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SURFACE WATER FLOOD WARNINGS IN ENGLAND: AN OVERVIEW, ASSESSMENT AND RECOMMENDATIONS BASED ON SURVEY RESPONSES AND WORKSHOPS

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ABSTRACT

Following the extensive surface water flooding (SWF) experienced in England in the summer 2007, progress has been made in improving the management and prediction of this type of flooding. A rainfall threshold-based Extreme Rainfall Alert (ERA) service was launched in 2009 and was superseded in 2011 by the Surface Water Flood Risk Assessment (SWFRA). Through survey responses from local authorities (LAs) and the outcome of workshops with a range of flood professionals, this paper examines the understanding, benefits and limitations of the current SWF warning service and explores ways to improve it. In general, the current SWFRA alerts are perceived as useful by district and county LAs, although their understanding of it is limited. The majority of LAs take action upon receipt of SWFRA alerts and their reactiveness to alerts appears to have increased over the years and as the SWFRA superseded the ERA service. This is a positive development towards increased resilience to SWF. The main drawback of the current service was found to be its broad spatial resolution. Alternatives for providing localised SWF forecast and warnings were analysed and a two-tier national-local approach, with pre-simulated scenario-based local SWF forecasting and warning systems, was deemed most appropriate by flood professionals given current monetary, human and technological resources.

KEYWORDS
Flood forecasting; flood risk management, flood warning, surface water flooding; urban pluvial flooding.

1. INTRODUCTION

Flood risk management in the UK has historically focused on fluvial and coastal flooding. However, the flooding events that affected the UK in the summer of 2007 brought into sharp focus the imminent risk imposed by surface water flooding (SWF) and the need for an improved approach to its management. These floods were the largest peacetime emergency since World War II, inundating 7,300 businesses and 48,000 houses, causing 13 deaths and resulting in £3.2 billion in damage (UK Parliament, 2010b). The Government commissioned Sir Michael Pitt to undertake an independent review of these flood events which revealed that two thirds of the damage was caused by SWF, a type of flooding for which no models, forecasts, warnings or management strategies existed (Pitt, 2008). Besides identifying surface water as a primary cause of flooding in the UK, the review called for a range of actions including clearer roles and responsibilities for SWF risk management and better modelling, mapping, forecasting and warning for this type of flooding.

The Government accepted all of Pitt's recommendations and since then has sought to improve the management of this type of flooding, a challenge given its rapid onset and localised nature. The recommendations that required legislation, including clarification of roles and responsibilities, were implemented through the Flood and Water Management Act 2010 (UK Parliament, 2010a). This Act required local authorities (LAs) to take a 'leadership role' in the management of local flood risk, including SWF, both in the spatial planning and the emergency planning spheres. Assuming this new role constitutes a significant challenge for LAs, especially in the face of current budget reductions. With regard to the technical recommendations, great efforts have been made to model, map and forecast SWF. As part of this process, the Environment Agency (EA) and the Met Office have joined forces to enhance the general flood forecasting capability and to develop SWF forecasting and warning systems for England and Wales. The first step in this direction was the 1st Generation Extreme Rainfall Alerts (ERAs) which were piloted between July 2008 and April 2009 and then issued operationally by a new joint Met Office-EA Flood Forecasting Centre (FFC). These alerts were based on national average rainfall thresholds likely to lead to SWF and were issued at county level to Category 1 and 2 emergency responders (UK Parliament, 2004) including LAs, emergency services and utilities companies (Flood Forecasting Centre, 2010). Although the ERAs proved generally useful to recipients, they did not reflect SWF risk accurately in all areas (Parker et al., 2011). In October 2011, the ERAs were superseded by the 2nd Generation Surface Water Flood Risk Assessment, which is the result of an objective assessment done with the Surface Water Flooding Decision Support Tool (SWFDST) and a subjective assessment carried out by a forecaster using a decision support flowchart. The SWFDST is an Excel based look-up tool which links extreme rainfall probabilities with parameters on the ground and maps of potential impacts in order to estimate the risk of SWF (Flood Forecasting Centre, 2011b). As part of the FFC's efforts to streamline its products, the new SWF risk assessment was incorporated into the Flood Guidance Statement (FGS) which is issued daily to Category 1 and 2 emergency responders and provides an assessment of the risk of all types of natural flooding (including SWF) at county level over the next 5 days (Flood Forecasting Centre, 2011a). Since the launch of the SWF risk assessment in 2011, the SWFDST tool has been continuously updated: it has been recalibrated as more rainfall and flood impact data have become available (e.g. the summer 2011 and summer 2012 flood data), the parameters that may exacerbate SWF have been reassessed and refined (including meteorological hazard, soil moisture deficit value, and degree of urbanisation and susceptibility to SWF estimated based on the EA flood maps for surface water (Environment Agency, 2010, 2012b)), and finer spatial resolution (i.e. 1.5 km instead of former 4 km resolution) extreme rainfall probability data have started to be used as input for the assessment (Lane, 2013). The new SWF risk assessment constitutes a step forward; however, it also has a number of drawbacks in particular its broad spatial resolution which is insufficient given the localised nature of this type of flooding. In order to improve this aspect, the FFC is working in collaboration with the Centre for Ecology and Hydrology (CEH) to link rainfall forecasts to the Grid-to-Grid distributed hydrological model of England and Wales (CEH, 2011) which uses spatial datasets of terrain, soil, geology and land-cover and can respond to spatial variation of rainfall input (which is not the case with the SWDST). The implementation of this model has the potential to be a significant improvement in SWF forecasting and warning. However, the FFC will continue to be a national service and it is unlikely that it will be able to deal with the very fine detail of small urban catchments where SWF is a major concern.

