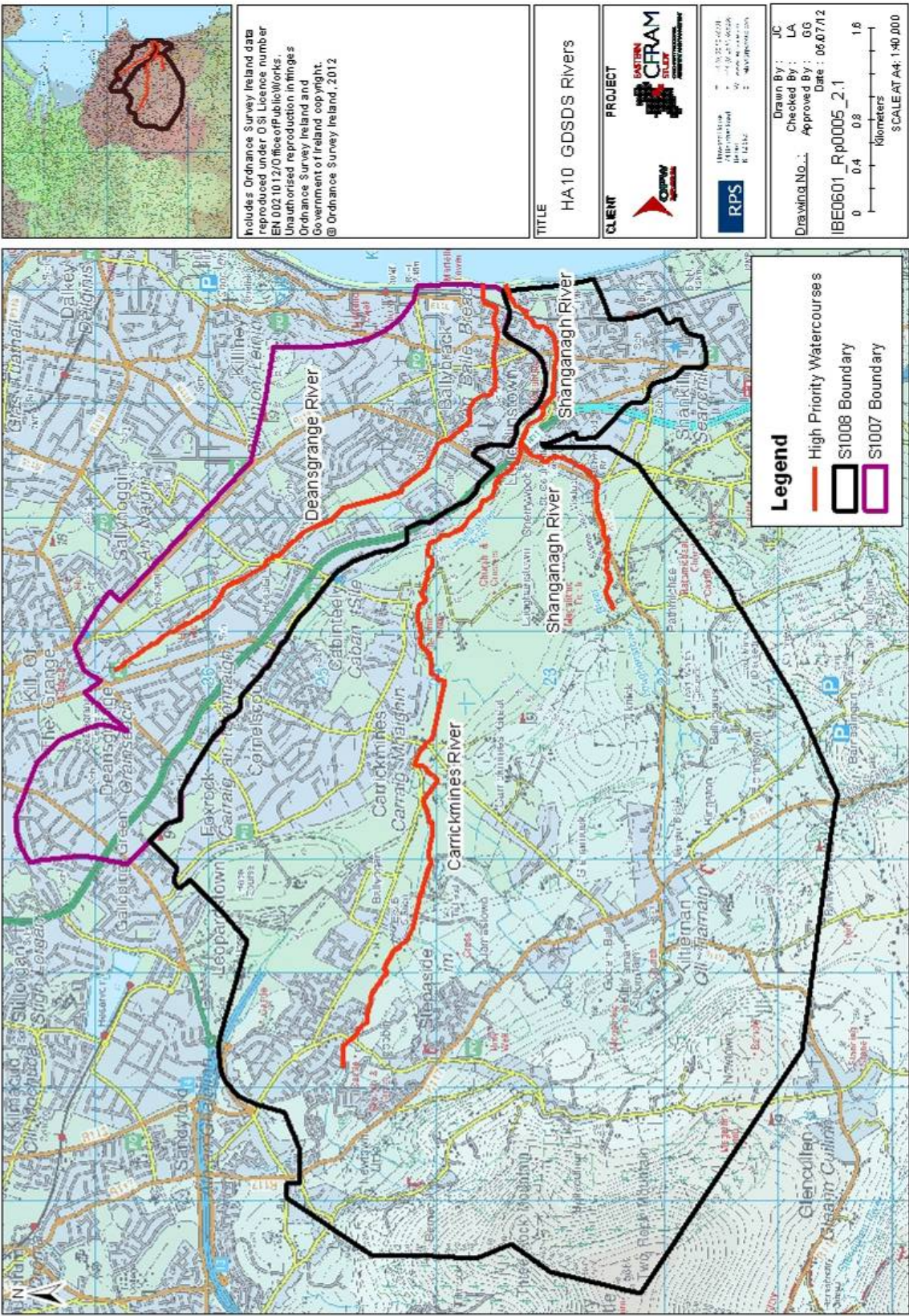


Figure 2.1: GDSRs Rivers that are HPWs in HA10

2.3.11.1 S1007 GIS Datasets

As depicted by Figure 2.1, area S1007 constitutes the Deansgrange River which discharges to the sea at Killiney Bay. There are no watercourses discharging to the Deansgrange River, but it receives storm water discharge from the surrounding storm sewer network serving the S1007 urban area. Table 2.3 lists the key GDSDS datasets made available for S1007 (Deansgrange).

2.3.11.2 S1008 GIS Datasets

As depicted by Figure 2.1, the Carrickmines and Shanganagh HPWs are within S1008,

The Carrickmines River is a tributary of the Shanganagh River which discharges to the sea south of the Deansgrange River outfall (S1007) at Killiney Bay. The GDSDS data was of benefit in defining the routes of these watercourses, since the EPA Blue Line River Network did not provide an accurate representation. A discrepancy was first encountered by RPS staff during site visits of the area. This was followed up by collecting GDSDS data within which the correct routes were available. The GDSDS watercourse polyline layers were then used to supersede the EPA dataset and provide an accurate representation of the watercourse routes on the ground.

Table 2.3 lists the GDSDS datasets collated for area S1008.

Table 2.3: GDSDS GIS Layers available within HA10

GDSDS Layer Number	Description	S1007	S1008	GDSDS Layer Filename
Development Data				
1	Proposed Development	✓	✓	Develop_1
1A	Population Seed Data			Popseed_1A
1B	Trade Effluent Discharges			Trade_1B
	Proposed Dublin Motorways	✓	✓	ProposedDublinMotorways_074512001
Ordnance Survey Map and Environmental Data Layers				
3	Low detail faded background map	✓	✓	Fadedmap_3
3A	Faded OS Maps (1 per tile)	✓	✓	Fadedos_3A_(mapname)
4	Wastewater Treatment works	✓	✓	WwTW_4
15	Rivers	✓	✓	Rivers_15
16	Basements	✓	✓	Basements_16
	Location Names	✓	✓	LocationNames_pt
76	General Labels	✓	✓	
75	District Labels	✓	✓	
	Existing Dublin Motorways	✓	✓	ExistingDublinMotorways_074512001
	National Primary Roads	✓	✓	NationalPrimaryGDSDS_Area_074512001
Asset Data Layers				
31A	Foul System Schematic Layer			Foulscheme_31A
31B	Combined Schematic Layer			Combinedscheme_31B
31C	Storm System Schematic Layer	✓	✓	Stormscheme_31C
33	Catchment notes			Notes_33
34	SUS Manhole database (links)	✓	✓	Suslink_34
35	Culverted Watercourses	✓	✓	Culverted_35
36	SUS Manhole database (nodes)	✓	✓	Susnode_36

GSDS Layer Number	Description	S1007	S1008	GSDS Layer Filename
37A	Model Database (Foul / Combined conduits)			Modelpipe_37A
37B	Model Database (Storm conduits)			Modelpipe_37B
38	Model Database (Rising mains)			Modelpump_38
39	Model Database (nodes)			Modelnode_39
40	Ancillary Structures	✓	✓	Ancillary_40
41	Model Catchment Areas			Modelcatch_41
42	Foul Catchment Boundary			Fboundary_42
43	Storm Catchment Boundary	✓	✓	Sboundary_43
Council Boundary Layers				
44	Map of Ireland and Counties	✓	✓	Ireland_44
45	Local Council Boundaries	✓	✓	Council_45
Historical Records Layers				
50	Historical/Reported Flooding Data	✓	✓	Repflooding_50
51	Previously Reported Grade 4/5 sewers			Repstruct_51
Site Investigation Data Layers				
60	CCTV Survey			Cctvsurvey_60
61	Flow Survey	✓	✓	Flowsurvey_61
62	Asset Survey	✓	✓	Assetsurvey_62
63	River Cross Section Survey	✓		Riverxsurvey_63
2	Flow Monitor Catchment Areas			Flowareas_2
17	Flooding Risk	✓	✓	Floodrisk_17
65	Permanent Flow Monitor Sites			Permanentflow_65
66	Rain Gauge Sites	✓	✓	Raingauge_66
73	Structural Deficiencies	✓	✓	Deficiency_73

2.4 DATA OUTSTANDING

RPS has made one final request for missing information / data from each of the relevant Local Authorities, Dún Laoghaire-Rathdown and Wicklow. No information has been requested from Wexford county Council as although part of HA10 lies within County Wexford there are no AFAs located within this part of the catchment. The request was made at the beginning of December 2011 via email (and re-issued in February 2012). 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 headings, Local Authorities have been requested to either provide any additional information they feel appropriate for the ECFRAM Study or confirm that they have no further information. Also detailed in this document is information that has been requested that has not been provided. In response to this request Dún Laoghaire Rathdown County Council provided additional information regarding their Coastal Defence Strategy and confirmed that they have no more information to supply for this project. A breakdown of areas where no information has been received from Wicklow County Council is detailed below:

- Existing Survey / Geotechnical Data;
- Other Receptor Data;
- Aerial Photography of flooding
- Indication of availability of rainfall gauge data.

2.5 DATA GAPS

At present RPS has not identified any significant data gaps that will impact on the completion of the Eastern CFRAM Study however this statement is made without having received any information from the various survey packages 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 subsequent 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 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 2.4 below.

Table 2.4: Summary of Data Quality and Validity Checks

Section Reference	Section Heading	Comment
2.5.1	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.
2.5.2	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.
2.5.3	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 HA10 was not supplied initially however full coverage has now been obtained following further data requests as described in Section 2.3.3.
2.5.4	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 of this report.
2.5.5	Meteorological	Meteorological Data has been reviewed by a member of RPS staff to

	Data	ascertain its fitness for purpose. The outcome of the review has been detailed in Section 5 of this report.
2.5.6	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.
2.5.7	Planning and Development Information	Some of the Planning and Development datasets received where not the latest revision of the County's Development Plans and therefore a request was made to obtain their most recent datasets, which depict the zoning areas required by RPS. This is further detailed in 2.3.7.
2.5.8	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.
2.5.9	Soil and Geological Data	Initial review of this data indicates that it will be sufficient for the intended purpose.
2.5.10	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 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 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 Eastern CFRAM study as this information shall be collected and recorded during subsequent planned onsite surveys.

3 SURVEYS

3.1 CHANNEL & CROSS-SECTION SURVEYS

3.1.1 Summary of Surveys Procured

RPS has prepared documentation to procure two survey contracts for HA10. The first was a small contract to survey the gauging stations in the catchment, that require rating review (refer to Section 5.1.1) which was procured on a restricted list basis and awarded to Coordinate Surveys Ltd on 19/08/2011. There are six gauging stations within HA10 of which four were included in the scope of this advance survey, the other two gauges being included in the main survey contract.

The main survey contract encompasses the full channel cross-sections, details of hydraulic structures and geometric survey of defences was advertised through e-tenders and OJEU on 07/11/2011. This is currently at the tender evaluation and award stage, and is expected to be awarded in June 2012.

3.2 FLOOD DEFENCE ASSETS

The identification of flood defence assets is a requirement of the main HA10 survey contract and thus at present we have not established a definitive list of flood defence assets for HA10. However the locations of the flood defence assets identified by RPS during the survey scoping site visits are indicated in Figure 3.1 and listed in Table 3.1 below.

Table 3.1: Flood Defence Assets Identified in HA10 Survey Spec.

Location	Asset Type
Wicklow	Walls
Bray	Walls
Greystones	Wall
Avoca	Wall
Aughrim	Walls
Loughlinstown	Walls



Figure 3.1: Locations of Flood Defence Assets in HA10

Survey data has been received for the four gauging stations included in the advance survey and successfully employed in the assessment of the relevant rating curves. Unfortunately at this time it is not possible to comment on the adequacy of the data from the main survey contract as no contractor has yet been appointed.

3.3 FLOODPLAIN SURVEY

The tender documents indicated that OPW would supply the results of a flood plain survey based on LiDAR techniques by November 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 received information for use in later stages of the 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 RPS will not be undertaking this work until draft flood hazard maps are available.

4 PRELIMINARY HYDROLOGICAL ASSESSMENT AND METHOD STATEMENT

4.1 HYDROMETRIC DATA

4.1.1 Hydrometric data – HA10

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 Eastern RBD including Annual Maximum (AMAX) Series data for those stations included in the OPW Flood Studies Update Programme (FSU). The OPW operates one river hydrometric station within HA10; details of this station are included in Table 4.1.

Table 4.1: OPW Hydrometric Stations with available data within HA10

Station Number	Station Name	River/Lake	Records Length
10042	Arklow Town Bridge	Avoca	Nov 2002 – Jan 2011

An additional 43 hydrometric stations are located within HA10. One of these is privately owned and 42 are owned by Local Authorities (operated by EPA) or ESB. Hydrometric data is available for 15 of these (all EPA) and has been acquired by RPS, as listed in Table 4.2. The data provided consists of flow and level data and rating curves where available.

Table 4.2: Local Authority (EPA) Hydrometric Stations with Available Data in HA10

Station Number	Station Name	River/Lake	Data Available	Records Length
10002	Rathdrum	Avonmore	Water Level & Flow	Sept 1952 - July 2011
10003	Laragh	Avonmore	Water Level & Flow	July 1945 - Oct 1986
10004	Laragh	Glenmacnass	Water Level & Flow	1952 - 1998
10017	Ballyman	Ballyman Stream	Water Level & Flow	Nov 1976 - Nov 1997 (intermittent)
10019	Vallombrosa	Ballyman	Water Level & Flow	June 1977 - Nov 1989
10020	Devil's Glen	Vartry	Water Level Only	May 1952 - June 1979
10021	Commons Road	Shanganagh	Water Level & Flow	May 1980 - July 2011
10022	Carrickmines	Cabinteely	Water Level & Flow	Nov 1980 - Jan 2005
10023	Powerscourt	Dargle	Water Level & Flow	Feb 1982 - July 1984
10024	Glencullen Br	Glencullen	Water Level & Flow	June 1982 - Dec 1997

Station Number	Station Name	River/Lake	Data Available	Records Length
10028	Knocknamohill	Aughrim	Water Level & Flow	Oct 1986 - Jan 2002
10029	Redcross	Redcross	Water Level Only	July 1987 - Sept 1987
10038	Druids Glen	Newtownmountkennedy	Water Level & Flow	Oct 2001 - June 2011
10039	Avonmore House	Avonmore	Water Level & Flow	2004-2011
10044	White Bridge	Avoca	Water Level & Flow	2009-2011

The remaining 28 Local Authority (EPA) / ESB hydrometric stations and the private hydrometric station have no continuous monitoring data available. 23 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. The historical ESB hydrometric sites have continuous water levels recorded on charts. However, the old chart recordings are currently stored in the ESB archive and are not yet digitized; therefore no data is currently available for these stations.

Therefore in total, 16 hydrometric stations (One OPW and 15 Local Authority (EPA)) located in HA10 have data available for use within this Study.

Each of the 16 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 data-logger. An autographic recorder is a simple float operated device that records water level on to 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. 13 of the 16 hydrometric gauges have flow data available that has been derived from continuous water level data using this methodology. The other three 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 estimates and the period of AMAX record analysed under the FSU programme (including AMAX 2009). An FSU generated rating classification was also assigned to these stations. Of the 16 stations listed in Table 4.1 and 4.2, five 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
10002	RATHDRUM	B
10004	LARAGH	B
10021	COMMONS ROAD	A1
10022	CARRICKMINES	{Post 10/07/84: A1} & {Pre 10/07/84: A2}
10028	KNOCKNAMOHILL	B

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 44 hydrometric stations within HA10.

