03 – STRATEGIC REVIEW OF OPTIONS FOR FLOOD FORECASTING AND WARNING IN IRELAND

Jeremy Benn[1], Sarah Conroy[1], Brian Golding[2],
1. *JBA Consulting, Limerick*
2. *UK Meteorological Office*

Abstract

JBA Consulting and the UK Met Office have undertaken a strategic review on behalf of the Office of Public Works of options for flood forecasting and flood warning in Ireland. The objectives of the review were to examine the potential benefits that flood forecasting and flood warning could achieve in Ireland, to identify and assess the options for delivery of such a service, including associated resource requirements, and to develop an appropriate and sustainable strategy for flood forecasting and flood warning in Ireland.

A preliminary analysis conducted under this review indicates that the Annual Average Damages from fluvial and tidal flooding are approximately €171-195 million (at 2010 prices) and that the potential tangible benefits from the provision of an effective flood forecasting and flood warning service across the country could reduce these damages by at least €8 million annually.

JBA conducted an assessment of the general characteristics of flood risk and hazard in Ireland, with areas of potentially significant risk identified using historic flooding records and draft outputs from the OPW's Preliminary Flood Risk Assessment (PFRA). The physical and technical constraints to flood forecasting and warning in Ireland were explored, including an analysis of time to peak for all catchments, and an assessment of the availability and accessibility of hydro-meteorological data.

The review included detailed examination of the existing context of, and current arrangements for, flood forecasting and flood warning in Ireland and six other countries. This included an assessment of all currently operational and trial flood forecasting and warning systems, from local/catchment scale systems such as the flood forecasting system for the Munster Blackwater at Mallow, to national and international systems, such as the storm surge forecasting system developed under the Irish Coastal Protection Strategy Study and the European Flood Alert System (EFAS). This was complemented by a review of international best practice, emerging innovations, and identification of options that could be applicable / transferrable to Ireland.

JBA carried out extensive consultation over the course of the project, by means of two national workshops attended by representatives of a wide range of stakeholder groups. A number of strategic options for the provision of a comprehensive service were considered as part of the review, from which a preferred option and plan for its implementation were developed.

1.Locations of flood risk and hazard

Areas of potentially significant risk of flooding are currently being defined as part of the Preliminary Flood Risk Assessment (PFRA) (OPW, 2010). The PFRA seeks to define indicative flood hazard areas and identified receptors located in those areas. By assessing the probability of the flood event, the 'importance' of the receptor and the magnitude of the potential impact on the receptor from flooding, an estimate of flood risk is defined for each receptor. Where the overall level of flood risk for a local area or community is determined as significant, an area of potentially significant risk (APSR) is identified.

Figure 1 provides an indication of the potential communities at significant risk as assessed in late 2010. It includes only areas at risk of river and tidal flooding and excludes 'linear receptors', such as roads and railways, and 'area receptors' such as agricultural land and environmentally designated areas. The number and location of these flood risk communities areas will be finalised by the PFRA.

Some of the communities at flood risk are much larger and contain many more receptors than others, and therefore have much higher flood risk index (FRI) scores. The spatial variation in flood risk index scores is shown in Figure 2. It can be seen that fluvial (from rivers and watercourses) risk is quite widespread, and particularly concentrated in a belt running from Fingal in the north-east to Counties Cork and Kerry in the south-west. Tidal risk is particularly evident on the east coast from Dundalk to Dublin and along the Wicklow and Wexford coast. On the south coast tidal risk is evident in Waterford, Dungarvan, Youghal and Cork City whilst on the west coast Galway City and the Shannon estuary are at risk.

It should be noted that the flood risk areas are preliminary and are subject to review by the OPW in conjunction with the local authorities and key stakeholders[1].

In any particular flood event it is unlikely that all flood risk areas across Ireland will be simultaneously affected. Real events can be localised (for example, due to summer convective rainfall) or widespread (for example, due to frontal rainfall). A recent example of a widespread event was November 2009 (McGrath et.al., 2010). The geographical distribution of locations from which flooding reports were available (dataset dated 16 July 2010) is shown in Figure 3. The locations marked on the map range from major flood incidents (such as in Cork) to minor local flooding of roads from surface runoff.

The large number of locations and their wide geographical spread suggests that any national flood forecasting and warning system will need to have the capacity and robustness to deal with a large number of catchments and locations during the same event.

