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# Use of weather radar by the water industry in Scotland

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**Abstract** Rainfall data are a key source of information used by the UK water industry to perform its diverse regulatory functions. Raingauges have traditionally been used, but radar rainfall data are increasingly being utilised. Within Scotland, the public body Scottish Water has the responsibility for supplying drinking water and the collection and treatment of wastewater. An outline of Scottish Water's requirements and use of weather radar data is presented along with a brief description of the Hyrad Weather Radar System. A case study illustrates a novel method for post-event analyses of storm events associated with surface water flooding incidents. These analyses combine the analytical capabilities of Hyrad with the Flood Estimation Handbook depth-duration-frequency rainfall model to obtain estimates of rainfall return periods. The estimates are used to assess whether urban drainage systems performed within design specifications or if remedial action is required to comply with the regulatory framework. Finally a look forward is given of future planned applications of weather radar within the water industry in Scotland.

**Key words** pluvial; flood; radar rainfall; rainfall return period; FEH; urban drainage

## INTRODUCTION

Rainfall data are a key source of information used by the UK water industry to perform its diverse regulatory functions. Raingauges have traditionally been used for this purpose, but national networks of permanent gauges rarely meet the water industry's spatio-temporal user requirement for rainfall data (Han, 2009), particularly in urban areas. In addition, the number of raingauges in these networks is generally in decline (Eden, 2009) and only a subset of them may be accessible to the water industry.

UK water utility companies may operate their own raingauge networks and can temporarily deploy local dense networks for particular activities, including for flow surveys and research studies such as the City RainNet project (Collier *et al.*, 2010). Taken on their own, the water company networks do not permanently meet their user requirement for spatio-temporal rainfall estimation, tend to be expensive to deploy and/or maintain, and are difficult to site in urban areas. In part, this has led to radar rainfall data increasingly being used by water utilities as an additional source of rainfall information. Another major attraction is the national coverage of the UK radar network (Harrison *et al.*, 2009) which provides real-time, frequent (5 min) and high-resolution (1 km) estimates of rainfall and meets many of the water industry's spatio-temporal user requirements for rainfall data.

## REQUIREMENTS FOR USING WEATHER RADAR WITHIN SCOTTISH WATER

Within Scotland, the public body Scottish Water has the responsibility for supplying drinking water and the collection and treatment of wastewater. A recent review of the Scottish raingauge network (McGregor & MacDougall, 2009) recommended that it should be expanded in urban, remote and upland areas. It highlighted that the density of tipping-bucket raingauges (TBRs) needed to measure sub-daily rainfall is generally low and did not meet the user requirement, particularly within Glasgow, Dundee and Aberdeen. In 2007, the construction of a large wind farm resulted in an existing radar at Corse Hill being replaced by two new C-band radars at Munduff Hill and Holehead (Fig. 1). The improved radar coverage over the Midland Valley of Scotland, encompassing the major cities of Glasgow and Edinburgh, presented an important opportunity for Scottish Water to consider the operational use of radar rainfall data (McLachlan *et al.*, 2008).

