FLASH FLOODING IN AN URBAN ENVIRONMENT

Causes, effects, potential damages and possible remedies, with particular reference to Keswick Creek in the inner suburbs of Adelaide

Christopher J. Wright

Master of Engineering Science Thesis
University of Adelaide
Department of Civil and Environmental Engineering

June 2001

TABLE OF CONTENTS

FIGURES

TABLES

GLOSSARY

AAD	Annual Average Damages: The integral of the potential flood damages from the complete range of floods, reduced to an annual cost.
AEP	Annual Exceedance Probability: statistical definition to describe flood frequency
AHD	Australian Height Datum: the standard datum for elevations
AIFS	Automatic Integrated Forecasting System: a centralised computer system used by the Bureau of Meteorology for forecast preparation and distribution.
ALERT	Automatic Local Evaluation in Real Time: acronym for an automatic detection system for rainfall and water level, used widely in Australia for detection of floods.
ANU	Australian National University
API	Antecedent Precipitation Index: A method of calculating soil moisture status in a catchment on a daily basis, used to estimate the amount of rain sufficient to cause runoff to occur.
ARI	Average Recurrence Interval: common term to describe flood frequency
ARR	Australian Rainfall and Runoff, 1987: the manual of hydrological estimation, published by the Institution of Engineers, Australia.
BOM	Bureau of Meteorology
CMSS	Catchment Management Subsidy Scheme, a State Government funding program which provides dollar-for-dollar funding support to local councils for flood mitigation and catchment management projects.
CFS	Country Fire Service: A South Australian volunteer service responsible for fire fighting.
CIRA	Cooperative Institute for Research in the Atmosphere
Contrib'n	Contribution
Crit.	Critical
Cum.	Cumulative

DELFT-FLS	A 2-dimensional flow analysis program used for flood inundation studies.
Div.	Division
Doppler Radar	Modern high technology radar, used for weather observation, particularly rainfall.
Email	Electronic mail, using the Internet
Exp.	Exposure
FEMA	Federal Emergency Management Agency: the USA department which coordinates emergency response to disasters, including floods. This agency runs the national flood insurance program.
FM88	Local community radio service in Euroa and Benalla, Victoria, which will broadcast flood information in an emergency.
GIS	Geographical Information System
HEC-2	A computer program for one-dimensional hydraulic design, now superseded by HEC-RAS.
HEC-RAS	A computer program for one-dimensional hydraulic design, in common use.
Hr or hrs	hour or hours
IFD	Intensity Frequency Duration: statistical data, relating rainfall statistical probabilities, described in *ARR* 1987.
IFDcheck	program used by BOM to analyse rainfall data during a storm and determine the storm intensity for a range of different storm durations.
ILLUDAS	A fore-runner of ILSAX, see below.
ILSAX	The name of a runoff routing model used primarily for urban stormwater drainage design.
ISMES	A professional consulting group which designed the Sydney-Newcastle-Wollongong flash flood warning system.
KURMIT	Keswick Creek Urban Mitigation Unit: proposed management team to undertake a flood damage mitigation program for Keswick Creek floodplain.
Min	Minutes

m	metres
mm	millimetres
Mt	Mount
no.	Number
MIKE 11	A quasi 2-dimensional flow analysis program used for flood inundation studies.
MIKE 21	A 2-dimensional flow analysis program used for flood inundation studies.
NSW	New South Wales
NWS	The US National Weather Service
PC COPS	An automatic high capacity telephone message distribution system used in Western Australia.
Pluviograph	An instrument for measuring rainfall, made by Dines, which provides a graphical record of rainfall intensity, formerly used by the BOM.
Pluviometer	An instrument for measuring rainfall, in this case a tipping bucket raingauge, which gives a digital record of rainfall intensity.
PMF	Probable Maximum Flood: the largest flood that is theoretically possible
PMP	Probable Maximum Precipitation: the maximum amount of rain that can be generated by a storm
QPF	Quantitative Precipitation Forecasts: meteorological estimates of rainfall
RAA	Royal Automobile Association of South Australia
RAFTS	The name of a runoff routing model in common use for flood hydrograph estimation, for rural and urban catchments.
Rec.	Years of Record
RMA-2	A 2-dimensional flow analysis program used for flood inundation studies.
RO	Regional Office of the Bureau of Meteorology.

RORB	The name of a runoff routing model in common use for flood hydrograph estimation, mainly for rural catchments.
RRR	Rainfall Runoff Routing: the name of the computational model developed by Kemp for flood estimation.
SA	South Australia.
SCARM	Standing Committee on Agriculture and Resource Management: the group which published guidelines on floodplain management
SES	State Emergency Service: a South Australian volunteer emergency response group
SMS	Short Message Service: used to send flood warning messages to mobile phones. The message is displayed on the read-out panel on the mobile phone.
Stn	Rainfall Station (usually an official Bureau rainfall measurement location)
Tc	Time of concentration: the time taken for rainfall at the upper end of a catchment to flow to the outflow or measurement point.
UK	United Kingdom
URBS	The name of a runoff routing model used by the Bureau of Meteorology in conjunction with ALERT systems.
URBS-CM	A runoff-routing networked model of sub-catchment based on centroidal inflows. The model is used by the Bureau for flood forecasting.
USA	United States of America
Vic	The state of Victoria
WBCM	A Consulting Engineering group which undertook a flood study of Brownhill and Keswick Creeks in 1984.
Z-R	Used in radar rainfall interpretation to indicate the relationship between rainfall rate and radar echo strength.

ABSTRACT

A flash flood warning system is considered, taking a local urban catchment in Adelaide as an example, to determine its potential to function effectively and including;

- ☐ the structure of warning systems in their current form;
- ☐ the state of awareness of the population at risk; and
- ☐ the amount of potential damage.

A proposed set of actions and measures by which a system can be developed to minimise any future flood damage is then presented.

The effects of flash floods are described, including the extreme danger and destructive power of fast flowing water, and the characteristic lack of preparedness of urban communities. A risk management approach to flash flooding is suggested.

The use of rainfall alarms for early warning, and ways for optimising their efficiency are investigated. A detailed analysis of rainfall intensity data reveals some interesting features of severe storms. The development of tools for improved detection of severe storms is described.

The state of preparedness of the community, the vulnerability, and the time available for a flood warning to be effective are considered.

A survey of businesses in the floodplain is described, including:

- ☐ the level of awareness of flood risk by the management;
- ☐ the vulnerability to flood damage;
- ☐ the type of damage that would be suffered.
- ☐ the total financial cost of a flood to each business;
- ☐ the reduction in vulnerability to flood damage that could be achieved; and
- ☐ the potential value of a flood warning process.

Communication of flood warnings is considered. Two methods for quick communication of warning messages which could be applied to the Keswick Creek situation are examined.

Warning and response processes are evaluated in total for Keswick Creek, considering risk analysis, and examination of the time available for each process in a warning.

A matrix approach is used to introduce KURMIT, a blueprint plan for flash flood damage mitigation. The planning and warning processes can be integrated to achieve a major reduction in flood loss exposure.

The findings emphasise the significant exposure to financial risk of a business community, the remedies that are available and the reduction in risk that can be achieved.

DECLARATION

I declare that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge it does not contain any materials previously published or written by another person except where due reference is made in the text.

Signed:__ ____Date: 31st August 2001

NAME: CHRISTOPHER JOHN WRIGHT COURSE: Master of Engineering Science

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Libraries, being available for photocopying and loan.

SIGNATURE: DATE: 4th July 2001

ACKNOWLEDGEMENTS

This Masters program, which began in February 1997, has been a time of great interest with many challenges. To return to full time studies after a professional career of 27 years in civil engineering has proved to be stimulating and an opportunity to learn many new skills.

It would not have been possible to undertake this work without the generous assistance of the Bureau of Meteorology, which granted a 12-month Study Award and paid all study-related expenses for that time. Among the many professional staff who offered their support and assistance I am particularly grateful to Graeme Furler, the Director of the South Australian Regional Office; to Jim Elliott, who heads the Hydrology Program in our Head Office in Melbourne, and to Soori Sooriyakumaran, Senior Engineering Hydrologist who gave constant encouragement and arranged visits to key research hydrologists in Melbourne, and to the staff of the Training Branch, also in Head Office. The library staff in Head Office have been most generous in their help and support, and I am most grateful to Laurie Long and her associates.

At the University of Adelaide, Department of Civil and Environmental Engineering, I thank my supervisors, Trevor Daniell and Dr Martin Lambert, for much support and guidance, time taken correcting my earlier drafts, and positive suggestions. Much valuable help with computing and programming was provided by Dr Stephen Carr. Help in the structuring and development of my thesis was given by Associate Professor Deric Oehlers. My sincere thanks to the staff of the Department who provided willing assistance at all times.

At the Australian National University, Centre for Resource and Environmental Studies, Dr David Ingle Smith has been a constant guide and source of encouragement. It was he who stimulated my interest in determining flood loss exposure to commercial and industrial businesses, and provided invaluable advice.

Eve Gruntfest at the Department of Geography, University of Colorado, Colorado Springs, welcomed me to the flash flood country in Denver, Boulder and Fort Collins. She organised for me to meet many key people, such as John Weaver at CIRA (Cooperative Institute for Research in the Atmosphere), and Bob Jarrett of the US Geological Survey, who had excellent personal knowledge of flash flooding and flood risk. She arranged for me to join a Meteorologists' training course in Fort Collins, which included a tour of the Big Thompson Canyon, scene of a major flash flood disaster in 1976. I am most grateful for her cheerful help.

Kevin Stewart at the Urban Drainage and Flood Control District, Denver, introduced me to flash flood warning systems in Denver, and to the National Weather Service staff at the local Met office. Kevin has been a regular correspondent since that time, offering much advice and help.

Financial support for the three stages of the flood loss exposure survey was provided by the Patawalonga Catchment Water Management Board. The funding enabled the services of a professional loss adjuster and a property valuer to establish industry standard accuracy to the flood

1. INTRODUCTION

Keswick Creek, in the inner suburbs of Adelaide, is extremely vulnerable to flood damage but has not experienced a severe flash flood for at least 50 years. By and large, those who live and work in the floodplain are not aware of the risk of floods. The fundamental problem is that extensive urbanisation had taken place across a river floodplain. The creek has been confined within a narrow channel, through residential suburbs and through a large commercial and industrial area where retail stores, factory and warehouse buildings are located alongside and, in some cases, over the creek. Although a comprehensive flood study which identified significant areas of high flood risk, including 560 private houses, was completed in 1984, little has been done to mitigate the flood risk. The capacity of the channel is not sufficient to carry a major flood and the process of increasing the capacity and the associated civil works to remove or relocate buildings is not feasible for a heavily urbanised catchment. A flood monitoring and alarm system, known as ALERT (described below), has been in use since 1992 but little has been done to link the monitoring of rainfall and water flow with an effective flood forecasting and warning process; nor is there a way of rapidly disseminating flood information to those affected by the flood. In a personal communication regarding flash flood warning systems, Eve Gruntfest said that "ALERT tells 2 or 3 people that in half an hour a lot of people are going to die!", pointing out the potential weakness in total reliance on technological "quick fix" solutions (Gruntfest, personal communication, 1998a).

1.1 Aims

The aims of this investigation are to:

❑ examine the hazard of flash flooding as it affects Brownhill Creek;
❑ evaluate the strengths and weaknesses of ALERT systems for flash flood warning;
❑ investigate the possibilities and limitations of forecasting a flash flood;
❑ determine the vulnerability of development in the floodplain;
❑ find ways of reducing the vulnerability; and
❑ look for solutions to the Keswick Creek problem with the object of wider application in Australia and overseas.

1.2 Definition of Flash Flooding

For the purposes of this study, a flash flood is defined as a flood which occurs within 6 hours of the rain that causes it, the definition used by the Bureau of Meteorology in Australia. Flash floods, where they threaten urban communities, are often a threat to human life and can cause serious damage to property. Their characteristic short duration and high intensity makes them difficult to predict.

1.3 Description of ALERT Systems for Flash Flood Monitoring

ALERT is the acronym for Automatic Local Evaluation in **Real Time**[1] and refers to:

- ☐ a network of rainfall and water level monitoring stations attached to radio transmitters within a flash flood catchment;
- ☐ one or more computers, known as local base stations, equipped with radio receivers to capture and process the rainfall and water level data;
- ☐ computer software to interpret the data and display rainfall maps and hydrographs; and
- ☐ computer-based alarm systems designed to send alarm messages to mobile phones when a flood situation occurs.

ALERT systems are fully automatic, operate 24 hours a day and are used to detect flash flood situations. ALERT flood monitoring systems are effective in detecting potential flash floods but the vital consideration is whether there is enough time available between the detection of the flash flood and the time when it strikes, to warn and protect the people and property in its path.

However, the problem is that although a relatively sophisticated **monitoring** system is in place to detect flash floods, the actual warning system as a whole is incomplete because it does not include any consideration of the process of transmitting the warning message to all of those who will be affected by the flood.

1.4 Bureau of Meteorology's Role in Flash Flood Warning

The Hydrology section of the Bureau of Meteorology (BOM) in Adelaide is required to forecast floods for the major river systems and issue warnings to people in the floodplain who may be affected but the Bureau role is restricted to rivers which take more than 6 hours for floods to develop.

For flash flood catchments, the rapid response to heavy rain allows little time for forecasting a flood, issuing warnings and for those in danger to respond. There is, at present, no agency which has the responsibility for forecasting and giving warnings of flash flooding.

The Severe Weather section of the BOM is developing techniques for monitoring the development and severity of severe storms but, although it is possible to forecast the imminent development of severe storms, it is not possible to determine the exact location until they form and, by then, there is very little time for warning.

---

[1] **Real time** means immediate or current. Rainfall and water level data is transmitted in real time and reaches its destination without appreciable delay. Real time data collection is a vital part of flash flood monitoring systems.

In 1988, the Bureau of Meteorology (BOM) established an ALERT automatic flash flood monitoring system in the upper reaches of Brownhill Creek. After the floods of 1992, the system was extended into Keswick Creek, a major tributary of Brownhill Creek, which responds to rain very quickly with rapidly increasing water levels, reaching its flood peak in less than 3 hours after the beginning of a storm. Brownhill Creek, on the other hand, because of its comparatively large rural catchment, tends to respond slowly to floods and it may take more than 10 hours after heavy rain for the flood to reach a peak within the city.

Although a flood monitoring system is in place and alarms will be sent to a few people when a flood situation on Keswick Creek occurs, a warning system for flash flooding does not exist. Nor is it clear, if it did exist, whether it would be effective in minimising flood damage.

1.5 Maximising the Effectiveness of Flash Flood Warnings

The effectiveness of a warning system can be measured after a flood by determining how many people received the warning and took action to avoid damage to property, personal injury, or even death. The conventional view of a warning system is shown on Figure 1.1 as a linear process, starting with detection of rainfall and water level and proceeding through the steps of flood forecasts, issuing of warnings and response by those affected by the flood.

This process is satisfactory when there is time for each step to be carried out. In flash flood situations it will be shown that there is unlikely to be sufficient time.

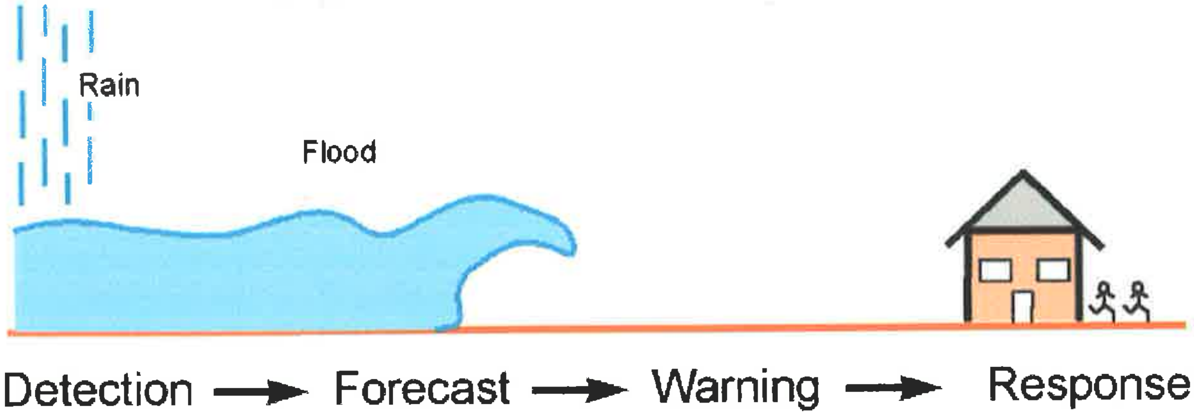


Figure 1.1 Conventional flood warning process

An alternative approach, which will be developed in Chapter 10, is for the problem of flood risk to be seen as a whole, including planning and risk reduction measures, and incorporating these into a flood awareness and warning process, as indicated on Figure 1.2. This "matrix" approach will demonstrate a more effective way of reducing flood loss exposure and avoiding reliance on a flood warning system that is likely to be limited in effectiveness by shortage of time.

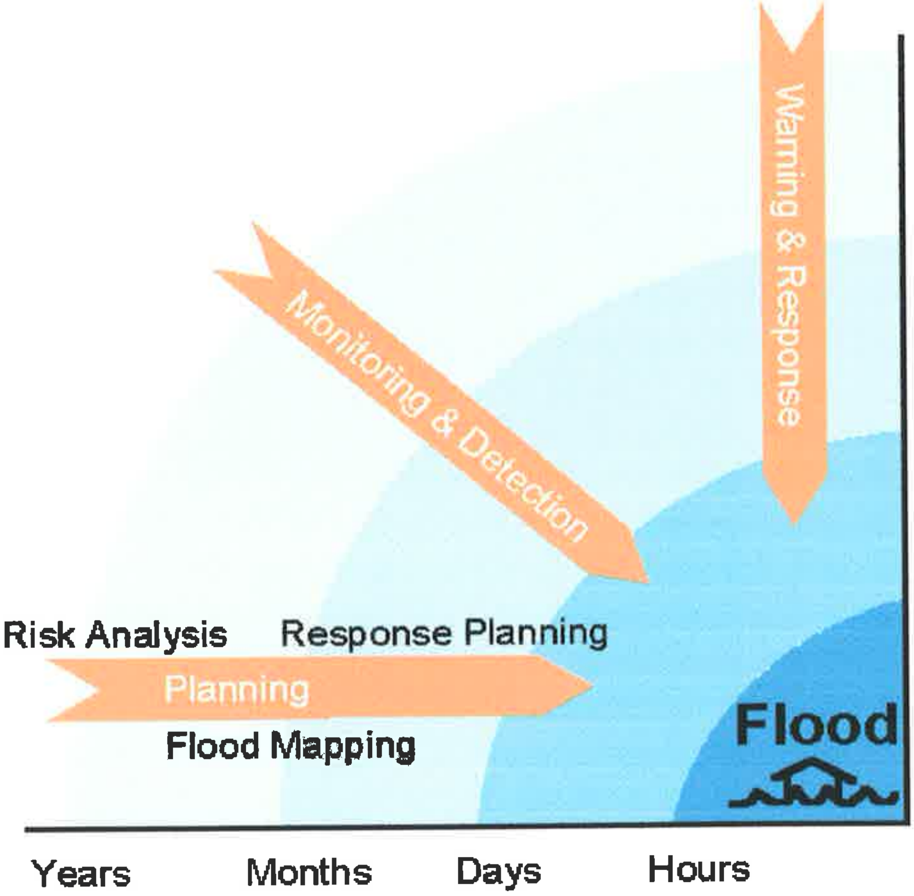


Figure 1.2 Matrix approach to flood risk reduction

1.6 Thesis Structure

In this investigation the total warning system is considered to determine its potential to function effectively, including;

- ☐ the structure of the warning system in its current form;
- ☐ the state of awareness of the population at risk; and
- ☐ the amount of potential damage.

A proposed set of actions and measures by which a system can be developed to minimise any future flood damage is then presented. The structure is shown on Figure 1.3 and is as follows:

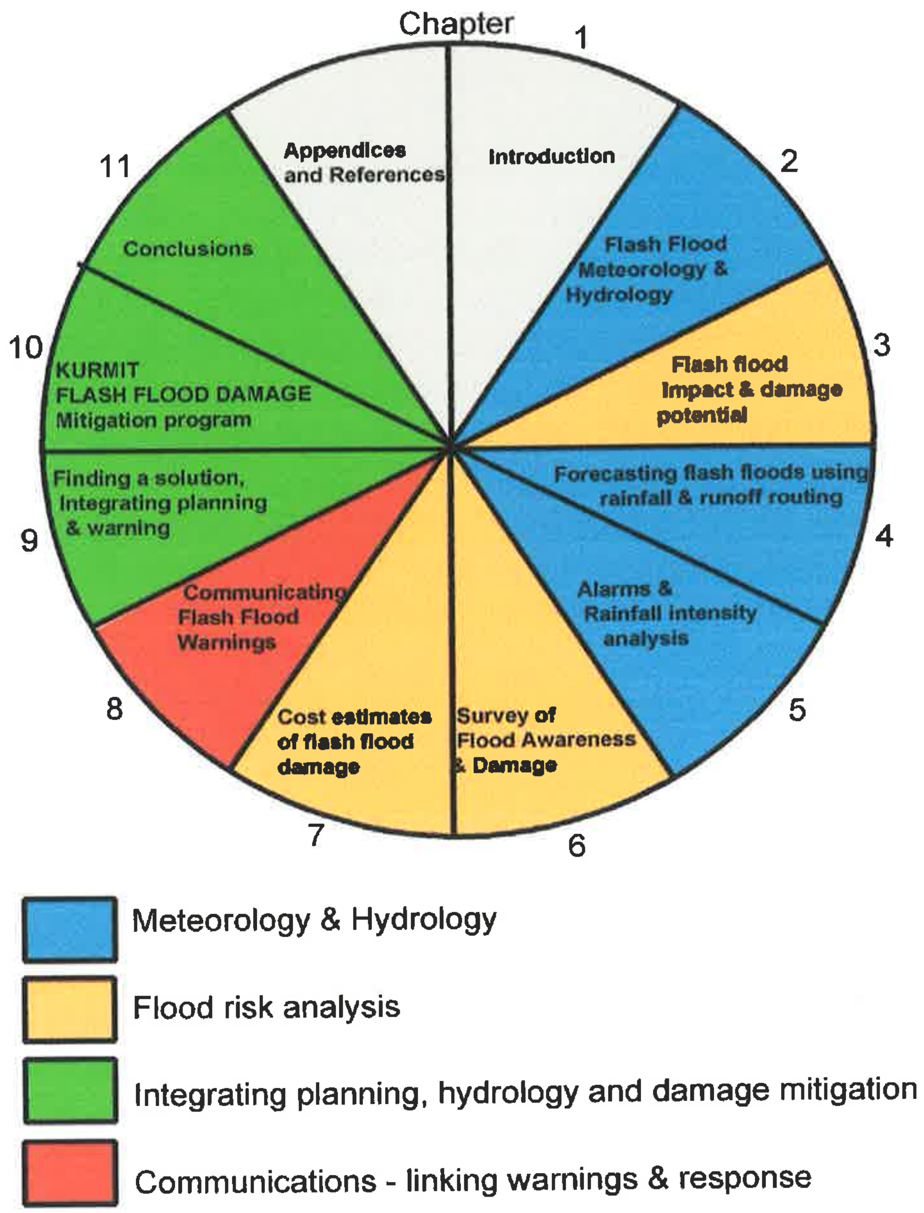


Figure 1.3 Plan of chapters, showing how the different subjects relate to each other and are integrated in the final sections.

Chapter 2: Definition and hydrology of the phenomenon of flash floods.

Chapter 3: Effects of flash floods, the suddenness with which disaster strikes a community, the extreme danger and destructive power of fast flowing water and the lack of preparedness which is characteristic of so many communities that are subject to this risk. A risk management approach to flash flooding is suggested and one of the paradoxes of flood warning is introduced, namely that more accurate flood forecasts can only be achieved by waiting until it is too late to issue a warning.

Chapter 4: The possibilities and limitations of rainfall measurement and analysis for flash flood prediction are examined. Keswick Creek is described, including the particular hydrologic characteristics that make it difficult to predict or detect floods in time.

Chapter 5: The use of rainfall alarms for early warning and ways for optimising their efficiency are investigated. A detailed analysis of rainfall intensity data reveals some interesting features of severe storms. The development of tools for improved detection of severe storms is described.

Chapter 6: The focus of the investigation changes to consider impacts of flash floods, the state of preparedness of the community, the vulnerability and the time available for a flood warning to be effective. Efficient response processes are essential if the warning is to have any value and since each component of the detection, forecast, warning and response processes take time, their sum will give an indication of how much time in advance a flood warning must be issued for it to be effective. It describes a survey of businesses in the floodplain which investigated:

❑ the level of awareness of flood risk by the management;
❑ the vulnerability to flood damage; and
❑ the type of damage that would be suffered.

Chapter 7: Cost estimates of flood loss exposure of the businesses surveyed in Chapter 6 are provided. They include:

❑ the total financial cost of a flood to the business;
❑ the reduction in vulnerability to flood damage that could be achieved; and
❑ the potential value of a flood warning process.

Chapter 8: With the benefit of direct knowledge of flood prone businesses that was gained in the survey, the question of communication of flood warnings is considered. Two methods for quick and efficient communication of warning messages which could be applied to the Keswick Creek situation are examined.

Chapter 9: The warning and response processes are considered in total for Keswick Creek, considering the risk analysis approach and an examination of the time available for each of the processes in a warning. The overall objective is to protect a business community from major financial loss.

Chapter 10: The matrix approach, described in Chapter 1, is used to introduce KURMIT, a plan for flash flood damage mitigation. It shows how, for Keswick Creek, the planning and warning processes can be integrated to achieve a major reduction in flood loss exposure. A distribution of actions and responsibilities is proposed for all owners and agencies who are involved in or affected by a flash flood.

Chapter 11: The concluding chapter summarises the findings, emphasising the significant exposure to financial risk of a business community, the remedies that are available and the reduction in risk that can be achieved. It notes the limitations of an ALERT system for flood warning, which is only part of an overall process and needs enhancement and integration into an overall planning process before it can be fully effective.

Appendices and References follow.

2. BASICS OF FLASH FLOOD HYDROLOGY

This chapter begins with the definition of flash floods and considers:

- ☐ the characteristics of rainfall that lead to flash flooding;
- ☐ rainfall measurement and intensity;
- ☐ illustrates the geographic variability in rainfall intensity and duration;
- ☐ use of flood magnitude by computational modelling;
- ☐ the particular problems of flood simulation for events outside the range of historical events;
- ☐ particular problems of use of flood modelling for forecasting flash floods in real time; and
- ☐ the relationship between flood magnitude and probability.

Characteristics of storms which produce flash floods are discussed, and some examples given. The use of radar as a means of identifying potentially dangerous storms is described, including the strengths and weaknesses of radar measurement.

2.1 Introduction to Flash Flooding

The problem of urban flash flooding, a natural hazard common to many countries, is not restricted to those with high annual rainfall. "Flash" flooding refers to floods which occur very suddenly, are usually very intense and dangerous, and for which there is little time to prepare and respond. The term "flash flood" is specified by the Bureau of Meteorology in the *Weather Services Handbook* (Bureau of Meteorology, 1995), to mean a flood which occurs within 6 hours of the rain which caused it. *Floods - An Insurable Risk?*, a worldwide review of flood risk by the Swiss Reinsurance Company (Hausmann et al., 1998), covers 24 countries, ranging from Switzerland, in the temperate zone, to Indonesia in the tropics. It confirms that flash flooding is a problem for all of them. Flooding is a natural process, the consequence of heavy rainfall over a catchment. Flash floods are of particular concern to urban communities because of the potential danger to human life when they occur and they are a leading cause of death from natural hazards. They tend to be relatively small in scale but, despite this, can cause great devastation. The American Meteorological Society Policy Statement (American Meteorological Society, 1993), notes that flash floods are the leading cause of deaths from natural hazards in the United States. It gives the example of the flash flood disaster at Shadyside, Ohio, where 26 people lost their lives, and emphasises the particular concern about this natural hazard which often affects quite small areas. The storm which produced the flash flood at Fort Collins in 1997 covered an area of less that 10 km^2. With increasing world population, the pressure to occupy flood-prone land is increasing and, with it, the need to consider the risk of flash flooding and the protection of the community.

2.2 Definition of Flash Flooding

The Bureau of Meteorology (BOM) gives three causes of flash flooding, as follows :

> "(A) *Severe Thunderstorms*: a thunderstorm that produces rainfall of sufficient intensity to cause flash flooding is, by definition, a severe thunderstorm.
>
> (B) *Heavy Rainfall*: rainfall of sufficient intensity to cause flash flooding, independent of antecedent conditions, can be the result of a meteorological event other than a thunderstorm. Flash flood warnings for these events are just as important as those resulting from severe thunderstorms.
>
> (C) *Non-Intense Rainfall*: flash flooding is not always the result of very intense rainfall. In some cases flash flooding can occur during periods of prolonged rainfall, resulting for example, from a weather event or a stationary front. River levels already high, but not yet in flood, can suddenly increase to flood level following a short burst of rainfall during these situations." (Bureau of Meteorology, 1996)

The insurance industry has a close interest in flash flooding. A review titled *Flooding and Insurance* by the Munich Reinsurance Company gives the following definition:

> "Flash floods usually develop from local precipitation of an extremely high intensity, as generated during thunderstorms, and they lead to flooding in a limited area with a high rate of flow and catastrophic amounts of damage." (Munich Reinsurance Company, 1997, p. 30)

The BOM definition of a flash flood (Bureau of Meteorology, 1995), as a flood which occurs within 6 hours of the rain, is important in Australia because the BOM is legally required to issue warnings only for non-flash floods and does not provide a service for flash floods. The rationale for this reflects the difficulty in providing a forecast for an event which develops extremely quickly and is of small scale at an indeterminate location. Keswick Creek, the object of this study, can produce a flash flood within 15 to 30 minutes of the rainfall. The relatively small scale of the event, the rapidity of development and the limited time to warn create a formidable challenge. By comparison, the Gawler River, which has a floodplain crossing the northern limits of Adelaide, is categorised as non-flash flood and takes 12 to 18 hours to reach Gawler.

It is the speed and intensity with which flash floods can develop that makes this phenomenon so dangerous. At the upper limit of 6 hours, a well prepared community, with a good rainfall detection system and a well developed communication system, could be expected to avoid loss of life and minimise the damage caused, but at the lower end of the scale there are formidable difficulties.

Floods are predictable, in the sense that it is possible to determine high flood risk areas and to estimate the extent of flooding in a floodplain for various flood intensities. Floods are defined in *Australian Rainfall and Runoff* (Institution of Engineers, Aust., 1987), in terms of Annual Exceedance Probability (AEP). Rightly or wrongly, the AEP 1 in 100 flood, which has a 1% chance of occurring or being exceeded in any year, is often used as the upper limit for flood protection. The problem with floods is that it is impossible to know in advance when they will strike. For flash floods there is the additional problem that there may not be time to issue warnings and respond before the flood strikes a threatened community.

2.3 Rainfall Characteristics and Forecasting

If the characteristic rainfall can be forecast, predicted or analysed in time to provide a flood warning, then it should be possible to avoid loss of life and minimise the damage. The BOM definition (Bureau of Meteorology, 1995), identifies rainfall intensity as a critical component, and an understanding of flash floods depends on the relationship between the frequency, intensity and duration of rainfall bursts. Chapter 2 of *Australian Rainfall and Runoff* (Institution of Engineers, Aust., 1987), provides a method for determining the statistical probability of intense rainfall bursts for any place in Australia. Usually flash flooding is caused by storms of 6 hours or less. Longer duration storms would be expected to cause less intense flooding but these longer storms could contain short bursts of high intensity rainfall which may lead to flash flooding.

2.4 Rainfall Intensity

Using a long record of rainfall for a particular location, all storms or rainfall bursts of a specified duration, for example one hour, can be extracted, categorised and ranked in intensity (mm/hr). Using probability analysis, the expected intensity of a storm of any Annual Exceedance Probability (AEP) for the particular duration can be obtained and the relationship extrapolated to give an indication of the expected intensity of rarer storms. Figure 2.1 gives the storm intensity statistics for the state capital cities in Australia. They are probabilities of occurrence of a 1-hour burst of rainfall being equalled or exceeded in any one year. The 1-hour rainfall amounts are given for each city, for the AEP 1 in 1, the AEP 1 in 100, and the Probable Maximum Precipitation (PMP) which is the theoretical greatest amount of rain that can occur.

Annual Exceedance Probability (1 in x)	1	100	PMP
% Chance of occurrence in any year	100%	1%	0.0001%
Max rainfall in any hour during the year (mm)	49	117	430

Table 2.1 Rainfall statistics for Darwin

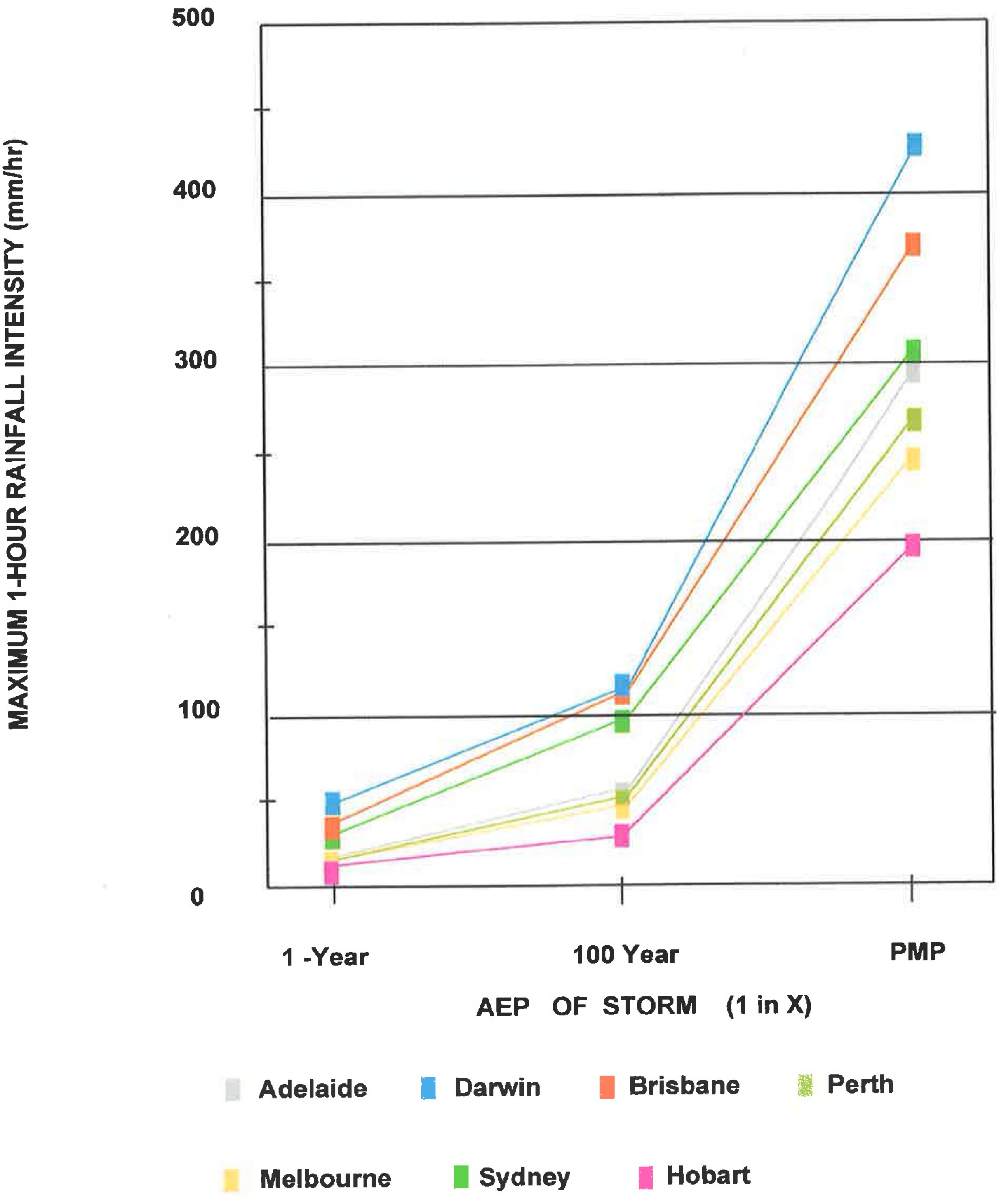


Figure 2.1 Rainfall maxima for capital cities (Maximum rainfall in one hour)

Table 2.1 gives the values for Darwin, taken from the Figure 2.1. Note that the storm burst duration in Figure 2.1 is specified as 1-hour and the figures are the maximum rainfall that would be expected to occur in any 1-hour period in any year. For Darwin, it is highly probable that a storm burst of 49 mm in 1 hour will occur or be exceeded at least once, while there is a 1% chance on average that a burst of 117 mm will occur or be exceeded and, finally, that there is a 0.0001% chance that a burst of 430 mm will occur.

The statistical data is useful in showing the range of rainfall maxima that can occur in a fixed time (1 hour in this case), and the relative risk of occurrence. Figure 2.1 illustrates the wide variation in extreme rainfall between different climate extremes in Australia. *Australian Rainfall and Runoff* (*ARR*) (Institution of Engineers, Aust., 1987) statistics can be obtained for anywhere in Australia, for AEP 1 in 1 to AEP 1 in 100, for any storm duration between 5 minutes and 72 hours. For engineering analysis, it is convenient to deal primarily with storms of fixed duration. The standard durations considered by *ARR*, are :

5, 6, 10, 20 and 30 ***minutes***
1, 2, 3, 6, 12, 24, 48 and 72 ***hours***

Storm intensity statistics in *ARR* were derived from a very limited series of pluviograph records, there being less than 20 pluviographs with continuous records longer than 50 years. The minimum time increment on the data base is 6 minutes. At the time of the analysis there were less than 300 pluviograph stations available for the whole of Australia. Therefore, it was necessary to interpolate between widely spaced data points and, because of the relatively short record, to extrapolate to obtain AEP 1 in 100 storm rainfalls. Because of the relatively small number of severe storms in the data set for each site, it was necessary to analyse high intensity storm bursts which were part of longer storms. The restricted size of the sample has led to some anomalies in the analysis, particularly noticeable in the published range of Temporal Patterns. It is important to understand that the Intensity Frequency Duration (IFD) data are only estimates based on a small data set, particularly for the short duration storms which produce flash floods.[1]

ARR describes the process of using storm bursts, rather than complete storms, for IFD analysis. This implies that **antecedent catchment wetness** could be critical in estimating flash flood intensity.

Flash flooding is commonly the result of severe thunderstorms concentrated over a small area. The effect of such storms depends on location, areal extent and intensity. It is not necessary for the storm to cover the whole catchment to produce a major flood. For instance, the catastrophic flood of Fort Collins, Colorado, in July 1997 described by Grimm in "Floodplain Management" (Grimm, 1998), was caused by a storm over only 40% (30 km^2) of the Spring Creek catchment but which produced an AEP 1 in 500 flood on Spring Creek in Fort Collins (the upper 60%, 46 km^2, of the Spring Creek catchment was totally protected by a storage reservoir).

---

[1] In contrast with the short duration analysis based on pluviograph data, there is data available for 24, 48 and 72 hour storms from approximately 7000 daily-read raingauges.

Radar installations are now used routinely to track events and to spot severe storms, as described in *Sydney-Newcastle-Wollongong, Flash Flood Warning System* (ISMES, 1992, pp. 48-51). Radar pulses are reflected off droplets of rain and ice and by measuring the strength of the reflected signal an analogue of rainfall intensity can be obtained and displayed on a computer screen. The radar images displayed actually represent discrete volumes of atmosphere. Within each volume sample the intensity of rainfall is assumed to be constant. Radar can be used to scan both in the horizontal and vertical planes, and the enormous variation of intensity within a storm can be demonstrated clearly. This contrasts with the assumption made for design storms used for engineering purposes to estimate catchment rainfall, that rainfall intensity will vary in time in accordance with an established pattern and be evenly distributed across the catchment, with an areal adjustment factor to take account of catchment size.

Radar reflectivity measures the combination of intensity and duration of rainfall, and is capable of sampling specific volumes of the atmosphere with the potential to build up a complete picture of the storm. Rainfall intensity measurement by radar is complicated by physical factors such as differences in reflectivity between large and small raindrops and, particularly, by the presence of ice in the cloud mass which gives rise to very much stronger echoes, known as bright band effects. There is ongoing research worldwide into the Z-R relationship between radar reflectivity [Z] and rain rate [R]. Examples are given by Sun in "Formulation and optimisation of the probability matching method for radar reflectivity and rain rate in the Darwin region" (Sun et al., 1999), *Hydrological Applications of Weather Radar* (Cluckie and Collier, 1998) and *Weather Radar Technology for Water Resources Management* (Braga and Massambani, 1997). In the United Kingdom, rainfall measurement by radar for non-flash flood purposes has advanced to the point that it can be used as an alternative to direct measurement, as described by Moore in "Rainfall and Flow Forecasting using Weather Radar" (Moore, 1995). However, in areas which are subject to flash flooding, the use of radar can be subject to considerable error and in "Some Unusual Aspects of the Fort Collins, Colorado Flash Flood of 28 July 1997" (Weaver, 1998), a discussion on the Fort Collins storm of July 1997, John Weaver explains how easy it can be to misinterpret rainfall intensity using radar imagery. In this case a summer storm was **not** identified as critical since the radar reflections did not suggest high intensity rainfall. In fact, the storm was unusual as it was generated within a warm, very humid air mass. Rainfall droplets were small and the storm contained neither hail nor ice. The typical convective storms at that time of year in Colorado characteristically contain both ice particles and hail, and the Z-R ratio is adjusted to take account of the stronger echo from the ice particles. The Fort Collins storm was very intense, as indicated in Table 2.2. Statistics for Australian capital cities are given for comparison.

The Spring Creek catchment had been saturated by 100 mm of rain the previous night and this was followed by a storm of 166 mm of rain in only 5 hours. Colorado is renowned for its severe storms but the Fort Collins storm data would not be out of place in an Australian situation and storms of similar intensity will occur. The Fort Collins storm had an estimated AEP of 1 in 500 and, since the *Australian Rainfall and Runoff* IFD data (Institution of Engineers, Aust., 1987) is limited to AEP 1 in 100, a direct comparison using *ARR* is not possible. In approximate terms only, the rainfall intensity would not be exceptional for Australian cities in tropical locations (see Figure 2.1), but the experience of severe storms indicates that even in drier and more southerly locations of Australia, high intensity rainfall events can be expected from time to time. The 1925 storm over North Adelaide is a typical example. It produced 125 mm of rain in only 5 hours. Therefore, the risk of such events occurring over sensitive, flood prone locations should be considered.

Rainfall (mm)	**AEP 1 in x**	**5 hours**	**24 hours**	**Maximum Recorded 24 hours**
Adelaide	100	76	119	142
Darwin	100	178	322	290
Brisbane	100	185	319	465
Canberra	100	85	143	126
Hobart	100	69	142	156
Melbourne	100	79	136	108
Sydney	100	167	293	216
Fort Collins Storm	500	165	266	

Table 2.2 Fort Collins storm statistics, 27-28 July 1997 compared with Australian capital cities

2.5 Rainfall Measurement

Flash floods are short duration events, and flash flood forecasting requires an accurate record of accumulation of rainfall in time. The instrument commonly used for this is the Tipping Bucket Raingauge, also known as a Pluviometer.[2] The instrument has a double-bucket arrangement and as each bucket fills, it tips, emptying the contents into a reservoir and exposing the second bucket to the inflow. The instrument is calibrated so that each bucket tip represents a constant amount of rainfall (usually 0.2, 0.5 or 1.0 mm). At each tip of the bucket a magnet passes in front of a micro-switch, causing the switch to close. By detecting the switch closure using an electronic logger, a time series record of rainfall can be compiled from which the cumulative rainfall and intensity can be determined.

Use of radar to measure rainfall has been described previously in Section 2.4 and, despite its

---

[2] This name distinguishes it from the Pluviograph, such as the Dines, which provides a graphic representation of the storm rainfall on a standard chart. These instruments provided vital data records up to 1990 but are now obsolete, partly because of the difficulty and cost in digitising the analogue record.