The 16 stations for which data is available are coloured green (water level and flow data), yellow (water level data only). Those which have additional data from the FSU work, including AMAX series are also highlighted. All 16 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 return periods.
- Stations with water level and flow data within the wider HA10 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 16 stations within HA10 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 elsewhere within the Eastern and Southeastern 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 (<100km²) are ungauged Pivotal Sites from outside HA10 may be used to transfer data in order to modify regression estimates of the index flood (Q_{med}) where the Pivotal Site is found to be sufficiently hydrologically similar as per FSU Work Package 2.3.

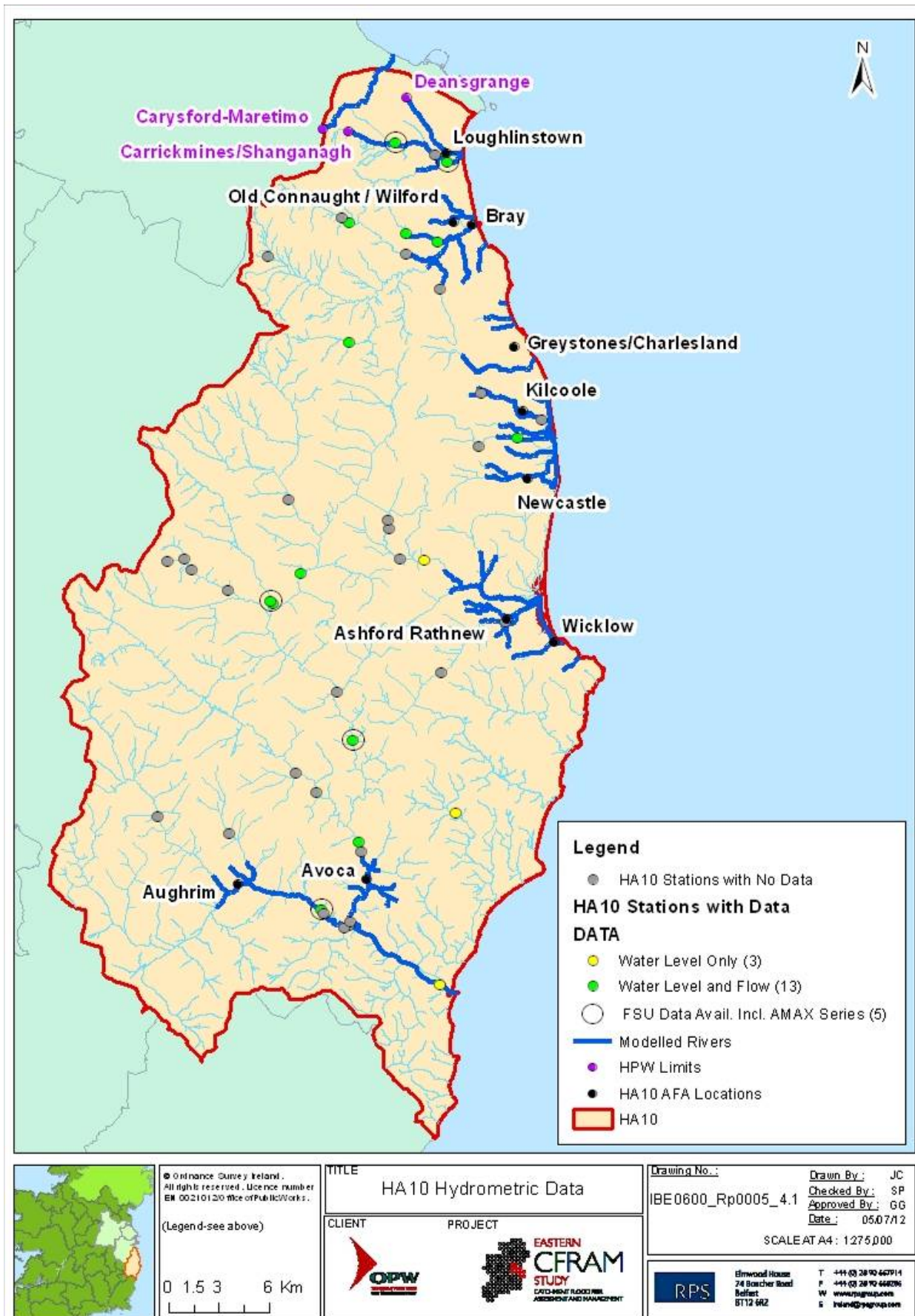


Figure 4.1: Hydrometric Stations in HA10

4.1.1.1 Hydrometric Stations along modelled watercourses

There are seven hydrometric stations along the rivers to be modelled as Medium or High Priority Watercourses (MPWs or HPWs). These are shown on Figure 4.2. Six of these stations have water level and flow data, whilst one has level data only. Three of these stations were included in the FSU programme which is also indicated on Figure 4.2.



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

4.1.1.2 Rating Reviews – 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 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. Six hydrometric stations have been specified for this analysis within HA10 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 HA10

Station Number	Station Name	Final Station Rating Quality Classification
10002	RATHDRUM	B
10017	BALLYMAN	NOT REVIEWED UNDER FSU
10021	COMMONS ROAD	A1
10022	CARRICKMINES	{Post 10/07/84: A1} & {Pre 10/07/84: A2}
10024	GLENCULLEN BR.	NOT REVIEWED UNDER FSU
10028	KNOCKNAMOHILL	B



Figure 4.3: Hydrometric Stations for CFRAM Study rating review in HA10

4.1.1.3 Summary of Hydrometric Data

Table 4.5 summaries the number of hydrometric stations with data available within HA10 overall, and those located on modelled watercourses only. Six of these stations require CFRAMS rating review, all of which have water level and flow data available.

Table 4.5: Number Summary – HA10 Stations with Data Available

Data Available	HA10	HPW/MPWs	CFRAM Rating Review
Water Level and Flow	13	6	6
Water Level Only	3	1	0
Total	16	7	6

Table 4.6 provides a more detailed summary of the type of data for each of the 16 usable Hydrometric Stations within HA10 that has been collected for the Eastern CFRAM Study.

The seven stations that are located on the watercourses to be modelled are highlighted in blue.

Hydrometric Station Data Status Tables for HA10 are provided in Appendix A.

Table 4.6: Summary of Hydrometric Data Provision within HA10

NUMBER	NAME	BODY RESPONSIBLE	STATUS	DATA AVAILABLE	Record Length (dates)	Rating Info Provided	Gaugings Provided	AMAX Series Provided	FSU Generated Data Provided	Located on HPW/MPW	CFRAMS RATING REVIEW
10002	RATHDRUM	Wicklow County Council	Active	Water Level and Flow	Sept 1952 - July 2011	Y	N	Y	Y	N	Y
10003	LARAGH	Wicklow County Council	Inactive	Water Level and Flow	July 1945 - Oct 1986	Y	N	N	N	N	N
10004	LARAGH	Wicklow County Council	Inactive	Water Level and Flow	1952 - 1998	Y	N	Y (Gaps 1976, 1979 - 1982)	Y	N	N
10017	BALLYMAN	Dún Laoghaire - Rathdown Council	Inactive	Water Level and Flow	Nov 1976 - Nov 1997 (intermittent)	Y	N	N	N	Y	Y
10019	VALLOMBROSA	Dún Laoghaire - Rathdown Council	Inactive	Water Level and Flow	June 1977 - Nov 1989	Y	N	N	N	Y	N
10020	DEVIL'S GLEN	Wicklow County Council	Inactive	Water Level Only	May 1952 - June 1979	Y	N	N	N	N	N
10021	COMMONS ROAD	Dún Laoghaire - Rathdown Council	Active	Water Level and Flow	May 1980 - July 2011	Y	N	Y	Y	Y	Y
10022	CARRICKMINES	Dún Laoghaire - Rathdown Council	Inactive	Water Level and Flow	Nov 1980 - Jan 2005	Y	N	Y	Y	Y	Y
10023	POWERSCOURT	An Foras Forbartha	Inactive	Water Level and Flow	Feb 1982 - July 1984	Y	N	N	N	N	N
10024	GLENCULLEN BR	Dún Laoghaire - Rathdown Council	Inactive	Water Level & Flow	June 1982 - Dec 1997	Y	N	N	N	N	Y
10028	KNOCKNAMOHILL	Wicklow County Council	Active	Water Level and Flow	Oct 1986 - Jan 2002	Y	N	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/MPW	CFRAMS RATING REVIEW
10029	REDCROSS	Wicklow County Council	Inactive	Water Level Only	July 1987 - Sept 1987	Y	N	N	N	N	N
10038	DRUIDS GLEN	Wicklow County Council	Active	Water Level and Flow	Oct 2001 - June 2011	Y	N	N	N	Y	N
10039	AVONMORE HOUSE	Wicklow County Council	Active	Water Level and Flow	2004-2011	Y	Y	N	N	N	N
10042	ARKLOW TOWN BRIDGE	Office of Public Works	Active	Water Level Only	Nov 2002 - Jan 2011	N	Y	N	N	Y	N
10044	WHITE BRIDGE	Wicklow County Council	Active	Water Level and Flow	2009-2011	Y	N	N	N	N	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 565 rainfall gauges both within and beyond the Eastern CFRAM Study Area. Additional information was also provided by Local Authorities for a further 43 stations giving a total of 608 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 Eastern CFRAM Study Area Only	215	43	258
Within Eastern CFRAM Buffer Area Only	350	0	350
Within Eastern CFRAM Study Area plus Buffer	565	43	608

258 of the daily rainfall stations are located within the Eastern CFRAM Study Area. An additional 350 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 for details).

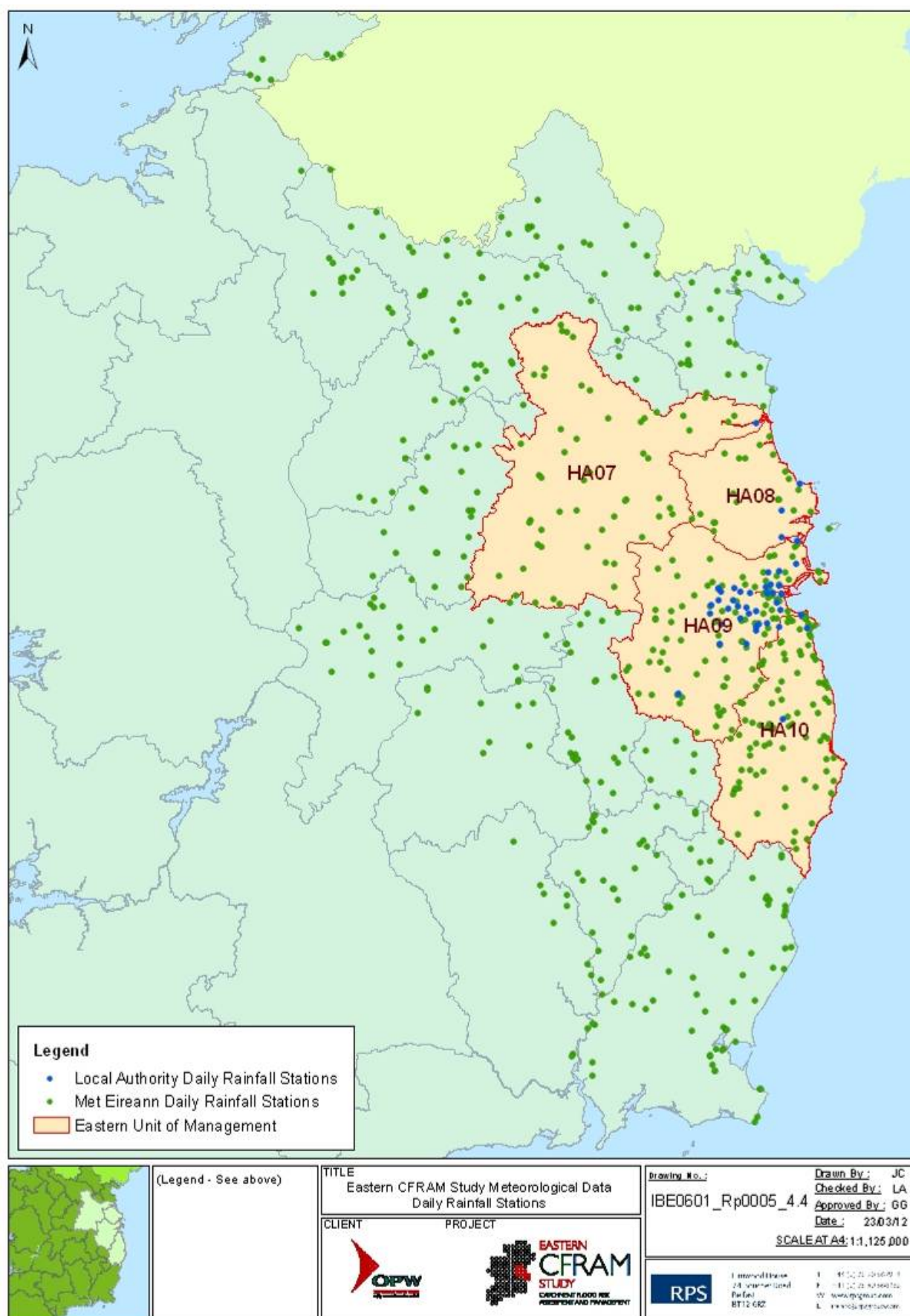


Figure 4.4: Location of Daily Rainfall Gauges

Within HA10 there are 86 Met Éireann daily rainfall gauges with three additional daily rainfall gauges provided by Dún Laoghaire Rathdown and Dublin City Council (one located on the border with HA09), giving a total of 89 rainfall gauges. A 20 – 30km buffer will also be applied to this area and the surrounding rainfall gauges within the buffer zone will also be considered for inclusion in the 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 time line 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 13 hourly rainfall gauges were provided. Their location is shown in Figure 4.5. None of these stations are within HA10. 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 ECFRAM Study (between RPS, HydroLogic, OPW and Met Éireann) identified an opportunity for exploring the use and benefits of rainfall radar data in hydrological analysis. The data collected is as follows:

- Hourly precipitation accumulation (PAC) data of the Dublin radar on a 1 x 1 km grid (from 1997)
- 15 minute Pseudo-CAPPI (PCR) data of the Dublin radar (from 1997)
- Plan Position Indicator (PPI) data of the Dublin 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 have occurred within HA10. 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 HA10, there are thirteen separate catchments in the hydrometric area. Searches were carried out for each of the rivers in the catchments as follows:

Catchment	River
<ul style="list-style-type: none"> • Avoca catchment 	Askanagap (Stream) Aughrim (Wicklow) Avoca Avonbeg Avonmore Ballycreen (Brook) Ballyduff (Stream) [Wicklow] Cloghoge (Brook)

	Coolalug (Stream)
	Derry Water
	Glendasan
	Glenealo
	Glenmacnass
	Gold Mine
	Ow
• Vartry catchment	Vartry
• Three Mile Water catchment	Three Mile Water
• Potters catchment	Potter's
• Redcross catchment	Redcross
• Dargle catchment	Dargle
	Glencree
	Glencullen
	Kilmacanoge
• Coastal (Loughlinstown) catchment	Kill-O-The-Grange (Stream)
	Shanganagh
• Coastal (Greystones) catchment	Newcastle [Wicklow]
	Newtownmountkennedy
• Coastal (Wicklow Head) catchment	-
• Coastal (Jack's Hole) catchment	-
• Coastal (Mizen Head) catchment	-
• Coastal (Killiniskyduff) catchment	Tempelrainy (Stream)
• Coastal (Kilmichael) catchment	-

The Carrickmines/Shanganagh and Deansgrange (Kill-O-The-Grange) rivers in the Coastal (Loughlinstown) catchment have been specified as HPWs. It should be noted that flood alleviation works were undertaken on the Shanganagh River in 2005 in connection with South Eastern Motorway project.

