The Reality of flood forecasting in Greater Metropolitan Adelaide – maximising forecast response time

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Abstract

Flood risk in South Australia affects many locations, but the greatest risk is to the Adelaide metropolitan area. The many creeks and rivers flowing from the Mt Lofty Ranges to the sea can overflow with potential to cause loss of life and property damage. At least 7,000 homes are at risk in a 100-year Average Recurrence Interval flood.

There are many issues which make flood forecasting and response difficult in this situation:

- Many of the creeks have a fast response time, are subject to flash flooding. There is little time to detect a developing flood and to warn the community
- Some urbanised areas can be affected by overland flow not originating from the creek system
- Antecedent conditions have a significant effect on potential flood flows, and
- floods are infrequent and therefore the community is not prepared

There are 160 rainfall monitoring sites in the Adelaide metropolitan area, equipped with automatic rain gauges reporting in real time. Adelaide does not have any system in place for rapid analysis of this rainfall and determining the location and intensity of potential flooding. However with flood modelling for flood inundation mapping, having been completed for many rivers and creek, there is an opportunity to implement current best practice techniques to apply these models for flood forecasting.

An innovative way to develop a rainfall-based flood forecasting system, using the existing modelling and potential rainfall is presented.

Introduction

Flash floods are defined in this paper as floods that develop in less than 6 hours(Bureau of Meteorology, 2016a). In Australia the Bureau of Meteorology (BoM) provides a flood warning service for river flooding, where the characteristic lead time is greater than 6 hours, and can be days or weeks. The BoM also gives generalised regional warnings, Flood Watch and Severe Weather Warnings(Bureau of Meteorology, 2016c, Bureau of Meteorology, 2016d). Flash floods are a problem most commonly experienced in urbanised areas, and are difficult to predict in time to warn the threatened community.

This paper reviews Australian solutions to flash flood forecasting that will enable emergency services to be informed with minimum delay, of the location and extent of immediate flood risk, and be given basic guidance for effective response. It describes two systems that have been developed in Australia, and suggests how one of them can be adapted for use in Adelaide, South Australia. The proposed system is basic, but is quick and is appropriate for Greater Metropolitan Adelaide, covering some thirty flash flood risk catchments.

Why is Adelaide different?

Much of the city of Adelaide was built on a floodplain and thus has a high flood risk. Circumstances particular to Adelaide are that:

- Most of the community flood risk is due to flash floods, often developing in an hour or less, because of the small catchment areas involved (10–20 km^2)
- In many cases, rural upstream catchments flow through urbanised areas
- Much of the flood risk is not mainstream flooding - flood producing rain may fall over a small part of the catchment, often in the urban part, and not as a result of water escaping from a creek channel
- Adelaide has a Mediterranean climate with an average annual rainfall around 600mm. Unlike Queensland and other wetter areas in Australia, catchments are usually dry at the start of an event, and losses may take up a large part of the rainfall.
- Many sections of the creeks are in private ownership which makes channel maintenance to maximise flood capacity difficult.

For flash flooding there is no time to use the traditional approach to flood warning for main stream flooding, which requires monitoring of water levels, runoff routing models, and predicting flows at key locations, are. Instead a rainfall-based flood forecasting procedure which can quickly produce a forecast in time to warn the threatened community can be used.

In Adelaide, since 1989, a network of automatic raingauges has been installed, reporting to the Bureau of Meteorology (BoM) by radio telemetry in real time[i]. This rainfall data is a vital resource for emergency response agencies for flash flood risk management.

Flood forecasts rely on detailed knowledge of the rainfall-runoff relationships for the creek or location concerned. Brown Hill Creek in the southern inner suburbs of Adelaide is well supplied with rainfall and river flow gauges and has been subject to extensive hydrologic and hydraulic analysis. e.g. (Transport SA, 1998) But flood processes are complex, and in the next flood the best forecast that engineering hydrology can achieve may only be approximate in terms of flood location and extent. Other flash flood creeks around the city have less historical data (rainfall, river flow, antecedent conditions, channel capacity) on which to base a flood response. This suggests that until sufficient experience and data on major floods has been documented, the forecasting method for flash floods should be basic and quick.

