Natural Hazards Partnership
Surface Water Flooding Hazard Impact Model: Phase 2

D2.4: Learning from Glasgow 2014 Commonwealth Games SWF trial

1 Introduction

The Scottish Government, through the Centre for Expertise in Water (CREW), commissioned an innovative pilot project to improve surface water flood forecasting in urban areas. A novel real-time system for forecasting surface water flooding and its potential impact was implemented as a trial over Glasgow during the 2014 Commonwealth Games. It was delivered by a research collaboration between the Centre for Ecology & Hydrology (CEH), Met Office, James Hutton Institute, SEPA and Deltares.

The Glasgow Pilot was operated by the Scottish Flood Forecasting Service (a joint initiative between SEPA and the Met Office) during June to August 2014 over a 10km by 10km domain. This covered the main areas of activity of the Games including Glasgow's East End, an area previously affected by major flooding in July 2002.

The Glasgow Pilot built upon some of the early NHP SWF HIM work so there are some synergies in approach: such as linking G2G Surface Runoff accumulations with the design storm effective rainfalls used in the creation of detailed off-line surface water flood maps.

As part of the NHP SWF HIM Phase 2 work, deliverable D2.4 required CEH to report on learning from the Glasgow 2014 Commonwealth Games SWF trial. This has largely been achieved through ongoing communication with the project partners and sharing of the project outputs which has influenced Phase 2 plans (e.g. visualisation within WP5). The CREW reports (Moore *et al*., 2015a,b) on the trial of the G2G Surface Water Flooding tool for the Glasgow 2014 Commonwealth Games can be found on the CREW website here. Additional to the published reports, CEH have shared information on the mathematical algorithms used to derive some of the Glasgow Pilot outputs: these are included here as Appendix A.

Beyond the information communicated above, this note serves to give a brief summary of the similarities and differences between the Glasgow Pilot and NHP SWF HIM and of the main operational feedback from the Glasgow Pilot.

2 Comparison of the Glasgow SWF Pilot and NHP SWF HIM approaches

A summary of the similarities and differences between the Glasgow SWF Pilot and the NHP SWF HIM approaches are outlined below in tabular form.

Glasgow SWF Pilot **Moore *et al. (*2015a)**	**NHP SWF HIM** **Aldridge & Gorce (2014), Cole *et al*. (2015)**
Platform	
Historical G2G: Delft-FEWS (National)	*Historical G2G*: NFFS-FFC (Delft-FEWS)
Forecast G2G: Delft-FEWS (Glasgow)	*Forecast G2G*: Met Office HPC
Impact calculations: Delft-FEWS (Glasgow)	*Impact calculations*: Met Office IT system (not HPC)
Impact visualisation: Delft-FEWS (Glasgow) real-time web reports of SWF impact	*Impact visualisation*: Met Office Visual Weather
Detailed off-line Surface Water Maps	
Product: Regional Pluvial Flood Hazard (RPFH) maps	*Product*: uFMfSW (updated Flood Map for Surface Water) Environment Agency (2013)
Model: JFlow+ over Glasgow study (JBA Consulting & Mott MacDonald, 2013)	*Model*: JFlow+
Design storms: 14 combinations of 2 durations (1 and 3 hours) and 7 rainfall scenarios (10, 30, 50, 100 and 200 years plus 30 year + 20% and 200 year + 20%)	*Design storms*: 9 combinations of 3 durations (1, 3 and 6 hours) and 3 rainfall probabilities (30, 100 and 1,000 years)
Rainfall calculation: 5 by 5km tiles using the FEH estimates for the centroid of the tile.	*Rainfall calculation*: 5 by 5km tiles using the FEH estimates for the centroid of the tile.
Urban/rural split: calculated at 2m resolution of JFlow+ using Land Cover Map 2007.	*Urban/rural split*: 250m resolution. If OS MasterMap >50% man-made then urban.
Urban runoff: 70% runoff coefficient. 50% FEH/FSR summer storm temporal profile. Constant drainage equal to 5 year return period rainfall.	*Urban runoff*: 70% runoff coefficient. 50% FEH/FSR summer storm temporal profile. Constant drainage of 12 mm/hr used unless known as high capacity (20 mm/hr) or low capacity (6mm/hr)
Rural runoff: 55% runoff coefficient.	*Rural runoff:* Revitalised Flood Hydrograph (ReFH) method applied on 1km grid.
Impact library: Flood outline	
SEPA generated flood outlines for each return period (using 3-hr duration only) based on depths > 0.1m.	The current approach uses one flood outline for each return period that is based on the maximum Hazard rating from the three durations (e.g. any pixel where the hazard rating is greater than 0.575 for at least one of the durations). The “Maximum Outputs” grids store, for a given return period, the worst case for each output (depth, velocity, hazard) over all durations and the critical storm duration is stored for each pixel.

