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From drought to floods in 2012: operations and early warning services in the UK

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Abstract The Flood Forecasting Centre (FFC) is a partnership between the UK Met Office and the Environment Agency, established in 2009 to provide an operational early warning system for flood risk across England and Wales. It was set up following the summer 2007 floods in England and Wales, and the subsequent recommendations of the Pitt Review, to provide longer lead-time warning of flooding. Since 2011, the FFC has delivered its 24/7 forecasting service from the Operations Centre at the Met Office in Exeter, primarily for the emergency response community. The FFC provides forecasts for all sources of flooding, namely fluvial, coastal, surface water and groundwater. Recent examples, most notably from the 2012 floods, are presented. Following the success of the FFC, the Environment Agency, Met Office and partner organisations have extended the methodology and services under the Natural Hazard Partnership.

Key words flood forecasting; flood warning; risk based; joined up communication

INTRODUCTION

The Flood Forecasting Centre (FFC) is a partnership between the UK Met Office, the Environment Agency (EA) and National Resource Wales (NRW), which provides flood risk forecasts for England and Wales. Following the unprecedented summer 2007 rainfall and severe flooding, the UK Government commissioned the Pitt Review (Cabinet Office, 2008). This recommended a joint centre combining EA and Met Office expertise and using warnings with longer lead times to allow a proportionate and risk-based response. Subsequently, the Flood and Water Management Act 2010 has introduced legislation to address the threat of flooding from different sources, highlighting the risk-based approach, and the arrangements for forecasting and warning across England and Wales.

The FFC, founded in 2009, and now based at the Met Office in Exeter, promotes an integrated approach to flood forecasting between its parent organisations and its emergency responder customers, which include the police, fire services and lead local flood authorities. Forecasts consist of an assessment of possible hydrometeorological events in the next five days, as well as their likely impacts. Our priority is to identify and warn where flood risk is highest – either through higher likelihood or levels of consequent disruption, in real-time, and up to five days ahead for all sources of flooding: fluvial, surface water, coastal/tidal and groundwater. This is communicated mainly through a Flood Guidance Statement, issued by the FFC directly to responders at least once a day and covering a five-day forecast period.

The start of 2012 was dominated by concerns of drought and standpipes on streets. The change arrived as the 5th driest March on record was followed by the wettest April on record. The UK then experienced the wettest April to June on record; June itself was the wettest on record, and for England, 2012 was the wettest year on record. This provided a great opportunity to assess the capabilities of the FFC to date; and fine-tune its development programme.

The FFC assess the flood risk using a number of different hydrometeorological models and techniques. The Met Office suite of deterministic and ensemble Numerical Weather Prediction (NWP) models is fundamental to assessing the flood risk over the short and medium range. This suite is coupled with hydrological and impact models which are used by the operational forecasters to assess flood risk.

The operational success of the FFC has endorsed the benefits of partnership working in England and Wales. As a result a broader partnership, namely the Natural Hazards Partnership

(NHP), has been instigated by the UK Cabinet Office to provide co-ordinated information on natural hazards from across UK government departments, agencies and research councils. In order to deliver more targeted risk assessments and advice to government and Civil Contingency Act Category 1 and 2 responders, a cross-agency Hazard Impact Model (HIM) framework initiative is developing impact models for specific hazards. The three hazards being considered initially are surface water flooding (led by the Centre for Ecology & Hydrology (CEH)), land instability (led by the British Geological Survey) and high wind (led by the Met Office). These hazards are underpinned by an impact and vulnerability mapping led by the Health and Safety Laboratory.

STRATEGY AND TECHNIQUES

The risk-based approach adopted by the FFC is shared with the UK National Severe Weather Warning Service (NSWWS) – the two services align during flood events in order to achieve maximum reach, effectiveness and authority. The FFC's collaborative process for assessing flood risk is underpinned by the flood risk matrix shown in Fig. 1. A team of operational hydrometeorologists who are responsible for making a national assessment of flood risk, create highly effective communication links between the meteorological, hydrological and responder communities. The following sections explain the current tools and future developments for assessing fluvial and surface water flood risk across England and Wales.

