05 - ESTABLISHING THE FLOOD FORECAST CENTRE AND EXPANDING MET ÉIREANN'S RAINFALL RADAR NETWORK

Eoin Sherlock[1] and Sinéad Duffy[1]
[1] *Met Éireann, 65/67 Glasnevin Hill, Dublin 9, Ireland*

Abstract

The Government Decision of January 2016 called for the establishment of a National Flood Forecast Warning Service (NFFWS). The operational element of the service was to be the Flood Forecast Centre (FFC) in Met Éireann with guidance and standards provided by an Oversight Unit in the Office of Public Works (OPW).

Stage 1 of the establishment of the NFFWS is centred on forecasting two types of flood; river and coastal at a national and catchment level. In order to do this a review was undertaken of all available fluvial models for use in an operational flood forecasting centre. A number of different models and integrator systems were reviewed and scored via a Multi Criteria Analysis. A short list of models were then built, calibrated and run in an operational setting for a period of time. At the end of this process model(s) would be selected to use in the trial of the operational FFC in 2021. The models will then be inserted into an operational environment within Met Éireann.

The OPW's Tide and Storm Surge Forecast Model has been run by the OPW for a number of years. The FFC and the OPW are working in transferring this system into Met Éireann's High Performance Computing Centre to avail of the parallel programming functionality. This will also allow the model to be run with both Met Éireann's Harmonie based Irish Regional Ensemble Prediction System (IREPS), which currently runs for 30 hours and the ECMWF's longer range EPS.

In terms of observations for the FFC, Met Éireann has recently expanded its number of climate stations with 60 new stations installed throughout the country in 2019. These stations can report on a minute basis and over time they will be used to recalibrate fluvial models for the FFC. There is an option for an additional 20 climate stations in the contract and it is expected that this option will be exercised.
Met Éireann is also improving the weather radar network for Ireland. The weather radar network will be upgraded and modernised in the coming years to enhance Met Éireann's provision of a quality meteorological and hydrological service to the nation. It is anticipated that the network will increase from two radars (at Dublin Airport and Shannon Airport) to at least five radars.

A contract is due to commence soon to plan all aspects of the Irish weather radar modernisation. It will identify the requirements, technology, locations and design for an upgraded and modernised weather radar network. In addition, the contract will assist Met Éireann to develop a strategic plan for the weather radar network in the long term, up to 2040.

The findings of this contract will then be used to begin the procurement and installation of the 5 new radars in the network. It is expected that the development of the radar network will take a number of years to complete. The additional climate stations and the expected increased radar coverage will greatly assist in forecasting fluvial and pluvial flood events.

1. INTRODUCTION

The meteorological winter of 2015/2016 will be remembered as another exceptional winter across Ireland, with numerous climate records broken and high impact weather events causing considerable disruption from flooding and high winds. A succession of winter storms tracked across the country, bringing persistent and in places record□breaking rainfall, including the highest 24 and 48 h rainfall accumulations on record, from storm *Desmond* on 4–6 December. Persistent rain, particularly through the first half of the winter, resulted in new records for both monthly and seasonal rainfall accumulations widely across Ireland (McCarthy et al., 2016).

It was the wettest December over Ireland in a time series from 1850, with the greatest anomalies in the south and southwest. Five stations in counties Cork and Kerry broke the previous Irish record monthly accumulation of 790 mm, with a new record of 943.5 mm occurring at Gernapeka, County Cork. Impacts, especially from severe flooding, were of national significance following a number of the weather events that contributed to these remarkable rainfall accumulations. The impact of this rainfall was exacerbated by the already saturated ground in many areas following the high rainfall during November. Figure 1 shows the accumulation of rainfall through the whole period for a selection of rain gauges representing some of the worst affected areas. The significant rainfall events such as *Desmond* in early December are particularly notable.