Background to flash floods and flood warning

Adelaide has suffered from floods periodically resulting in damage to property, and occasional deaths (e.g. Brown Hill Creek, Gawler River, Cudlee Creek. Refer to Floods in South Australia,(McCarthy D et al., 2006)). The Bureau of Meteorology (BoM) has worked with local councils and State Government agencies to establish a rainfall and river flow gauging network that could provide data for both river flooding and flash flooding. At the present time, the use of this data for flood warning is limited to a Short Message Service (SMS), which advises the State Emergency Service (SES) and local council flood management staff that a rainfall intensity threshold at a particular location has been exceeded.

SMS messages are useful in that they are cheap, instantaneous and automatic. The BoM SMS service is based on rainfall thresholds (14 mm in 30 minutes or 30mm in 3 hours), and specific water levels, being exceeded. SMS messages triggered by rain intensity and water level are delivered to BoM Staff, the SES and to some local councils. They have been used for flood alerting since 1995. The pre-set threshold does not take account of any differences in catchment conditions, (refer to Section 4.4).

The problem of flash flood warning has been experienced widely in Australia. Severe storms occur periodically in all states, and it is when these storms occur over urban areas that there is the potential for rapidly flowing water to pour down streets, damage properties and in some cases cause injury or death. Such events are difficult to predict. Since 1988 (the start of BoM flood warning in South Australia) there have been advances in experience and technology which include:

- Advanced computer systems
- Rapid and efficient communications
- Reliable telemetry systems which instantly transmit data from the catchments
- Much improved radar (and satellite) technology for remote detection of severe rainfall
- Sophisticated hydrologic and hydraulic modelling techniques
- High quality photogrammetry and Lidar survey, supported by ground survey, providing data for accurate Digital Terrain Modelling (DTM)
- Major improvements in the understanding of hydrologic processes

By making use of these capabilities, and experience interstate, a system suitable for flash flood forecasting for Adelaide can be created.

Two systems in use in Australia developed specifically for flash flooding have been chosen for review in this paper. Each has taken a different approach.

Melbourne Water

Flash floods have occurred in the City of Melbourne from time to time, for example the Elizabeth St flash flood which occurred in central Melbourne in 1972(Bureau of Meteorology, 2016b) and (Danno, 2014). Rasmussen (2013) states that *"over 100,000 properties are subject to inundation from flooding*." Trial flash flood warning systems were set up at:

- Croydon North in the Brushy Creek Catchment, and
- Blackburn North/ Laburnum catchments.

They were chosen because of high vulnerability, potential for loss of life, and damage potential. Flood warning system development was chosen because the cost of structural mitigation (larger capacity stormwater systems, increased flood storage, or raising of house floor levels) was prohibitive. Warning times are characteristically very short, usually less than an hour, therefore warnings are generated automatically and distributed to local residents. Those receiving warnings can contact Melbourne Water and the SES for confirmation. The flash flood warning systems are designed for the particular risk conditions in a known location vulnerable to flash flooding. Rasmussen (See Figure 1) indicates that there are 25 catchments subject to flash flooding, two of which have been provided with a warning service. Note that Figure 1 shows another 12 extreme catchments, indicating that they may also require separate warning systems.