Flood Risk Matrix
(river, tidal/coastal, surface water & groundwater flooding)

Likelihood	Minimal	Minor	Significant	Severe
High	Green	Yellow	Amber	Red
Medium	Green	Yellow	Amber	Amber
Low	Green	Green	Yellow	Amber
Very Low	Green	Green	Yellow	Yellow

Potential Impacts

Overall Flood Risk

HIGH	Red
MEDIUM	Amber
LOW	Yellow
VERY LOW	Green

Fig. 1 The flood risk matrix.

FLUVIAL FLOOD RISK

Grid-to-Grid and regional models

The FFC has introduced Grid-to-Grid (G2G), a physical-conceptual distributed hydrological model developed by the Centre for Ecology & Hydrology (Moore *et al.*, 2006); a schematic of the model is shown in Fig. 2. G2G is used operationally to provide an overview of river flood risk across England and Wales for five days ahead (Price *et al.*, 2012); with a similar set up implemented by the Scottish Flood Forecasting Service (SFFS; Cranston *et al.*, 2012). The G2G uses rainfall inputs in gridded form (both observed and forecast), physical parameters derived from soil property associations and terrain data; it has been calibrated across England and Wales, operates at a 1-km spatial resolution, and produces forecasts at a 15-min temporal resolution. Probability-distributed model theory is applied to represent how the spatially-varying water holding capacity of the land controls runoff production. Water accounting within each grid square provides gridded surface and subsurface runoff for input to the G2G routing scheme representing fast and slow translation paths respectively. G2G runs twice a day using a combination of deterministic and ensemble precipitation forecasts out to T+120 hours. The Regional forecasting teams across England and Wales use locally calibrated models driven by deterministic precipitation forecasts, and concentrate on the period to T+36 hours. The integration of National and Regional flood forecasting models across England and Wales therefore combines the benefits of longer lead-time

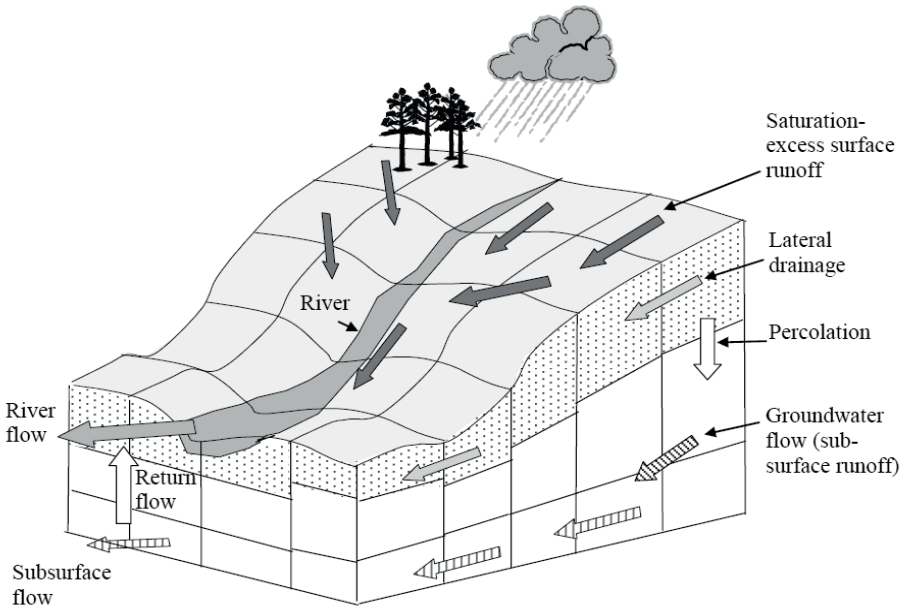

Fig. 2 Schematic of the G2G model.