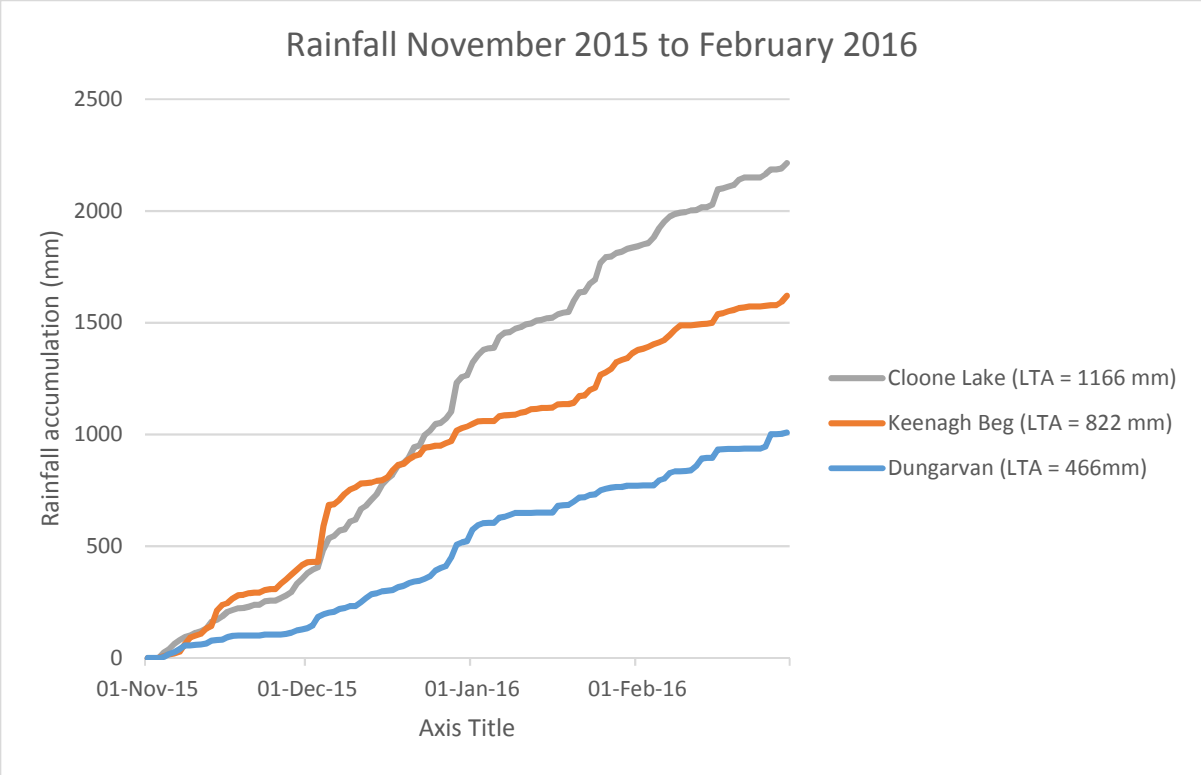


***Figure 1**: Rainfall November 2015 to February 2016*

Flooding was widespread during the winter of 2015/2016 and it was comparable to the flooding events of November 2009. Estimated damage to the road network was over €100m (Kilgariff, 2018). Nationally €1.8 million in humanitarian assistance was paid to affected households. A significant number of households were affected by the flooding.

In June 2010, JBA Consulting commenced work on 'The Strategic Review of Options for Flood Forecasting and Warning in Ireland'. The Steering Group for the review comprised of staff from Met Éireann, The Office of Public Works (OPW) and the County and City Managers Association (CCMA).

This review was completed in late 2012 and contained a number of recommendations as to how a National Flood Forecasting and Warning Service could be implemented in Ireland. In early 2016, the Minister for Public Expenditure and Reform, on behalf of the Minister of State with special responsibility for the Office of Public Works (OPW), requested the Government to agree to the establishment of a National Flood Forecasting and Warning Service (NFFWS). The flood forecasting service would be a new operational unit within Met Éireann with guidance for standards and performance overseen by the Office of Public Works.

At the same time, Met Éireann had started to plan for two large capital projects. The first is the modernisation of its weather radar network, and the second was the modernisation and expansion of its climate network. These projects will be of enormous assistance to the nascent NFFWS.
This paper describes the development of the National Flood Forecast Warnings Service and the establishment of the Flood Forecast Centre (FFC) within Met Éireann. It also details the current projects to produce a strategy for Met Éireann's rainfall radar network and the modernisation of its climate network.

2. ESTABLISHING THE FLOOD FORECAST CENTRE

2.1 An overview of the functions of the NFFWS

The Implementation Plan for the NFFWS came out of the Strategic Review The Plan called for the establishment of a number of different components.
The operational element of the NFFWS will be in Met Éireann and it will be named the Flood Forecast Centre. Met Éireann has experience of running operational systems and weather forecasting operations since 1936. An Oversight Unit in the OPW will provide Standard and Performance Guidelines to the FFC.
An important element of the NFFWS is the development of sub-groups. These sub-groups have the responsibility to deliver on specific tasks such as the development of a Communication Strategy for the NFFWS.
These three sections will report to the NFFWS Steering Group, which the OPW chairs. Other stakeholders include the Department of Housing, Planning and Local Government, Department of Agriculture, Food and the Marine and the Local Government Management Agency. The NFFWS Steering Group then reports to the Interdepartmental Flood Policy Coordination Group.

2.2 The Flood Forecast Centre

This paper will focus on the establishment of the Flood Forecast Centre within Met Éireann. It will provide details on the steps that the FFC has taken to develop its capacity and capability in operational fluvial flood forecasting at a National and Catchment level.

To inform and support the establishment of the NFFWS there was an urgent requirement to review, develop and trial a range of existing available hydrological models for potential use in operational flood forecasting in Ireland at both National and Catchment level. There was also an urgent need to review a range of existing integrator systems for potential use in conjunction with these operational flood forecasting models.