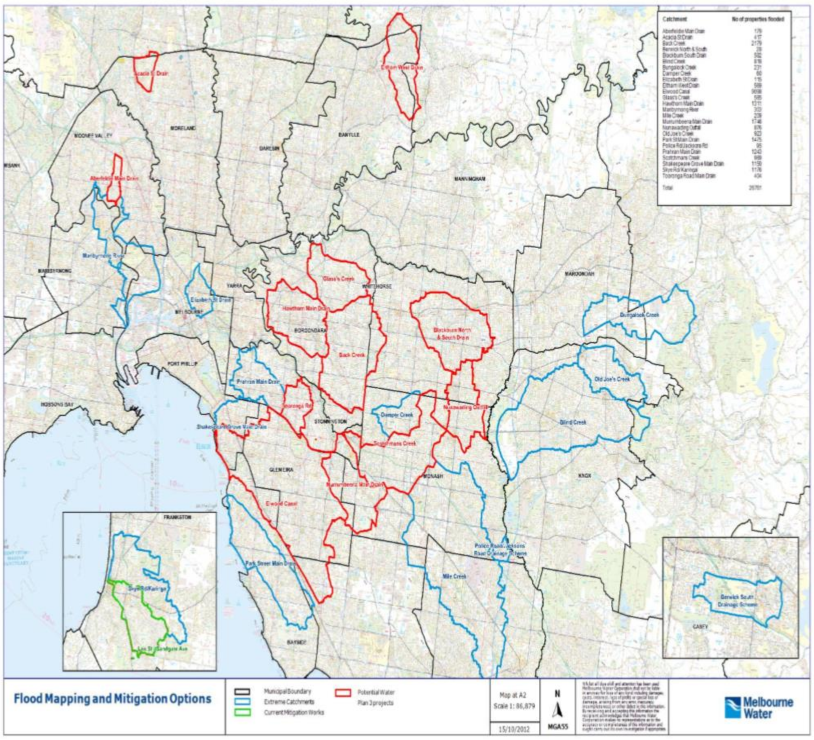

Figure 1 Location of flash flood problem areas in Melbourne (Rasmussen Fig 11, 2013)

Three questions in respect of the defence of the Melbourne communities from flash flooding are:

1. Will Melbourne Water be prepared fund the extension of the service to all of the 25 catchments? And what provision is being made for the extreme catchments?
2. The list of 25 catchments does not appear to include central Melbourne where the 1972 flash flood occurred. What arrangements may be made for areas affected by overland flooding?
3. Recent effort by Rasmussen and others has raised level of community awareness. How long can this be maintained between flood events. It could be many years until the next “direct hit” of a thunderstorm over Bushy Creek, Blackburn North and Laburnum. Keeping the awareness program fresh and effective will require significant effort and ongoing cost.

By comparison the flash flood warning system for Adelaide needs to capable of forecasting and warning for many catchments, possibly simultaneously.

Moreton Bay Regional Council

The climate in coastal Queensland is characterised by periodic major rainfall events. With the rapid urban and suburban development along the coast, there is a large and vulnerable population at risk of floods. Moreton Bay Regional Council (MBRC), on the northern fringe of Brisbane has experienced major floods. *“The responsibility of council for Flash flood Warning was reiterated by the 2012 Queensland Floods Commission of Inquiry.” (Salter L et al., 2015).* Over the years, a network of telemetered rainfall and water level sites has been established (see Table 1), and flood data is collected continuously over an area of some 2000 km^2. Floodplain mapping has been undertaken for most of the rivers and creeks, using current hydrological and hydraulic analysis. *"Flood Warning in the MBRC region is challenging because of short response time (less than 6 hours) and distribution of trouble spots over various catchments"* (Salter L et al., 2015). The BoM had provided the ALERT [ii] and ENVIROMON [iii] systems for flood monitoring and detection. This system collects rainfall and water level data continuously for flood risk assessment, but has limited capability for analysis and display. MBRC, in association with Townsville and Sunshine Coast MBRCs, developed a system known as TARDIS[iv], to use data from ENVIROMON, analyse it and present the results in a user-friendly form.

TARDIS is designed to meet user requirements in a stressful real time flood situation and provides the following features:

- "*Flood effects predicted from rainfall (actual and/or forecast)*
- *Relating water level gauge levels to flood effects*
- *Automation of flood situation reporting*
- *Reports on roads and likely effects at water level gauges*
- *Maps showing flood warning message thresholds and status of warning messages*
- *Tools for managing flood warning system including gauge status and gauge status reporting*
- *Flood Dashboard – An overview of the emergent situation"* (Salter L et al., 2015)

The forecasting system relies on a data base of flood information. MBRC took the WBNM (Boyd, c.1987) models developed for the flood studies within their area, and ran them with a full range of rainfalls and storm durations to create the data base. It was subsequently incorporated in TARDIS. The method assumes that for a particular flood forecast point, the average rainfall in given time for the contributing catchment upstream can be used to estimate flood magnitude at that point. Figure 2(below) shows a map of MBRC area with more than 200 colour coded dots indicating forecast flood severity. Each dot is a forecast point, and the catchment upstream of each dot is described by the GIS system in a .kml file. All pluviometers within the catchment or just outside, are used to calculate average rainfall for the specified duration, using Thiessen Polygons e.g. (River Forecast Center, 2009) to calculate the weightings of each. An advantage of the method is that for a flash flood situation when time is at a premium, a "lookup" function can be used to estimate very quickly the flood peak for a range of durations at each of the 200 forecast points. Colour-coded displays indicate the flood potential magnitude, and as seen on Figure 2, it is easy to focus on the locations at risk. Other features of TARDIS, such as Intensity Frequency Duration analysis of rainfall at each rainfall point, are valuable in cross-checking storm and flood severity. MBRC has added much information on:

- hydraulic capacity of channels
- critical breakout points, and
- water levels at bridges and low-lying roads.

