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Introduction

The Met Office led development of a real-time end-to-end trial Surface Water Flooding (SWF) Hazard Impact Model (HIM) system that operates within Met Office infrastructure. The Flood Forecasting Centre (FFC) consulted with the project team to create a Visualisation Specification document (FFC, 2015b) that captured the user requirements and informed the subsequent implementation.

The system has been designed to be compatible with the emerging Hazard Impact Framework (HIF) specification, an initiative of the Natural Hazards Partnership (NHP). The HIF envisions a future Hazard Impact Production System (HIPS) composed of loosely coupled components (primarily impact models and user interfaces) communicating via Web Services conforming to Open Geospatial Consortium (OGC) standards. Standardising around interfaces gives great latitude to those building HIMs to select appropriate hardware, software and internal data formats. OGC standards are supported by a range of client software applications and programming libraries, giving flexibility in selection / customisation of the user interface. The HIF approach will make it possible to easily add or upgrade any given component of the HIPS without major impacts on the rest.

During the development, User Acceptance Testing of the web services and the front-end visualisation system was undertaken by FFC. Detailed Quality Assurance by Met Office, Health and Safety Laboratory (HSL) and the Centre for Ecology & Hydrology (CEH) was undertaken using historical case study data to ensure the real-time SWF HIM trial system outputs matched the off-line CEH/HSL analysis. Real-time SWF HIM outputs have been available via the Visual Weather desktop software since April 2016 and these are supporting an ongoing operational trial by FFC users.

System overview

Figure 1 below gives an overview of the SWFHIM trial system. The system is spread across three hardware platforms: the Met Office supercomputer (HPC: High Performance Computer), a virtual server (which was the focus of most of the development effort in this work package) and a number of desktop PCs. On the HPC, G2G software (authored by CEH) models the distribution of surface runoff on the basis of a 24-member ensemble of rainfall forecasts. Data on predicted runoff and rainfall patterns is passed to the server where it is processed further.
The key tasks undertaken on the server are:

- **Impact scenario selection**: on a 1km grid basis, runoff totals are compared with threshold figures to determine which (if any) modelled impact scenario is likely to occur.

- **Detailed impact determination**: impact scores appropriate to the scenario are retrieved from the pre-calculated Impact Library for each 1km grid square.

- **Area impact summation**: 1km grid square results are grouped across administrative areas (mostly counties) and a summary impact rating for each individual area is calculated.

- **Generation and publication of cartographic and graphical outputs**: outputs (in image and text file formats) are created and then published (via GeoServer software) in accordance with the Visualisation Specification.

**Figure 1**: Overview of the SWFHIM end-to-end trial system
There are two parallel implementations of the trial system: one processing very short range “nowcast” data every hour, the other short range forecast data every six hours. Each publishes more than 60 web services on each run. The outputs can be broadly categorised as follows:

- Probabilistic mapping of rainfall and runoff:
  o 1km grids showing the likelihood of these phenomena exceeding various threshold levels.
  o County level maps summarising the gridded data.

- Maximum runoff time series graphs: presented at a county level. This is the only output in which individual ensemble member data is portrayed.

- Probabilistic mapping of impacts: 1km grids showing the likelihood of different levels of impact (Minimal, Minor, Significant and Severe) upon:
  o Population
  o Property
  o Transport
  o Key Infrastructure

  Plus a summary (maximum impact across all categories) layer.

- Mapping of maximum impact: utilises the five (four plus summary) categories used for probabilistic impact mapping. 1km grids showing highest impact modelled for each square.

- County level impact verdict map and probability tables. County verdicts (Minimal, Minor, Significant and Severe impacts, plus a default “None” option) are determined by comparing the number of grid squares in each impact category with an area-specific threshold. The map displays the most severe verdict reached, with a pop-up table giving a probabilistic view of verdicts across the ensemble.