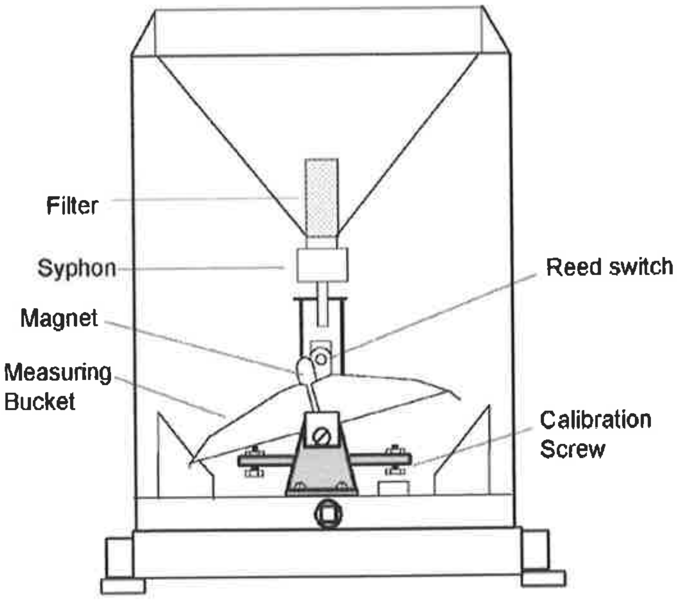


Figure 2.2 Tipping Bucket Raingauge (Pluviometer)

limitations, its use for this purpose is increasing. Integration of radar scanning and ground measurement of rainfall will allow calibration of the radar analogue signal in real time so that cumulative rainfall estimation by radar can be compared with the actual amount recorded in raingauges. Radar gives an analogue of the areal variation in intensity across the catchment, potentially value-adding the point rainfall data provided by raingauges.

Radar rainfall data is readily available since it is collected continuously by the BOM, over approximately 60% of the Australian land mass (and extending over the oceans wherever there is a specific need). Radar imagery is now available to approved users, updated every 10 minutes, and the BOM uses software which allows the user to view a time series of images so that the movement of storms can be tracked. Radar images are also available on the Internet, although displayed on a smaller scale. On the down side, the radar units scan a radius of 125 to 250 km and are not designed for detection at flash flood catchment scale.

2.6 Flood Development Processes

Runoff processes, whereby rainfall landing on a catchment surface moves towards the outlet, are extremely complex and variable. For the purposes of simulation and flow prediction by computational modelling, it is usual to make relevant assumptions to simplify the physical process. A model is essentially the best approximation that can be made to reality. The modelling process is discussed in Section 4.3.

When rain falls on a catchment there is an initial “wetting up” period when rainwater covers exposed surfaces of vegetation and ground, after which water begins to infiltrate the ground. If the rainfall intensity is greater than the infiltration capacity of the soil, water will start to collect on the surface, in pools, and excess water will run downslope into channels or larger

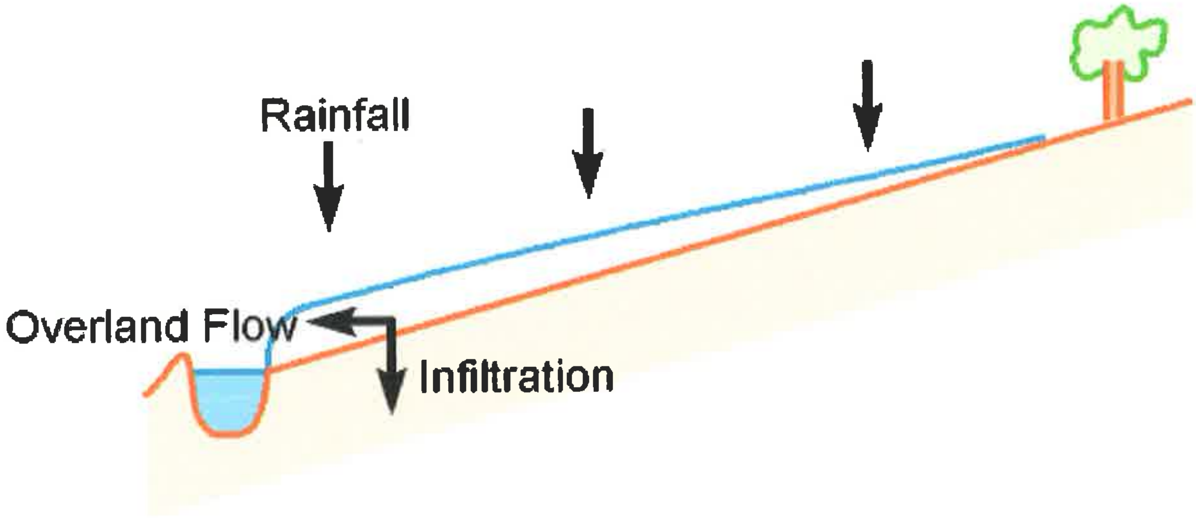


Figure 2.3 Hortonian Overland Flow

storage of some kind. This surface flow, described in *Water in Australia* (Smith, 1998), is often referred to as **Hortonian Overland Flow**, after Horton, the American engineer, who described it in "The Role of Infiltration in the Hydrological Cycle" (Horton, 1933).

Once the overland flow reaches a natural channel or drain, its movement can be determined by hydraulic analysis. Water that infiltrates the soil surface may re-emerge further down the slope or may enter the flow into the groundwater aquifer, perhaps returning to the surface as a spring or seep. The process varies with soil type, ground conditions and vegetation cover; they are in constant interaction and do not necessarily occur separately. There is a clear distinction between "natural" catchment surfaces, which can absorb, retain, hold and delay stormwater; and urbanised catchments where paved and roofed surfaces cause rain water to flow directly off them. By contrast, the vegetation which covers natural catchments holds, absorbs and delays the flow of water and slows its path to a stream or river.

Urbanised catchments direct stormwater to stormwater pipes and channels, with the objective of removing the water as efficiently as possible. For urban flash flood estimation purposes, the major consideration is how much of the rainfall flows from the catchment into river channels and how quickly.

In discussing his Rainfall Runoff Routing (RRR) model for flood forecasting on rural catchments, Kemp, in Section 4.1 of "A Proposal for a Rainfall - Runoff - Routing (RRR) Model" (Kemp and Daniell, 1996), separates the flow processes within a catchment into three phases:

☐ *Base flow*, the steady state regional groundwater system. It is known that the lag between rainfall and runoff by discharge to streams can be substantial due to the long flow path length in the groundwater system;

- ☐ *Slow flow*, capillary fringe flow. This mechanism acts with a lag from rainfall to stream flow that is less than that of the base flow above, due to the quicker response time from rainfall to runoff into the stream; and
- ☐ *Fast flow*, similar to Hortonian overland flow, either from a part of the catchment area or the full catchment area. The response time of this mechanism is short compared with the two above, as no groundwater flow is involved.

These are equivalent to the physical processes occurring in the catchment. The RRR model is able to treat each process separately in terms of storage and lag. Kemp identifies the third process as a phenomenon that occurs quite rarely, but which is important for flash flood purposes because it can lead to very rapid runoff. An instance of this effect was noted by Daniell, Kemp and Dickins for a storm at Olary, to the east of the Flinders Ranges in South Australia, (Daniell et al., 1998). In this storm, despite a lack of data on the temporal distribution of the storm, it was possible to identify a preliminary wetting-up period, followed by very intense rainfall. The analysis suggested that this sequence of events led to direct runoff, with virtually no losses, and it contrasts with less severe events in South Australia where losses in excess of 80% of the rainfall are common. Studies of soil erosion, described in *Soil and Water Conservation Engineering* (Schwab, 1955), have shown that when raindrops impact directly on bare earth, the impact breaks down soil particles, causing capping of the soil surface to occur, leading to rapid runoff of stormwater and consequent soil erosion. Other causes have also been noted. Jarrett, in a paper entitled "Effects of rainstorms on water and sediment runoff following the 1996 wildfire, Buffalo Creek, Colorado" (Jarrett and Browning, 1998), showed that areas which had been burnt prior to rainfall had produced up to 20 times the runoff from unburnt areas. He attributed this effect to hydrophobic (water repellant) soil conditions developing as a result of wildfire, resulting in an impermeable surface with no capacity for water absorption. A similar effect was noted when a major storm occurred over First Creek, just after the Adelaide bushfires of 1983, producing enormous amounts of runoff, ash, sediment and other debris. The problem is that the phenomenon occurs rarely and is difficult to measure, but is a real possibility if severe storms occur over un-vegetated or burnt catchments. Nevertheless, it is intuitively clear that if vegetation is removed from an area, leaving bare ground, and if a storm occurs, there will be a large amount of runoff and the possibility of severe erosion. The publication *Flooding and Insurance* (Munich Reinsurance Company, 1997), makes the point that the damaging impact of flood water is often increased considerably when it contains silt, stones and other debris. Urbanisation similarly replaces trees and grass with bitumen, concrete and house roofs, and a quantum increase in runoff is to be expected.

2.7 Flood Storage in Relation to Flood Forecasting

The estimation of storage of water in a catchment during a storm is critical to flood forecasting. Storage of water occurs whenever rainwater is held and released gradually or instantaneously to flow further down the catchment. The effect of catchment storage is to modify the outlet hydrograph. For example, a reservoir in a catchment will store water during a flood and release it afterwards, resulting in reduction in the peak discharge at the catchment outlet, potentially delaying the peak and providing more time to warn the community downstream.

Storage can affect all or part of the stormwater. At the time when a storm begins, there is no flow at the outlet but, after some time, flow will start, then build up to a maximum and finally subside. Early in the storm, before flow starts at the outlet, rain will have fallen and, therefore, the water is being held in storage for subsequent release. Some of the storage, such as wetting of the foliage of trees, the ground and depression storage, is lost by evaporation. Some is lost to seepage into the ground and a part flows into adjacent channels and creeks, eventually to reach the outlet. The storage effect is a combination of "live" storage on flooded catchment surfaces and in channels, and the delay between rain falling and the time when the water flows out of the catchment. In the same way that the size of the reservoir determines the amount by which the flood peak is reduced and delayed, so does the amount of storage in the catchment by other processes affect the subsequent discharge. Therefore, determination of these storage effects is critical to the correct estimation of floods resulting from storms.

The proper treatment of storage is critical to hydrologic modelling of water flow in a catchment. The use of linear and non-linear storage in the modelling process is described by Kemp in Chapter 8 of "The Development of a Rainfall-Runoff-Routing (RRR) Model", his doctoral thesis (Kemp, 2000), and Laurenson, in a set of workshop notes entitled "Flood Estimation by Runoff Routing" (Laurenson et al., 1975, see pp. 15-25, 93-101 in particular). Section 7.2 of *Australian Rainfall and Runoff* (Institution of Engineers, Aust., 1987), also deals extensively with storage processes.

It is easy to comprehend the delaying and storing processes in a natural catchment but in urban drainage systems which are often designed to remove stormwater as quickly as possible, the storage effects are less obvious. In heavily urbanised catchments where runoff occurs very soon after a storm begins, storage is occurring in the gutters and drains, although the volumes are generally smaller than in natural catchments. Importantly, storage can also occur on a large scale when floods break out from the river and creek channels and spread across the floodplain. The water in the floodplain is stored temporarily until it finds its way back into the channel.

Catchment storage is not constant. In a natural catchment, the storage effects will vary from storm to storm depending on the intensity of the rainfall. Storage will also vary seasonally with the different amounts of vegetation present and with varying soil conditions. Human impact on catchment storage can be a major factor. Apart from the construction of reservoirs, human activities, such as agriculture, will modify the ability of catchments to store water by removing natural vegetation and replacement with bare earth or row crops. Urbanisation replaces natural vegetation with:

- ❑ roads with bitumen surfaces;
- ❑ concrete paving
- ❑ house roofs; and
- ❑ concrete drains and pipes.

All of these have the effect of increasing the amount of stormwater runoff, reducing the water storage in the catchment and reducing the response or lag time of the catchment.

2.8 Flood Simulation Models for Flash Flood Warning

Simulation of floods by some process of modelling is done routinely by engineers:

- ❑ to determine the magnitude and rarity of past floods;
- ❑ for flood estimation, for design purposes, for bridges, culverts, dam spillways and the like; and
- ❑ for flood forecasting in real time, ahead of a major flood event.

Models can be simple or complex and can take a variety of forms; physical, graphical or computational. A simple example is the construction of a physical model of a catchment to a specific scale, applying simulated rainfall to it, and measuring the flow which occurs. This approach is useful for demonstration purposes but is not generally suitable for flood estimation due to:

- ❑ the difficulty in simulating catchment conditions;
- ❑ problems such as scaling effects on rainfall, water viscosity and simulating sediment transport; and
- ❑ the high cost of construction.

These days physical models are still constructed for examining complex flood level problems, such as flood defences in China. They are also used for public exhibitions because they catch the eye and do not require elaborate explanation.

Graphical modelling methods are still widely used, particularly for situations where emergency response staff, with limited engineering skills, can interpret flood information and, by use of simple graphic procedures, obtain a flood forecast. In South Australia in the late 1980s and early 1990s, simple graphical models were developed for flood prediction in the Gawler

Catchment. These were plots of all maximum flood heights recorded at upstream and downstream points on the river, with the upstream station plotted on the x-axis and the downstream station on the y-axis. The correlation between upstream and downstream water levels for a range of floods was reasonably good and, although this type of model is somewhat crude, it was useful in giving an immediate and early appreciation of the approximate magnitude of the flood. A more sophisticated example is given by Bruist in "Flash Flood Warning Services" of a flood warning system for the Woronora River, which describes a series of graphical procedures using recorded rainfall and the storage level in Woronora Dam to predict flood levels at Woronora Bridge and further downstream at The Needles (Bruist, 1999, see p. 38 in particular). The method is easy to follow and clear colour coding is provided to minimise the potential for mistakes. Hydrology staff at the BOM in New South Wales developed the graphical process from an analysis based on spreadsheets. The method gives a series of outcomes for a range of starting conditions combining catchment wetness, storage level in the dam and recorded rainfall.

There are difficulties in creating physical similarity between the model and the real catchment, and it is impossible to recreate the actual catchment conditions at model scale. Instead, computer-based computational models are routinely used. Over the years models have become more sophisticated and powerful, but basically use the method described by Laurenson, Mein and McMahon in "Flood Estimation by Runoff Routing" (Laurenson et al., 1975). A model to be used for flood estimation would usually include (in order of importance):

- rainfall (distributed across the catchment, and in time steps during the storm);
- losses, due to surface storage and infiltration;
- catchment area, usually divided into sub-catchments;
- major catchment storages such as dams;
- flow path lengths within the catchment and sub-catchments;
- channel slope and sub-catchment surface slope; and
- flow velocity across the catchment surface and in the creeks/channels.

A range of computational models is available for flood simulation. Models such as RORB and RAFTS, for general catchments, and ILSAX and URBS for urban catchments have become industry standards. General descriptions of them are given in Chapters 7 and 14 of *Australian Rainfall and Runoff* (Institution of Engineers, Aust., 1987), RAFTS is described in *RAFTS XP, Runoff Analysis and Flow Training Simulation*, (WP Software, 1992). The Bureau of Meteorology commonly uses the URBS model which is described in *URBS-CM. A Catchment Management and Flood Forecasting Rainfall Runoff Routing Model* (Carroll, 1999).

Output from the models usually includes:

- hydrographs of flow at the outlet of the catchment and at specified points within the catchment;

☐ time to peak after the start of the storm; and

☐ reservoir storage, discharge and maximum water level.

Some models, such as RORB, are relatively simple to set up and run. Others require greater detail and are more complex to operate but allow the operator greater ability to interact with the modelling process. URBS, for instance, is designed for operational flood forecasting and calculates flows progressively down the catchment, which allows the model input data to be updated rapidly during a flood. This use of actual recorded hydrographs as the floods progress is a valuable feature.

Despite the proliferation of models and the wide use of them for hydrological prediction, it should not be forgotten that they are computational methods of simulating a complex physical process, and contain many short cuts and assumptions. The modelling process relies heavily on comparison of flood predictions made by a model with what actually happened, referred to as calibration. In a paper entitled "A Flexible Real-Time Forecasting Model", Wilson gives an example which he developed for the Hydro-Electric Commission in Tasmania, and shows the comparison of a recorded hydrograph with the modelled hydrograph, reproduced as Figure 2.4 (Wilson et al., 1994, p. 85).

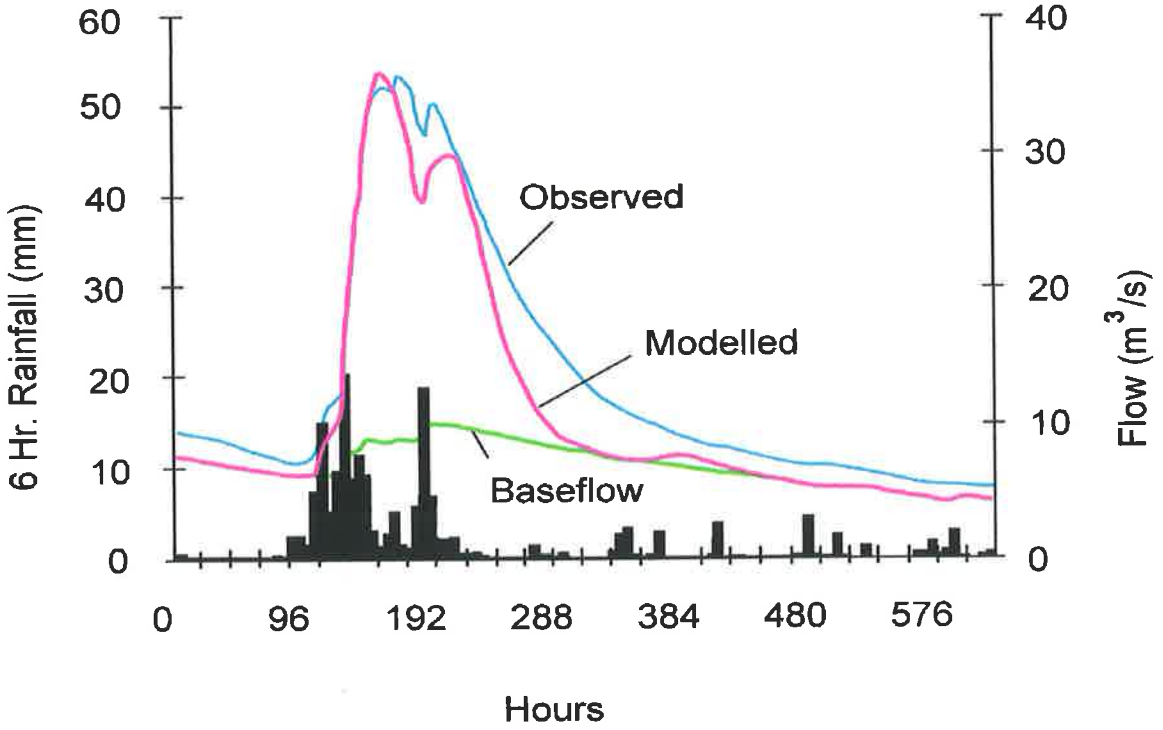


Figure 2.4 Comparison of recorded versus modelled Hydrograph, (and recorded rainfall hyetograph), Tasmania (adapted from Wilson, 1994)

The objective is to design a model which will provide accurate simulation under all circumstances. Firstly, for flood warning purposes, the time of greatest need for model prediction is during the occurrence of extreme floods and the common problem is that there is insufficient information on past extreme floods to calibrate against. Secondly, large and small floods can be expected to behave quite differently. Small floods are generally retained within the channels and comparatively little of the flow is spread across the floodplain. In major floods, channel storage is small in comparison to the volume of the flood, and the shape and characteristics of the floodplain are the main determining factors in flood behaviour. A model which has been built and calibrated for floods which remain within the channel cannot be guaranteed to simulate an event in which most of the flow is outside the channel. It can be designed to take account of the storage and flow characteristics of the floodplain but, since calibration is not possible, there will be a degree of uncertainty in the model predictions when simulating a major flood. This can be overcome after the event, with time available to modify the parameters and achieve better simulation, but is a challenge when using the model for flood forecasting and warning in real time. It should be remembered that while hydrology and flood forecasting concentrate on estimating flood discharge, for a person in the floodplain it is more important to know the flood height, rather than the peak flow.

The estimation of flood levels from flood flows is a hydraulic problem and has been the subject of extensive studies. *Open-Channel Hydraulics*, (Chow, 1959), and *Open Channel Flow*, (Henderson, 1966), provide the foundations upon which current hydraulic practice is based. A wide range of sophisticated hydraulic models is available for computation of discharge and water levels across a floodplain. The HEC-2 One-Dimensional Backwater flow model developed by the United States Army Corps of Engineers (US Army, 1982), now replaced by HEC-RAS, is a computational tool that has been used widely by engineers in Australia for calculation of water surface profiles for floodplains. In its early form it was costly in computing time and was not user friendly. Recently it has been modified, is much easier to use and is available at no cost via the Internet.[3]

Despite the fact that it is only capable of one-dimensional analysis and computes steady flow conditions only, its use for floodplains has been reasonably successful. Two-dimensional flow models are now available which are capable of handling unsteady flow conditions. These models will handle storage within the floodplain and provide a much more satisfactory simulation process. Flash floods are characterised by rapid changes in flow in the channel and floodplain, and the modelling process needs to be able to handle the varying flow conditions.

---

[3] Internet site for download of HEC-RAS is:
http://www.wrc-hec.usace.army.mil/software/software_distrib/hec-ras/hecrasprogram.html

Models now available include MIKE 11, MIKE 21[4], RMA-2[5] and Delft[6]. Accurate description of the shape of the channel and floodplain is vitally important for precision in estimation of flood levels. Improved methods of photogrammetry and laser scanning, are capable of providing ground surface elevations to within 100 mm according to information provided by Hydro-Tasmania in their study for the Patawolonga Catchment Board (Hydro-Tasmania, 2001). The hydraulic and digital terrain models are then integrated for flood simulation to determine depth and flow velocity at any point in the floodplain.

2.9 Specific Difficulties in Flash Flood Prediction

Flash flooding is a short duration and intense form of flooding. It presents particular problems for minimising the potential for loss of life and damage to property and facilities due to the short time available to detect a flash flood and issue a warning, together with the enormous destructive power that can be unleashed in such events. Flash flooding can be the result of a dam failure, usually after heavy rain, causing a destructive wave to travel rapidly down a watercourse and inundate a community. The failure of Teton Dam in 1976 was a rare but severe example, which took place suddenly with a warning time of less than an hour. This is described briefly in "The Bureau of Reclamation and Dam Safety" in *Twenty Years Later. What we have learned from the Big Thompson Flood* (Gunnarson, 1997). A large community downstream was evacuated and, miraculously, only 11 lives were lost. It was fortunate that the failure occurred during daylight, making rapid warning and evacuation possible. More commonly, flash flooding is caused by heavy rain in all or part of a catchment, with rapid accumulation of water which quickly inundates adjacent houses and facilities, which may not have experienced much rain and whose inhabitants are unprepared for a flood. An example of this was the catastrophic flood on the Big Thompson River, described in Gruntfest's "Introduction and Overview" to *Twenty Years Later* (Gruntfest, 1997, pp. 1-3) where rainfalls of 300 to 360 mm were recorded in the upper catchment, leading to a flash flood passing down the canyon and destroying everything in its path, including many holiday homes, and causing 139 deaths. Flash flooding can occur directly as a result of a severe storm on a small catchment, with deep fast flowing water creating a hazard to people and property. The Elizabeth Street flood in Melbourne in February 1972 was typical of this type of event.

For each type of flash flood event there are formidable difficulties in monitoring the development of a flood, predicting the magnitude and issuing the warnings in time for the

---

[4] Internet site for information on MIKE 11 and MIKE 21 is: http://www.dhi.dk/Products/

[5] Internet site for information on RMA-2 is:
http://www.cerc.usgs.gov/rss/rfmodel/5-Appendix/referenc.htm
There is considerable discussion of RMA-2 in the accompanying paper at:
http://www.cerc.usgs.gov/rss/rfmodel/2-Methods/methods.htm
Also, the U.S. Army has a set of videos about RMA-2, which are described under '2-D Modeling' at:
http://www.hec.usace.army.mil/training/videotape_catalog/rh.html
Further descriptive information is on the RMA website at: http://www.rmanet.com/models.htm

[6] The website of the Delft Hydraulics Lab, which has considerable detail on the Delft-FLS model, at:
http://www.wldelft.nl/soft/fls/index.html

threatened community to respond. Severe weather forecast techniques are improving all the time but, although it is possible to forecast conditions likely to produce severe storms, it is not possible to determine the exact location and severity of the storms until they actually form and, by then, there is little time for warning. Once the potential for damage has been identified, people likely to be affected must be warned in sufficient time for them to protect themselves and their property. To this must be added the possibility that storms will occur in the early hours of the morning, on weekends and Public Holidays, when duty staff and those at risk are off duty or asleep. Achieving successful flash flood damage mitigation is a difficult task.

2.10 Flood Magnitude and Probability

The size of a flood is often described by referring to its frequency. An AEP 1 in 100 flood is one which would occur or be exceeded on average 10 times in 1000 years, or 100 times in 10,000 years.

The AEP 1 in 100 flood has been shown by Linsley, Kohler and Paulhus in *Hydrology for Engineers* (Linsley et al., 1972, pp. 368-369), to have a 63.4% chance of occurrence in a 100 year period. However, it is commonly misconstrued to be a flood which occurs regularly every 100 years. It is also common for the AEP 1 in 100 flood to be the largest flood risk event to be used for urban planning. Hassell, in a paper on “Stormwater Management and the Development Plan”, (Hassell, 1998), illustrates this misconception, ignoring the possibility of greater floods simply because their risk of occurrence is less. This is a common attitude amongst planners, leading to unwillingness to acknowledge the risk of a major flood event on areas which lie outside the AEP 1 in 100 floodplain. The situation is not helped by the common practice of preparing flood maps showing the extent of flood events, of which the largest is the AEP 1 in 100 event. This can lead to arguments about exactly where the flood line on the map should be located and the incorrect assumption that if a property lies outside the AEP 1 in 100 boundary it is free of flood risk.

Floods, in both engineering and scientific terms, are predictable in that their size and frequency can be determined. In parallel with the development of computational flood modelling processes, the collection, editing, storage and recovery of rainfall and water flow data has become very much more efficient and cost effective. Despite this rapid progress, the accuracy and increased capability of flood estimation is still limited by the length of flood history available. Hydrologists are frequently required to estimate a rare flood, for example the AEP 1 in 10,000 flood, on the basis of perhaps 50 years (or less) of record. The design of large dams, for which the consequence of failure would be catastrophic, has been a significant spur to the estimation of such floods. In Australia, many dams were constructed during the first half of the twentieth century, mainly for water supply and irrigation. For each dam the designers were required to design the height of the wall and the size of the spillway. This was treated as an engineering problem, similar to Limit State analysis for structural design, with the objective of “Building the dam so that it doesn’t fail”. Subsequently, in the light of worldwide experience, which included some very large floods and dam failures, engineers began to realise that dam and spillway design were problems in risk management, rather than Limit State design, requiring:

- ☐ an understanding of the full range of possible floods, including the biggest flood that could ever occur, the Probable Maximum Flood; and
- ☐ the use of risk analysis for the consequences of dam failure.

This, in turn, required an estimation of the cause of the flood event, termed the Probable Maximum Precipitation, the maximum rain that can be extracted from a very moist atmosphere using a very efficient storm.

2.11 Conclusion

Chapter 2 has provided a general description of flash flooding as a consequence of rainfall, and has considered the causes of the problem and some of the difficulties in flash flood prediction. The inherent assumption is that flash flood warning can be achieved by flood prediction based on rainfall measurement but rainfall prediction is imprecise and rainfall measurement is likely to be too late to allow warnings for flash flooding to be effective. The subject is taken up in more detail in Chapter 4, which considers the use of rainfall measurement and rainfall forecasts for flood estimation and the difficulties in obtaining Quantitative Precipitation forecasts. In Chapter 5 the potential value of rainfall alarms, and their limitations, for early warning of floods is evaluated.

In the following chapter, attention is given to the effects of flash floods, the way in which communities are impacted and their vulnerability to damage and loss of life. This will introduce the question of risk analysis and the need for effective planning for flood damage mitigation, rather than reliance on a warning system based on rainfall measurement on the day of the flood.

By considering both the causes and effects of flash flood damage and by approaching the problem from a risk management perspective an effective approach to flood damage mitigation can be achieved.

3. THE EFFECTS OF FLASH FLOODING

The purpose of this chapter is to show that flash floods are phenomena which occur sufficiently often to require action to reduce their effects. Floods kill people and cause great damage and, in general, communities at risk of flash flooding do not appear to manage the risk situation particularly well. While floods and their accompanying disaster scenes make a deep impression at the time, it becomes progressively more difficult thereafter to maintain a flood aware community. There is a tendency to assume that direct technological solutions, such as flood warning, can in themselves provide the solution to flood risk. This is certainly not the case.

The second half of the chapter considers ways of reducing potential flood damage, by moving out of the path of floods and using flood prone land appropriately. It considers a risk management approach to floods, rather than upper limit design, recognising a range of floods from the less rare, AEP 1 in 100, to rare floods such as AEP 1 in 500 and Probable Maximum Flood, which have a lower risk of occurrence but are capable of greater damage.

The potential use of warning systems is discussed in this chapter. It is shown that, in themselves, flood warning systems for flash flooding are not likely to be fully effective since there is insufficient time to prepare and warn. The chapter ends by suggesting that a flood risk management approach to flood damage mitigation, which combines planning and warning processes, could provide a solution.

3.1 Flash Flood Risk

Flash floods occur naturally and unpredictably from time to time and only become a problem when they interact with human activities. The history of flash flooding contains dramatic accounts of the damage and destruction that they cause. The hydrological profession has advanced to the stage that the effects of flash flooding can be predicted with reasonable accuracy. The problem is to convince the planners and those who wish to occupy a floodplain that there is a risk. The problem is greatest in situations where there is no historical record of a flood on which to base arguments for flood-wise development. Even where there is historical evidence of a major flood, it may be difficult to withstand pressures for development on flood prone land. An example given in *Automated Local Flood Warning Systems Handbook* (National Weather Service, 1977), states that in June 1972 a flood struck Rapid City, South Dakota, causing 254 deaths and major destruction. After the flood, considerable efforts were made to provide flood control and a large floodplain was vacated by moving buildings away from the high risk areas. However, despite the history, there are now moves by developers to construct a shopping complex within the floodplain.

3.2 Examples of Flash Flood Disasters

Flash floods are well reported in the world news media and there is seldom a month in which a flood disaster does not demand the attention of the public.

In an insurance industry publication entitled *Floods - An Insurable risk?* (Hausmann et al., 1998, p. 13), it is reported that:

> "On 3 October 1988, a stationary thunderstorm cell led to torrential rainfall lasting several hours in the area at Nimes, France. Nine dead and a damage toll of around US $1 billion were the result. In Switzerland, on 24 September 1993, the town of Brig was devastated by the raging torrents of the Saltina river. Damage amounted to over US $400 million".

Similarly *Flooding and Insurance* (Munich Reinsurance Company, 1997, p. 32), states that:

> "... the historical bridge at Vaison-la-Romaine, which was almost destroyed by a savage flash flood on 22nd September 1992. Torrential rain - up to 300 mm in only 3 hours - had swollen rivers in the southeast of France. Numerous houses in the town were completely destroyed, a camp site nearby was devastated. Throughout the region there was severe damage to the infrastructure and power lines. The catastrophe claimed the lives of 38 people. The insured losses came to more than US $300 million".

The November 1985 Appalachian floods in the aftermath of Tropical Storm Juan, followed by a strong low pressure system, are described by Summer in "Comparison of Deficiencies Associated with the Big Thompson Flash Flood Events and Recent Flood Events in the Eastern United States" (Summer, 1997, p. 92):

> "Record floods occurred in portions of the James and Roanoke basins in Virginia, and in the upper Monongahela, upper Potomac, and Greenbrier rivers in West Virginia. The number of people who lost their lives was 56, and total damages exceeded US $1.3 billion".

In Australia, perhaps because of the lower population density, flood tragedies have been on a lesser scale. The newly drafted *Floodplain Management Manual* (NSW Govt, 1987, p. 1) describes how Maitland in New South Wales experienced a massive flood in 1955, which killed 14 people, destroyed 160 homes, inundated 5,000 houses and caused damage estimated at $650 million in today's dollars.

At Gundagai in New South Wales, a local flash flood in 1865 drowned 89 of the 250 inhabitants, described by Smith in *Water in Australia* (Smith, 1998, p. 229). He also mentions a major flood event in 1870 at Terrara, after which the settlement relocated to Nowra.

Another example is the failure of the Briseis dam in April 1929. A paper entitled "The Failure of Briseis Dam" (Livingston, 1993), describes how the dam, which was constructed on the Cascade River, failed after 267 mm [10.5 inches] of rain had fallen in 40 hours. The rainfall event began with 106 mm in the first 24 hours, followed by 120 mm in 3 hours. The failure of the dam produced a wall of water, moving quickly down the valley, with disastrous consequences. The resultant flood killed 14 people and the Briseis mine, which the reservoir supplied, was closed down. Briseis Dam was designed with a spillway capable of passing a flood produced by "5 inches (125 mm) of rain in 6 hours, or 10 inches (250 mm) in 24 hours"(Livingston, 1993, p. 427). This was equivalent to estimated AEPs of 1 in 200 or1 in 500. The flood was estimated by Livingston to have had an AEP of 1 in 10,000. Livingston concludes that "events with very small probabilities do happen, and when they do, the results are disastrous" (Livingston, 1993, p. 430).

3.3 Characteristic Vulnerability to Flash Floods

Flash floods are characterised by their rapid rate of rise and deep, fast-flowing water. The hazard posed to human life increases rapidly with depth and velocity of the flow. Guidelines for safety are given in *Floodplain Management in Australia - Best Practice Principles and Guidelines*, (SCARM, 2000) presented here on Figure 3.1.

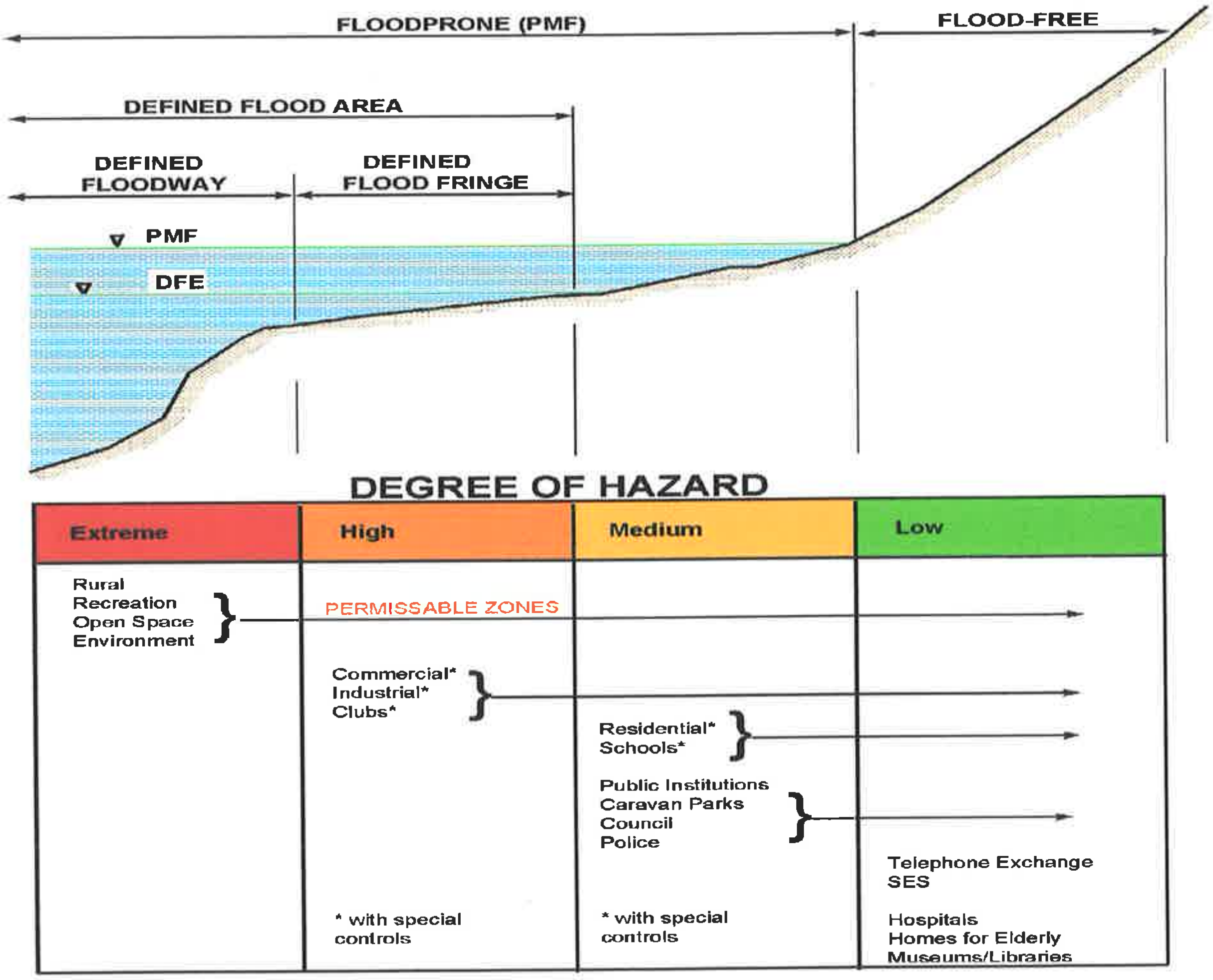


Figure 3.1 Recommended use of flood prone land, adapted from Floodplain Management in Australia *(SCARM, 2000)*

In flash floods, people frequently underestimate the power of water or perhaps rely on instinct, rather than reason. At the height of the Fort Collins flood, which is described in Section 3.4, a woman was rescued from her caravan but unfortunately then tried to go back to rescue her dog and was drowned. Similarly, drivers frequently try to cross flooded sections of road and are then caught by the flood and drowned, or perhaps saved under conditions which put the lives of the rescue teams at risk. There is much video evidence of this, in part because it provides dramatic footage for the media. The media coverage shows the tremendous power exerted by fast moving water and the danger posed to people who try to cross it or save others. Despite this, it is invariably the case that some drivers will not stop until the vehicle fails. In the "Introduction and Overview" to *Twenty Years Later*, Gruntfest reports that:

> "Even when roads are closed, people drive around barriers. In the Susquehanna River flood in New York in January 1996, 30 people received tickets after the police posted signs indicating that the road was closed. The police actually had to stand in the water in waders and give people tickets for crossing the flooded, barricaded road!" (Gruntfest, 1997, p. 5).

Velocity-depth conditions are also important with respect to danger to people and damage suffered by buildings. Perhaps due to the relatively infrequent occurrence of floods large enough to destroy buildings, there appears to be little guidance available. Specific reference to velocity-depth effects has been made by Smith in a paper presented to the insurance industry, "Extreme Floods and Dam Failure Inundation: Implications for Loss Assessment" (Smith, 1991), drawing attention to the dramatic increase in flood damages once the combination of velocity and depth is sufficient to destroy buildings. Relationships between velocity-depth and building failure have been published in a report by Black entitled *Floodproofing Rural Residences* (Black, 1975), for single storey weatherboard and brick veneer buildings. Reference is made by Smith to later North American studies which give similar information for masonry and concrete buildings. The Australia Day flooding at Ipswich in Queensland during the floods of 1974 destroyed more than 30 houses, (David Ingle Smith, personal communication, April 2000). Velocity-depth constraints in relation to flood hazard for people and vehicles, as recommended in *Floodplain Management in Australia* (SCARM, 2000), are given on Figure 3.2.

For urban flooding in Adelaide, flood depths are most likely to be relatively shallow, generally less than one metre. However, flash flooding in the Mt Lofty ranges produced deep and dangerous flows in the Upper Torrens at Gumeracha in August 1992, leading to loss of 2 lives at the Cudlee Creek caravan park. Such conditions would have destroyed any buildings in the path of the flood but fortunately there were none. The creek systems on the western face of the Mt Lofty Ranges, which discharge through the urban area, have the potential to generate dangerous, high velocity flows and to damage buildings, particularly near the foothills. Houses have been built alongside and over First Creek/Waterfall Gully which has the capability of producing a severe flash flood and the risk of destruction of buildings is very high. This catchment is just to the north of Keswick Creek, and is shown on Figure 4.2.

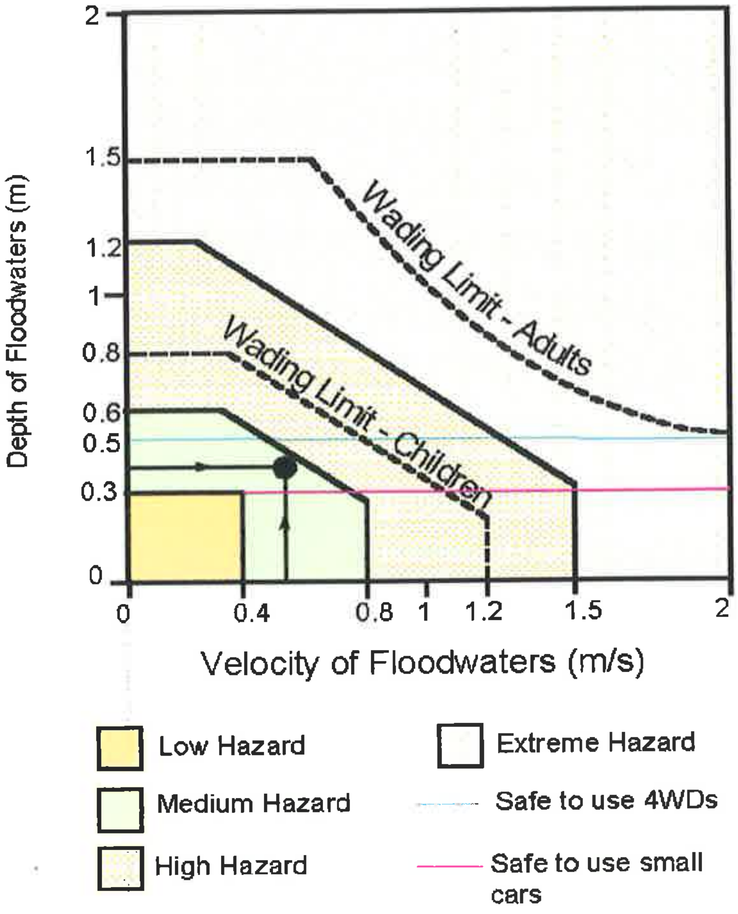


Figure 3.2 Flood Velocity-Depth constraints for danger to people and vehicles taken from Floodplain Management in Australia *(SCARM, 2000)*

3.4 Inherent Difficulties in Issuing Warnings for Flash Floods

This study began with the objective of investigating the potential for flash flood warning systems to mitigate flood damage. However, it soon became clear that even if a perfect flash flood warning system could be developed, it would be of no use if:

- ☐ the warning could not be efficiently disseminated; and
- ☐ the threatened population did not have time to protect itself.

For non-flash floods, there is sufficient time between the rainfall and the subsequent flood to educate the response agencies and people in the path of the flood. They can be made aware and be advised what to do to save themselves. In essence, the requirements are:

☐ that the warnings be treated seriously;
☐ that efforts should be made to prevent danger to human life; and
☐ that potential damage to buildings, goods and services should be minimised by appropriate on-the-spot action in accordance with an emergency preparedness plan.

The main objectives of the warning agency are:

☐ to have sufficient monitoring equipment in the catchment;
☐ to detect a flood at an early stage;
☐ to forecast the magnitude of the event; and
☐ to communicate a warning to all who need to know.

Note that, although this work relates to flash floods, these requirements may be equally useful for non-flash flood situations.

In the case of flash floods, the time available between the storm and the flood is a maximum of six hours, and could be under an hour in some circumstances. It is difficult to detect and forecast a flood within the time-frame available given that the storm could occur any time, day or night, and the tools for rainfall forecasting for flash floods cannot be guaranteed to pick the location and severity of severe storms.[1]

The principle in respect of flash flood damage mitigation is that a warning system should be the **last line of defence.** For it to be effective, the business and residential community must be made aware of flood risk well in advance, so that it is prepared for a flood and ready to act promptly when it happens. The task is to introduce planning and preparation, in just the same way as the community treats the risk of fires and fire damage. The actual flood warning needs to be the last step in the overall process, only required when all other measures have failed. Planning and preparation steps have been identified as being necessary for all flood prone communities, common to flash or non-flash flood. In the case of non-flash flooding, if the community is **not** prepared and has **not** done its homework, provided that the warning is issued in good time, there is still the opportunity to get preparations under way before the flood arrives. For flash flood situations a warning system is likely to be of little benefit, unless

---

[1] While methods for quantitative precipitation forecasts (QPF) in Australia are still under development, progress has been made in the USA. Stewart, in a conference paper entitled "Effecting Timely Responses to Urban Flash Floods", has described a system developed for Lena Gulch, near Denver, Colorado, which uses QPFs, issued by a privately owned meteorological service, to initiate flash flood warnings (Stewart, 1988). However, even here, the technology is somewhat uncertain and, in the case of the Fort Collins flood, a meteorologist employed to provide early warnings did not become aware of the severity of the flood until too late. This is not a criticism of the meteorologist, rather a confirmation of the great difficulties faced by those with the responsibility of issuing warnings for flash flooding.

the community:

- ☐ is fully aware of the risk well in advance;
- ☐ has taken steps to minimise flood loss exposure; and
- ☐ is ready to respond.