All in all Moreton Bay's flood forecast and warning service is impressive, and it worked well during the floods of 20 and 21 January 2015 (see below).

> *"In the lead up to this event, TARDIS was used to prepare scenario reports providing predictions of flood magnitudes, flood levels and road closures likely to result from the various BoM rainfall forecast scenarios. These reports were prepared morning and evening when the BoM updated forecasts and TARDIS automatically retrieved ADFD(Bureau of Meteorology, Undated)*

rainfall forecasts for 50%, 25% and 10% chance of exceedance scenarios. During the event, TARDIS was used to prepare flood situation reports, manage issuing of warning messages, monitor rainfall and water levels at gauges, monitor likely flood effects and keep abreast of the flood situation. TARDIS was used extensively during this event by both technical and non-technical users.

Following the event, the feedback received about TARDIS by all, including technical and non-technical users and flood response operations, was very positive." (Salter, 2015)

Numerous flash flood warning systems have been reviewed in Australia and overseas. Many have been designed and developed, however there are few accounts of successful operation of a system. The work by MBRC, and the success in warning the community on 20 and 21 January 2015 should be noted.

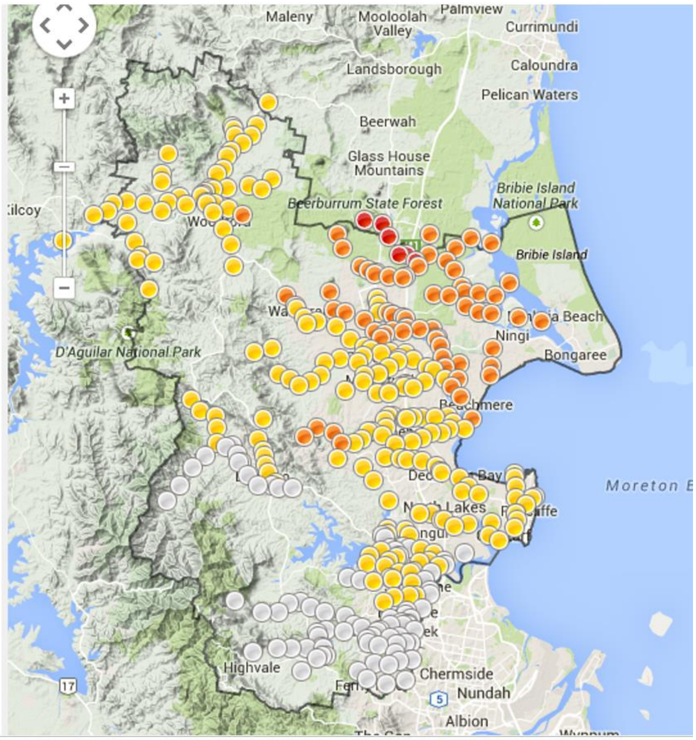

Figure 2 Flood Warning output display (Salter L et al., 2015)

Comparison of system features

How can the experience gained in the examples above be used for development of a monitoring and warning system for Adelaide?

Table 1 Comparison of flash flood monitoring and warning systems

	Melbourne Water**	Moreton Bay City Council	Adelaide - Current	Adelaide - Future
Approximate Area covered (sq km)	4	2000	1000	1000
Number of catchments (currently)	2	14	0	30
Rainfall sites (Real time telemetry)	3	90	102	150
Water Level/Flow monitoring sites	3	30	40	50
Forecast Locations (estimated)	2	500	0	60
Real Time Rainfalls puplished	☑	☑	No	☑
Real Time Water levels published	☑	☑	No	☑
Forecast Rain assessed?	No	☑	No	☑
Flash Flood Warning service available	☑	☑	No	☑
Alerting of Response Agencies	☑	☑	☑	☑
Alerting of the Targeted people at risk	☑	No	No	☑
Warnings via the media*	No	☑	No	☑
Message type -SMS	☑	☑	☑	☑
Message type -Landline/Mobile Phone	☑	☑	No	☑
Message type -Internet	☑	☑	☑	☑

Note *: Generalised warnings issued by the Bureau of Meteorology to the media, for all locations.
Note ** this includes only the Blackburn/Laburnam area

Table 1 gives a summary of features of the systems described above, for comparison purposes, and suggests what may be achieved for Adelaide.

