NEW TECHNOLOGIES FROM THE UK TO SUPPORT FLOOD RISK MANAGEMENT

Jon Wicks[1], Rob Berry[1], Paul Wilkinson[2], Beccy Dunn[2], Frazer Rhodes[3]

[1]Halcrow Group Ltd, UK, wicksjm@halcrow.com
[2]Halcrow Group Ltd, Brisbane, QLD
[3]Environment Agency, Leeds, UK

Abstract

Advances in software, computer hardware, mobile devices, live data feeds and remotely-obtained datasets has enabled significant opportunities for new decision support tools to improve flood risk management.

This paper introduces a range of technological advances that have or are being introduced in the UK for use by flood management operating authorities, the public and other stakeholders. The innovative technologies covered are:

- Smartphone application which provides real-time flood warning information for specific locations enabling the public to receive warnings through new channels.
- Web-based flood visualisation tool for emergency management.
- Rapid flood inundation models for broad scale modelling and real-time inundation prediction.
- Decision-pathway approaches for communicating potential climate change adaptation options.
- Probabilistic analysis tools to help understand and communicate uncertainty in flood predictions.
- Social media to foster stakeholder engagement and collect flood incident data through crowd-sourcing to improve flood response.

The technologies present opportunities for benefiting floodplain management, community engagement, understanding climate change impacts, floodplain development control and emergency management.

Introduction

In the UK, significant investment has been made in flood incident management since 1996 particularly with flood warning and river level telemetry networks and systems. Introduced in 2006, the Environment Agency's (England & Wales) main flood warning system, Floodline Warnings Direct (FWD), has cost in excess of £12.5 million (20 million $AUD) to date in terms of its development and maintenance.

Since 2006, there have been a number of drivers and policy developments within Flood Risk Management in England and Wales that have led to the 'opening up' of live flood risk management data held in such systems as FWD and the recognition that Flood Risk Management Authorities such as the Environment Agency can achieve corporate outcomes by enabling innovation and delivering results through others.

The summer floods of 2007 in England and Wales and the subsequent Pitt Review (Pitt, 2008), presented significant challenges for the Environment Agency, namely:

- The need to provide improved flood visualisation for emergency responders in tactical and strategic command centres;

- Providing probabilistic flood forecasting information to enable improved flood response decision making;
- The need to model defence/reservoir failure scenarios providing emergency responders with sufficient information on likely flood extents;
- Adopt and develop social media as an intelligence tool to gather information on incidents, improve response to major incidents and engage proactively with communities; and
- Providing targeted flood warnings for infrastructure operators to enable utility companies in particular to deliver a more efficient flood response.

In order to deliver Government-supported recommendations from the Review, innovative approaches were sought to enable greater access to data and information through the creation of pilot systems, working with industry and through Value Added Resellers (VARs).

As an example, a pilot service developed by the Environment Agency with Western Power Distribution, an Electricity Network Distributor, demonstrated the value of opening up live flood warning data feeds to enable tailored and specialised warning services to be developed (Rhodes, 2011). This demonstration was progressed with the backdrop of funding within Government organisations being constrained with significant reductions in budgets requiring alternative sources of funding to be sought.

During this period, sharing and opening up access to data sets has also become encouraged and has politically gained momentum. Francis Maude, Minister for the Cabinet Office, stated in May 2011, "*We have entered a new era of transparency in Government and have already made an unprecedented level of data available. But we want to go further and faster, this agenda is more important than ever. Public sector information underpins a growing part of the economy. The technology that is around today allows people to use and re-use this information in new and different ways*".

As data processing power has improved, demand for availability and access to data has also increased and the development of web-based applications, crowd-sourcing and social media developments, particularly on mobile devices, has become widespread. In Flood Incident Management, individuals, businesses and Flood Management Authorities want access to live information through different channels, for the information to be targeted and relevant either as an individual or as a business and be able to contribute and share information concerning the incident.

During 2010/11 the Environment Agency initiated the development of a 'Data Distribution Hub' to enable secure and regulated access to the live flood warning data and hydrometric (river and sea levels) data to authorised subscribers. This provided access to live flood data feeds via two routes:

- Direct access to live flood warning data (XML & GIS). Organisations can take this directly from the Data Distribution Hub under an internal business use licence and use it to develop their own in-house tailored warning service to meet their requirements.
- Value Added Resellers (VARs) can take the data under licence from the Data Distribution Hub and develop tailored products and services (royalties apply).

The Data Distribution Hub was formally launched on the 28th January 2011 and enabled for the first time, live flood warning and hydrometric data to be accessed by external organisations both for internal development and for value added services to be created by commercial companies. The Wider Markets Initiative[1] in 2006 provided a national policy to enable charging for Government provided goods and services. It

[1] *Wider Markets Initiative*, 2006. National Audit Office, London.

gives discretion to set commercial rates for some services including delivering a return on the use of resources acquired with public funds. Putting the Frontline First[2] (Dec 2009) outlined a shift in Government policy to the free provision of data and information that are not personal, classified or commercially sensitive.

The Environment Agency aims to provide a balance between services offered at no cost and those tailored services where commercial licences and charges apply. Any products that are developed and provided free of charge do not attract royalties. Any income from data licences or royalties from commercial products are reinvested to deliver more for people and the environment.

