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# Surface water flood forecasting for urban communities: A Review

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## Summary and recommendations

The CREW project "Surface water flood forecasting for urban communities" aims to assist SEPA in increasing its surface water flood forecasting capabilities. Two detailed review reports have been produced. The first report (Golding et al., 2013) reviews recent advances in rainfall estimation and forecasting techniques with a view to identifying the best rainfall data for surface water flood forecasting. The second report (Ghimire et al., 2013) reviews current surface water flood modelling techniques commonly used in the UK with a focus on their potential application for real-time forecasting in urban communities. These reviews are informing the next stage of the project which aims to run a real-time pilot system for surface water flood forecasting during the Glasgow Commonwealth Games 2014.

An overview of the planned activities resulting from the review process follows. The Grid-to-Grid (G2G) model will be applied to the Commonwealth Games pilot study, supported by further studies that are being undertaken through the Natural Hazard Partnership Surface Water Flooding initiative. Exploratory work will also be undertaken in the next project phase to link outputs from complex surface water flooding models to G2G to better resolve the real-time G2G surface water runoff forecasts. The G2G model will be run with rainfall inputs from the blended precipitation ensemble forecast, combining the 2km STEPS radar extrapolation forecast with the MOGREPS-UK 2.2km Numerical Weather Prediction model forecast. How to best present and communicate to responders the risks and impacts of surface water flooding, and that reflect spatial uncertainty in the forecast rainfall, will be investigated. The resulting guidance on surface water flooding aims to support practical decision-making during the Glasgow Commonwealth Games 2014.

A summary of the main points from the reviews is given below.

**Surface Water Flood Modelling**

- The elements of a forecasting system for surface water flooding from intense rainfall are the modelling of surface runoff production, surface water inundation and movement, and any dependence on water transfers via surface and sub-surface pathways including urban sewerage and drainage networks.
- For detailed modelling of surface flow pathways, the primary requirement is an accurate treatment of the surface topography, particularly the presence of roads, buildings, bridges, walls etc. This requires a high degree of spatial detail, and significant uncertainty derives from different data sources (e.g. resolution and accuracy) and model representations of these features.
- Detailed modelling of sewer systems requires precise knowledge of the network and pipe capacities.
- For planning purposes, surface water flood maps have been constructed, using a combination of modelling and historical evidence, for specific design rainfall scenarios. Accuracy of these maps depends on simplifying assumptions of the modelling approach used (e.g. space resolution) and the quality and resolution of supporting datasets (e.g. digital terrain models). Run-times of the most detailed models are currently prohibitive for real-time use.
- Simplified surface water flood modelling approaches have been proposed for real-time use, but no operational system has been implemented anywhere to enable assessment of their value.

Apart from the computation cost, an operational forecasting system requires regular model initialisation, preferably by continuous running with data assimilation, and be capable of running forecast ensembles.

- Managing surface water flooding risk in real-time can benefit from information on the likelihood of water depth and/or velocity exceeding specified thresholds as a function of time and space. Ideally lead times of 6-12 hours or longer are required along with knowledge of the detail of flooding to within an hour and the scale of a block of properties in a specific street. However information up to the scale of a few kilometres and a few hours ahead can still be of real value in mitigating surface water flooding impacts.

**Current Inputs to Surface Water Flood Forecasting**

- Current real-time forecasting of surface water flooding is based on rainfall threshold exceedance, coupled with use of the fixed planning maps of surface water flooding. Accuracy of real-time surface water flood forecasts is constrained by rainfall forecast accuracy. Beyond six hours ahead, Numerical Weather Prediction (NWP) provides the most accurate forecasts of rain-rate. Following recent implementation of the United Kingdom Variable grid (UKV) model with a 1.5km grid, NWP is often very skilful at predicting maximum rainfall accumulations. However, the timing and location are subject to substantial uncertainty (typically one hour and 25km respectively).
- The remaining forecast uncertainty, particularly in the location and timing of convective rainfall, makes it necessary to always base management decisions on probabilistic rainfall forecasts.
- At very short lead times, the Short Term Ensemble Prediction System (STEPS) nowcast provides useful radar-rainfall extrapolation ensemble forecasts, blended with the deterministic UKV model up to six hours ahead.
- At longer lead times, ensemble NWP is the preferred forecasting approach. The existing Met Office Global & Regional Ensemble Prediction System – Regional (MOGREPS-R) 12km grid ensemble has recently been replaced by the Met Office Global & Regional Ensemble Prediction System – United Kingdom (MOGREPS-UK) 2.2km ensemble, which was trialled in 2012. Substantially improved results have been obtained. The information from this ensemble is now being delivered to SEPA as part of the MOGREPS-R replacement, albeit at reduced resolution.
- Initialisation, calibration and verification of forecasting systems depend on good quality rainfall observations. Currently significant parts of Scotland are under-observed, due to sparseness of the real-time reporting raingauge network, distance from a weather radar and other factors influencing radar's ability to estimate ground-level rainfall, and the hilly and remote nature of the terrain that makes extensive ground monitoring difficult.