[1] The draft PFRA maps are currently out for public consultation and available at www.cfram.ie.

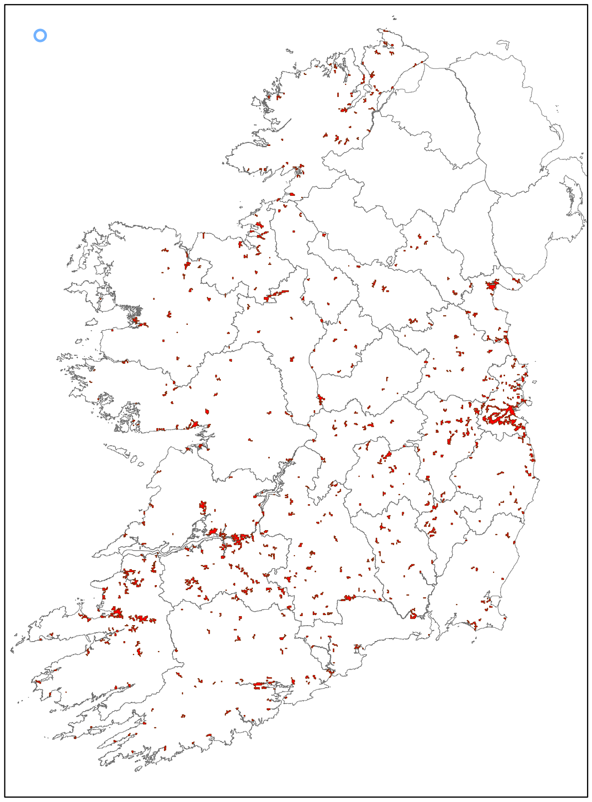

Figure 1: Distribution of identified communities potentially at significant flood risk (November 2010)

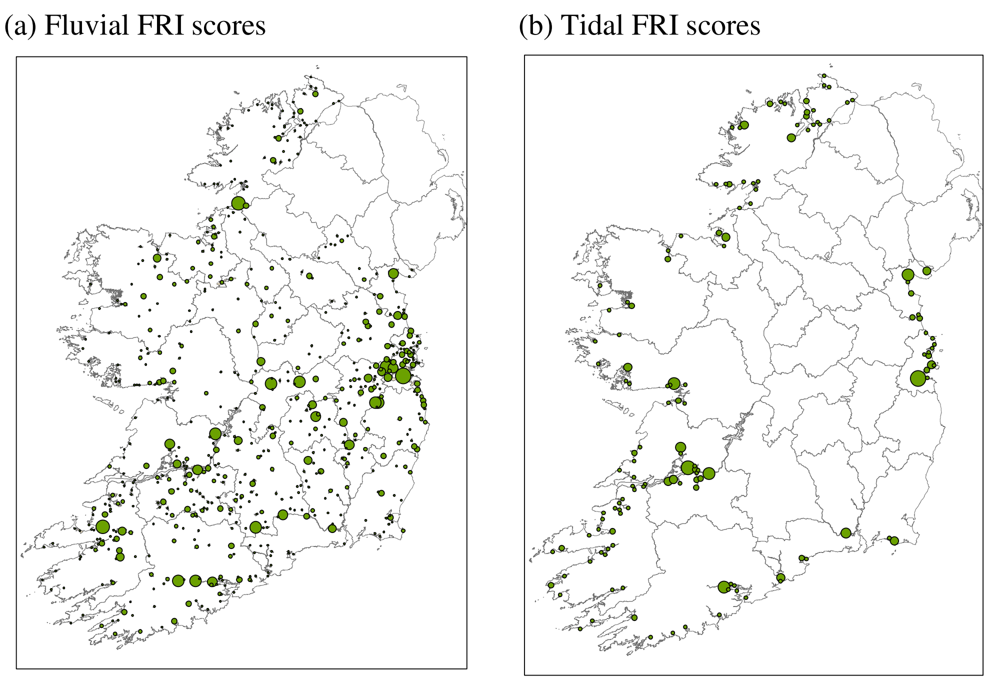

Figure 2: Flood risk index score for each community potentially at significant flood risk. Larger symbols indicate higher scores (November 2010 data)