Internet Search Engines

The results of the search carried out on the OPW National Flood Hazard Mapping website yielded details of floods which had occurred pre-2005. No results relating to floods after 2005 were returned.

A wider search for information on more recent flood events, such as the August 2008 and November 2009 floods, was carried out for each AFA in HA10 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 little or no details on flows, flood extents, flood return periods, etc. Some Development Plans were also found but again, these generally contained only basic information on flooding.

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 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.

In the case of HA10, no Local Authority/EPA hydrometric stations or OPW hydrometric stations are located in/near an AFA. Some are located upstream or downstream of an AFA which enables the verification of flood dates in an AFA, but not flood levels or flows in the AFA.

In relation to the HPWs in HA10, an EPA hydrometric station is operated on the Shanganagh River at Commons Road, and also further upstream at Carrickmines, on the Cabinteely River.

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 HA10 are summarised in Table 4.8. As mentioned previously, two HPWs have been identified for further assessment, namely the Deansgrange and Carrickmines/Shanganagh Rivers. It should be noted that the Deansgrange River is referred to as Kill-O-The-Grange River on the OPW National Flood Hazard Mapping website.

Table 4.8: Summary of Historical Flood Events for each AFA

Event	Asford/ Rathnew	Avoca	Bray	Greystones/ Charlesland	Arklow	Aughrim	Wicklow	Old Connaught/ Wilford	Newcastle	Kilcoole	Deansgrange River HPW	Carrickmines Shanganagh HPW	Carysfort- Mareimo HPW
Oct- 2011			✓	✓	✓	✓		Reports of historical flooding at Woodbrook Downs, No Dates Given For Flood Events, Flooding reported at Old Connaught in January 2010	Recurring event. Dates not specified. Heavy rain causes the stream flowing through Newcastle to flood the Sea Road and make it impassable	✓			✓
Jan-2010	✓		✓		✓	✓				No Dates Given For Floods – stated as recurring			
Nov-2009					✓	✓	✓						
Jul-2009													✓
Jul-2007													✓
Nov-2002			✓	✓	✓							✓	
Feb-2002			✓		✓		✓						
Autumn/ Winter 2001											✓		
Nov-2000		✓	✓		✓	✓	✓						
Dec-1997												✓	
Jan-1996			✓										
May-1993												✓	✓
Aug-1986		✓	✓		✓	✓						✓	
Nov-1982											✓	✓	
Dec-1981			✓										
Jan-1969			✓										
Nov-1965	✓	✓	✓		✓	✓	✓						
Nov-1954			✓										
Mar-1947	✓		✓				✓						
Aug-1946			✓	✓		✓							
Sep-1931			✓										
Jan-1930				✓									
Aug-1905			✓		✓								

These flood events are discussed in the following sections, with additional details summarised in Table 4.10, such as dates, flows, return periods and flood mechanisms.

As mentioned previously, the majority of the results yielded from searches on the OPW National Flood Hazard Mapping website related to floods which had occurred pre-2005. An internet search was carried out for information on the more recent flood events to supplement the records for each AFA in HA10.

4.3.2.2 Flood Event of October 2011

Internet search engines were used to find details of a flood event which occurred in October 2011 following a day of heavy rainfall, when it was reported that a month's rainfall fell in 24 hours.

The Carysfort/Maretimo stream burst its banks as a result of the torrential rainfall and caused widespread damage in the Stillorgan/Blackrock area. Floodwaters up to two feet deep damaged scores of private homes along a two kilometre stretch of the route of the stream and affected estates including Open Estate, Avondale Lawn, Carysfort Park and Barclay Court. Carysfort Avenue in Blackrock was almost completely impassable due to severe flooding.

The rail service between Bray and Dún Laoghaire was suspended due to flooding on the rail line. The National Sealife Centre in Bray was flooded when storm waters leaked through the walls of the building into the basement area of the facility. No additional details were found relating to flooding in Bray.

The search yielded reports that floods occurred on the road between Greystones and Kilcoole, while flooding occurred near Aughrim, between Coats Bridge and Woodenbridge.

In Arklow, pictures were found showing floodwaters on roads. Roads at Worsboro Terrace and South Green were closed for a period. Sandbags were deployed to minimise damage.

4.3.2.3 Flood Event of January 2010

The review indicated that flooding occurred in Ashford/Rathnew, Bray, Arklow and Aughrim on 16th January 2010 due to heavy rainfall.

The Vartry River burst its banks between Ashford and Rathnew. Mount Usher Gardens was badly flooded with the entire width of the Gardens covered in water. The head gardener stated that the water level almost reached that seen during Hurricane Charlie.

In Bray, around nine houses off Old Connaught Avenue were flooded and residents of three of the houses had to be evacuated. Water level reached 2.1m in a garden off Old Connaught Avenue.

In Arklow, the Nineteen Arches Bridge through Arklow Town was closed after the River Avoca burst its banks, due to heavy rainfall and the melting of snow on higher ground. A number of residents were forced to leave their homes. Bus services were suspended through the town and the railway line was flooded. Severe flooding also occurred in Lower Main Street, South Quay and Ferrybank.

In Aughrim, heavy rainfall caused flooding. Houses were evacuated and roads from Vale Road to Aughrim were severely flooded and damaged. Information from the EPA hydrometric website (<http://hydronet.epa.ie>) indicated an average daily flow of 106.9m³/s occurred at Knocknamohill Hydrometric Station, approximately 5km downstream of Aughrim, during this flood event. This is the highest recorded flood at this station. No reports were found for this flood event detailing return periods.

4.3.2.4 Flood Event of November 2009

The review of the historical data indicated that flooding occurred in Arklow, Aughrim and Wicklow during November 2009.

In Aughrim, on November 1st, heavy rain and strong winds caused flooding. The peak flow at Knocknamohill Hydrometric Station was recorded as 92.7m³/s during this flood event, according to an EPA report entitled OSPAR Convention – Comprehensive Study of Riverine Inputs – Hydrometric Data for 2009” (Reference 6). For the period April to October 2009, the low flows did not vary much outside the range 2.7 -2.3m³/s at this station.

In Arklow, a press article outlines how heavy rains and high winds saw the town's coastal areas come under attack on November 17th. The town's protective sea defence, the rock armour, was breached in a number of areas. Roads were closed due to dislodged stones being washed onto the road.

In Wicklow, while no information is available for flooding in the town, it was found that the event led to the rail line between Wicklow and Gorey being closed due to the instability of an embankment south of Arklow, and a landslide south of Wicklow.

No reports were found for this flood event detailing return periods.

4.3.2.5 Flood Event of July 2009

Flooding occurred on July 2nd after several hours of heavy rainfall in the Dublin area from midnight to 9.00am. 38.2mm of rain fell at Dublin Airport over 9 hours, with 26.5mm falling in one of those hours.

In the Carysfort area, extensive damage was caused to both residential and commercial properties as a result of the flood event. No further details were provided however.

4.3.2.6 Flood Event of July 2007

Intense rainfall in South County Dublin in mid July 2007 caused the Carysfort-Maretimo stream to flood as it could not cope with the volume of water. Damage ensued to four areas through which the stream flows and flood waters of up to two feet deep damaged houses and commercial premises at Carysfort in Blackrock as a result.

4.3.2.7 Flood Event of November 2002

The historical data indicated that flooding occurred in Bray, Greystones, Arklow and in the Carrickmines/Shanganagh HPW during November 2002.

In Bray and Greystones on November 27th 2002, heavy rainfall along with extensive roadworks and debris caused many roads to become flooded. Several houses flooded in Season Park and Redford Park in Greystones.

In Arklow, on November 15th, heavy rainfall caused flooding. Several shops and houses in Arklow were seriously damaged. The worst affected areas were The Brook, Lower Main Street and Tinahask on the southside and Dublin Road and Worsboro Terrace on the northside.

In the Carrickmines/Shanganagh HPW, the historical review indicated that the Shanganagh River overflowed onto Commons Road and completely flooded the road. Sandbags, pumps, etc were used but flooding of nearby properties still occurred. From hydrographs at the Commons Road hydrometric station, it can be seen that the third highest flow on record occurred on 27th November 2002, measuring approximately 12.2m³/s (Reference 7). Further upstream, at the Carrickmines hydrometric station, the second highest flow on record occurred on the same date according to the same source, measuring approximately 5.7m³/s.

No reports were found for this flood event detailing extents or return periods.

4.3.2.8 Flood Event of February 2002

Information was found for a flood event which occurred in Bray, Arklow and Wicklow on February 1st 2002.

In Bray, flooding occurred as a result of heavy rainfall and strong winds. Waves lashed the promenade and flooded a number of streets. The Rosslare Rail line between Bray and Greystones was closed.

In Arklow, flooding occurred as a result of heavy rain and gale force winds. The areas around the South Quays were badly affected and the Dublin Road at Ferrybank was impassable. Worsboro Terrace flooded to a depth of 0.6m while Upper Condren's Lane flooded to a depth of 0.25m. Flooding of the Lifeboat House occurred due to breach in rock protection. The tide level in Arklow harbour reached 1.49mOD (Malin), which corresponds to its highest known level, according to a report entitled "Arklow Flood Study Report", by PH McCarthy and Partners Consulting Engineers (Reference 8). This is 1m higher than the mean high water spring tide.

Similarly in Wicklow, the Quay area was flooded by the sea.

No reports were found for this flood event detailing flows, extents or return periods.

4.3.2.9 Flood Event of Autumn/Winter 2001

A flood event occurred in the Deansgrange HPW in the autumn/winter of 2001, although the exact date could not be ascertained. The event occurred when the Deansgrange stream overflowed, causing a number of houses at Seafeld Court to be flooded. No information was available on the exact extents and cause of the flood.

4.3.2.10 Flood Event of November 2000

The historical data indicates that flooding occurred in Avoca, Bray, Arklow, Aughrim and Wicklow during November 2000 caused by heavy rain and gale force winds.

In Avoca on November 6th, flooding and fears over the integrity of the bridge resulted in the town being cut off. Rising flood waters resulted in a car being washed into a river.

In Bray, the promenade was badly flooded and closed off for a day. Flooding occurred on many of the side roads in Bray.

In Arklow, on November 6th, the Avoca River burst its banks. Dozens of families were evacuated as their homes were flooded by up to 0.9m of water. The town was almost completely cut off with the only access into the town being from the Wexford Road via the Arklow Bypass.

In Aughrim, weather conditions resulted in power cuts and severe black outs. The town was cut off due to floods in the area. A map showing the flood extents indicates that flooding affected over 20 houses at Jubilee Cottages, Fogarty's Cottages and Meath Cottages.

In Wicklow, the Rosslare-Dublin train service experienced disruptions when the sea encroached on the line between Greystones and Wicklow.

No reports were found for this flood event detailing flows, return periods, etc.

4.3.2.11 Flood Event of December 1997

In the Carrickmines/Shanganagh HPW, the historical review indicated that the flow at the Carrickmines hydrometric station, measuring approximately $5.6\text{m}^3/\text{s}$, reached its third highest level on record, according to hydrographs produced in the EPA report entitled "Flooding in the Shanganagh Catchment 27 November 2002", (Reference 7). However, the flow rate downstream at the Commons Road hydrometric station (approximately $9.8\text{m}^3/\text{s}$) was approximately the sixth highest on record indicating heavy rainfall in only part of the catchment. There were no details of extents or damage available for this event.

4.3.2.12 Flood Event of January 1996

Information was found for a flood event which occurred in Bray on January 7th 1996. There is no information on the extents of the flood which seems to have been caused by high tides. Press articles report that an elderly man drowned after a large wave swept him off a pier at Bray Harbour. An ambulance crew was injured when another gigantic wave crashed against them. A mother and her baby daughter were taken to hospital after they were hit by a large wave when it crashed over the sea wall.

4.3.2.13 Flood Event of May 1993

Heavy rainfall in late May 1993 caused flooding in the Carysfort area. The Carysfort/Maretimo Stream burst its banks at many locations, the extent of which can be seen in a series of photographs. No additional details on the flow or damage caused were provided. A DLRCC report which may provide more information on this event has been requested from DLRCC by OPW.

In the Carrickmines/Shanganagh HPW, the historical review indicated that the highest flows on record were recorded at both the Carrickmines hydrometric station (approximately 6.7m³/s) and the Commons Road hydrometric station (approximately 14.5m³/s) on 26th May 1993, according to hydrographs produced in the EPA report entitled “Flooding in the Shanganagh Catchment 27 November 2002” (Reference 7). Photos at Commons Road and Carrickmines indicate flooding of low lying areas, including roads, adjacent to the river. There were no further details of extents or damage available for this event.

4.3.2.14 Flood Event of August 1986

On the 25th and 26th of August 1986 Hurricane Charlie occurred and was deemed exceptional with large rainfall totals accompanied by strong to gale force winds causing flood events in Avoca, Bray, Arklow and Aughrim, and also in the Carrickmines/Shanganagh HPW. On the 26th of August rainfall was in excess of 100mm in the 24 hour period in many areas. The rushing water resulting from Hurricane Charlie did damage in excess of IR£3m to roads and bridges in County Wicklow.

In Avoca, flooding of regional roads occurred. Lions Bridge, approximately 4km upstream of Avoca, was washed away due to flood flows in the river. Damage was also caused to Avoca Bridge following undermining of a pier on the upstream side.

In Bray, a total of 520 houses were flooded together with retail, industrial and commercial premises. Unofficial estimates of the total cost of the damage at the time of flooding were put at approximately IR£2m. Five gas tanks were ripped from their stands on the banks of the River Dargle located beside the Lithographic Universal Printing Works and proceeded to leak liquid gas. The flood waters of the Dargle caused a sea-going cruiser to be swamped. The clubhouse at Bray Golf Club was almost surrounded by water which reached the bottom steps of the building.

A report by John B. Barry & Partners entitled "Hurricane Charlie An Overview - The Dargle River Experience" (Reference 9) describes how the storm followed a number of other active weather systems earlier in the month, which gave high rainfalls. Furthermore, drying conditions during the summer were poor, and soil moisture content was near field capacity. This report also identifies an estimated flow of $300\text{m}^3/\text{s}$ in the Dargle and equates this to an AEP of significantly less than 1.33%. A more accurate prediction cannot be made due to the lack of data. Highest flood depths of approximately 1.5m were observed at Green Park Road at Fair Green and Adelaide Villas.

In Arklow, many areas were flooded including the Golf Course, areas near the Leisure Centre, Arklow Caravan Park and Lower Main Street. This was a result of fluvial flooding where the River Avoca breached its banks and inundated the adjoining areas. According to the report entitled "Arklow Flood Study Report", by PH McCarthy and Partners Consulting Engineers (Reference 8), there was a 0.66%AEP flow in the Avoca.

Flooding in Aughrim during this flood event caused up to IR£140,000 worth of fish to be washed into the Aughrim River from fish farms on the river. No reports were found for this flood event detailing flows, extents or return periods in the Aughrim area.

In the Carrickmines/Shanganagh HPW, the historical review indicated that the flow at the Carrickmines hydrometric station reached its fifth highest level on record ($5.3\text{m}^3/\text{s}$), while the flow rate downstream at the Commons Road hydrometric station reached its fourth highest level on record ($11.4\text{m}^3/\text{s}$), according to a Dún Laoghaire-Rathdown County Council Report entitled "Hydrometric Review Shanganagh River" (Reference 10). However, there was no available information for flood extents or damage caused due to flooding of this river.