**Current advances in rainfall observations**

- Improvements to rainfall observation across Scotland will be enabled by work in progress to increase the use of real-time polling of SEPA's tipping bucket raingauge network and to complete the UK radar network upgrade. Further work is required to optimise the use of the new radar technology, particular its dual polarisation capability, and to combine raingauge and radar observations more effectively.

**Current advances in rainfall forecasts**

- A blended precipitation ensemble forecast will be introduced in October 2013, combining the 2km STEPS extrapolation forecasts with the MOGREPS-UK 2.2km forecasts. This will provide the best probabilistic forecast up to 36 hours ahead on a 2km grid.
- An hourly precipitation forecast using an enhanced data assimilation method will be implemented at the Met Office in 2015/6. Based on experience for a small area of Southern England in 2012, it is anticipated that this will provide a further improvement in rainfall forecast accuracy. However, spatial uncertainty will still exceed 10km and ensemble processing will remain a key part of the forecasting chain.

**Surface Water Flood forecasts using an inundation model**

- Developing real-time flood forecasting for operational use means that model run-time should be short enough to allow the production of longer lead-time ensemble forecasts required to facilitate effective mitigation actions. Because of this, detailed flood modelling combining both surface runoff and the underground sewerage network system - which demand longer run times - will not prove feasible. Instead, an estimate of the sewer capacity is required to be made to take into account the amount of flow that is expected to enter the sewerage network during extreme events. Even then, 2-D hydraulic modelling of surface water flooding remains infeasible to meet the real-time forecast run-time requirements at the present time. Although advances in computing are expected to make this possible in the future, the sustained investment required to support a robust and verified operational system should not be underestimated.
- A further consideration for real-time application is the need for continuous running of a model, involving maintaining model states (e.g. antecedent conditions of water volumes) across all time-steps up to the time the forecast is made. Not all inundation models originally implemented for design and planning are well suited in this respect for real-time application, and may require considerable development and restructuring of the software. Also, their inputs may relate to an "effective rainfall" design storm profile and may not include an explicit space-time representation of runoff production and water loss accounting. As a result, areas of inundation are not necessarily drained and fully evacuated in the aftermath of a surface water flooding episode, remaining inundated indefinitely.
- The above considerations indicate that real-time surface water flood inundation modelling is still in a research phase and not suitable for development and use in the Commonwealth Games 2014 Pilot. Of the candidate surface water inundation models reviewed, only ISIS-FAST is identified as fast enough to run in real-time but will not be considered for use in the pilot as it requires significant further development, testing and verification for use as an operational tool. However, the future real-time use of ISIS-FAST will be explored within the Pilot through off-line trials using G2G surface runoff as its "effective rainfall" input. This work will aim to guide

possible future investment in making ISIS-FAST operational as a practical way of obtaining more detailed information on surface water flooding in real-time.

**Surface water flood forecasts**

- Real-time surface runoff forecasts can be provided by the Centre for Ecology & Hydrology's (CEH's) Grid-To-Grid (G2G) distributed hydrological model. G2G is currently used operationally in real-time across Scotland by the Scottish Flood Forecasting Service with a focus on providing guidance on fluvial flooding over the next few days. Surface runoff in the model is routed through the river network to obtain fluvial flood forecasts and also is available to be configured as an output to support forecasting of surface water flooding.
- Existing approaches for real-time surface water flooding alerts are based on rainfall threshold exceedance methods which identify in map form areas at risk. G2G offers a potential advance on such approaches, through bringing in dependence on surface cover, soil properties and antecedent wetness condition.
- Under the Natural Hazard Partnership Surface Water Flooding initiative, a case study has pointed to the potential value of G2G for surface water flooding alerts and further studies are ongoing. It is therefore recommended that the model be applied to the Commonwealth Games Pilot and be guided by these additional ongoing case study investigations.
- In contrast to G2G, the more detailed hydraulic model JFlow+ has been applied for planning and design purposes under the Glasgow Pluvial Flood Mapping (GPFM) project and under the Regional Pluvial Flood Hazard (RPFH) project. An outcome of these projects are datasets on surface water flooding providing detailed information on flooding associated with design storms of varying severity/rarity. It is recommended that exploratory work is done in the next project phase on linking these off-line datasets with G2G to better resolve the real-time G2G surface water runoff forecasts.
- Scoping study work is underway between CEH and SEPA on combining the G2G flooding hazard footprint with impact datasets; related work is also ongoing between CEH and the Health and Safety Laboratory under the Natural Hazard Partnership. It is recommended that the outcome of this work should be pulled through to this CREW project (where possible) so as to produce surface water hazard impact maps of practical relevance to decision-making during the Commonwealth Games.
- Further work is required to determine how best to present the surface water flooding forecasts and any impact information within FEWS Scotland, and communicate to responders, particularly bearing in mind the spatial uncertainty in the input rainfall data.
- In order to provide an adequate estimate of the probability of flooding, it will be necessary to run the G2G model with rainfall inputs from the blended ensemble members. If necessary for efficiency purposes, a dedicated small domain version of G2G should be run for just the Glasgow area. This should not have any undesirable impact, given that the collection area for surface water floods is usually very small.

## References

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