The final element of the system is client software on the users’ desktop PCs. For the trial period, FFC have selected Visual Weather as the main client software, taking advantage of its familiarity for users. Due to a minor shortcoming in the way Visual Weather interacts with OGC web services, a workaround has been implemented so the time series graphs are viewed via a web page, as are the system’s status messages. Configuration of Visual Weather was led by FFC, with web services organised into page views that fit the Centre’s workflows.
Server processes

As noted above, in this work package the bulk of the effort has been expended on the data processing and output publication code running on the server. Figures 2 and 3 give an overview of the work done by this code. Data is processed on a per-member basis, with results sorted in “tallies” until the entire ensemble has been processed, at which point output products are produced (Figure 2).

**Figure 2: Server based data processing routine.**

At the ensemble member level, the processing is organised around the nine (3 storm duration * 3 return period) scenarios considered. The code loops through the durations (outer loop) and return periods (inner loop) performing accumulation and thresholding operations. For the 1-hour storm duration additional steps are performed to produce an impact forecast. Figure 3 describes the process for runoff and impact outputs associated with this storm duration: for other durations (and
rainfall at all durations) a subset of the process is performed. Note that at this level a tally across the scenarios needs to be maintained as the final impact outputs are a composite of results for all three return periods.

**Process Runoff (hazard) data**

![Diagram of process runoff data]

Figure 3: Hazard and Impact processes for a single ensemble member

**User Visualisation**

The Visualisation Specification document (FFC, 2015b) was used to create a collection of Visual Weather maps showing various key parameters. There are duplicate maps for both nowcasting data (NCENS), which covers the first 6 hours, and short range data (SRENS), which covers 36 hours. The maps available to the user include:

- Rainfall Exceedance Probabilities
- Rainfall Exceedance Summary
- Runoff Exceedance Probabilities (Figure 4)
- Runoff Exceedance Summary
- Surface runoff ensemble member time series (separate webpage not created in Visual Weather – Figure 5)
- Impact summary
- Maximum impact severity and summary
- Likelihood of minimal impacts, minor, significant and severe impacts (all impact categories)
- Top Level Summary of 1km and county level impacts (Figure 6)

Figure 4: Runoff Exceedance Probability Maps
Figure 5 - Surface runoff ensemble member time series

Figure 6 - Top Level Summary of 1km and county level impacts
Lessons learned / general comments

- The decision to incorporate a prototype into Phase 2, rather than wait for the work described in previous sections to be completed, has been vindicated. The work has proven the practicality of the web service based approach to delivering outputs, has provided FFC with the means to conduct an operational trial and has forced all of those involved to move beyond the science and the raw outputs to consider the content and design of the displays that will appear before end users.

- In the early stages, much effort went into the drawing up of a specification of the new system and particularly the content of its outputs.
  - Having all parties (users, scientists, developer) involved in the specification ensured that the prototype would showcase all aspects of the HIM whilst remaining achievable given the limited technical resources available.
  - Even though the specification was extensive and detailed, when validation was performed there were found to be minor differences between the test system and the off-line process. These were chiefly down to differing interpretations of language in the specification: for instance what exactly constituted an hour in system terms. In future projects we would look to capture these definitions in the specification.

- Use of OGC web services had a number of consequences:
  - FFC were able to take the lead in configuring their user interface (in Visual Weather). They combined the services published by SWFHIM to build a series of views that fitted with their workflows. Figure 7 shows one of these – 9 web services (1 per scenario) are displayed (and animated through time) on a single screen, making large volumes information available “at a glance”.
  - Conforming to OGC standards necessarily limits what can be published (and in what form). Having developer input at the requirement fixing stage ensured that these constraints did not become obstacles to delivering the information required.
  - Client software does not always completely implement the standards in a satisfactory manner. For example: the test system front end includes a web page because Visual Weather could not display the time series data correctly.
The development has at times pushed the supporting technology to its limits. To give two examples:

- For much of the development period, memory problems plagued the system due to the sheer volume of data being processed. These were solved by switching from 32- to 64-bit processing.
- The recommended configuration for the web service publication software (GeoServer) emphasises the use of a database to index the large number of image files produced. The very large number of published services in SWFHIM led to a collapse of this arrangement as the database could not handle the number of simultaneous connections GeoServer was making. An alternative method was substituted and found to be satisfactory.

Figure 7: FFC user interface example: nine web services displayed and updated on a single screen.