On balance, it is clear that rapid progress has been made in improving the management and prediction of SWF since 2007. However, there are still a number of technical, social and management challenges that need to be overcome in order to effectively forecast, warn and respond to SWF. The purpose of this paper is to examine the experiences of LAs with the 1st and 2nd Generation SWF warnings, identify their needs and preferences and explore options for improving the current warnings and making best use of them. This is done based on survey responses from LAs and on the outcomes of workshops comprising a range of professionals involved in flood forecasting, warning and management. It is worth noticing that the results included herein are preliminary, as the online survey to local authorities is still on-going. This research is part of the European Union Interreg RainGain Project (http://www.raingain.eu/en).

2. SOURCES AND METHODS

This paper draws upon two main sources of information to gather feedback on the usefulness of, and experiences with, the 1st generation ERAs and 2nd generation SWF warnings and the alternatives for improving them given current monetary, human and technical resources:

1. An online survey was undertaken between April and May 2013 targeted at flood risk managers, emergency managers and highways and drainage engineers from county and district LAs in England and Wales, who are the main users of the FFC's SWF warnings. The questionnaire comprised 16 questions split in three sections. The first section aimed at obtaining information about the respondent's organisation and his/her role in it, and about the importance and characteristics of surface water flooding within their local area. The second section included questions designed to reveal the usefulness of the ERAs and SWF warnings

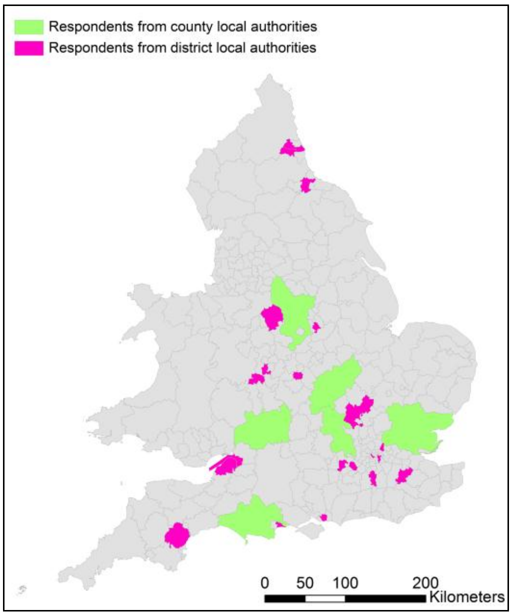
provided by the FFC as well as the respondents' perception and understanding of these services. The information collected in this section constitutes an update and expansion of the work undertaken by Parker et al. (2011) and Priest et al. (2011). The third section was intended to assess the potential response of LAs to more localised SWF warnings in a range of hypothetical scenarios characterised by different levels of certainty and lead times. In order to standardise responses, and given that it was an online survey, most questions had pre-defined answer choices. However, respondents were allowed to include additional comments at each of the questions and many did so.

