2.3 **INTRODUCING RADAR BASED QUANTITATIVE PRECIPITATION ESTIMATES (QPE) IN AUSTRALIA – POTENTIAL APPLICATIONS AND PARTNERSHIPS**

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1. INTRODUCTION

Observations of rainfall continue to play a significant role in various sectors of the Australian economy; in the monitoring of the climate and in the management of the environment. The first observations of rainfall were made in 1830's and then expanded to include various forms from simple manual volumetric measurement, semi-automatic chart recorders to automatic recording by dataloggers sitting inside a Tipping Bucket Rain Gauge (TBRG). The TBRG also became an essential component of the Automatic Weather Stations (AWS) in the Bureau of Meteorology (the Bureau) basic observational network. These measurements have formed the vital backbone of every hydrological enterprise within Australia, providing invaluable input into the infrastructure development of the last two centuries. More recently remotely sensed surrogate observations for rainfall have been gaining acceptance, especially given the size of the continent, the sparsity of population in many areas, and the high cost of in-situ observations. Ongoing maintenance is a significant component of the cost of the ground observational network.

The Bureau has developed an extensive network of radars, driven mainly by the needs for weather watch and tropical cyclone detection and tracking. The potential to also utilise these radars for rainfall estimation for purposes such as flood forecasting was always recognised but never fully developed. Over the past ten years or so however, there has been a much more concerted attempt to exploit the potential of radar to contribute to the national effort at rainfall measurement and the purpose of this paper is to summarise the main components of that work, including the partnerships that have been developed with clients to match developments with their needs.

2. THE AUSTRALIAN WATER INDUSTRY

The natural variability of Australian rainfall (and streamflow) is high by international standards and there has been a considerable effort invested in establishing the science (and art) of hydrology to manage this variability.

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The government at the State level has played a key role in establishing streamflow networks, with the Bureau taking the lead role at a national level in the observation and analysis of rainfall. The water industry is highly developed and demands for rainfall data and products come from most sectors of the industry, including:

- Government instrumentalities responsible for maintaining water supplies;
- Government instrumentalities responsible for drainage management;
- Authorities responsible for the collection, processing, analysis and publication of data;
- Consultants specialised in the provision of hydrological expertise;
- Providers of systems such as software, instrumentation and IT infrastructure; and;
- Researchers looking for improvements in observation, analysis and use of data;

To be fully effective, any new initiative involving the introduction of a new data type will require participation at various levels with groups from most or all of the above categories.

3. A LITTLE BACKGROUND HISTORY

The ability to see rainfall as a continuum rather than as a set of point data has always appealed to the community at large and other users of rainfall data. So much so, that some water authorities had systems that converted point rainfall observations into a grid view by analysis. This view of the data with an animation capability was used by the response arm of these authorities to understand the extent of the rain and its possible movement. It is no surprise that the Bureau radar web site is among the most popular sites in Australia.

Although the potential for radar to provide improved quantitative estimates of rainfall was always recognised, there was very little of the essential research necessary to enable that potential to be realised until recent years. So the history of a quantitative radar rainfall capability in Australia follows the natural path of initial research activity gradually moving into more focus on service delivery.

3.1 Research gets underway

An opportunity to bring together expertise to consolidate research specifically in the hydrological use of radar came with the establishment of the Cooperative Research Centre for Catchment

Hydrology (CRCCH) in the early to mid 1990s. The cooperative research centre model involved partnerships between research groups (including the Bureau) and a range of industry partners and acted to drive research closer to meeting the user (client) needs. The objective of the radar rainfall work in the CRCCH was to exploit the radar data to better characterise rainfall spatially and temporarily, and to produce quantitative estimates of rainfall. The initial work here had it's own challenges starting with the need to establish a proper 16 level archive of the reflectivity, but the research proceeded under a number of projects and developed a bank of knowledge and tools for use in analysing Bureau radar data. These included a range of radar data visualisation and management tools, algorithms for combining radar reflectivity and raingauge data to produce quantitative precipitation estimates and a stochastic nowcasting model (S_PROG) for making short to medium term forecast of rainfall (one or two hours ahead) essentially using advection. (Seed, 2003)

S_PROG has been tested in Australia, New Zealand, the United Kingdom and Spain, and was the simplest and one of the best performers amongst rainfall nowcasting models tested during the Sydney Olympics in 2000 as part of the World Weather Research Program (WWRP) (Pierce et al, 2003). The research effort, in collaboration with the UK Met Office, then concentrated on extending the forecast lead time by combining the stochastic nowcasting of S_PROG with deterministic rainfall forecasts from numerical weather prediction models out to six hours or more. This system (the Stochastic Ensemble Prediction System (STEPS)) is now close to operational availability both in the UK and Australia.