Impact Library: offline impact assessment per receptor/impact criteria Simple static assessment made by SEPA using flood outline for existing datasets on 6 receptors: 1. Population (number of properties affected per 1km pixel: e.g. 1 to 50, 51 to 100) 2. Community Services (point locations) 3. Utilities (point locations) 4. Commercial Properties (point locations) 5. Railway (lines of affected railway) 6. Roads (lines of affected roads) Then used impact criteria from the Flood Risk Matrix to assign rules as to when each receptor reached Minor, Significant, Severe at a 1km level.	The impact criteria from the Flood Risk Matrix methodology directly used to derive offline impact assessments from uFMfSW outline and depth, hazard, velocity datasets together with receptor datasets (National Population Database, National Receptors Database). Five key impact criteria: Danger to life Damage to buildings Disruption of key sites and information Disruption of transport Disruption of communities For each impact criteria, derived set of rules as to when each receptor reached Minor, Significant, Severe at a 1km level.
Impact Library: 1km offline impact assessment For each receptor and impact severity (Minor, Significant, Severe), the "minimum effective rainfall" could be calculated from the 7 design storms, i.e. the minimum effective rainfall needed to generate that level of impact. These could be pooled over receptors, e.g. receptors 1 to 4 were grouped as "People and Property' and Railway and Roads grouped as 'Transport'. The 6 "minimum effective rainfall" grids calculated were: People and Property x 3 (minor, significant, severe), railways, roads and combined railways and roads (transport). So for each grid, the impact level is the same but the effective rainfall threshold (and associated design storm) can vary in space.	Three 1km impact grids produced, one for each return period, which stored the maximum impact level across all criteria. So, for each grid, the impact level can vary with space.
Impact Library: gridded impact forecasts Outputs for the whole forecast period or sub-period possible. Grids of maximum 3-hr G2G surface runoffs calculated for each period and ensemble member. An example of the real-time web reports is given in Figure 1. *Probabilistic outputs* The probability of 3-hr G2G surface runoffs exceeding the 6 "minimum effective rainfall" grids could be displayed and coloured according to Flood Risk Matrix. Also 3-hr maximum rainfall and G2G Surface Runoff totals could be compared against static thresholds (e.g. 20mm for rain, 13.5 or 16mm for G2G Surface Runoff) *Combined Risk output* Contained the highest risk for each pixel.	*Deterministic outputs for each ensemble member* Based on Fig. 4.2 of Aldridge & Gorce (2014). 1. Grids of maximum 3-hr G2G surface runoffs calculated for each time period and assigned a return period based on which 3-hr uFMfSW rainfall threshold is crossed (30, 100, 1000-yr) 2. Converted to impact using Impact Library. *Probabilistic outputs* Gridded maps of the probability of maximum 3-hr G2G Surface Runoff totals exceeding the uFMfSW thresholds were provided and 3-hr rainfall exceeding 30 or 40 mm.

Impact Library: regional summary Not calculated as only one 10 by 10km area studied.	Methodologies for creating regional summaries derived (Equations 3.1 and 3.2). Note important to summarise regional impact per ensemble member before assessing probabilities (and risk) across ensemble members. Once an ensemble of regional *impact* summaries were calculated, regional *risk* forecasts could be made, aligned to the Flood Risk Matrix. Phase 2 will further develop these.
Other G2G Surface Runoff outputs The gridded outputs show collated information across all ensemble members. To give some insight into the ensemble spread, a surface runoff time-series display was produced showing the maximum 3-hr surface runoff accumulation in any grid-cell for each ensemble member over each time-step of the whole forecast. These plots include the surface runoff accumulation thresholds of 13.5 and 16mm used in the gridded outputs as a reference.	Methods of visualising the ensemble spread wasn't included in the proof-of-concept SWF HIM but could be considered in the future.
Spatial domain Glasgow trial was over a 10 by 10km area.	Large regions encompassing several counties/authorities.
Real-time trial Real-time trial operated during the Glasgow 2014 Commonwealth Games.	Phase 2.

3 Operational feedback from the Glasgow Pilot during the Commonwealth Games

A major strength of the Glasgow Pilot is that it ran as a real-time trial during a high-profile event. This ensured wide stakeholder and responder community engagement and meant that outputs were really used in earnest. As such, the Glasgow Pilot provided a wealth of valuable feedback on operational use rather than offline studies.

Section 3.6 of Moore *et al.* (2015a) gives details of how the G2G-based SWF impact forecasts were used within the operational procedures and timelines of the Glasgow 2014 Multi Agency Control Centre. Although rigorous verification of the Glasgow Pilot's probabilistic impact outputs were not possible, the general feedback from users is that the system performed well and was useful. Further information, including a summary of performance during 3 events, is given in Moore *et al.* (2015a). This gives further support to the approach being followed within the NHP SWF HIM.