2. Two workshops were held in February 2012 and April 2013 with over 40 flood professionals, including specialists, practitioners, academics and local and central government policy-makers from the UK and EU (RainGain Project, 2012). During the first workshop, participants were split into three groups according to their expertise and interest: (1) rainfall as an input for SWF modelling and forecasting; (2) hydrological/hydraulic models for SWF modelling and forecasting; and (3) management of SWF. Within each group, experts discussed the current situation, needs and challenges in their specific areas. During the second workshop rainfall experts, urban drainage modelling experts and flood risk managers were brought together to discuss different ways to improve SWF forecasting and warning systems in England in order to enhance the resilience of local communities to this type of flooding. A set of pre-defined questions was used for guiding the discussion during the two workshops.

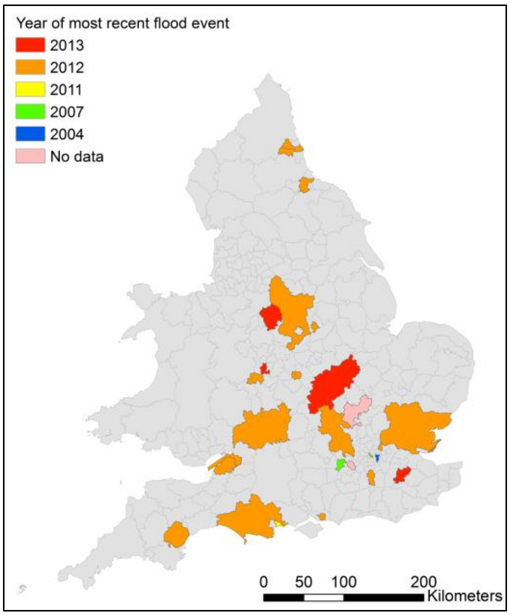
3. RESULTS AND DISCUSSION

3.1 Experiences, views and requirements of local authorities with regard to the SWF products provided by the FFC

The results presented in this sub-section are based on the analysis of the survey responses from LAs. Twenty eight (28) responses have been received so far from district and county authorities from across England (see Fig. 1a). 67 % of the survey respondents are flood risk managers, 23 % are drainage and/or highways engineers, and 11 % are emergency managers. Moreover, 85 % of respondents reported SWF in their area of jurisdiction in the last 3 years (see Fig. 1b) and all of them were familiar, although to different extents, with the SWF risk related services provided by the FFC.



(a)



(b)

Figure1. (a) Location of survey respondents; (b) Year of most recent SWF event in the area of jurisdiction of survey respondents

3.1.1 Local authorities' awareness and understanding of 1st Generation ERAs and 2nd generation SWF risk assessment

The survey contained 4 questions designed to reveal the LAs' awareness and understanding of the 1st Generation ERAs and 2nd generation SWF risk assessment provided by the FFC. The results are summarised in Fig. 2.