While the above research and development efforts aimed at real time operational use of radar based rainfall, there was corresponding interest in better spatially defining rainfall for design use and a further output of the research was a space-time rainfall model called MOTIVATE (Seed et al, 1999). This generates stochastic sequences (10 minutes or less) of spatial rainfall down to 1 km resolution for a given mean areal rainfall and storm duration. MOTIVATE is based on a multiplicative cascade concept, where rainfall is characterised by variability over a wide range of scales and the temporal evolution of a feature in a rain field is dependent on scale. MOTIVATE proved particularly useful for providing stochastic realisations of design storms, with Melbourne Water and Sydney Water Corporation now beginning to use outputs from this model as inputs into their systems to assess their sewerage network performance.

The above research involved adapting extensive improvements in removing errors in reflectivity observations and in using point ground observations to adjust the radar based rainfall estimates. The corrections applied are now part of the operational radar data management system and have contributed to enhancing its quality.

3.2 Services Development

The Bureau has recently been funded to upgrade around 20 existing radars and to install six new Doppler radars. This project (the Radar Network and Doppler Services Upgrade Project (RNDSUP)) (Canterford, R.P., 2007) has from the start taken a services outcome focus. That is, the success or otherwise of the project was going to be measured by how well the project delivered real services outcome. In this regard, the services the Bureau is focussing on in particular are those where direct community benefits are expected such as in disaster mitigation or in the provision of hydrological information. Tables 1 to 3 provide some basic indication of how the services development is being structured.

Service Outcome	Product (s)
Improved access to better coverage real time rainfall data.	Accumulations over durations 60 minutes, 24 hours and rain since 9am; 10 min rainfall as a sequence. Better spatial definition. Relative accuracy and comparison with gauge information.
Basic Forecast rainfall information	Forecast rainfall in 30min, 60min and 90min accumulation period. Uncertainty estimates and verification supporting information.

Table 1: General Rainfall Services

The general rainfall services are for the larger community which will be looking for rainfall information to plan and modify their response. The typical user could vary from someone conducting an outdoor wedding function to a construction site supervisor overseeing a concrete pour. This will supplement those currently provided through various outreach arms of the Bureau, such as the Data Services of the National Climate Centre, web displays and faxed bulletins from the Regional Flood Warning Centres.

Service Outcome	Product (s)
More accurate and timely flood forecasts	Fields of observed rainfall, accumulated over 1-3 hrs and aggregated over (sub)catchment areas of the models. Ensemble fields of forecast rainfall (0-12 hrs); aggregated over (sub)catchment areas of the models.
More useful and relevant flash flood warnings.	Rainfall fields of various durations to be input to a flash flood guidance estimation.

Table 2: Flood Warning Services

Improvements to the flood warning service (Table 2) will be limited to catchments with effective radar coverage. For example, Figure 1 illustrates a situation where beam blockage by hills and other features means that the radar only covers a part of the subject catchment. This situation is quite common in many cases requiring rainfall inputs to flood forecasting models.