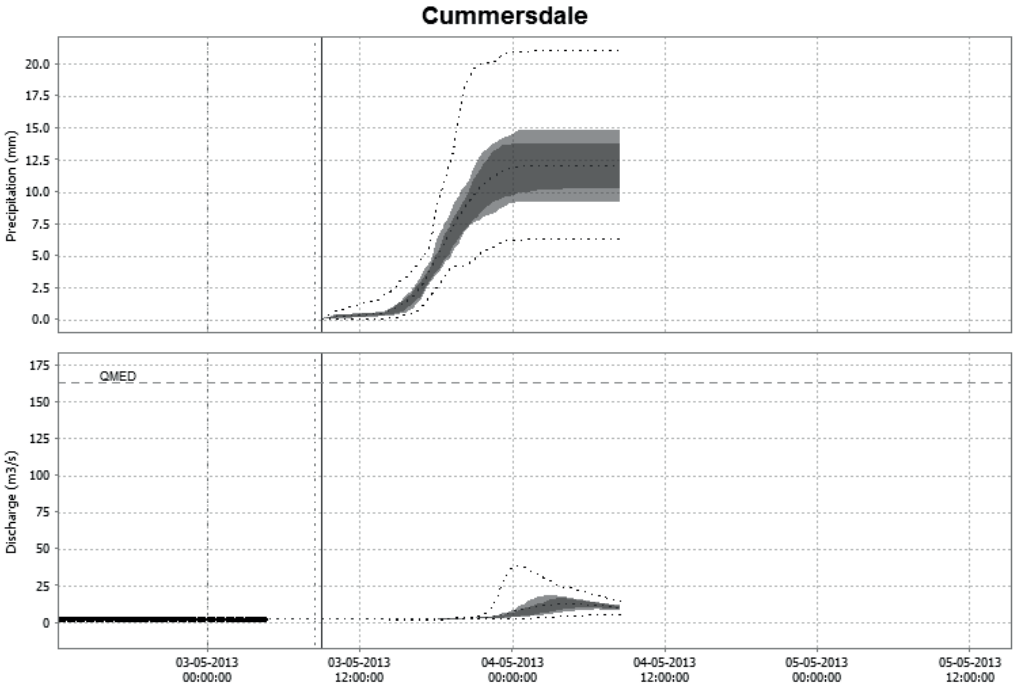

Fig. 3 Example of quantile plume visualisation for rainfall and river flow forecasts.

output from G2G, with the benefits available from more detailed catchment-specific models run at shorter lead-times by the Regional teams.

The operational hydrometeorologist needs to be able to identify locations of particular risk quickly from the wealth of forecast data available. The principal use of the G2G forecasts by the FFC is to provide an overview of flood risk at county level. Initial visualisation is the gridded probability of exceeding a flow of specified return period. This enables identification of the most likely areas at risk. Catchment average rainfall is calculated for each ensemble member and displayed alongside ensemble fluvial forecast data for selected catchment drainage points. This enables a visual comparison of the ensemble spread in both the rainfall and flow forecasts. Hydrological sensitivities can potentially be identified where there is a discrepancy between the

spread in the two ensembles. A sample hydrograph is shown in Fig. 3. In this example the rainfall spread is considerable but none of the resulting hydrographs represents increased flood risk.

Initial results and case studies

A selection of case studies are being analysed where river and surface water flooding across England and Wales during 2012 affected many communities with several thousand properties flooded.

Northern England: 22–24 June 2012

A slow-moving area of low pressure brought a prolonged period of heavy rain to northern England during this period; 50–80 mm fell within 24 h and more than 100 mm fell in 48 h on already wet catchments across Lancashire, Cumbria and West Yorkshire. Exceptionally high river levels led to extensive river and surface water flooding with over 1000 properties affected. As confidence increased in the location of the forecast rainfall, G2G was able to provide increasingly useful information on flood risk. The forecast available from G2G at 0900UTC on 21 June indicated an elevated flood risk of broadly between a 2- and 25-year return period (Fig. 4, left; shaded areas across northwest England). This, combined with successive high-resolution NWP model runs supporting the higher rainfall totals, and "what-if" scenarios run by the Environment Agency Regional flood forecasting teams, allowed the existing Yellow warning already in place to be increased to Amber for significant disruption at 14:30 h on 21 June (Fig. 4, right, darker shading across northwest England on Friday and Saturday). Working together, the FFC provided an early overview of flood risk, which was supported by models run by North West Region at shorter lead times to provide more detailed community specific forecasts.