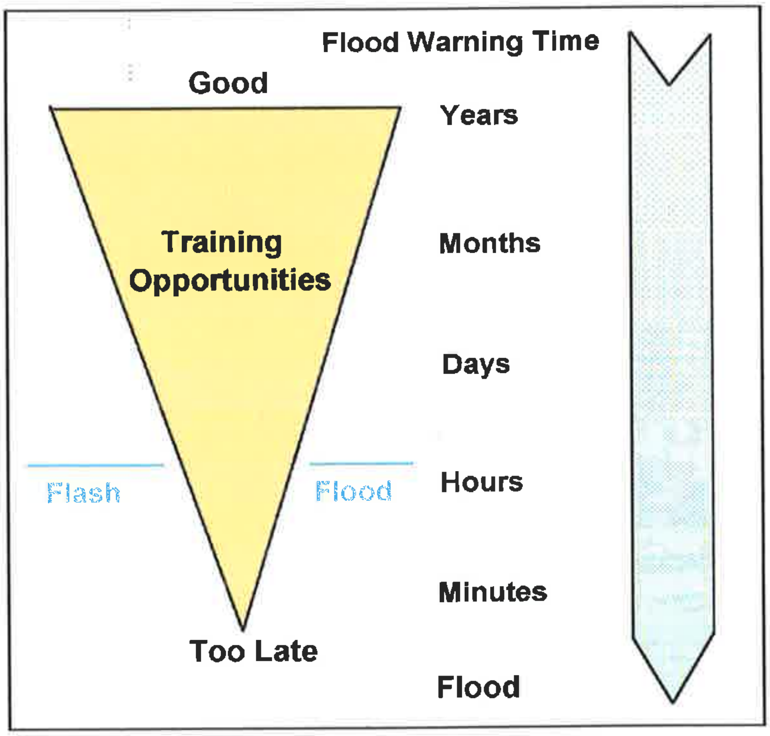


Figure 3.3 Flood Warning time versus training time.

Figure 3.3 illustrates the concept, showing that the more time there is available, the better the opportunity for training and flood preparation. Conversely, by the time a flash flood is developing, it is too late to undertake training and education of a threatened community.

Two brief case studies illustrate the advantages of training, planning and preparation.

Case 1: Keswick Creek, Adelaide, 22nd May 1999

Keswick Creek has a catchment area of 32 km^2, in the urbanised inner suburbs of Adelaide. It is known to be subject to flash flooding and a network of rainfall and water level recorders has been set up to monitor floods in real time. Full details of the creek hydrology and flood inundation mapping are provided in the next chapter. A flood awareness program was undertaken, beginning with surveys of businesses in the high risk areas of the floodplain, and followed by meetings and discussions with the owners of businesses to explain the flood risk. Personal contacts were established with managers of a group of businesses. Emergency after-hours telephone numbers were obtained.

On 22nd May 1999 a severe storm developed over the catchment. Severe weather forecasts indicated the probability of flash flooding. The ALERT flood monitoring system detected heavy rainfall and triggered alarms. Once the centre of the storm had been located and it was clear that there was the potential for flooding to occur in Keswick Creek, attempts were made to warn the owners of the businesses. However, it was a Saturday night, the business premises were unattended and phone contact was impossible. Where private phone numbers and mobile phones were available, they were switched to message bank or tape recorders. The warning process failed completely. The process would have worked satisfactorily for non-flash flooding because there would have been time to remedy these deficiencies and ensure that the community was prepared. For a flash flood, even though a basic warning system was in place and a relatively sophisticated weather detection and monitoring system was available, the warning process did not work. In this case the flood damage caused was relatively minor, estimated to be less than $10,000, but the flood was not particularly rare or intense.

Case 2: Fort Collins, Colorado, USA, 28 July 1997

Spring Creek at Fort Collins has a catchment area of 30 km^2, predominantly urbanised. The city of Fort Collins was aware of flood risk and had spent considerable resources on minimising the potential for flood damage, such as moving buildings and providing a retention dam. The city had not installed an ALERT system and there were no rainfall and water level monitoring stations. A huge storm occurred, greater than AEP 1 in 500. There was no warning but the awareness level of flood risk was high, there was a well-trained emergency response team ready and, despite the adverse circumstances, the disaster that occurred was a fraction of what could have occurred. Five people were drowned but in a journal article entitled "Floodplain Management" (Grimm, 1998), Grimm has estimated that the number of casualties could have been as high as 100 without the benefits of the mitigation program. Hilmes, in her "Special Report on July 1997 Fort Collins Flood" (Hilmes, 1997), supports this conclusion. A flood warning system could perhaps have been a major benefit and saved all of the 5 lives. The problem is that, if a flood warning system had been selected for Fort Collins, **it could well have been seen as sufficient in itself** and the program of self-protection and flood loss exposure might not have taken place.

In Case 2, with no warning system in place but with considerable efforts to mitigate flood damage, the city was able to protect its citizens from a natural disaster.

For flash flood situations, effective remedies in planning and flood exposure minimisation are essential pre-requisites for effective disaster mitigation.

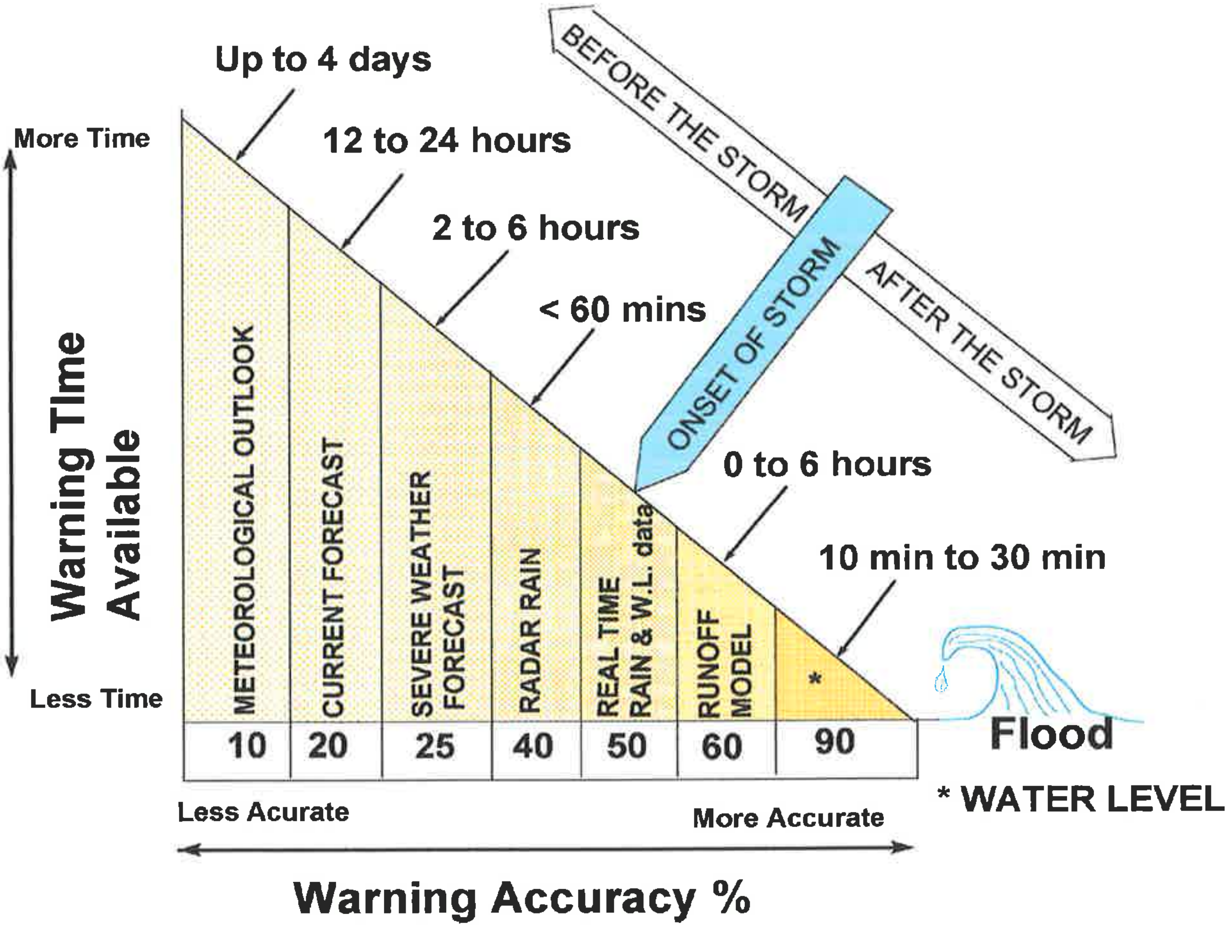


Figure 3.4 Forecasting a severe storm, comparison of time available with forecast accuracy.

3.5 Flash Flood Prediction Difficulties

Chapter 2 introduced the difficulties posed by shortage of time for flash flood warning. The objective is to predict storms capable of producing flash floods with sufficient lead time and confidence. Figure 3.4 shows steps in forecasting severe storms and subsequent flash floods. The forecast stages are:

☐ *Meteorological outlook (up to 4 days in advance):* This is the earliest forecast step, based on a suite of four Global Atmospheric Models (European, UK, USA, and BOM Melbourne), which predict wind speed and pressure at all levels, humidity trends and rainfall, up to 10 days in advance. The BOM uses the models to forecast 4 days in advance. Beyond 4 days the performance of the models is inconsistent. The potential for development of severe rainfall systems can be detected at this early stage but only in general terms;

☐ *Current Forecast (12 to 24 hours in advance):* Forecasts are prepared each day for the next 24 hour period using current observations, plus the model output. The anticipated movement of highs, lows and troughs can be more accurately predicted and it is normally possible to forecast severe weather systems, although their location and severity is known only in general terms;

☐ *Severe weather forecasts (2 to 6 hours in advance):* Meso-scale forecasts, 6 hours or less in advance, provide more confident predictions of severe storms and their locations by region, such as Mt Lofty Ranges, mid-North, or the Eyre Peninsula. Severe weather forecasts include a map showing the probable storm locations but not to catchment scale;

☐ *Radar rainfall (less than 60 minutes before the storm):* weather radar, routinely used to show the location, movement and intensity of rainfall, is a useful tool showing the development and decay of storms and has good capabilities for locating and describing the storm profiles. In its present state of development, however, information on the amount of rain falling, as detected by radar on its own, tends to be inaccurate;[2]

☐ *Real Time Rainfall (once the rain has fallen):* ALERT rainfall monitoring networks record rainfall data in real time, relaying the data back to base stations instantaneously. By this stage, time is short and quick response models are needed to make effective use of the rainfall data. However, there is more confidence in the flood forecast at this stage because the rain has been physically measured, albeit by point samples;

☐ *Real Time Water Level Data:* ALERT systems also provide water level data in real time but by this time the rain has fallen, water has flowed into the channels and the flash flood will be virtually at its peak. The flood may be forecast with confidence but in many situations the forecast will be useless because it is too late.

Each forecast stage has a characteristic accuracy, with approximate values listed on the x-axis of Figure 3.4. The problem is that severe storms, predicted with reasonable confidence by a Severe Weather Forecast, will be forecast for a region, not a catchment. It is only when the rain actually starts to fall that the location can be picked up by radar, and then by pluviometers, by which time there may be little lead time before the flood peak reaches a critical location.

The paradox in forecasting and warning for flash floods is that by the time it is possible to make an accurate forecast there may not be sufficient lead time to take action to mitigate the damage. Conversely, a forecast prepared and issued with sufficient time for those affected to

---

[2] This is correct for Adelaide and possibly the whole of Australia. Some European nations, and the USA seem to have achieved better success.

respond, is likely to be inaccurate.[3]

On the basis that an accurate forecast which arrives too late is useless, the options are:

- ☐ to concentrate on improving the accuracy of rainfall forecasts;
- ☐ to make the best possible use of inaccurate forecasts.

Flash floods are defined as occurring within 6 hours of the rainfall which causes them. However, some floods will be generated in less than an hour. For Keswick Creek there may be less than 3 hours and, quite possibly, less than an hour to the start of flooding. Bruist's paper on "Flash Flood Warning Services" (Bruist, 1999), indicates that for Woronora the time between storm and flood is approximately 6 hours. Perhaps this is sufficient to confirm the rainfall, forecast a flood, issue a warning and allow time for response.

3.6 A Risk Management Approach to Flood Damage Mitigation

While it may be very difficult to tell when the next flood is coming, hydrological procedures for determining the anticipated magnitude and frequency of floods are well established. Flood inundation maps are routinely prepared for floodplains, showing the extent and depth of flooding for a range of flood events. Recent examples include the "River Torrens Flood Hydrology Study" (Lange and SMEC, 1995) and the "Sturt River Flood Hydrology Study" (Tonkin, 1995). Communities appear to be prepared to accept that development within the AEP 1 in 100 floodplain should be restricted to activities appropriate to the risk. Hassell is a group of planning consultants active in this field that indicate a willingness to adopt this standard and the New South Wales *Floodplain Development Manual* states that "many councils have adopted the 1% flood as the flood standard for planning and development control purposes", (Hassell, 1998; NSW Government, 1987, p. 12). Nevertheless, the acceptance of the AEP 1 in 100 year standard implies that the risk floods of greater magnitude and extent tend to be ignored. It is those rare, but severe, floods which paradoxically cause the greater damage. Perhaps, it would be better to adopt a risk management approach and to consider the full range of floods, assigning the appropriate risk to each and then considering the risk to facilities and people in the floodplain. This would mean that the floodplain could be divided into zones, with appropriate activities permitted in each zone. This approach is recommended by *Floodplain Management in Australia* (SCARM, 2000) as shown on Figure 3.1.

---

[3] A parallel situation also occurs for non-flash flood situations, mainly due to rainfall occurring after the forecast has been completed, which has not been allowed for in the prediction. In 1993 major floods occurred in the Mississippi Basin. Flood forecasts were routinely issued up to 28 days in advance of the flood peak at specific downstream locations. The problem was that the forecasts did not allow for exceptionally heavy rain that fell in the days subsequent to the forecast, in the lower catchment close to the forecast locations, which caused much higher flood levels than had been predicted.

3.7 Conclusions

The effects of flash floods have been discussed in this chapter and some examples have been given. A risk management approach to flash flood damage minimisation is proposed. Limitations in the ability to forecast floods and issue warnings have been introduced in general terms.

For Keswick Creek, a flash flood monitoring system exists but there is no forecasting or communication system capable of ensuring that the community can be warned about a flood. The following chapter considers how the monitoring system can best be utilised to provide early warning, using hydrological techniques and procedures.

4. RAINFALL DATA AND FORECASTING FLASH FLOODING

Flash flood causes and effects have been described earlier, in general terms. In this chapter, ways of forecasting flash floods are examined. Keswick Creek is used as the example, and the possibility of providing an effective flood forecasting procedure is considered. It is suggested that, although it is possible to develop flood forecasting procedures, on the day of the flood there may be inadequate time to convert the forecast into effective warning.

4.1 Water Level Measurement for Flash Flood Forecasting

Detecting water level (or flows) will provide a direct means of flood prediction and maximum confidence in accuracy of the forecast but, by waiting for stormwater to flow into channels where it can be measured, there is less time for warning. If, as in the case of Keswick Creek, there is already flow monitoring equipment in place then during a flood the water level information would be used, but its greatest value would be in confirmation of information already obtained from the rainfall data and for future use in calibrating runoff routing models, rather than directly for flood warning.

It is assumed for the purposes of this study of small urban catchments, that to rely on water levels in the upper catchment to forecast floods in the lower areas would not give sufficient time for flash flood warning.[1] Therefore, rainfall detection is the means of flood forecasting to be examined.

4.2 Using Rainfall to Provide Early Warning of Flash Flooding

4.2.1 Measured Rainfall in Real Time

Three possible ways of using **rainfall** information for flash flood warning are considered. These are:

- ☐ obtain the rainfall data in real time and input into a runoff routing model, to estimate the peak flow rates at critical locations;
- ☐ measure the rainfall intensity, and trigger an alarm when a threshold intensity is exceeded; and
- ☐ compare the measured rainfall intensity with statistical storm intensity data and determine whether the storm is critical or not.

For the first option a runoff routing model was developed specifically for Keswick Creek, which can be run in real time using all rain and water flow data to estimate peak flow and timing of the peak at critical points.

---

[1] This is not to deny that there are situations in which it may be possible to provide flash flood warnings based only on water level measurement, but they are not considered here.

The second option uses automatic rainfall measurements to trigger alarms. The alarm process is described by Wright in "Rainfall Alarms for Flash Flood Warning" (Wright, 1998) and is a standard feature of ALERT automatic rainfall and water level monitoring systems. It is a simple process but does not appear to be used very widely in Australia for flash flood warning.

The third option is a refinement of the alarm system which has been developed as part of this study. The attributes and value of each of these options are considered hereafter.

4.2.2 Forecasting Rainfall for Early Warning

Warning time for flash flooding can be extended by forecasting the rainfall event days or hours ahead. The term used for short term forecasting stated by Dickins in "Nowcasting with AIFS - A South Australian Perspective" (Dickins, 1997, p. 1) is "... **nowcast** has been defined as the 0-6 hour forecast. The nowcast plus an outlook for the following 6-24 hour period make up the short term forecast". Tools for forecasting rainfall using professional meteorological skills and techniques include:

☐ global atmospheric models;
☐ satellite pictures, with various computer-aided enhancements;
☐ meso-scale short term forecast models; and
☐ radar.

The combination of technology and skills ***is*** providing improved forecasts but they are not yet good enough to be able to predict flash flood conditions on a specific catchment. (Jenny Dickins, personal communication, January 2000).

Keswick Creek is the prototype for this study because it exhibits many of the features that make flash flood warning so difficult, including:

☐ small catchment area (less than 50 km^2);
☐ a fully urbanised catchment;
☐ very rapid runoff;
☐ little infiltration due to roads, roofs and concrete replacing natural vegetation;
☐ very little catchment storage;
☐ few engineering possibilities for mitigating the risk; and
☐ infrequent occurrence of severe floods, leading to complacency in the flood prone community.

4.3 Runoff Routing Models

The use of runoff routing models for flash flood forecasting presents specific problems to the user which make the outcomes somewhat uncertain:

- The model is required to operate in real time, so any data input to the model must be entered automatically as there is no time for manual data handling processes;

- Automatic data entry means that error correction can be a problem. Errors in rainfall recording tend to be incorporated in the model data, causing errors in the forecast hydrographs;

- Parameter selection for running the model must be done "on-the-run" with little time for optimising;

- The greatest need for accurate model predictions will be at the time of the biggest flood because it will pose the greatest danger to the community. However, model calibrations are invariably done against a very limited set of flood events, usually minor floods. Information on a range of major floods is seldom available. Therefore, confidence in a model's ability to predict flood events will diminish as the flood event gets bigger. This dilemma is shown diagrammatically on Figure 4.1; and

- For a model to be used for flash flood forecasting, Peddie, in "Real Time Flood Forecasting for the Upper Parramatta River" (Peddie and Ball, 1993), says that it will in most cases require, in addition to the rainfall already recorded, an estimate of forecast rain. But in the opinion of Dickins in "Nowcasting with AIFS - A South Australian Perspective" (Dickins, 1997), the ability to forecast rain and the accuracy of the forecasts are subject to considerable doubt.

The basic problem in developing a model is to obtain a range of historical flood flows for calibration and validation. For Keswick Creek, measurement of flows has been undertaken since 1993 and, although several minor floods have occurred since then and full details of the rainfall and flows were recorded, virtually all of the flows were within the creek channel. The modelling process relies on accurate simulation of storage of water and of catchment lag (delay time). Both these processes will be highly dependent on whether the flood is contained within the creek channel or whether it spreads out over the floodplain. To some extent it should be possible to predict the behaviour of flood flows through an urban area, even though there may be no data for Keswick Creek, because the characteristic layout of urban areas is similar and there are plenty of examples of floods through other urban areas which can be used as a guide. There are also 2-dimensional unsteady flow hydraulic models available to a high degree of sophistication.

Given these limitations, what is the value of runoff routing models for flash flood forecasting? Firstly, it may be possible to use runoff routing models in Design mode to run a series of rainfall events, large and small, and to derive graphical relationships which can then be interpreted on the day simply by determining the rainfall, combined with current catchment conditions (wet or dry), and other important considerations such as the storage level of any reservoirs. Bruist, in "Flash Flood Warning Services" (Bruist, 1999) gives an example of this for Woronora in New South Wales. The method appears to work well for Woronora because it is simple to apply and to allow for the current state of storage in the reservoir.

Secondly, for the flash flood catchments in the upper end of the time scale, 6-hour time of concentration, there may be time to correlate the model predictions based on rainfall with actual flow measurements in the upper part of the catchment. The URBS model is particularly good for this application as it calculates flows progressively from the top end of the catchment downwards. This means that model flows in the upper catchment can easily be compared and, if required, the measured flows can be substituted for estimated flows to determine flood forecasts further down the catchment. RORB, described by Laurenson (Laurenson and Mein, 1990), which has been an industry standard runoff routing model, has very similar structure to URBS (described by Carroll in *URBS-CM. A Catchment Management and Flood Forecasting Rainfall Runoff Routing Model* (Carroll, 1999)). URBS can be run in a form which is identical to RORB. But Boyd, in "Effect of Catchment Sub-Division on Runoff Routing Models", says that RORB tends to give inaccurate flow estimates within the catchment (Boyd, 1985). In its standard form, RORB cannot substitute measured flows for forecast flows during a model run.

4.4 Keswick Creek Research Program

In this section, Keswick Creek is taken as a case study. It drains a catchment of 32 km^2 in the inner suburbs of Adelaide, to the south and west of the city centre. The catchment has been covered by urban development, although there remain some small rural areas to the east on the slopes of Mt Osmond.

4.4.1 General Description

Figure 4.1 is a map of Keswick and Brownhill Creeks showing the two major tributaries, Glen Osmond Creek and Parklands Creek.

Glen Osmond Creek is predominantly urbanised throughout the middle and lower reaches. In its headwaters it is traversed by the South-Eastern freeway leading to Melbourne. A freeway tunnel and road realignment construction project has led to the potential for increased and more rapid runoff in this area but the design of the stormwater system has included diversion and retention works sufficient to mitigate any increase in runoff. This area amounts to only 11% of the total catchment and in its present state is not expected to contribute significantly to flooding downstream. Stormwater flow into Glen Osmond Creek is significantly enhanced by urbanisation and there are no easy options for providing flood storage to mitigate peak flows.

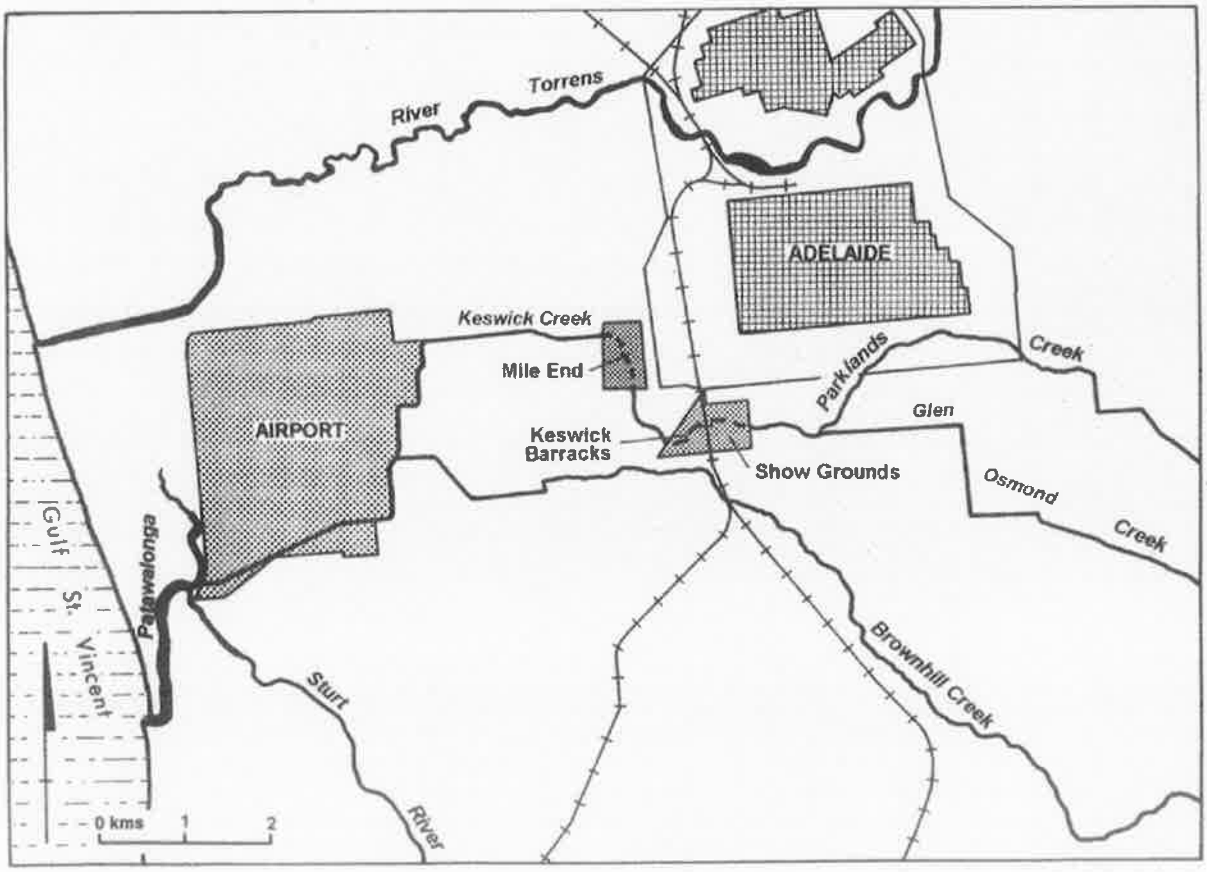


Figure 4.1 Map showing Keswick Creek and Brownhill Creek and the major tributaries, Glen Osmond Creek and Parklands Creek

The other main tributary, Parklands Creek, is steep in its upper reaches, with significant lengths running underground in culvert. The Glenside Detention basin is designed to protect against flow from Parklands Creek flooding across Fullarton Road which has a limited culvert capacity. Thereafter, the creek crosses the South Parklands, providing the opportunity for a large amount of flood storage, before crossing Greenhill Road, back into Unley and its junction with Glen Osmond Creek.

Urbanisation of the catchment has taken place steadily and covers most of the catchment. Table 4.1 gives the statistics of Keswick Creek Catchment. It should be noted in particular that the urbanised fraction is high (89%), and the average time to flood peak is very short, in all cases less than 3 hours. Furthermore, in recent years it has become common practice for large house blocks to be subdivided and additional houses built, which increases

Area	**km^2**	**Proportion**		**Elevation (AHD)**	
Urban High Density	5.0	16%		Headwaters - Crafers	330 m
Urban Medium Density	17.1	54%			
Urban Low Density	1.4	4%		Confluence - Nth Plympton	8 m
Urban Parklands	4.9	15%	89%		
Rural (Glen Osmond Freeway)	3.5		11%	**Length along channel**	16 km
Total	**31.9**		100%	**Average slope**	0.02
Approximate time to flood peak	**hrs**			**Annual Rainfall at:**	
(varies with flood magnitude, see Table 4.3)					
Ridge Park	2.0			Crafers	1000 mm
Charles Street	2.1				
Glenside	2.2			North Plympton	450 mm
Roberts Street	2.3				
Keswick Barracks	2.3				
Airport	2.3				

Table 4.1 Keswick Creek (including Parklands and Glen Osmond creeks) catchment statistics

impervious areas, resulting in larger volumes of stormwater flow and shorter times of concentration. Furthermore it has become standard practice for roof and gutter pipes to be connected directly to the street drainage, rather than onto lawn areas. This exacerbates the already serious problem of diminishing storage and enhanced runoff.

4.4.2 Flood History & Urban Development

The historical record of flooding on Keswick Creek is scant. The WBCM report, "South Eastern Suburbs of Adelaide - Stormwater Drainage Study", mentions a search of newspaper files but does not give any detailed information (WBCM, 1984). During the February 1925 storm, which was actually centred over North Adelaide, rather than Keswick Creek, the old BOM office on West Terrace recorded 140 mm of rain in 5 hours. Had it been centred over the creek, it would have produced major flood flows. *A Pictorial History of West Torrens* (Marles, 1980), shows a flood through the old Humes Pipe factory on Richmond Road in 1930. This reference contains several other pictures of flooding, dated 1920, 1923, 1924, 1925 and 1930. The 1925 storm is well documented in the BOM records but there does not appear to be any detailed record of the others. The archives of the Royal Agricultural Show Society refer to construction of the tunnel, which carries Keswick Creek under the showgrounds, and to one or more floods that occurred while construction was under way, possibly during 1916. During the recently completed flood damages survey, interviews with the owners of businesses revealed several reports of flooding that had not, apparently, been covered by the media.

4.4.3 Hydrology Modelling Studies

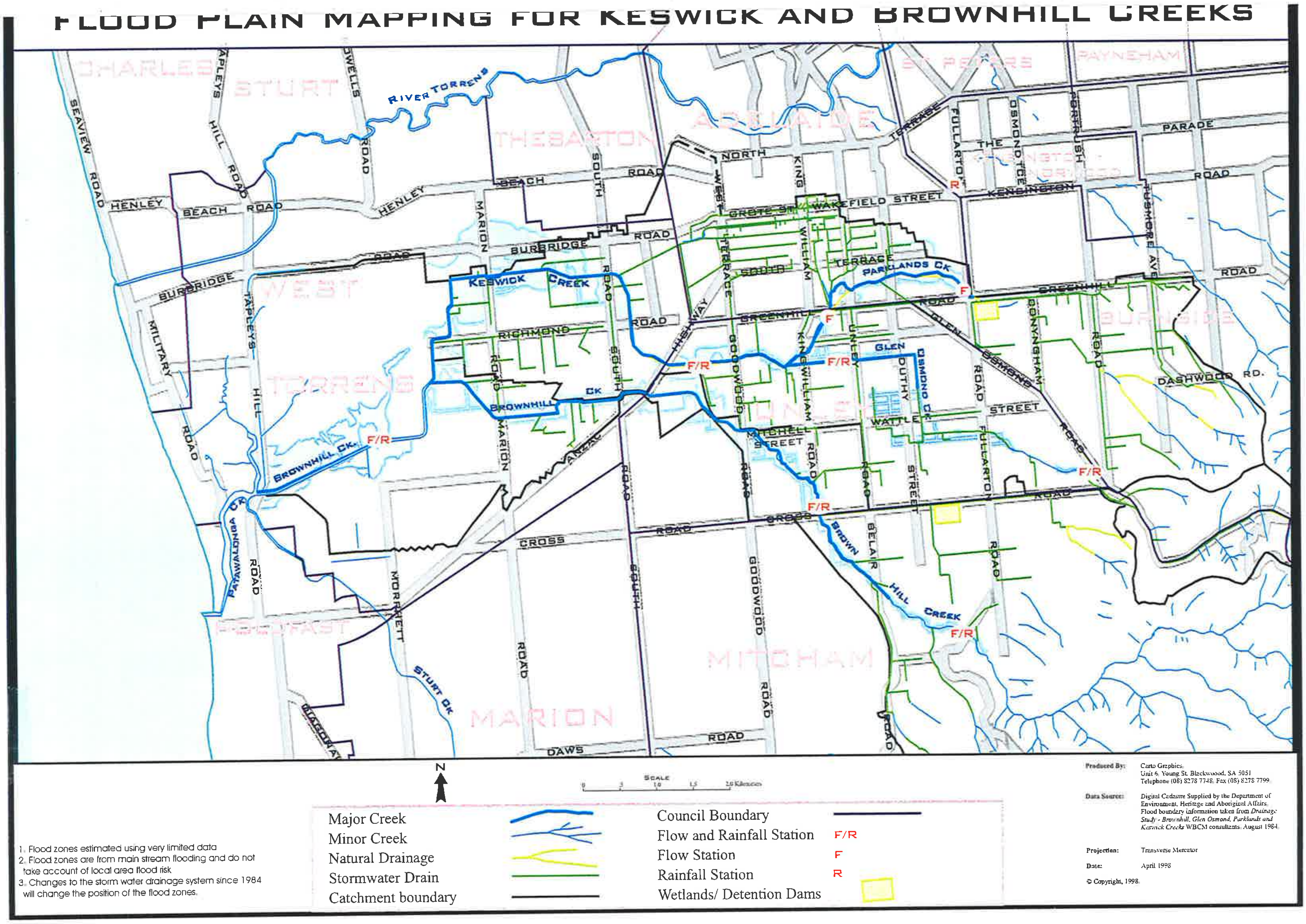
In the early 1980s a flood study was carried out for Brownhill and Keswick Creeks. The study was entitled "South Eastern Suburbs of Adelaide - Stormwater Drainage Study" (WBCM, 1984). This was a major project, undertaken by WBCM Consultants to:

- ☐ determine the extent of the floodplain in each creek system;
- ☐ consider possible flood mitigation actions; and
- ☐ estimate the potential flood damages.

The study used the RORB model, described by Laurenson in *RORB - Version 4 Runoff Routing Program User Manual* (Laurenson and Mein, 1990), and ILLUDAS (a forerunner of ILSAX) to estimate flood flows in the catchment. The HEC-2 1-dimensional hydraulic model (now replaced by HEC-RAS) was used to determine water surface profiles in the main channels, and ILLUDAS was used for modelling flood flows across the floodplain. From the results of these studies flood maps were drawn. The maps, which include floods of AEP 1 in 5 to 1 in 200, indicated that a significant urban area was subject to flooding (see Figure 4.2). The number of houses vulnerable to the AEP 1 in 100 flood was estimated to be 560, and this number does not include commercial and industrial businesses, although flood damage estimates were published for these.

As part of the flood loss exposure study carried out under this research program, and described in Chapter 6, a hydrology and modelling study of Keswick Creek was carried out by Kemp and a report published entitled *Keswick Creek Hydrology Review* (Kemp, 1997). The purpose was to assess the accuracy of the hydrology and floodplain mapping done by WBCM consultants in 1984, with the aid of currently available rainfall and creek flow records. For this study Kemp used the Rainfall Runoff Routing (RRR) model, fully described in *The Development of a Rainfall-Runoff-Routing (RRR) Model* (Kemp, 2000), in preference to other models because of its ability to handle a range of different catchment flow conditions, as described in Chapter 2, Section 2.6.

Table 4.2 gives estimates of flow in Keswick Creek by WBCM (1984) and Kemp (1997). The estimates are substantially in agreement. Hydrology is an imprecise science and estimates of flood risk are fraught with uncertainty. The WBCM flow estimates were established using data from adjacent catchments, since no data were available for Brownhill or Keswick Creeks. Kemp had access to flow data collected since 1992, including the events listed below, to use for calibration and validation of his model. However, no recorded event was large enough to cause major flooding. Given these limitations there is some reassurance in the fact that two independent studies have produced very similar estimates.



1. Flood zones estimated using very limited data
2. Flood zones are from main stream flooding and do not take account of local area flood risk
3. Changes to the storm water drainage system since 1984 will change the position of the flood zones.

Produced By: Carto Graphics
Unit 6, Young St. Blackwood, SA 5051
Telephone (08) 8278 7748, Fax (08) 8278 7799

Data Source: Digital Cadastre Supplied by the Department of Environment, Heritage and Aboriginal Affairs. Flood boundary information taken from *Drainage Study - Brownhill, Glen Osmond, Parklands and Keswick Creeks* WBCM consultants, August 1984

Projection: Transverse Mercator

Date: April 1998

Figure 4.2 Flood map of Keswick and Brownhill Creek

Storm Duration (hours)	**2**	**3**	**6**	**12**	
AEP (Annual Exceedance Probability)	Maximum Flow Rate (m^3/s)				
20 Years	27.4	23.4	26.2	25.3	WBCM '84
50 Years	32.1	27.4	31.4	28.8	WBCM '84
	27	27.5	29.5	28	KEMP '97
100 Years	37.1	32.1	34.9	31.5	WBCM '84
	32	32.8	34.3	33.5	KEMP '97
200 Years	43.4	37.8	39.8	34.1	WBCM '84
	43.6	44.5	41.6	39.2	KEMP '97

Table 4.2 Keswick Creek flood discharge estimates at Goodwood Road, comparison between Kemp in "Keswick Creek Hydrology Review" (Kemp, 1997) and the "South Eastern Suburbs of Adelaide - Stormwater Drainage Study" (WBCM, 1984)

Further confidence in the flood estimates was obtained during the course of the studies, during which, in the period October 1997 to October 1999, five floods in Keswick Creek have affected Mile End. These were:

Year	Month
1997	October
1998	April
1998	October
1999	May
1999	October

The floods were minor events and the damage was not extensive. Nevertheless, in each case, channel capacity was exceeded in Mile End and it would have taken very little additional rain to cause major problems. The recorded flood discharges were in close agreement with the hydrographs modelled by Kemp.

Virtually none of the owners of businesses interviewed at the start of the investigations appeared aware of flood risk.[2] Keswick Creek, which runs in a narrow, trapezoidal

---

[2] In the second phase of the damages study, covering a wider range of businesses, there were several reports of floods, and some photographs.

concrete-lined channel, confined and built over in places, is inconspicuous. At Mile End it has a cross section area of only six to eight square metres, according to "South Eastern Suburbs of Adelaide - Stormwater Drainage Study" (WBCM, 1984), and is bridged in several places by factory buildings. It seems that if anyone notices the channel at all, it is thought to be a local stormwater drain, rather than a main creek. It is many years since the last major flood and the seemingly low capacity of the channel has not given rise to concern. Given this lack of awareness, there is a high level of vulnerability to flood damage. In a few cases, where minor flood damage has been experienced, it is seen as a local stormwater problem requiring action by the council, rather than a possible indication of a natural hazard such as fire or earthquake.

The threshold of severe flood damage in Keswick Creek and its tributaries is approximately the AEP 1 in 20 storm, over the whole catchment. There does not appear to have been a storm of this magnitude, or larger, since about 1930.

4.4.4 Development of a Runoff Routing Model for Flood Forecasting

The use of runoff routing models for forecasting.

The use of runoff routing models for flood forecasting has now become standard practice for the BOM in Australia, but the primary BOM forecasting and warning responsibilities are for non-flash flood catchments. For flash flood catchments, there are specific demands which make the successful use of runoff routing models for flood forecasting questionable. These are:

☐ *Model Parameters*. The loss, lag and storage parameters are chosen, and the performance of the model is checked against known events, a process of optimising and refining, leading to a final selection which is used for the actual run. For flash flood forecasting, there will only be time to run the model once or twice, after which a decision must be made whether or not a flood is imminent, and how big it is. There is little opportunity for optimising the parameters, therefore they need to be chosen beforehand, bearing in mind that the actual flood might behave differently to the calibration runs;

☐ *Forecast Rainfall*. It is usually necessary to include an estimate of the rain still to fall during the current storm, because to wait until the rain has fallen, would delay the flood forecast to the point that it is too late to be of use. A runoff routing model relies on accurate knowledge of the rainfall amounts and distribution, but current state-of-the-art forecasting of both the amount and distribution of rain could be in error by greater than 50%; and

- ☐ *Timing*. For a runoff routing model forecast to be of value, it should be available in time for warnings to be distributed, received and acted on. The time required for this process is uncertain, particularly since in the Keswick Creek case, the flash flood warning distribution and response arrangements are still rudimentary. Those who are warned and required to respond would need to have time to travel to the danger area, mobilise their resources, move sensitive equipment, protect buildings and ensure the safety of all people in the path of the flood. It is difficult to see how this could be done in less than 2 hours. The forecasting, warning and message distribution will take additional time. In the upper limiting case, where flash flooding takes 6 hours to develop, there may be time to optimise a runoff routing model and produce useful results but for Keswick Creek, with a characteristic response time of less than 3 hours, it will be difficult to use a runoff routing model to forecast floods in time to issue warnings.

Given the constraints listed above, what value might there be in a runoff routing model for Keswick Creek?

- ☐ *Ease of operation* is a critical requirement. The BOM has developed computing facilities that will extract data collected by the ALERT system, and input it to a model without delay. Development of an URBS modelling package described by Carroll in *URBS-CM. A Catchment Management and Flood Forecasting Rainfall Runoff Routing Model* (Carroll, 1999), has enabled the model to be run in conjunction with ALERT, using rainfall and runoff data as it is received. The model is run interactively, requiring decisions to be made on-the-spot. Deletion of corrupted rainfall data readings can be done quickly. Provided that proper attention is paid to setting up the model and developing guidance for the catchment, so that as far as possible the choice of storage parameters and rainfall losses is a simple process, it should be possible to run and optimise the results during a rainfall event within 10 minutes or so. If the model is satisfactorily calibrated, it should require minimal effort to determine the parameters for the model.

- ☐ *Forecasting of Rainfall* for input to the model is an area of uncertainty. Rainfall is the major input to the model and if forecast rainfall cannot be predicted accurately, it would be unreasonable to expect accurate results. If it is necessary to wait until the rain has fallen and been measured, the flood may already have developed and be approaching its peak.

- ☐ *Time Available for the Forecast* is of the essence in flash flood forecasting but the time available for the forecast will vary from storm to storm, and is very difficult to determine. The "Keswick Creek Hydrology Review" (Kemp, 1997) is the most recent that has been done for Keswick Creek. His estimates of time to flood peak are given in Table 4.3.

AEP 1 in 50 flood. Keswick Creek, Time to peak at Goodwood Road		
Storm Duration	Peak Discharge m^3/s	Time to Peak
30 min	26.3	38 min
1 hr	28.4	44 min
2 hrs	27.0	56 min
3 hrs	27.5	55 min
6 hrs	29.5	3.3 hrs
9 hrs	29.6	3.3 hrs
12 hrs	28.0	3.3 hrs
18 hrs	28.7	4.3 hrs
24 hrs	29.4	4.0 hrs

Table 4.3 Variations in time to peak at Goodwood Road, for a range of storm durations. From "Keswick Creek Hydrology Review" (Kemp, 1997)(for other locations, see Table 4.1)

Apart from the 30 minute storm, all times to peak, calculated from the start of the storm, are less than the storm duration.

As a check on catchment response time, Kemp has provided RRR model runs for a 10-minute storm over the catchment. Figure 4.3 shows the results. From the start of the storm, to the hydrograph peak at Keswick, 500m downstream from Goodwood Road, the time to peak is 30 minutes. The peak flow rate for this example is 19.2 m^3/s, which would be contained within the creek channels and would move rapidly down the catchment. A flood which spread out across the residential areas and the South Parklands would take longer.

A flood greater than 19.2 m^3/s will exceed the capacity of the creek channels and would be starting to cause flooding, impeding road access, particularly in the Mile End/South Road area. The build-up of flood water to the peak would happen quickly thereafter. For people and businesses close to the creek, flooding would be expected to start about 30 minutes after the start of the storm and during a major flood would increase for up to 3 hours or so, depending on the storm duration. For other occupants of the floodplain, further away from the overflow points, the initial flooding could be a little slower, depending on the location.

On Keswick Creek, if a severe short duration storm occurs and is followed by a flash flood, the chances of being able to run a model and issue forecasts in time for people to respond are slim. Nevertheless, a rainfall runoff routing model should certainly be set up, and experience gained in operating it and using it for forecasting, bearing in mind that it should not be depended upon. In time, with better capability for rainfall forecasting, and with more experience of large flood events, it could become a useful tool.

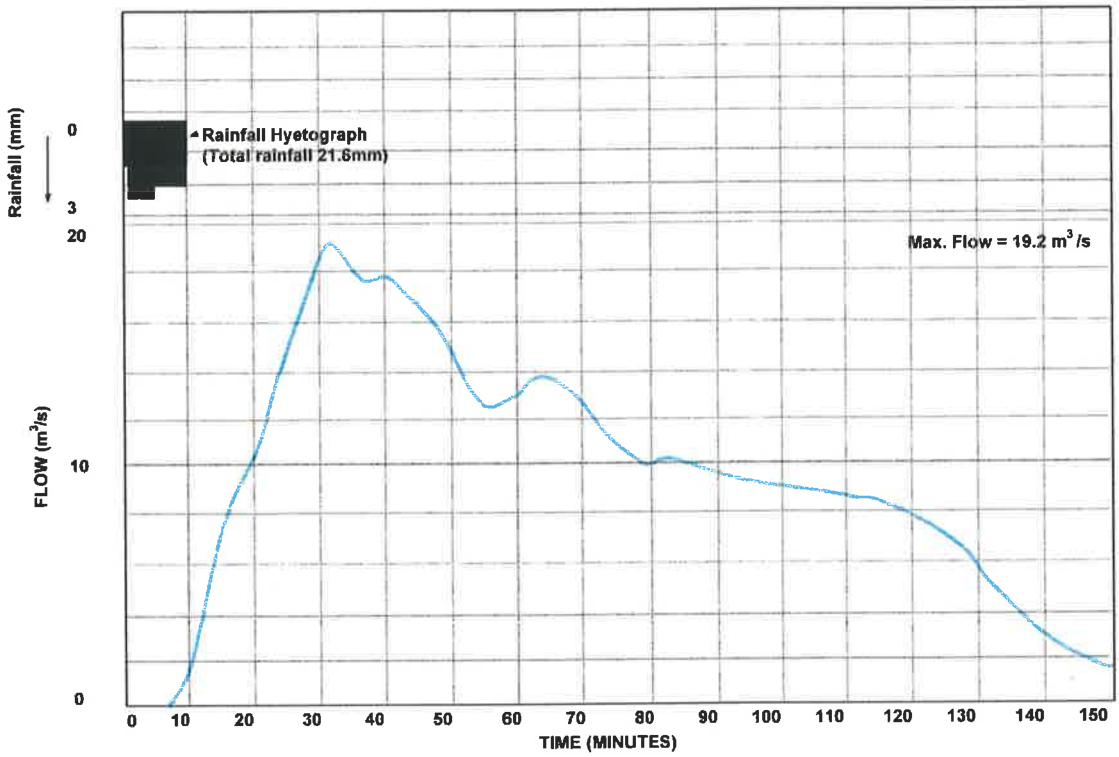


Figure 4.3 Hydrograph at Goodwood Road for AEP 1 in 100 design storm over Keswick Creek, 10-Minute storm duration (Kemp, 2000).