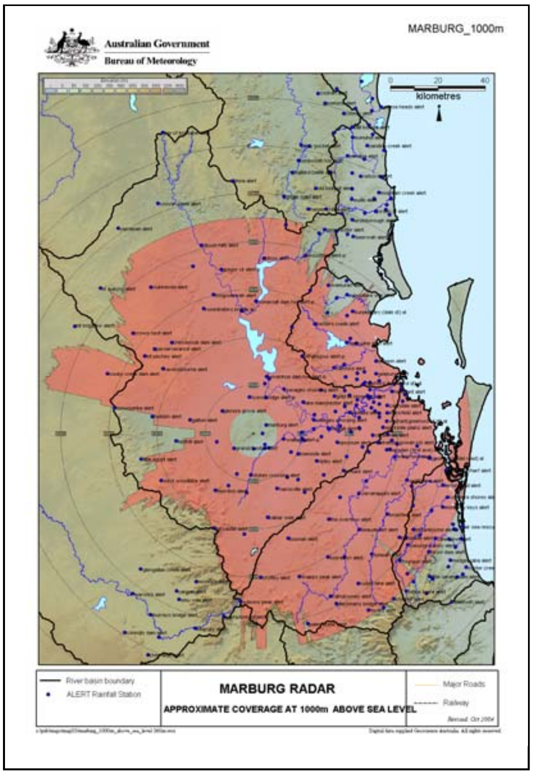

Figure 1: Marburg radar coverage

The ability to extract radar based QPE for individual radars for direct ingestion into the Bureau flood forecasting models has been established. The data is provided as rainfall amount for each hour or model time step for each sub catchment of the model. The Bureau uses the semi distributed conceptual model *URBS* extensively in addition to lumped models such as the unit hydrograph model. Testing with the Bureau and elsewhere have concluded that even with uniform model parameters, improvement in the spatial distribution of rainfall will greatly contribute to reductions in the uncertainty of flood estimates. The ensemble forecasts of STEPS are expected to contribute to better characterisation of the rainfall input uncertainty in the future.

The need for rainfall data by specialist users such as water managers, drainage managers or primary industry (Table 3) will be quite different because of the higher levels of accuracy required. This group also would require more detailed assessment and publishing of the inherent errors. There also would be a greater expectation that the method of estimation is stable so that any decisions taken based on such radar based QPE estimates remain valid into the future. In this regard, there is a good likelihood that where economic decisions are substantial, then uptake will be slow with an inclination to wait for the technology to mature further.

Service Outcome	Product (s)
Improved access to design rainfall data.	Multiple simulations of rainfall fields for specified design return period for given duration. Statistics on spatial average values.
Improved access to better quality real time rainfall data.	Various accumulations as required with gauge and radar rainfall blended to provide the optimum combination. More detailed information on relative accuracy and verification.
Forecast rainfall information	Forecast rainfall from 0 to 12 hours as ensembles to provide uncertainty estimates.

Table 3: General Water Management Services

The radar QPE displays will highlight local areas where very heavy rainfall is likely to be occurring for emergency management as well as public information to a level of detail that is not possible to describe in weather warnings - particularly for flash flood locations. This will have to be delivered through allow graphical warning products. The Bureau has recently begun to issue graphical warning products highlighting areas of potential severe thunderstorm or severe weather development. (Bally, 2004). The addition of potential heavy rainfall areas will add value to this product.

3.3 Systems gets implemented

The use of C++ language using object oriented programming has helped in being able to bring what was developed for research in Windows environment to a LINUX based operational development environment. RNDSUP has provided the ideal environment to invest in proper system implementation.

Rainfields (Seed, A.W et al. 2007) is a system developed to serve radar based rainfall data. It will run on the *Nowcast* Application Server that also hosts other applications such as *TITAN* and *WDSS*. *Rainfields* is capable of serving a request for data from various client applications for viewing such as *2D-radar* and *3D-Rapic*., and for other uses such as for ingesting into hydrological modelling systems. This is based on the web services technology, which allows for data serving across the Internet to any requesting system. *Rainfields* will the basis of all radar based rainfall in the future, and is expected to play a significant role in radar based QPE within Australia.

The RNDSUP project funded the installation of additional rain gauges under the radar to augment the existing rain gauges. The location of these additional ones were determined on the basis of a fairly uniform distribution gauges desired in the segment between 20 – 60 km from the radar.

The RNDSUP project also funded improved communication for uninterrupted reception of the data to a central location.

4. WHERE ARE WE NOW?

The RNDSUP project is well underway in terms of radar installation as well as associated systems and services implementation. The capability has now been developed to serve data based on each radar in the network. A capability to merge the outputs of one or more radars into a mosaic has also been developed. All data are served for a box of 128km by 128km, at 2km grid resolution. This capability is being implemented radar by radar starting with the RNDSUP project funded Doppler radars. It is preceded by a proper recalibration of the climatic Z-R relationship (Seed et al, 2002). The data server will be able to provide on request (depending on the data availability)

- Gauge only based rainfall
- Radar only based rainfall
- Merged product giving the optimum combination of gauge and radar based rainfall.

The above products are available at 10min intervals either as ASCII values or as images. The server is also capable of providing the following standard accumulations commonly required:

- A 9am based 24 hour accumulation (this is the standard "daily" rainfall in use);
- A rain since 9am product (again, a common Bureau rainfall product to reflect current situation as compared to the 9am);
- Hourly accumulations based on local clock;

The current forecast capability is limited to the use of S-PROG, providing 30, 60 and 90 min forecast accumulations. Plans are however underway to introduce the STEPS based ensemble forecast.