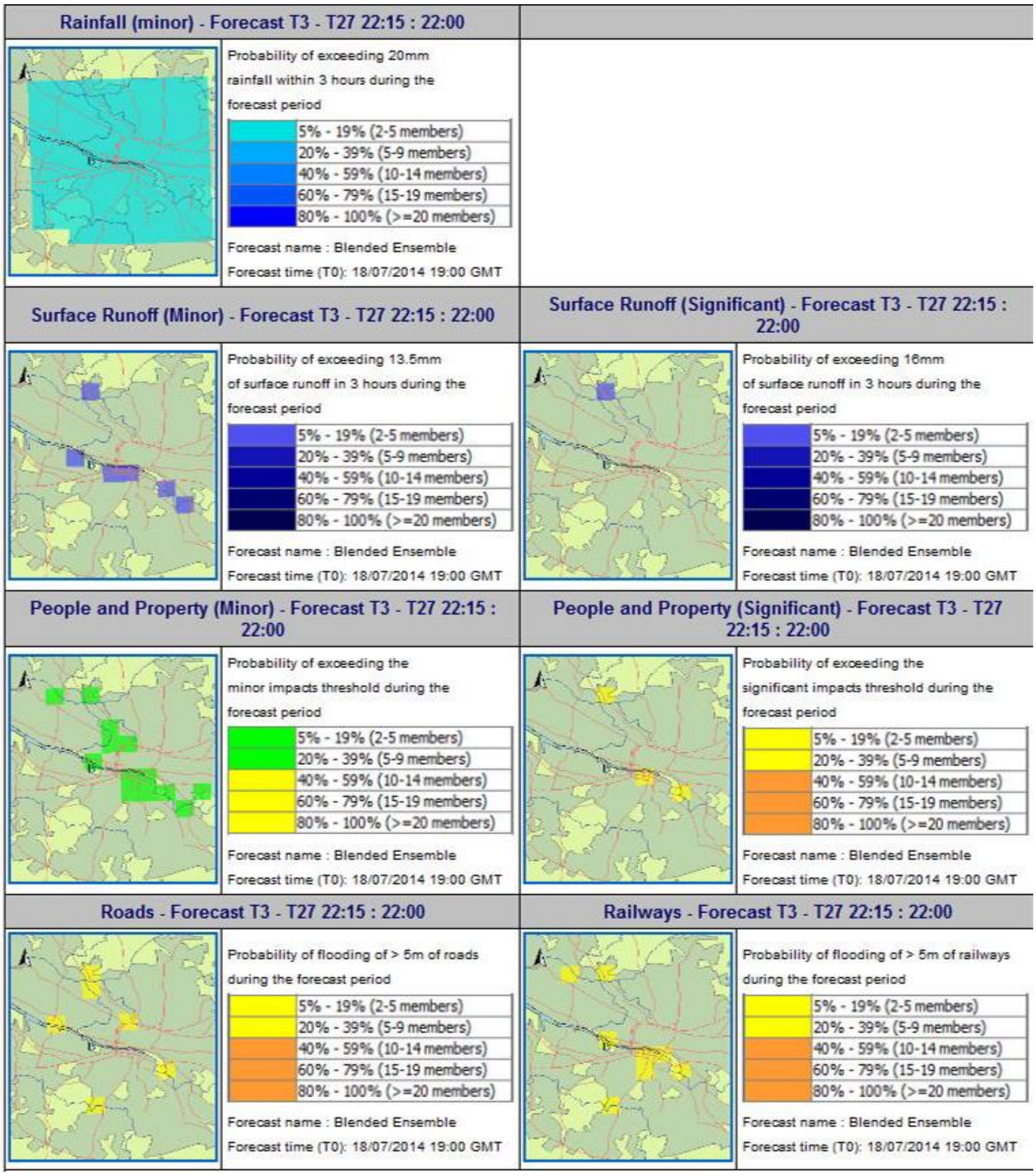

Figure 1 FEWS Glasgow 24 hour Summary using the blended ensemble forecast from 19:00 18 July 2014.

References

Aldridge, T. and Gorce, J.-P. (2014) Surface Water Flooding: Hazard Impact Model Research. Technical Report MSU2014/14 for the Flood Forecasting Centre, Research Contractor: Health & Safety Laboratory, 43pp + appendices.

Cole, S.J., Moore, R.J. and Mattingley, P.S. (2015). Surface Water Flooding Component for NHP HIM: Phase 1 Report. Contract report to the Environment Agency. Research Contractor: CEH Wallingford, Environment Agency, Bristol, UK, 55pp.

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Moore, R.J., Cole, S.J., Dunn, S., Ghimire, S., Golding, B.W., Pierce, C.E., Roberts, N.M. and Speight, L. (2015a). Surface water flood forecasting for urban communities, CREW report CRW2012_03, CREW, 32pp.