4.5 Rainfall Forecasts for Keswick Creek

If rainfall can be forecast in advance of the start of a storm, as discussed in Sections 4.3 and 4.4, there will be more time to provide early warning, prepare the community and minimise flood damage. The issue can be separated into 3 parts:

- *Weather outlook:* This is part of the weather forecasting process, undertaken 24 hours a day by BOM staff. Based on Global Atmospheric Models, it is now possible to obtain predictions of rainfall up to 4 days in advance. However, the predictions are general and cover the continent at regional scale. They are useful in picking up the potential for development of rain-producing systems well in advance. Outlook forecasts are issued more than 2 days in advance by Email to emergency response agencies and local council staff, advising of the possibility of heavy rain. Performance has not been particularly accurate in that already there have been several occasions when the forecast rainfall did not occur. Nevertheless, the recipients have found the warnings useful, particularly at weekends, for alerting duty personnel to the possibility of a storm, enabling basic procedures to be carried out, such as duty staff being required to carry a mobile phone and keep it switched on.

The inherent problems with the outlook forecast include uncertainty in the expected amount, intensity and distribution of rainfall, the slower or faster development of atmospheric processes, and the differences in prediction between the four different Global Atmospheric Models as described in "Nowcasting with AIFS" by Dickins (Dickins, 1997). The small scale of the models is also a problem. A small adjustment in the model forecast at global scale can mean hit or miss for the whole Greater Metropolitan Adelaide area. However, Email distribution of outlook rainfall forecasts has been well received, despite the uncertainty.

☐ *Rainfall Forecasts, short term:* It is far more difficult to obtain quantitative rainfall forecasts. The BOM forecasting office in each state has a Severe Weather Section, which specialises in analysis and prediction of severe weather events including storms which produce flash floods. At the present level of technology it is not possible to predict severe weather events over an individual flash flood catchment. In "Nowcasting with AIFS", Dickins has said "Rainfall is considered by forecasters to be the most difficult element to forecast" and "While rain is recognised as one of the toughest elements to forecast, few forecasting techniques have been developed to provide guidance" (Dickins, 1997, p. 2).

☐ *Radar as a tool for Flash Flood Forecasting:* The use of radar has been discussed in Chapter 2. It is a useful qualitative tool for observing the movement and intensity of storms, and much work has gone into improving radar data for quantitative rainfall measurement. There is a rapidly growing body of literature on the subject and, in the UK in particular, as stated by Moore in "Rainfall and Flow Forecasting using Weather Radar", the use of radar is gaining acceptance as a tool which can offer good rainfall estimation (Moore, 1995). However, there can be major difficulties in using radar for severe storm monitoring. The problems identifying the severity of the Fort Collins storm are noted in "Some Unusual Aspects of the Fort Collins, Colorado Flash Flood of 28 July 1997" by John Weaver (Weaver, 1998). He describes the analytical processes that are available to the National Weather Service in the United States, including a combination of remote sensing devices (satellite imagery and Doppler radar) and advanced computer modelling techniques. Even though the radar worked satisfactorily in locating and estimating severe storms in the Denver region, the fact that this extremely severe storm was missed by the interpretation processes is a cause for concern. Weaver notes the serious underestimate of rainfall by Doppler radar and draws attention to the potential pitfalls associated with relating reflectivity data (Z) directly to rainfall rate (R), the Z-R relationship.

4.6 Conclusion

This chapter has focussed on the use of runoff routing models for flash flood forecasting, with particular reference to Keswick Creek, which is an urbanised catchment with a very short time of concentration, and so very little time to detect a flood and issue a warning. Accurate forecasts are possible using runoff routing models, but the more accurate the forecast, the later in the storm and the shorter the time-span available for issuing warnings. Radar has potential for increasing the accuracy of the model but may not be able to provide the forecast any earlier. An earlier flood forecast could be achieved by forecasting the rainfall that will produce it, but techniques for forecasting rain are insufficiently accurate. Nevertheless, under the right circumstances, runoff routing models could be useful and may provide a valuable contribution to flood forecasting.

Automatic rainfall intensity alarms provide another way of using rainfall data to forecast floods and are considered to be complimentary to runoff routing models. These will be investigated in Chapter 5.

5. RAINFALL ALARMS FOR EARLY WARNING

In the last chapter, the use of runoff routing models for flash flood warning was examined, using Keswick Creek as the example. There is very little time available for running models in a flood situation even if duty staff are in attendance when the storm begins. Due to limited resources and the long time between floods, it is not practical to keep 24 hour attendance at the flood desk, even in the eastern states where floods are more frequent. It can often be the case that a severe storm begins while duty staff are at home or away from their desks.

The use of alarms based on detection of critical rainfall intensity offers an opportunity to warn operational staff at the BOM and local councils of a potential flood but little work appears to have been very done on the analysis and design of rainfall alarm criteria. In the following chapter, the design and optimisation of alarms and their potential for providing early warning of flash floods is examined.

5.1 The ALERT Alarm System

Since 1987, the Bureau of Meteorology (BOM) has been encouraging the installation of ALERT automatic monitoring systems for detection and warning of the onset of flash flooding. These are described in "Advances in Flash Flood Warning in South Australia", a paper given at the Water Down Under Conference in 1994 (Wright, 1994). ALERT systems, described in Chapter 1, use radio telemetry to transmit rainfall and water level data to a central base station computer which uses software to analyse the data and to display rainfall and water level information in various forms, hydrographs and tables. This information can then be used to assess the magnitude and timing of flood events. However, the problem remains that the operators of the system, generally BOM Hydrology personnel or local council engineering staff, need to know when a potential flood situation is developing and, since there is very little time to respond to the situation, the monitoring system needs to alert the operators as early as possible in the storm event.

5.2 Functions, Value and Limitations of Alarms

The ALERT system generates alarms automatically, using rainfall data received from radio telemetry raingauges (pluviometers), as described in Chapter 2. A time period and maximum rainfall depth can be preselected for the alarm for each rainfall station. If the depth is exceeded within the time, the alarm will be triggered. During a storm event the system software continuously analyses the rainfall data and determines whether the alarm criteria have been exceeded. In South Australia ALERT systems have been set up by the BOM, working with local councils, for a number of flash flood catchments in the Greater Metropolitan Adelaide, the Mt Lofty Ranges and at Clare. The alarm facility has been used for all of them but the standard alarm triggers chosen vary from catchment to catchment, within the range shown on Table 5.1.

	Alarm settings ('x' mm of rain in 'y' hrs)	
Catchment	Rainfall (mm)	Time (hrs)
Brownhill Creek/Keswick Creek	12	3
Little Para River at Salisbury	20	4
Upper Torrens at Gumeracha	20	3

Table 5.1 Rainfall alarm settings used for ALERT systems in South Australia

The choice of x mm of rain in y hours was made on a trial basis for South Australian conditions. Initially 12mm in 3 hours was used but some local councils found that their alarms went off too frequently, or not enough, and the values were adjusted accordingly, although there was no engineering or scientific basis for the selection. It seems that the same approach has been used elsewhere in Australia where the ALERT alarms are used.[1]

Alarms provide potential advance warning for residents of houses, owners of factories and commercial premises, to prepare for a flood and take action to avoid flood damage. Therefore, it is critical that the alarm process operates early enough in the storm so that there is time for organised response. But there was no standard procedure for selecting the alarm criteria.

5.3 Rainfall Alarm Optimisation

If alarm criteria are selected on the basis of the actual rainfall intensity characteristics, it should be possible to optimise the criteria for each rainfall location and set the alarms accordingly. In considering optimum alarm efficiency, there are four important aspects:

☐ *Alarm System Failure:* What is the risk of an alarm totally failing to operate during a flood event due to system failure?

☐ *Early Warning:* How soon after the start of the storm will the alarm be tripped?

☐ *False Alarm:* How many times will the alarm trip when a flood does not eventuate?

☐ *Rainfall Alarm Intensity Failure:* Rainfall intensity is not great enough to trip the alarm, but is sufficient to cause a flash flood.

---

[1] Personal communications by BOM Hydrology staff; Terry Malone, Queensland and Gordon McKay, New South Wales

5.3.1 Risk of Total Failure of the Alarm System

Papers on alarm criteria are few, and research was unable to locate any published work specific to Australia. The work reported by Krzysztofowicz in the USA, "Performance Tradeoff Characteristic of a Flood Warning System", is a useful approach in stating the problem and establishing the criteria (Krzysztofowicz, 1992). ALERT systems are operated by the BOM in most of the Regional offices in Australia, as well as Local Councils, police stations and emergency service offices at many locations.

Krzysztofowicz has noted that there is always the potential for system failure of alarms, meaning that a component of the alarm system fails, causing the whole system to crash (Krzysztofowicz, 1992, p. 194). Alarm failure can be due to power cuts, breakdown of field equipment, battery failure, software lockups, and a range of other potential causes unrelated to the storm event. This possibility cannot be ignored and must be included in any evaluation.

In Krzysztofowicz's paper a figure for system failure of 15% is adopted, implying that an alarm system of this type will operate at an upper limit of 85% efficiency, rather than 100% (Krzysztofowicz, 1992, p. 197). This assumption is made because of the possibility of outside influence, or effects which have no particular relationship to the storm. The percentage assumed is not justified by example or reference, but is an estimate of deficiencies in the logic and technical limitations of alarm systems. But **it would be unwise to rely entirely on the correct operation of the alarm system** because, for a percentage of occasions, it could fail.

5.3.2 Developing Better Alarm Performance

A research program was undertaken to develop a method for selection of alarm criteria, using storm rainfall data supplied by the BOM. The data set was obtained from long term rainfall stations equipped with Dines Pluviographs. Some of these stations had more than 80 years continuous record, with a minimum time increment of 6 minutes. Table 5.2 lists the rainfall stations that were analysed.

The approach adopted for each site within a flash flood catchment was to select the critical storm duration for the catchment, for example, 4 hours for Keswick Creek, and to work through all pluviograph data for the whole period of record, identifying the maximum 4-hour rainfall in each storm, referred to as the maximum 4-hour "burst". Storm bursts longer than 4 hours were assumed to be less critical for Keswick Creek, since short duration storms have a higher average intensity than longer duration storms.

A data set was built up, containing intensity details of each burst. Figure 5.1 shows the cumulative rainfall graph for the whole of a storm, where A-B is the maximum intensity burst that occurred during the storm. For a given set of alarm criteria, for example 12 mm in 1 hour, the whole storm burst data set is analysed to find out how many times the alarm would trip, and exactly when it trips in relation to the start of the critical burst because the object is for the alarm to trip as early as possible after the start of the burst. Figure 5.2 illustrates the process. For the purpose of analysis, the alarm criteria ('x' mm of rain in 'y' hours) form a moving triangle or "window" which is applied to each data point recorded. As soon as the cumulative rainfall gradient within the window exceeds the height of the triangle, the alarm criteria have been exceeded and the alarm is tripped. The analysis works in effect on a graph of cumulative rainfall over time, a triangular "window", and the maximum storm intensity is the steepest gradient during the storm. An alarm will work most efficiently if the cumulative rainfall gradient is steeper at the start of the storm, causing the alarm to trip at an early stage.

Alarm criteria were chosen and the data analysed to find out how often the alarms were activated and how well they performed. A more detailed analysis was done for West Terrace, the old BOM Regional Office, which was within Keswick Creek catchment.

Location	State	Bureau No.	Start Year	End Year	Length of Record
Darwin	Northern Territory	14015	1953	1997	44
West Terrace	South Australia	23000	1897	1979	82
Waite Institute	South Australia	23031	1963	1979	16
Adelaide Airport	South Australia	23034	1967	1991	24
Kent Town (RO)	South Australia	23090	1977	1992	15
Blackwood(SA)	South Australia	23704	1959	1971	12
Mt Crawford	South Australia	23763	1971	1997	26
Brisbane	Queensland	40214	1911	1994	83
Sydney	New South Wales	66062	1913	1966	53
Canberra	ACT	70014	1937	1974	37
Euroa	Victoria	82014	1967	1997	30
Lake Nillahcootie	Victoria	82107	1968	1993	25
Bright	Victoria	83067	1969	1993	24
Calignee North	Victoria	85236	1961	1995	34
Melbourne	Victoria	86071	1973	1997	24
Blackwood(Vic)	Victoria	87017	1974	1993	19
Little River	Victoria	87033	1965	1982	17
Parwan	Victoria	87097	1954	1973	19
Geelong North	Victoria	87133	1972	1993	21
Ballarat	Victoria	98002	1954	1997	43
Hobart	Tasmania	94029	1911	1997	86

Table 5.2 Stations used for rainfall alarm analysis of pluviograph data

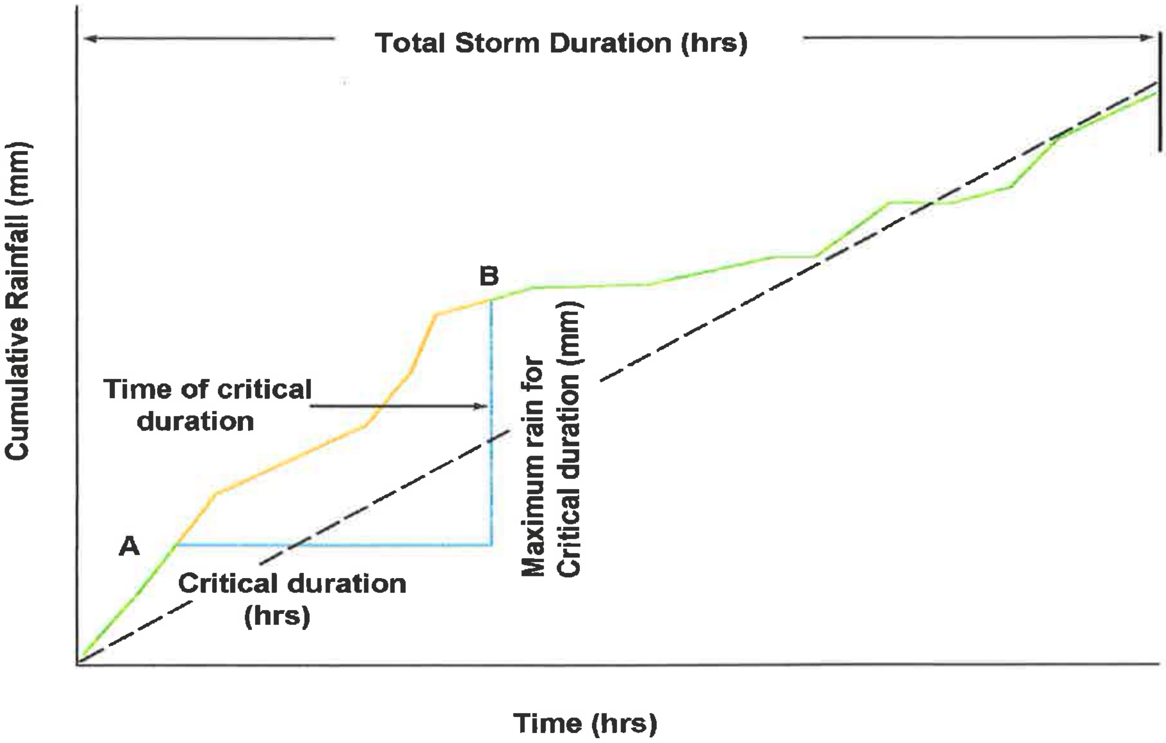


Figure 5.1 Cumulative Rainfall with time for the whole of a storm. The blue lines indicate the critical storm "burst", with a duration the same as the critical duration for the catchment

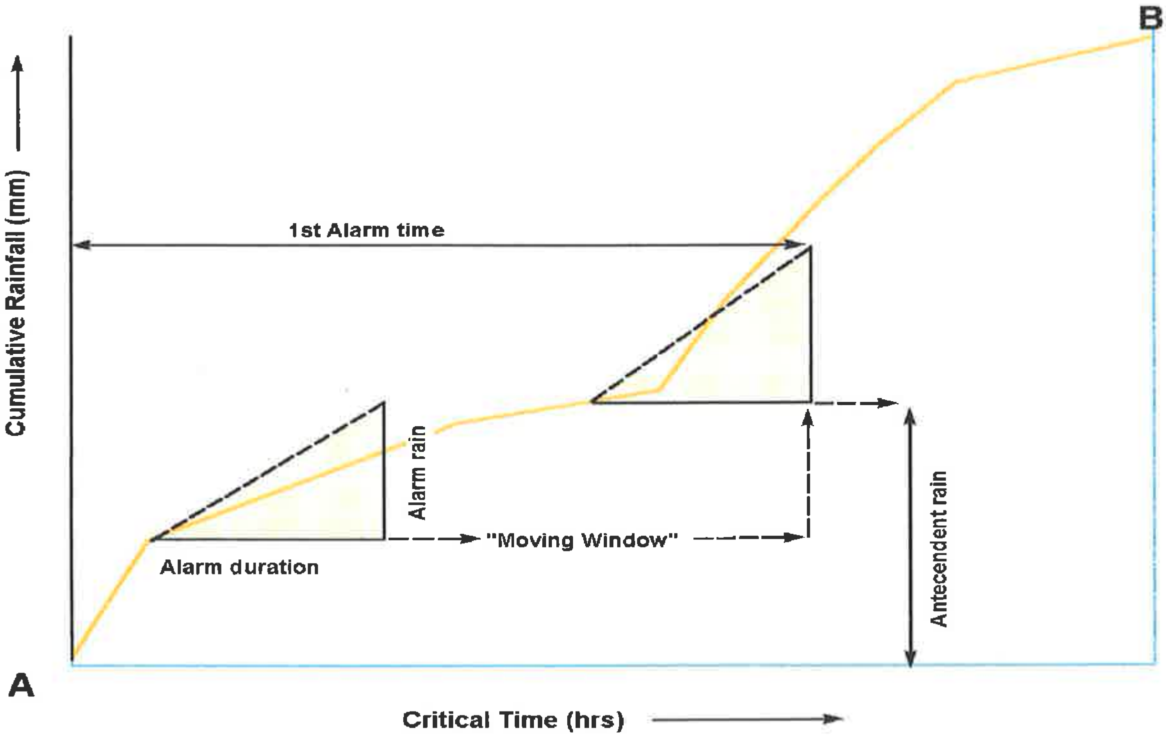


Figure 5.2 Analysis of a storm "burst", the triangle represents the alarm setting as a moving window. Whenever the rainfall exceeds the height of the triangle, the alarm will be set off.

A custom-designed program was used to examine the pluviometer data set andextract all significant storms. If there was no rainfall for any period exceeding 2 hours, the storm was assumed to have ended. If the total rainfall recorded during any storm was less that 15 mm, the storm was ignored. The extracted data for each storm was then analysed to test for alarm occurrences.

5.3.3 Alarm Criteria Selection

A decision on the range of alarm criteria to be analysed had to be made for each rainfall station, and varied widely according to the climate and location. Alarms must be designed so that they operate sufficiently often that duty personnel will respond correctly. If an alarm is designed to operate rarely, it may be that when it does function duty staff will have forgotten the procedures and requirements. Alternatively, if it is set to operate frequently, there is a danger that it could be ignored.

Limiting conditions assumed for alarm settings are:

☐ *Alarm setting too high:* If an alarm is set so that it will only trip at a rainfall intensity equivalent to the AEP 1 in 100 storm, then it will trip very rarely. The danger is that a person required to respond to an alarm that operates perhaps only once in his/her lifetime, has no chance to practise, to develop credibility. What are the chances of a successful outcome?

☐ *Early alarm trip:* An alarm needs to trip early in a storm event, requiring that it should be set at a low threshold; and

☐ *Alarm setting too low:* If an alarm trips too often, the responders to the alarms will tend to ignore it (the "Cry Wolf" problem).

By trial and error analysis, alarm values were chosen so that the alarm would trip, on average once a year, with the object of obtaining an approximate equivalent to an AEP 1 in 1 storm. Subject to this constraint, a full range of alarm criteria was tested so that it was possible to determine the differences and whether there is an optimum range of values for the alarms. The process simulates the way in which the ALERT alarm system operates, with the exception that, for this analysis, the smallest time interval between rainfall increments in the data set is 6 minutes, whereas ALERT data is normally recorded to within the nearest 6 seconds, according to the ALERT hardware design standard.

At the time when the analysis program detects each alarm trip, a full record is saved of the data for that particular storm. The analysis also includes an estimate of catchment initial loss (catchment dryness) at the start of the storm, using the Antecedent Precipitation Index (API) procedure, Any subsequent trips of the alarm during the same storm are also recorded.

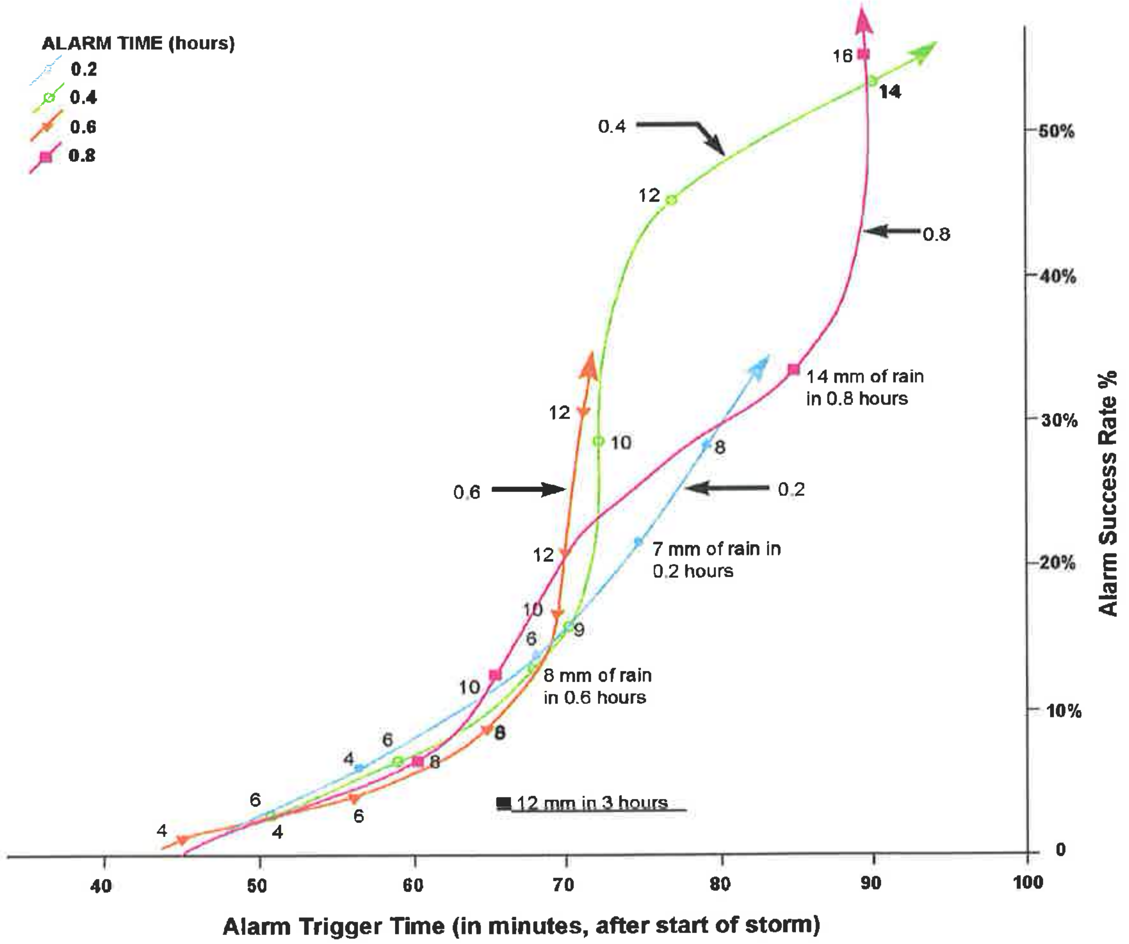


Figure 5.3 Example of comparison of alarm performance, West Terrace rainfall, analysed for Keswick Creek.

The storms were sorted to identify the most severe storms. The total number of storms which caused the alarm to trip was noted. For each storm, statistics were given such as:

- ☐ the time when the alarm tripped in relation to the start of the period of maximum storm intensity for the critical storm duration;
- ☐ the initial loss condition at the start of the event; and
- ☐ the excess rainfall during the storm.

An estimate was made as to which of the storms might have caused flash floods to occur[2] and, if the alarms had tripped, they were recorded as successes.[3] If for any of these major

---

[2] This was a value decision based on experience, and considered the type of catchment and typical storm intensity for the location. For Keswick Creek, an urban catchment in temperate Adelaide, a minimum flood-producing threshold of 40 mm of rain in any 4-hour storm was assumed. In the light of subsequent experience, the value is a little high, rainfalls as low as 35 mm having given risk to minor flooding.

[3] It would have been possible to use a runoff routing model to determine the maximum flows, but the rainfall data set was limited to only one station and the objective was to establish a lower threshold, below

storms **an alarm failed to trip**, this was assumed to be unsatisfactory and that particular criteria was abandoned.

Figure 5.3 gives a set of results of the analysis for Keswick Creek. The x-axis gives the alarm trip time after the start of the storm. The minimum value of about 45 minutes is interesting because it shows that it is very difficult to achieve a rainfall alarm trip earlier than 45 minutes after the start of a major storm, on the basis of measured rainfall. The y-axis gives a measure of alarm efficiency showing how many successful alarms will be triggered compared with unsuccessful alarms, that is, those that are triggered but which are not followed by floods.

Alarm	Alarm	No. of	No. of	Mean	Standard	Performance
Rainfall mm	Time hrs	Alarm Trips	Suc- -cess	Time Minutes	Deviation Minutes	Efficiency E%
12	3	343	11	66	32	4.5%
4	0.2	202	12	57	36	5.9%
6	0.2	72	10	68	38	13.9%
7	0.2	42	9	75	38	21.4%
8	0.2	32	9	79	43	28.1%
10	0.2	16	7	134	149	43.8%(***)

(***) this is the most efficient of all the alarm settings but has the disadvantage that it does not trip until 134 minutes after the start of the storm.

Table 5.3 Analysis of alarm efficiency, Keswick Creek. Time of concentration is 4 hours. Critical storm burst is 40 mm or greater.

Note, for comparison, the characteristic performance of the standard 12 mm in 3 hours shown on Figure 5.3, will not trip until 66 minutes after the start. Earlier alarm trips can be achieved by setting the alarm more finely, but this sacrifices efficiency and the alarm will go off more frequently. A notable feature is that if it is decided that the alarm efficiency is to be maximised, giving fewer false alarms, then the alarm will tend to trigger later in the storm, perhaps up to 90 minutes after the start, and the performance is likely to be erratic, evidenced by the scatter of the points on the right hand side of the graph. A sample of the results obtained for Keswick Creek, using the pluviometer record from West Terrace is given in Table 5.3. The length of this record is 87 years, long enough to provide reasonably consistent results. The figures correspond with those on the Figure 5.3 for the 0.2 hour case. The figures are derived for a catchment time of concentration of 4 hours, and a critical storm burst rainfall of 40 mm or more. Note that for the case of 12 mm in 3 hours, the standard used by the BOM, the alarm would have tripped 343 times in the 87

---

which it was unlikely that the rainfall was sufficient to cause a flood.

years of operation, during which time there would have been approximately 11 floods (defined to mean overbank flow would have occurred). This represents a 1-in-33 success rate. Bearing in mind that this is calculated for only one station in the catchment and that there are 8 pluviometers in Keswick, frequency of alarm trips may be unacceptably high. Better criteria could be selected.

5.3.4 Potential Value of Alarm Optimisation

Alarm analysis was undertaken for the 21 pluviometer sites listed in Table 5.2, covering a broad range of climatic conditions around Australia. In most cases it was possible to determine efficient alarm settings. Once it was set up, the procedure for analysis of alarm performance was straightforward but the trial and error process of optimising alarm criteria was time consuming and relied on there being sufficient pluviograph data to make it reliable. The analysis of the BOM Dines Pluviometer data did not include checks on the validity of the data. Therefore, no account is taken of gaps in the record, or situations where part of the data from a storm had been lost. In the case of the Hobart data, this led to the analysis missing a heavy storm, but the overall effect of these gaps on the analysis is believed to be only slight.

A technique for making the analysis much quicker was considered, and is similar to Intensity Frequency Duration (IFD) analysis described in *Australian Rainfall and Runoff*, (Institution of Engineers, Aust., 1987). It is described in Section 5.5.2.

The alarm process works best when the storm begins with a heavy burst of rain and so alarms are particularly well suited to locations where severe thunderstorm events are the main causes of flash flooding. The alarms are likely to be less efficient in situations where a cloud band and frontal system interact and contain storm cells within the general system, since these storm cells can occur at any time and at any location within a major storm, and might not trigger the alarm until late in the storm. In general, the problem of late alarms is more critical for the storms of lower average intensity (storms for which the flood risk is less). It is reassuring to realise that if the alarm works satisfactorily for smaller storms, it is likely to trigger sooner for the more severe events. In contrast, this is quite the reverse to the problem with runoff routing models, where the lack of data for major storms and associated lack of confidence in model prediction is a serious drawback to the accuracy of prediction. So, despite its limitations, an alarm facility should always be provided as one of the means of detecting and warning of flash floods.

The possibility of the alarm system failing due to the failure of individual components must be taken into account. For ALERT systems the possibilites include:

☐ computer hardware or software failure;
☐ mains power failure;

- ☐ field station battery failure;
- ☐ telecommunications breakdown;
- ☐ radio traffic interference; and
- ☐ repeater station breakdown.

Krzysztofowicz suggests a figure of 15% failure but does not substantiate it (Krzysztofowicz, 1992). With this in mind, the design of a flash flood warning system should not rely absolutely on a single process. The warning system must have redundancy in the design, allowing several different paths to initiate the flood forecasting and response process. The more redundancy and backup that can be provided, the less likely it is that the overall warning system will fail when it is most needed. The ALERT system, as operated by the BOM in South Australia, incorporates the following redundant features:

- ☐ alarms will be triggered from more than one rainfall station, so if the hardware fails at one station, the system can still function;

- ☐ signals from rainfall stations are received by multiple local base stations, so that if one base station fails, others should receive the signals;

- ☐ alarm messages are despatched automatically by at least 2 local base stations;

- ☐ the repeater network has sufficient redundancy to ensure that failure of one repeater in the system will not cause the whole system to fail;

- ☐ all local base stations have backup power supplies; and

- ☐ all alarm messages are sent to at least two destinations.

Nevertheless, there are weaknesses in the system, such as the Mt Lofty repeater which, if it failed, could seriously reduce the efficiency of the data collection network. Further work would be needed to determine whether 15% is a reasonable estimate for total system failure.

5.3.5 Comments and Conclusion on the Optimising of Alarms

An alarm system that responds to rainfall is a potentially valuable aid to early warning of a flash flood. Rainfall alarms have been shown to be useful, particularly if there is a burst of high intensity rainfall early on in a storm. The method described allows the selection of alarm criteria to be optimised to give either:

- ☐ earliest possible warning of heavy rainfall (more false alarms); or
- ☐ an efficient alarm which is triggered later in the storm (fewer false alarms).

The appropriate selection of alarm criteria will be a compromise between these two requirements.

The analysis of West Terrace data showed that much better performance than 12 mm in 3 hours (the current standard for Keswick Creek) can be achieved by a setting of 6 mm in 0.6 hours. This obtains the same efficiency, but the warning is triggered 10 minutes earlier.

Similarly 10 mm in 0.8 hours triggers at the same time as the standard but gives much better efficiency. This suggests the possibility of a combined alarm which could utilise both criteria, giving both initial and final warnings.

Analysis of the Hobart pluviograph record confirmed that the approach used for Keswick Creek is sound. Alarm settings were recommended for Hobart, but the problem was that the results are not transferable from Hobart Airport, where the pluviograph data were recorded, to Springs, a rainfall station on the slopes of Mt Wellington, at the top of the Hobart Rivulet, which is in the flash flood problem catchment. A transfer relationship or means of obtaining alarm criteria for other sites is needed.

5.4 Extending the Rainfall Alarm Process

The intrinsic value of the alarms is that they will generally work more efficiently for the rarer storms because the intensities of rare storms will generally be higher. Analysis of the alarm performance showed how soon the alarm would trip after the start of each critical storm burst. Table 5.4 gives a summary of the analysis for three locations in South Australia, Victoria and Queensland. The remainder are in Appendix B.

"Tc" on Table 5.4 is the time of concentration assumed for the catchment, the critical storm duration. The Alarm Rainfall and Time are the criteria, for instance 48 mm in 3 hours. Alarm performance is given for the five severest storms within the period of record. A '+' sign indicates that the alarm tripped before the **start** of the critical rainfall burst, which gives optimum warning. The "worst" alarm performance for the five storms is the time taken for the alarm to trip after the start of the critical rainfall burst, for the most severe of the five critical storms. In the first example, this was 4.7 hours after the start of the storm. The case of the severest storm on record is considered important as the more extreme the storm, the greater the need for an effective alarm. For Brisbane, in the sub-tropics, short duration alarm criteria do not work very well. It is better to use at least 1.5 hours as the minimum alarm time period because times shorter than this will give unreliable results. Given this limitation, the alarms work reasonably well, although there could be times when an alarm did not trip until 4.7 hours after the start of a 6 hour critical rainfall burst. For Werribee, the alarm criteria can be selected to work satisfactorily although, again, the short duration alarm settings are not so good. For

Werribee, in certain storms, it could take more than 3 hours after the start of a 6-hour storm before the alarm was tripped. For Keswick Creek it was generally found that the alarm process works well, and can be expected to trip within 1.5 hours after the start of a 4-hour storm. Bearing in mind that an alarm is a simple "trigger" device, and cannot make allowance for storm complexities, alarms are useful and it is worth paying attention to optimising them.

On the right hand side of Table 5.4 statistics are given for the probability of further rainfall occurring after an alarm has tripped. From a response perspective, it would be useful to know whether there is any guidance or indication, after an alarm has gone off, as to how much rain might be expected. The analysis for Brisbane indicates that there is 50:50 chance of receiving 20 mm more rain after an alarm has tripped. This amount of rain is probably insignificant in the Brisbane situation. For Keswick Creek, the statistical possibility of flood producing rain after an alarm (which would be about 40 mm), is 1%. In other words, for every 100 times that the alarm tripped, one major flood might be expected. This is logical enough, since the alarm criteria were selected for an AEP 1 in 1 storm, whereas a major flood can be expected from an AEP 1 in 100 storm. As will be seen later, the problem of using alarms to detect severe storms can be refined by other methods, rather than relying on a simple alarm trip. Therefore, the analysis and investigation of the Table 5.4 results has not been taken any further.

5.4.1 Alarms Settings and Operation

Alarms are used for a variety of purposes. Fire alarms are accepted as part of our defences against fire danger. Smoke alarms are now installed in houses as a matter of routine. Sirens were used widely during the Second World War to warn communities to defend themselves against bombing raids. Alarms are used for many situations, such as tanks overflowing, pumps not working or motors overheating. These are all relatively straight-forward situations, based around a decision whether or not to issue an alarm. False alarms are inevitable.[4] Flash flood alarms pose a slightly different problem in that, although they are caused to trip by rainfall, there may not be a clear-cut decision as to whether or not a flood is about to occur. Secondly, if the decision to sound the alarm comes too late, the alarm will be of little value. The example of alarm analysis for West Terrace suggests that waiting until there is at least a 50:50 chance of a flood occurring will lead to a sacrifice of response time and an increase in the risk that the alarm will not trip at all.

If the flash flood warning system relies solely on the use of alarms, and an in-principle decision is made that the alarm must be received as early as possible, then it must be accepted that there will be a high percentage of false alarms, and the percentage of false alarms could be from 90% to 99%.

---

[4] False alarms are a more complex problem for burglar and security systems because they may be tripped frequently without there being a burglary or break-in, and the "Cry Wolf" syndrome means that they may not be heeded.

Catchment	Area km^2	Tc hrs	Rain Stn	Data Rec. yrs	Alarm Rainfall mm	Alarm Performance (5 worst storms)			Worst Storm hrs	Chances of 'x' mm of rain falling after the alarm has triggered				
						Time hrs	Best hrs	Worst hrs		50% mm	20% mm	10% mm	1% mm	0.1% mm
Brisbane	*	6	**Reg.Office**	84	48	3	+	4.7	+	20	47	68	136	203
					42	2	+	4.7	+	20	47	68	135	203
Rainfall range (crit. dur) mm			181 - 127		39	1.5	+	4.8	+	20	46	65	130	195
					33.7	1	1	5	3.6	19	43	62	124	186
					31	0.8	0.9	4.8	3.7	18	43	61	122	183
					27.7	0.6	0.9	4.8	3.6	19	43	61	123	184
					22.8	0.4	0.8	4.8	4.8	17	44	58	116	174
Werribee R	240	6	**Parwan**	20	23	4	+	3.3	+	13	31	44	89	133
to Bacchus Marsh					20	3	+	3.3	+	13	31	44	89	133
					17.5	2	+	3.4	+	13	29	42	83	125
					16	1.5	+	3.7	+	12	27	39	78	116
					13	1	+	3.6	+	12	28	40	80	119
					9.5	0.5	0.3	3.6	0.8	13	29	42	83	125
Keswick Creek	1461	4	**West Tce**	82	17.5	3	0.5	1.4	1.4	6	15	21	43	64
					14.5	2	0.4	1.6	0.3	7	17	24	49	73
Rainfall range (crit. dur) mm			138 - 49		13.5	1.5	0.4	1.6	1.3	7	17	24	49	73
					11.7	1	0.4	1.6	1.3	7	17	25	50	75
					10.5	0.8	0.4	1.6	1.4	8	18	26	52	79
					9.4	0.6	0.3	1.6	1.4	7	17	24	49	73
					7.8	0.4	0.4	1.5	1.4	8	18	25	51	76

* Nominal flash flood catchments

\+ indicates that the alarm tripped before the start of the critical storm burst

Table 5.4 Statistical analysis of rainfall alarm performance for three representative locations in Australia

Whether or not the false alarm level is tolerable is a decision which must be made by the organisation responsible, although such decisions seem to be made at present on a trial-and-error basis. Frequent false alarms may not be a problem for BOM staff, who would normally expect to be on call anyway for severe weather situations.[5] But for response agencies such as local councils, using staff who are required to respond to a wide range of situations, of which flood danger is just one, false alarms can be a problem. Alarms are normally transmitted to emergency staff by Short Message Service (SMS) on a mobile phone. On a typical stormy night in Adelaide, the experience with the standard alarm settings (12mm in 3 hours), is that the alarm goes off frequently, every few minutes, but that serious flooding does not often follow. The risk is that council staff will, after a number of false alarms, tend to ignore them, or worse, switch off the pager or mobile phone, thus defeating the purpose. A regular program of flood warning practices linked to emergency response trials would help to keep the awareness of flood risk fresh in the mind, overcoming the tendency to ignore alarms but, at present, trials are somewhat haphazard and irregular and do not include emergency response.

The recommended alarm settings are designed to trip on average once a year for each rainfall station. The reasoning is as follows:

- ☐ once a year is frequent enough to remind people that an alarm system is in place and to check that it is working correctly; and
- ☐ if the once-a-year frequency corresponds approximately to the AEP 1 in 1 storm, then the storm intensity is probably not severe enough to cause flooding, and it can be expected that more severe storms **will** be detected earlier in the life of the storm.

The suggested 1 in 1 year standard for alarms is roughly equivalent to the AEP 1 in 1 year storm. If the threshold for serious flooding is AEP 1 in 20 year, the average number of false alarms for each rainfall station per flood would be 20.

It is believed that the performance of alarms for flash flooding, based on analysis of a time series data record, is likely to give better and more predictable performance than rule-of-thumb selection. The risk of alarm failure can be reduced to a minimum, but at the expense of a larger number of false alarms. Optimising of alarms requires that each rainfall station will need a specific alarm setting.

5.4.2 A General Method for Rainfall Alarm Setting

---

[5] BOM Hydrology staff in Adelaide accept a high rate of false alarms, preferring to ensure that they are in attendance as early as possible, allowing maximum time for issuing warnings if required.

It is believed that increasing use of ALERT flood monitoring systems has introduced an expectancy that these systems have the potential to provide flood warnings for flash flood catchments. But the primary warning capability of an ALERT system is the use of alarms; these are not flood warnings, and they are only received by one or two people. It is not clear from discussions with BOM staff who have been involved in the installation of ALERT systems around Australia, whether the alarms are actually being used outside South Australia, and if they are, how the alarm criteria were selected. No references were found on alarm analysis for rainfall in Australian literature. A paper on the subject, entitled "Rainfall Alarms for Flash Flood Warning" (Wright, 1998), was presented at an ALERT users' conference in California in 1998, which attracted considerable interest, but there was no mention of other work.

The investigations into alarm settings were specific to individual rainfall stations, and relied on availability of a long period of pluviometer record, from which a set of alarm criteria can be selected. Examples of the analysis were given for West Terrace and Hobart, each with 80 years of data record, and analyses were also done for the Australian capital cities and for a selection of pluviometer stations in Victoria.[6] It was concluded that the correct selection of alarm criteria can improve the chances of the alarms operating satisfactorily:

☐ as early as practicable after the start of the storm; and
☐ without providing an excessive number of false alarms.

On the premise that it is better that alarm settings should not be chosen by rule-of-thumb, but rather that some sort of optimising is preferable, how should the alarm criteria be set for each location? The analysis which was described in the previous section requires considerable time and effort for each rainfall station. It also assumes that there is adequate length of record to provide representative results. It would be difficult to justify the resources for undertaking the analysis for a large number of stations due to the lack of interest by potential users of the more efficient alarms. Also, there are not enough sites with pluviograph record of sufficient length, so a means of transferring the results of one site to another, based on known topographic and meteorological differences needs to be found.

The objective is to find a procedure which will enable optimum alarm criteria to be selected, without the need for extensive analysis. The assumption is that alarm operation frequency should be approximately once per year, and that the criteria are specific to the chosen location.

---

[6] The stations in Victoria were analysed at the request of the Bureau of Meteorology, Hydrology Section, with the object of using ALERT alarms for flash flood warning in critical catchments. Benalla, Euroa and Werribee have experienced major flooding, and have been provided with ALERT flood monitoring systems.

Location	ARR 1-hour Rainfall mm	Alarm Analysis mm	Alarm ARI (Approx) Years
Darwin	50.3	49.0	1.0
West Terrace	13.0	12.2	0.8
Waite Institute	13.0	11.5	0.8
Adelaide Airport	13.0	11.0	0.8
Kent Town (RO)	13.0	11.0	0.8
Blackwood (SA)	13.0	11.0	0.8
Mt Crawford	13.0	12.2	1.0
Brisbane	36.0	33.8	0.8
Sydney	32.0	28.4	0.9
Canberra	17.0	14.5	0.7
Euroa	18.0	16.0	0.9
Lake Nillahcootie	19.1	15.7	0.7
Bright	19.2	14.0	0.5
Calignee North	13.3	10.0	0.6
Melbourne	14.0	15.0	1.3
Blackwood(Vic)	15.2	10.5	0.5

Table 5.5 Comparison of IFD statistical data with rainfall alarm analysis, for storm duration of one hour and AEP 1 in 1

The procedure described above for determining alarm performance for a variety of alarm conditions is basically the same as the procedure for obtaining Intensity Frequency Duration (IFD) statistics described in *ARR* (Institution of Engineers, Aust., 1987) where, during any storm, the maximum intensity burst is determined, together with its frequency. Therefore, if the alarm analysis is carried out for an alarm condition that will trip once a year, the results should be similar to the IFD data for the same location, for an AEP 1 in 1 storm. Table 5.5 gives the comparison for all the locations analysed. The first column of data was obtained from *ARR* (Institution of Engineers, Aust., 1987) for the Annual Exceedance Probability (AEP) 1 in 1. The second column was the result of analysis of alarm criteria, using data from each pluviograph, also for a 1-hour duration storm, and an AEP 1 in 1. As expected, the two sets of figures are very similar,[7] although in all cases but one, the figures for the alarms are slightly lower.