4.3.2.15 Flood Event of November 1982

In the Carrickmines/Shanganagh HPW, a Dún Laoghaire Rathdown County Council Report entitled "Hydrometric Review Shanganagh River" (Reference 10), indicated that the second highest flow on record was recorded at the Commons Road hydrometric station on 6th November 1982, measuring $13.3\text{m}^3/\text{s}$, while at the Carrickmines hydrometric station, the fourth highest flow on record was recorded, measuring $5.4\text{m}^3/\text{s}$. Flooding was caused when the Shanganagh River overflowed. However, at Cabinteely, debris was washed downstream and this, in conjunction with vegetation which had been growing in the stream, blocked up a culvert. Some minor road flooding occurred at Commons Road due to overflowing of the Shanganagh and flooding also occurred at Pottery Road/Johnstown Road in Cabinteely.

A flood event was also found to have occurred in the Deansgrange HPW, where flooding of Johnstown Road and Pottery Road areas occurred. Houses and gardens were flooded due to the Deansgrange river overflowing. This was caused by debris being washed down the stream into culverts, causing a loss of capacity.

4.3.2.16 Flood Event of December 1981

In Bray on the 3rd of December 1981, a press article describes how blizzards and Force 10 winds led to sleet, snow and large scale flooding across the country. Flooding meant that houses along the seafront in Bray required evacuation and sandbagging.

No information was found detailing flows, extents or return periods for this flood event.

4.3.2.17 Flood Event of January 1969

The historical data indicated that flooding occurred in Bray January 1969, caused by gale force winds and heavy rain. A press article reported that heavy seas drove waves about 9m high over the Esplanade wall. Strand Road in Bray was flooded to a depth of about 0.6m and Albert Avenue and Fitzwilliam Terrace also flooded.

No information available on flows, extents, return periods, etc.

4.3.2.18 Flood Event of November 1965

The review of information indicated that a flood event occurred in Ashford/Rathnew, Avoca, Bray, Arklow, Aughrim and Wicklow on the 16th of November 1965. The flood was caused by continuous heavy rain and high to gale force winds.

In Ashford/Rathnew, flooding occurred near Rathnew Cemetery in the afternoon and there was also considerable water near the Railway Bridge at Bollarney. Traffic diversions were required due to road flooding. The Glen Motor Inn at Ashford required assistance from the Wicklow Fire Brigade due to damage caused by flooding.

In Avoca, three days of continuous torrential rain caused flooding resulting in passengers being marooned in a bus for five hours and requiring rescuing by a boat due to swirling floodwaters. Flooding occurred of a large section of the railway line at Avoca causing it to be uprooted and ending up in the river. A number of families in Avoca Village were evacuated as the water poured into their homes. Damage occurred to a bridge in the Vale of Avoca due to flooding on the main railway line between Dublin and Rosslare Harbour.

In Bray, flooding was caused by the occurrence of two depressions over two days. Precipitation for the first depression was slight and mainly took the form of snow in areas of higher ground. The second depression was much different however with heavier rainfall associated with it. This rain coupled with the melting of snow caused the River Dargle to overflow its banks immediately downstream of the Weir, where the flood wall had become undermined and collapsed.

The River Dargle Flood Protection Scheme Preliminary Report by John B. Barry & Partners (Reference 11) estimated the flow through Bray for the 1965 event to be 200m³/s, which corresponds to an estimated AEP of 3.33 to 4%. The floods entered many shops, offices and homes on the Lower

Dargle Road, Little Bray, The People's Park, Green Park Road, Castle Street and the Golf Links. The area of Little Bray in particular was badly affected as it is surrounded by the sea and the Upper and Lower Dargle Road.

In Arklow, the surrounding area was cut off, as many streets were flooded including the North Quay. More than 150 premises were flooded in Arklow, including private homes, business premises and garages. The main railway line between Rosslare and Dublin was out of action with passengers being carried by bus between Arklow and Wicklow.

In Aughrim, 23 houses were flooded to a depth of 0.9-1.2m. The side wall of a recently built store alongside the river was knocked down. The road at the bridge was ripped up and water flowed through Lawless's Hotel.

In Wicklow, the continuous rain and gale force winds caused flooding, albeit not to the same severity as other towns in the county. Many parts of the main Dublin Road were covered with several inches of water and The Bridge Hotel in Wicklow was flooded. Railway lines in the town were flooded with the Wicklow-Arklow line particularly affected.

4.3.2.19 Flood Event of November 1954

A flood event occurred in Bray on 29th November 1954. Heavy rain accompanied by gale force winds led to high seas. Flooding was severe where the promenade was overtopped causing flooding in the basements of houses in Martello Terrace and on Strand Road.

No information available on flows, extents or return periods.

4.3.2.20 Flood Event of March 1947

A flood event was found to have occurred in Ashford/Rathnew on 16th March 1947. Heavy rain caused the River Vartry to overflow its banks and it inundated the whole valley at Ashford. The flood cut off the main Dublin Road leading to traffic congestion. The road from Ashford to Roundwood was impassable.

In Bray, the River Dargle overflowed causing boats, washed up from the seashore, to float through Strand Road in approximately 1.2m of water. About 200 people were evacuated from their homes, in which furniture was floating around rooms in the flood waters. In Little Bray, about 15 families were evacuated.

In Wicklow, many streets in the town were flooded, especially Church Street which was 0.9m deep in water. Roads were impassable with Wicklow County Council warning motorists of flooded roads via radio broadcasts.

No information available on flows, extents or return periods was found.

4.3.2.21 Flood Event of August 1946

A flood event was found to have occurred in Bray, Greystones and Aughrim in August of 1946. The flooding was caused by rainfall and high winds.

In Bray, a press article states that a rainfall depth of 43mm was recorded at Rathfarnham Castle on 12th August 1946. The River Dargle overflowed its banks and about 20 streets in the vicinity were flooded to a depth of 0.9m.

In Greystones, gale force winds were recorded and waves broke over the sea road making it impassable in places.

The bridge over the River Ow in Aughrim was swept away along with a portion of the roadway which was closed to traffic. A hotel in the village and several houses were flooded.

No reports were found for this flood event detailing flows, extents or return periods.

4.3.2.22 Flood Event of September 1931

Flooding occurred in Bray on 2nd September 1931 due to heavy rainfall. The roadway across Calary Bog, between Bray and Roundwood, was deeply flooded in several areas. No reports were found for this flood event detailing flows, extents or return periods.

4.3.2.23 Flood Event of January 1930

A flood event was found to have occurred in Greystones on 17th January 1930. The flood was caused by a spring tide combined with a strong south east wind. Fourteen dwelling houses at North Beach, Greystones, disappeared as they were engulfed by the sea and completely destroyed. Three of the houses were dismantled the previous year in expectation such an occurrence but eleven families (43 people) were forced to vacate their homes and remove their furniture.

No information on flows, extents or return periods was found.

4.3.2.24 Flood Event of August 1905

Information was found for a flood event which occurred in Bray and Arklow on 24th August 1905, caused by torrential rain.

In Bray, the water came down from the surrounding hills and encountered the high tide causing the River Dargle to overflow. Water flooded the houses in the low lying streets of the town to a depth of ten feet. Two bridges were destroyed and up to a mile of road was damaged. The bulk of the damage was done at Little Bray where hundreds of dwellings were flooded and over 400 families left destitute and homeless. A man drowned in the floods.

In Arklow, serious flooding took place, particularly in the low-lying portions known as the Fishery. Many houses were flooded with beds, bedding and other belongings of people destroyed.

No information is available on flows, extents or return periods.

4.4 PRELIMINARY ASSESSMENT OF PAST FLOODS AND FLOODING MECHANISMS

A preliminary assessment of a number of major historical flood events which occurred within HA10 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 HA10 have experienced a number of major flood events in the past, most notably in December 1905, September 1957, October 1960, November 1965, August 1986, November 2000 and January 2010. The 1986 and 2010 flood events were the worst among these. The August 1986 flood event was locally known as Hurricane Charlie.

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 five gauging stations located on or upstream of watercourses to be modelled within HA10 as shown in Table 4.9 below.

Table 4.9: Flow Data Availability for Gauges on Watercourses to be Modelled in HA10

Station Number	Station Name	Watercourse	Catchment	AMAX Series Provided	Continuous Flow Record Available
10021	Carrickmines	Carrickmines/Shanganagh HPW	Loughlinstown-Coastal	Y	Y
10022	Commons Road	Carrickmines/Shanganagh HPW	Loughlinstown-Coastal	Y	N
10028	Knocknamohill	Aughrim River	Avoca	Y	N
10002	Rathdrum	Approx 8km Upstream of Modelled Portion of Avoca River	Avoca	Y	Y
10038	Druids Glen	Newtownmountkennedy	Coastal	N	Y

These have been used to conduct flood event analysis within HA10. Table 4.10 presents the selected events on the affected AFA basis.

4.4.2 Flood Mechanisms in HA10

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

The various types of flooding can be categorised as follows:

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

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

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

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

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

Most flooding events which have occurred in HA10, were of the 'fluvial' category. Some 'tidal' and/or 'combined fluvial and tidal' types of flooding occur in the coastal river catchments, for example the Newtownmountkenedy River catchment.

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 catchments physical and meteorological characteristics and in particular, the catchment area, slope, catchment soil type and the antecedent wet condition, drainage density, 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. Flash flood 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 a catchment can result from the joint occurrences of fluvial and tidal flood events. The frequency of selected flood events within HA10 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 distributions. As an example of flood event analysis within HA10, a hydrograph plot of the January 2010 event on the Carrickmines/Shanganagh River as recorded at Hydrometric Station 10021 (Commons Road) is shown on Figure 4.6.

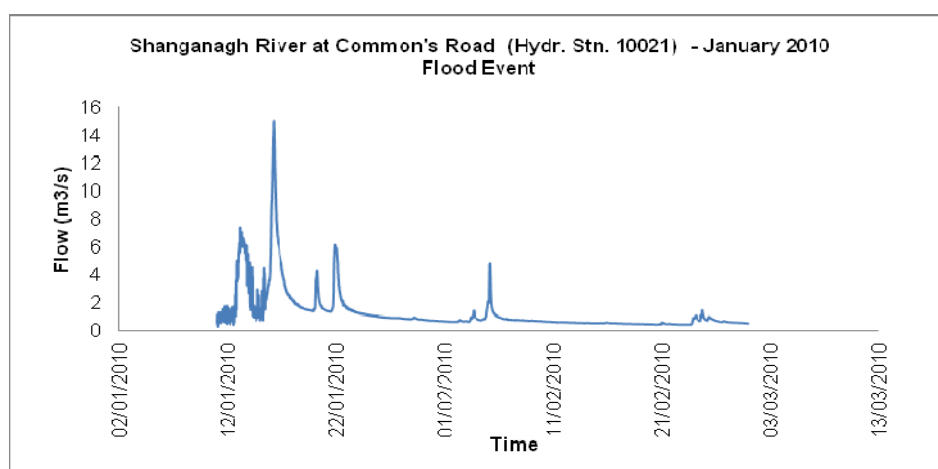


Figure 4.6: Observed flood hydrograph during the January 2010 flood event at the Commons Road Hydrometric Station (10021)

Figure 4.7 shows the observed AMAX flow records for Carrickmines/Shanganagh River at Commons Road for the period of 1980 to 2010. Figures 4.8, 4.9 and 4.10 show the fitted EV1, GEV and 2-parameter Lognormal distributions to these records respectively.

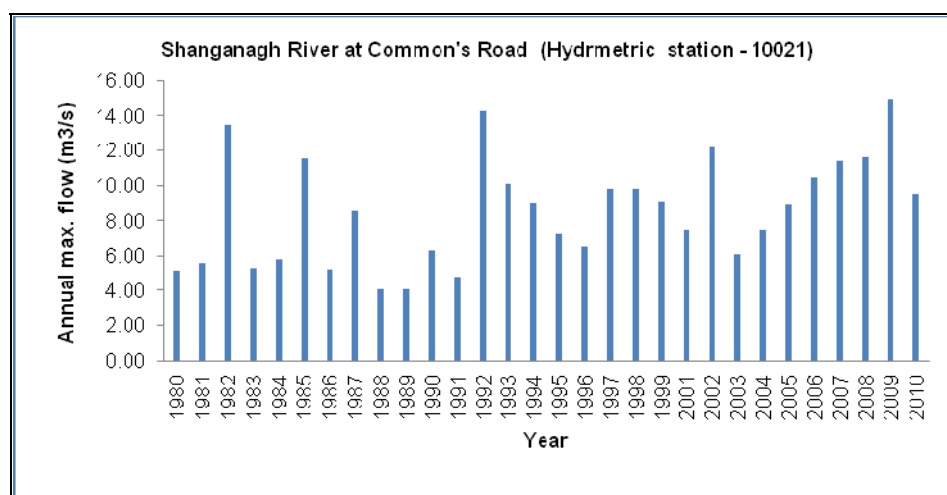


Figure 4.7: Observed Annual Maximum Flows for Shanganagh River at Commons Road (1980 – 2010).

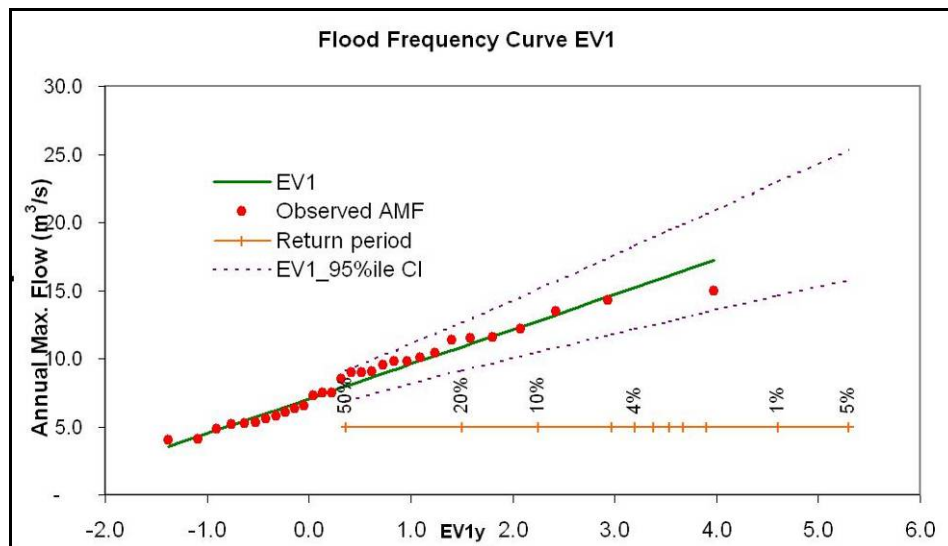


Figure 4.8: Fitted EV1 frequency Curve to the observed annual maximum records for Shanganagh River at Commons Road (Hydro.Stn.10021).