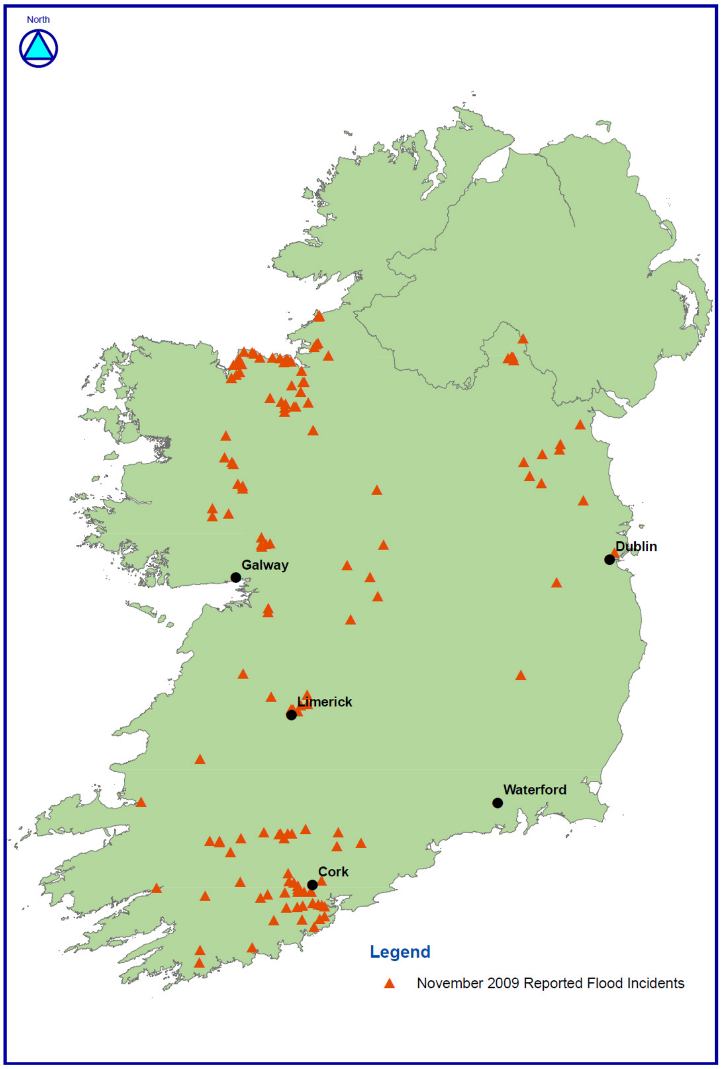

Figure 3: November 2009 reported flood incidents

Source: www.floodmaps.ie (July 2010)

2. Physical and technical constraints to flood forecasting and flood warning in Ireland

Successful flood warning systems must predict rainfall, high flows and surge tides accurately and with enough lead time to take action. The overriding technical constraint on any national system will almost certainly be its ability to reliably forecast rainfall. Once rainfall has been measured, it is usually possible, with the right models and real-time data, to predict river flows accurately and even to anticipate pluvial flooding (although not its precise location or timing). Making useful forecasts for large rivers, with long response times and a record of observed data, is therefore much easier than forecasting for small, flashy, rivers with response times of just a couple of hours or less. Pluvial flooding, which occurs even more quickly, is almost impossible to predict accurately with any lead time, given its dependence on accurate rainfall forecasts.

<u>Rainfall forecasting</u>

Rainfall forecasts will underpin any fluvial forecasting system. They are currently made for Ireland by Met Éireann and the European Centre for Medium-Range Weather Forecasts (ECMWF). Met Éireann's predictions cover the short range and are based on the HIRLAM forecast system. Currently, a synoptic scale (10km grid) and meso scale (2.5km grid) model are run every 6 hours producing forecasts of total hourly precipitation out to 54 hours and 30 hours ahead respectively. It is planned to assimilate radar observations in the meso scale model in the near future[2]. For lead times of more than 2 days and ensemble products, Met Éireann uses the ECMWF predictions. While the capacity potentially exists, radar-based advective forecasts are not available although the country is to some degree covered by Doppler weather radars at Shannon and Dublin Airports and at Castor Bay (Co. Antrim).

After the accuracy of rainfall forecasts, constraints become more economic than technical. Hydrometric measurements of rainfall and river levels are needed to calibrate models and input to them in real time. Once gauges are installed it can take a minimum of 2-3 years of measurement for sufficient results to be acquired to allow model calibration - although the data is of immediate use to help trigger flood warnings. Models need to be developed and calibrated by experts and configured into a system capable of running them efficiently.