It is not clear why this difference occurs. For the IFD analysis, the AEP 1 in 1 is the lower end of the scale and statistically does not really exist unless the analysis is extended to monthly frequency. Also, the data set available for the IFD analysis may not have included

---

[7] Note that the analysis described was based on Dines Pluviograph records, which were also used for the original IFD analysis by the BOM Hydrometeorology section for deriving the IFD statistics. As the data base of ALERT data becomes more comprehensive, there will be opportunities for refining and extending this analysis.

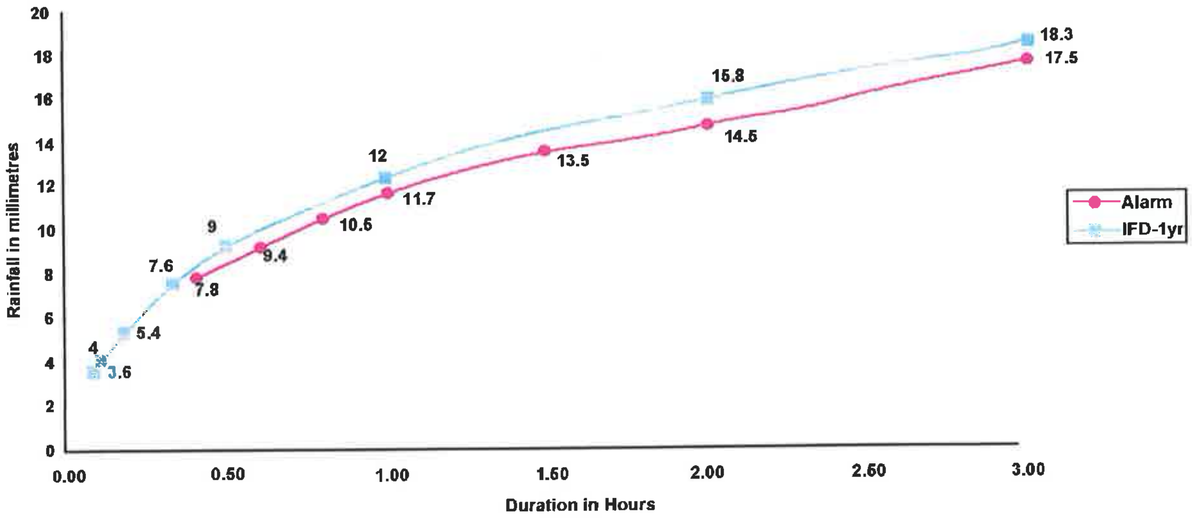


Figure 5.4 IFD statistical data compared with rainfall alarm analysis (West Terrace, Adel.)

the pluvio data which was analysed for the alarms, leading to potential differences. Finally, the data set available for the IFD analysis relied heavily on the record of a relatively small number of pluviometers. For the whole of Australia, there were less than 20 Dines Pluviographs which had more than 50 years of record. For practical purposes, as a guide for setting alarm criteria, use of IFD statistics is recommended. This would give an expected alarm performance of slightly more often than once per year for each location, an acceptable frequency for alarms to trip.

A comparison of IFD statistics with the alarm criteria evaluation is given on Figure 5.4 for West Terrace, a close parallel, and Figure 5.5 for Bright in Victoria where the comparison is not so good. This is not suggesting that the alarm analysis is better or worse than the IFD analysis, but that there are limitations on accuracy which may be due to lack of pluviograph data.

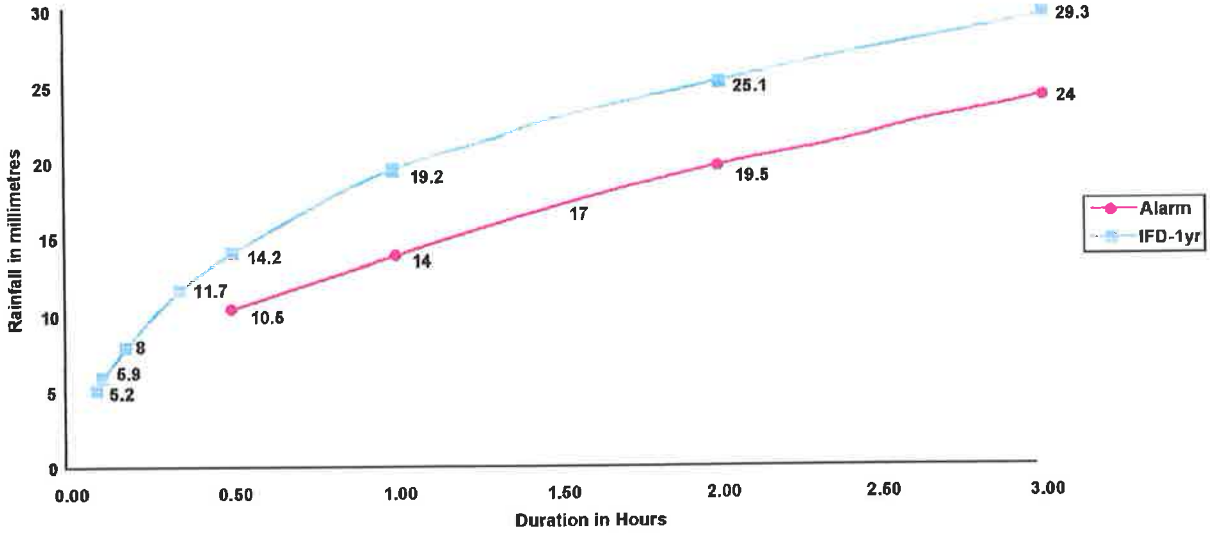


Figure 5.5 IFD statistical data compared with rainfall alarm analysis (Bright, Victoria)

5.5 Alarm Criteria Using Intensity Frequency Duration (IFD) Statistics

In the previous sections, the use of alarms was discussed and a method proposed for maximising alarm efficiency. The alarm process is a useful first step in monitoring and detection of heavy rainfall as a precursor of possible flooding. It has the disadvantage that in order to ensure that an alarm is received as early as possible in the storm, it needs to be set at a low threshold of rainfall, which means that it will tend to trip frequently. The problem for the person who has to respond to the alarm is to decide whether this particular alarm is the herald of a flood event or one more false alarm. While the Regional Forecasting Centre duty staff would normally give some indication of current and future storm severity, this is a qualitative assessment and not necessarily appropriate for individual catchments.

The alternative of making the alarm settings less sensitive will result in less alarm trips but, as indicated on Figure 5.3, will also mean that the alarm trips later, with the associated loss of warning time and the possibility that it may be too late to issue a warning.

The investigations into alarm efficiency showed that:

- alarm efficiency can be maximised;
- the use of a single alarm standard (12 mm in 3 hours for example) will lead to lower alarm efficiency;
- individual alarm settings need to be selected for each rainfall station location; and
- by using the IFD statistical data, it is possible to select alarm settings specifically for each rainfall station and to be reasonably confident of the performance efficiency.

If the alarm efficiency benefits are to be realised, then the users of the ALERT alarms for flash flood monitoring need to be convinced that there are advantages in optimising alarm settings. It has proved to be difficult to obtain any response from the users of ALERT systems. Bruist indicates in his paper "Flash Flood Warning Services - What the Bureau can do for you" that there are nearly 50 ALERT systems in Australia (Bruist, 1999). The results of the analysis showing the benefit of improved alarms were discussed with BOM staff in Victoria, New South Wales, Queensland and Tasmania, but to date there has been little interest. This appears to be because:

- most ALERT systems have been set up in catchments for which the time of concentration is at the upper limit for flash flooding (around 6 hours), and there is perhaps not quite the same urgency to use the alarm process;

- in situations where alarms are used, the application needs to be as simple as possible, whereas the process of maximising alarm efficiency requires a more sophisticated approach.

The alarm criteria selection method described in this section was applied for all of the ALERT systems in South Australia in July 2000. All station alarms were set at the AEP 1 in 1 year rainfall. The storm duration was set at 30 minutes. The results have been encouraging, with the BOM staff and local council duty personnel reporting that the alarms have been less frequent and that they are giving a better indication of storm severity. A problem was encountered in that the storm duration was set at 30 minutes. Some winter storms with longer duration and lower intensity did not trip the alarms but due to the wet winter catchment conditions produced minor flooding.

5.6 Analysis of Storm Burst Data

What is needed is a "value added" process which will make the operation of the alarms provide improved information on the storm intensity. Analysis of time series rainfall data for optimising of alarm criteria included finding the maximum intensity rainfall bursts for all of the period of record, for a series of standard durations from 6 minutes to 72 hours. This was done as part of the process for comparing the optimised alarm criteria with the Intensity Frequency Duration statistics, and it produced interesting results. A sample of the analysis for the West Terrace pluviograph is given in Table 5.6. There are 87 years of rainfall data in the record, with a minimum time increment of 6 minutes. Each storm was identified by its date (hour-day-month-year). The whole time series record was analysed for each of the specified storm durations, to pick out all of the storm bursts for this duration. For the 12-minute duration, each storm was analysed to find the maximum storm burst, the amount of rain that fell during that burst, and the maximum burst in each year was determined. For a specific storm burst duration, the rainfalls were ranked, with the highest rainfall ranked 1 and with successive smaller bursts numbered sequentially. Table 5.6 shows the results with red indicating the highest ranking storm. The 3-hour storm burst duration was chosen, and the top 10 rainfall amounts selected, shown on the table with different colour highlights. The storms during which these bursts occurred were then analysed for **all the other durations**, and their rank determined. Thus, for a 30-minute duration, the storm ranked second for the 3-hour duration, is ranked first for the 30 minute duration, and fifth for the 24-minute duration. What is interesting is that the storm which produced the highest intensity 3-hour burst in the whole 87 years on record (coloured red), also produced the highest intensity for 48 minutes through to 72 hours at any time in 87 years of record.

Furthermore the ranking was seventh or higher for **all** the remaining storm burst durations except for the 12 minute duration (which was ranked twenty-fourth).
Table 5.7 gives a summary of the coloured cells in Table 5.6. The top-ranked 3-hour storm is among the top 10 storms for 16 out of 17 standard storm durations. The second ranked storm is in the top 10 for 11 out of 17 durations, and so on. In all, the top 10 ranked 3-hour storms appear no less than 106 times out of 170 possible.

	Rank of Storm Burst (1 is most intense 3-hr storm on record)									
Duration	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
6-min	19	6	66	35	9	17	1	39	32	8
12-min	11		62	20	2	10	4	23	45	7
18-min	5	2	48	14	1	4	3	16	46	9
24-min	4	1	31	13	2	3	5	17	48	8
30-min	2	1	23	11	4	3	6	15	48	5
48-min	1	2	10	6	4	3	9	17	45	5
1-hr	1	2	7	6	3	4	11	15	33	5
2-hr	1	2	3	4	5	6	9	8	16	7
3-hr	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
6-hr	1	4	5	2	6	11	3	9	10	19
12-hr	1	4	6	3	11	21	2	16	18	10
18-hr	1	7	6	4	11	22	2	20	21	10
24-hr	1	7	6	4	12	23	3	21	22	10
36-hr	1	7	6	4	12	23	3	19	22	11
48-hr	1	7	6	5	14	23	4	19	22	11
60-hr	1	7	6	5	15	23	4	13	22	11
72-hr	1	7	6	5	15	24	4	13	22	11

Examples:
1. Storm duration 6-minutes. The maximum 3-hr storm on record, noted in red, included a burst of rainfall that was the seventh highest 6-min intensity in 87 years.
2. Storm duration 6-hrs. The second largest 3-hr storm on record, included a 6-hr storm burst that was the fourth highest 6-hr intensity in 87 years.

Table 5.6 Analysis of storm burst intensity, based on 3-hour critical storm duration, and ranked for each of the standard durations. (West Terrace, using 87 years of data)

Colour Code	**Description**
1	Worst 3-hour storm on record
2	Second worst 3-hour storm
3	Third worst 3-hour storm
4	Fourth worst 3-hour storm
5	Fifth worst 3-hour storm
6	Sixth worst 3-hour storm
7	Seventh worst 3-hour storm
8	Eighth worst 3-hour storm
9	Ninth worst 3-hour storm
10	Tenth worst 3-hourstorm

Colour codes for storm intensity analysis

Rank of Storm	Number of Occurrences
1	16
2	11
3	11
4	16
5	12
6	14
7	10
8	4
9	5
10	7

Table 5.7 Highest ranked storms versus number of occurrences (see Table 5.6)

There are several implications that come out of this analysis:

☐ rare storms of high intensity are likely to be classified as rare over a wide range of durations. It is remarkable that the 1925 North Adelaide storm should have produced maxima over such a wide range of durations;

☐ if intensity analysis is used to detect a rare short duration storm, then the storm is likely also to be classified as a relatively rare storm for other duration categories;

☐ if an intense storm occurs over a catchment, it will produce flooding on a large scale, on sub-catchments of much shorter times of concentration than the main catchment of say of 3-hour critical duration and on larger catchments subject to the areal extent of the storm;

☐ during a severe storm, the duration of flooding in the catchment is likely to be extended, starting with local small-scale "nuisance" flooding and developing into major flooding in the main channels. Consequently, people who need to respond to major flooding will run the risk of being hindered by, or unable to cross areas of local flooding in their efforts to reach their place of work; and

☐ the analysis process used for the IFD statistical data by the BOM (*ARR*, Institution of Engineers, Aust., 1987), will have used the same storm to produce statistical data for a variety of different storm durations because that was the only data available.

The design approach adopted by professionals, using the Intensity-Frequency-Duration data, relies on finding exactly which storm duration is critical over the whole catchment. In fact, storms do not occur conveniently within the range of durations specified in *ARR,* nor necessarily over the whole catchment, and the IFD data represent rainfall bursts within storms of longer duration. It is not surprising that use of this data for modelling purposes can lead to difficulties in determining the critical duration. The IFD analysis was based on a relatively small number of pluviometers. Emphasis in the analysis inevitably gave particular weight to a small number of severe storms, which produced maxima for many durations. Perhaps future derivations of IFD data, with the benefit of longer pluviometer records and plenty of additional severe storm events, will help to resolve this issue.

Nevertheless, as will be seen in the following section, these deductions are potentially useful for detecting critical storms at an early stage. How representative is the West Terrace rainfall intensity record of other locations, and to what extent are the same conclusions true? The West Terrace record is strongly influenced by the North Adelaide 1925 storm, which was a severe summer thunderstorm, and no doubt this type of event has dominated the record. For comparison, a similar analysis was done for Brisbane (BOM Regional Office), which also has 84 years of data. Table 5.8 gives the summary.

The Brisbane data shows the same relationship between storm durations as the West Terrace data, although the correlation is not quite as strong. The short duration storm intensities (less than 30 minutes) do not appear to be linked with the longer duration storms. But from the 48 minute burst onwards, the correlation is good, and the conclusions which were reached on the basis of the West Terrace record are the same. It is also likely that if another set of rankings was done for one of the shorter durations, the correlation would be good.

The link that intensity analysis has shown between storm durations leads to the next step in value-adding to ALERT alarms.

5.7 Development of "IFDcheck"

The limited potential of runoff routing modelling to provide timely forecasts of flash flooding has been described in Chapter 4. The ability to obtain longer warning time depends on accurate forecast rainfall which at the present cannot be achieved. Quantitative Precipitation Forecasts specifying the rainfall amount, intensity and spatial distribution are not available in Australia.

The procedure for optimising rainfall alarm criteria led to the development of an improved method of utilising measured rainfall. It has been common practice during a potential flood situation for duty staff to examine the data collected by ALERT, and make a judgement whether or not a flood is imminent. Standard ALERT software gives tabulated data, showing the rainfall that has occurred in the last hour, and for 3-hour periods in the preceding 24 hours. Data is also displayed for each station on a catchment map, for a fixed data period. It is difficult to decide on this basis alone whether sufficient rain has fallen to cause flooding since, for urban flash flooding, the rainfall intensity is a critical parameter.

Duration	Rank of Storm Burst (1 is most intense 6-hr storm on record)									
	1	2	3	4	5	6	7	8	9	10
6-min	57	56	15	45	81	41	27	29	24	17
12-min	35	69	9	47	77	40	27	56	12	11
18-min	24	69	7	52	65	36	40	72	30	9
24-min	17	57	6	50	54	35	39	69	38	7
30-min	11	53	4	49	57	42	22	65	33	9
48-min	7	43	1	49	57	24	13	55	41	12
1-hr	5	32	1	53	59	21	11	52	44	13
2-hr	3	12	1	27	25	20	2	26	40	16
3-hr	1	4	2	15	8	10	3	14	25	23
6-hr	1	2	3	4	5	6	7	8	9	10
9-hr	2	1	5	3	9	4	11	6	8	10
12-hr	1	2	5	3	11	4	14	7	8	13
18-hr	1	3	6	2	14	4	16	12	9	18
24-hr	1	3	7	2	20	6	21	12	8	22
36-hr	1	3	8	2	21	6	22	12	7	23
48-hr	1	4	8	2	22	6	23	12	7	24
60-hr	1	4	8	2	22	6	23	12	7	24
72-hr	1	4	8	2	22	23	12	7	24	10

Example: Storm duration 48-min. The maximum 6-hour storm on record, noted in red, included a burst of rainfall that was the third highest 48-minute intensity in 84 years.

Table 5.8 Analysis of storm burst intensity, based on 6-hour critical storm duration, and ranked for each of the standard durations. (Regional Office Brisbane, using 84 years of data)

Colour Code	Description
1	Worst 6-hour storm on record
2	Second worst 6-hour storm
3	Third worst 6-hour storm
4	Fourth worst 6-hour storm
5	Fifth worst 6-hour storm
6	Sixth worst 6-hour storm
7	Seventh worst 6-hour storm
8	Eighth worst 6-hour storm
9	Ninth worst 6-hour storm
10	Tenth worst 6-hourstorm

Colour codes for storm intensity analysis

Secondly, for catchments, such as those that drain the Mt Lofty Ranges, there is a wide variation in rainfall between the headwaters and the outlet,[8] a situation common to many flash flood catchments in Australia. Along the eastern seaboard, in particular, the variation in rainfalls and intensities from the coast to the adjacent hills is very marked, which makes the quick assessment of the potential for flooding, based on rainfall totals, fairly difficult. What is needed is a quick way to process the data into a form that can be checked against the Intensity-Frequency-Duration statistics for each location. This program, referred to as IFDcheck, was developed using software that automatically extracts the data from the ALERT data base. Steps in the process which are carried out by the computer are:

1) select the rainfall station for analysis;
2) extract data from the data base for this station, far enough back in time to cover the full storm;
3) use a "moving window" analysis to find the maximum rainfall intensity for each of a series of standard storm durations. These will be the maximum bursts in the current storm;
4) obtain the standard IFD data for that rainfall station from file;
5) for each storm burst duration, compare the actual rainfall with the IFD data to determine the Average Exceedance Probability of the current storm for that duration, and note the AEP and the time when it occurred. If there are no significant bursts, end the task and display a default message;
6) if there are significant storm bursts, store the results to file; and
7) display the results on the screen, colour coded to emphasise any rare storms.

Figure 5.6 shows a typical output file, as displayed on the computer monitor. It gives the current date, time and location of the rainfall station, followed by an analysis of the AEP, for each of the standard storm durations. Colour coding is used to highlight the more extreme storms and enables the user to see at a glance whether the storm rainfall is critical. The display is used in real time, during a storm, to obtain current information on a storm intensity. In this case the maximum storm intensity is 23 mm in 60 minutes, equivalent to an AEP of 1 in 5 to 1 in 10. If the catchment has a time of concentration around 1 hour, this storm could be critical. Above 6 hours duration the storm is not particularly intense, at least at the moment when the analysis was done.

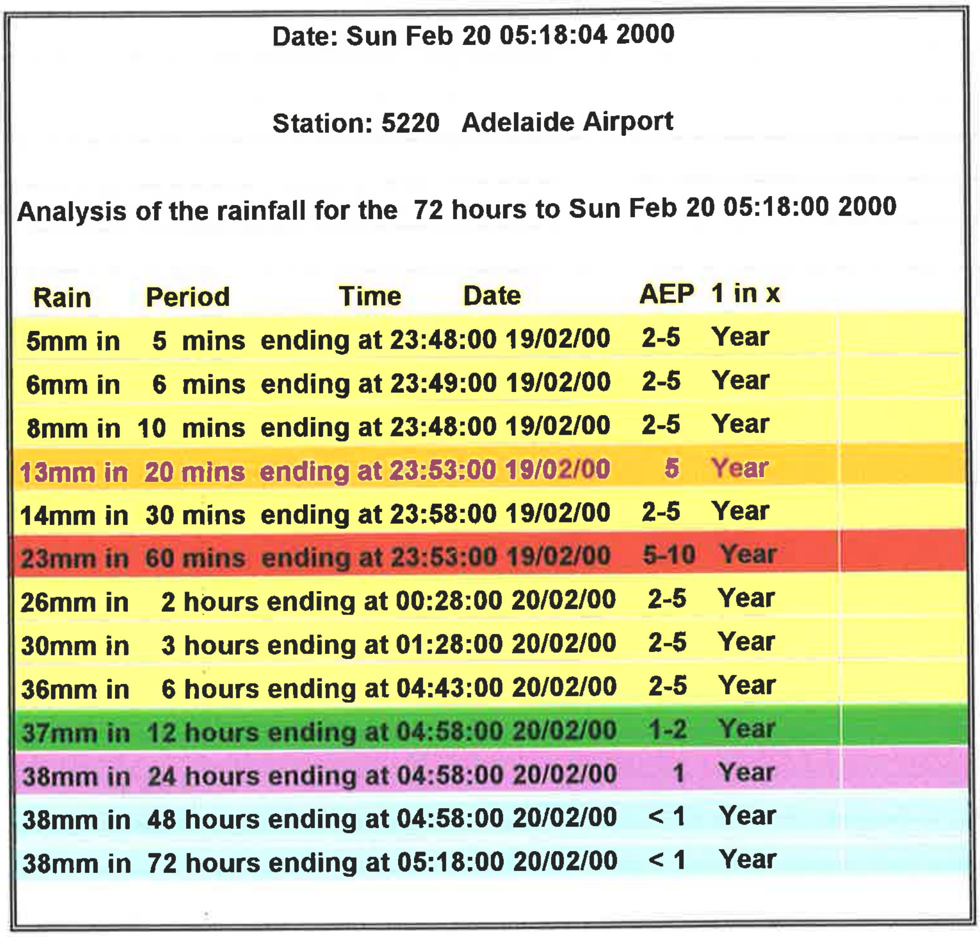
The colour coding of the display on the ALERT base station computer, is designed to make sure that where severe rainfall bursts have been identified, they catch the eye. This simple program has proved to be useful and is now a standard tool used by Hydrology section duty

---

[8] An illustration of this effect in Adelaide is that from the west end of Cross Road, some 12 km east to the intersection with Glen Osmond Road, representing about half the length of the Brownhill Creek catchment, the annual average rainfall has increased by about 200 mm, or 30%.

staff in a potential flood situation.

In Figure 5.6 the maximum intensity 23 mm in 60 minutes stands out, and indicates an AEP of 1 in 5 to AEP 1 in 10 maximum storm burst, with the potential for flooding if the catchment is sensitive to short duration storms. It also indicates that for longer durations, from 24 to 72 hours, the intensities are not critical at this stage. An operator would know the range of storm durations likely to be critical for each catchment, and is able to determine at a glance whether there is a possible need to issue warnings, or merely maintain a watch.



Date: Sun Feb 20 05:18:04 2000

Station: 5220 Adelaide Airport

Analysis of the rainfall for the 72 hours to Sun Feb 20 05:18:00 2000

Rain	Period	Time	Date	AEP	1 in x
5mm in	5 mins	ending at 23:48:00	19/02/00	2-5	Year
6mm in	6 mins	ending at 23:49:00	19/02/00	2-5	Year
8mm in	10 mins	ending at 23:48:00	19/02/00	2-5	Year
13mm in	20 mins	ending at 23:53:00	19/02/00	5	Year
14mm in	30 mins	ending at 23:58:00	19/02/00	2-5	Year
23mm in	60 mins	ending at 23:53:00	19/02/00	5-10	Year
26mm in	2 hours	ending at 00:28:00	20/02/00	2-5	Year
30mm in	3 hours	ending at 01:28:00	20/02/00	2-5	Year
36mm in	6 hours	ending at 04:43:00	20/02/00	2-5	Year
37mm in	12 hours	ending at 04:58:00	20/02/00	1-2	Year
38mm in	24 hours	ending at 04:58:00	20/02/00	1	Year
38mm in	48 hours	ending at 04:58:00	20/02/00	< 1	Year
38mm in	72 hours	ending at 05:18:00	20/02/00	< 1	Year

Figure 5.6 IFD check display of storm intensity statistics in real time

When accessing rainfall data in real time, it can be very confusing during periods of heavy rainfall over all the catchments to determine which locations are actually critical. While the radar display can be accessed easily, indicating the distribution of high intensity areas of the storm, this is only an instantaneous "camera shot" of the storm, and not the synthesis of intensity and duration that will indicate flood potential. Radar data is often displayed as a sequence of 10-minute frames and, although the pattern of the storm can be tracked, it is a qualitative rather than a quantitative tool. New radar software which calculates cumulative rainfall and displays the results in map form has been developed, but provides results at a relatively small scale. The calibration of radar data to recorded rainfall has not been developed to the stage it can be used with confidence, but indications from the radar display can be used in conjunction with IFDcheck. During a storm, the IFDcheck program is run in batch mode on all rainfall stations, and an output file generated. A quick look at the file indicates which of the rainfall stations are showing high AEPs, which then allows duty staff to pay close attention to that catchment.

5.8 Use of IFDcheck with ALERT Alarms

Difficulties in optimising the use of ALERT alarms have been described in this chapter. The problem is that simple alarms based on intensity do not give duty staff enough information to make a decision. If the alarms are set to trip only when there is a severe event, then they are likely to trip too late and their potential benefit is diminished.

Therefore, a facility has been developed within ALERT so that each time a rainfall alarm trips, the computer runs IFDcheck and produces the output file. The file is then scanned by the computer and the highest AEP value is noted. The computer then sends a message to mobile phones containing the rainfall station identity and the maximum AEP value, as follows;

ALERT Alarm "Adelaide Airport" recorded 23mm in 60 mins ending at 23:53:00 19/02/00 5-10 Year AEP

This is value-added information, which should make it easier to decide what action should be taken, given the location of the station and the expected response time of the catchment. In this case, a 60 minute storm is likely to be critical for sub-catchments, leading to local stormwater problems, but not main creek flooding.

5.9 Conclusions - Flash Flood Warning Using Hydrological Methods

Analysis of historical pluviograph data has resulted in improved criteria for rainfall alarms. A method for determining efficient alarm criteria for any rainfall station location has been proposed. Further work on the relationship between storms of different durations has established some useful conclusions:

- ☐ a warning system based on optimised settings of alarms is feasible, but its performance is not guaranteed, since it could fail to operate in an emergency;
- ☐ rainfall alarms in current use can be made more efficient to give earliest possible warning of a flash flood;
- ☐ analysis of rainfall intensity in real time to determine the severity of a storm, using the **IFDcheck** program, enables critically severe storms to be located quickly using

ALERT automatic monitoring systems;

- ☐ linking the output of **IFDcheck** to the automatic alarm system will provide "value added" alarms, making it easier to decide whether a flood is imminent;

- ☐ alarm messages can be sent quickly to mobile phones, using the Short Message Service (SMS);

- ☐ a severe storm is likely to be critically intense over a wide range of durations, not just one. The Adelaide 1925 storm was the maximum on record for all storm durations from 48 minutes to 72 hours; and

- ☐ the use of runoff routing models in real time can provide accurate flood forecasts, but requires **forecast rainfall** to be used (in addition to measured rainfall). However, current technology/meteorology for Quantitative Precipitation Forecasts in Australia is rudimentary and cannot be depended upon.

This chapter completes the analysis of forecasting processes for flash flood warning. Storm identification in time to issue warnings has been shown to be extremely difficult and there is a strong possibility that flash floods may occur before a warning has been issued.

Since flood warning can only be effective if the warnings are received and acted upon, it is important to understand the situation within the community that will be affected by flooding. Are the people who would be affected prepared to respond to a flood situation? Do they have the training and resources to act efficiently to minimise damage? How would they receive flood information? How quickly will flood warnings be distributed? How long will it take for people to get to the locations which are threatened?

All of these questions need to the satisfactorily resolved if the rainfall alarms and storm information is to be of value.

6. FLOOD LOSS EXPOSURE, VULNERABILITY AND RESPONSE

Chapters 4 and 5 have investigated flash flood forecasting, the limitations in time available, and the difficulty in obtaining flood forecasts from runoff routing models in advance of the actual flood. Tools for improving rainfall alarm criteria and for determining the critical storm intensity were developed. However, none of this work has been linked to the actual situation in the floodplain to determine whether any alarm or flood forecast information which might be provided would achieve an efficient response and be effective in minimising damage and loss of life. The link between flash flood forecasts and the use of that information by those required to respond to a flood situation is critical to effective flood damage mitigation. Chapter 6 describes a survey of the occupants of the Keswick Creek floodplain, in the zones of highest flood risk, most of which are commercial and industrial businesses.

6.1 Response to Flood Danger

This research program into urban flash flooding began because of a perceived risk of flooding in the inner suburbs of the city of Adelaide. In 1988, the newly formed Hydrology Section of the Bureau of Meteorology (BOM) in Adelaide was required to identify catchments with the potential for flash flooding which would be suitable for the newly introduced flood ALERT systems for real time monitoring of rainfall and water levels. At that time the (then) Highways Department was the responsible agency for the management of a South Australian Government program to encourage local councils to undertake stormwater management programs. The Highways Department provided advice to the BOM on the general flood risk situation in the state, and for urban flooding in particular. Two creek systems were considered to present significant risk to urban Adelaide. These were:

- ☐ First Creek, Waterfall Gully; and
- ☐ Brownhill Creek Catchment, which includes Keswick Creek.

The BOM agreed to install a pilot ALERT system in the upper reaches of Brownhill Creek. In the early 1980s, the catchment had been the subject of a flood study and report by WBCM Consultants, "South Eastern Suburbs of Adelaide - Stormwater Drainage Study" (WBCM, 1984), and each participating local council had a set of flood maps showing flood risk up to AEP 1 in 200.

Flood damages were assessed at $76 million for the AEP 1 in 100 flood (dollar values updated to 2000), but the figure does not appear to have been given much prominence at the time, even though the risk seems high. The BOM funded the installation of a pilot ALERT system in 1989/1990. In 1992 a series of floods occurred in the Mt Lofty Ranges and, as a result of a number of heavy storms over the city, there was a considerable awakening of interest in flood risk and flood warning. The seven local councils which cover the Brownhill Creek catchment agreed to an extension of the ALERT system, covering the whole of the catchment. The project was a joint venture development, combining the following interests:

- ☐ the BOM Hydrology Section was concerned about the risk of flood damage and saw the ALERT system as a step in the process of minimising the risk; and
- ☐ the local councils were faced with the dilemma that there was a significant flood risk within their boundaries, for which there were no easy structural remedies.

The ALERT system offered a partial solution to both interests, and counterpart funding support was made available by the State Government through the Highways Department.

Once the ALERT system was installed and became operational, the question of how the information that was being collected could be used to best advantage became important. It was quickly found that the largely rural Brownhill Creek catchment responded very slowly to rainfall, there is seldom any runoff at all until late winter after prolonged rainfall. On the other hand, runoff from the highly urbanised Keswick Creek, together with its two branches Glen Osmond Creek and Parklands Creek, was almost instantaneous. What could be done about issuing a warning and responding to a flood under such circumstances? The use of technical hydrology to solve this problem has been discussed in Chapters 4 and 5 and is able to offer only a partial solution, which could fail on the day of the flood.

In an effort to find a solution, the following questions were considered:

> If a severe storm occurs over the catchment, the ALERT system functions perfectly and an accurate forecast is prepared describing the fast approaching disaster:
>
> - ☐ what would actually happen?
> - ☐ would the warning process be effective? and
> - ☐ would the threatened community respond appropriately?

Given the very limited time available, the first problem is that there is no straightforward way of getting information to the people who would be affected by the flood and who would need to take action of some kind. Apart from quick action by people "on-the-spot", there would be no organised response.

Arrangements are already in place to contact local council duty staff and the State Emergency Services and Police, but these organisations are concerned more with recovery from a disaster than with avoiding damage. A public warning system would rely on the normal media outlets, but what chance was there of the people affected hearing or seeing the warning in time? A more direct means of notification is by telephone, but experience has shown that direct dialling of individual contact people is a slow and frustrating method of issuing warnings and is inefficient. Modern information technology systems, as described in Chapter 9, will send messages automatically to a target list of phone numbers, but these have not yet been used for flood warning in South Australia.

The associated question is whether people who are likely to be affected would be aware that they were at risk at all? Would they know that their location was within a floodplain and that they would need to take some sort of action?

6.2 Initial Flood Loss Exposure Survey

With the above questions in mind, a sample area of the floodplain was chosen for an initial survey, covering part of Keswick and Mile End, in the inner southern suburbs of Adelaide (see Figure 6.1) and was chosen because the WBCM flood mapping shows a well defined high risk area from AEP 1 in 5 upward, containing a large number of business premises. Advice from Dr David Ingle Smith of the Australian National University (personal communication, November 1997) was that these business premises were likely to show a high degree of flood loss exposure. An initial Flood Awareness survey was carried out in this area with the intention of determining the situation regarding peoples' perception of flood risk and what they could or would do in a flood event.

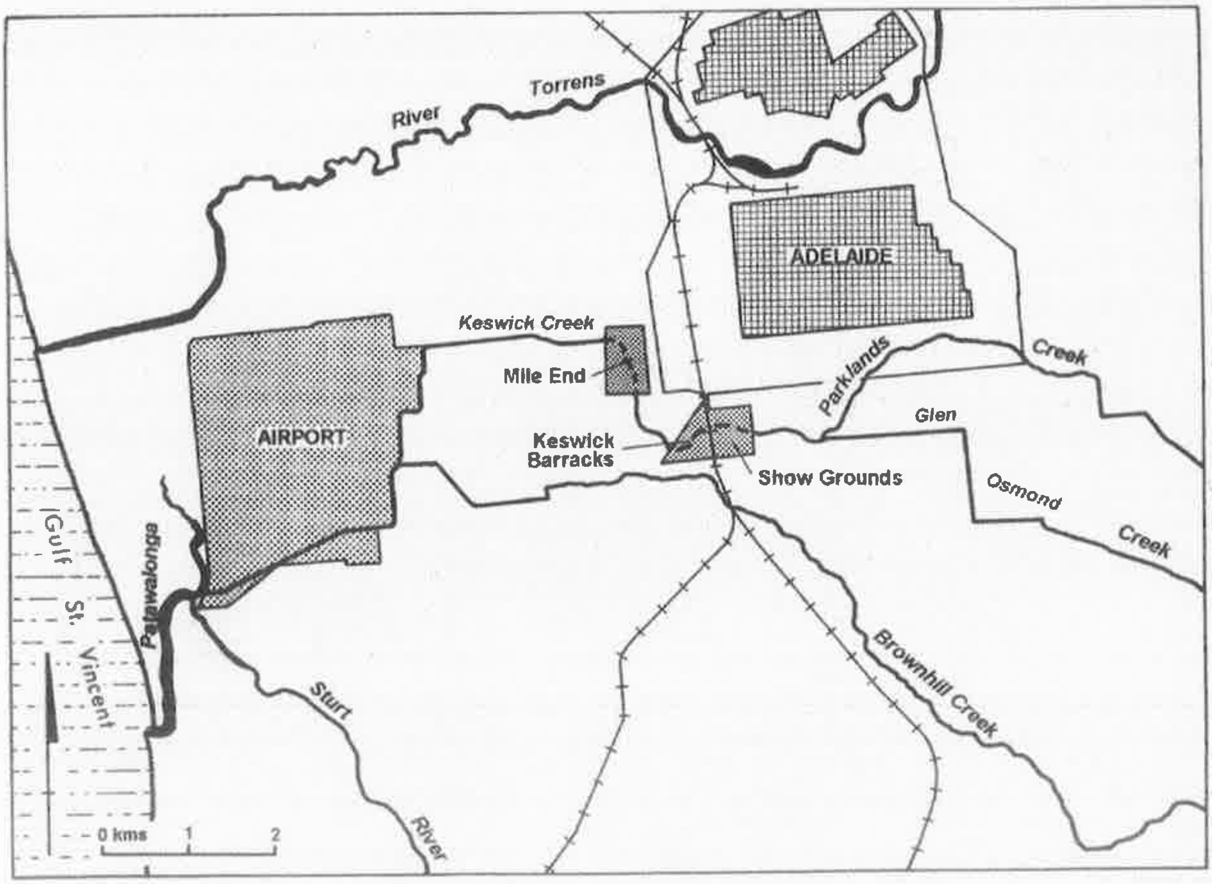


Figure 6.1 Location of Keswick and Mile End on Keswick Creek

In order to obtain information about the area, and to tie in with earlier work, contacts were made with WBCM consultants, who had undertaken the original study. Although memories of the study had faded, some information on the job remained and a visit to the consultants' offices in Melbourne was arranged. All archived material was extracted and the consultant made it available for the research program. Material received included:

☐ copies of original reports;
☐ assorted maps;
☐ original survey books with the channel survey data; and
☐ a set of aerial photographs, covering the whole area.

It was not possible to obtain any information on the hydraulic and hydrologic analysis by computer, apart from some hard copy printout. Original input and data files that might have facilitated development of a new study could not be located.

To begin the flood awareness and damages survey, the flood inundation areas were transferred from the flood maps to the aerial photos. Stereo pairs of photos were then inspected to locate the largest buildings and building complexes. Finally the building locations and flood map information were transferred to a street directory of Adelaide, for ease of navigation around the study area.

The survey was conducted by visiting each of the buildings in turn. Most of the large complexes turned out to be commercial or industrial. Several retail businesses were included and there was one aged-care home. The survey did not include any private residences. The WBCM study indicated that there are about 560 residences affected by an AEP 1 in 100 flood, but no work was done on these since the indications were that the total flood loss exposure from residential housing will be small in comparison with the flood loss experienced by businesses.

At each business premises the problem was to find a member of staff who would understand the request and could provide the information. From the beginning, the intention was, while obtaining details about the business, to try at the same time to develop flood awareness and a willingness for the business to minimise the flood loss exposure. For larger businesses, the manager was generally not available. It often took several visits and phone calls to establish effective contacts with appropriate management staff. For small businesses, it was possible to talk briefly to the manager. It was difficult to gain his/her attention and establish credibility. A technique was gradually worked out for making the correct approach and establishing confidence but, even so, in some situations it was not possible to get further than the front door and, in others, it has taken months to make the right connections, obtain relevant information and start to achieve some sort of response. Initially the interview concentrated on establishing the credibility of flood risk and suggested possible ways of minimising the risk.

In most cases it was possible to get permission to look around the premises. A data base was compiled with all of the contact details, initial impressions of the business and its vulnerability.

The survey focussed on the largest buildings and complexes identified from aerial photos but, with growing knowledge of the area and types of businesses, it was extended to include samples of medium and small businesses. Some 40 businesses were contacted in this way.

6.3 Outcomes from the Initial Survey

The initial survey gave the following preliminary conclusions:

☐ only one business, indicated any knowledge of flooding. They had experienced flooding in their warehouse;

☐ one business had used engineering consultants to design the new premises, and the design included provisions for flood damage mitigation;

☐ all other businesses were unaware of flood risk and if their staff were aware of Keswick Creek at all, they regarded it as a local stormwater drain;

☐ among the businesses interviewed there was not one who could give an example of a flood from their knowledge of the history of the area. Subsequent, more detailed, survey work among a wider range of businesses has indicated some awareness of floods and the potential for damage; and

☐ nobody who was interviewed could remember the subject of flood risk from Keswick Creek being discussed. This was despite the fact that WBCM consultants, as part of their study in 1983, had interviewed at least one of the businesses, which was part of the current survey. There was apparently no recollection of this survey.

6.4 Establishing the Flood Risk Framework

Given the apparent lack of awareness of floods and flood damage in an area which the flood mapping indicates to be very high risk, it is reasonable to ask the questions:

☐ are the hydrological predictions correct? and
☐ is there really a problem at all?

Chapter 3 referred briefly to the flood history of Keswick Creek, mainly because there is very little on record. The WBCM study used data from 3 pluviograph sites, two of which were outside the catchment, but there was no flood data available at all and no flood events occurred during the study. *A Pictorial History of West Torrens* by Marles (Marles, 1980), shows a photo of the Humes Pipe Factory with a flood from Keswick Creek passing through

Figure 6.2 Keswick Creek in flood through Humes Pipe Factory on Richmond Road circa 1930. Taken from A Pictorial History of West Torrens *(Marles, 1980).*

it (see Figure 6.2), and there is occasional anecdotal evidence of floods which have occurred since then.

Three factors may be at work here:

- ☐ flooding in this area is generally understood to be caused by Brownhill Creek. In fact, Keswick Creek and its tributaries is subject to more frequent and damaging flooding. However, few people were aware of its existence, probably because it is confined in a concrete channel and parts of it are in culvert underground;
- ☐ floods in Keswick Creek develop very quickly and disperse equally quickly. Evidence over the last 3 years has been that floods pass within a few hours, leaving a mess to clear up in specific locations, but not a lot of evidence of their presence. Unless a business was directly affected, the management could well remain unaware of the risk;
- ☐ in the last 3 years, most floods occurred at night, on Public Holidays or during a weekend, when few people were there to witness them; and

❑ there has not been a major flood (AEP 1 in 50 or greater) over the whole Keswick Creek catchment since about 1930;

The "Keswick Creek Hydrology Review" (Kemp, 1997), confirms the hydrological estimates earlier made by WBCM Consultants in "South Eastern Suburbs of Adelaide - Stormwater Drainage Study" (WBCM, 1984). The occurrence of no less than 8 minor floods (see Chapter 4), during the study period suggests that flood exposure in this area is real, despite the lack of awareness and experience.

6.5 Flood Forum Meetings

At the end of the initial survey, it was clear that there was almost no awareness of flood risk in a location that, according to the flood maps produced by WBCM Consultants (WBCM, 1984), has the highest risk of flooding in Adelaide. On the basis of initial contacts only, there appeared to be an extremely high value of goods and plant in the area, and potentially high flood loss exposure.

The pilot study included a flood awareness program, covering as wide a range of businesses as possible, and in order to try to develop an awareness of flood risk, and to try to find solutions to the problem, a series of meetings for representatives of the businesses which had been included in the survey was arranged. These were referred to as "Flood Forum" meetings. Three Flood Forum meetings were held with the purpose of informing the local businesses about the risk, and to encourage the process of Flood Action Plan preparation.

The meeting venue was in the Mayor's Parlour at the West Adelaide Football Oval, chosen because it is within the high risk part of the floodplain in Mile End. The City of West Torrens made these premises available.

The speakers were:

❑ Dr David Ingle Smith, Centre for Resource and Environmental Studies, Australian National University, Canberra, who provided flood risk management advice based on experience in Australia and overseas, and advised the meeting that flood risk on Keswick Creek should be taken seriously.

❑ Erik Kroon, of EK Loss Management, Professional Loss Adjuster, who described the proposed Flood Loss Exposure study, and explained what it involved and how it would be carried out.

❑ Les Payne, Risk Management Consultant to the Royal Show Society, who spoke about the Emergency Response Plan which had been developed for the Wayville Showgrounds; and

- Peter Hughes of Raven Products, who gave information about the ways in which entrance doors and warehouse roller doors can be sealed.

The meetings provided an opportunity for discussion of flooding issues and opportunities for risk mitigation. Each of the Flood Forum meetings was attended by approximately 30 people, about half of which were the owners or managers of businesses. It was extremely difficult to get business people along to the meetings, mainly because of other commitments, but also, no doubt, due to a perceived low priority of flood risk as an issue.

6.6 Outcomes of the Flood Forum Program

The program of Flood Forum meetings achieved considerable strengthening of communication between all agencies and businesses for whom flash flood risk is an issue. Points of importance were:

- a much improved level of personal contact, and useful feedback;
- involvement of a wide range of people with concerns and responsibilities for flood damage, including the local council, the emergency services, the BOM, and local business representatives; and
- a few instances where the advice was taken seriously, and Flood Action Plans were developed by businesses.

A series of major inadequacies have inhibited the adoption of flood risk mitigation on a wider scale. These are:

- inadequate flood mapping information which meant that it was impossible to determine what depth of water could be expected at individual business premises;
- several instances where the flood mapping information is wrong, and does not show significant areas of risk; and
- no line of responsibility for advising the community about flood risk and what to do about it, leading to an absence of information or advice, apparent in most cases.