Further releases of further live data feeds such as rainfall, river flow and flood forecast data are currently being considered by the Environment Agency. The number of VAR-developed flood risk management products and tailored warning services has also continued to grow. These applications range from those intended for use by members of the public through to bespoke services for multi-national corporations.

Whilst the Environment Agency retains a core flood warning service, Value Added Resellers are actively developing specialised warning services for utilities and transport operators, specialist insurance products, and smart phone applications. These services ensure that more people are receiving flood warnings in the way they want to access this information. The adoption of these services will improve flood response, reducing the impact of flooding on communities due to disruption to essential services and critical infrastructure.

This paper highlights some of the new products that have been developed recently, both in response to the Pitt Review and to the increased availability of Environment Agency data.

Smartphone application for real-time flood warnings

The Environment Agency's Floodline Warnings Direct service sends registered users a message when flooding is expected which may affect their property. Flood warnings are available by telephone, mobile, email, SMS text message or fax. The service has proved very popular but the recent opening up of the Environment Agency's data has provided opportunities to supplement the service with alternate means to obtaining the flood warnings. An example of the new services is Flood Alert (Figure 1) which is a Smartphone application developed by Halcrow to allow users to get real time updates on flood warnings near them, at locations important to them and a national overview for England and Wales.

For large organisations Flood Alert (www.halcrow.com/floodalert) provides benefits in that, instead of receiving potentially several thousand individual flood warning messages during a significant flood for each individual site, the application will bring the messages together into a single prioritised list. For individuals, the benefits of Flood Alert are that it allows users to quickly, efficiently and conveniently monitor flooding in areas that are important to them (such as home, workplace, school, parent's home). Through the use of Smartphone geo-location functionality it also enables users to see flood warnings for their current location (which could be a campsite or construction site in a floodplain for example).

In addition to the customised and current location views, a national view of the Environment Agency flood warnings is also available within the application. In each Environment Agency region the current flood warnings in force are displayed allowing the user to monitor flooding events on a national scale.

---

[2] *Putting the Frontline First*, 2009. HM Government, London.

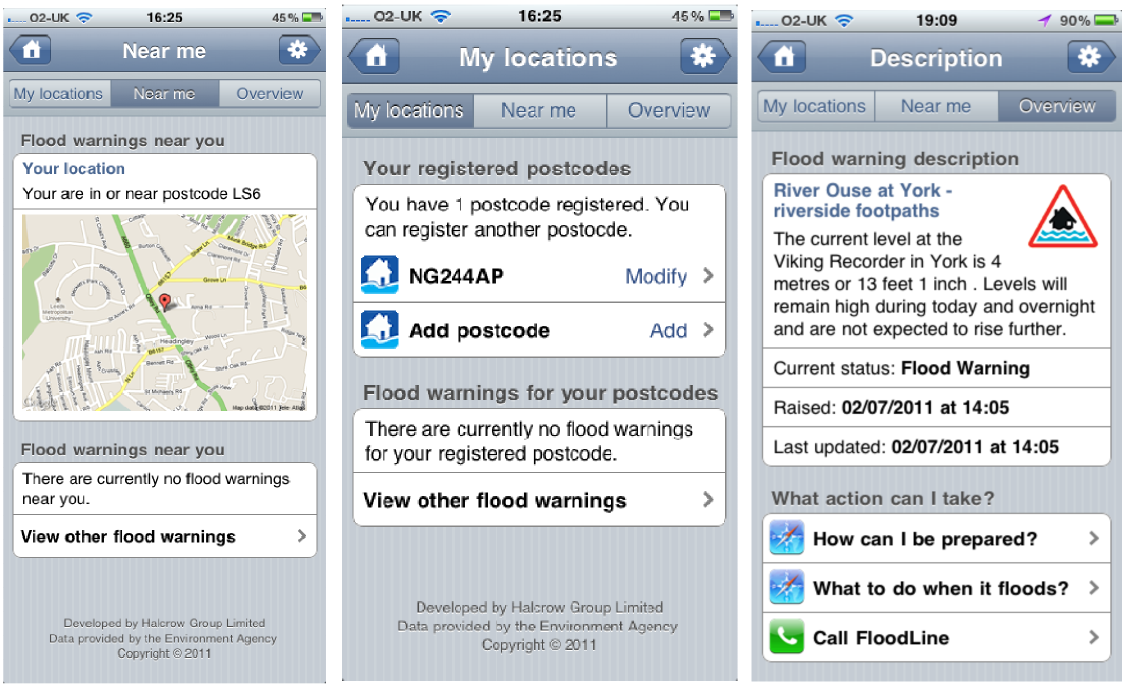


Figure 1 – Flood Alert

Each flood warning contains specific information on the flood event which can help users understand their current risk and the expected future changes. It also provides information on when the alert was raised and last updated.

Flood Alert also acts as an educational tool in flood risk management. It provides information and advice on how to prepare for a flood and what to do if it floods, helping users to help themselves. The information additionally promotes health and safety, gives emergency contact information and links directly to the Environment Agency website through the phones web browser, allowing the user to access further information.

As the application is fully integrated with the users' Smartphone, they can also communicate the risk of flooding to a friend or family member by text, email or telephone call. This helps spread the flood warning to other potentially affected people who might miss a traditional FWD message.

Flood alert is available for free in the Apple 'App Store' and in Blackberry 'App World'. Android users will also be able to download it from the Android Market in the near future. A professional version for larger organisations is available which links with an intranet dashboard.