- The Melbourne Water flash flood warning system is focussed on specific flood prone locations, and requires close communication with the threatened community. The monitoring, detection and alerting is fully automated, requiring precise knowledge of the hydraulic behaviour of stormwater, and the thresholds for each level of warning. The current system also transmits the BoM Severe Thunderstorm warnings, which advises recipients that a severe storm is approaching. It is a true warning system, designed and built to warn a target group of people. To extend the service to the many other flood prone catchments may prove to be challenging.
- MBRC's TARDIS system analyses and displays flood data in real time for 14 catchments with:
  - capability of using forecast rainfall seamlessly with observed rainfall
  - a simple flash flood forecast model using a lookup table to find the rainfall which most closely matches the current situation
  - forecasts of flash floods at each of some 200 flood forecast locations (see Figure 2)
  - Intensity-Frequency-Duration calculations for each rainfall site, analysed and updated instantaneously
  - flexible and easy to understand map displays
  - ability to forecast flood levels, overtopping of roads and bridges
  - a data base of historical events that can be reviewed and modelled

The system is primarily designed for use by a single agency, MBRC, which then distributes information to emergency response staff, and via the media to the general public. It is a true flash flood forecasting system able to supply flood information that can be used for making emergency response decisions.

Requirements for Adelaide

When considering how Adelaide can be provided with flood forecasting and warning arrangements there are basic conditions that need to apply. The system must:

- cope with the infrequent occurrence of floods
- serve all locations around Adelaide that could be affected by flash floods. This suggests that the warning system needs to be Metropolitan-Regional based, using a single agency or control centre with the task of developing skills and capability to support the service.
- operate full time, be fault tolerant and capable of crash-recovery
- be relatively basic, not using high level technology, and designed so that improvements can be incorporated in the future
- be available to all who need the information including SES, SA Government Departments, Local Councils and to the general public. This suggests a web-based service, with a special Registered User access.
- incorporate both measured and forecast rainfall
- present the information in a readily understood form appropriate for the users which are generally emergency response agencies
- be linked to a Decision Support System, so that a viewer of the output has firm guidance as to what to do with the information
- use all available flood intelligence, which in an Adelaide situation means including the hydrological and hydraulic modelling that has been and will be generated in ongoing floodplain mapping studies.

Opportunities for Adelaide.

Pluviometer data centralisation

At the present time rainfall data from is collected from 162 sites by 4 different agencies (see Table 2)

The ALERT system was introduced by the BoM in 1988 to provide real time monitoring of rainfall and water level for flash flood catchments. The network around Greater Metropolitan Adelaide consists of 102 Tipping bucket raingauges (Pluviometers) and 33 water level recorders (Fathollahzadeh F pers.com. 2016). These are linked by telemetry to the ENVIROMON system and data is received, processed and stored in a central server. Other agencies can also deliver real time data to inform a flash flood warning system. A summary of telemetered sites is given on Table 2. For an integrated monitoring system all data needs to be available on a common platform, updated sufficiently often for flash flood analysis. It is suggested that the rainfalls reports align with BoM Buckland Park Radar, located just to the north of Adelaide, which updates every 10 minutes.

Table 2 Pluviometer sites that can supply data in real time

Telemetred Rainfall (Pluviometer) sites			Web
Owner	**Operator**	**No of Sites**	**Access**
Bureau of Meteorology (ALERT)**	BoM	102	BoM*
BoM Automatic Weather Stations**	BoM	13	BoM*
DEWNR sites	DEWNR	18	E-NRMS
AMLR sites	WDS	12	AMLR
Local Councils	WDS	10	WDS
	Total	155	
Notes: * Website updated hourly			
** Currently reporting in real time			

Flood modelling and flood mapping

Flood studies and flood risk mapping have been undertaken for some 30 catchments around Great Metropolitan Adelaide. The models used for these studies were calibrated against all available flood gauging record and flood history. These models can be run in flood forecast mode, for a full range of rainfall amounts and storm durations to develop a data base of rain-flood response.