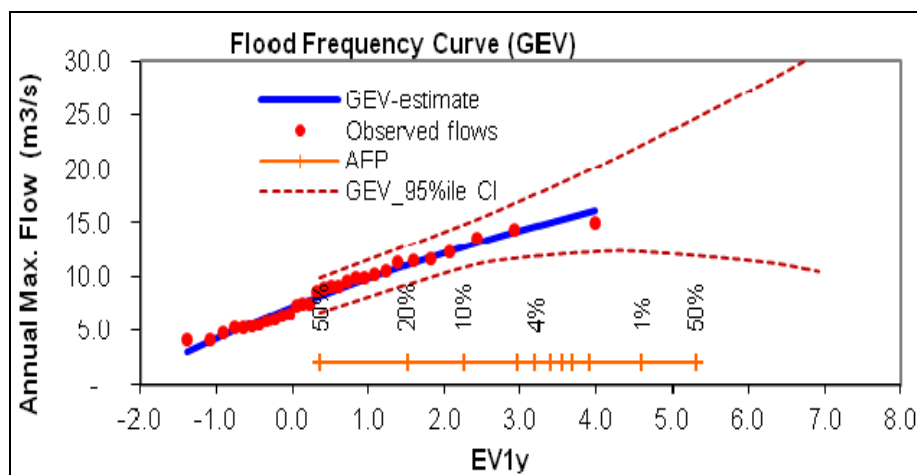


Figure 4.9: Fitted GEV frequency curve to the observed annual maximum records for Shanganagh River at Commons Road (Hydro.Stn.10021)

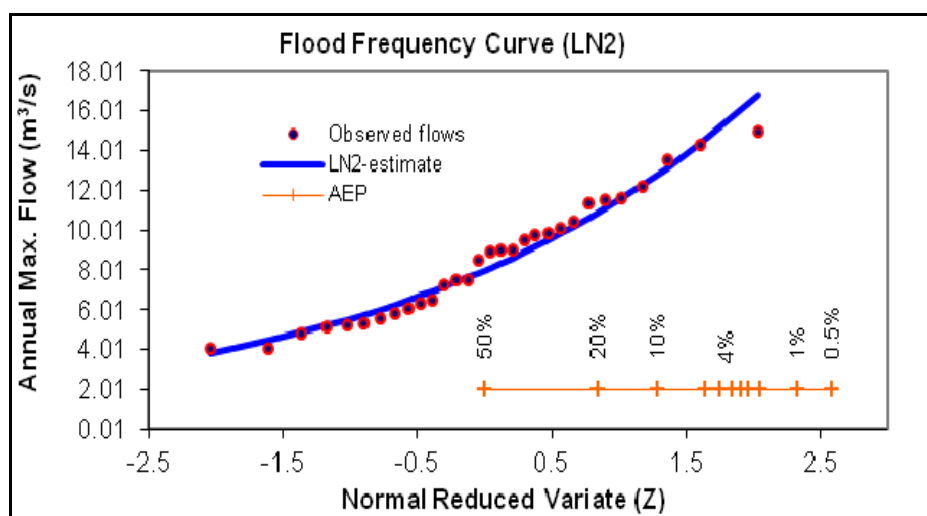


Figure 4.10: Longnormal (2-parameter) frequency curve to the observed annual maximum records for Shanganagh River at Commons Road (Hydro.Stn.10021)

It can be seen from these figures that GEV distribution provides slightly better fit to the observed annual maximum records. Based on this, the estimated AEP of the observed flood flow of 14.90 m³/s during the January 2010 flood event (16/01/2010) is approximately 4% (1 in 25 years return period).

For many of the hydrometric stations in HA10 sufficiently long records were not available to estimate the frequency of the observed events using the associated at-site data (as mentioned in Table 4.10). 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 November 2000 at Aughrim would be approximately 10% based on the corresponding estimate for Aughrim River at Knocknamohil (Hydrometric station No. 10028), which is located approximately 6km downstream of Aughrim town.

Table 4.10 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 Avoca, Vartry and Carrickmines/Shanganagh River catchments were the August 2008 and January 2010 flood events. Most parts of these catchment areas were affected during these events and the causes of flooding were the prolonged intense rainfall (fluvial). The estimated approximate AEP of the January 2010 flood event recorded at Station 10028 (Knocknamohil) on the Aughrim River (a major tributary river of Avoca River) is less than 1% (greater than 100 year return period).

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 5.2.2, Hydraulic Model Calibration.

Table 4.10: Significant flood events, their generation mechanisms and frequency in HA10

AFA/HPW	Nearest Gauging Stations		Major flood events				
	Stn. No.	Location	Date	Peak flow (m ³ /s)	Rank ²	Approx. AEP (%)	Flood mechanisms
Carrickmines/Shanganagh HPW	10021	Shanganagh River at Commons Road	06/11/1982	13.50	28	10-6.67%	Fluvial: heavy and prolonged rainfall
			26/05/1993	14.30	29	6.67-5%	Fluvial: heavy and prolonged rainfall
			27/11/2002	12.20	27	20-10%	Fluvial; Flooding caused by intense rainfall followed by prolonged antecedent wet condition. Flood duration was 3-days. Fast response catchment, time to peak is approximately 1 day; slightly slower recession
			16/01/2010	14.95	30 (highest)	5-4%	Fluvial; Flooding caused by intense rainfall followed by prolonged antecedent wet condition. Flood duration was 5-days. Fast response catchment, time to peak is approximately 1 day; slightly slower recession.
Carrickmines/Shanganagh HPW	10022	Cabinteely River at Carrickmines	26/08/1986	5.1	14	20 – 10%	Fluvial; heavy and prolonged rainfall
			26/05/1993	6.9	17 (highest)	5%	Fluvial; heavy and prolonged rainfall.
			27/11/2002	5.7	15	20 – 10%	Fluvial; heavy and prolonged rainfall; time to peak is approximately 1 day. Flood duration was approximately 9 days.
			16/01/2010	No records	-	No records	Fluvial: Intense rainfall.
Bray	10019	Ballyman River at Vallombrosa	25/12/1905	No records	-	No records ¹	-
			03/09/1931	No records	-	No records ¹	-
			17/11/1965	No records	-	No records ¹	-
			26/08/1986	No records	-	No records ¹	-
			05/11/2000	No records	-	No records ¹	-
			15/11/2002	No records	-	No records ¹	-
			16/01/2010	No records	-	No records ¹	Fluvial: Intense rainfall.

AFA/HPW	Nearest Gauging Stations		Major flood events				
	Stn. No.	Location	Date	Peak flow (m ³ /s)	Rank ²	Approx. AEP (%)	Flood mechanisms
Greystones/Charlesland	No gauge	Stream Charlesland at	Dates not known	No records	-	No records	-
Kilcoole	10038	Stream at Druids Glen	15/11/2002	9.07	8	20 – 10%	Fluvial; intense rainfall; time to peak is less than 1 day. Flood duration was approximately 15 days.
			16/08/2008	9.46	9	10 – 6.67%	Fluvial; Intense rainfall; time to peak is less than 1 day. Flood duration was approximately 3 days.
			16/01/2010	9.50	10 (highest)	10 – 6.67%	Fluvial; Intense rainfall; time to peak is less than 1 day. Flood duration was approximately 7 days.
Newcastle	No gauge	Stream Newcastle at	Dates not known	No records	-	No records	-
Ashford Rathnew and Wicklow	10014	Stream Rathnew at	Nov. 1965	No records	-	No records	-
			Aug., 2008	No records	-	No records	-
			16/01/2010	No records	-	No records	-
			25/09/1957	No records	-	No records	-
			02/10/1960	No records	-	No records	-
			18/11/1965	No records	-	No records	-
Aughrim	10028	Aughrim river at Knocknamohil	25/08/1986	No records	-	No records	-
			05/11/2000	93.5	19	20 – 10%	Fluvial; prolonged and heavy rainfall.
			05/07/2008	113.5	21	10 – 6.67%	Fluvial; intense rainfall, time to peak is approximately 15-17 hours. Flood duration was approximately 5-days.
			16/01/2010	203.5	22 (highest)	>1%	Fluvial; Intense rainfall, time to peak is approximately 15-17 hours. Flood duration was approximately 7-days.
			25/09/1957	140.82	48	20 – 10%	Fluvial: Intense rainfall. Time to peak was 2-3 days, slightly slower recession. Flood duration was approximately 10-days.
			02/10/1960	162.10	50	6.67 – 5%	Fluvial: Prolonged and heavy rainfall. Flood duration was approximately 10 days.
Avoca	10002	Avonmore river at Rathdrum	18/11/1965	266.44	51	>1%	Fluvial: Intense rainfall. Flood duration was 4-days.
	10042	Avoca River at Arklow Townbridge	25/08/1986	155.32	49	10 – 6.67%	Fluvial: Intense rainfall. Flood duration was approximately 3 days.
			Nov. 2000	Missing	-	No records	-
			16/01/2010	287.80	52 (highest)	> 1%	Fluvial: Intense rainfall, time to peak is approximately 2-3 days. Flood duration was approximately 7 days.

AFA/HPW	Nearest Gauging Stations		Major flood events				
	Stn. No.	Location	Date	Peak flow (m ³ /s)	Rank ²	Approx. AEP (%)	Flood mechanisms
			18/11/1965	No records	-	No records	Fluvial and coastal
			25/08/1986	No records	-	No records	Fluvial and coastal

Note: 1 Intermittent flow records for Ballyman stream at Ballyman (Hydrometric station 10017) were obtained from EPA for the period from 1980 to 1997. These records were not considered suitable for the flood event frequency analysis.

- 2 For each hydrometric station, the observed annual maxima time series was ranked in ascending order i.e. the smallest record has **rank 1** and the highest peak flow has the **highest rank**. For example, at the hydraulic station 10042 (Avoca River at Arklow town bridge), the peak flow recorded on 16/01/2010 (287.80m³/s) is the highest record in the 52 years of data.

5 HYDROLOGICAL ANALYSIS METHOD STATEMENT

5.1 ANALYSIS OF HYDROMETRIC AND METEOROLOGICAL DATA

5.1.1 Gauging Station Rating Review

A rating review of six hydrometric stations in HA10 is being undertaken. This 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, AMAX 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 the 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 levee 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 entire 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 complete 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; 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 HA10 Hydraulic Models

To facilitate hydrological assessment and hydraulic modelling, 13 hydraulic models have been conceptualised for HA10 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 13 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).

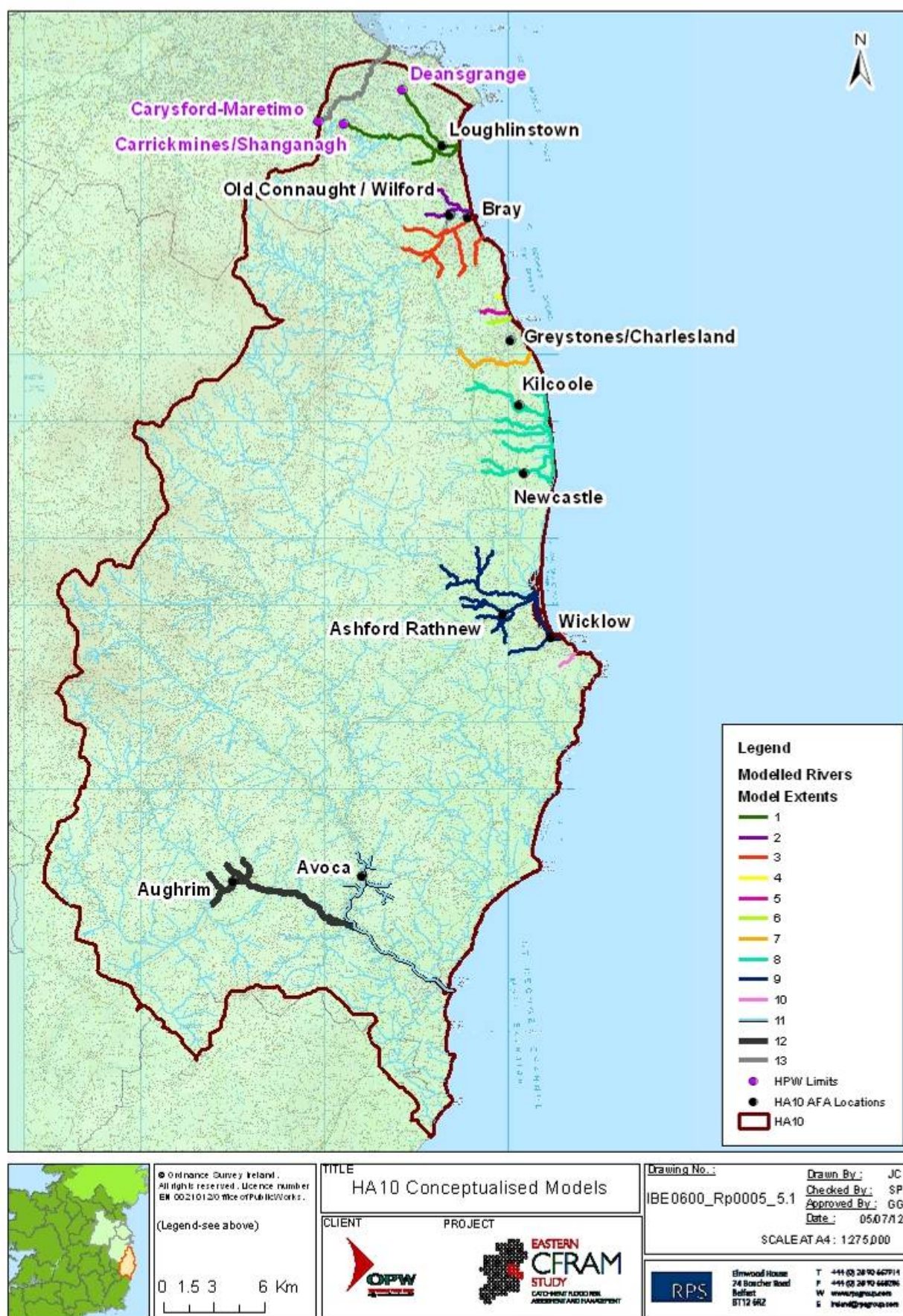


Figure 5.1: HA10 Conceptualised Models

5.2.2 Hydraulic Model Calibration

Based on the review of historical flood events (Section 4.3.2) 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 Station Number	Hydraulic Model Number	Selected Flood events for hydraulic model calibration and verification	
		Date	Peak flow (m3/s)
10018	Model 1	-	No flow records are available
10021	Model 1	06/11/1982	13.50 (No continuous flow records)
		26/08/1986	11.50 (No continuous flow records)
		26/05/1993	14.30 (No continuous flow records)
		27/11/2002	12.20
		04/12/2009	11.59
		16/01/2010	14.95
10022	Model 1	25/08/1986	5.09 (No continuous flow records)
		26/05/1993	6.89 (No continuous flow records)
		18/12/1997	5.71 (No continuous flow records)
		27/11/2002	5.72
10017	Model 3	-	Some intermittent flow records for Ballyman stream at Ballyman (Hydrometric station 10017) were obtained from EPA for the period from 1980 to 1997. These records were not considered suitable for hydraulic model calibration.
10019	Model 3	-	No flow records are available
10010	Model 3	-	No flow records are available
10032	Model 3	-	No flow records are available
10030	Model 8	-	No flow records are available
10031	Model 8	-	No flow records are available
10038	Model 8	15/11/2002	9.07
		16/08/2008	9.46

Hydrometric Station Number	Hydraulic Model Number	Selected Flood events for hydraulic model calibration and verification	
		Date	Peak flow (m3/s)
		16/01/2010	9.51
10014	Model 9	-	No flow records are available
10008	Model 11	-	No flow records are available
10027	Model 12	-	No flow records are available
10028	Model 12	29/11/1995	88.90 (No continuous flow records)
		29/10/2004	102.0
		05/07/2008	113.54
		16/01/2010	203.46
10009	Model 12	-	No flow records are 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 will include 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.

Note that Model numbers 2, 4, 5, 6, 7, 10 and 13 have no hydrometric data with which to undertake model calibration. The historical review outputs will be used as much as possible for Models 2, 4, 5, 6, 7, 10 and 13 to calibrate based on historical information such as flood extents, recorded flood levels in urban areas, or aerial imagery (refer to Section 4.3) .