Flood visualisation for emergency management

Extensive programmes of flood risk mapping in the UK means there is now good coverage of fluvial, tidal and surface water flood mapping across England and Wales. By presenting these flood maps interactively, their value can be significantly enhanced. For example, interactive flood maps:

- help to make flood mapping more accessible and meaningful;
- enable rapid analysis of flooding scenarios by non-flood modellers; and
- present quick and reliable evidence to support operational decisions.

To enable the true potential of flood maps to be realised, Halcrow has been working with the emergency planning and response community to develop FloodViewer. This is an interactive flood visualisation tool, developed to meet the specific needs and operational constraints of emergency planners and responders.

Using outputs from existing modelling studies, FloodViewer presents flood maps in a consistent, user-friendly format. The base maps change dynamically as users zoom in or out of an area, alternatively the flood information can also be displayed against aerial photography. To avoid constraints around IT security, and to facilitate sharing information quickly between professional partners, no installation is required and no GIS software is needed to run FloodViewer. This makes the tool very quick, easy and reliable to use in an emergency situation.

The tool includes an innovative water-level slider bar, which allows the user to visualise the expected extent of flooding for forecast or observed peak water levels, without needing any expertise in flood modelling or GIS. It also allows those without expert local flood knowledge to quickly understand the impact of uncertainty in observed or forecast water level on the potential flood extent. For example, the forecast maximum water level at a particular gauge site may be 11.5m and so the slider is first set to 11.5m (and the flood extent corresponding to this local level will be displayed). The user could then move the slider up to 11.8m or down to 11.2m to see what the estimated flood extent would be if the actual maximum water level was 0.3m higher or lower than that currently forecast.

A key infrastructure layer is also included, so decision makers can see what infrastructure might be affected and contact those concerned. To further support this, FloodViewer can be configured to include details such as contact names and numbers of asset owners and the key vulnerabilities and threshold levels associated with locally or nationally important infrastructure. Figure 2 shows the expected flood extent corresponding to a 11.5m water level at the local Summertown gauge – it also shows an example of the 'pop-up' information which can be displayed if the user clicks on the residential home icon. The figure also demonstrates the very simple and clean user interface to the software which is accessed through a web browser (with data either held on an internet/intranet server or on the local client PC).

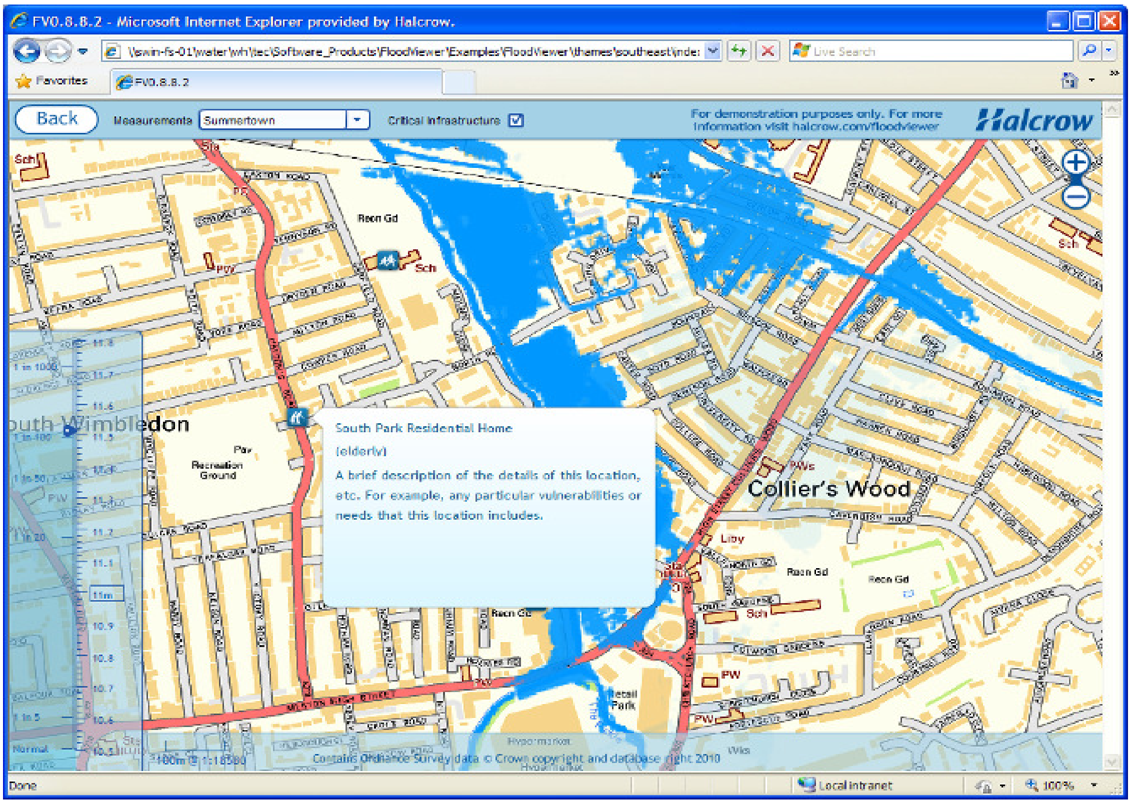


Figure 2 – FloodViewer

FloodViewer is already being used by emergency planners and responders in the Midlands region of England, having been successfully tested by Category 1 responders during Exercise Watermark (a recent extensive flood exercise held in response to the Pitt Review). During the exercise, FloodViewer was shown to help responders see how forecast water levels would translate into flood extents, what infrastructure will be affected by a forecast flood, and where to focus deployment of demountable defences and emergency response units. Indeed, the tool has even caught the attention of the media, with the BBC describing FloodViewer as a "new weapon in the war against water".