It was agreed at the NFFWS Steering Group to pursue a Contract for the Review, Development and Trial of a Range of Hydrological Models and Integrator Systems for Use in Operational Fluvial Flood Forecasting in Ireland. The Contract included a comprehensive literature review of a number of hydrological models and integrator systems. The literature review recommended that four hydrological models (HYPE, wFLOW, WRF-HYDRO and URBS) and two integrator systems (FEWS and MIKE-Operations) should be trialled. The Contractor would build, calibrate and validate functioning

hydrological models for five representative catchments using the four recommended hydrological models from the Literature Review. The next step would be to trial the application of the four validated hydrological models on the five representative catchments for operational fluvial flood forecasting purposes. At the same time the four hydrological models would be trialled in conjunction with the two recommended integrator systems on one of the representative catchments for operational fluvial flood forecasting purposes.

The Contract would conclude with a Final Report outling in detail all of the findings and outcomes of the various stages. It would provide conclusions and recommendations on the models, integrators and ICT requirements for operational fluvial flood forecasting in Ireland.

2.3 Fluvial Modelling Contract

2.3.1 Stage 1: Literature Review

The FFC made a call to all interested parties to acquire information of available hydrological models and integrator systems. There NFFWS requested a number of high-level requirements for the hydrological models such as calibration, input, output, maturity etc. The models also had to be able to run on a National and Catchment scale. The models obtained scores via a multi-criteria analysis (MCA), based on the ten high-level requirements (Table 1).

***Table 1**: MCA Requirements*

Hydrological Models	**Integrator Systems**
Model structure – suitable for Irish catchments	*Modularity* – coupled to hydrological model
Output – calculate flow at all modelling points	*Input/output* – meet all requirements
Input – the model can handle the available input	*Efficiency* – ease of use, licensing etc.
Calibration – can be calibrated with tools	*Maturity* – proven stability and maturity
Accuracy – predict peak +/- 10% in 6 hours with a lead time of greater than 24 hours	
Maturity – proven stability and maturity	
Computational speed – acceptable time span	
Ease of set up - set up by a trained user	
Code availability – readily available for usage	
Coupling – easily coupled to other components	

2.3.2 Stage 2: Model Development for Representative Catchments

The five representative catchments are the Moy & Killala, Shannon, Nore, Barrow and the Slaney and Wexford Harbour. For each of the catchments four hydrological models had to developed and calibrated. Model development for an additional seven catchments is planned for early 2020. The additional seven catchments are shaded green in Figure 2.

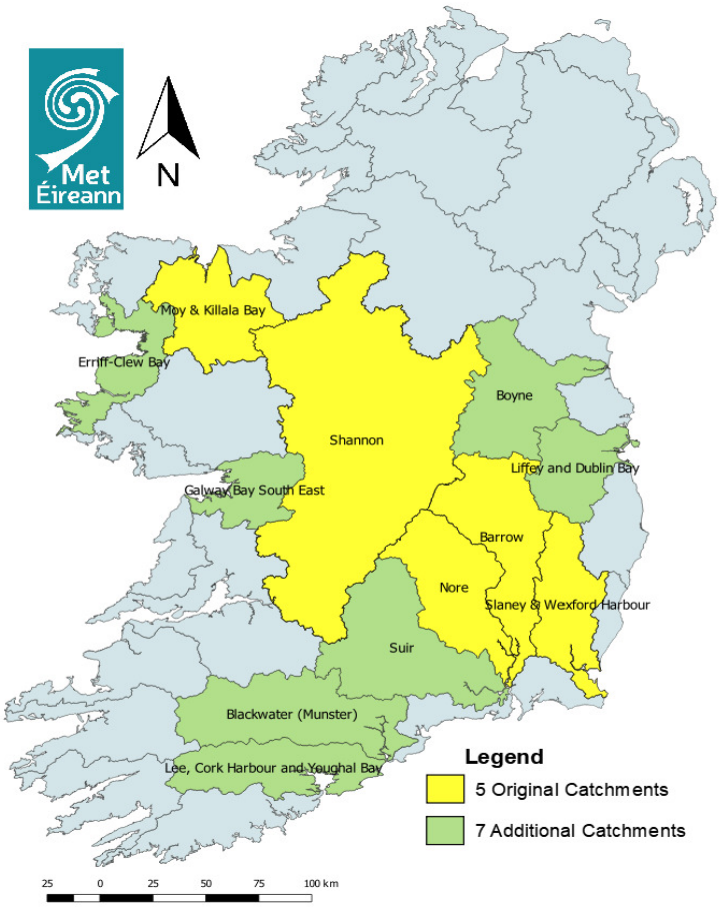


***Figure 2**: Fluvial Model Catchments*

A number of different data sources were used in this process and both Met Éireann and the OPW provided these to the Contractor, International Marine and Dredging Consultants nv. The data sources included gridded daily rainfall, rainfall radar, synoptic observations, the MÉRA reanalysis, historical flow data, and catchment information.

The Contractors worked closely with the developers of the hydrological models and integrator systems to overcome any obstacles. They succeeded in building 20 hydrological models, four for each of the five catchments. A set of high flow events was used to calibrate the models. Approximately 20 events were selected for each catchment, 10 of these are the extreme events in the period 1981 to 2016. The remaining 10 events are less extreme events with a minimum return period of 0.5 years.