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 or for model calibration. 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 was undertaken to identify HEPs in HA10. These were 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 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 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), an 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. Gauging stations upstream of modelled reaches will also be used in calibration exercises as appropriate.

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 channels 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 and 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.

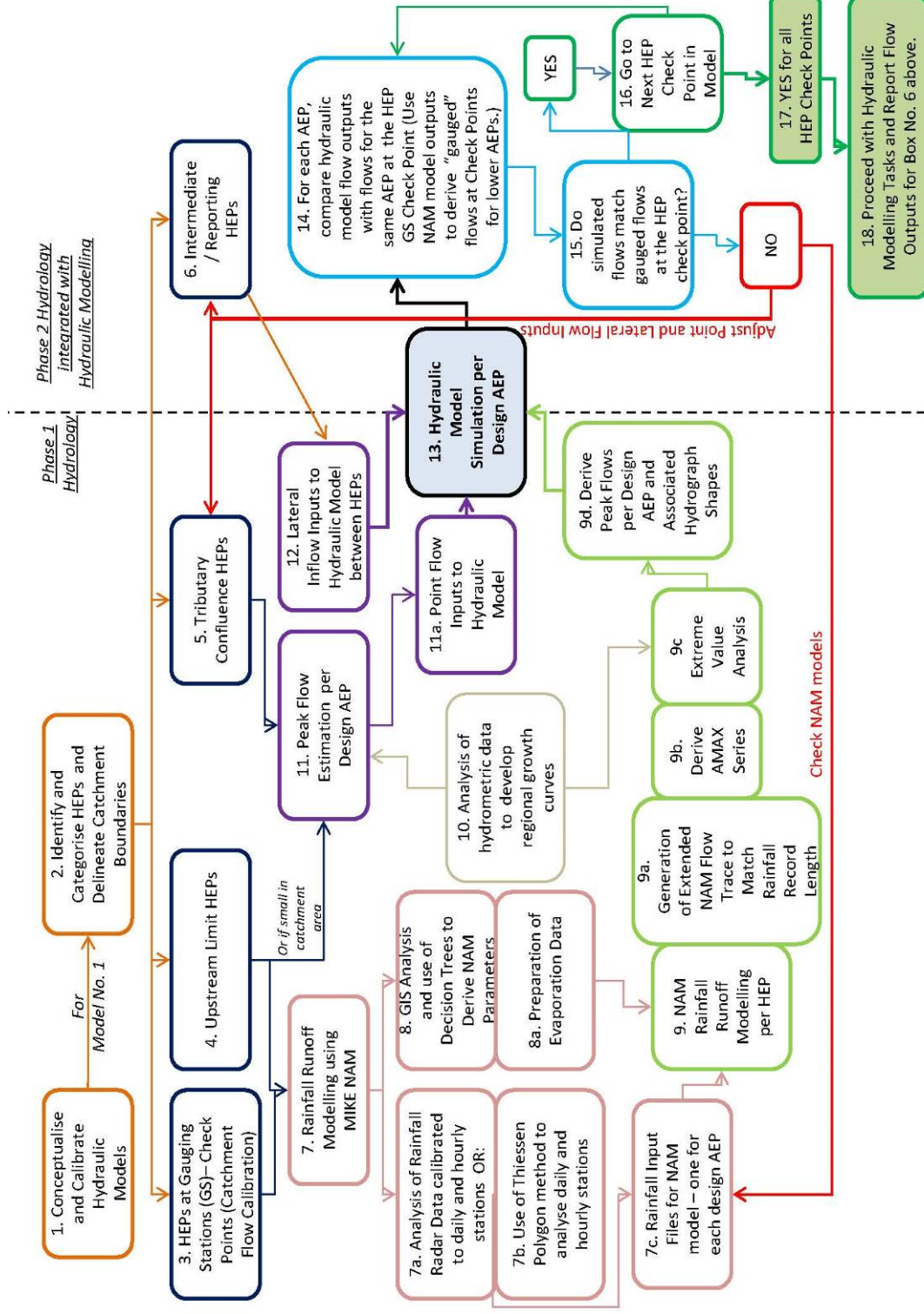


Figure 5.2: Two Phased Hydrology Analysis Process Chart

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 HA10 – (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 12).

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 HA10 there are only 145 station-year records therefore records from other gauged catchments with similar physiographic and climatological characteristics need to be pooled to develop a growth curve.

5.4.3 Phase 1: Calculation of Design Flows at HEPs

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 return periods. 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 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 per return period will be further analysed in terms of its characteristics: intensity, duration, volume and spatiotemporal distribution (if radar data is used). These rainfall events that cause the design peak flows per return period will also be further compared to the Depth Duration Frequency (FSU Work Package 1.2 – Reference 13) growth curves to infer correlation characteristics.

Each Upstream Limit HEP is 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 14) 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 HA10 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 15) 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 associated with 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_{medpcd}) associated with the HEP being considered. Pivotal site(s) are then used to adjust the Q_{med} estimation based on catchment descriptors by donating gauging data from a suitable station. This donation is achieved through the use of an adjustment factor which is the ratio of the Pivotal Site's $Q_{medgauged}$ and Q_{medpcd} . The Q_{medpcd} calculated at the HEP is then multiplied by the adjustment factor to arrive at a final Q_{med} estimation. This can be further adjusted for urbanisation if required.

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

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

Geographical closeness is calculated automatically by the FSU Q_{med} estimation spreadsheet based on distance from the HEP. 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, S_{1085} and ARTDRAIN2. It is important to check similarity of these characteristics (attenuation from rivers and lakes, drainage density, catchment slope and whether or not the pivotal site has been arterially drained), as these will affect how appropriate the gauged data will be for donation to the HEP. To compare these descriptors, charts will be plotted showing the relevant values with respect to the HEP value for the same descriptor. The pivotal site which compares best will be chosen. If two pivotal sites are prominent, both can be used in the adjustment, by applying a

weighting to each. This weighting will be based on the user's judgement after having looked closely at the catchment descriptors.

Sensitivity analysis on the choice of pivotal site will also be undertaken by plotting the resulting Q_{med} values from each to identify trends and outliers. This will also be done in the context of the 68% and 95% confidence limits associated with the Q_{medpcd} estimation for the HEP, using the FSU factorial standard error of ± 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 CFRAMS rating review is undertaken, consideration will be given to updating adjustment factors depending on RPS' recommendation on the robustness of the revised rating. The factorial standard error associated with the Q_{med} estimation will also be used to calculate 68% and 95%ile confidence intervals to assist in pivotal site selection and to inform any adjustments to derived flows in catchment flow calibration.

However, if a larger tributary catchment is gauged (say $>100\text{km}^2$ decided on a case by case basis), it is likely to be more appropriate to construct a rainfall runoff model, calibrated to the gauged data, so that a calibrated inflow hydrograph is derived. This will be undertaken where applicable. Flow contributions from tributaries $5\text{km}^2 \sim 100\text{km}^2$ will be estimated using 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 and 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 5.2.2).

The peak flow output from the design event hydraulic model will be compared with that of the combined NAM Check model output at the HEP Gauging Station Check Point **(Box 14, 15)**. Where differences in discharge occur, the NAM models will be checked in terms of model parameters **(Box 7,8,9)** and point and lateral flow inputs will be iteratively adjusted **(Box 11,12)** within relevant confidence intervals until calibration to the gauged data is achieved for each design event **(Box 16)**.

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

Of the seven hydrometric stations located on modelled watercourses in HA10, six have water level and flow data available for catchment flow calibration (refer to Table 4.6), and are therefore viable as HEP Check Points. The 7th station (Arklow Town Bridge) 10042 only has eight years of 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 16) provides 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 (Reference 16, 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 return period (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 Reference 16, section 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 points 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 HA10 AND ASSOCIATED ANALYSIS

Appendix E contains a map showing the layout of HEPs in HA10, 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 CFRAMS	MODEL NUMBER	HEP CATEGORY	HYDROLOGY
10022	MODEL 1	HEP Gauging Stations	CATCHMENT FLOW CALIBRATION
10021	MODEL 1	HEP Gauging Stations	CATCHMENT FLOW CALIBRATION
10_1211_1	MODEL 1	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_1518_4	MODEL 1	HEP Upstream Limit	RAINFALL RUNOFF MODELLING
10_1220_3	MODEL 1	HEP Tributary	PEAK FLOW ESTIMATION
10_1245_1	MODEL 1	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_1487_2	MODEL 2	HEP Upstream Limit	PEAK FLOW ESTIMATION
TBC	MODEL 2	HEP Upstream Limit	PEAK FLOW ESTIMATION
TBC	MODEL 2	HEP Tributary	PEAK FLOW ESTIMATION
10_1332_13	MODEL 3	HEP Tributary	PEAK FLOW ESTIMATION
10_1277_10	MODEL 3	HEP Tributary	PEAK FLOW ESTIMATION
10_1327_1	MODEL 3	HEP Tributary	PEAK FLOW ESTIMATION
10_534_5	MODEL 3	HEP Tributary	PEAK FLOW ESTIMATION
10019	MODEL 3	HEP Gauging Stations	CATCHMENT FLOW CALIBRATION
10_1328_2	MODEL 3	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_1414_5	MODEL 3	HEP Upstream Limit	RAINFALL RUNOFF MODELLING
10_1277_5	MODEL 3	HEP Upstream Limit	RAINFALL RUNOFF MODELLING

NODE ID CFRAMS	MODEL NUMBER	HEP CATEGORY	HYDROLOGY
10_1332_9	MODEL 3	HEP Upstream Limit	PEAK FLOW ESTIMATION
TBC	MODEL 3	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_534_2	MODEL 3	HEP Upstream Limit	PEAK FLOW ESTIMATION
TBC	MODEL 4	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_1242_1	MODEL 5	HEP Upstream Limit	PEAK FLOW ESTIMATION
TBC	MODEL 6	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_1461_2	MODEL 7	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_1369_13	MODEL 8	HEP Tributary	PEAK FLOW ESTIMATION
10_1356_4	MODEL 8	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_514_5	MODEL 8	HEP Tributary	PEAK FLOW ESTIMATION
TBC	MODEL 8	HEP Upstream Limit	PEAK FLOW ESTIMATION
TBC	MODEL 8	HEP Tributary	PEAK FLOW ESTIMATION
TBC	MODEL 8	HEP Tributary	PEAK FLOW ESTIMATION
10038	MODEL 8	HEP Gauging Stations	CATCHMENT FLOW CALIBRATION
10_1369_1	MODEL 8	HEP Upstream Limit	PEAK FLOW ESTIMATION
TBC	MODEL 8	HEP Upstream Limit	PEAK FLOW ESTIMATION
TBC	MODEL 8	HEP Tributary	PEAK FLOW ESTIMATION
TBC	MODEL 8	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_1575_5	MODEL 8	HEP Upstream Limit	PEAK FLOW ESTIMATION
TBC	MODEL 8	HEP Tributary	PEAK FLOW ESTIMATION
TBC	MODEL 8	HEP Tributary	PEAK FLOW ESTIMATION
10_514_1	MODEL 8	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_1494_2	MODEL 8	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_1369_8	MODEL 8	HEP Intermediate	Reporting/Checks
10_1369_11	MODEL 8	HEP Intermediate	Reporting/Checks
10_1488_5	MODEL 8	HEP Intermediate	Reporting/Checks
10_1589_2	MODEL 8	HEP Intermediate	Reporting/Checks
10_1207_1	MODEL 9	HEP Tributary	PEAK FLOW ESTIMATION
10_1207_4	MODEL 9	HEP Tributary	PEAK FLOW ESTIMATION
10_1463_2	MODEL 9	HEP Tributary	PEAK FLOW ESTIMATION
10_506_4	MODEL 9	HEP Tributary	PEAK FLOW ESTIMATION
10_540_3	MODEL 9	HEP Tributary	PEAK FLOW ESTIMATION
10_1097_2	MODEL 9	HEP Tributary	PEAK FLOW ESTIMATION
10_1167_2	MODEL 9	HEP Tributary	PEAK FLOW ESTIMATION
10_1189_6	MODEL 9	HEP Tributary	PEAK FLOW ESTIMATION
10_1607_3	MODEL 9	HEP Tributary	PEAK FLOW ESTIMATION
10_1603_4	MODEL 9	HEP Tributary	PEAK FLOW ESTIMATION
TBC	MODEL 9	HEP Upstream Limit	PEAK FLOW ESTIMATION
TBC	MODEL 9	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_1492_2	MODEL 9	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_1189_3	MODEL 9	HEP Upstream Limit	PEAK FLOW ESTIMATION

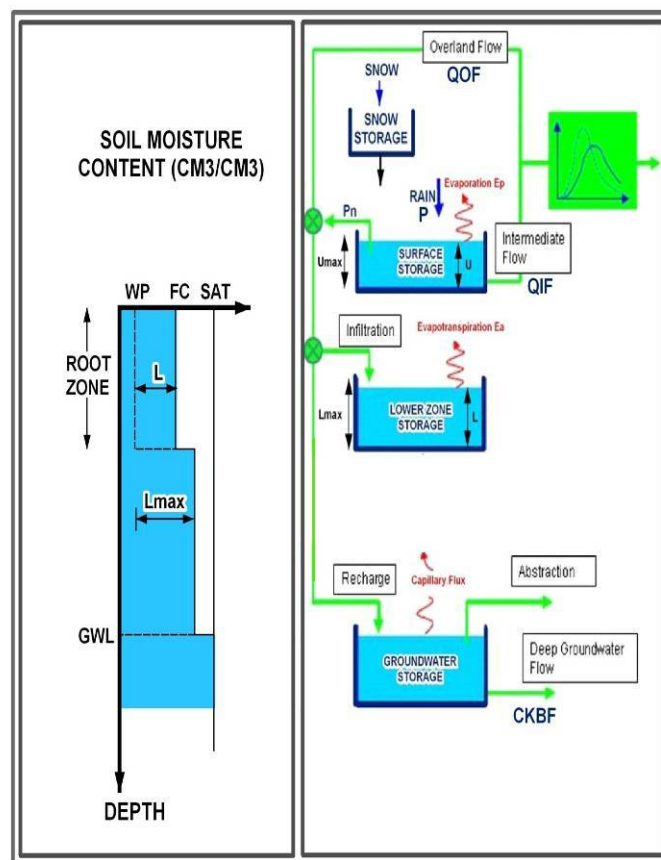
NODE ID CFRAMS	MODEL NUMBER	HEP CATEGORY	HYDROLOGY
10_1203_3	MODEL 9	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_1530_5	MODEL 9	HEP Upstream Limit	RAINFALL RUNOFF MODELLING
10_488_2	MODEL 9	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_1463_1	MODEL 9	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_506_1	MODEL 9	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_1191_1	MODEL 9	HEP Upstream Limit	PEAK FLOW ESTIMATION
TBC	MODEL 10	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_279_1	MODEL 11	HEP Tributary	PEAK FLOW ESTIMATION
10_76_2	MODEL 11	HEP Tributary	PEAK FLOW ESTIMATION
10_209_1	MODEL 11	HEP Tributary	PEAK FLOW ESTIMATION
10_209_3	MODEL 11	HEP Tributary	PEAK FLOW ESTIMATION
10_227_4	MODEL 11	HEP Tributary	PEAK FLOW ESTIMATION
10_1394_3	MODEL 11	HEP Tributary	PEAK FLOW ESTIMATION
10_1477_5	MODEL 11	HEP Tributary	RAINFALL RUNOFF MODELLING
TBC	MODEL 11	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_227_1	MODEL 11	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_98_4	MODEL 11	HEP Upstream Limit	RAINFALL RUNOFF MODELLING
10_250_4	MODEL 11	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_902_3	MODEL 11	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_250_6	MODEL 11	HEP Tributary	PEAK FLOW ESTIMATION
TBC	MODEL 11	HEP Upstream Limit	PEAK FLOW ESTIMATION
TBC	MODEL 11	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_131_2	MODEL 12	HEP Tributary	PEAK FLOW ESTIMATION
10_843_5	MODEL 12	HEP Tributary	PEAK FLOW ESTIMATION
10_1340_3	MODEL 12	HEP Tributary	PEAK FLOW ESTIMATION
10_1382_1	MODEL 12	HEP Tributary	PEAK FLOW ESTIMATION
10028	MODEL 12	HEP Gauging Stations	CATCHMENT FLOW CALIBRATION
10_230_4	MODEL 12	HEP Upstream Limit	RAINFALL RUNOFF MODELLING
TBC	MODEL 12	HEP Upstream Limit	PEAK FLOW ESTIMATION
10_111_3	MODEL 12	HEP Upstream Limit	RAINFALL RUNOFF MODELLING
10_1388_1	MODEL 12	HEP Upstream Limit	RAINFALL RUNOFF MODELLING
10_40000_U	MODEL 13	HEP Upstream Limit	RAINFALL RUNOFF MODELLING

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;
- (CKBF1- 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 17)

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 a 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 per return periods 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/Umax); L - lower zone storage (L/Lmax); QR1 - Initial runoff from routing reservoir #1; QR2 - Initial runoff from routing reservoir #2.