Looking forward, there is the intention to make FloodViewer a live system, by developing real time links to flood forecasting telemetry systems and compiling a mobile version for use out in the field. There is undoubtedly much greater potential for flood visualisation tools in general to be further developed, and for them to be used more widely by emergency planners and responders in future flood events.

Rapid flood inundation models

Two dimensional (2D) hydrodynamic flood models which solve the full equations of momentum and mass conservation have, over the last decade, become the standard approach in the UK for detailed flood inundation modelling. However, such models tend to require simulation run times lasting many hours (especially where computational cells sizes are less than 10m). There are many situations where these large run times mean that the full 2D models cannot normally be used; examples include real time flood inundation forecasting, probabilistic analysis and national scale flood mapping. A new class of 2D model has evolved over recent years to meet this need and make best use of the increased availability of digital terrain data (e.g. LiDAR and SAR). So called 'rapid flood spreading (or inundation) models' focus on replacing the time consuming components of the computation with simplified representations that run much faster but retain sufficient accuracy for specific uses. Examples of these rapid models include Lhomme et al (2008), Liu et al (2009) and ISIS FAST (Wicks et al, 2011). The remainder of this section introduces the methods used in ISIS FAST (www.halcrow.com/isisfast) and examples of how it has been used.

The computational engine of ISIS FAST is based on a set of rules to simulate spreading of flood water over a floodplain (as defined in a Digital Terrain Model, DTM). The basic sequence of calculations can be broken down to the following steps:

- Pre-processing of the input raster grid. The pre-processor identifies every point in the DTM that has all its neighbouring points at a higher elevation than itself. Correspondingly, it also finds the set of all points such that water falling on these points will flow towards an identified low point. This set of points is termed a 'depression'. Hence, the entire DTM can be broken into a collection of depressions. Further, the pre-processor sets up stage-area-volume relationships for each depression, defines its neighbours and finds the minimum connection level with each neighbour.
- Main computation phase. The computational engine now introduces water into the depressions linked to the boundary conditions specified. It then checks the water level in each depression. If the water level in any depression is higher than the connection level with its neighbouring depression (and the water level in the neighbour is lower then the water level in depression being considered), then water is distributed between the depression and its neighbour such that volume is conserved and water levels equalized.
- Post-processing phase. Finally, the post-processor projects final water levels for each depression on to the DTM to generate the flood maps.

There are a number of enhancements to this basic sequence which can bring in the effect of roughness and produce 'time slices' of outputs. Boundary conditions can include spatially distributed effective rainfall and dynamic links through to other modules in the ISIS suite (www.halcrow.com/isis).

An example of the use of rapid flood inundation models is in the identification of areas susceptible to surface water flooding (stormwater flooding). ISIS FAST has recently been used to provide the Scottish Environment Protection Agency, SEPA, with a 'first generation' surface water flooding map for Scotland (78,000km^2). The method used to generate the mapping is summarised in Figure 3 and essentially consists of four main calculation blocks:

- Preparation of the Digital Terrain Model
- Preparation of effective rainfall data for a range of rainfall probabilities
- Flood spreading using the ISIS FAST software
- Processing of results to identify 'at risk' areas