For each gauge, model performance statistics were calculated. Two of the models appear to be performing at a higher level than the other two. HYPE and URBS scored higher than wFLOW and WRF-HYDRO. It is important to stress that both HYPE and URBS were easier to build and calibrate and one can expect to achieve higher scores. If additional resources are used on wFLOW and WRF-HYDRO the user should be able to improve on the current performance statistics.

2.3.3. Stages 3 and 4: Trialling of the Hydrological Models and Integrator Systems

The Contract is currently at Stages 3 and 4. The four models are running in an operational setting for the Barrow Catchment in both the FEWS and MIKE Operations integrator systems. The trial will last for 8 weeks. The MIKE Operations integrator system is show in Figure 3 below.

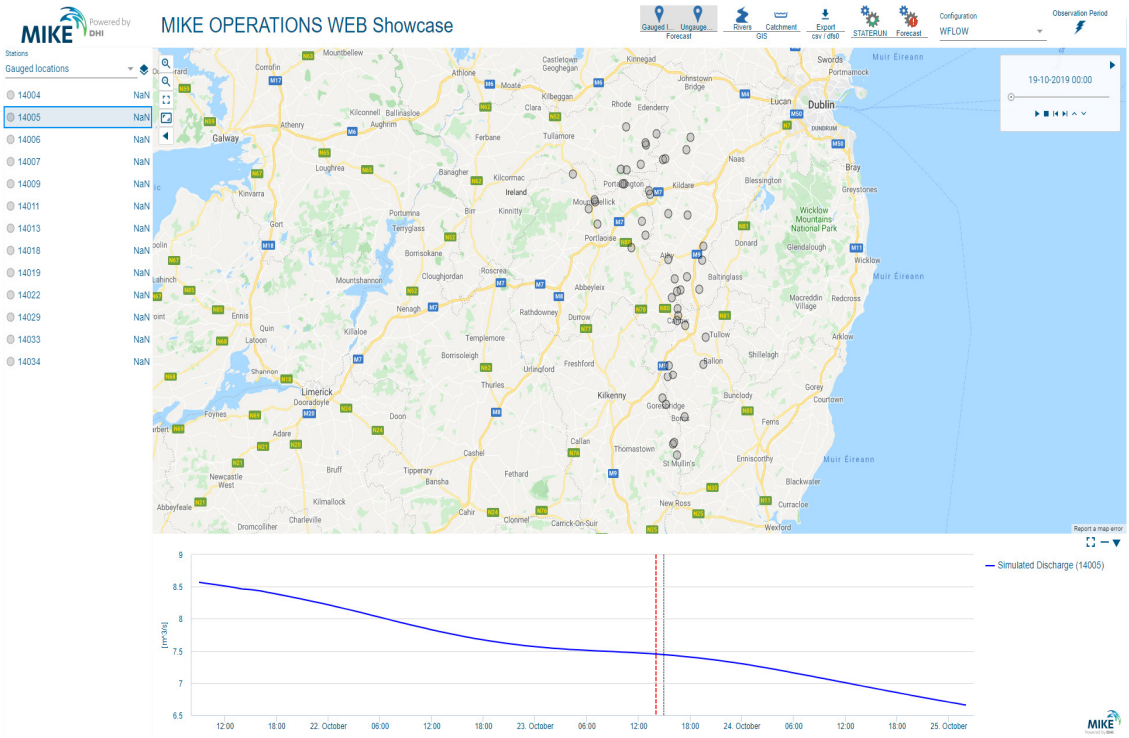


***Figure 3**: MIKE Operations Integrator System*

2.3.4 Final Reporting and Next Steps

The final report shall present in detail all of the findings and outcomes of each Stage of the project. It will include conclusions and recommendations as to the modelling and other related systems to be used for operational flood forecasting in Ireland.

Met Éireann and the OPW will examine the recommendations in the Final Report in order to arrange for operationalising the hydrological models. A trial of the FFC will occur in Q3 of 2021. This means that the fluvial flood forecasting models would need to be operational and coupled to an integrator system. A dissemination system will be required to ensure that all flood alerts and advisories are sent in a timely manner to all stakeholders.

The models will reside in an operational environment within Met Éireann that will cater for disaster recovery and business continuity measures. This will mirror the current configuration for our Numerical Weather Prediction (NWP) models.

2.4 Coastal Modelling

The OPW's Tide and Storm Surge Forecast (TSSF) Service has been in operation for a number of years. The TSSF service provides information to assist with the early alert of the potential risk of coastal flooding at eighteen locations around the coast of Ireland, and additionally at higher resolution locations comprising Cork Harbour, Wexford Harbour, Dundalk Bay, Galway Bay and Shannon Estuary. Figure 4 displays the TSSF's morning summary forecast.