Flood data analysis and display

The system developed and used by MBRC and Sunshine Coast councils offers features that are suitable to adoption in Adelaide. The system analyses rainfall amounts and intensities and displays a flood hazard map. Key to successful adaptation of this system will be development of a “lookup” data base, using model runs from all calibrated hydrologic models that are available. The “lookup” function finds the event that most closely matches the current situation, it can also forecast flood levels, overtopping of roads and bridges. Work has commenced at the University of South Australia to extract this information for flood forecasting. So far 5 catchments have been modelled and there are already 25 flash flood forecast points (See Table 3). It should be noted that parts of Adelaide, not within formal catchments have experienced flooding. Future research is required into detection and forecasting of flooding due to intense storms over such locations.

Table 3 “Lookup” Forecast locations available for Adelaide (March 2016)

Flash Flood Forecast points	Location	No of Forecast points
Brown Hill Creek	Adelaide inner suburbs	17
Pedler Creek	McLaren Vale-Moana	5
Dry Creek	Pooraka-Mawson Lakes	1
Cobblers creek	Salisbury	2
Mt Barker creeks	Under development	

There are many more catchments and flood forecast locations that can be added to the data base, and there is good potential to use the forecasting system to enhance stormwater harvesting. (Pezzaniti D pers comm 2016).

Loss estimation

When rain falls on the ground, part of the falling water is taken up in wetting the soil surface, soakage into the ground, detention in puddles, wetting of foliage. The remaining water flows overland, enters streams and stormwater systems. The term initial Loss refers to the amount of rain that is held up in detention/retention processes and does not contribute to runoff and floods. MBCC advised that when floods occur on the Queensland coastal area the ground is generally saturated, and the volumes of runoff are so large that it is not necessary to take accurate account of initial loss. By contrast around Adelaide, initial loss may take up a significant part of the total rainfall, and must be taken into account for flash flood forecasting For example Table 4 shows an estimated 60% difference in flow between wet and dry initial catchment condition.

Table 4 Effect of initial loss on peak flow (Brown Hill Creek at Scotch College)

Effect of Initial Loss on rainfall amount and flood magnitude		
Storm Duration (hr)		3
Rainfall amount(mm)		60
Peak Flow rate (m^3/s)		
1	Dry catchment	4.2
2	Wet catchment	6.7
	Increase	60%

Notes:

1. Water loss also continues during and after a storm e.g. by infiltration and evaporation. This is allowed for in hydrologic modelling and is referred to as continuing loss. For flash flood estimation in and around Adelaide, continuing losses are of the order of 2 to 3 mm/hr and have not been taken into account at this initial stage.
2. There are many farm dams in the rural parts of the catchments. These retain flow during an event, and allowance must be made to account for their effect.

For ***urban areas***, most runoff comes from impervious areas, but little is known about the point at which the previous areas start to contribute to flood flow. Stormwater drainage conditions for Adelaide have changed over the years, and the percentage impervious area is increasing due to urban infill, this effect needs to be allowed for in flash flood estimation. In addition blockage of bridges, culverts, and accumulation of debris in river channels will affect flood flows and accuracy of prediction.

Estimation of catchment rainfall

Section 4.3 (above) describes how flood flows can be estimated at many flood forecast points within a catchment. The method requires that the average rainfall must be estimated for the contributing area upstream of the forecast point. MBCC uses *"Thiessen Polygons based on the rainfall gauge ……to define the notional area of influence of each* *gauge. Using these areas the weighting of each gauge contributing to the catchment of the stream point is calculated and used to calculate the Area Average Rainfall."*(Salter L et al., 2015). The BoM uses a similar method of weighting the rainfall input at a point for flood modelling, by using the inverse square of the distance of each Pluviometer from the central point. (Dartiguenave C and Maidment D, 1996)

Using either of the methods above, a single average rainfall amount can be calculated for each storm duration for the contributing catchment at each forecast point.

For Adelaide allowance must be made for initial catchment wetness condition (see previous section), the rainfall amount must be adjusted by deducting the estimated initial loss, current on that day, modified if necessary, by any pre-storm rain. Further work is needed to refine the process of loss estimation and at the present time loss estimation will rely on the judgement of a qualified hydrologist.

The net rainfall is referred to the "lookup" table to estimate of flood magnitude at the flood forecast point for all durations (currently 1 to 12 hours). The largest value at each forecast point will be displayed on a map similar to the example on Figure 2.

Use of area averaged rainfall is a simplification of the natural variability of rainfall in time, duration and intensity that occurs in storms. The assumptions are as for the Rational Method, described in Main Roads Western Australia .