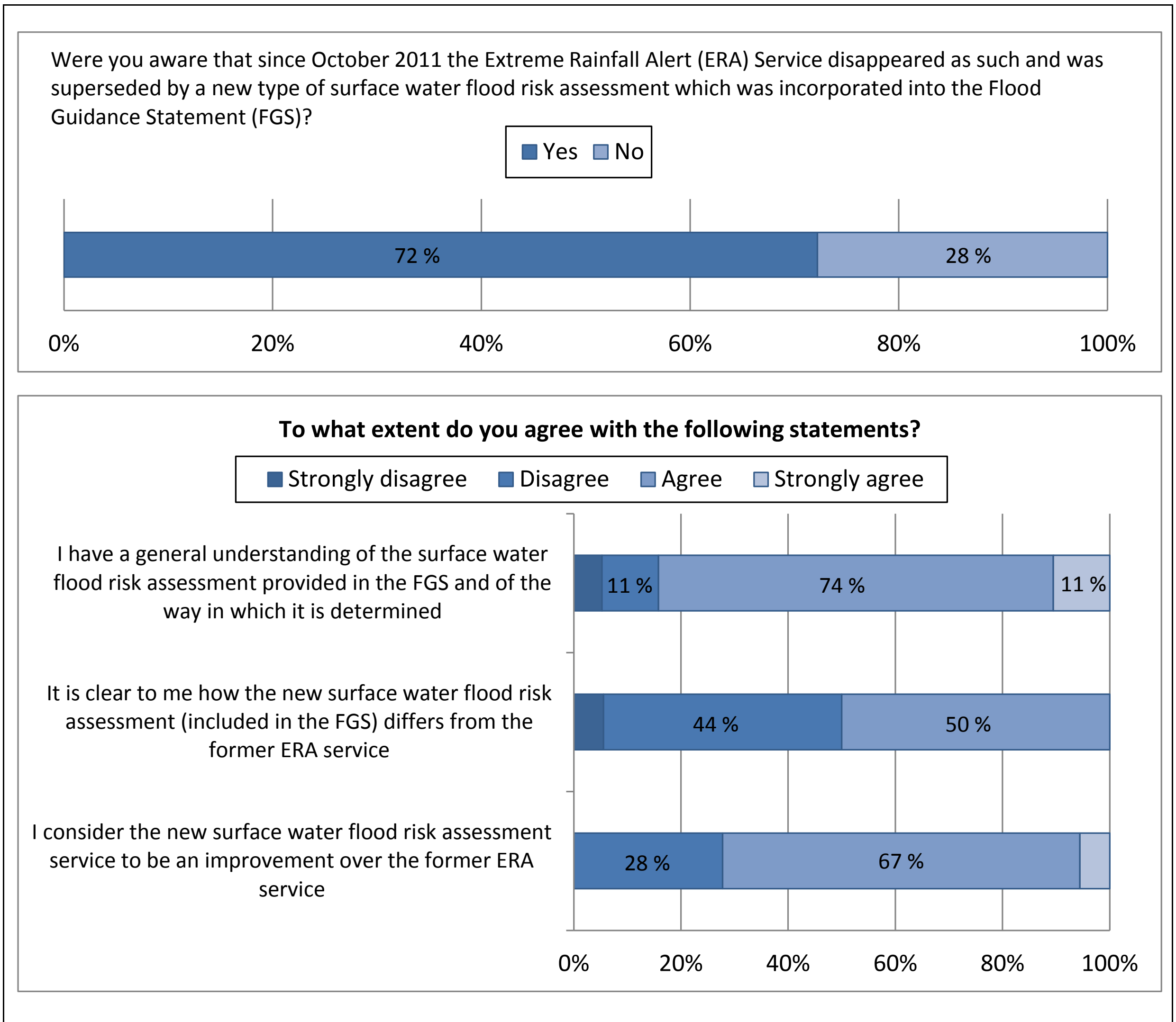


Figure 2. Local authorities' awareness and understanding of the 1st Generation ERAs and 2nd generation SWF risk assessment provided by the FFC

It can be seen that, in general, LAs have a basic understanding of these services, but do not understand the rationale behind them nor the differences between the two products in depth. Only few respondents (11 %) 'strongly agreed' with the statement regarding their understanding of the services provided by the FFC. In addition, the percentage of participants who were unaware of the change from ERAs to SWF risk assessment (28 %) and who indicated that they did not understand the differences between the two products (50 %) is concerning. It was expected that highways and/or drainage engineers and emergency planners would have a better understanding of these products in comparison to flood risk managers, as the former are proactive responders (i.e. upon receipt of early warnings, they may take essential actions to reduce damage potential or to be prepared for flooding in advance) (Parker et al., 2011). However, the statistics do not support this hypothesis. Moreover, additional comments provided by respondents suggest that the general feeling is that they wish to have more information about the services provided by the FFC, especially about the way in which forecasted rainfall is translated into potential flooding and impacts in their area. An examples of comments provided by respondents is the following:

"A key issue we have is that some parts of the organisation don't understand the difference between likelihood and potential impacts. I don't know if this could be incorporated into the five day maps at the top of the statements in a graphical way?"

The FFC aims to ensure that its partners, including in local government, have access to the best possible information. To help it meet this aspiration, the FFC should consider working to further raise user awareness of its services by providing easy-to-understand background information, especially about the new SWF risk assessment.