5. PROGRESS WITH INTRODUCTION

The use of these new radar based rainfall products in Australia has been so far quite limited and ad-hoc. They are only just becoming available and awareness is still quite low. The request for radar rainfall data has come from groups such as:

- Researchers from universities;
- Stormwater management authorities to compare with their rainfall network observations and for simulation exercises;
- Water management authority to estimate flows into their storages.

5.1 Registered user survey

A survey was recently conducted among potential users of the data, but the response was disappointingly poor. It was however conducted during the time when the rainfall was at a record low. The questions were aimed at getting user feedback on matters such as:

- By what method and how often the data was accessed
- What periods of accumulations are useful
- What is the expected accuracy of radar based QPE
- What was the experience so far of the accuracy

The recipients were selected from a range of potential industry users such as water authorities, emergency managers who were given access to some limited radar QPE at that stage.

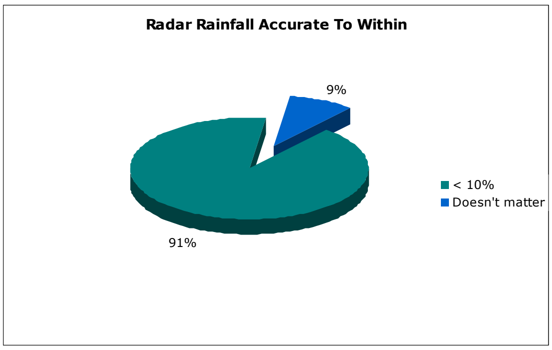

Figure 2: Expected accuracy of radar rainfall

On the question of what accuracy the users expect from radar rainfall, an overwhelming majority expected it to be within 10% to be useful.(Figure 2). Only 9% thought the accuracy wasn't important enough. This certainly places a significant burden in raising the awareness on practically achievable accuracy ranges.

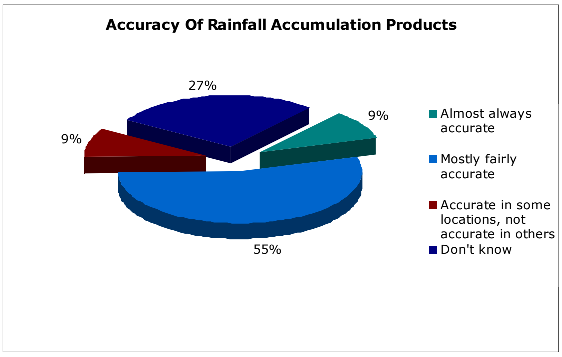

Figure 3: Perceived accuracy of radar rainfall

However, only 36% were currently not confident of or didn't know the current accuracy (Figure 3). The lack of sufficient rainfall makes it difficult to draw any conclusions from this.

The users were also asked to provide additional information. As an example, one question asked users the reason for needing this type of rainfall information, and the responses included such varied uses as:

- Managing spraying programs and irrigation schedules;
- Co-ordinating catchment water quality sampling and for runoff trials;
- Decision making for various farm activities;
- Scheduling or to halting irrigation;
- Catchment management- modelling and water quality monitoring;
- Help plan trips to various areas;

The Bureau is planning to make the radar based QPE available to the public via the web. The data also will be made available in NetCDF format. Plans are already underway to get together appropriate educational material to support this, as well as presentations of information on errors in easily understood form. This will be limited to new or newly upgraded radars that gone through a proper calibration process, and where the hardware and configuration are stable.

6. IN THE MEDIUM TERM

There will more and more radars coming on line with this capacity and the Bureau will be reviewing its capacity to serve the data via the internet and also will review and if required upgrade the serving capabilities of its IT infrastructure.

With sufficient users getting on board, opportunity will be there to set up and foster user forums. Such forums will provide the facility to air specific issues, discuss and resolve. The Bureau will also facilitate workshops to both provide training as well as exchange information among the users. User surveys to capture user needs and feedback will be an ongoing mechanism.

6.1 Data archive and new technologies

The Bureau will need to establish a database of real time as well archived data to make this access easy and convenient. As users become familiar with the data, there will be the demand to be able to access the past data of any events they may have missed testing. As new users get introduced, they will look for easy access to data from past heavy rainfall events. Therefore, a proper archive facility is imperative for further consolidation of the interest in this data type.

New technologies such as *web services* will be expected to be incorporated to take advantage of developments in other areas data servicing.