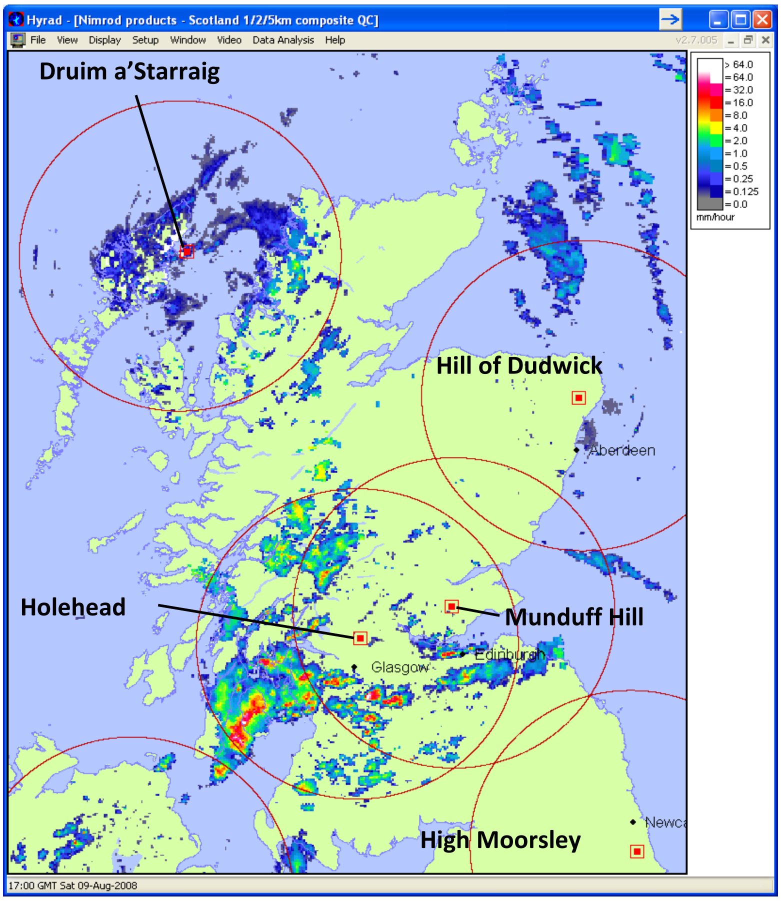


**Fig. 1** Hyrad display of the UK composite radar data over Scotland. Also shown are the radar sites (red squares) which provide coverage over Scotland, along with their respective 100 km radar range circles.

The following issues were considered:

– Could radar data be used in rainfall return period analyses for sewer flood compliance monitoring?
– What other radar-based applications could support business processes?
– What platform and infrastructure is required to retrieve, store and analyse radar data?

A particular requirement was the post-event analysis of storm events associated with surface water (pluvial) flooding incidents, including reliable estimates of rainfall rarity or return period. Such estimates can then be used to assess whether urban drainage systems performed within design specifications if remedial action is required to comply with the regulatory framework. An ability to perform these post-event analyses "in-house" was desirable as previously such reports were obtained from outside organisations, incurring expense and delays of several weeks.

During this process a wide range of other potential weather radar applications and spatio-temporal rainfall requirements have been identified, here summarised in Table 1. Whilst there are many applications that can take advantage of historical records of radar rainfall, such as hydraulic model verification, there are also several real-time or near real-time applications (e.g. predictive maintenance) that require appropriate automated systems to be in place. The review concluded that radar data should be used, in conjunction with raingauge data from all possible sources, and in 2009 resulted in Scottish Water commissioning the Hyrad Weather Radar System.

## THE HYRAD WEATHER RADAR SYSTEM

Spatial rainfall information from weather radar and/or raingauge networks can be of limited use for routine and real-time water management applications unless tools for automated reception,

**Table 1** Summary of current and planned (grey) use of radar rainfall data by Scottish Water.

| Team | Use | Resolution Time resolution | Space resolution | Reporting frequency |
|---|---|---|---|---|
| Asset Intelligence | Capital scheme review - assessment of rainfall events relative to design standards | 5 min | 1 km | Sporadic |
| Asset Intelligence | Hydraulic models (model verification) | 5 min | 1 km | Sporadic |
| Flood Investigation | Event analysis – real-time and historical | 5 min | 1 km to catchment | Daily |
| Pollution Incident | Event analysis – real-time and historical | 5 min | 1 km | Sporadic |
| Environmental | Event analysis for bathing water quality | 5 min | Catchment | Sporadic |
| Distribution, Operation and Maintenance Strategy | Network investigation - linking rainfall to major pipe bursts | Daily | 1 km | Sporadic |
| Leakage Planning | Consumption analysis - relationship between rainfall and water use | Daily | 1 km | Monthly |
| Regulatory Reporting | Flow return for regulatory body (WICS) | Daily | Catchment | 6 monthly |
| Annual Return Reporting | Yearly rainfall by region & wastewater treatment work areas for SEPA | Daily | 1 km | Yearly |
| Water Resources | Water resource planning | Daily | Catchment | Monthly |
| Predictive Maintenance | Use of rainfall for predictive maintenance | Daily | 1 km | Daily |
| Control Centre | Forecast data – extreme weather | 5/15 min | 1/5 km | 24/48 h |

processing and visualisation are available. The Hyrad Weather Radar System (Moore *et al.*, 2005) meets this need by supporting real-time receipt of radar rainfall and other hydro-meteorological products. Hyrad is the standard system for weather radar display, processing and analysis used by government agencies in support of flood warning across England, Wales, Scotland and Belgium.

A schematic of the Hyrad client-server system and its functionality is summarised in Fig. 2. It incorporates a hydrological processing kernel which improves rainfall estimation and forecasting by merging raingauge and radar data and removing anomalies. The analytical capabilities of Hyrad can be used either interactively through the display client or via an automated interface to flow forecasting and modelling systems (e.g. Delft-FEWS in the UK and FloodWorks in Belgium).