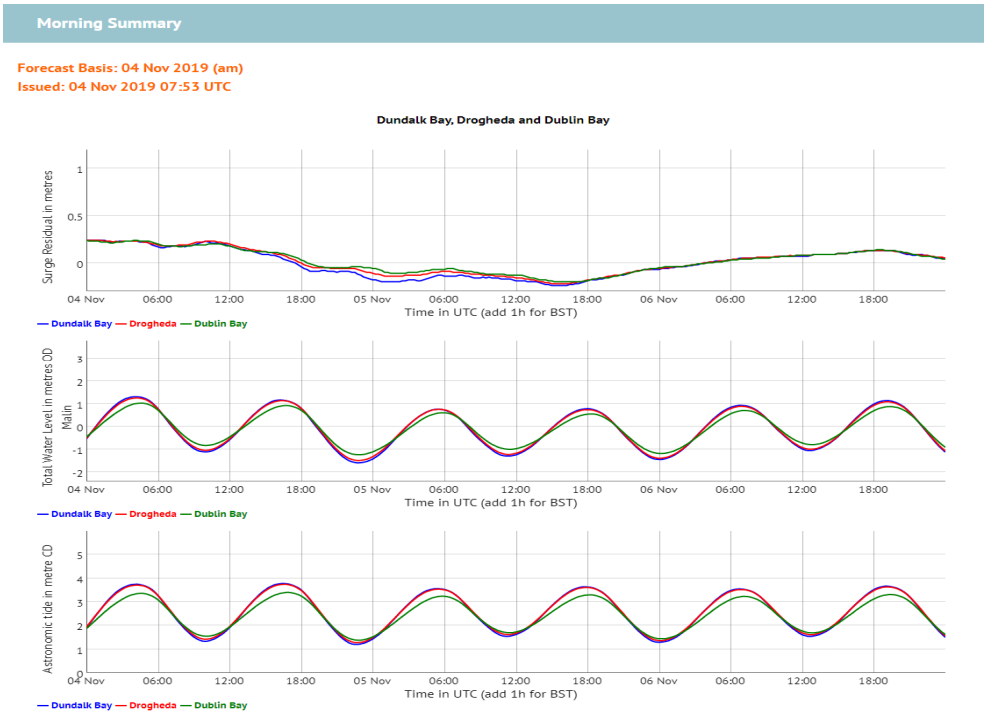


Figure 4: *TSSF Morning Summary Forecast*

The OPW and Met Éireann are exploring a trial of running the TSSF on a High Performance Computing platform. This trial is likely to start in early 2020.

Met Éireann is a member of the European Centre for Medium-Range Weather Forecasting (ECMWF). As a member, Met Éireann has access to a state of the art High Performance Computing Centre (HPC). The ECMWF's supercomputer is a Cray, which has over 250,000 compute nodes. Access to such computing power will enable Met Éireann to use the parallel features of the TSSF service to its benefit. The TSSF should be able to run much quicker as the number of computational cores increases.

Another advantage of running the TSSF on a HPC will be the ability of the system to run with Ensemble NWP forecasts. This will allow the TSSF to use Met Éireann's Harmonie model Irish Regional Ensemble Prediction System (IREPS), and ECMWF's longer-range ensemble forecast data. The TSSF service will become part of Met Éireann's operational NWP. The NWP suite is monitored 24/7 by operations both in Reading, UK and in Glasnevin, Dublin.

3. EXPANDING MET ÉIREANN'S RAINFALL RADAR NETWORK

Weather radars provide a steady stream of near real-time information 24 hours a day, 365 days a year. They are used to provide information on precipitation amounts and intensities within a radius of circa 240km. Currently there are only two weather radars in the entire state. These are maintained and operated by Met Éireann and are located at Shannon Airport and Dublin Airport. Together they comprise a strategic component of Ireland's meteorological infrastructure. Data from the weather radar is integral to the provision of services such as aviation forecasting, weather forecasting, nowcasting, flood alerts and warnings, severe weather alerts, and is freely accessible to the public through the Met Éireann website and apps. It is also a key tool for response to major emergency incidents (e.g. radiological).

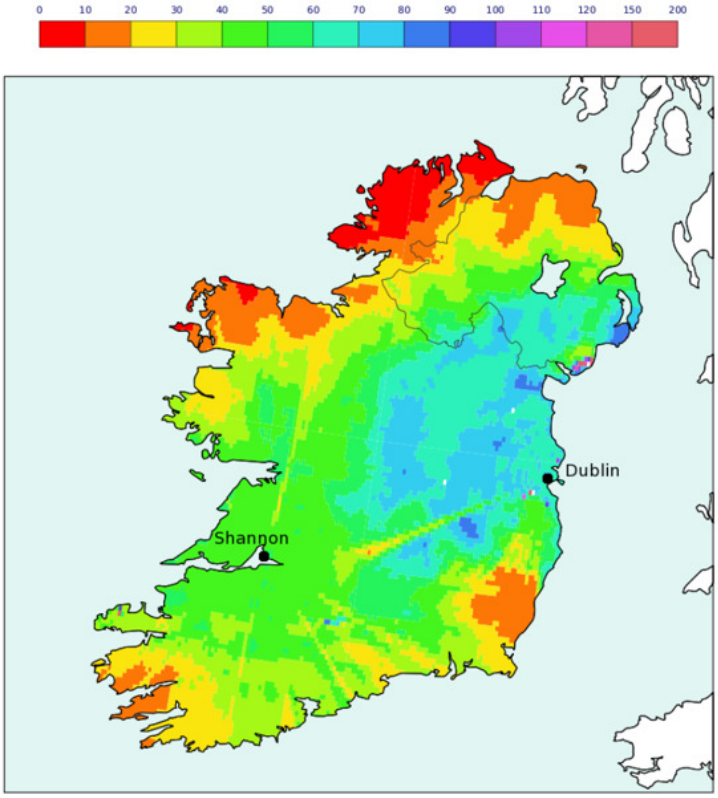


Figure 5*: Irish radar performance 2012*

Figure 5 above details the total annual radar-detected rainfall expressed as a percentage of the total annual gauge-observed rainfall (Fitzpatrick, 2013).