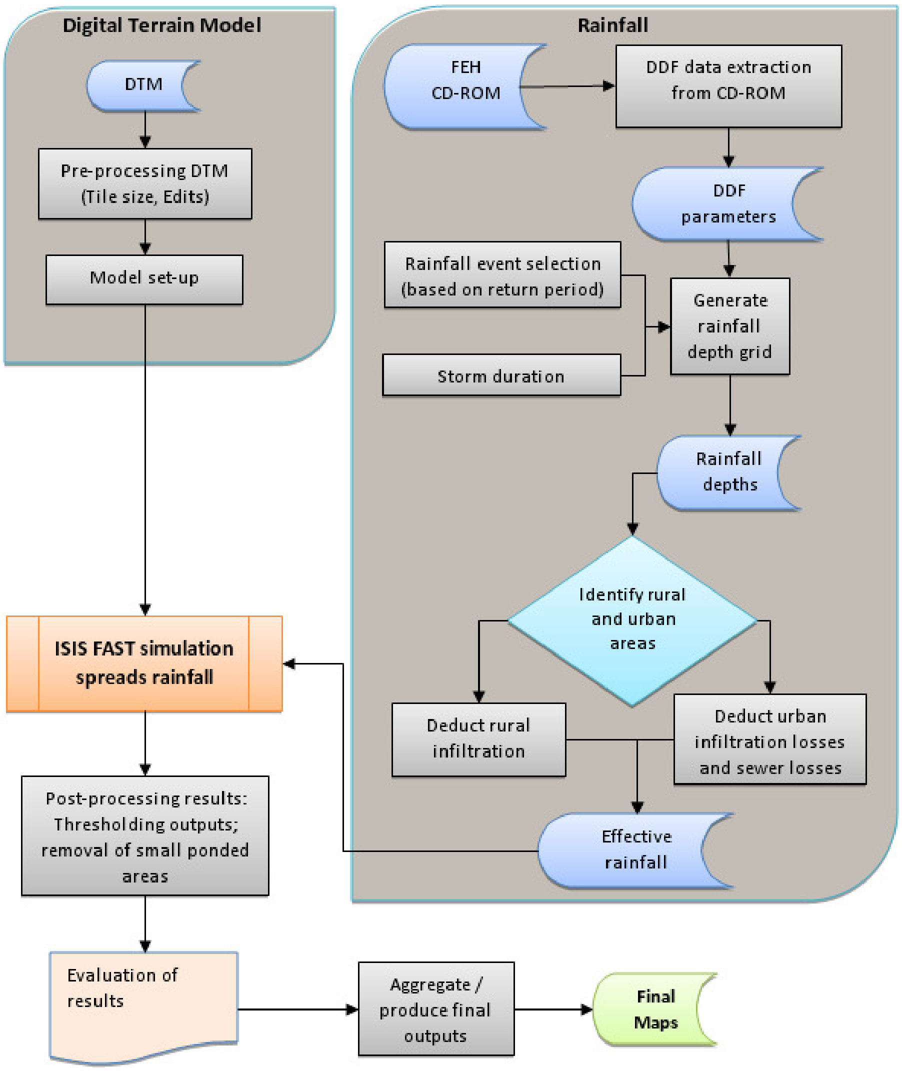


Figure 3 – Method used to generate national surface water flood mapping

For this national scale application significant assumptions were applied (e.g. representing the subsurface drainage capacity through use of standard loss of 12mm/hr in urban areas). The high computational efficiency of rapid flood inundation models make them suitable for this type of broad scale analysis, for example the whole of Scotland was simulated using some 4000 ISIS FAST models with the total simulation run time being under 48hours per rainfall scenario.

The results of the simulations were assessed using three approaches:

- Comparison with historical observed surface water flooding data
- Comparison with simulated results generated by other, more detailed, methods
- ‘Sensibility’ checks, for example to identify non-physical behaviour

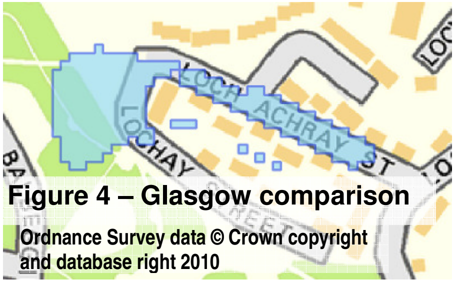


Figure 4 – Glasgow comparison

Ordnance Survey data © Crown copyright and database right 2010

Qualitative comparisons with available datasets identified some areas where there was good agreement and other areas with poor agreement. Figure 4 shows a street in Glasgow where predicted surface water flooding shows good agreement with the post event flood report data (which identified Loch Achray Street as having been subjected to extensive internal and external flooding). It was not appropriate to undertake quantitative comparisons due to lack of full data sets and differences in rainfall scenarios. The ‘sensibility’ checks at sample locations did not identify unphysical behaviour other than some locations associated with underlying issues with the DTM, a common issue with all surface water modelling methods.

The use of rapid flood inundation methods enables best use of nationally available data sets and is capable of being rapidly implemented over very large areas. Although significant assumptions must be made in the representation of some of the physical processes, the methods can provide satisfactory results in many situations, such as for identification of areas susceptible to surface water flooding influenced by topography at national and regional scales.

Decision-pathway approaches for communicating adaptation options

Decision pathways provide a very useful approach for helping to develop and communicate adaptive strategies for flood risk management. There is a range of ways to develop and represent decision pathways – Figure 5 show one approach taken from the Thames Estuary 2100 project. The figure shows five main options for improving the flood defence system for London and the Thames Estuary in response to a range of drivers including sea level rise. Each of the five ‘decision pathways’ uses different portfolios of responses which would be designed to provide protection against different levels of change in extreme sea levels.

Note that the horizontal axis is shown in terms of increase in extreme sea levels, rather than a timeline by decade, to allow the options to be shown independent of climate change scenario. One can overlay on the figure current knowledge of climate change scenarios, for example in 2008 the standard climate change allowance guidance would have been shown as a vertical line on the figure at 1m which would have been labelled as ‘2100 water level rise using standard Defra guidance’. More severe or less severe climate change scenarios could also have been shown on the figure as vertical lines to the right or left of the ‘standard Defra guidance’.

The aim of the figure is to show that there are a range of adaptation options (each made up of portfolios of interventions which would be sequenced over time) and that some will provide protection against the more extreme climate change scenarios (e.g. decision pathway 5) while others (such as decision pathway 1) are more limited. Where there are common elements in the pathways (such as ‘raise defences’) then these may be seen as preferential ‘no regrets’ interventions. This approach is consistent with the Defra (2006) guidance on adaptive decision making that seeks to identify solutions that are robust and adaptable in the face of uncertainty as they are considered to be inherently more sustainable than solutions whose effectiveness is constrained or strongly influenced by change.