Fluvial forecasting

It is possible to make some generalisations about the generic accuracy of the different types of model used in real time forecasting. River routing models are usually more certain than rainfall runoff models, and rainfall runoff forecasts are typically more accurate than rainfall forecasts. River routing models are therefore preferred where data and catchment lead time allow. Rainfall runoff models and rainfall forecasts are only relied on when there is insufficient data and catchment lead time.

Forecasting for fast responding catchments (or to provide longer lead times in other river systems) relies on the availability and accuracy of rainfall runoff modelling and rainfall forecasts. An analysis of catchment response times in Ireland for the review showed that 40-50% of potential flood risk communities will probably rely on a rainfall runoff model, and even a rainfall forecast, to provide any kind of warning. Minimising uncertainty in runoff prediction is therefore a key factor in building an accurate forecasting system. Best modelling practise is to undertake a thorough hydraulic routing of the flows within the river system.

Even when carefully calibrated, forecasting models are inherently uncertain. They are fed with a range of inputs from a hierarchy of preferred sources and they assimilate observed data at multiple locations. Forecasts therefore change hour to hour, which can be disconcerting for the end user. To address this, recent research efforts have focused on quantifying the uncertainty in real time river forecasts. For errors emanating from the hydrological models, this might be done by hindcasting many historic events and analysing the errors. Dealing with errors from the rainfall forecast may require the running of several ensembles through the forecast network. The Environment Agency in England and Wales has recently undertaken a research project to investigate ways of dealing with forecast errors probabilistically. That research is not yet fully published, but some of the methods developed are being published (e.g. Weerts, et al. 2010). The more promising of these methods use errors from past events to put an uncertainty band on a forecast.

Coastal forecasting

Relative to forecasting rainfall, predicting still-water sea levels (i.e. tide and surge) is generally more straightforward, depending largely on accurate predictions of tide level, atmospheric pressure and wind speed. However, coastal flooding can also be a function of wave overtopping, rather than simply the still-water levels. Forecasting the impacts of wave

---

[2] Pers. Comm. Ray McGrath (Met Éireann), 22 Nov 2010.

action is highly uncertain and requires considerable investment. Inclusion of wave overtopping forecasts necessitates the use of a series of models, including deep water wave forecast models, nearshore wave transformation models and wave overtopping models. Each of these carries with it high levels of uncertainty. Combining the results of these models for a forecast therefore suffers from a cumulative uncertainty effect.

The calibration of any coastal flood forecasting system requires measured sea-level and wave data. Whilst the tide gauge network in Ireland is developing, the density of gauges is currently low, making the calibration of forecast systems in ungauged locations difficult. This issue is exacerbated by the low density of wave buoys available.

3. Existing schemes

Figure 4 and Table 1 provides a summary of the existing flood forecasting and flood warning systems.

Table 1: Summary of existing flood forecasting and flood warning systems

System	Source	Models and software used	Lead-time provided	Cost (capital and running)
Met Éireann Severe Weather Warnings	Pluvial and Coastal	Meteorological forecasting. Dissemination by fax/email; sms in future.	48 hrs	Costs absorbed by Met Éireann as part of forecasting remit.
EFAS	Fluvial	LISFLOOD (GIS-based routing model); web portal	3+ days	Not known - research project currently (but due to be operational in late 2011)
Munster Blackwater Mallow IFFS	Fluvial	Upstream gauge level based model with routing, originally in Excel spreadsheet (now contained in PFFS)	5-6 hrs	Standalone IFFS only: Capital: €39,000 Annual running costs: €26,400
Munster Blackwater Mallow PFFS	Fluvial	URBS rainfall runoff model; FloodWorks software by MWH Soft	7-8 hrs	Capital: €335,000 Annual running costs: €230,000
Suir Clonmel IFFS	Fluvial	Routing model in Excel Spreadsheet	5 hrs (up to 12 hrs for less accurate forecasts)	Capital: €57,000 Annual running costs: €28,800
Suir Clonmel PFFS	Fluvial	URBS rainfall runoff model; FEWS software by Deltares	Expected: 7-8 hrs; (and longer lead times associated with lower accuracy)	Capital: €335,550 Annual running costs: €195,900
Bandon FEWS	Fluvial	Level to level correlation model; HYDRAS 3	5hrs	Capital: €60,000 Annual running costs: €10,000 (preliminary estimate)