There are many parallels that can be made between urban flood risk and urban fire risk. In the case of fire danger, considerable resources are allocated by the community to minimise the damage done by fires; a fire fighting service, fire hydrants, fire extinguishers and smoke alarms are all standard items in a city. Even though the risk of floods is high for specific urban areas, there is no equivalent allocation or awareness.

6.7 Flood Loss Exposure Survey - Stage 1

A Flood Loss Exposure Survey was carried out in conjunction with Mr Erik Kroon, of EK Loss Management Pty Ltd, a professional in the insurance assessment field. Arrangements were made to visit 11 businesses which had been selected from earlier surveys. At each site, a meeting with the manager took place, information was provided and a questionnaire was filled in to provide a framework for estimated overall flood loss exposure. Some information was given in confidence and could be used only for obtaining generalised cost estimates. After the meeting, the manager or a nominee showed the team around the premises and answered questions about the facilities, goods, materials, buildings and fixtures. The team took the opportunity to point out any obvious flood risk situations and offered preliminary advice on possible improvements. The criterion for estimation of flood loss was a depth of water of 0.5 metres above the floor of each building, roughly equivalent to the AEP 1 in 100 flood. Later, Erik Kroon spent time estimating the financial value of flood loss exposure for each site, using site plans to work out building areas, and subsequent contacts with the manager to obtain cost details. A report was produced and sent to each business, including the potential cost of flood risk exposure.

6.8 Case Studies of Commercial and Industrial Flood Loss Exposure

The effectiveness of the survey was directly influenced by the degree of co-operation and support of the owners. This restricted to some extent the range of types and sizes of the businesses sampled. It was not possible, for instance, to obtain information from a major quality paper distribution warehouse, which has since relocated to new premises out of the floodplain, or from a manufacturer of industrial and mining grade rubber products. However, given the limited resources of the investigation, a wide range of businesses was sampled.

Case 1 - Food Production

The business which appeared to be exposed to the greatest risk is a manufacturer of "fast" foods. The business employs a staff of approximately 100, and has a reputed daily production sales value around $100,000. The owner was not prepared to take part in any more than a preliminary discussion, and a full flood loss exposure survey was not possible, although a visit to the factory was arranged. However, there were several points of interest and concern.

The business is located within 100 metres of Keswick Creek, on flat ground and is identified by WBCM Consultants (WBCM, 1984), as being within the AEP 1 in 5 zone. An AEP 1 in 100 flood would result in flood depths averaging about 0.5 m throughout the premises. Even assuming that doors were closed before the flood, sealing of warehouse doors was found to be poor. Inside, there is a large sterile food preparation area. In a flood situation, water would enter the area via the doorways, but can also enter by backflow up the many floor traps that are used for cleaning and wash down of the area. This would flood the sterile area with water containing sewage. Food production could not resume until a major cleanup had taken place and the Health Department was satisfied that there is no possibility of contamination. Both the

Garibaldi food poisoning problems in 1997 and the Nippy's juice contamination in 1998, demonstrate the importance of maintaining highly sterile conditions for mass production of food. It would require considerable effort, delays and expense for the company to satisfy the health inspectors that completely sterile conditions had been re-established, and obtain permission to resume manufacture.

A further difficulty facing the company is that their stock of raw material for cooking would also suffer contamination. Finally, if water enters the refrigerated storage areas, major disruption would occur, requiring complete de-frosting, emptying and cleaning. Without the support of the owners, any flood loss exposure estimates for an AEP 1 in 100 flood are speculative, but it appears that flood loss exposure for an AEP 1 in 100 flood would run into several million dollars. The owner stated confidently that his insurance policy covered all risks including flood, but experience in the insurance industry with major claims suggests that this is seldom the case (Erik Kroon, personal communication, February 1998).

Case 2 - Furniture Retailers

The survey included two furniture retailers, which were:

- ☐ a large South Australian company, selling all types of furniture; and
- ☐ a smaller franchise business, part of a national furniture chain, selling mainly bedroom furniture.

Since the information they provided was given in confidence, they will be referred to, fictitiously, as "Ausfurn" and "Bedroom Specials" respectively.

Ausfurn occupies a large warehouse, used formerly for motor vehicle construction. Most items of furniture are stored at floor level for display. Furniture is ordered in large consignments, and about 90% of the inventory is available for sale and direct delivery. There is a large showroom containing the higher value display items. The premises are within the AEP 1 in 100 floodplain of both Keswick and Brownhill Creeks, and a flood of this magnitude would inundate the whole of the warehouse to an average depth of approximately 0.5 m.

Modern furniture is largely constructed from particle board (chipboard). Under current standards, these materials are not water resistant and deteriorate rapidly if exposed to water. The owners of both businesses said that if their products get wet, they would not be resalable, and that all furniture would be dumped. It is common practice in flood damages studies to assume that flood loss exposure increases rapidly with depth of flooding, but for chipboard furniture, it would not matter whether flood depth was 0.15 m or 0.5 m, the whole inventory would have to be written off.

The effects of a major flood on Ausfurn would be devastating, with the following major damage items:

- ☐ direct losses estimated at nearly $5 million;
- ☐ considerable cleanup and dumping costs;
- ☐ delivery of a complete new inventory would take approximately 3 months; and
- ☐ additional marketing costs would be incurred by needing to offer a range of "Special" deals to entice customers back to the business.

Bedroom Specials is a much smaller business, a franchise outlet of a national company. The showroom furniture would be written off after a flood. However, Bedroom Specials is better protected against financial loss due to floods because the showroom is used primarily for display and all customers' orders are supplied and delivered directly from interstate. In the aftermath of a flood, the delivery of orders will be relatively unaffected. The owner said that all he needs is a desk and a phone, and he will be back in business. The main recovery costs for Bedroom Specials will be:

- ☐ cleanup and renovation of the showroom;
- ☐ resupply of sample items so that customers can see what they are ordering; and
- ☐ business interruption costs due to delays in re-establishing the business and consumer confidence.

An interesting problem faced by both Ausfurn and Bedroom Specials is that the same flood which affects them, will also damage the furniture in some 600 private houses in Richmond, Cowandilla and Plympton. Neither Ausfurn or Bedroom Specials will be able to take advantage of the surge in demand for new furniture due to destruction of their own inventory of goods. There could perhaps be some market potential for Bedroom Specials to trade on a flood experience shared with private houses, "We are suffering too!" and offer special deals to resupply from franchise partners interstate.

Case 3 - Automotive Components Distributor

This is a small business which sells vehicle air conditioning systems. The WBCM flood maps show that it is located in a very high risk part of the floodplain, and an AEP 1 in 100 flood would produce flood depths of approximately 0.5 m. There is a front office which processes orders, arranges for supplies and carries out the administration for the business. At the back is a warehouse with a large inventory of air conditioning components, stacked on racks, mostly packaged and ready for delivery. Warehouse doors are well constructed, but not designed to keep water out. The building is of block-work construction and not likely to be damaged by floods but the administration/office area is enclosed by glass panels to floor level, which are vulnerable to impact by floating objects during a flood.[1]

The building was constructed in September 1996 by the current owners. At the time, they were not aware of flood risk and, in retrospect, the design of the building makes it difficult to protect with:

- ☐ slab-on-ground construction;[2]
- ☐ doorways difficult to seal; and
- ☐ glass panels on the office front extending down to floor level.

After the initial interviews and the first Flood Forum meeting, the owners took steps to protect the business against flood damage. They made contact with an associated business in the UK, which had experienced flooding, took advantage of the lessons and obtained guidance and suggestions for flood proofing. They have prepared a Flood Action Plan which will allows them to seal off the building. Watertight barriers have been manufactured for each of the doors, stored nearby for ready access. When a flood is imminent they can be bolted into place. A pallet of sandbags, plastic sheeting and tape are stored alongside, ready for use. Emergency lighting is provided, along with waterproof clothing and protective gear. There is a special cupboard containing all the equipment, and copies of the Action Plan are fixed to the cupboard door.

If the owners had been aware of the risk at the time of planning and construction, the design could have been modified to reduce the risk of flooding to a minimum. Raising of floor levels is an obvious option but is not feasible once the building is complete.

Under the circumstances, the owners have taken all reasonable steps to minimise the risk of flood damage but, for their Action Plan to be effective, they need to be warned that a flood is coming. There is no warning system available at present, and no confidence that the careful provisions will be put to good use. On two occasions there was a possibility of flash flooding, and the business was advised but flooding did not eventuate. The owner has not said whether he in fact flood-proofed the building before closing the doors after work. How often would he be prepared to carry out this action without any certainty that a flood is coming?

---

[1] In discussions with people who had experienced floods, the effect of heavy vehicles driving along the flooded South Road produced waves of water that augmented the flood water problem significantly. The effect was direct, but also produced considerable stress in people trying to minimise damage who saw the flood waves as a danger, and made attempts to stop the traffic causing the disturbance.

[2] Slab-on-ground refers to construction of the ground floor of a building at the same level as the adjacent ground. It is useful for situations where people and materials are moved in and out of buildings, because there is no need for steps. It is also preferred in some situations because of lower construction costs. Buildings which are constructed slab-on-ground are difficult to protect against flood water.

Case 4 - Quality Furniture Manufacturer

This section examines a quality furniture manufacturer located within the AEP 1 in 5 year flood zone, with a potential flood depth of the order of 0.5 m for an AEP 1 in 100 flood, and with high velocity flow (greater than 1 metre per second) around the building. The business is small, employing a staff of 9 full time, plus owner and partner, and makes furniture to order. The premises are located right alongside the creek. There is a large office and showroom and, at the back, a workshop and timber store. The owners participated in the survey and some weeks later, on 22 May 1999, the premises were flooded.

As mentioned earlier, furniture for large volume resale is manufactured from chipboard and is highly susceptible to water damage, but the furniture manufactured by this company is mainly solid pine.

Notable features of the survey and review were:

☐ the business is run by craftsmen, whose emphasis is on producing a quality product;
☐ despite encouragement at the time of the interviews, the business had not arranged special flood insurance cover at the time of the flood;
☐ the furniture items carry a high degree of finish and are highly susceptible to damage;[3]
☐ during the flood of 22 May 1999, it was not possible to warn the owners. Despite having their contact numbers at office and home, there was no answer from the office and the home phone was switched to a message recorder;
☐ on initial appraisal after the flood, it appeared that the business had suffered severe damage and might not survive;
☐ in fact, the solid timber furniture was not badly affected by water and was quickly repaired;
☐ the insurance company paid the claim, despite prima facie lack of cover for flood damage; and
☐ repairs to carpets and fixtures were paid by the owner of the building. It is not known whether, in turn, the owner was able to claim for damages against his insurance.

In October 2000, the owner advised that the landlord had installed a new front door with a Raven door-seal and was upgrading the front fence. These protection measures will significantly reduce the risk of flood damage.

---

[3] For example, the owner advised that aerosols from silicone products used by an adjacent car detailing company have severely affected the French polish finish on furniture on a number of occasions.

The business has survived a potentially disastrous event. It appears, nevertheless, that a business of this type is highly vulnerable to flood damage and may not survive a major flood. Relocation is probably the only reasonable course for this business.

Case 5 - Quality Printer

This is a specialist printer, catering for a specific high value market. It is located within the AEP 1 in 5 year flood zone, and the premises are slab-on-ground construction, giving ready access for pallet trucks carrying heavy loads and a correspondingly high vulnerability to flood. Manufacture is divided between two major sections on adjacent premises. In the older building there is a print process train, producing a standard range of gummed labels, which has been in operation since 1903. Across the street is a new building which contains the office, administration, design and development section, and a large warehouse with high-tech trains of computer-operated printing machinery. This building was constructed in 1996/97 and new printing machinery to the latest printing technology standards were installed.

The business specialises in manufacturing a single high value product, and holds about 50% of the Australian market. It also has major export contracts with South Africa and the United States.

The flood loss exposure for this business was estimated to be almost $13 million, which should give rise to considerable concern. Given that the premises are fully developed, slab-on-ground, the options for reducing flood loss exposure are very limited. A major flood protection program for the buildings is recommended. This will require:

- ☐ attention to flood proofing access doors in emergency;
- ☐ sealing all weak points, such as backflow from toilets and floor traps, and any ventilator and wall penetrations.

A Flood Action Plan is urgently needed so that those on site at the time of a flood will know what to do. A flood warning system is probably essential if the Action Plan is to be fully effective but is of course subject to the limitations of flash flood warning.

Critical issues for this business appear to be:

- ☐ a risk management plan which, in the event of a major catastrophe, would allow production to be continued at a business competitor's premises until recovery was effective. The owners have advised that this arrangement is already in place;
- ☐ flood insurance cover which includes business interruption;
- ☐ flood proofing of the buildings as far as possible;
- ☐ development of a Flood Action Plan; and
- ☐ active participation in the development of a flood warning system.

Case 6 - Courier (National)

The courier operates throughout Australia, with a receiving and delivery depot near Adelaide Airport, in a high flood risk location. The site includes an office, shared with a management company, and a large, open-sided warehouse used for loading and unloading packages and freight. There is a fleet of light delivery vehicles and several pallet trucks and tractors. There is a large, semi-automated vehicle loading and unloading system, mounted on a ramp about 1 metre above ground level.

The business handles incoming consignments from interstate, loads a fleet of light trucks which delivers around the city, and then collects packages from the city for delivery to the depot. Consignments are loaded onto semi-trailers for delivery interstate. In the normal run of business, packages and freight are not held in the depot for more than a few hours. The fleet of trucks is not particularly susceptible to flood damage, and trucks could be driven away from the flooded area if need be. Forklift trucks with controls located near ground level are more susceptible.

The company has a computer-based pickup and delivery recording system which would be affected by flooding. The manager said that if the computerised system is not available, they would revert to the manual "docket" system which was formerly used; hopefully the staff will remember how to use it. Nevertheless, in terms of general vulnerability to flooding, this business is reasonably well protected and would not be expected to suffer severely even in a major flood.

Case 7 - Management Company, Services

This business operates nationally and is listed on the Stock Exchange. It provides the administration structure for the courier company and for other service-related businesses. The premises consisted of an office-administration area, a work area with desks and computers, and a main computer room containing banks of servers, hard drives and associated peripheral devices. The business handles customer records, invoicing and payments for client companies for the whole of Australia. At the time of the initial survey, if the premises had been flooded, the consequences would have been serious, since the servers were imported specially from the USA, and would take up to 3 months to replace. Recovery of backed up data would be required and, in the meantime, invoices and orders could not be processed, nor could client history be accessed. A delay of 3 months or more would do serious, possibly irretrievable, damage to the financial viability and public perception of the business.

In the months between the initial survey and the full damages survey, changes took place. These resulted in major improvements in the ability of the business to withstand a serious flood:

☐ an arrangement has been made to gain access to office facilities in the city (outside the floodplain);[4]

☐ the computer system has been upgraded and split into two units. The "active" server remains at the existing site, for normal operations, while the "passive" server is located in the new city site, and processes any overflow. The "passive" server is accessed remotely, apart from any direct maintenance requirements. In a flood disaster situation, the "passive" server will be activated to become the main "active" server. The temporary office will be taken over by the company, and the computer facilities re-programmed as nearly as possible to operational use. The company believes that it could recover close to normal operations within a few days, albeit at somewhat lower capacity. The full-time employees would occupy the temporary premises. The company employs many of its staff on contract, working from home. Once the links were set up with the temporary office, it is planned that they would continue normal business, but there would no doubt be considerable short-term challenges in making the temporary facilities operational.

It was noted during the last visit that the company has now outsourced the whole of this facility. This is an unfortunate postscript, particularly in view of the excellent risk management initiative. The premises are now unoccupied. It is not clear whether this outsourcing was a result of the flood risk, nor is it known whether a risk analysis was carried out on the outsourcing firms which have taken over the business.

Case 8 - A Statewide Service Provider

This business is a key service provider to the community. The head office is in the city. The facility beside Keswick Creek provides a vehicle inspection service, acts as a centre for the mobile customer service vehicle fleet, and a 24-hour communications centre catering for stranded motorists. The premises are within the AEP 1 in 10 year flood zone.

Re-development of this site took place in 1996. Plans were prepared by engineering consultants. Flood risk was addressed at design stage, and the following provisions were made:

☐ the central administration block, which houses the communication centre, has its floor level raised well above natural surface level, achieving significant reduction in flood risk;

---

[4] The office is shared between several businesses from around the city, all of whom require contingency arrangements to cope with various risks. The office is supplied with basic office furniture, computers and facilities, but is not normally in use. The rent is shared between the participants in the scheme.

- flood protection banks along the adjacent roadway provide protection for the whole site, up to the AEP 1 in 10 flood; and

- workshops are located at the lower part of the site but essential controls and services, such as electric power and communications, are overhead, and not particularly susceptible to water damage. In the event of a flood, the workshops will be inundated, but can be cleaned and brought back into use with minimum delay.

The business has addressed flood risk satisfactorily. While it is true that a major flood will cause damage and disruption, the problems will be manageable and the cost of business interruption is unlikely to be excessive. This is an excellent illustration of the benefits of planning for floods at the design stage, and minimising flood risk.

Case 9 - Local Council Depot

This is a large depot, shown on Figure 6.3, owned by the local council, from which it carries out roadworks, traffic signal repairs, gardening and street-scape maintenance operations. The property covers an area of 2.3 hectares, much of which is buildings or covered storage. The flood risk for this site is high. A two-storey office building contains a control room, office administration and meeting rooms. There is a large warehouse area containing plant, equipment, electrical maintenance equipment and storage of a wide range of items and materials.

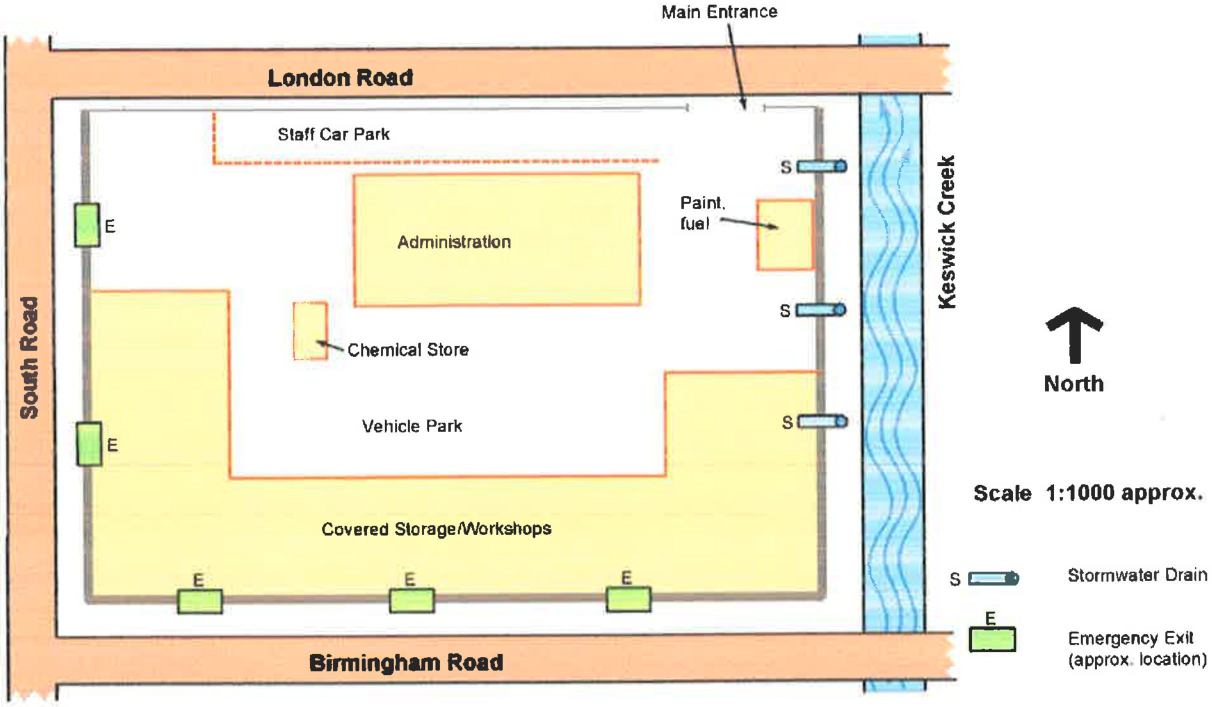


Figure 6.3 Layout of Adelaide City Council Works Depot

Keswick Creek runs along the east side of the property and, during the period of the study, three floods affected the site. Water entered the site by backflow through the stormwater drains from the creek, and overflow at London Road bridge entered council's car park. Since the depot has already been affected by minor floods, there is every reason to take the threat of a larger flood seriously. The flood damage exposure situation is as follows:

- ☐ the depot was developed in 1992 and is protected on 3 sides by high walls. Presumably the intention was for flood protection, since council had copies of flood mapping available (WBCM, 1984), but nobody who was interviewed had any knowledge of this risk. The protection is only partly effective since there are stormwater pipes on the east side, discharging under the wall and into the creek. These are uncontrolled, water can flow backwards from the creek and into the site during a flood;
- ☐ the south and west walls of the site have a number of emergency exit doors, none of which would keep much water out; and
- ☐ the depot has no protection on the north side and is vulnerable during major floods to inflow across the car park and access gate.

Construction of a wall alongside London Road, and gates which are capable of keeping out a flood would offer considerable protection.

Council is aware of flood risk to the site and has taken steps to minimise exposure to flood damage. An example is the chemical store, which has a floor level about 1 metre above ground level. It is understood that Council is also considering installation of backflow prevention devices on the stormwater drains and is working on a more comprehensive flood prevention program with the help of engineering consultants.

Case 10 - Royal Adelaide Showgrounds

The Royal Adelaide Showgrounds are located in Wayville, between Goodwood Road and the main railway line from the city to the south. The junction of Parklands and Glen Osmond Creeks forms the start of Keswick Creek, just upstream of Goodwood Road. Keswick Creek flows under the Royal Adelaide Showgrounds, in a large tunnel, constructed around 1917. The tunnel capacity is sufficient to carry a flow of 25 m^3/s (WBCM, 1984, p. 75), which is adequate to carry approximately the AEP 1 in 20 flood. For larger floods, pondage will occur upstream of Goodwood Road, followed by overland flow through the Showgrounds. If the grounds are occupied at the time, there would be significant risk to people and animals, and potentially major damage to goods, plant, machinery and buildings.

The risk of a major flood through the Showgrounds is significant. The Showgrounds have been on the present site since 1928 and are not likely to move in the foreseeable future. If they remain at one location for 100 years, the chance of experiencing an AEP 1 in 50 year flood or greater is 87%, according to *Hydrology for Engineers* (Linsley et al., 1972, pp. 368-369). Occupancy of the Showgrounds premises is at a peak for the 2 weeks of the Royal Show, and at that time the grounds are fully occupied. The Showgrounds are also used for the remainder of the year although the usage is less intense. Management tries to ensure that these continuous activities are concentrated in the north of the site where there is higher ground. The Showgrounds has an emergency plan which takes account of the risk of flood water passing from east to west in the vicinity of the main arena. As a consequence of the Keswick Creek flood research program, management has arranged for the local council to inspect the tunnel regularly to ensure that its condition is satisfactory, since failure of the tunnel could have catastrophic consequences.

Discussions with staff at the Showgrounds and a site inspection suggest that the "South Eastern Suburbs of Adelaide - Stormwater Drainage Study" (WBCM, 1984), flood mapping is incorrect, and that the main path of the flood would be to the south of the main arena affecting mainly the pavilions that house the stock. There are gates into the arena that would allow a flood to pass through and would provide some flood storage. More detailed mapping to current standards should help to clarify the issues. At the west side of the site, the mapping is also incorrect, indicating flow across the area covered by the sheep pavilion. In fact, this building is robust and solid, and would cause flood water to pond against it. There is a section of fencing to the north which could act as the weak point and provide an exit for the flood, with possibly exacerbated consequences downstream.

In addition to the events that are staged at the Showgrounds through the year, there are offices and facilities that operate continuously. These include:

- the offices of the Royal Agricultural and Horticultural Society of SA Inc.;
- offices of the SA Stud Marino Sheep-breeders Association;
- Rural Services offices; and
- Spotless Services Australia Ltd, a professional catering organisation which provides food for major events, including the International Tennis competitions and the Clipsal 500 street scape car racing.

These offices, fittings and equipment would be prone to severe damage. There are also extensive restaurant and bar areas at the Main Arena which would be extremely vulnerable to flood damage, even when not in use. Flood loss exposure for the remainder of the Showgrounds facilities fluctuates widely, due to the occasional nature of occupation. For much of the year, the individual display booths, food outlets and stands contain only basic furnishings and services and are not particularly vulnerable. During shows, however, flood loss exposure would be very large.

For the Showgrounds a Flood Action Plan is required, based around a conceptualised flood scenario, together with long term planning measures to minimise flood exposure. Obviously, flood warning would be desirable, but the nature of urban flash flooding is such that an advance warning even of 30 minutes may not be achievable. Emergency planning should consider evacuation routes which direct people and animals away from the main path of the flood. It would be necessary to close part of Goodwood Road at an early stage. Training of staff and Emergency Services would be essential so that the intentions of the Flood Action Plan are clearly understood. There is already a training program in place, which covers fire and other emergencies. Additional training to include flood response actions is proposed. The situation at the west side of the Showgrounds, with buildings and solid fencing which will block the path of a flood, and cause significant ponding, requires further study. Ponding of water within the Showgrounds would be a hazard to people and animals. Also, the effects of sudden release of ponded water into the channel downstream by collapse of the back fence could increase the flood peak through Mile End, causing greater damage. The facilities manager suggested that, during a flood, fence panels could be removed and ponded water released. This could increase the danger to emergency response staff due to the sudden onrush of water. Consideration might be given to designing a section of fence which could be released in a flood, before ponding had occurred. The effect would be to pass the flood straight through the premises and avoid possible responsibility for causing incremental damage downstream.

Close contacts would be required with the Bureau of Meteorology (BOM), and efficient communications on days when flood risk is high will be particularly important. It is noteworthy that for both the Royal Show and the Boat Show, the BOM has a display stand, with personnel in attendance and direct communications to the Forecasting Centre. A flash flood warning facility could be incorporated into the BOM display.

Case 11 - Aged Care Home

This facility houses some 80 elderly people, most of whom have limited mobility. Many are very frail and are confined to their beds. Most of the usable space of the building is at ground level for easy access by wheelchairs. At the time of the survey, the owners did not realise that there was a flood risk. They did not have a flood emergency plan. A flood through the premises would have caused major traumas to the patients, and the shock may well have been sufficient to cause death in some cases.

The hospital management has since paid attention to the risk, and has prepared an emergency plan. Critical components of the Flood Emergency Plan for the hospital are:

- ☐ a decision not to move the patients away from the hospital (trauma minimisation), but to move them to existing buildings with elevated floors;

☐ systematic storage of all personal irreplaceable valuables (family photographs, and treasured personal items) above flood level; and

☐ planned protection of high value furnishings by lifting them above flood level.

Case 12 - Hobby/Model Retailer

This is a retail business, located in a small commercial building, with a display area, small office at the front, and a storage/workshop at the back. The building backs onto Keswick Creek, and would be flooded to a depth of 0.3 m to 0.4 m during an AEP 1 in 100 flood. Flood water could penetrate the building from the Keswick Barracks side to the north but is probably a greater threat by entry from Maple Street in the front. The counter and display area is crowded with boxes containing a wide range of model kits, engines, radio control and other model components.

The main shop doors are poorly trimmed, and would allow water to enter easily. There is an unused warehouse door at the side of the building which would leak, allowing a large amount of water to enter the premises. The business has a high level of flood exposure and would suffer badly from a major flood.

Possible remedies are:

☐ risk spreading by arranging full insurance cover is regarded as an essential first step;

☐ attention to door seals will ensure that entry of water to the main shop is kept to an absolute minimum;

☐ the unused warehouse door could be bricked up, effectively sealing the storage/warehouse area;

☐ attention should also be paid to any low level wall penetrations for services or ventilators, by either closing them off, or providing covers which can be installed when a flood threatens; and

☐ some thought should be given to prevention of backflow of sewage through floor traps and toilets. Sandbags can be used to block toilets and floor traps if there is someone on the premises at the time.

6.9 Potential Costs of a Flash Flood - Stage 1 Findings

Table 6.1 gives a summary of the Estimated Flood Loss Exposure for an AEP 1 in 100 flood on 9 of the 12 business premises surveyed. The loss estimates were provided by Erik Kroon, who assisted with the Stage 1 Survey. Losses were estimated on the same basis as assessment of insurance claims, on the assumption that the buildings had been flooded to a depth of 0.5 m. Professional judgement was used to estimate the damage and replacement costs of all items which were considered as exposed to flood loss. Flood Loss Exposure has been considered in the following categories:

- ☐ *Building cost* is the potential for the buildings to suffer flood damage, and includes fixtures, repair to wall partitions, repainting and repairs to electrical services;
- ☐ *Contents* includes process machinery and controls, plant and equipment, computers, office furniture and equipment, carpets on the premises;
- ☐ *Stock* includes raw material, part processed and finished goods, and display materials for sale; and
- ☐ *Business interruption costs.* These are not directly due to goods getting wet, but are consequential losses as a result of the flood. The only category that was included in this evaluation is loss of profit to the business, also referred to as business interruption cost. Other potential indirect losses have not been included. It should be noted that the flood loss exposure figures given above, are "financial losses"; they are estimates of the losses that each business will suffer.[5]

6.10 Initial Flood Loss Estimates - Rationale for Extending the Survey

The scope of this initial study allowed for 12 businesses to be surveyed and the complete analysis of flood loss exposure to be estimated for 9 of those. To obtain some idea of the overall situation, the figures need to be extended to allow for all of the development on the floodplain. It was not possible to do this with confidence on the basis of a small sample, since:

- ☐ *The Benefits of Flood Alleviation - A Manual of Assessment Techniques* in the United Kingdom by Penning-Rowsell (Penning-Rowsell, 1977);
- ☐ "Commercial and Industrial Flood Damage - A Case Study for the Taminda Estate - Tamworth, NSW" by Smith and Greenaway (Smith and Greenaway, 1984); and
- ☐ personal communications with Dr David Ingle Smith,

all indicate that flood loss exposure will vary widely, even between businesses of the same size and type. Furthermore the depths of inundation for the AEP 1 in 100 flood are not provided on the WBCM flood mapping. For the purposes of the study, an average depth of 0.5 m was assumed for the AEP 1 in 100 flood. This could be high for some buildings and low for others.

---

[5] The term "Economic Loss" is used in the literature to refer to the losses to the community as a whole, and would allow, for instance, for the loss of production by one company to be taken up by increased production at another (competitor) business, an offsetting or transfer process, which would have the effect of reducing the flood loss exposure. "Financial Loss" is the term used to describe the actual loss suffered by individual businesses.

Type of Business	**Specialist Printer**	**Furniture Retailer**	**Nursing Home**	**Retailer Automotive**	**Furniture Retailer**	**Courier Service Div.**	**Retailer Hobbies**	**Service Provider**	**Courier**	**All Businesses**
Size	**Large**	**Medium**	**Medium**	**Small**	**Large**	**Large**	**Small**	**Medium**	**Large**	
Building Cost	$130,000	$35,000	$1,000,000	$50,000	$425,000	$350,000	$20,000	$500,000	$10,000	$2,520,000
Contents	$7,900,000	$95,000	$900,000	$100,000	$325,000	$5,000,000	$45,000	$1,370,000	$350,000	$16,085,000
Stock	$1,300,000	$180,000	n/a	$50,000	$4,000,000	nil	$335,000	$80,000	$500,000	$6,445,000
Total Direct Loss Exposure	**$9,330,000**	**$310,000**	**$1,900,000**	**$200,000**	**$4,750,000**	**$5,350,000**	**$400,000**	**$1,950,000**	**$860,000**	**$25,050,000**
Direct Loss Exp./Unit area	$1,736	$282	$525	$167	$220	$3,147	$1,832	$363	$261	$8,532
Business Interruption	$3,500,000	$140,000	$400,000	$50,000	$6,000,000	$750,000	$400,000	$250,000	$250,000	$11,740,000
Total Indirect Loss Exposure	**$3,500,000**	**$140,000**	**$400,000**	**$50,000**	**$6,000,000**	**$750,000**	**$400,000**	**$250,000**	**$250,000**	**$11,740,000**
Overall Loss Exposure	**$12,830,000**	**$450,000**	**$2,300,000**	**$250,000**	**$10,750,000**	**$6,100,000**	**$800,000**	**$2,200,000**	**$1,110,000**	**$36,790,000**
	34.9%	1.2%	6.3%	0.7%	29.2%	16.6%	2.2%	6.0%	3.0%	
Floor Area (Square Metres)	5375	1100	3616	1200	21600	1700	218	5039	3300	
Damages per unit area	$2,387	$409	$636	$208	$498	$3,588	$3,663	$437	$1,627	$1,495

Table 6.1 Stage 1 Flood Loss Exposure Survey - Results

6.11 Flood Damages Survey - Stage Two

Stage 1 of the flood damages survey indicated that the potential vulnerability to flood losses among commercial and industrial businesses was extremely high. However, the sample size was small, covering 11 businesses of which only 9 included a full financial analysis of flood loss exposure. "Keswick Creek - Flood Risk Management - Pilot Study Report" by Wright (Wright, 1999), extrapolated the estimates of flood loss exposure to cover the whole of the floodplain, but it was acknowledged that the estimates were only approximate.

As a contribution towards the project, Planning SA developed a method of interfacing flood risk information with the cadastral data base in order to identify flood prone businesses. This produced a comprehensive table of data containing the names, addresses and additional information such as land value and area of site for:

- ☐ industrial businesses;
- ☐ retail businesses; and
- ☐ retail tenancies.

Analysis of this data was undertaken, with the aim of identifying each business within the floodplain, and estimating the flood loss exposure. Each entry in the data base was examined and each street within the flood risk area was visited. All flood prone businesses were visited, at the following level of detail:

- ☐ survey by Erik Kroon on 9 properties, with full financial analysis of flood loss exposure;

- ☐ survey by Megaw & Hogg on 50 properties, mostly retail, covering office fittings, plant and equipment, raw and processed goods, but excluding damage to the buildings and business interruption;

- ☐ survey by Chris Wright covering approximately 60 properties, including interviews of the managers, advice on flood loss exposure minimisation, estimates of potential damage to buildings, contents, plant and equipment, raw and finished goods, and business interruption; and

- ☐ final survey by Chris Wright, approximately 50 properties, confirming flood prone status, and assessment of the flood damage potential, no interviews conducted.

From the surveys, a comprehensive data base was compiled, including all estimates of flood loss exposure. It was then subdivided into specific damage zones within the floodplain to develop an understanding of the distribution of flood risk. There is considerable variation between zones, which may well lead to a targeted program for flood mitigation, adapted specifically to the needs and options for each zone.

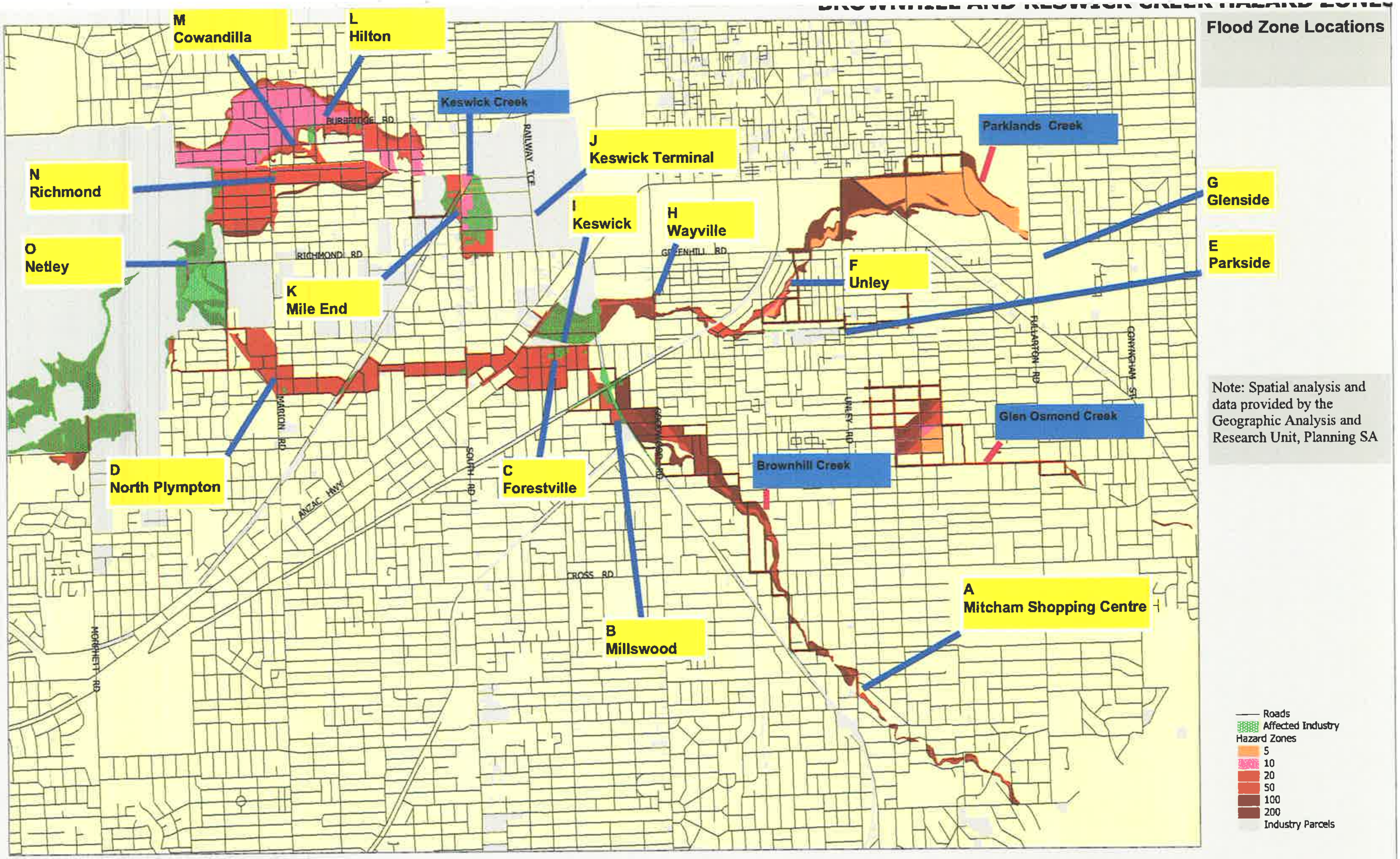


Figure 6.4 Floodplain map, showing locations of flood zones and suburbs of Adelaide

Produced by Planning SA
Department for Transport, Urban Planning and the Arts
Data Sources DEHAA - cadastre and roads
Projection Lamberts Conformal Conic
Datum Australian Geodetic Datum, 1984

October 1999

0.5 0 0.5 1 1.5 2 Kilometers

Government of South Australia

DATABASES

The identification of zones shown on Figure 6.4 is as follows:

Flood Loss Exposure, Location of Areas of Commercial/Industrial losses

Brownhill Creek

A	Mitcham Shopping Centre
B	Millswood (Goodwood Road)
C	Forestville
D	North Plympton

Keswick Creek

E	Parkside	(Glen Osmond Creek)
F	Unley	(Parklands Creek)
G	Glenside/Eastwood	(Keswick Creek)
H	Wayville	(Keswick Creek)
I	Keswick	(Keswick Creek)
J	Keswick Terminal	(Keswick Creek)
K	Mile End South	(Keswick Creek)
L	Hilton	(Keswick Creek)
M	Cowandilla	(Keswick Creek)
N	Richmond/West Richmond	(Keswick Creek)
O	Netley	(Keswick Creek)

The flood risk for each zone of Brownhill and Keswick Creek catchments is given in the following section.

6.11.1 Stage 2 Results for Brownhill Creek

In the upper reaches of Brownhill Creek from Crafers in the east to a point just upstream of Belair Road, Mitcham, there is no record of any retail or commercial businesses on the valuation or planning data bases. It is possible that some businesses are located in flood prone areas, particularly those which can be run from normal domestic housing, but none were identified.

The first occurrence of business activity is the Mitcham Shopping Centre.

Belair Road at the Mitcham Shopping Centre (Reference "A" on the map, Figure 6.4)

The creek runs in a long box culvert, beneath the Mitcham Shopping Centre and emerges on the west side of South Road between Angas Road and Wemyss Avenue.

Culvert capacity is 125 m^3/s, which is far greater than the estimated AEP 1 in 200 peak discharge of 35 m^3/s according to "Brownhill Creek Hydrology Review" by Kemp (Kemp, 1998). The entrance to the culvert is in a narrow section of the drain, immediately upstream of a large car park. Although culvert capacity is satisfactory, the channel upstream has a capacity of only 22 m^3/s, according to "South Eastern Suburbs of Adelaide - Stormwater Drainage Study" (WBCM, 1984). It is likely that during a major flood, overflow from the channel will bypass the entrance to the culvert and will pass through the shopping centre. There is also the risk that if the culvert entrance becomes partially or completely blocked by fallen trees and debris during a flood, water will flow at high velocity into the shopping centre which straddles the creek. Water depths could reach 1.5 to 2.0 metres at critical locations, and conditions would be hazardous for any people in the vicinity.

There are many shops in the shopping centre, all under lease-hold. There is a section of the complex which has raised floors (nearly 2 metres higher), with much lower risk of flooding. Existing flood mapping is not sufficiently detailed to predict the extent of flooding or to estimate flood damage with any accuracy.

On the west side of Belair Road at Mitcham there is a line of shops, which the flood mapping indicates will be less likely to be inundated. There would still be a risk of flooding for these shops, but the actual flood loss exposure level cannot be defined.

Flood loss potential is difficult to estimate because of uncertainty about the path, velocity and depth of a flood, but the potential damages will be of the order of \$5 million to \$10 million, plus the cost of business interruption and the diversion of shoppers to other centres. There is also a risk of loss of life due to people being trapped by deep and fast flowing water. However, for Brownhill Creek, *if* current hydrology studies are correct, development of a flood in this location would take 10 to 12 hours. This would allow for proper precautions to be taken by the Police and Emergency Services to keep people away from the shopping centre until the danger had passed.

The creek flows to the north west, through residential housing areas for several kilometres, but it is not until it reaches Goodwood Road in Forestville, that there are businesses located within the floodplain.

Goodwood Road at Millswood (Reference "B" on the map, Figure 6.4)
The creek runs through the "Orphanage" in a fairly narrow, confined channel, under Mitchell Street, and shortly afterwards runs in culvert under Goodwood Road. According to the flood mapping, overflow is likely to occur for floods of AEP 1 in 50 and greater, running down the roads, through housing areas and will affect the shops and restaurants located along Goodwood Road. It appears that flooding is likely to be relatively shallow and that the water will spread out over fairly flat ground, with flow direction controlled by fences and roadways. Eight businesses are listed. Four of them were interviewed by

Megaw & Hogg, and indicated a potential loss exposure between $100,000 and $150,000. There would be some additional costs due to business interruption.

Downstream from the Goodwood Road crossing the creek runs through residential areas. There is a retirement homes complex to the north. According to existing mapping, it appears to be outside the high risk part of the floodplain. It is not until the creek passes under the railway line at Victoria Street that it threatens business premises. Close to the railway line on Lyons Street, there are two businesses, Allan J Olson & Associates, a manufacturer of medallions and trophies, and TW Ingham, makers of plaster mouldings. The creek runs beneath the factory buildings.

Leader Street at Forestville (Reference "C" on the map, Figure 6.4)

The creek passes under the tramway and turns west, running parallel with Leader Street. Buttercup Bakery is within the floodplain. This is a combined administration complex and factory, which will be rearranged during 2001 to concentrate entirely on bakery products, with the administration moving to Brompton. It is understood that a computer centre, currently located in a vulnerable location, close to the creek and low-lying, will be relocated. Disruption of the bakery would result in considerable loss of production, but the company has contingency arrangements in place which would allow for supply of bread orders from Mt Gambier and Victoria if the Keswick premises were damaged.[6] The machinery operated by the bakery is conventional mechanical plant, not particularly vulnerable to flood damage. Some of the plant is already elevated, fixed to loading ramps that were perhaps part of a vehicle manufacturing plant which formerly occupied the premises.

There is a small engineering warehouse to the west of Buttercup, which did not appear to be either vulnerable to flood damage, nor to involve high-tech equipment.

At the point where Brownhill Creek crosses under the ANZAC Highway, there is a cluster of shops including a Pizza Hut and a Hungry Jacks restaurant, a hairdresser, a "take-away" chicken shop, and a small store which sells fireworks. The two restaurants would present the largest flood exposure. An inspection of the kitchens and administration/office would give an indication of possible flood damage, but there was insufficient time available to do this. A damage potential of $100,000 to $200,000 is anticipated. This could be reduced significantly by flood preparedness and flood warning.

---

[6] The contingency plans were used during 1998 after the Longford Gas Plant disaster when the Victorian branch of Buttercup was unable to function. The Keswick branch put on extra shifts and supplied bread to the Victorian market.