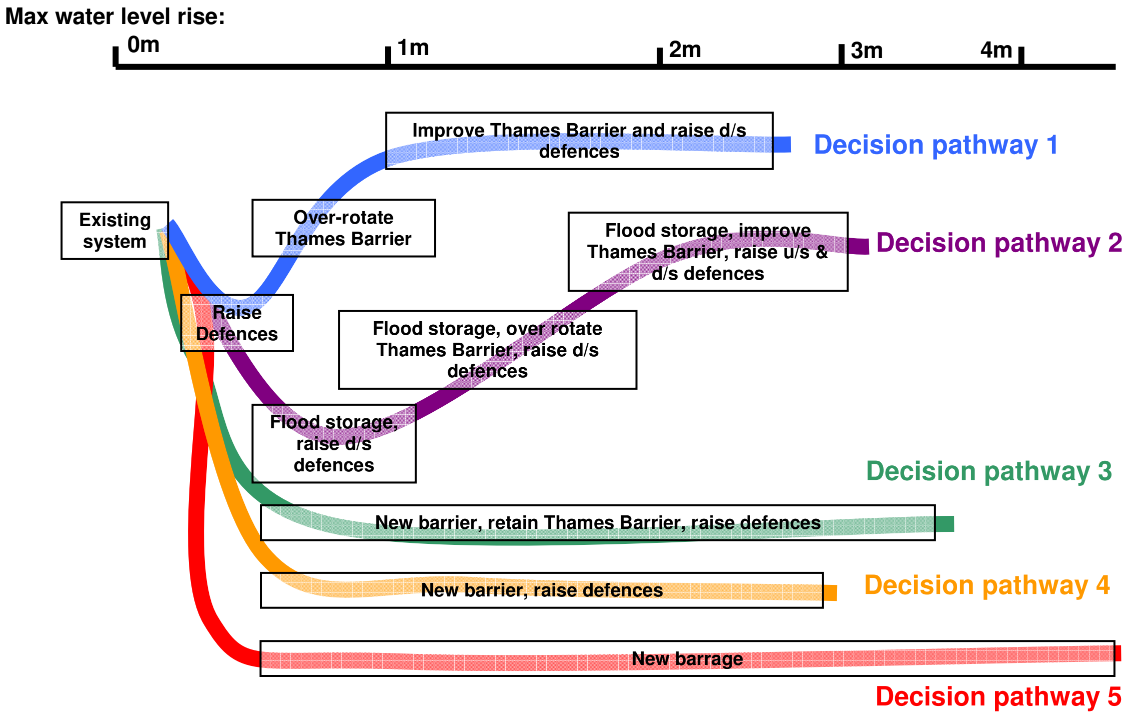


Figure 5 – Decision pathways to communicate adaptation options

Communicating uncertainty in flood extents

Traditionally flood maps show 'crisp' outlines of flood extents for historic or 'design' flood events. They usually do not provide end users with any local information on the implications, in terms of flood extent, of the often large uncertainties in the mapping. This may result in poor decision making. The reasons that may be stated for not communicating the local uncertainty in the flood mapping range from technical computational issues of modelling multiple (probabilistic) scenarios through to concerns on how users will be able to make 'binary' decisions when confronted with an 'uncertain flood map'. However, recent advances in methods and technology mean that many of the barriers to calculating and communicating local uncertainty in flood mapping are no longer valid.

Full probabilistic analysis using Monte Carlo type methods in which uncertainties are propagated through the calculation sequence can have very high computational demands, which for full 2D flood inundation solvers, may require many hundreds of simulations. Such approaches remain generally not feasible (although the rise of the graphics processing unit for numerical computing may resolve some of the issues). Use of simpler solvers (such as the rapid flood inundation methods discussed above) do make many hundreds of simulations practical, but introduce new uncertainties. Wicks et al (2008) introduced a method which required only two simulations to be able to estimate local uncertainties in flood extents. The method includes an approach where an additional single 'worst case' simulation is required (as well as the traditional best estimate) and an approach which uses a simple scoring method to assess local uncertainty with no requirements for an additional runs. The scoring method requires the analyst to score the uncertainties related to the hydrology, channel conveyance and overall hydraulic complexity and the method then combines these to provide local uncertainty values for water level. These 'vertical' uncertainties are then added to and subtracted from the best estimate local water levels and mapped to derived confidence lines for the flood mapping. Figure 6 shows an example where the uncertainty in local (horizontal) flood extent is communicated through the line style of the outline (e.g. low confidence in extent of greater than 40m is shown by a dotted line, where as high confidence, <20m, is shown using a solid line). This simple approach to communicating the horizontal uncertainty has selected for this application because it still allowed an uncluttered map to be produced, even when multiple flood extents are shown together.