System	Source	Models and software used	Lead-time provided	Cost (capital and running)
UCC Flood Warning Service	Fluvial	Level to level correlation model; Web portal	Information not provided	Information not provided
Tidewatch and Triton	Coastal	Tidewatch: Excel Spreadsheet using O'Connell-Coe formula; Triton: still water and wave overtopping model based on UKMO system	Tidewatch: 3-4 days Triton: 36 hrs	Capital: €300,000 Annual running costs: €50,000 Major Updates: €20,000 (every 4 years)
ICPSS	Coastal	Hydrodynamic surge and tidal model; MIKE 21 software	72hrs/144hrs	Costs based on trial period only: Capital: €87,000 Annual running costs: €68,100
PRISM	Coastal	Hydrodynamic models: - POLCOMS 3D - POM 2D - DIVAST 2D Surge model: POM Wave model: PRO-WAM	48hrs	Information not provided
Marine Institute	Coastal	Ocean forecast model: ROMS Wave model: SWAN	Sea surface height: 3 days Wave height: 6 days	Capital (Hardware only): €400,000 Annual running costs: €280,000
ESB Shannon Lakes	Fluvial	Hydrological forecasting model based on unit hydrograph methodology	Days	Approximate Set up costs: 5 Engineer Man Years. Annual running/maintenance: 0.5 Engineer Man years per annum.

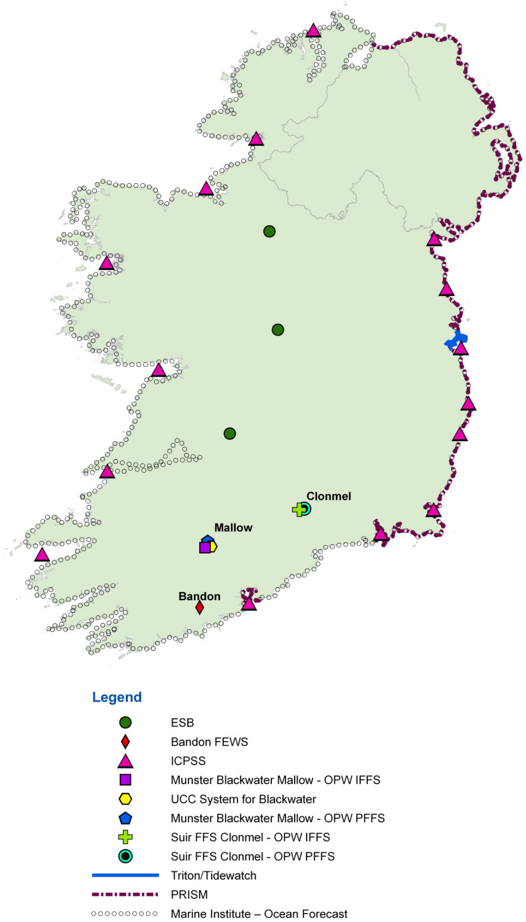

Figure 4: Locations of existing flood forecasting and warning systems

<u>Benefits of Flood Warning</u>

There is some confidence (based on a range of data sources and sensitivity tests) that national Annual Average Flood Damage is in the range of €171 million to €195 million with monetized annual average benefits from flood forecasting and warning of at least €8 million (2010 figures). The benefits largely derive from removal of property to reduce losses. Pluvial, groundwater and asset failure flooding, plus intangible benefits will significantly increase these benefits.

4. Future Forecasting Requirements

The consensus from stakeholders through two national workshops was that the highest priority benefits were those which impacted directly on people, with loss of life being given the top priority. Many stakeholders also felt that critical infrastructure and emergency response activities were important. While reducing the flood damage to property contents was considered important it was ranked by stakeholders as being some way down the priority order, suggesting that other benefits were considered to be of equal or greater importance than property content damage.

There are unlikely to be any generic forecasting problems in Ireland that are unique; modelling tools exist throughout Europe that forecast for a large range of catchment types in real time. If a forecast is needed for a flood warning in Ireland, there will almost certainly be a tool readily available to provide it - with the possible exception of the karst catchments in

County Clare and County Galway. The current and potential state of forecasting models in Ireland is illustrated in Figure 5, which gives some suggestions for what might be technically achievable based on international examples. The figure distinguishes between models that provide general information suitable for issuing alerts (open circles) and models that are geographically precise enough to allow creation of flood warnings (closed circles).