3.1 Radar Issues

3.1.1 The existing radar mechanical hardware is becoming obsolete

The lifespan provided by the refurbishment of both the Shannon and Dublin Radars conducted during 2010 and 2011 will be coming towards its end in the coming years.

3.1.2 Gaps in radar coverage over large areas

The present two radars provide adequate detection coverage over most of Ireland, but there are significant gaps in the South-east, South-west and North-west, for weather and flood forecasting purposes.

3.1.3 Poor coverage for quantification of precipitation amounts

For other uses for which weather radars can be employed, such as Quantitative Precipitation Estimation (QPE), for hydrological purposes i.e. flood forecasting, the coverage is very poor. Best coverage is in the Dublin and Shannon regions. Major river catchments such as the Lee, Munster Blackwater, lower Suir, Nore, Barrow, Slaney, Upper Shannon, Upper Liffey and others are not adequately covered. For QPE, radars are only effective to a range of 75km, which implies radars should be spaced no more than about 120km apart. To meet this target an expansion of the existing network is required.

3.1.4 Poor detection of convective events in parts of Ireland

Detection of convective events such as thunderstorms lessens incrementally the greater the distance from an operational radar site. The density of the existing network is insufficient to give reliable,

consistent information of this high-impact convective event. This inhibits the provision of nowcasting information for aviation, transport, public safety, agriculture etc.

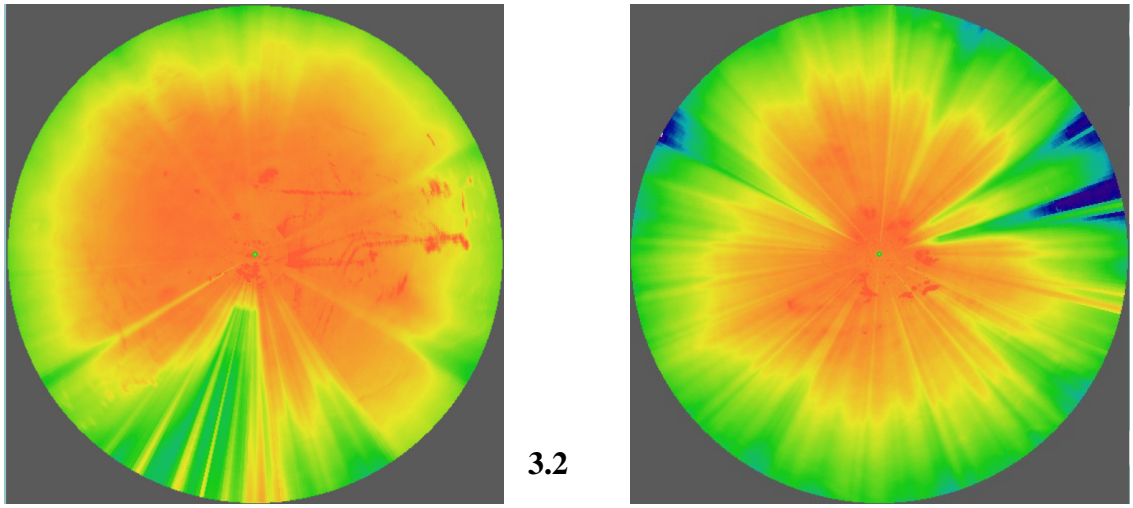
3.1.5 Limited detection capability

The technology used in the current radars has limited capability to discriminate between different types of precipitation (e.g. rain, hail snow) which, is of particular importance during extreme snow events for example. This also limits correction for signal attenuation as well as unwanted signals from the surrounding environment (e.g. buildings, birds etc.) – affecting overall data accuracy and reliability.

3.1.6 The locations of existing radars may no longer be optimal for future requirements

Planned developments at Dublin airport may make the site for the Dublin radar nonviable in the coming years. The site is also subject to high levels of interference from local Radio Local Area Networks (RLAN). For these reasons, continued operation at the present location may be significantly impaired. Shannon radar is located at a low altitude, (25m AMSL) surrounded by rising terrain significantly limiting the effective range of the radar due to occultation of the radar beam.

Figure 6 below shows the coverage of the Dublin and Shannon radars. The Dublin Airport radar has a good view (Figure 6a) apart from the southeast and southwest. The Shannon radar (Figure 6b) is a low-lying installation and is blocked by mountains.