"With the Rational Method, the assumption of uniform, steady rainfall tends towards underestimation of the peak discharge. On the other hand, neglecting storage effects within the catchment tends towards overestimation of the peak discharge. It follows that the catchments most conducive to valid results from the rational formula are those with small channel storage and short design storms"

In the case of Adelaide, the method is used for flash floods for short storms and it is necessary to estimate peak discharge at many different points on many catchments when time is of the essence. Quick analysis and interpretation of this data will allow maximum time for emergency services to respond.

General principles for a flash flood warning system

In a flash flood situation, those with the responsibility of issuing warnings must have access to all the data in a form that is clearly displayed and readily understood. On the day of a flash flood, time is of the essence and all possible evaluation, assessment and modelling must be done long before the start of a possible flood event. The following features are required in the new system:

- Map displays of the catchment, with the ability to zoom in to locations of concern
- Current rainfall totals at all locations, with options to display totals for whatever time period the forecaster desires
- Capability of including forecast rainfall, and integrating seamlessly with observed data
- Intensity-Frequency-Duration analysis for each rainfall location, displayed in graph or tabular form
- Comprehensive Rainfall-response data base, i.e. for each flood forecast location, how much rain over what time period will produce a flood of what magnitude

- Capacity to estimate initial loss at the start of the rain event, and to determine excess rainfall (see Section 4.4)
- Good quality flood inundation mapping, in a form that can be rapidly accessed to decide where breakout points are likely, and the critical flow at which breakout will begin
- The ability to assimilate all available data into a model, to forecast the magnitude and speed of development of flash floods
- Knowledge of which roads and infrastructure may be affected and the flows and water levels which may be critical

A system for flash flood monitoring, data display and forecasting as used by MBCC is well suited for use in Adelaide. A centralised system is recommended. By developing a central Flood Information Centre, and sharing the costs of setup and operation between State and Local government, it should be possible to run a full time operation, staffed by experienced hydrologists, and serving all of the flood-prone locations around Greater Metropolitan Adelaide. The system would be internet based, and provide access to all emergency response agencies under a Registered Uses arrangement.

Disclaimer

It should be noted that the research program undertaken and described in this paper is carried out by an independent team of researchers at the University of South Australia. Wherever mention has been made of other systems, agencies and councils, references to source material are given. The views expressed are independent of any affiliation with other organisations.

Conclusions and recommendations for further work

It is feasible to set up a flash flood forecasting service for Adelaide, adapted from systems developed interstate and fitted to local conditions.

The system described will minimise on-the-day tasks for flood monitoring, assessment and forecasting, thus giving maximum possible time for decision-making and response.

A centralised service developed and run by a team of expert hydrologists and emergency response experts is feasible, and the resources in people and technology are available to manage it.

A relatively simple system is recommended in the first instance, with the capability of adding features and complexity with the benefit of experience of actual flood events.

Further work is required to complete the coverage of all catchments and populate the “Lookup” table. Also further research is needed for forecasting partial area storms and stormwater overland flow.

Work is required on evaluating the performance of the average area rainfall method of flood estimation, particularly in relation to partial area storms.

Additional research is required to estimate initial and continuing loss rates for both rural and urban catchments for inputting to the flood forecast model.

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[i] [i]Real time means that the information is available now.

[ii] Automated Local Evaluation in Real Time (ALERT) The ALERT system was initially developed in the 1970s by the California-Nevada River Forecast Center in Sacramento, California (U.S. Department of Commerce. 1997a), and consists of automated event-reporting meteorological and hydrologic sensors, communications equipment, and computer software and hardware.

[iii] ENVIROMON is a software program developed by the Bureau of Meteorology to handle the rainfall and water level data collected by the ALERT telemetry systems operated by local councils for flash flood monitoring. It accepts and processes rainfall and water level data continuously. It has basic features for map displays of rainfall, and it will display single or multiple river hydrographs. ENVIROMON is very good at collecting, storing and transmitting data to other systems. It handles data from only ALERT systems, not from other SCADA systems.

[iv] TARDIS (Torrent and Rainfall Distribution Information System) TARDIS is a joint venture initially developed by Townsville City Council (TCC) then further developed and enhanced by Moreton Bay Regional Council (MBRC) and Sunshine Coast Council (SCC). TARDIS utilises the real time rain and water level information captured using the Bureau of Meteorology Enviromon software and stores the data using Microsoft SQL Server.