3.1.2 Usefulness and limitations of the SWF products provided by the FFC

All survey respondents consider the current SWF risk assessments provided by the FFC to be useful for their organisation (Fig. 3). The common feeling is that, in spite of being too broad, the SWF risk assessment does provide an overview of the potential risk and helps them to prepare for flooding. The main challenge for LAs is dealing with localised flooding, which, according to respondents, is happening with increasing frequency. Another limiting factor of the current SWF risk assessments is the short lead time frequently associated to high risk notifications. The following comments from survey respondents reflect their general opinion in this regard:

"We have been able to understand the potential for an impact on the ground based on the warnings. We understand that for key risk areas when we are likely to see an impact on the ground. This is harder for the more isolated and local issues, but it helps us to prepare for flooding."

"It's too broad ranging but does provide an overview."

"We are a small Unitary Authority and simply have limited resources to take action. We can call on others but everything happens so quickly that by the time they got here, it was all over."

Regarding the response to SWF risk assessments, the actions implemented by LAs vary according to the risk level. 93 % of participants indicated that their organisation usually takes action upon receipt of **high risk** of SWF notice while only 31 % of take action upon receipt of **low risk** SWF notice (Fig. 4). The type of action implemented also varies according to the level of risk. Low-cost precautionary measures such as monitoring of critical areas, are usually taken upon receipt of SWF risk assessments of any level while more costly measures such as cleansing of gullies are only implemented upon receipt of medium or high SWF risk notice. The most expensive and/or compromising options, such as placement of staff and resources on stand-by, notification of the general public and road closures, are only implemented upon receipt of high SWF risk alerts. The response to SWF risk notifications also varies according to the lead time (this topic is further discussed in Section 3.1.3) and depending on whether the notification is received during working hours or not. Moreover, some respondents indicated that, before taking action, they complement the information received from the FFC with other sources including the EA's Flood Advisory Service, current river levels, telemetry data from screens and other critical areas, ground saturation conditions and several general weather forecasting websites.

Participants were also asked about their response to the former ERAs (Fig. 4). Although these answers may entail high uncertainty, as participants may not have clear recollections of the service, it can be observed that, in general, LAs are more reactive to the new SWF assessments than they were to the former ERAs. This can be attributed to a number of factors, including increased confidence in, and better understanding of, the service provided by the FFC, improved awareness and understanding of SWF risk in their local area and the creation of standard procedures for reacting to these notifications. Whatever the reason, this is certainly a positive development.