Significant recent developments include the "Statistics Analysis" module within the display client and the "Merging Tool" server utility. The statistics module allows a user to interactively interrogate a sequence of spatial data and derive a statistical summary for a selected rectangular region, a set of points or a catchment. This is particularly useful for post-event analysis as it can identify the maximum pixel rainfall total and location within a rainfall event and/or catchment which can then be used for deriving rainfall return period estimates.

The Merging Tool can merge different sources of actual and forecast data, allow for different spatio-temporal resolutions, convert between projections, create averages or totals (e.g. hourly or daily), cut out smaller regions and join images together. Of particular interest for the water industry are automatically derived products that support daily monitoring and reporting of storm events. These make everyday analytical work more efficient by avoiding the need for users to repeatedly form daily products from the base data (usually available at a 5- or 15-min interval).

## RETURN PERIOD ANALYSIS METHODOLOGY USING RADAR DATA

The return period analyses use the industry standard Flood Estimation Handbook (FEH) CD-ROM (Centre for Ecology & Hydrology, 2009) depth-duration-frequency rainfall model (Faulkner, 1999) to obtain estimates of rainfall return periods. For a given event, time-series of radar rainfall data are extracted via Hyrad for locations and catchments of interest at the base temporal resolution (5 min here). Rainfall accumulations of these time-series are made using rolling windows of varying length (e.g. 30 min, 1, 6 or 24 h) and the maximum accumulation extracted for each window length. Different durations are required to identify the "maximum" return period of the rainfall event as the return period varies as a function of both duration and depth. When radar rainfall totals for an individual 1 $km^2$ radar pixel are considered, an appropriate Areal Reduction Factor is inversely applied to obtain the equivalent point rainfall for use with FEH.

Furthermore, when attempting to derive an estimate of the rainfall return period at a given point (e.g. a pluvial flooding location), all radar pixels within a given distance of the point are considered (e.g. a 3 × 3 km box). This attempts to mitigate the impact of the positional uncertainties of the radar data (e.g. wind drift and antenna pointing accuracy (Harrison *et al.*, 2009)), issues that may affect an individual pixel (e.g. clutter) and the fact that the rain causing a pluvial flood may have fallen a small distance away from the actual flood location. For pluvial events in larger catchments, the maximum pixel rainfall within the catchment and the catchment average rainfall are also considered.