3.2

Figure 6: *(a) Dublin Airport, (b) Shannon Airport Radar*

Modernised Radar Network Project

In order to address the issues raised above, Met Éireann in 2018 commenced a project to upgrade and modernise the national weather radar network in order to enhance the quality and reliability of meteorological and hydrological services provided to the Irish public. To assist in the planning of the project, a procurement competition for "A Scoping Exercise on an Upgraded and Modernised Weather Radar Network for Ireland" was undertaken in May 2019.

The aim of the Contract is to specify the radar system requirements for Ireland. The findings of the Contract will be used to design an optimal weather radar network, including radar systems and site locations.

The final element of the Contract will be to draft a plan for the implementation of the modernised weather radar network. The Contract will commence in November 2019 and it is expected that given the complexities involved it will take at least five years before the first of the five new radars is installed. The before and possible after configuration are given in Figures 7a) and b) below.

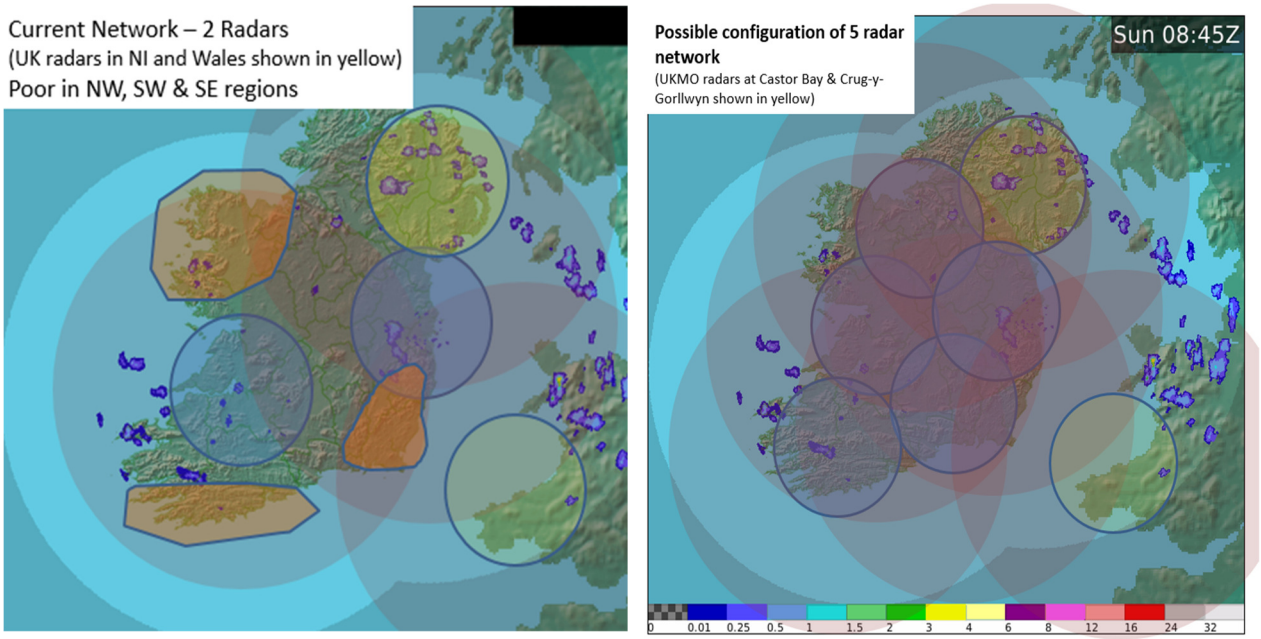


Figure 7: *Current and future (possible) networks*

4. EXPANDING MET ÉIREANN'S CLIMATE NETWORK

In terms of observations, rainfall gauges are a vital part of any flood forecasting service. Met Éireann has an extensive climate network but the data can be delayed, and the daily gridded rainfall is always one day behind. The Climate and Observations Division of Met Éireann is drawing to the end of its climate network modernisation project. This involved the supply, installation and maintenance of sixty Automatic Climate Stations (ACS). Each ACS shall consist of a data logger, sensors (including a weighing gauge precipitation sensor "Gauge"), and Stevenson screen and data transfer capabilities.

This will be a welcome addition to the observation network that the FFC will use a) to calibrate its models and b) for now-casting events. Sixty ACS stations will be installed by the end of 2019 and there is an option for another 20 for 2020, which will be optioned.