Marion Road at North Plympton (reference "D" on the map, Figure 6.4)
From ANZAC Highway to Marion Road, there are no business premises noted on the data base. There is a group of small businesses located along Marion Road, close to the creek. One is a steel fabricator, which, interestingly, was included in "South Eastern Suburbs of Adelaide - Stormwater Drainage Study" (WBCM, 1984). Apart from corrosion of raw steel products, some minor damage to plant, and a fairly basic office, there does not appear to be much risk of damage. Certainly, the owners were not cooperative in discussing the potential for flood damage and what to do about it.

An auto-repair shop on the west side would suffer considerable damage during a flood, but the overall losses are unlikely to exceed $20,000. Part of this would be damage to vehicles and would be recovered through insurance. There is a group of small businesses fronting onto Marion Road which would be vulnerable; they are listed as small services, such as hairdressers, mini-mart, bakery and chemist. No valuations were done for these, but these small businesses would be unlikely to recover after suffering flood damage.

From Marion Road downstream to the junction with Sturt Creek and its mouth at the Patawalonga, the creek flows beside Adelaide Airport. The flood mapping shows large inundation areas to the south of the airport and affecting some suburban areas near the north end of Morphett Road. Recent earthworks within the airport are likely to divert flood water to the south, and could exacerbate the flood risk in residential areas along James Melrose Road.

Summary of Flood Risk for Businesses Located on Brownhill Creek
The potential for Brownhill Creek to cause damage to commercial businesses, for flood intensities up to about the AEP 1 in 200, is far lower than Keswick Creek as will be seen in the following section. Mitcham Shopping Centre represents the highest concentration of risk, mainly due to possible overtopping of the creek channel, or in the case of the entrance to the culvert becoming blocked by flood debris. For major floods, such drainage channels often become blocked with objects that are not moved by smaller floods, such as shopping trolleys, logs and fallen trees. If this happens, the damage will amount to several million dollars, and there is potential for loss of life.

The remainder of the creek represents a flood risk to a number of residences. The damage potential for businesses is low, due mainly to the small number of businesses and their small size.

Both WBCM and Kemp indicate that Brownhill Creek will take many hours to reach peak flood conditions, and it should be possible to operate a flood preparedness program and warning system successfully ("Brownhill Creek Hydrology Review", Kemp, 1998, pp. 37-38; "South Eastern Suburbs of Adelaide - Stormwater Drainage Study", WBCM, 1984, pp. 147-162). Brownhill Creek has neither the rapid response nor the very high flood loss exposure which characterises its tributary, Keswick Creek.

Because the creek channel is narrow and restricted in many parts, has houses built over it and most appears to be under private ownership, there is a very real danger of creek blockage during a flood, leading to flooding of areas which would otherwise have been safe. Maintenance of the creek channel by the local councils is difficult due to private ownership, and limited access for maintenance vehicles.

6.11.2 Stage 2 Results for Keswick Creek

Keswick Creek starts at the junction of Glen Osmond and Parklands creeks:

Glen Osmond Creek at Parkside (reference "E" on the map, Figure 6.4)

Glen Osmond Creek has its headwaters along the South Eastern Freeway and runs north west, through suburban areas, to the junction in the suburb of Unley. The "rural" part of the creek, upstream of the Toll Gate, comprising 11% of the catchment area, is dominated by civil engineering construction associated with the South Eastern Freeway. Design of the freeway incorporates detention storage which limits the flows to pre-development state. Consequently, the flows from this area are not expected to exacerbate flood risk in the lower reaches of the creek system. In the middle reaches the creek runs through the suburbs of Myrtle Bank, Fullarton, Malvern, Parkside and Unley. There are several sections which are prone to overflow, and have done so several times since January 1997. Unley council is reconstructing part of the channel. This will mitigate flood risk in Fullarton and Malvern, and may reduce the risk of flooding of businesses along Duthy Street in Malvern. However, the new works do not include any flood storage and so it is probable that there will be a corresponding increase in flood risk downstream. There is a flood prone section along George Street in Parkside which will affect several small businesses and one mechanical workshop.

Glen Osmond Creek at Unley (reference "F" on the map, Figure 6.4)

Glen Osmond Creek flows under Unley Road. There have been several small floods in this area in the last three years, affecting a series of businesses close by, particularly Unley Disposals. Photographs were obtained of recent floods (Appendix C shows some examples). The most recent event which caused minor flooding at this location, was on Wednesday 25 January 2001, an event caused by 35-45 mm of rain.

From Unley Road, the creek flows down a narrow rectangular channel, past the City of Unley Depot, and under King William Road, to its confluence with Keswick Creek. The damage potential for this section is minor, according to the flood maps.

Parklands Creek at Glenside (reference "G" on the map, Figure 6.4)
Parklands Creek begins in Beaumont and has two branches which meet in the Glenside Hospital grounds. The upper reaches are steep and at an early stage the creek runs underground in a culvert. In recent years there have been many situations where the culvert capacity has been exceeded, causing manhole covers to blow off, and flow has occurred down the streets. The WBCM flood mapping does not cover this area. Flood prone locations of particular concern are:

- ☐ a Retirement Home complex, known as Victoria Grove and Pineview. Flooding through this area with a large population of elderly people, possibly of limited mobility, is a concern. An inspection of the area suggests that the design of the complex did not take flood risk into account. Modification of the entrance driveway roadworks, and bunding[7] along Conyngham Street could divert flood flow onto Greenhill Road. This may be preferable to permitting a high risk of flooding in a retirement homes area;

- ☐ if the Glenside Detention Basin overflows, water will cross the intersection and flow into a series of buildings along Fullarton Road, north of Greenhill Road. Flood mapping does not cover this area but a visual inspection indicates that there is a significant risk. No attempt has been made to evaluate flood loss potential for this area.

- ☐ a major flood is likely to overtop the Glenside Detention Basin, and some flow will run down Greenhill Road, affecting the many ground floor businesses and low level car parks. This is not indicated on the WBCM maps but is a real risk. Again, no attempt has been made to estimate the potential damages resulting from a flood in this area.

After crossing Fullarton Road, Parklands Creek flows north west towards South Terrace. WBCM flood maps indicate flooding along part of East Terrace and all of South Terrace, east of Hutt Street. A short section of Hutt Street would also be affected. The mapping does not show that any buildings are affected and it is not possible to determine flood loss exposure until information on actual water levels becomes available. No allowance for flood loss exposure has been included for this section.

The creek spreads out through the South Parklands, providing significant flood storage. This area also offers the opportunity for construction of a large detention storage dam, if it can be shown that there are sufficient benefits. It then flows south west and across

---

[7] The bunding would consist of earth banks running parallel to the road. They would be sufficiently high to prevent water from entering the site, and could be landscaped.

Greenhill Road into Unley, passing through suburban housing blocks, including the Knox Court block of flats which have been flooded on several occasions. It then flows under King William Road, on to the junction with Glen Osmond Creek and the start of Keswick Creek There do not appear to be any businesses in this section. Several houses have been flooded in recent flood events.

Keswick Creek at Wayville (reference "H" on the map, Figure 6.4)

The first 500 metres of the creek passes through suburban housing, to Goodwood Road. This is a critical point in terms of flood development because this is the starting point of the tunnel which runs under Goodwood Road and the Showgrounds, and exits at the railway line. The tunnel has a limiting capacity of some 25 m^3/s, compared with the AEP 1 in 100 flow of 35 m^3/s according to "Keswick Creek Hydrology Review" (Kemp, 1997, p. 40). Once the culvert entry is overtopped, there will be a delay while flood waters build up along Goodwood Road and flow into the Showgrounds. The construction of buildings and facilities in the Showgrounds, together with the improved quality of the fence along the western boundary of the property, can be expected to provide a significant amount of storage until the fence gives way, and water flows quickly onto the railway lines. The Show Society management staff are now aware of the risk and have prepared a response plan. The Showgrounds, while acting as a temporary detention storage, may suffer considerable damage in the process, and contributes significantly to the flood loss exposure total.

Keswick Creek at Keswick (reference "I" on the map, Figure 6.4)

The limiting capacity of the Showgrounds Tunnel, of 25 m^3/s, is nevertheless sufficient to cause flooding through Keswick Barracks. This could be exacerbated by overland flow which has passed through the Showgrounds. Discussions with military personnel on site revealed that flooding had already occurred within the period of the study, and provided confirmation of the flood hydrology estimates and hydraulic capacity of the channel. Obviously the potential flood loss exposure will be greater during a major flood, and the effects of a sudden release of water from the Showgrounds could be extremely serious. Maple Avenue runs parallel to the creek, about 50 metres to the south. The WBCM flood mapping shows this area as flood prone and there is evidence in recent times of flood flows down Maple Avenue. There are many businesses along this street, half of them backing onto the creek. They have emergency fire exit doors, and would be subject to flooding from north and south sides. On the south side of Maple Avenue, there are several businesses with varying levels of flood loss exposure, and a large furniture store, representing a major part of the total exposure bill.

Keswick Creek at Keswick Terminal (reference "J" on the map, Figure 6.4)

There is a flood path running north along the railway line, under Keswick Bridge, following a spur line to the north west, and threatening the east side of the

*Advertiser*newspaper production complex. This path is not shown on the "South Eastern Suburbs of Adelaide - Stormwater Drainage Study" (WBCM, 1983) flood maps, but an inspection on site confirmed that it exists. It is difficult to estimate the potential damage to the *Advertiser* site, but discussions with the management indicate that there is considerable risk to the power supply and distribution, the paper store and to print machinery. Management is very conscious of the high costs of business interruption and has taken out full insurance cover. This is the one case encountered during the study where the Insurance Company (Factory Mutual), has taken a close interest in flood risk and is looking at ways of minimising the risk. In the case of the *Advertiser* complex, flood proofing of the site is a relatively simple option. It is understood that the management is giving it serious consideration.

Keswick Creek at Mile End (reference "K" on the map, Figure 6.4)
The next flood prone area indicated on the flood maps is in Mile End, from Richmond Road to the north. This is seen as having the greatest flood loss exposure, with a group of industrial businesses, some of which are very flood sensitive, with many millions of dollars worth of potential damage. A financial analysis is given in the following Chapter 7.

Keswick Creek at Hilton, Cowandilla and Richmond (ref. "L, M and N" on the map, Figure 6.4)
Keswick Creek bends to the west, crosses South Road and flows towards Adelaide Airport. Channel capacity will be exceeded for floods greater than AEP 1 in 20, and the flood maps indicate an extensive area of inundation, mostly residential housing, but which includes an aged care home, for which flood loss exposure was assessed in the first stage of the damages survey. There are also numerous businesses along Burbridge Road and Marion Road. While these do not make a major contribution to the overall flood loss exposure, there is the potential for considerable disruption, financial loss and bankruptcy to individual businesses.

Other facilities of note in the flood risk area include:

☐ West Torrens council offices, of which the underground car park, senior citizens recreation facilities and the council library are the most vulnerable. Council office floor levels are elevated by 0.5 metres or so, hence reducing flood risk significantly, but there is a below-ground car park that is vulnerable;

☐ West Torrens council maintenance depot which is in the middle of the floodplain. Although it is elevated and not particularly at risk, it may be difficult for council to provide support to its residents during a flood, since the depot will be isolated;

- ☐ Emergency Service Metro West offices, located next to the council maintenance depot, and for which the same comments apply; and

- ☐ Aircraft navigation facilities owned by the Federal Airports Corporation on the corner of Press Road and Edwin Street. It is not known how critical these are, nor whether they are vulnerable to water damage, but the Corporation has been made aware of the possibility of flooding.

Keswick Creek at Netley (reference "O" on the map, Figure 6.4)
The creek runs south, following the eastern boundary of Adelaide Airport. The airport is protected by a large embankment which will cause any surface flow to be diverted through the adjacent residential area. At the western end of Richmond Road, there is an industrial area, and several businesses are vulnerable to flood damage. In this area, the grades are very flat and the potential is for a large area of shallow flooding. Businesses which, by planning or good fortune, have built slightly higher than the adjacent ground have achieved a significant level of flood protection. With such flat grades in the area it is very difficult to decide which places will be flooded and which will not. The floodplain mapping study by Hydro Tasmania, which started in August 2000, should help to resolve this.

Confluence of Brownhill and Keswick Creek, and Areas Downstream
South of Richmond Road there are no obvious high risk business facilities, and the study was terminated at the junction with Brownhill Creek.

6.12 Conclusions from Flood Loss Exposure Survey

Chapter 6 described a series of surveys of businesses in the floodplain to determine the vulnerability to flood damage, and the state of preparedness of the flood-prone community. The survey showed that knowledge of flood risk was at an extremely low level and that the flood loss exposure was large. An analysis and summary of flood loss exposure follows in the Chapter 7. The question was raised in Chapter 5 as to whether the flood prone community would receive and respond to a flood warning. At the start of the survey, the answer is that the response, if any, would be minimal due to a total lack of awareness and flood mitigation planning. By the end of the survey, all of the high risk businesses had been contacted, with efforts to make the owners aware of flood risk and what to do about it. Some progress could be observed, in the form of preparations, planned mitigation works and requests for flood information. Issues such as flood insurance (described in Appendix A), could not be determined, although there was anecdotal evidence that some businesses had taken out flood risk cover.

Important considerations which came out of the survey include:

- ☐ very large differences in flood damage potential across the floodplain;

- ☐ the highest vulnerability is within the Keswick Creek floodplain, from Goodwood Road to South Road in Mile End;
- ☐ Brownhill Creek has relatively minor flood loss exposure, has a much slower response to heavy rainfall, allowing more time to prepare flood damage reduction measures; and
- ☐ Keswick Creek has high flood loss exposure and very rapid response to rainfall, with little time available to forecast a flood or distribute a warning.

One of the objectives of the survey was to determine the potential value of a flood forecasting and warning system for Keswick Creek, bearing in mind the difficulty in providing such a service. It seems clear from the survey that before there can be any benefits from a warning system, it will be necessary to increase the level of flood awareness in the owners and managers of businesses, and for them to be ready to respond appropriately to minimise flood losses. Each of the businesses surveyed had a unique set of problems and issues related to flood risk, and the Action Plan required for each would be different. As will be seen in the Chapter 7, a flood mitigation program, based around solving specific flood risk issues, has the potential to achieve a far greater reduction in flood loss exposure than a warning system per se. This does not mean that a flood warning system should not be introduced, since it would be useful to minimise damage in residential areas, and could save lives, but that in the initial stages it may be better to concentrate on:

- ☐ improving the level of flood risk awareness;
- ☐ planning improvements for new development;
- ☐ self-protection for existing development;
- ☐ preparation of Action Plans by individual businesses;
- ☐ improved communication arrangements for flood warnings; and
- ☐ a program of training and education about flood risk for all who may be involved in floods and floodplain management.

Development of these processes is discussed in Chapters 8 to 10.

7 FINANCIAL ANALYSIS OF FLASH FLOOD DAMAGE POTENTIAL

The flood loss exposure survey described in Chapter 6 has provided potential costs to businesses in the floodplain that would be caused by an AEP 1 in 100 year flood. These costs are summarised and analysed in the following sections. The potential for reducing the vulnerability to flood damage and consequential loss after a flood is also investigated.

7.1 Overall Flood Loss Exposure Estimates

In Chapter 6, the stages of the survey were described. The stages, composition and numbers of businesses surveyed are provided on Table 7.1. Businesses identified as on the fringes of the floodplain and only marginally at risk, were excluded from the survey.

Stage	Businesses surveyed by:	
1	Kroon & Wright	11
2	Megaw & Hogg (Joe Tabaszewski)	50
3	Wright	108
	Total	169

Table 7.1 Number of businesses included in the survey stages

Table 7.2 summarises the flood loss exposure to commercial, industrial and retail businesses in the whole of Brownhill and Keswick Creek floodplains. The figures were obtained from the 3 stages of the survey. They include upper and lower limits, and losses are given for each category of damage.

Flood Loss Exposure in $ million, assessed for:		Range*		
		Lower		Upper
a)	Direct damage to buildings	$5.3		$7.8
b)	Damage to contents, including plant & equipment	$26.8		$35.8
c)	Damage to stock, raw and finished goods	$19.2		$27.1
d)	Business interruption costs	$29.3		$41.7
	Total flood loss exposure for businesses	$80.6		$112.4

Table 7.2 Total Flood Loss Exposure for businesses in Brownhill and Keswick Creeks

Note: Range* Flood loss exposure costs are estimates, based on information provided by the managers, on judgement by the person doing the survey, and based on an approximate value for flood depth on the premises. Because of the uncertainty in determining the damages figure, in each case an upper and lower value was estimated, with the purpose that the correct value lies somewhere in between. In some situations, where costs and values are reasonably well known, the difference could be fairly small but in others a much wider range must be assumed.

An example is the Showgrounds, where flood loss exposure varies dramatically from day to day due to the occurrence of public events with large numbers of people and property, interspersed with periods of inactivity when the flood loss exposure is low.

Total flood loss exposure for the AEP 1 in 100 flood for the whole of Brownhill and Keswick Creek Catchment is between $80.6 million and $112.4 million.

This estimate **does not include any allowance for damage to private housing**, which were estimated in "Keswick Creek - Flood Risk Management - Pilot Study Report" (Wright, 1999), at $5.6 million.

The costs of **damage to services, bridges, roads, electric power, gas, water and sewerage are not included**. In a major flood, these may amount to many millions of dollars.

Costs of pollution due to flood damage causing release of **toxic wastes, spilled chemicals or sewage contamination have not been estimated**.

The figures are **direct financial costs** to businesses. Since many of the businesses interviewed were tenancies, and did not include landlords' costs for building reinstatement, carpets and fittings, an allowance for these was included.

Business interruption costs were included, these being the cost to the business of being unable to trade for the period after the flood until full business activity is resumed. Additional costs would be incurred after a flood due to personnel being discharged, temporarily or permanently, from their jobs while the business goes through the recovery process.

No attempt has been made to allow for intangible costs, such as stress and health problems resulting from a flood. These costs could increase the overall figure significantly.

The difference between Financial and Economic cost has been discussed in Chapter 6. In the case of furniture warehouse sales, which contribute significantly to the flood loss exposure total, flood damage to one or more businesses will not have much affect on the overall market, as there will be plenty of other suppliers ready to fill the gap, and perhaps the Economic cost is small. However, the importing of new furniture from overseas will be a cost to the nation. The furniture to be imported would include both replacement items for domestic housing and replacement of flood damaged furniture in retail warehouses. Construction of new kitchen furniture and cabinets would give a boost to the local joinery industry but would divert resources away from the normal domestic market.

Comparison of Flood Loss Exposure Estimates

Study by Wright (2000)

	Lower Estimate	Upper Estimate	Mean	Proportion
Brownhill Creek	$460,000	$730,000	$595,000	0.6%
Keswick Creek	$80,200,000	$111,700,000	$95,950,000	99.4%
Total	$80,660,000	$112,430,000	$96,545,000	100.0%

Study by WBCM (1984)

Year		1980*	1999	
Consumer Price Index		47	122.3	
Brownhill Creek		$6,787,000	$17,660,640	23.5%
Keswick Creek		$22,049,000	$57,374,313	76.5%
Total		$28,836,000	$75,034,953	100.0%

Comparison between study estimates and locations

	WBCM	Wright
Brownhill Creek	$17,660,640	$595,000
Keswick Creek	$57,374,313	$95,950,000
Total	$75,034,953	$96,545,000

Note: * WBCM Costs were given in 1980 dollars

Table 7.3 Brownhill and Keswick Creek flood loss exposure estimates WBCM (1980) and Wright (2001) compared.

7.2 Distribution of Flood Exposure

Flood Loss Exposure by catchment is given in Table 7.3, with a comparison between the estimates by WBCM Consultants in 1984, and current estimates.

Of a total flood loss exposure of approximately $96.5 million, the contribution by Keswick Creek alone is estimated to be $95.9 million or 99.4%. The **total** estimates for damages are similar to those estimated by WBCM, with allowance for inflation, but the distribution of costs is quite different. The WBCM costs include the cost of damages to private housing, which the current study costs do not. The WBCM report gives no indication of the proportion of private housing compared with business costs. Both studies were based on the same floodplain mapping.

The two studies, despite the substantial agreement on overall flood loss exposure, are not really comparable, since the current study has focussed on damage potential to businesses and has not addressed damages to residential housing. Nevertheless, it is believed that the results of this study demonstrate a high degree of vulnerability to flood damage in the Keswick Creek floodplain, particularly to commercial and industrial businesses, and comparatively low vulnerability in the Brownhill Creek catchment. It is expected that further studies to be undertaken as part of the new floodplain mapping consultancy, which began in August 2000, will help to confirm these conclusions.

In respect of flood loss exposure for commercial, industrial and retail businesses, the mean flood loss exposure for Brownhill Creek is $595,000, compared with $17.6 million estimated by WBCM. There is very little business activity in the Brownhill Creek floodplain, virtually all the exposure to flood loss is in the floodplain of Keswick Creek, estimated at $95,950,000. The contrast is remarkable, but confirms the need to concentrate flood risk mitigation efforts on Keswick Creek.

7.3 Cost Distribution Across the Floodplain, by Suburb

The area with the greatest concentration of flood risk is on Keswick Creek from Goodwood Road, Wayville, to a point a few hundred metres downstream of South Road in Mile End.

The distribution of flood damage potential on Keswick Creek floodplain through the suburbs is shown on Table 7.4. The catchment map included in Chapter 6, Figure 6.4, gives the location of the suburbs. The joint contribution of the suburbs of Keswick, Keswick Terminal and Mile End to the overall flood loss exposure total is 76.6% and covers less than 25%, or 2 km, of the floodplain of Keswick Creek. A flood risk mitigation program focussed on this area could provide the best benefit/cost ratio. Most of the remaining damage potential is in Hilton, Cowandilla, Richmond and Netley, close to Adelaide Airport.

On Brownhill Creek, the main problem areas were identified as Millswood, along Goodwood Road, and Forestville, which included two factories built over the creek, and a large bakery within the floodplain. The flood loss exposure for Mitcham Shopping Centre is not assessable, but is potentially very large for rare floods that break out from the creek or if the tunnel is blocked. Detailed flood loss exposure estimates are given on Table 7.5.

Location	**Contribution to Damages**
Parkside	0.6%
Unley	0.2%
Glenside*	0.0%
Wayville	11.5%
Keswick	16.0%
Keswick Terminal (between railway and Keswick Creek)	8.2%
Mile End	41.0%
Hilton	1.4%
Cowandilla	6.5%
Richmond	12.0%
Netley	2.6%
Total	100.0%
Note: Glenside damage estimates not included	

Table 7.4 Keswick Creek Flood Loss Exposure across the floodplain

Zone	Suburb	Flood Damage Potential						Business	Business
		Building Direct	Building Direct	Contents	Contents	Stock	Stock	Interruption	Interruption
	Brownhill Creek								
A	Mitcham Shopping Centre	Flood maps indicate that this area is outside the zone of the 200-Year ARI flood							
B	Millswood	$23,000	$39,000	$34,500	$39,500	$110,500	$110,500	$51,000	$103,000
C	Forestville	$29,000	$53,000	$63,000	$99,000	$121,000	$227,000	$26,000	$61,000
D	North Plympton	Several small Shops, a petrol station, mechanical workshop, car detailer, neglibible contribution							
Totals	Brownhill Creek	$52,000	$92,000	$97,500	$138,500	$231,500	$337,500	$77,000	$164,000
	Keswick Creek								
E	Parkside	$60,000	$80,000	$249,000	$249,000	$141,000	$146,000	$90,000	$125,000
F	Unley	$25,000	$45,000	$52,000	$57,000	$76,000	$76,000	$50,000	$80,000
G	Glenside	Outside the area of mapping, not possible to estimate.							
H	Wayville	$1,000,000	$2,000,000	$2,000,000	$4,000,000	$2,000,000	$4,000,000	$2,000,000	$5,000,000
I	Keswick	$608,000	$843,500	$1,087,000	$1,631,000	$5,464,000	$6,739,000	$6,998,000	$7,256,000
J	Keswick Terminal	$200,000	$300,000	$350,000	$500,000	$100,000	$200,000	$6,000,000	$8,000,000
K	Mile End	$1,688,000	$2,209,500	$16,005,000	$19,661,000	$6,647,667	$9,648,167	$9,534,000	$13,367,000
L	Hilton	$117,500	$209,000	$474,500	$509,500	$353,000	$367,000	$222,500	$448,000
M	Cowandilla	$1,222,000	$1,397,000	$1,414,300	$1,615,300	$2,053,400	$2,532,400	$945,000	$1,354,200
N	Richmond	$258,000	$429,500	$4,469,000	$6,668,000	$1,531,000	$2,174,000	$2,566,500	$4,909,000
O	Netley	$145,000	$180,000	$645,000	$790,000	$612,000	$825,000	$785,000	$1,030,000
Totals	Keswick Creek	$5,323,500	$7,693,500	$26,745,800	$35,680,800	$18,978,067	$26,707,567	$29,191,000	$41,569,200

Note: 1 Each cost category gives upper and lower estimates of cost

2. For locations of Zones, refer to Figure 1.4

Table 7.5 Distribution of Flood Loss Exposure for Brownhill and Keswick Creek by Suburb.

The relative magnitude of flood loss exposure by area is shown diagrammatically on Figures 7.1 for Brownhill Creek and Figure 7.2 for Keswick Creek.

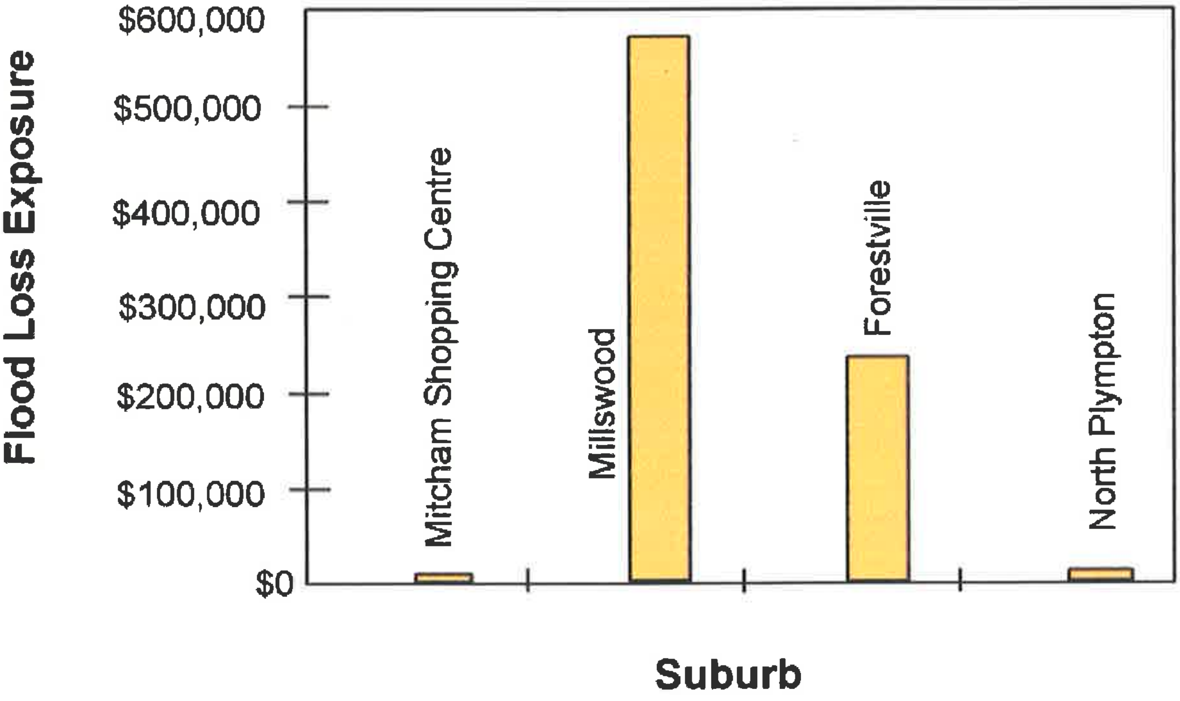


Figure 7.1 Distribution of Flood Loss Exposure for businesses for Brownhill Creek by suburb

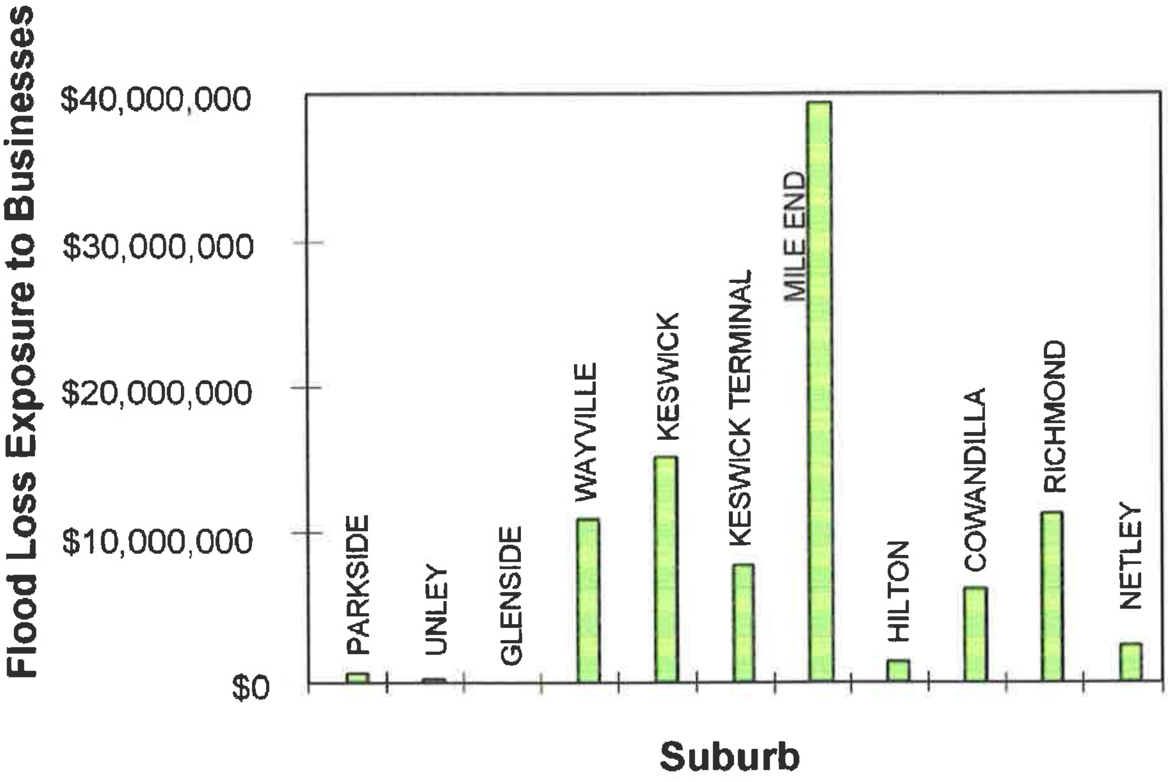


Figure 7.2 Distribution of Flood Loss Exposure for businesses for Keswick Creek by suburb

7.4 Contribution by Individual Businesses towards Flood Loss Exposure

Businesses have been ranked by total flood loss exposure. The total is influenced heavily by a small number of businesses as shown in summary on Table 7.6.

Major Contributors to Flood Loss Exposure Total	Percentage of Total	Amount of Exposure
Business with worst flood exposure	13%	$12,830,000
Four worst businesses	45%	$43,230,000
Nine worst businesses	64%	$61,880,000
Thirteen worst businesses	69%	$66,980,000
Twenty one worst businesses	76%	$73,387,500

Table 7.6 Relative contributions by large businesses towards the Flood Loss Exposure total.

A full analysis of the contribution towards overall flood loss exposure is shown on Table 7.7,[1] which includes the upper and lower limits of estimates for each category. Since the total flood loss potential for all businesses is approximately $100 million, there is considerable benefit/cost incentive to minimise the potential flood loss impact by concentrating a flood risk mitigation program on a small number of businesses. Once the program is established, it could be extended to cover the remaining businesses at risk, and residential housing.

In the following sections, some opportunities for flood loss exposure minimisation are explored.

7.5 Flood Loss Exposure Reductions; Opportunities and Implications

The flood loss exposure estimates represent financial loss, the direct losses in dollar terms suffered by each business. Some of these losses can be minimised after a flood by transferring production to another business premises or site. This is not necessarily taking up redundant capacity in their system, since there are added operating costs, overtime and transport to make up the shortfall in production. Transferability from a flood affected business to a non-affected business has not been examined in detail. It is known to vary widely between companies. In one example, a bakery can transfer production to Mt Gambier, Melbourne and Perth. In another example, production of a printing contract can be carried out under arrangement by a competitor. In each case there will be an unknown additional cost involved in the transfer. The flood loss estimates given here do not represent the losses suffered by the community as a whole, or by the economy. Such losses will occur, but the process of estimating them needs to be different. They include:

- ☐ where workers are made redundant, temporarily or permanently, they will be transferred to social security and are a transfer cost to the government;

---

[1] For reasons of confidentiality of information, the individual names of businesses have not been included.

	Flood Damage Potential		Range (Upper and Lower Estimates)												
	Street/Road	District	Building Direct Cost	Building Direct Cost	Contents	Contents	Stock	Stock	Business Interruption	Business Interruption	Survey by	Total Flood Loss Exposure	Contrib'n Single	Cum. Percent	Cumulative Total
1	SOUTH	MILE END SOUTH	$130,000	$130,000	$7,900,000	$7,900,000	$1,300,000	$1,300,000	$3,500,000	$3,500,000	k	$12,830,000	13.2%	13%	$12,830,000
2	GOODWOOD	WAYVILLE	$1,000,000	$2,000,000	$2,000,000	$4,000,000	$2,000,000	$4,000,000	$2,000,000	$5,000,000	w	$11,000,000	11.3%	25%	$23,830,000
3	MAPLE	FORESTVILLE	$425,000	$425,000	$325,000	$325,000	$4,000,000	$4,000,000	$6,000,000	$6,000,000	w	$10,750,000	11.1%	36%	$34,580,000
4	MANCHESTER	MILE END SOUTH	$200,000	$300,000	$3,000,000	$5,000,000	$300,000	$500,000	$3,000,000	$5,000,000	w	$8,650,000	8.9%	45%	$43,230,000
5	DEACON	RICHMOND	$20,000	$50,000	$4,000,000	$6,000,000	$150,000	$300,000	$2,000,000	$4,000,000	w	$8,260,000	8.5%	53%	$51,490,000
6	LONDON	MILE END SOUTH	$100,000	$150,000	$1,000,000	$1,500,000	$2,000,000	$3,000,000	$500,000	$800,000	w	$4,525,000	4.7%	58%	$56,015,000
7	BURBRIDGE	COWANDILLA	$1,000,000	$1,000,000	$900,000	$900,000	$0	$0	$400,000	$400,000	k	$2,300,000	2.4%	60%	$58,315,000
8	RICHMOND	MILE END SOUTH	$500,000	$500,000	$1,370,000	$1,370,000	$80,000	$80,000	$250,000	$250,000	k	$2,200,000	2.3%	62%	$60,515,000
9	BURBRIDGE	COWANDILLA	$50,000	$80,000	$71,000	$71,000	$929,000	$929,000	$200,000	$400,000	m/w	$1,365,000	1.4%	64%	$61,880,000
10	SOUTH	MILE END SOUTH	$50,000	$80,000	$71,000	$71,000	$929,000	$929,000	$200,000	$400,000	m/w	$1,365,000	1.4%	65%	$63,245,000
11	SOUTH	MILE END SOUTH	$8,000	$12,000	$700,000	$900,000	$150,000	$300,000	$200,000	$400,000	w	$1,335,000	1.4%	66%	$64,580,000
12	MANCHESTER	MILE END SOUTH	$100,000	$100,000	$200,000	$300,000	$350,000	$500,000	$350,000	$500,000	w	$1,200,000	1.2%	68%	$65,780,000
13	HUDSON	NETLEY	$100,000	$100,000	$350,000	$350,000	$500,000	$500,000	$250,000	$250,000	k	$1,200,000	1.2%	69%	$66,980,000
14	RICHMOND	NETLEY	$25,000	$50,000	$250,000	$350,000	$100,000	$300,000	$500,000	$700,000	w	$1,137,500	1.2%	70%	$68,117,500
15	LONDON	MILE END SOUTH	$80,000	$120,000	$400,000	$600,000	$40,000	$60,000	$150,000	$300,000	w	$875,000	0.9%	71%	$68,992,500
16	SOUTH	MILE END SOUTH	$50,000	$80,000	$150,000	$250,000	$300,000	$500,000	$150,000	$250,000	w	$865,000	0.9%	72%	$69,857,500
17	DEACON	RICHMOND	$25,000	$40,000	$40,000	$60,000	$450,000	$600,000	$200,000	$300,000	w	$857,500	0.9%	73%	$70,715,000
18	MAPLE	FORESTVILLE	$20,000	$20,000	$45,000	$45,000	$335,000	$335,000	$400,000	$400,000	k	$800,000	0.8%	74%	$71,515,000
19	MAPLE	FORESTVILLE	$10,000	$20,000	$40,000	$60,000	$250,000	$1,000,000	$20,000	$45,000	w	$722,500	0.7%	74%	$72,237,500
20	MANCHESTER	MILE END SOUTH	$50,000	$100,000	$150,000	$300,000	$20,000	$300,000	$100,000	$200,000	w	$610,000	0.6%	75%	$72,847,500
21	SOUTH	RICHMOND	$10,000	$20,000	$150,000	$200,000	$100,000	$200,000	$100,000	$300,000	w	$540,000	0.6%	76%	$73,387,500
							Total Flood Loss Exposure contribution for top 21 businesses						75.6%		$73,387,500
							Total Flood Loss Exposure for all businesses						100.0%		$97,134,967

Note: 1 Upper and lower estimates are given for each category of damages
2 Surveyed by: K=Kroon, W=Wright, M/W=Megaw & Hogg + Wright

Table 7.7 Flood Loss Exposure Estimates for individual commercial, industrial and retail businesses (including Upper and Lower Estimates)

- ☐ the physical and emotional stress suffered directly by people and their families affected by the flood will be transferred to the community through increased health costs;
- ☐ the destruction of large amounts of furniture within houses, as well as furniture retailers, will result in greater level of imports from overseas, representing a cost in foreign exchange;
- ☐ part of the cost of replacement of infrastructure, roads, bridges and services is a direct cost to the community and the economy; and
- ☐ where loss of life occurs, there is a significant cost to the community.

If the government were to undertake a flood mitigation scheme which removed flood risk from Keswick Creek, this would result in a direct reduction in financial loss exposure to businesses. The businesses would, in effect, receive a windfall benefit towards which they were making only a marginal contribution through taxes.[2]

The most feasible short-term means of reducing flood loss exposure is by flood-proofing of individual businesses. This would normally be carried out by the owners at their own expense. In times of economic rationalism, it may be argued that businesses should protect their own interests. This would be a reasonable argument for other hazards such as market trends or foreign exchange variations, but is probably not valid for flood since there is no structure for ensuring that proper and effective flood risk evaluation and loss minimisation is carried out by businesses. As discussed earlier, there are many parallels between flood risk and fire risk. For fire risk, there are procedures and regulations laid down which have the effect of ensuring that no building or business can be constructed without due attention being paid to fire prevention. Such is not the case for flood risk and results in the unsatisfactory situation that major developments which are vulnerable to flooding have been carried out in the floodplain:

- ☐ without the owners of the business being aware of flood hazard, even when that hazard has been identified and quantified by local and state government agencies; and
- ☐ where owners or developers are aware of the risk, there is no mechanism to ensure that they take responsible informed decisions and carry out effective planning to minimise risk to their business and to any tenants or subsequent owners.

---

[2] The recently introduced Emergency Services Levy is paid by all, including businesses. It could be argued that this money should be used to mitigate flood risk to businesses.

After the next major flood happens and damages such as have been identified above have actually occurred, it is possible that the owners of businesses which have suffered will take legal action against the authorities who, despite knowing the risk of flooding, still allowed major investment to occur without advising the developer or owner that the risk exists. This subject has been explored by Wright in "Flood damage to commercial and industrial businesses, Part 1. Introduction to urban flood risk on Keswick Creek, Adelaide" (Wright, 2000a), and Richard Smith in "Part 2. Possible legal ramifications consequent upon flood damage" (Smith, 2000) and by Wright in "Part 3. Looking for remedies - before the flood" (Wright, 2000b), in respect to a hypothetical flood on Keswick Creek. The fact that planning authorities knew of the risk and did not advise those who were, because of their proposed development, exposed to the risk, may be significant. It remains to be seen whether the protection afforded to local councils by the law is sufficient to prevent such claims from being successful. Whatever the outcome, being a matter for legal defence by local and state government, there will be a cost to the community and the economy. It would be better from all perspectives to implement a flood damage mitigation program at all levels, including introduction of planning controls to ensure appropriate development in floodplains. With such controls in place, there will be an obligation on authorities which are required to approve development, to introduce checks on flood risk:

☐ legislation relating to construction standards within the floodplain, for example David Ingle Smith's "Proposal for the Addition of Flood to the Building Code of Australia" (Smith, 1999);

☐ statutory obligation, on any new lease, for an owner to advise tenants (businesses), of flood risk and its implications;

☐ setting up of advisory/flood awareness groups which ensure that people living and working within the floodplain are aware of flood risk;

☐ consideration of structural flood mitigation measures where economically feasible; and

☐ setting up and operation of an effective flood warning system.

7.6 Estimates of Avoidable Flood Loss Exposure

As indicated on Table 7.7, the potential for flood damage from a major flood on Keswick Creek is about $96 million, 76% of which is contributed by 21 particularly vulnerable businesses.

A concentrated effort at flood exposure reduction for a limited number of the high risk businesses could be extremely cost effective. Particular issues are:

☐ some businesses such as the Courier company, are already well protected against damage and do not need flood warnings;

☐ some are so vulnerable to flood damage that they should not be located in the floodplain. Aged care homes are examples of this, but when they have already been constructed, it is vital that flood damage potential to people, especially bed-ridden patients, and property, should be minimised;

☐ several sites can be protected against flood water entry by completing a perimeter wall and providing waterproof gates;

☐ all would require prevention of possible backflow from sewers during a flood; and

☐ each business would need its own Flood Action Plan, together with a program for training staff to respond in a flood.

Table 7.8 indicates that more than 50% of the total flood loss exposure may be avoided by physical protection measures. Flood warning has the potential to achieve a further 15% reduction. In view of the huge amount of flood loss to which retail, commercial and industrial premises are currently exposed, there is a need for urgent action to take up the opportunities for flood loss exposure mitigation. As can be seen from Table 7.8, there are some businesses which can achieve a high level of self-protection. It is believed that in most cases this protection can be achieved for very reasonable capital cost in relation to flood risk reduction.

7.7 Estimation of Annual Average Damages

It is useful to convert flood damage potential into an annual amount, referred to as Annual Average Damages (AAD), since this figure can be used to decide how much it would be reasonable to spend annually on a flood risk mitigation program. It can also be compared with annualised capital costs of structural mitigation works, for calculation of the Benefit/Cost ratio. To obtain AAD, it is necessary to estimate the damages cost of a full range of possible floods. The risk factors are then integrated with the damages estimate.

The calculation of Annual Average Damages for Keswick Creek was based on the damages estimates of $96 million for an AEP 1 in 100 flood. It was assumed that the threshold AEP at which serious flood damage can be expected is the AEP 1 in 20 year flood. For the upper limit, the Probable Maximum Flood, it is highly likely that extensive building damage will occur, plus severe damage to services, and business interruption will be very large. It was assumed for this case that the damage would be four times the AEP 1 in 100 damages, and an AEP of 1 in 1 million was assumed for the Probable Maximum Flood. The estimated flood losses are given on Figure 7.3.

Keswick Creek Flood Loss Exposure Study											All Businesses
Type of Business	Specialist Printer	Furniture Retailer	Nursing Home	Retailer Automotive	Furniture Retailer	Courier Service Div.	Retailer Hobbies	Service Provider	Courier	Furniture Manufact.	
Size	Large	Medium	Medium	Small	Large	Large	Small	Medium	Large	Small	
Overall Loss Exposure	$12,830,000	$450,000	$2,300,000	$250,000	$10,750,000	$6,100,000	$800,000	$2,200,000	$1,110,000		$36,790,000
Flood Exposure Minimisation Potential effectiveness											
Prevention (Waterproofing etc) *3	50%	60%	30%	60%	80%	80%	90%	0%	0%	40%	
Potential value *1	$6,415,000	$270,000	$690,000	$150,000	$8,600,000	$4,880,000	$720,000	$0	$0	?	$21,725,000
Preparedness (flood warning etc)	15%	20%	50%	40%	10%	5%	10%	50%	0%	40%	
Potential value *2	$1,924,500	$90,000	$1,150,000	$100,000	$1,075,000	$305,000	$80,000	$1,100,000	$0	?	$5,824,500

Note: *1 This is an estimate for each of the businesses sampled, of what can be achieved by flood proofing the premises, including attention to gaps in cladding, door seals, closing of wall penetrations, and sewerage etc.