The model parameters are:

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

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

- The **surface storage Umax** [mm] is defined as the volume of water stored on foliage and generally on the surface following rainfall, but also in dips and puddles and subsurface non

groundwater storage, which can feed the interflow discharge component. It is usually in the order of 5-25 [mm], is available for immediate evaporation and excludes moisture stored in soil and subsoil. Steep ground tends to have less surface storage compared to for example drumlin landscapes, also for large vegetation types i.e. trees or shrub the storage is greater compared to grass or rocky surfaces. Calibration of this parameter is often achieved through assessment of the overall water balance; this requires good evaporation information ideally varying on a weekly or monthly interval. Once the surface storage is depleted interflow ceases to exist in the model and evaporation takes place from the lower or soil moisture storage at a slower rate. Overland flow is only present while the surface storage is fully replenished in the model.

- The maximum amount of overland flow is given by the **overland flow runoff coefficient CQOF** [/], which is often higher compared to other deterministic models, as the actual runoff is also proportioned in relation to the soil moisture at each time step.
- The time constant for **interflow CKIF** [hour] controls how fast water can be discharged from the surface storage into the stream, though as with the overland flow this is proportioned by the ratio of available soil moisture to the total soil moisture storage.
- The **discharge from the ground water** reservoir is simulated through a recession relationship defined by a time constant **CKBF** [hour]. As the constant already suggests the flow simulated is baseflow, i.e. a very slowly varying stream flow component, often attributed to the groundwater reservoir, though in some instances this might also be due to large peat layers in the catchments. Attempts have been made to simulate this behaviour through splitting the baseflow into two components with varying discharge time constants often found in peat catchments in wet and dry seasons.

As part of the Water Framework Directive further characterisation study 'An Integrated Approach to Quantifying Groundwater and Surface Water Contributions of Stream Flow (Reference 17)', 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 (Umax). 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			Low percentage of poorly drained soils (<20%): lower end of limit		1B, 2C
	Forestry 0%, Pastures <40% and Bare rock >20%	8 - 15	Relatively flat slope (<5%): upper 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.

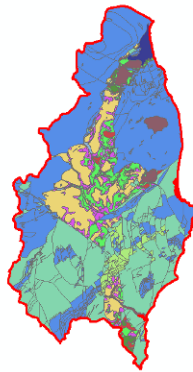
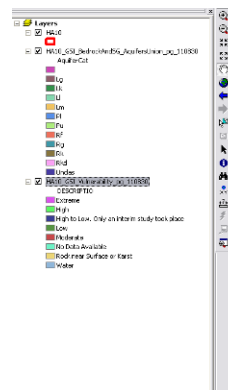
The selected value of U_{max} for a catchment can be further refined dependent upon the average slope, coverage by lakes, coverage by wet soils and the amount of urban area. For example, the U_{max} value would be expected to be at the lower end of the land cover ranges if the average slope of a catchment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

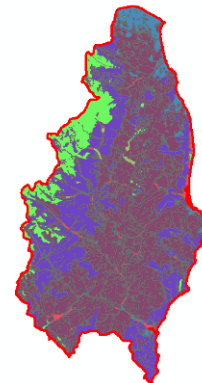
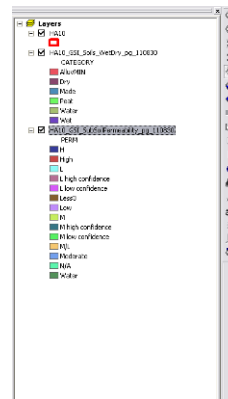
The initial estimation of the four parameters (Umax, CQOF, CKIF and CKBF) driving the rainfall-runoff process will be done using the available GIS datasets, namely:

- 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

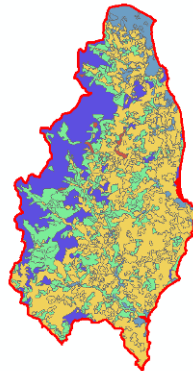
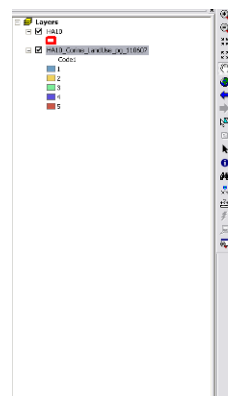


Figure 5.4: Available GIS datasets for deriving the NAM model parameters in HA10

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 (Lmax, measured in mm) and the threshold values for overland flow, intermediate flow and deep groundwater flow (the L/Lmax value at which that component of flow occurs).

Based on NAM modelling of the Neagh Bann catchment study in Northern Ireland (Reference 18) 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 Lmax: 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 1 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: Umax,
- 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 7 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 manually 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.

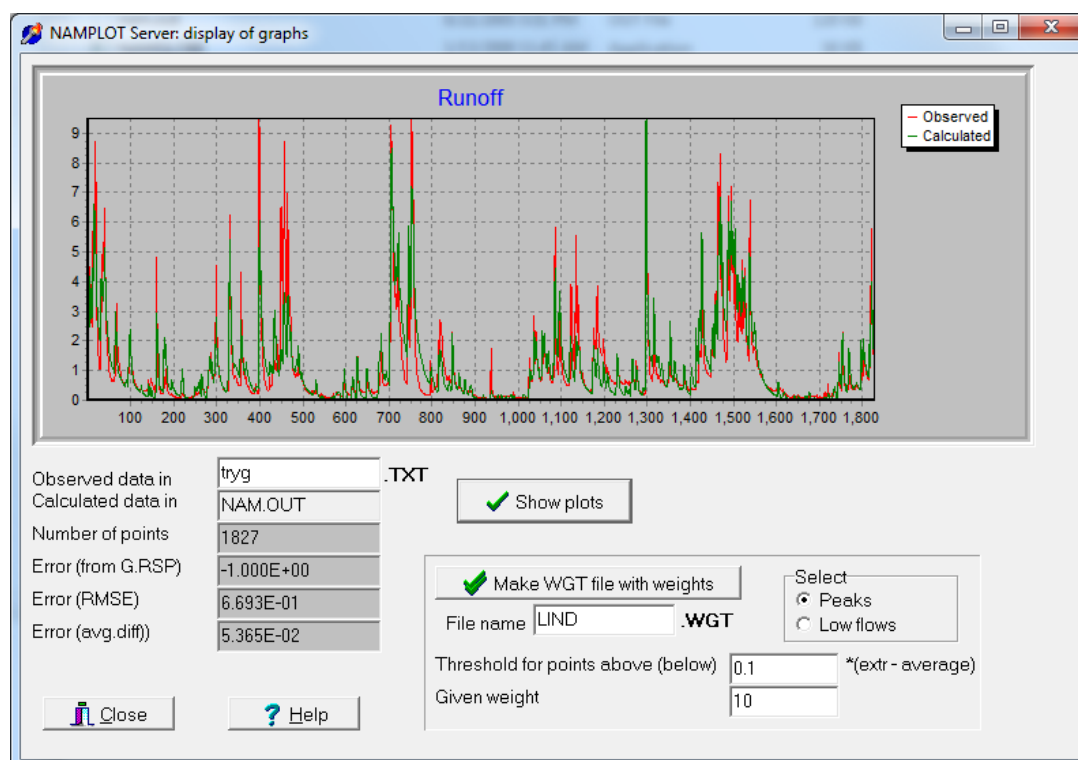


Figure 5.5: Visualization tools for the NAM model calibration component.

It may be necessary in urban areas such as Loughlinstown (Deansgrange, Carrickmines/Shanganagh Rivers), 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 done 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 12 at Aughrim has three upstream limit NAM models with a HEP Gauging Station Check Point further downstream. In this case, four NAM models will be set up - three 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, a joint hydrological and hydrodynamic calibration exercise 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 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 13) 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) (Reference 14). 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) Q_{med} 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 – Reference 19). 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 return periods. 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 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 IoH 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 20) 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 used 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 15). 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 return period, 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 Eastern CFRAM Study Inception Report - HA 10 (Avoca - Vartry), 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, 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 HA10 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.
- 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 HA10. 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 HA10 to date.
- Flood Risk Assessment – there is no tendered methodology change proposed in HA10 to date.
- Environmental Assessment – there is no tendered methodology change proposed in HA10 to date.
- Consultation And Engagement – there is no tendered methodology change proposed in HA10 to date.
- Development Of Flood Risk Management Options – there is no tendered methodology change proposed in HA10 to date.
- Preparation Of Flood Risk Management Plans – there is no tendered methodology change proposed in HA10 to date.
- Reporting And Deliverables – there is no tendered methodology change proposed in HA10 to date.

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

Flood Risk Review – Technical Note 1 (IBE0600 TN0001) details an updated methodology for flood risk review (FRR) in the Eastern study area based on the progress with the 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 HA10, 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 HA10, these surveys are not yet scheduled to commence, no methodology change is proposed at this stage.
- Floodplain survey – project specific specification applies to HA10, 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 – project specific specification applies to HA10, these surveys are progressing to tender award stage, due to concerns regarding survey resourcing across several simultaneous CFRAM Study contracts RPS are proposing methodology amendments.

The procurement of channel and structure survey data is on the Eastern CFRAM Study's critical path with regard to preparing flood mapping for consultation during 2013. A variety of procurement strategies have been explored and/or adopted including an OPW initiative to obtain pre-contract survey data via a national survey framework. In relation to the Eastern CFRAM Study the pre-contract survey is limited to HA09 (the Liffey catchment).

The channel and structure survey contracts relevant to HA10 are as follows:

- On behalf of OPW, RPS procured pilot data for prioritised gauging station reviews using restricted list tendering of work below €25,000 in value which is attractive to smaller survey contracting companies. This survey data informed the hydrological analysis and piloted hydraulic modelling using surveyed data. Four of the nine stations in the overall contract were in HA10. The survey data has been delivered to RPS and the contract is substantially complete.
- On behalf of OPW, RPS are procuring a single larger survey contract to provide the remaining channel and structure survey throughout HA10 (including the remaining two gauging stations for which rating review is required in the project brief – Carrickmines and Commons Road). The tender was advertised via e-tenders and OJEU. RPS have

undertaken tender evaluation and identified a preferred tenderer. A critical constraint was identified given the limited number of bidders and the overall capacity of the survey companies tendering for this and other similar sized CFRAM contracts in that many of the tenderers for the HA10 Survey contract are already undertaking other CFRAM surveys. Following a review of overall resource and financial capacity a contractor has now been identified and an appointment is imminent. However given procurement delays with individual CFRAM studies and the pre-contracted survey contracts there are several survey contracts of similar size and nature running concurrently consequently RPS has a genuine concern that survey data delivery and quality will jeopardise flood map delivery.

Whilst strategies at national level have been considered regarding recombining contracts to potentially attract larger survey company interests, the focus of mitigation to address concerns in survey contract for HA10 is as follows:

1. RPS have undertaken review of the survey scope to optimise the number of required cross sections by refining the extent of AFA boundaries and modelled watercourses.
2. RPS have proposed survey work packages within the contract which seek phased delivery of priority datasets such as gauging stations or particular model reaches to accommodate modelling work programmes.
3. OPW, RPS and other CFRAM consultants have met to discuss survey procurement and programme risk mitigation, a number of measures have been put in place including circulation of weekly survey progress and programmes, permission to authorise small variations in survey contracts, exploring the option of transferring survey management and establishment of an overall survey programme across various contracts. These measures are currently under consideration.

This type of survey also carries an inherent high degree of weather risk and potential delays due to high water levels, poor accessibility or frozen waters which may result in further programme delays. It should be noted that these constraints go beyond HA10.

Hydraulic Modelling – Technical Note 4 (IBE0600 TN0004) sets out a proposed alternative modelling methodology for those watercourses with a high degree of culverting such as the three defined HPWs in the greater Dublin Area. The generic CFRAM Study specification required that all fluvial modelling be undertaken using one of two packages;

ISIS / ISIS-2D / Tuflow

MIKE 11 / MIKE 21 / MIKE Flood

These packages are widely recognised as being industry standard for modelling of river and coastal environments in both the 1D and 2D domains however they are not particularly suited to the modelling of complex culvert systems. Consequently RPS has proposed an approach involving the application of InfoWorks ICM (Integrated Catchment Modelling) to heavily culverted watercourses in order to improve the accuracy of the flood hazard mapping. This approach has been accepted in principle by the OPW for the Camac and Poddle catchments in HA09 and its application to the more complex Deansgrange, Carysfort-Maretimo, Loughlinstown and Carrickmines rivers is currently under consideration.

There are no further additional risks and associated methodology amendments identified at present in the HA10 Unit of Management.

6.2 OPPORTUNITIES AND PROPOSED METHODOLOGY AMENDMENTS

Data Collection – Technical Note 2 (IBE0600 TN0002) details RPS's proposed Flood Event Response Plan so that the response team members are appraised of requirements before an event occurs. The plan was available before first contract duration flooding to properties which occurred in HA10 during the Eastern CFRAM Study (24/10/11). There was extensive flooding in parts of HA10 and the plan was successfully enacted with several RPS team members in attendance.

In addition RPS has reviewed the data available in the Greater Dublin Strategic Drainage Strategy (GDSDS) study which covers parts of HA10 and HA09 in the Eastern CFRAM Study area. RPS identified existing datasets which were extracted and formatted by the GDSDS team in order to inform the specification of surveys in urbanised areas with highly altered watercourses (Loughlinstown). This provided the opportunity to provide robust survey specification and save field time in identifying underground routes and culvert interconnections.

Hydrological Analysis – 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 second stage would apply to the whole eastern study area and therefore HA10. If the RADAR trial is unsuccessful 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.