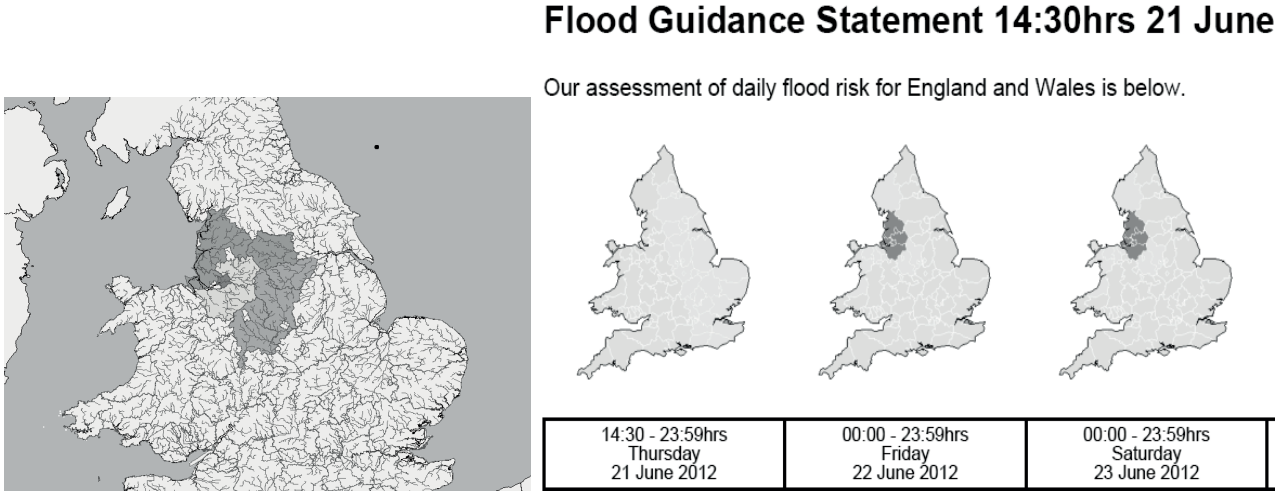

Fig. 4 G2G flood risk assessment (left) alongside issued Flood Guidance Statement (right).

SURFACE WATER FLOOD RISK

Currently the FFC uses a Surface Water Flooding Decision Support Tool (SWFDST, Halcrow (2011)) along with expert judgement and feedback from Regional flood forecasting teams and the Met Office chief forecaster to produce the surface water flooding element of the FGS. The SWFDST is an easy-to-use spreadsheet tool which combines the maximum probability of exceeding national rainfall thresholds for 1-, 3- or 6-h durations and return periods of 1 in 10 and 1 in 30 years, a sensitivity to surface water flooding categorisation based upon the Environment Agency's flood map for surface water, an average soil moisture deficit value and a FFC forecaster's assessment of the meteorological hazard. In this way, likelihood and sensitivity are used to produce an assessment of surface water flood risk in line with the Flood Risk Matrix at a county level. The tool was recalibrated using the Met Office UKV (~1.5 km) rainfall forecast (Halcrow, 2013), with the latest version being used operationally since spring 2013.

The move to higher resolution models has enabled the convection to be better resolved with Tang *et al.* (2012) demonstrating that dynamic convective processes are better captured when compared to the 4 km resolution model. The UKV model provides a more realistic shower distribution compared to the 4 km resolution model which tended to make convection too vigorous and storm cells too large.

The NHP Surface Water Flooding (SWF) Hazard Impact Model (HIM) initiative is exploring the use of G2G estimates of surface runoff. CEH working in partnership with the Health and Safety Laboratory (HSL) are creating dynamic maps that represent the possible impact of surface water flooding (Cole *et al.*, 2013). These combine the dynamic SWF hazard footprint with time-varying national impact datasets. Low and high exceedence thresholds on G2G surface runoff are set for 1-, 3- and 6-h durations. At the prototype stage, two simple types of 1 km SWF hazard footprint have been derived: (i) low hazard footprint – pixels where any of the low thresholds have been crossed, (ii) high hazard footprint – pixels where *all* of the high thresholds have been crossed. Initial work has focussed on assessing impacts to population, property and vulnerable locations. A prototype SWF hazard impact map is shown in Fig. 5. A near operational deployment by FFC is planned for summer 2014.