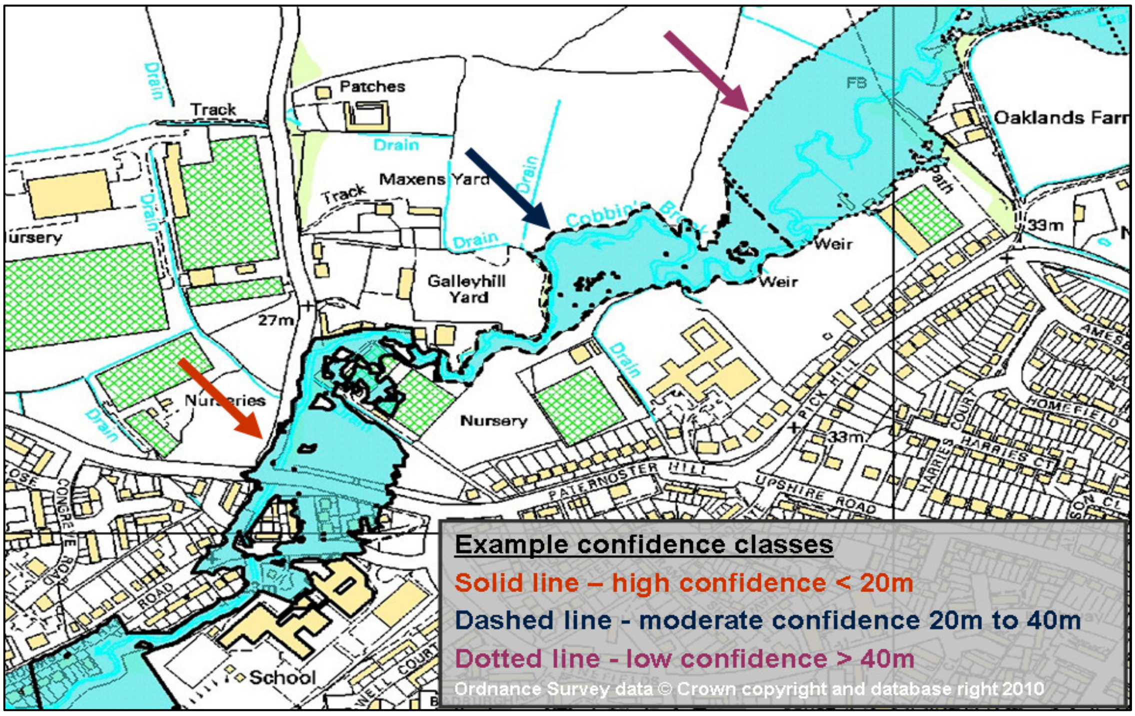


Figure 6 – Confidence in flood extent communicated via line style

Figure 7 provides a much more comprehensive communication of uncertainty in flood mapping. This interactive map allows users to select a design event, then move the 'slider' at the bottom to select a confidence level (shown as 50% in the figure). As the slider is moved the area shown as flooded extends and contracts. In addition, users can click at specific locations to see a small graph of the probability of the water depth exceeding a range of water depths at that location (example graph shown in the bottom right of Figure 7). In order to provide this level of detail, many hundreds of 2D model simulations had to be run.

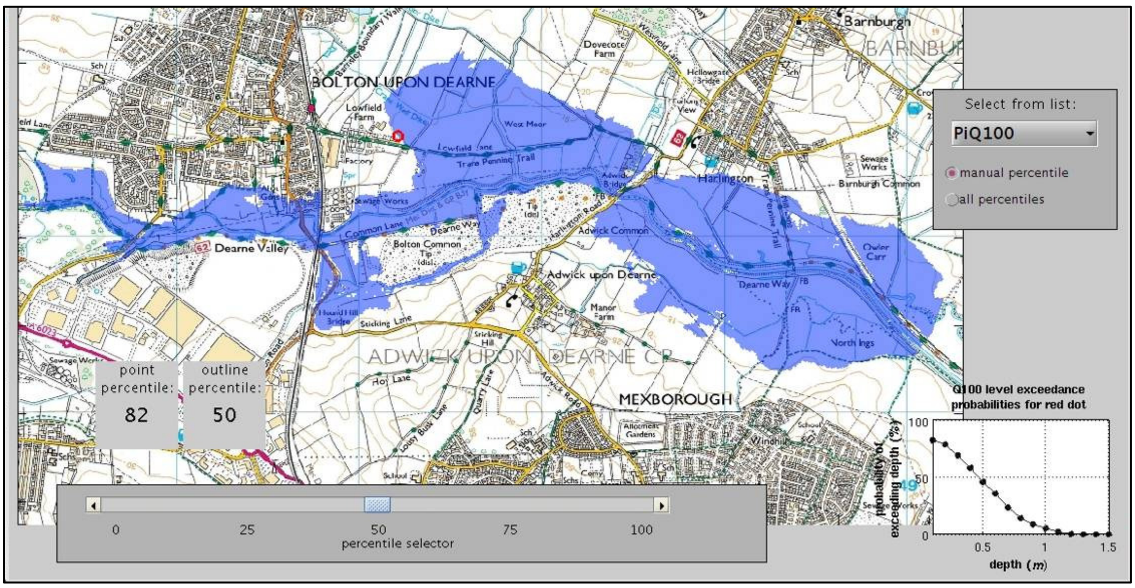
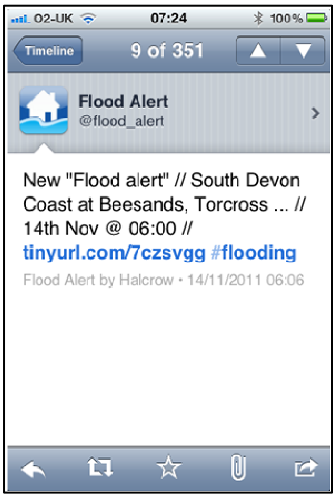


Figure 7 – Confidence in flood extent communicated via interactive slider

Social media tools



Social networks such as Twitter and Facebook are driving new forms of social interaction, dialogue, exchange and collaboration. They enable users to swap ideas, to post updates and comments, or to participate in activities and events. Social networking services are bringing users into fast-flowing online conversations – social media are also helping people to follow breaking news, keep up with friends or colleagues, contribute to online debates or learn from others. It is now one of the fastest ways to disseminate information and engage with communities.