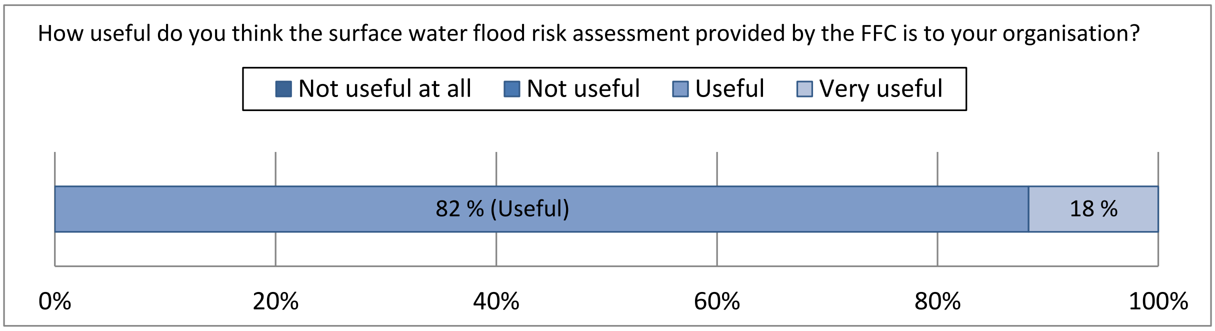


Figure 3. Usefulness of the SWF risk assessment service to local authorities

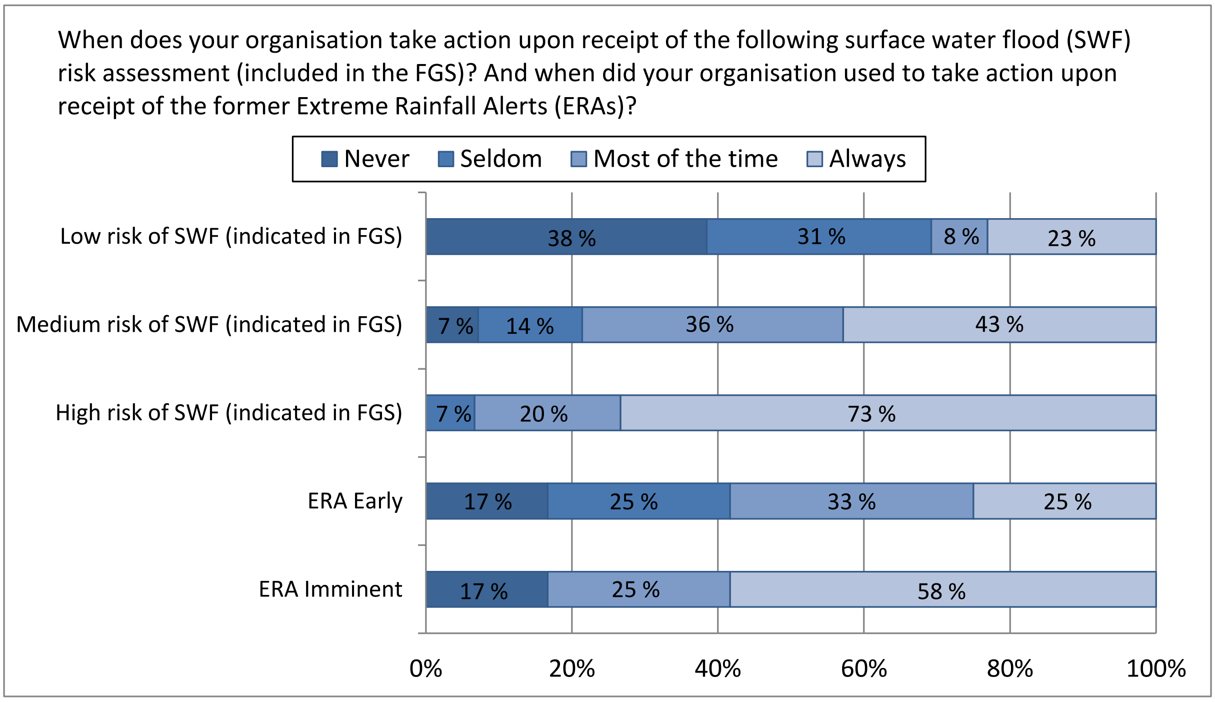


Figure 4. Response of local authorities to current SWF risk assessments and former ERAs of different levels.

3.1.3 Potential response of local authorities to more localised SWF warnings of different probability of occurrence and lead time

Survey participants were asked to indicate which actions (out of a list of pre-defined actions) they would implement if more localised SWF warnings of different probability of occurrence and with different lead times were available. The results are summarised in Table 1. The combinations of probability of occurrence and lead time were based on current knowledge (see for example Liguori et al. (2012)) given the fact that the confidence levels of SWF prediction increase significantly closer to the rainfall event. The answers to this question provide the following insights about the perception and tolerance of LAs to probability of occurrence and warning lead time and about the actions that they can currently implement in order to respond to SWF:

- 20 % probability of occurrence seems to be deemed too low and not worth implementing costly actions. At this level of confidence, less than a third of LAs (27 %) would monitor gullies, trash screens and other critical areas and less than a one in ten (7 %) would notify partners and contractors to send an alert. Some respondents mentioned that they can monitor critical areas by means of telemetry and, therefore, the cost of responding in this way is very low.

- 40 % probability appears to be the threshold at which LAs would be willing to start implementing more actions. At this probability level, more LAs would be willing to actively monitor, clean gullies and screens and even place resources on stand-by.
- The actions most sensitive to the probability of occurrence of a flood event are the notification of the general public, the placement of resources on stand-by, the closure of road and areas at highest risk, and the placement of flood defences. The notification of the general public only when confidence levels are high is in agreement with previous studies (Parker et al., 2011; Priest et al., 2011; Environment Agency, 2012a).
- Lead times as short as 30 min would enable responders to implement actions that could help in reducing the risk of flooding. 40 % of respondents indicated that they would notify the general public, 60 % would place resources in stand-by and 47 % would activate control elements upon receipt of more localised high probability warnings with only 30 min lead time.
- The combination of probability and lead time at which the greatest response would be possible is 60 % probability - 2 h lead time.
- Resources such as control elements for preventing flooding and flood warden schemes are not currently available to most local authorities. While implementing control elements may require high investment and expertise, low-cost training provided by flood warden schemes could help to significantly improve community response to flood risk.