Moore, R.J., Cole, S.J., Dunn, S., Ghimire, S., Golding, B.W., Pierce, C.E., Roberts, N.M. and Speight, L. (2015b). Surface water flood forecasting for urban communities: Research Summary, CREW report CRW2012_03, CREW, 2pp.

Appendix A: FEWS Glasgow post-processing calculations

Below is a copy of a note describing the post-processing impact visualisation algorithms used within the Glasgow Pilot. These algorithms underpinned the FEWS (Flood Early Warning System) Glasgow web reports used during the trial.

1. Surface Runoff thresholds

The following describes the process for a given grid cell.

1. Surface Runoff, $S_{i,j}$, in 15-min time-steps is generated from G2G model for ensemble member i, where j is the time-step in hours.
2. Accumulate surface runoff, $\tilde{S}_{i,j}$, to form a 15-min sequence of 3-hr surface runoff values for each ensemble member. Thus

$$\begin{aligned}
&\tilde{S}_{1,t+3} = S_{1,t+.25} + S_{1,t+.5} + \ldots + S_{1,t+3} \\
&\tilde{S}_{1,t+3.25} = S_{1,t+.5} + S_{1,t+.75} + \ldots + S_{1,t+3.25} \\
&\vdots \\
&\tilde{S}_{1,t+27} = S_{1,t+21.25} + S_{1,t+21.5} + \ldots + S_{1,t+27}\,.
\end{aligned}$$

3. Then for each of the 5 forecast horizons *t*+3 to *t*+9, *t*+9.25 to *t*+15, *t*+15.25 to *t*+21, *t*+21.25 to *t* + 27 and the whole forecast *t* + 3 to *t* + 27, and each ensemble member i, calculate a threshold crossing indicator $I_{i,(t_1,t_2)}$ which takes a value of 1 if the sequence of 3-hr accumulated runoff values ($\tilde{S}_{i,j}$) cross the threshold, x, at some point during the window or zero otherwise. Thus

$$I_{i,(t_1,t_2)} = \begin{cases} 1 & \text{if } S_{i,j} \geq x \text{ for some } j \in [t_1, t_2] \\ 0 & \text{otherwise} \end{cases}.$$

4. Once calculated for all n ensemble members, the probability of (reaching or) exceeding the threshold x for forecast window (t_1, t_2) is given by

$$\text{Prob}\left(\tilde{S}_{i,j} \geq x, \text{ for } i \in [1,n] \text{ and } j \in [t_1, t_2]\right) = \frac{1}{n}\sum_{i=1}^{n} I_{i,(t_1,t_2)}\,.$$

This method gives the probability of (reaching or) exceeding x mm of surface runoff in 3 hours at any time during the reported forecast horizon and can be calculated on a pixel by pixel basis. This method also ensures threshold exceedances are not lost between the forecast-horizon windows.

The threshold x is 13.5 mm for the low threshold and 16 mm for the high threshold.

2. People and property impact thresholds

The “People and Property” impact probabilities are calculated exactly the same as for surface runoff except that x is a gridded set of surface runoff threshold values which will vary for each grid cell. CEH supplied three sets of grids for the minor, significant and severe impact thresholds.

The “Overall People and Property” impacts grid for the whole forecast is assigned a colour-coding as follows:

If P(QS > x_{severe}) > 60% = red
Else If P(QS > x_{severe}) < 60% AND > 40 % = amber
Else If P(QS > $x_{significant}$) > 40 % = amber
Else If P(QS > x_{severe}) < 40% AND > 5% = yellow
Else If P(QS > $x_{significant}$) < 40% AND > 5% = yellow
Else If P(QS > x_{minor}) > 40% = yellow
Else If P(QS > x_{minor}) < 40% AND > 5% = green
Else no colour

Here QS denotes the 3-hr accumulated surface runoff.

[Note the 5% threshold means that 2 members of the 24 member ensemble would need to be above the threshold to colour-up the risk.]

3. Transport impact thresholds

The impact probabilities are calculated exactly the same as for surface runoff except that x is another gridded set of surface runoff threshold values which will vary for each grid cell. CEH supplied three sets of grids for the roads, railways and combined thresholds.

4. Maximum surface runoff time-series

This is not a gridded output. Each line on the plot relates to a single ensemble member and is a time-series of the maximum value of the 3-hr accumulated surface runoff (*QS*) at any point over the model domain e.g. (Max(Qs_{t+3}), Max($Qs_{t+3.25}$), Max($Qs_{t+3.5}$), Max($Qs_{t+3.75}$),…, Max($Qs_{t+26.5}$), Max($Qs_{t+26.75}$), Max(Qs_{t+27}).

SEPA and CEH
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