Since social media are becoming more popular every day, organisations can no longer ignore them. The flood risk management sector in the UK is realising this and is actively engaging with social media audiences to help them prepare for flooding and to offer advice after a flood event.

Flood warnings are a form of 'breaking news'. Posting flood warnings to Twitter and Facebook extends their reach, providing another communication mechanism over the current traditional forms of communication. In turn, readers often forward messages to friends or colleagues, forming a pyramid approach to disseminating information. Twitter and Facebook accounts are often monitored by news agencies, providing a further method of gaining national and local press coverage.

There is also the potential for flood warning posts to be used in the aftermath of flood incidents. When people 'tweet' (the process of posting a message on Twitter) or post on Facebook, people describe what is happening where they are. Many people also attach photos and these often contain 'location' information which can pinpoint what happened in an area. This can be facilitated by the use of specific 'hash tags', creating groupings on social media networks.

The Environment Agency has a number of Twitter feeds where it posts updates about their business. In total, they run eight feeds: one national feed and seven feeds which serve regional areas. The national Environment Agency Twitter service has approximately 19,000 subscribers and their regional feeds around 1000 subscribers each. They currently post news about their business and are developing a social media plan to make further use of social media to engage its readers in issues related to flood risk.

Flood Group UK is a Facebook page which contains information to help its users prepare for and recover from a flood. It provides a forum where people can share experiences of flooding. It can be accessed via http://www.facebook.com/floodgroupuk. The page has been set up by the Environment Agency, Scottish Environment Protection Agency, National Flood Forum, Scottish Flood Forum, Rivers Agency of Northern Ireland and Cockermouth Flood Action Group to make flood risk management information more accessible following the summer 2007 events in the UK.

Another example of social media related initiatives is 'Know Your Flood Risk' which includes a website campaign to raise awareness of the issue of flood risk, and to provide guidance to all communities across the public and private sectors in educating homeowners and businesses. Its members aim to raise the profile of flooding and ensure consumers are not only aware of the risks they face, but also how to mitigate them. The website can be accessed via http://www.knowyourfloodrisk.co.uk.

Thus, in the UK there is growing awareness of the potential benefits for engaging with social media audiences, but much more needs to be done to actually realise these benefits.

Conclusions

Technological advances in recent years have underpinned important advances in flood modelling, mapping and incident management.

The Environment Agency has provided new ‘end to end’ detection, forecasting and warning systems such as the warnings delivered to customers via the Floodline Warnings Direct service. The Agency has also opened up access to flood risk data, including live data feeds. Suppliers have responded by developing new ways to ‘add value’ to the Agency data through, for example, the Flood Alert smart phone application.

Current warnings are largely based on predicted rainfall/surge and river/coastal water levels rather than predicted areas of flooding. Interactive tools such as FloodViewer are available to the Agency and some professional partners to visualise the potential flood extents (based on pre-calculated flood extents) but such interactive incident-focussed flood mapping is not widely used and is not available to the public. Rapid flood inundation models (such as ISIS FAST) may provide one approach for generating event-specific flood extent forecasts and the continued advances in computer processing power (including graphical processing units) will facilitate such on-the-fly predictions.

Irrespective of whether pre-calculated flood mapping or real time flood mapping is used, it is important that uncertainties in the mapping are understood and communicated to end users. There are a number of approaches for communicating the confidence in the mapping to end users - it is recommended that approaches are used that visualise the local impact of the uncertainty in a way appropriate for specific end user needs (rather than simple textual ‘disclaimers’). Similarly, it is recommended that visual representations (such as decision pathways) are used to help communicate the options that are available to respond uncertain futures.

The revolution in interaction and communication that social media provides is already with us. While there has been some progress in using social media to benefit flood risk management, much more needs to be done in the UK to make best use of these new communication channels (alongside more traditional channels).

Acknowledgments

The authors wish to thank their colleagues in Halcrow and the Environment Agency, in particularly Joe Clarke (Halcrow and Bristol University). Figure 7 is taken from Lancaster University outputs for the Flood Risk Management Research Consortium (www.floodrisk.org.uk).

References

Defra (2006) Flood and Coastal Defence Appraisal Guidance: FCDPAG3 Economic Appraisal: Supplementary Note to Operating Authorities – Climate Change Impacts.

Lhomme J., Sayers P., Gouldby B., Samuels P., Wills M. and Mulet-Marti J. (2008). “Recent development and application of a rapid flood spreading method”, River Flow 2008.

Liu Y, Neélz S. and Pender G. (2009). “Improving the Performance of Fast Inundation Models Using v-Support Vector Regression and Particle Swarm Optimisation”, The 33rd IAHR 2009 Congress, 2009, pp. 1436-1443.

Pitt M, (2008) ‘The Pitt Review - Learning lessons from the 2007 floods’, The Cabinet Office of the UK Government.

Rhodes F. (2011) “Flood Warning for Infrastructure: Tailored Flood Warning Services”, 5th International Conference on Flood Management (ICFM5), September 2011, Tsukuba, Japan

Wicks JM, Horritt M, Adamson M (2008) Communicating uncertainty in flood maps – a practical approach’, Environment Agency FCM 08 Conference, Manchester 2008.

Wicks JM, Lardet P, Shaad K (2011) ‘Developing a National Surface Water Flood Map for Scotland’, CIWEM WaPUG Spring Conference, Birmingham, 18 May 2011.