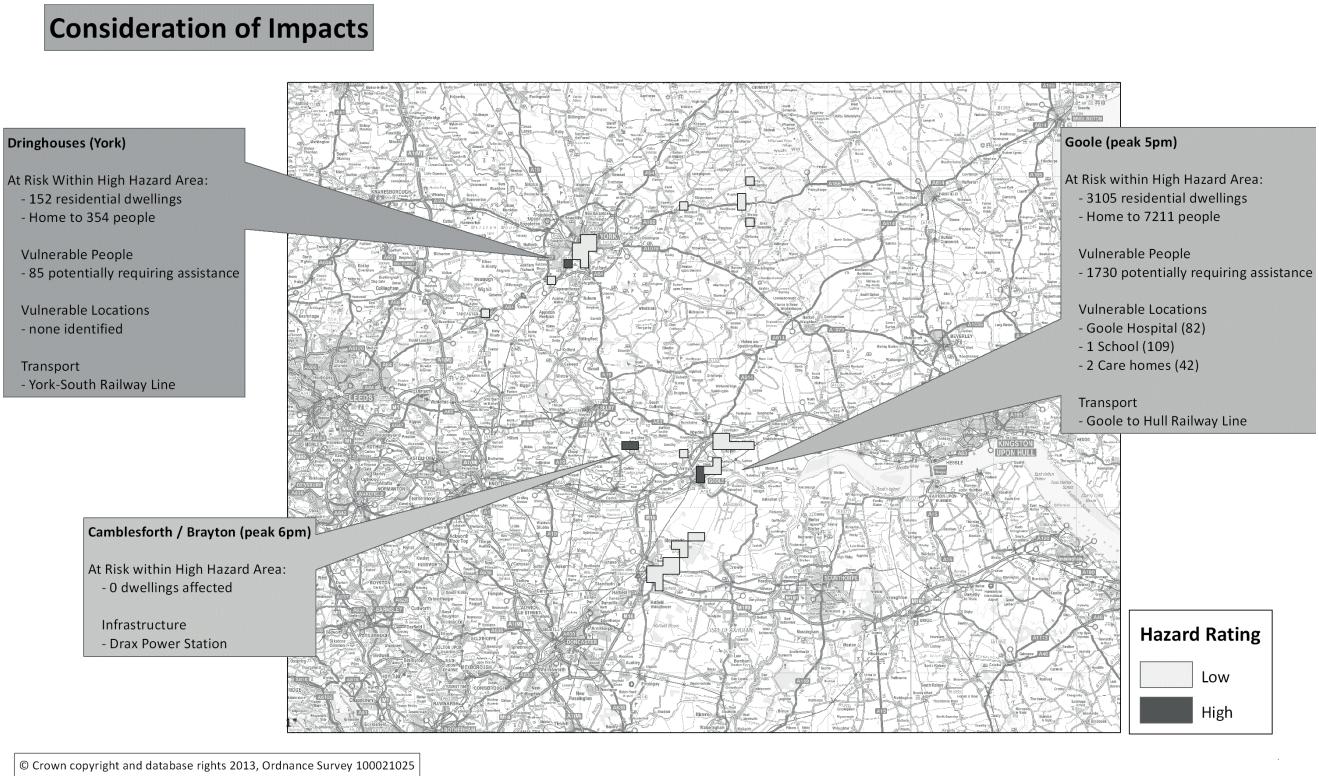

Fig. 5 A prototype surface water flooding hazard impact map: Goole and York, 3 August 2011.

SUMMARY

Strong working relationships and a truly collaborative approach are fundamental in making key operational decisions effectively and efficiently from all sources of flooding. The use of G2G for river flow forecasting provides valuable guidance for the warning of flooding and flood risk across England and Wales at longer lead-times. The end-to-end flood warning service is optimised by 'blending' the national forecasts at longer lead-times from G2G, with regional, catchment-specific models at shorter lead-times, and drawing on the local knowledge of the Regions. The FFC is well-positioned to exploit future modelling advances, act as a test-bed for evaluation of new science, and fast-tracks new techniques into operational flood forecasting.

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