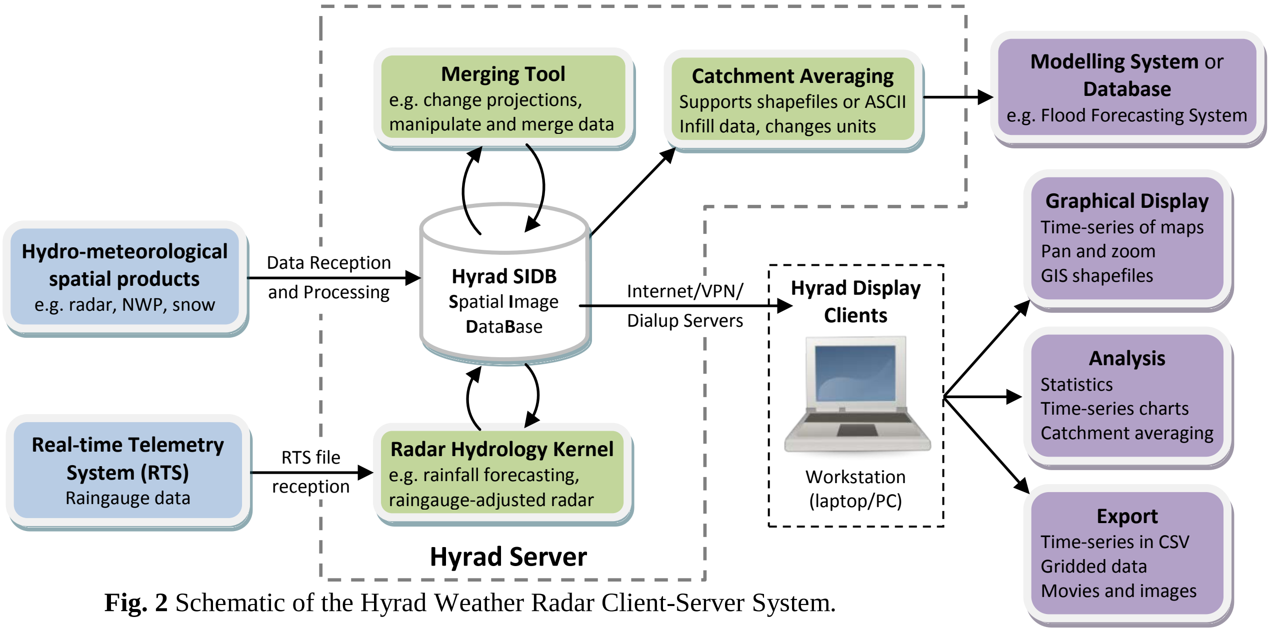


**Fig. 2** Schematic of the Hyrad Weather Radar Client-Server System.

## CASE STUDY: POST-EVENT RETURN PERIOD ANALYSIS

At about 09:30 GMT 14 August 2008, localised showers began to develop south of Glasgow. Some individual storm cells were very intense and did not move very quickly or very far but the region of storm initiation spread northwards over Glasgow. Figure 3 shows the daily radar rainfall total for 14 August and reveals the high spatial variability of the rainfall totals due to the passage of individual showers. Subsequently, several reports of pluvial flooding were received with the most serious incidents at locations 1 and 6 in Fig. 3 which are associated with areas of relatively high rainfall totals.

Hyetographs for the pixels with the largest rainfall totals within a 3 × 3 km box centred on locations 1 and 6 are presented in Fig. 4: these show that most of the rain fell in a short period of time and, for location 1, was very intense at times. Due to the nature of the event, rolling windows of 3, 2, 1 and 0.5 h were deemed appropriate for calculating the maximum rainfall totals and these are presented in Table 2 along with their associated FEH return periods.

According to this radar data analysis, the location that experienced the most extreme rainfall was location 1 with the four nearest radar grid-cells having daily totals ranging between 39.2 mm and 43.1 mm. This was mostly due to a particularly intense and localised shower which passed over between 13:30 and 14:30 GMT; see Fig. 4. The resulting short duration totals had very high return periods with 132 years estimated for the 30 min total of 28.5 mm.

In this case, had an asset designed to withstand a 1 in 20 year, 1-h rainfall event failed at location 1, the analysis would have given strong evidence to the regulator that the failure was due to extreme rainfall beyond the design specification of the asset. In general, the preference would be to include raingauge data but none were available for this case study. However, the study still serves to highlight the potential utility of radar data for return period analysis, especially for localised events which are a challenge for conventional permanent raingauge networks to capture.