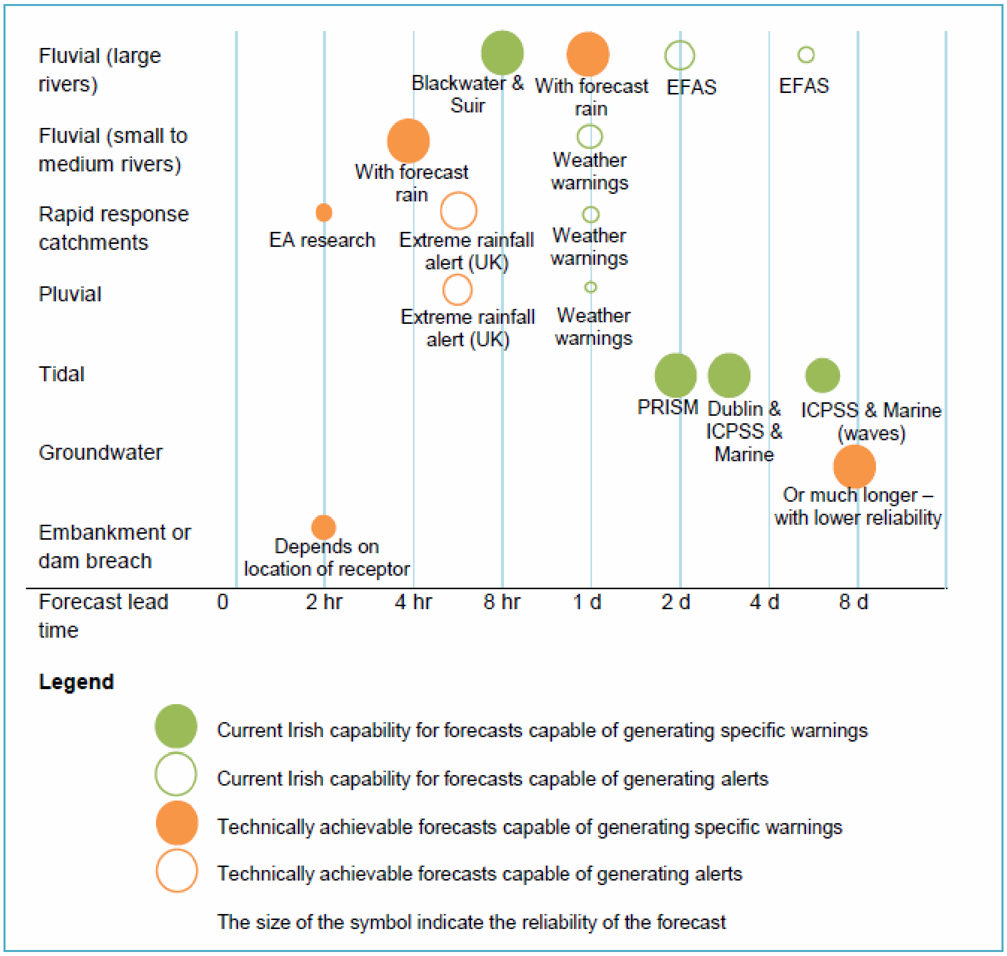

Figure 5: Illustration of lead times for different forecasts

Flood forecasting models can be developed from existing hydraulic models of the river system, which may be available from flood mapping or similar studies. This approach has the potential to save costs compared with developing a new river system model from scratch. Using detailed hydrodynamic models for flood forecasting can be particularly valuable when the propagation of flood hydrographs is affected by hydraulic influences that cannot be represented in simpler flow routing models, such as the operation of moveable river structures. However, when considering the re-use of existing models it is important to be aware that real-time application puts additional demands on models, which may be difficult for them to meet without requiring extensive modification.

River models for flood forecasting need to be:

- Fast.
- Stable.
- Accurate.

In some cases the above requirements can be more easily met by developing a new simple river model, typically a flow routing model, rather than trying to modify an existing one. Routing models can be developed at much lower cost than hydrodynamic models, and they are often more suited to flood forecasting. For example, it is possible to adjust wave speed and attenuation parameters to ensure that a routing model gives an accurate match to calibration data at a downstream flow gauging station. In contrast, with a hydrodynamic model it may be necessary to spend a long time on trial and error adjustments of hydraulic roughness, bank levels etc.