Table 1. Potential response of local authorities to localised SWF warnings of different probability of occurrence and lead time

Actions / Lead time - probability	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
12h - 20% prob.	47%	27%	7%	7%	0%	0%	0%	0%	0%	0%	0%
12h - 40% prob.	13%	47%	27%	27%	0%	7%	13%	33%	0%	0%	0%
6h - 20% prob.	40%	27%	7%	7%	0%	0%	0%	0%	0%	0%	0%
6h - 40% prob.	0%	53%	27%	27%	7%	7%	13%	47%	0%	0%	0%
2h - 40% prob.	13%	47%	27%	13%	7%	0%	7%	33%	7%	0%	0%
2h - 60% prob.	0%	53%	47%	40%	20%	20%	27%	53%	7%	13%	0%
1h - 40% prob.	7%	40%	33%	20%	7%	0%	13%	40%	7%	0%	0%
1h - 60% prob.	0%	40%	40%	47%	20%	20%	27%	47%	13%	7%	0%
1h - 80% prob.	0%	40%	40%	47%	27%	20%	40%	60%	20%	20%	13%
0.5h - 60% prob.	0%	40%	33%	40%	20%	20%	27%	53%	13%	7%	0%
0.5h - 80% prob.	0%	40%	33%	47%	27%	20%	40%	60%	20%	20%	13%

A1: do nothing; **A2:** Monitoring of watercourses, gullies, trash screens and the like; **A3:** Cleansing of gullies and screens in high risk areas; **A4:** Notification of contractors and partners; **A5:** Activation of control elements (e.g. pumps, storage); **A6:** Notification of flood wardens; **A7:** Notification of the general public; **A8:** Placement of staff and resources on stand-by; **A9:** Deployment of temporary flood defences; **A10:** Road closures; **A11:** Closure of public locations susceptible to pluvial flooding (e.g. underground passages).

3.2 Analysis of alternatives for improving the current SWF forecasting and warning systems

As indicated in Section 3.1.2, the main drawback of the SWF assessment currently provided by the FFC is that it is too broad (i.e. county level) and therefore of insufficient spatial resolution given the localised nature of SWF. Although the FFC is working on the implementation of the Grid-to-Grid model in order to improve the quality and spatial resolution of the forecast, the service provided by the FFC will remain a national service and as such it is unlikely that it can deal with the fine detail of urban catchments (including local topography, sewer system and its dynamic interactions with the surface) which are the ones at highest risk of SWF. Alternatives for overcoming this problem and fulfilling the needs of local authorities were discussed during the workshops held in February 2012 and April 2013. Through these workshops answers to the following questions were sought:

- **Which general approach would be more appropriate for implementing localised surface water flood forecasting and warning systems in England: (a) a single national service or (b) a two-tier (national/local service)?**

  Participants were of the view that a two-tier approach was most suitable, with a main rainfall and broad flood forecasting and warning service at the national level provided by the FCC, and local systems, especially for "hotspots", operated by LAs in collaboration with the EA. At present, the technical skills and expertise do not exist locally and LAs are facing budgetary cuts which make the implementation and effective use of these systems ever more challenging. These constraints and alternatives for overcoming them are next discussed.

- **What type forecasting system (technical speaking) would be most appropriate for local areas in England, considering the users' requirements and resources currently available? What are the constraints for implementing and making effective use of such system?**

  In general, flood forecasting systems can be of three types (in increasing order of complexity and cost) (Henonin et al., 2010):

  (a) Empirical scenarios-based system: flood forecast system with no hydraulic model involved in any part of the process. Warning thresholds correspond mainly to forecasted rainfall thresholds and may include other parameters that exacerbate SWF (e.g. antecedent precipitation and soil moisture, leaf fall and water levels at critical locations). Warning thresholds are defined based on historical flood events and/or knowledge of local the area.