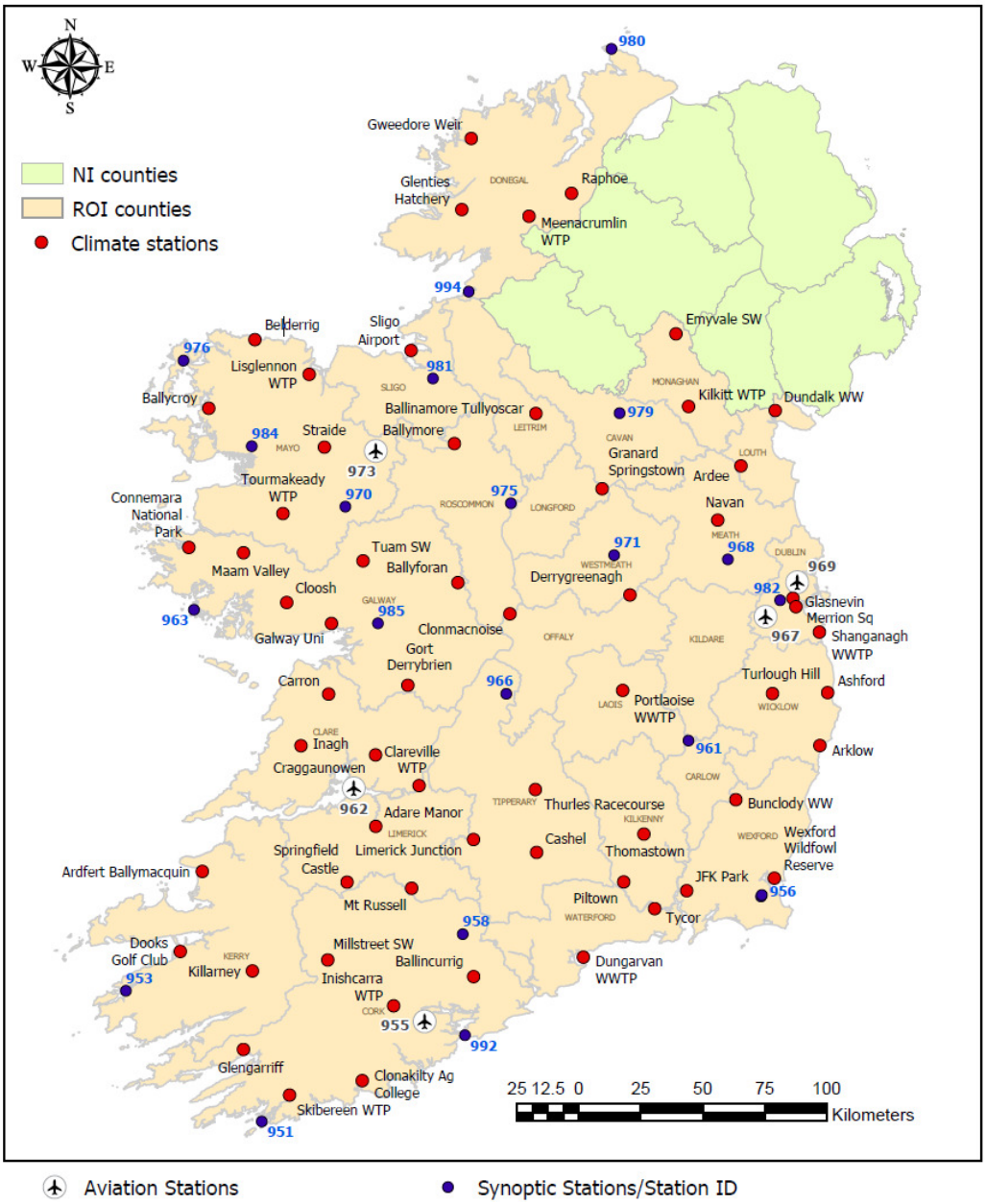


***Figure 8**: Locations of ACS*

5. CONCLUSIONS

This paper has described how the FFC came into existence. It has detailed the governance of the NFFWS. It also expanded on the current research of the FFC in terms of fluvial and coastal models. Met Éireann as the Irish Meteorological Service is well placed to provide support to the FFC through its core services such as observation network and High Performance Computing resources. The expected improvement in the weather radar network and climate network will be of great assistance to the refinement of fluvial models and nowcasting of pluvial events.

As a non-capital investment, Flood Forecast Centres have proven to be cost effective. A paper by Pappenberger *et al.* (2015) suggests that benefits of 400 Euro are achieved for every one Euro invested in early flood warnings in Europe.

The process will be lengthy. In order to develop fluvial and coastal models requires time and resources. If the set up times of other FFCs are reviewed, it can be seen that the establishment of a service like this can take a considerable amount of time; anytime from 15, up to 20 years.

6. ACKNOWLEDGEMENTS

It is important to acknowledge the contribution of all the members of the NFFWS Steering Group; the OPW, County and City Management Association, National Directorate for Fire Emergency Management, Department of Agriculture, Food and the Marine and in particular the staff of the Hydrology and Coastal Section of the OPW. IMDC nv have carried out the model selection and development on behalf of Met Éireann and their guidance and experience has been of great assistance, The Technology Division in Met Éireann is providing support to the Weather Radar expansion project and the support staff in both Shannon and Dublin Airports have helped to shape the project.

7. REFERENCES

McCarthy, M., Spillane, S. (2016). The meteorology of the exceptional winter of 2015/2016 across the UK and Ireland. UK Met Office, Met Éireann.

Kilgariff, P (2018). The impact of flooding disruption on the spatial distribution of commuter's income, Teagasc.

Fitzpatrick, N. (2013). Verification of Met Éireann Weather Radar. Technical Note No. 62.

Pappenberger, F., and Cloke, H, (2015). The monetary benefit of early flood warnings in Europe, ECMWF