There are no further additional opportunities and associated methodology amendments identified at present in the HA10 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:** EPA, 2011: "OSPAR Convention – Comprehensive Study of Riverine Inputs – Hydrometric Data for 2009"
- Reference 7:** EPA, 2002: "Flooding in the Shanganagh Catchment 27 November 2002"
- Reference 8:** PH McCarthy and Partners Consulting Engineers June 2002: "Arklow Flood Study Report"
- Reference 9:** John B. Barry & Partners, 1987: "Hurricane Charlie An Overview - The Dargle River Experience"
- Reference 10:** Dún Laoghaire Rathdown County Council, 1993: "Hydrometric Review Shanganagh River".
- Reference 11:** John B. Barry & Partners, 1986: The River Dargle Flood Protection Scheme Preliminary Report
- Reference 12:** Office of Public Works, 2009: "Flood Studies Update - Work Package 2.2 - Frequency Analysis"
- Reference 13:** Met Éireann, 2004: "Flood Studies Update - Work Package 1.2 – Estimation of Point Rainfall Frequencies"
- Reference 14:** Institute of Hydrology, 1994: "Report No. 124, Flood Estimation for Small Catchments"
- Reference 15:** 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 16:** Office of Public Works, JBA, 2010: "Flood Studies Update - Work Package 3.4, Guidance for River Basin Modelling"
- Reference 17:** RPS, SWRBD, 2008, "Further Characterisation Study: An Integrated Approach to Quantifying Groundwater and Surface Water Contributions of Stream Flow"
- Reference 18:** 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 19: Office of Public Works, 2011: “Flood Studies Update, Alpha Testing Users Guide”

Reference 20: Office of Public Works, JBA, 2009: “Flood Studies Update - Work Package 3.5 – IBIDEM (Interactive Bridge Invoking the Design Event Method)”

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APPENDIX A

HYDROMETRIC DATA STATUS TABLE

Hydrometric Data Status Table

HA10 - Hydrometric Stations

[illegible]

Key

	Annual Max Data
	Daily Data
	15 Min Data

APPENDIX B

DAILY AND HOURLY RAINFALL

DATA STATUS TABLE

Daily Rain - Data Status Table

[illegible]

Daily Rain - Data Status Table

[illegible]

Daily Rain - Data Status Table

[illegible]

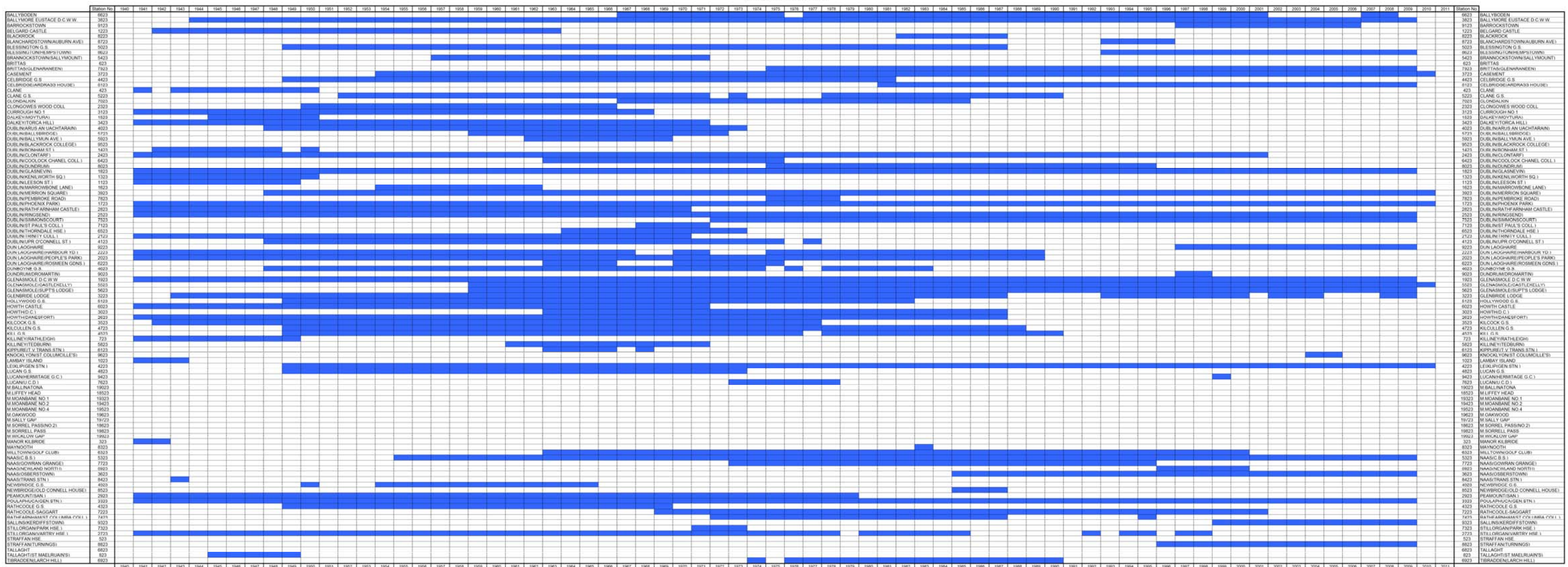
Daily Rain - Data Status Table

[illegible]

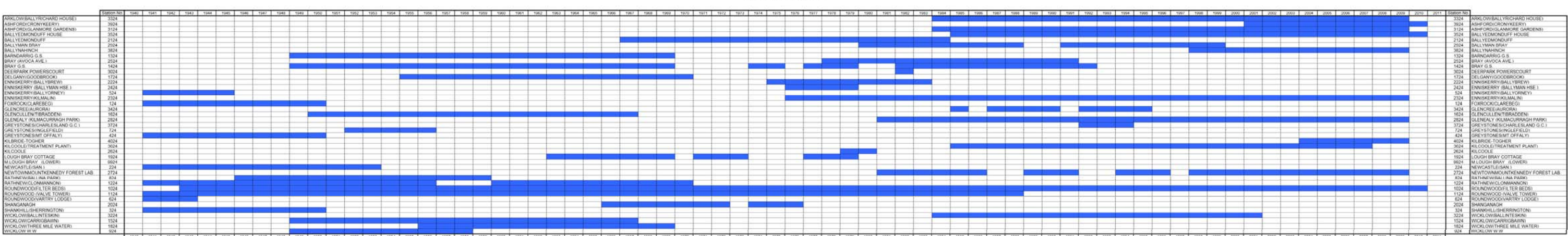
Daily Rain - Data Status Table

[illegible]

Daily Rain - Data Status Table



Daily Rain - Data Status Table



Daily Rain - Data Status Table

[illegible]

Daily Rain - Data Status Table

[illegible]

Daily Rain - Data Status Table

[illegible]

Daily Rain - Data Status Table

[illegible]

Hourly_Rain
Data_Status_Table

Station No	Catchment	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	Catchment	Station No
Kivimäki	3613	13																															13	3613	Kivimäki
Oja Park	375	14																															14	375	Oja Park
Lohjonselkä Castle	475	15																															15	475	Lohjonselkä Castle
Rosasten	2615	15																															15	2615	Rosasten
Iso	4819	19																															19	4819	Iso
Gurteen	1475	19																															19	1475	Gurteen
Multinmäki (Autio)	875	22																															22	875	Multinmäki (Autio)
Multinmäki (Hänken)	2562	22																															22	2562	Multinmäki (Hänken)
Cementist	3723	23																															23	3723	Cementist
Phoenia Park	23	23																															23	23	Phoenia Park
Oulun Aikoo	532	32																															32	532	Oulun Aikoo
Bathhouse	675	37																															37	675	Bathhouse
Clones	2431	37																															37	2431	Clones
	Catchment	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	Catchment	

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 Eastern Study area, rainfall radar data for Dublin 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 Dublin rainfall radar data as applied to HA10. The number of rain gauges used for calibration of radar is variable; the resulting 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 CFRAM area if proven beneficial.

Stage 1 of the Dublin radar data analysis for the Dodder catchment (refer to report of Stage 1 of this analysis) 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 HEP. For hydrological modelling and estimation of the design 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.

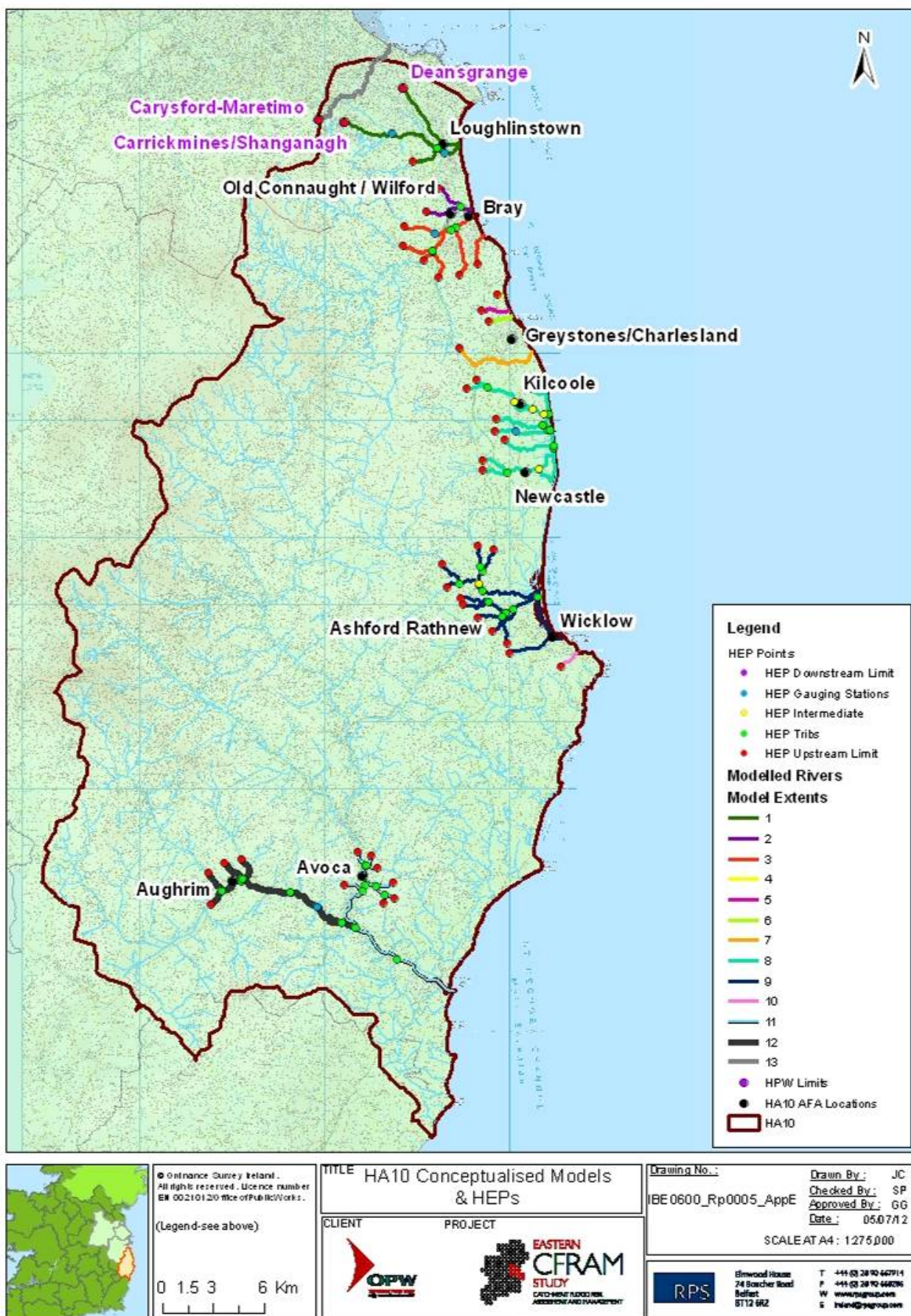
APPENDIX D

Hydrology Method Process Chart – Used Datasets Table

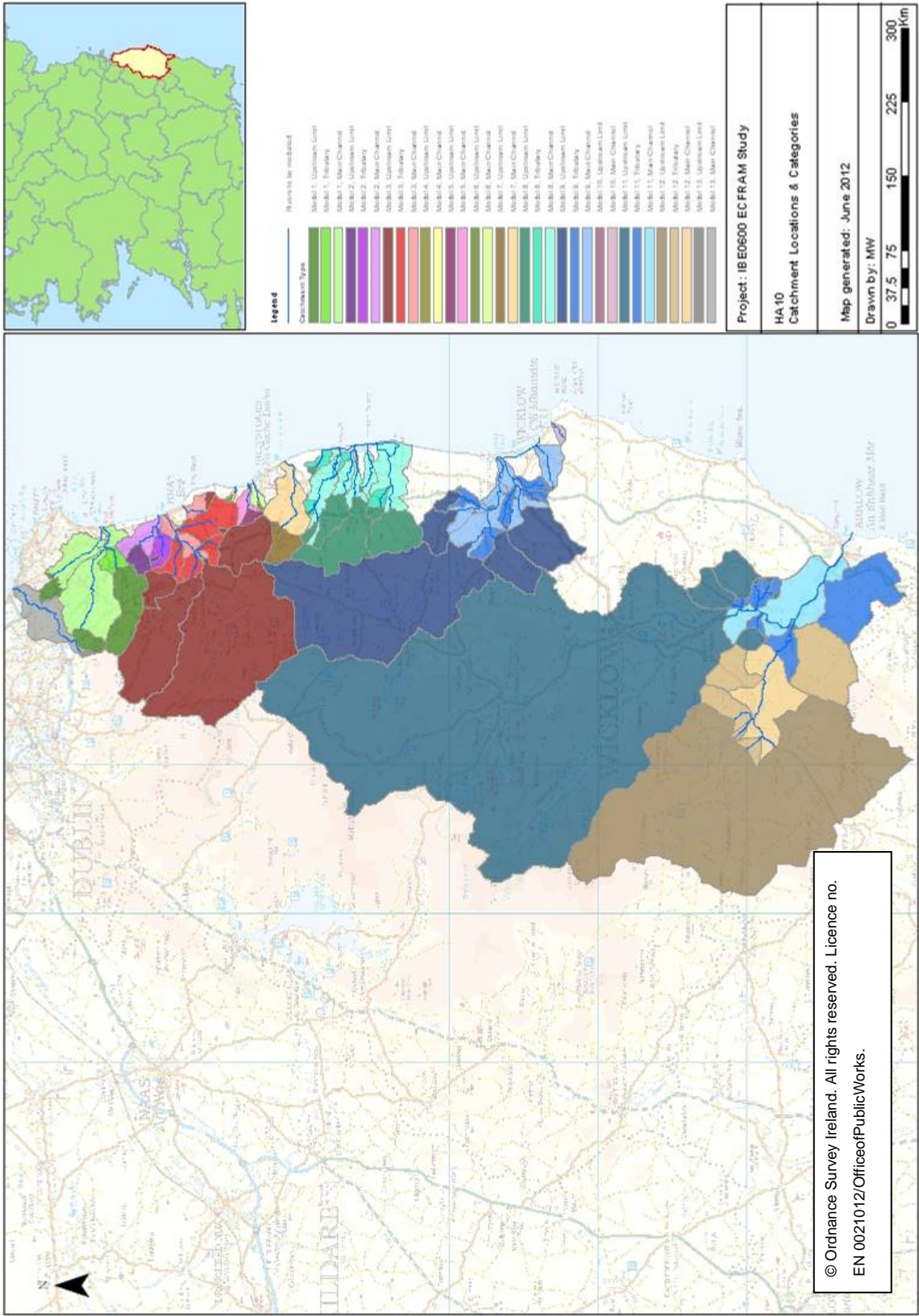
Box Number (Figure 2.2)	GIS Shapefile of River Network	DTM, Mapping, Aerial Imagery	FSU Ungauged Catchment Descriptors GIS Point File	FSU Gauged Catchment Descriptors GIS Point File	FSU Ungauged and Gauged Catchment Outlines GIS Polygon Layer	Rainfall Radar Data (if approved)	Daily and Hourly Rainfall 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



Rivers to be Modelled



Model Catchment Boundaries