Hydrometric Requirements

The total number of new raingauges needed for flood forecasting will depend on which catchments require forecasting models. Most raingauges required for flood forecasting will also be useful for flood modelling in CFRAM studies and so they may already have been installed by the time some forecasting systems are developed. The mean number of new raingauges required per catchment is estimated to be 3-4.5 (although some catchments may require considerably more than this).

There may also be a requirement for some new raingauges to allow creation of a national system for flood alerts.

For operating a flood warning scheme it is highly desirable (although not always essential) to have a river level gauge at the main risk locations, and usually necessary to have one or more additional gauges located further upstream. Warnings can then be issued based on simple level to level correlations. More sophisticated flow forecasting models require flow gauges, both close to risk locations and also further upstream on the main river and its significant tributaries. For the purposes of the strategic review it was assumed that cost estimates can be developed using an average of around five new level gauges per local forecasting scheme.

The Marine Institute operates 17 tide gauges, all on telemetry. Data from these gauges is used to validate the Institute's storm surge forecasting model. There are plans to incorporate other tide gauges (existing or new) into the Irish National Tide Gauge Network, up to an eventual total of 33 gauges (JBA Consulting, 2008).

There is a need to access real-time information from gauges in Northern Ireland. In November 2009 there was difficulty accessing river gauge data in real time for trans-border catchments (this was two-way - neither OPW nor the Rivers Agency could readily access each other's hydrometric network).

Other Considerations

The success of any flood warning service in reducing flood risk depends on local mitigating actions being taken. These local actions (e.g. evacuating people, moving possessions, installing temporary flood defences, moving livestock, trash screen cleaning) are taken primarily by local authorities and third parties. For them to take action they need to be aware of and understand the risks, have confidence in the warnings and be supported. A national service could eventually require circa 120 flood forecasting models (20 catchment and 100 sub catchment models) and up to 600 community focused flood warning procedures; underpinned by a network of additional rainfall and river gauges and appropriate staffing to develop and operate the service.

To deliver such a service for the entire country and covering all areas of significant flood risk, significant capital investment and annual running costs will be incurred. Staffing costs represent the majority of these annual costs. Some of these staff would require high level skills. Such skills are available and could be externally procured or could be developed within the public service.

An economic appraisal of the preferred option, based on tangible benefits alone, demonstrates a positive cost ratio – in other words the benefits should substantially exceed the costs. If intangible benefits were to be included in the assessment this ratio would increase significantly. A national flood forecasting and warning system can therefore be robustly justified and represents a very worthwhile investment.

Conclusions

International practice shows that flood forecasting and flood warning systems in other countries have developed incrementally and largely in reactive response to flooding (particularly severe or geographically extensive events). In most cases the resources and cost of flood forecasting have grown substantially as operational experience and coverage grows. It is relatively rare to see the coverage of flood forecasting and warning reduce.

While there is understandably a great focus on the modelling aspects of forecasting amongst specialists (especially the hydraulic modelling), this is only one of many technical components (e.g. hydrological models, GIS, databases, website, contact databases, written procedures and protocols, hydrometric gauges).

Flood forecasting and warning is a major investment in terms of staffing, equipment and running costs. It requires a dedicated core team and also a stepped increase in resources during flood events. Significant investment is also needed in emergency response and public awareness if the warnings are to be effective (i.e. acted upon).

There are significant opportunities for Ireland in developing a world-leading flood forecasting and flood warning system helped by the:

- CFRAM Studies
- The existence of few legacy systems
- New technology (especially in uncertainty modelling)
- Ability to learn from good practice elsewhere
- Ability to identify long-term costs and benefits
- Possible joint working of meteorologists and hydrologists
- Cross-border collaboration

References

JBA Consulting (2008). Strategic Review of the Hydro-metrological Monitoring programme, Final Report for Office of Public Works.

McGrath, R. Fealy, R. and Sheridan, T. (2010). Royal Irish Academy 9th Scientific Statement: Recent Irish weather extremes and climate change.

Office of Public Works (2010). Preliminary Flood Risk Assessment - The Republic of Ireland. The definition of areas of potentially significant flood risk. Report by Mott MacDonald for the Office of Public Works.

Weerts, A.H., Winsemius, H.C. and Verkade, J.S. (2010). 'Estimation of predictive hydrological uncertainty using quantile regression: examples from the national flood forecasting system (England and Wales)'. Hyrol. Earth Syst. Sci. 7, 5547-5575.