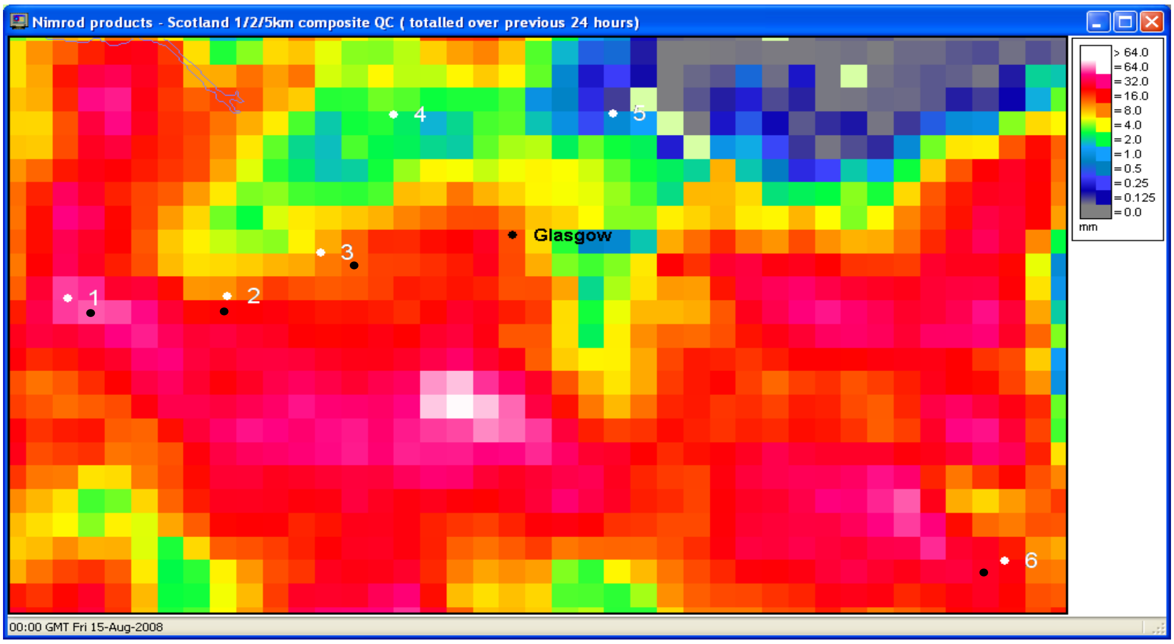


**Fig. 3** 24-h 1 km radar rainfall accumulations for the period ending 00:00 GMT 15 August 2008. Black circles are the "max" pixels identified within a 3 × 3 km box for locations 1, 2, 3 and 6.

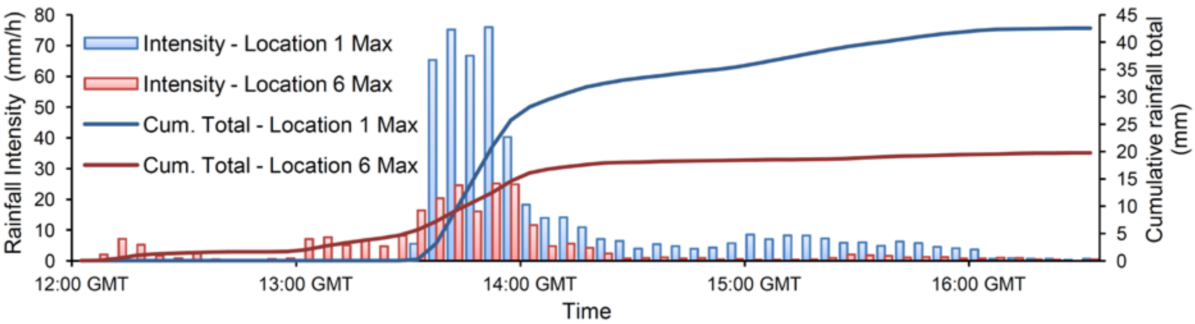


**Fig. 4** Radar hyetographs during 14 August 2008. Bars are rainfall intensities at 5-min intervals.

**Table 2** Radar rainfall return period (peak-over-threshold) analyses during 14 August 2008 for locations 1 and 6.

| | Location 1 Max (242500 661500) | | | Location 6 Max (276500 650500) | | |
|---|---|---|---|---|---|---|
| Duration | End time | Rainfall | Return period | End time | Rainfall | Return period |
| 30 min | 14:00 GMT | 28.5 mm | 132 years | 13:55 h GMT | 10.6 mm | 5.9 years |
| 1 h | 14:25 h GMT | 33.3 mm | 86 years | 14:00 h GMT | 14.3 mm | 7.3 years |
| 2 h | 15:30 h GMT | 39.4 mm | 58 years | 14:05 h GMT | 16.8 mm | 5.3 years |
| 3 h | 16:25 h GMT | 42.6 mm | 41 years | 15:00 h GMT | 18.5 mm | 4.2 years |

## A LOOK FORWARD

Over the last few years, Scottish Water have moved to using radar data routinely in several aspects of their business and plan to apply it more widely, as indicated in Table 1. The Hyrad Weather Radar System has played a key role in this uptake and an active development plan is in place to refine existing applications and to facilitate new ones (e.g. interfacing to IBM SPSS to run predictive maintenance models in real-time). In particular, automation of the FEH return period analysis of radar rainfalls is planned for both the Hyrad server and display client. This will save significant time and remove many of the manual steps that can introduce human-errors.

Another area of active operational research is how to combine radar and raingauge data. One method being considered is the multiquadric surface fitting scheme that forms part of the Hyrad Hydrology Kernel: this has been shown to have benefits for hydrological modelling when compared to using radar rainfall alone (Cole & Moore, 2008). The Probability Matching Method is another approach being considered under the City RainNet project (Collier *et al.*, 2010).

Scottish Water is also planning significant investment in their observing network, in stark contrast to recent reductions in their raingauge network. Having already invested in a dense raingauge network for the City RainNet project, there are plans to strategically increase their permanent network, possibly use “fill-in” X-band radars and to exchange and share rainfall data with others such as the Scottish Environment Protection Agency (SEPA). The combination of investing in observations, systems and operational research means that the use of radar rainfall by the water industry has a bright future in Scotland.

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