  (b) **Pre-simulated scenarios-based system:** flood forecast system with scenario and results catalogue built from previous hydraulic simulations (for example, data driven models trained with results from hydraulic models). The complexity and quality of this system will depend on the type and quality of the hydraulic model and of the rainfall inputs used to generate the flood scenarios. The implementation of a system of this type is costly; however, the operational cost is rather low and does not require highly skilled staff.

  (c) **Real-time simulations-based system:** flood forecast system with real-time hydraulic models. The type of model that is used in this system must comply with real-time forecasts standards such as short computational time and fast display of results, while keeping acceptable accuracy. Both the implementation and operation of this type of system are costly (the cost of software licences must be taken into account) and require highly skilled staff.

  In all types of systems the rainfall forecast will most likely come from the Met Office or the joint FFC. Moreover, all systems would benefit from telemetry data (including water levels at critical locations) which could be incorporated as a variable of the system.

From a **technical** point of view, workshop participants concluded that all three types of forecasting could be implemented with the technology that is currently available. However, the high uncertainties associated with currently available rainfall forecasts would dominate the overall uncertainty of the flood forecast, regardless of the type of forecasting system that is used. Efforts should therefore be concentrated on improving the accuracy of rainfall estimates and forecasts, while bearing in mind the limits of predictability and finding a balance between costs and benefits. Concerning **monetary** resources, it was felt that that the budget available to LAs for flood risk management would be enough for implementing and operating type 'a' and 'b' systems, but not 'c' as its operational costs are very high given the cost of software licences and of skilled staff able to operate the system. A common constraint for the implementation of any of the three forecasting systems is the currently high costs of accessing radar rainfall estimates and forecasts by 'new to radar' stakeholders, such as LAs. Partnership working and establishing of cost sharing arrangements would be necessary, should local SWF forecasting systems be implemented. With regard to the **skills required** for operating and effectively using a local forecasting and warning system, workshop participants felt that, in general, LAs do not yet have the capacity for it. As such, starting with a simple system would be prudent and efforts should be made to gradually build capacity. Overall, a type 'b' system was seen as a good balance between cost, benefits and practical delivery. The development of such a system could be outsourced to consultants or local universities and cost savings and synergies could be achieved by working in partnership with neighbouring LAs, water companies, the EA and the FFC. Moreover, participants concluded that implementing telemetry monitoring systems would be a 'quick win' as this would significantly enhance the quality of any forecasting system that is implemented while at the same time collecting data for future model calibration and verification.

Another important aspect highlighted by participants, and which remains a major challenge, is awareness raising and engagement of community members in local flood risk management. Community ownership is at the heart of any future service and low awareness would limit the use of improved SWF warnings. Significant efforts are being made in this direction and should continue.

4. CONCLUSIONS

The 1st Generation ERAs and the 2nd Generation SWF risk assessment constitute a step forward in the forecasting, warning and management of SWF in England. In general, these services are perceived as useful by district and county LAs, although their understanding of the rationale behind these alerts is low. The majority of LAs do take action upon receipt of the SWF alerts and their reactiveness appears to have increased over the years and as the 2nd Generation alerts superseded the 1st Generation ones. This is a positive and encouraging development towards increased resilience to SWF. The main drawback of the current SWF forecasting and warning service is its broad spatial resolution which is insufficient given the localised nature of this type of flooding. Flood professionals believe that, despite improvements, the service provided by the FFC will continue to be a national service and it is unlikely that it can ever deal with the fine detail of local areas. Therefore, a two-tier national-local approach is considered more appropriate for generating localised SWF forecasts and warnings. In this case, a main meteorological and broad flood forecasting and warning service at the national level would be provided by the FFC, and local forecasting and warning systems (which would get input from the national service) would be operated by LAs in collaboration with the EA. Considering current monetary, human and technological resources, a pre-simulated scenario-based system was deemed to be more appropriate in the short term for generating local SWF forecasts and warnings. The development of such a system is complex and could be outsourced to consultants or local universities. However, its operation is simple and could be handled by LAs. Moreover, cost savings and synergies for the implementation and operation of these systems could be achieved by working in partnership with neighbouring LAs, water companies and the EA. Existing constraints for the implementation of any local forecasting and warning system that require action include the insufficient accuracy of currently available rainfall estimates and forecasts, the lack of capacity at LAs and the low-levels of public flood risk awareness.

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