6.2 Partnerships in service provision

The flood warning service, in particular, is provided through well established collaborations involving all three levels of government. For example, in NSW, while the Bureau is primarily responsible for the collection of rainfall data, the State water agencies contribute significantly towards the collection of vital river level data. The State Emergency Services (SES), the key response agency combating flooding as it happens, plays a key role in establishing the warning needs, providing interpretation to the Bureau warnings and in establishing a 'flood intelligence' database. The Local Agencies or the councils are responsible for controlling developments in the planning stages, and supporting the SES during floods with staff and equipment. They also play a lead role in monitoring floods that are quick acting or flashy. The Figure 4 shows the typical information flow involved in such partnership arrangements. These arrangements vary from informal to Memorandum of Understanding (MoU) or Service Level Arrangements (SLA).

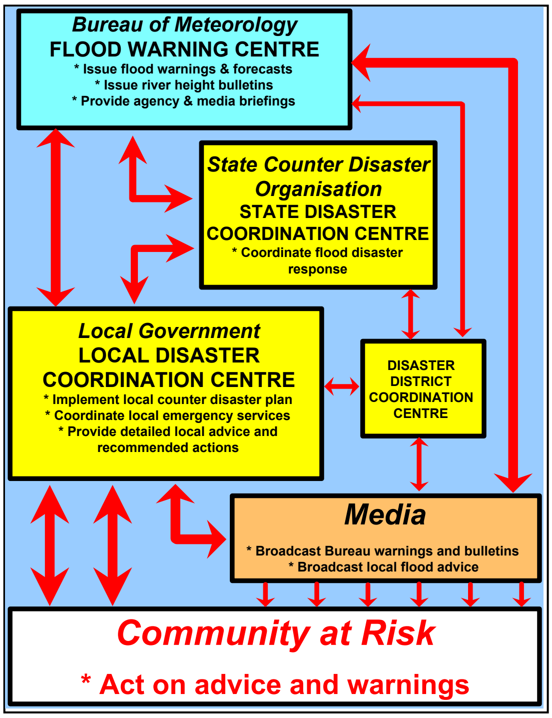

Figure 4: Collaboration during flood warning operations

The Bureau has been approached by various local and State level government agencies to provide radar based QPE to help with their flash flood warning operations.

Here the challenge would be able to provide data that is as site specific as possible, while conveying the uncertainty well. The general understanding is that the radar will be able to provide such higher resolution data.

A newly emerging partnership arrangement could be in the water management industry given the increased focus on "water". Here, the emphasis is on improved prediction of inflows into water storages using a better spatial coverage of rainfall, and in the short term, an improved ability to respond more quickly to unpredictable weather.

7. THE CHALLENGES

Most users will want simple descriptions of relative accuracy as compared to gauge observations such as a percentage error. This will be the most challenging aspect of the use of radar based QPE. It will be extremely difficult to expect the ordinary users of this data, who has no exposure of the complexity of the measurement process, to understand fully how different the radar rainfall estimation process is as compared to the point observations. It is more than likely that the numbers provided will be taken to mean the same as any other rainfall amount. This concern has resulted in the Bureau adopting broad ranges for proposed external displays. The aim is to use the ranges to provide some qualitative indication of rainfall rather than absolute numbers. While substantial educational material will be provided, there should be no expectation that the public will take the time to understand the full extent of complexities involved.

On the other hand, the more specialised users of rainfall data such as water managers could be expected to take the trouble to understand the differences. However, up to now, they have been heavily involved in the use of point observations, and while they may have looked at contoured rainfall patterns, a full visualisation of an in-filled field view of rainfall is relatively new experience. They may also expect a spatially and temporally consistent bias – that is, any systematic error to be either positively or negatively biased across then whole domain and across time periods as well. It will take time for such users to see the balance of errors across a whole domain and relate to the radar based QPE better. It is important to give the time for such users to adapt to this new data type.

8. CONCLUDING REMARKS

The use of radar based QPE in Australia was introduced through a structured research and development process in line with international best practices. The water industry has been involved from the start at various levels, and is waiting for a stable and reliable system to serve the data in a timely and efficient manner. Existing partnerships in disaster mitigation activities will be further strengthened by the availability of high resolution, locally more useful radar based QPE, especially in the flash flood warning service.

As is the standard practice in emergency management, the public will be provided with the same data for confirmation with other warning messages they may receive. This data also will be of extreme interest to the public who have shown immense interest in the radar data as even raw reflectivity.

The radar based QPE will begin to enhance the flood warning services of the Bureau through the availability of much improved spatial resolution of rainfall, albeit, limited to where the catchment has the necessary radar coverage.

The introduction of the radar based QPE will have to be carefully managed to achieve its full potential and to minimise any unintended or unacceptable use of this data.

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