Note: *2 This estimates the additional benefit of flood warning. It is important to note that for some situations, flood warning is necessary to obtain the full benefit of sealing the buildings as outlined above.

Note: *3 The percentages (%) indicate the estimated effectiveness of Prevention and Preparedness measures for each type of business considered.

Table 7.8 Potential for Flood Loss Exposure reduction for 10 businesses

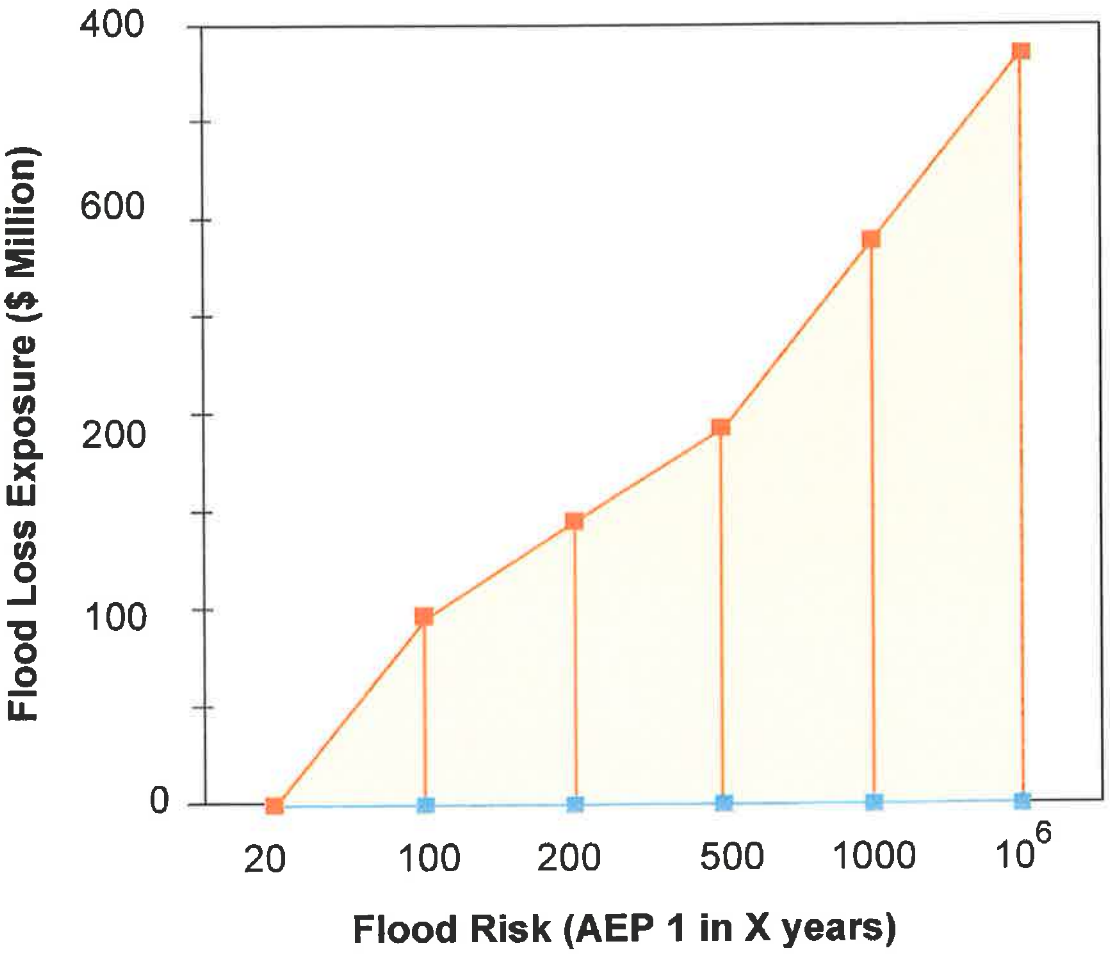


Figure 7.3 Estimate flood loss exposure for Keswick and Brownhill Creeks, up to the Probable Maximum Flood.

AEP Years	Flood Risk in any year	Estimated Flood Damages $ million	Annual Damages $ million
20	0.05	$0.0	
			$1.9
100	0.01	$96.0	
			$0.6
200	0.005	$144.0	
			$0.5
500	0.002	$192.0	
			$0.2
1000	0.001	$288.0	
			$0.3
PMF	0.000001	$384.0	
Total Annual Average Damages			**$3.5**

Table 7.9 Average Annual Damages calculation for businesses in Keswick and Brownhill Creek floodplains

The calculation of Annual Average Damages (the area under the graph) is given on Table 7.9. This indicates that the equivalent annual average damages estimate for flood damage on commercial, industrial and retail businesses in the floodplain of Keswick Creek is $3.5 million.

7.8 Conclusions

The question that initiated the initial survey, the pilot study, Flood Forum meetings and the flood loss exposure survey was whether a flood warning, ahead of a real flash flood on Keswick Creek, would achieve any damage mitigation? It seems that flood loss exposure to businesses in the floodplain is very large and, although a flood warning system could achieve a reduction in the potential flood damages, there is a need for a comprehensive flood risk management program because the benefits are potentially very large. It is concluded that:

- ☐ the risk of a major flood on Keswick Creek is significant;
- ☐ when the flood occurs, the damage to commercial, industrial and retail businesses is likely to be large;
- ☐ the "Keswick Creek Hydrology Review" (Kemp, 1997), and the occurrence of minor floods during the research program, confirm the existence of the risk;
- ☐ if an AEP 1 in 100 flood occurred over Brownhill and Keswick Creeks, more than 99% of the damage suffered by commercial, industrial and retail businesses would be in Keswick Creek catchment;
- ☐ for a flood of this magnitude, the damages bill is estimated at $100 million, of which about half is avoidable, by relatively low cost self-protection measures;
- ☐ a further reduction in damages of approximately $15 million could be achieved by an effective flood warning service;
- ☐ 21 of the 169 businesses in the floodplain of Keswick Creek contribute 76% of the total flood loss exposure. Therefore, to target these few would have the potential to obtain maximum reduction at minimum cost;
- ☐ the estimated Annual Average Damages for Keswick Creek is $3.5 million; and
- ☐ by comparison, the flood loss exposure of the residential housing is relatively small. Nevertheless, even this at approximately $5.6 million for the AEP 1 in 100 flood, is similar to the Gawler River floodplain, which in terms of priority in South Australia has rated far more attention, and is being considered for flood mitigation works valued around $7 million.

There is a contrast between the approach taken by our community to mitigation of damage by fire, compared with that of flood. Even though floods are equally dramatic in their effects,[3] from the review of published material on flood mitigation, it appears that communities around the world seldom consider floods as risks, but rather as "natural disasters". During this century millions of dollars have been spent each year on flood mitigation but the approach taken has been to engineer a solution, to build bigger and better dams or levees. In the Keswick Creek situation it may not be possible or practicable to engineer a solution that totally removes flood risk.

The issue of risk to private housing and people living in the floodplain has not been addressed. Flood damage and flood risk to residential housing has been given wide coverage by others. Smith, in the first chapter of *Flood Warning in Australia* (Smith and Handmer, 1986), provides a general introduction and references. However, a flood risk mitigation program for Keswick Creek should certainly include risk mitigation for people and their houses.

This completes the evaluation of flood loss exposure costs, and opportunities for mitigation. In Chapter 8, the particular issues related to effective communication of flood warnings are considered. Warnings are developed from flood forecasts and have to be transmitted to those who are threatened by a flood and need to take action to avoid danger to life and damage to property. If flood risk mitigation measures, such as building protection, are introduced by businesses, then there will be a need to close gates, install barriers and generally carry out the requirements of the Flood Action Plan, and for these measures to be effective, the warnings must be transmitted efficiently.

---

[3] The dramatic media coverage of the flood damage in Mozambique in May 2000 is just one example. Each flood provides a new boost to our awareness of the huge power of this natural hazard.

8. COMMUNICATION OF FLOOD DANGER INFORMATION

Chapters 6 and 7 demonstrated the high vulnerability to flood damage to which businesses in Keswick Creek floodplain are exposed, the need for a program of flood risk mitigation and the development of Flood Action Plans, so that flood loss exposure is kept to a minimum. These mitigation measures will require warning to be provided on the day of the flood so that there is time to implement them, but there is a very little time to distribute the warnings.

Flood forecasting procedures were investigated in Chapter 4, and the use of alarms for early identification of potential floods were discussed in Chapter 5. In flood situations, the information needs to be transmitted to those who are required to respond, such as the emergency services, and the owners and managers of businesses. For the very rapid flood development which is characteristic of flash floods, the speed and efficiency with which these messages are transferred will be critical. Existing methods of flood warning distribution and the limitations for flash flood warning are described. Improved message transmission systems have been introduced interstate, and could be effective for warnings on Keswick Creek.

8.1 General Arrangements for Dissemination of Flood Warnings

The Bureau of Meteorology (BOM) is responsible for issuing flood warnings for non-flash flooding. The BOM Hydrology section monitors rainfall and water flow, using various models to forecast flood magnitude and timing, and prepares and distributes warnings. The schematic, Figure 8.1, shows how warnings are distributed.

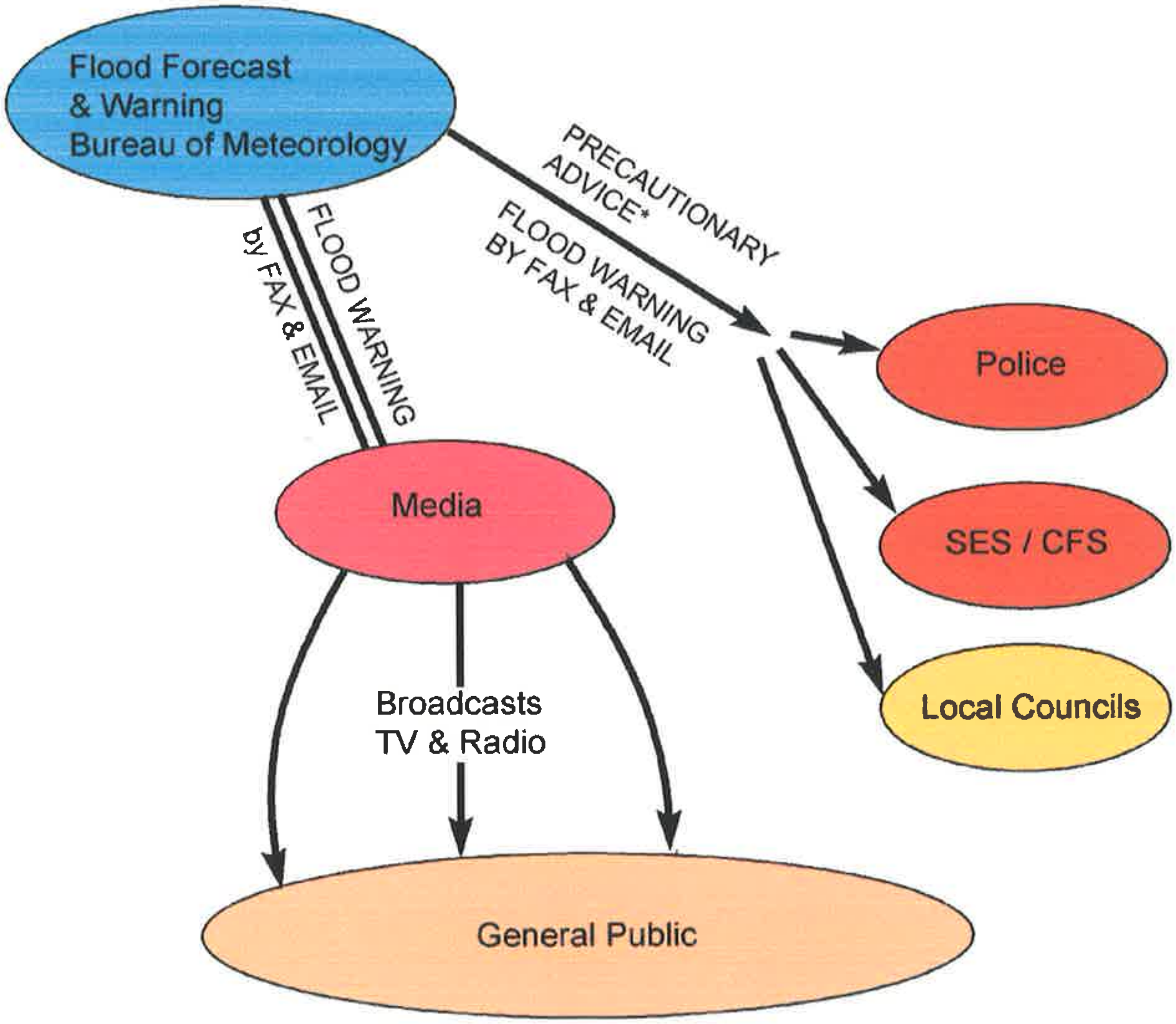
Early in a flood event, while the magnitude of the flood is still uncertain, a precautionary advice is issued to the Police, State Emergency Services (SES), Country Fire Service (CFS), and local councils. This is to advise that there is a strong possibility of flooding, and suggests that each of these agencies carries out any preliminary procedures such as alerting duty staff and checking equipment. If the flood event develops and is likely to reach Minor[1] flood level, a formal warning is issued by fax to all the recipients mentioned and to the media, for direct distribution. The general public is warned via the media and, if necessary, the warnings are given directly to people in the floodplain by Police, SES, CFS or the local council, by vehicle mounted loud speaker and/or doorknocking.

This warning system has proved to be satisfactory for non-flash floods, even though it depends to a great extent on the people in the floodplain receiving flood warnings indirectly, by a passive process via the media. Its success is due to there being adequate time between the warning and the flood. There is time for flood-affected people to talk to neighbours, phone the

---

[1] The terms Minor, Moderate and Major describe the 3 categories into which flood events are divided, as used by the BOM and emergency services throughout Australia. For Keswick Creek, Minor floods would not cause significant damage, however, Moderate and Major floods would be expected to inundate large areas, and there would be the potential for loss of life and major damage to property.

council and emergency services or the BOM, to confirm the flood information, and carry out necessary action to minimise damage. This warning distribution system is not suitable for flash flood warning because there is not enough time, and what is needed is a direct warning by an active process ensuring that, as far as possible, each and every person at risk is contacted as soon as the risk is realised.



Note: * If flooding is anticipated precautionary advice is issued to the emergency services by direct phone calls. As soon as actual flood conditions arise, a formal warning is issued by Fax and Email.

Figure 8.1 Standard Bureau of Meteorology flood warning communications for non-flash floods

8.2 Flash Flood Warning Distribution

For a warning system for flash flooding to be effective, it must be positive, stimulating action, and must;

- ☐ reach the target population at risk very quickly;
- ☐ avoid reliance on passive systems such as the media;
- ☐ give as little room as possible for confusion or misunderstanding;
- ☐ provide an opportunity for the recipients to confirm/be confident that the information is correct;
- ☐ be updated frequently with the current forecast and reports of the flooding; and
- ☐ be auditable after the event so that the sending and receiving of each message is recorded.

Two systems have been developed in Australia, one exclusively for flooding, the second for Police/Neighbourhood communication of information on crimes but which can be readily adapted for flood warning.

8.3 High Speed Flood Warning Communication System

The first of these systems has already been developed and put into use for Euroa and Benalla in Victoria, and is described in a paper by McPherson, "Flood Warning Alert - A Practical Solution" (McPherson, 1999). Details of the message preparation are given in "Euroa Flood Plan, Operation Procedures for Flood Warning System" (Shire Council of Strathbogie, 1997), and the procedure is as follows:

- ☐ the BOM detects a potential flood situation and initiates an automatic, pre-recorded, warning message, such as; "This is a flood ALERT for flooding on Castle Creek, for information tune in to FM88 radio";

- ☐ the message is sent automatically, as a recorded voice message, to a pre-determined list of recipients in the selected location which is threatened by the flood;

- ☐ recipients have already been given information about the warning system, and what to do when a warning is issued; and

- ☐ in the meantime, the local FM88 station is switched over from Community Radio to emergency broadcast mode, and broadcasts continuous updates of flood warnings and information to the local community.

The phone message distribution system is computerised, and is able to send messages to a target population very quickly. McPherson, in "Flood Warning Alert - A Practical Solution", states that the system can alert up to 400 properties within 15 minutes (McPherson, 1999, p. 1). A log is kept of all phone calls so that, after the event, proof can be obtained of the contacting details, such as phone engaged, no answer, message bank or mobile phone switched off, and any other particulars. Key features of the system are:

- ☐ automatic message sent quickly to multiple recipients;
- ☐ FM radio broadcasts give actual up-to-date information on the development of the flood; and
- ☐ recipients have to tune in to the radio station for current information.

The system is shown diagrammatically on Figure 8.2.

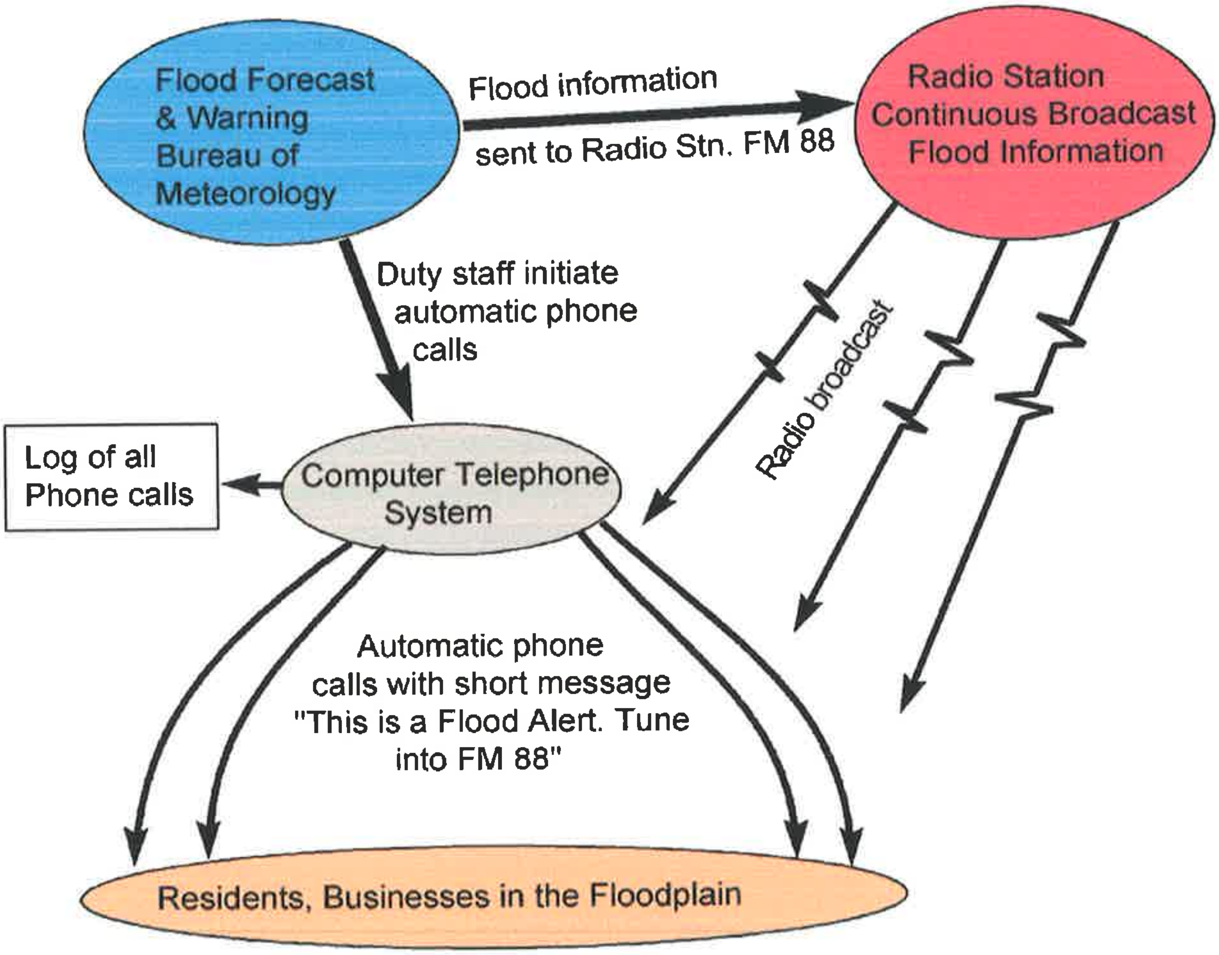


Figure 8.2 High speed Flood Warning System for Euroa and Benalla, in Victoria

8.4 PC COPS - Community Warning System Adapted for Keswick Creek

In Western Australia a community alarm and information system has been put into operation, linking the Police with local communities. Referred to as PC COPS, it was developed primarily for crime watch and response, and for emergency use such as finding children and elderly people who have gone missing, but the system is readily adapted for flood warning purposes. It is described by Dance in "PC COPS A Crime Prevention and Emergency Management Resource" (Dance, 1998) and the essentials are illustrated in Figure 8.3.

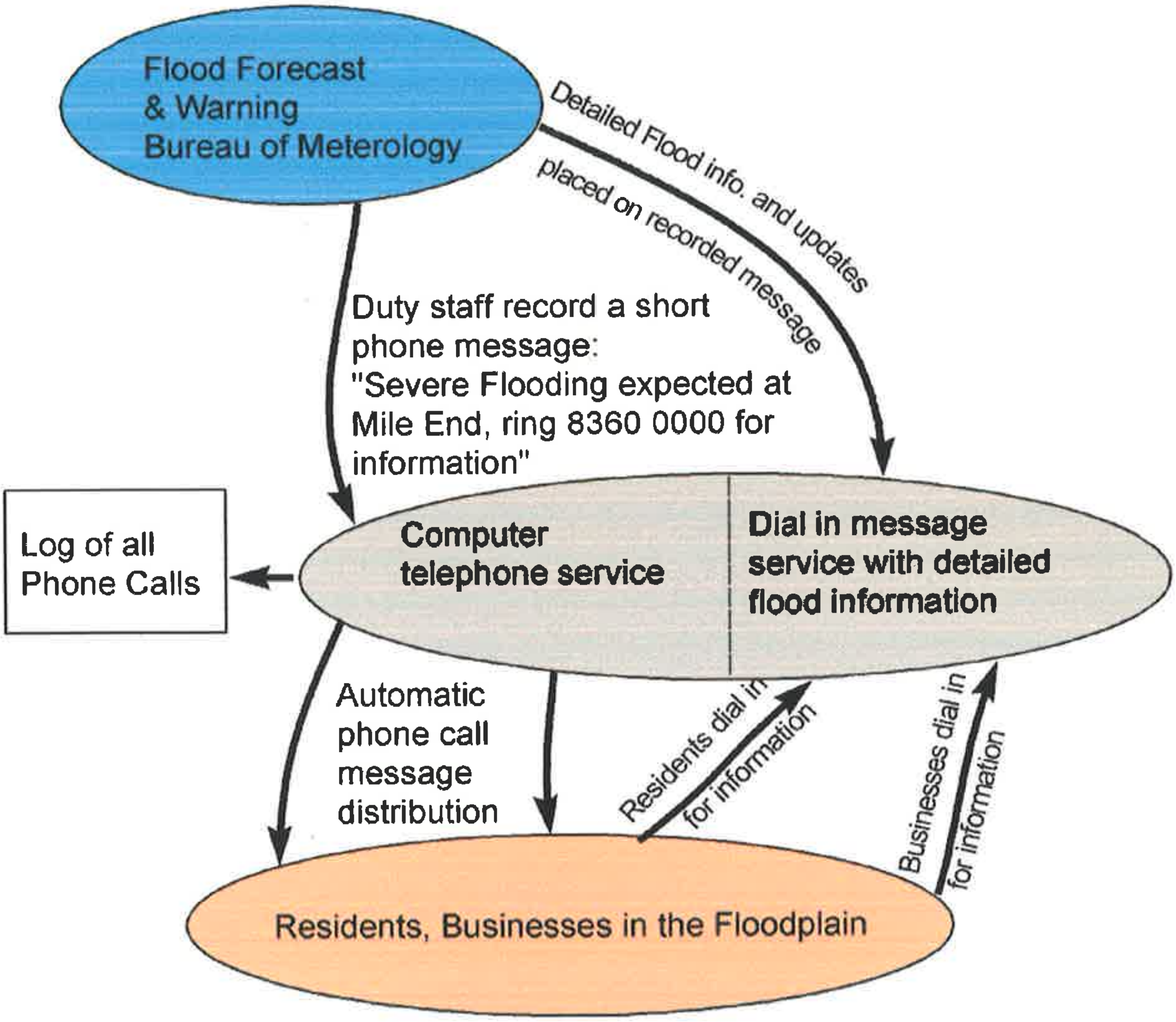


Figure 8.3 PC COPS alerting system adapted for flood warning for Keswick Creek

For Keswick Creek, it would work as follows:

- ❑ Flood information and forecasts are determined by the BOM, which would then prepare a short warning text; for example, "Severe flooding expected at Mile End, ring 8360 0000 for information";

- ☐ The message would then be sent by BOM staff using an ordinary tone dial phone, by dialling an access code, reading the message, and then choosing a distribution list;
- ☐ As soon as the phone is hung up, a computer-based system would dial each of the people on the list. In this case, rather than using community radio, a phone number is given, and recipients must ring the number to receive recorded information; and
- ☐ The BOM, and possibly the Emergency Services, are required to keep the information updated on the dial-in service. The dial-in service needs to be capable of handling a large number of calls so that it does not overload in an emergency. A log would be kept of the history of all phone calls made to recipients, as is done for the Euroa and Benalla systems .

The essentials of the PC COPS system are:

- ☐ specific flood information message sent quickly to multiple recipients advising a dial-in number for further information;
- ☐ dial-in phone service provides actual up-to-date information on the development of the flood; and
- ☐ recipients are required to phone the dial-in service for the information.

Both systems have inherent strength in that they provide both a basic warning message and confirmation, either by phone or FM88 emergency radio. Neither system is available in South Australia at the present. Installation of PC COPS is being considered by the South Australian State Government for use by the emergency services, and this could include shared use for flood warning. The cost of establishment is between $50,000 and $100,000 according to "PC COPS: A Crime Prevention and Emergency Management Resource" (Dance, 1998, p. 10), depending on the scale of the system adopted. PC COPS, because it is a multi-use system with the ability to do far more than just flood warning, would also be used for crime watch and other functions. The opportunity for wider application could assist in speeding up its adoption.

8.5 Conclusions

Chapter 8 has discussed the transmission of flood warning messages, and has identified an efficient system, PC COPS, for sending warnings by phone and a providing a means for the people warned to keep up to date with the progress of the flood. This is an essential tool for flash flood warning and links together the warning process of Chapters 4 and 5, with the response requirements described in Chapter 6. This leads, in Chapter 9, to an integration of the detection, forecasting, warning, and response processes which was introduced in Chapter 1. A sample system is proposed for Keswick Creek in Chapter 10.

9. MITIGATION OF FLASH FLOOD DAMAGE BY KESWICK CREEK

9.1 Combining the Elements, Warning, Preparedness and Response

Chapter 9 brings together elements of forecasting, warning and response to flash flooding, and links them together. Successful mitigation of flash flood risk will require the integration of several different strategies. The matrix diagram for flood risk mitigation (Figure 1.2), introduced in Chapter 1, is developed in Chapter 9 to integrate all the agencies and activities related to flash floods, incorporating planning and preparation procedures, with a focus on long-term and short-term activities.

In the case of Keswick Creek, the risk of urban flash flooding is real, and appears to be becoming worse due to a combination of factors which include:

- ☐ increased housing density leading to greater runoff;
- ☐ direct connection from house and shed roof drainage into the street, increasing the quantity of runoff and reducing time of concentration;
- ☐ increased exposure to flood damage due to location of sensitive industry in a floodplain; and
- ☐ lack of advice on flood risk for planners of new development.

Since the middle of 1997, discussions about flood risk have been taking place with;

- ☐ the owners of businesses located in flood prone locations;
- ☐ the Patawalonga Catchment Water Management Board; and
- ☐ local council staff.

During that time, there has been a gradual change and a growing awareness that:

- ☐ for specific locations a flood problem exists;
- ☐ it is not just a local stormwater problem; and
- ☐ something should be done about it.

Simple solutions such as flood retention dams or levees to remove the flood risk are not financially feasible. It is believed that, on the basis of information provided:

- ☐ from the surveys;
- ☐ in discussions at the Flood Forum meetings; and
- ☐ subsequent discussions during the interviews,

both the councils and the business managers would prefer the solution to the flood risk problem to be a flood warning system. However, flash flood warning systems are not "quick fix" solutions and, if they are to be effective, need to be integrated with flood loss exposure minimisation and the introduction of Flood Action Plans.

In the absence of a simple solution, a series of measures has been identified which need to be tied together in a coordinated plan. This is done in Chapter 10, where a "blueprint" or prototype system is proposed for Keswick Creek. It is likely that the plan for Keswick Creek in Adelaide will not totally fit the needs of other places, such as Wollongong in New South Wales, nor will it copy the procedures adopted for Fort Collins in Colorado, USA. Each situation is unique and requires its own particular combination of measures. However there is common ground, and out of the blueprint there will be lessons, guidelines and directions which should be usefully applied to other flash flood situations.

Changing the perception is an essential step in obtaining a solution. The following are popular misconceptions:

☐ floods are "Acts of God"; phenomena which are inflicted on human communities from time to time, and from which we just have to recover; and/or

☐ "The government's job is to fix problems like these, we should not be exposed to such disasters."

In South Australia, with relatively infrequent floods, the perceptions above are common and lead, periodically, to a large amount of unnecessary flood damage and personal stress.[1] In both cases above the attitude is one of denial of any sort of responsibility or involvement in the problem. The same would not generally be true of fire risk. Even though individuals may not do more than is absolutely necessary to minimise fire risk, it is generally accepted that fire is a particular hazard for South Australians; there are regulations which specify the necessary fire prevention measures, and it is reasonable to commit resources towards minimising the risk of fire. Similarly, in New Zealand structural standards for earthquake loading have reduced the risk of earthquake damage significantly. Following the 1974 Cyclone Tracey in Darwin, building regulations were introduced which ensure that in the future cyclone damage will be minimal. This has been extremely effective in reducing damage.

The alternative view for floods is to accept that, for some people, their lives and livelihood will from time to time be affected by flash flood and that they must maintain an awareness of that risk. This may require that they make some changes to the way in which they run their lives and manage their resources, because the next flood could happen any day. By managing the

---

[1] Local councils design and construct stormwater systems. There are design standards for these, often AEP 1 in 5, or 1 in 10. However, there is a difference between the design of drainage to remove stormwater, and a flood hazard mitigation program for major floods.

risk and being ready, they will prevent it from threatening their lives and destroying their property.

For businesses in Keswick Creek floodplain, the risk is significant. A flood which, for example, destroys the fast food manufacturing company in Mile End, may not deprive South Australians of their pies because other companies in the state and interstate will take over the production. But the financial loss to the company could be enormous and, for a person working in the Mile End factory which is destroyed by flooding, his/her life may be severely disrupted. It will be no use, on the day after the flood, to say "If only I had done (such and such) ... the damage done by the flood could have been avoided!" After the Fort Collins flood, response agents and local residents identified many things that could have been done better and which might have saved lives. However, the flood event was extremely severe, stated by Grimm in "Floodplain Management", to be greater than an AEP 1 in 500 (Grimm, 1998, p. 64). The implication is that, although it may not be possible to prevent floods, there are sensible measures which can be taken and a proportion of damage from floods that can be avoided.

Flood Risk AEP Years	**Chance of Occurrence**		**Planning Objective**
5	100.0%	Definite	Minimise flood damage exposure asap.
20	92.3%	Definite	Minimise flood damage exposure asap.
50	63.6%	Probable	Plan to minimise exposure within (say 5 years)
100	39.5%	Probable	Plan to minimise exposure within (say 5 years)
1000	4.9%	Possible	Reduce exposure appropriate to risk, support flood warning syst
PMF	0.005%	Unlikely	Distribute risk by flood insurance, support flood warning systems
Note: Assumed life of business 50 Years			

Table 9.1 Planning objectives for flood risk level versus time of occupation of the floodplain

By accepting the flood risk and taking preventive action at once, without waiting for the day of the storm, flood damage can be avoided, the business can continue without undue disruption, and the stress to which the staff are subjected can be kept to a minimum.

If it is accepted that urban flash flood potential should be treated as a risk management problem, the way in which the risk is managed should depend on the seriousness of the risk. Table 9.1 considers a range of risk levels for a business that expects to be at its location in the floodplain for 50 years, ranging from flood of AEP 1 in 5 years to the Probable Maximum Flood. In respect of planning objectives for flood risk minimisation, Table 9.1 indicates that sensible approaches appropriate to the risk can be made to flood loss exposure minimisation. If a business is located in the AEP 1 in 5 floodplain, then the need to take appropriate action is much greater than in an AEP 1 in 50 or AEP 1 in 1000 risk location. The choice of appropriate action and who should be responsible for it is discussed later.

In searching for solutions to urban flash flooding, it needs to be recognised that conditions and standards are changing all the time:

- According to Smith in "Greenhouse Climatic Change and Flood Damages: The Implications" (Smith, 1993) global climate change is a threat, the effects of which are difficult to determine, but which are generally expected to create greater extremes of weather phenomena, and could lead to greater intensity rainfall over our cities;

- There is continually increasing pressure on land for development; in Adelaide the confining of creek systems to concrete channels and pipes, and the building of houses and factories over the creeks, are examples which are common to most cities and which, in most cases, result in rapid concentration of stormwater, reductions in storage and increased flood loss exposure;

- The discharge of stormwater from the roofs of buildings, directly into the street, has become common practice. This has the effect of minimising storage of stormwater on site, increases the volume of runoff, and speeds up the concentration of flow in the creeks;

- Subdivision of housing blocks, and building a second house on the block increases the area of roof, paving and bitumen, and decreases the area of lawn and garden. The net result is an increase in runoff;

- Changes in the way that Australia undertakes its business are resulting in higher levels of flood exposure. Earlier generations of Australians relied heavily on primary production and the export of minerals. Engineering and manufacturing processes were based around heavy industry, smelting, mining, railways, road construction. In today's world the emphasis is on "The Clever Country", relying on high levels of technology, electronics, automatic processes, high value products, and with increasing use of computers. It is believed that warehouses and factories, formerly containing heavy engineering equipment, now house high value flood prone equipment and facilities, with a large increase in vulnerability to flood damage; and

- An increased awareness of the detrimental effects which urban development has had on the environment has led to stricter controls on the collection and disposal of stormwater. The use of trapezoidal concrete channels to dispose of stormwater, universally accepted in the past, is now open to question. The construction of dams to store and or hold stormwater is no longer accepted by the community as an obvious public benefit, and environmental issues must be considered at length before construction can go ahead. The emphasis on environmentally sustainable solutions can lead to compromises in standards of flood protection. A "natural" channel may be desirable in an urban situation for aesthetic reasons, but it may not have the same capacity as a less desirable concrete channel. Hence flood risk needs to be balanced against other factors and the residual risk determined and, in general, opportunities for mitigation of flood risk by structural measures are becoming very limited.

9.2 Finding Solutions to Flash Flood Risk

While preparations for flood events can take place months or years in advance of an actual flood event, it is common experience that only when a flood is actually on its way does concern about avoiding damage and loss of life become critical. In Australia, some outback flooding takes weeks to develop and in the case of the Charleville and Nyngan floods of 1990 several days elapsed between the main storm event and the subsequent flood. In South Australia, the River Murray can take several months to flood, and even the main rivers which can cause flood damage to Greater Metropolitan Adelaide, the Gawler, Torrens and Onkaparinga, take 12 to 18 hours to affect the urban areas. In these circumstances, even fairly rudimentary warning processes can be set up, and the people in the path of floods given reasonable notice of the impending event and what to do about it. Such is not the case for urban flash floods, where there could be less than an hour between the storm and the subsequent flood. If there is to be effective action to minimise flood damage, a full mitigation strategy must be in place beforehand, so that all that is left to do when the flood arrives is to carry out on-the-spot defences at predefined locations. At Fort Collins, the city council had completed a major flood mitigation program and had developed a Flood Action Plan. On the day of the flood the emergency services knew which were the critical road intersections, and that the caravan park should be carefully watched. For urban flash flooding, such as the Woronora example, where a flood takes up to 6 hours to develop, there is a chance that alarms based on rainfall will allow rapid response and damage mitigation but, again, it is necessary to undertake careful preparations and training so that people on the spot know what is required of them.

This requires a combination of:

☐ *Long term planning*: A floodplain management program, combining the resources of the community, providing education about flood risk, support from all levels of government, resources to undertake improvements, and generally trying to respond to flood risk before, rather than after, the disaster; and

☐ *Short term response plans*: Being ready for the flood, having people aware of what is required during the event and capable of quick and efficient response. Weather and flood forecast information is important, but it must be realised that storms producing flash floods can occur quickly and unpredictably, and there is no certainty that a flood forecast can be provided.

9.3 Approaches Taken to Solving Flash Flood Problems

☐ Wollongong has suffered severe flooding, most recently in August 1998. Damage was caused by overland flow and flooding from the creeks. A flash flood warning system has been proposed ISMES Consultants in "Sydney-Newcastle-Wollongong, Flash Flood Warning System" (ISMES, 1992), but not implemented. Much public comment and interest has centred on the insurance cover and whether claims will be paid. However, there appears to be little prospect of reducing flood risk, either through planning, mitigation, or a public awareness program, nor at the current state of development of the flash flood warning system. If a flood occurred there tomorrow, would the consequences be much different from the August 1998 flood, or could they in fact be worse?

☐ Coffs Harbour experienced severe flash flooding in November 1996, with widespread damages, as reported by Webb in "Coffs Creek Flood Mitigation" (Webb, 1997). In this case, flood mitigation works, a combination of diversion channels and detention dams, had been constructed to the estimated AEP 1 in 100 standard. The flood exceeded the capacity and damage was caused to 380 houses. No mention is made of damages to business properties, although pictures indicate that there were significant losses. A risk management approach which includes consideration of the effects of rarer floods and plans for response, might lead to a better protected community.

☐ Fort Collins experienced severe flooding in July 1997. The flood was far more severe than the AEP 1 in 100 flood, but a mitigation program starting in the 1980s had resulted in high risk facilities being removed from the floodplain.[2] Damage was severe, but could have been far worse. Installation of an ALERT rainfall monitoring and alarm system could have provided earlier warning of the flood, and it is understood that this is being planned.

☐ The vulnerability of the business and residential community in the Keswick Creek

---

[2] Grimm, in his article "Floodplain Management", notes that "In 1995, Fort Collins revised its code to include regulations prohibiting critical facilities inside the AEP 1 in 500 floodplain. One result of these regulations was the relocation -just months before the flood of July 28 - of a retirement home that had been acquired by the city" (Grimm, 1998, p. 64).

floodplain has been discussed in detail. Flooding has not occurred in recent years but there is no reason to consider that the risk of flooding has diminished. There are opportunities to reduce the risk of damage and loss of life by following the example of the city of Fort Collins.

9.4 Extending the Flash Flood Warning Process

Flood warning is generally understood to be a process of warning people that they are about to be flooded. For flash flooding, this requires that the process has to be done very quickly, generally in less than 6 hours, and in some cases much less time is available. In considering the time between the storm and the flood, the warning process includes:

- ☐ detection of the storm;
- ☐ recording the rainfall;
- ☐ generating a forecast;
- ☐ preparing a warning; and
- ☐ transmitting it to people who then have to respond to it, in sufficient time for the response to be effective.

ALERT systems have been discussed in Section 1.4, and are often referred to as “flood warning systems”, however this can lead to overlooking some basic limitations. An ALERT system is a means of automatically recording rainfall and transmitting the information instantaneously to a central point where assessment can be done with the objective of determining when a flash flood is imminent and issuing a warning. The computer software system that runs ALERT can be programmed to determine whether preset rainfall thresholds have been exceeded and can issue alarms.

The quote by Gruntfest in Chapter 1 that “ALERT tells 2 or 3 people that in half an hour a lot of people are going to die!” implies that an ALERT system may be suitable for alerting duty staff, but not necessarily to provide a warning service to the general community (Gruntfest, personal communication, May1998a). The problem faced by duty staff in charge of ALERT, is that on one hand there is an expectation that the system is capable of executing a general warning of flooding but, on the other, is the realisation that the information collected and alarms which have been actuated, alert only a handful of people, and the problem of notifying the general community remains.

There is a further disadvantage that, in a flash flood situation, by the time the alarms have sounded, there is very little time left to carry out the rest of the process. Figure 9.1 shows the processes, in five steps, which must to take place for a successful warning. There must be time for step 5 to be completed before the flood. Step 4, the warning distribution process, must reach all of those who are required to respond. It must, therefore, be both quick and direct. Steps 1 to 3, each in turn, will have a finite time to be carried out.

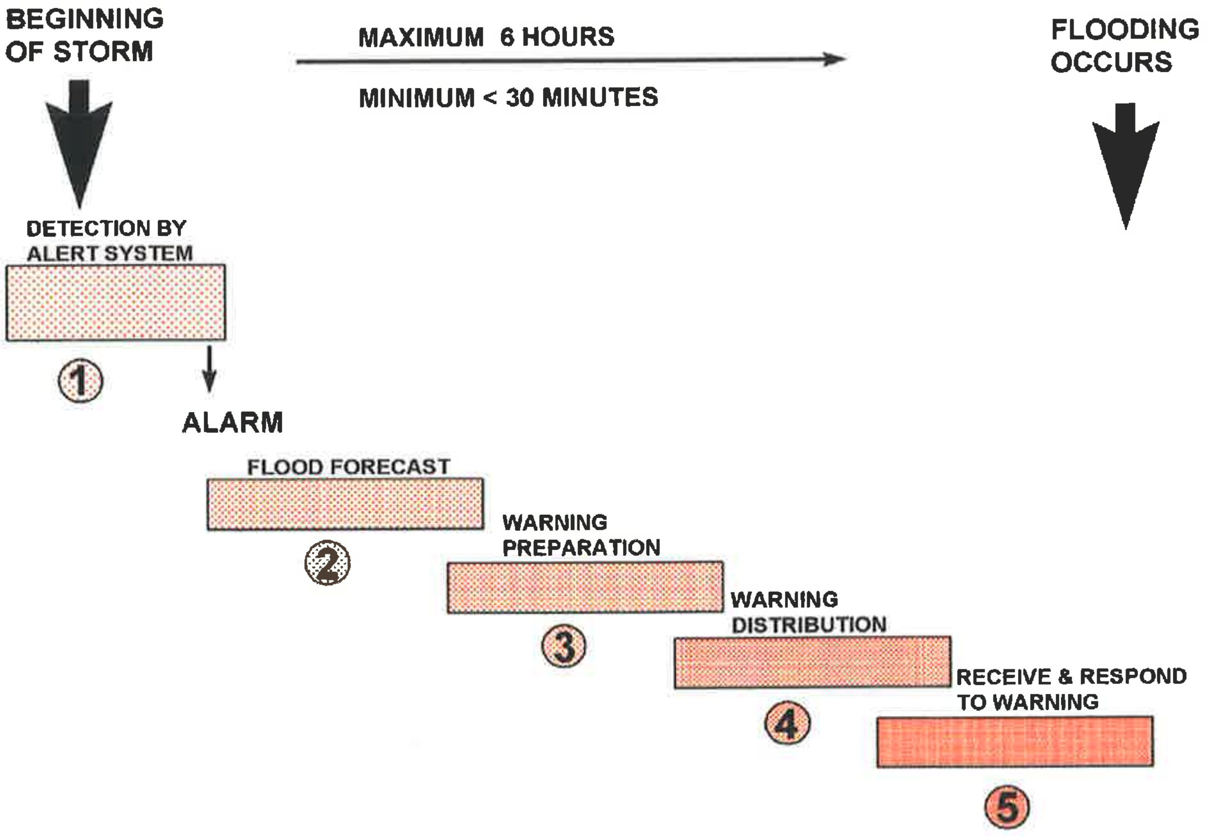


Figure 9.1 Processes required for a successful flood warning

Any particular flash flood catchment will have its own characteristic response time between storm and flood. Therefore, for each case the time available for the 5 steps can be calculated. What happens if the time available is less than the time taken for each of the steps? Table 9.2 gives typical times for each step and compares the total with actual time to flood on Keswick Creek.

Step	Description	Time Minutes
1	Detection of storm by ALERT system	45
2	Flood Forecast	15
3	Warning Preparation	10
4	Warning Distribution	10
5	Receive and respond to warning	15 to 60
	Total:	95 to 140
	Time for flood in Keswick Creek to reach critical level	60 to 180

Table 9.2 Estimated times for flood warning steps for a flood on Keswick Creek, compared with time taken for a flash flood to develop.

It is assumed that duty staff are available at their desks in the BOM. If they are not, the warning time will be much longer. The time suggested for warning distribution assumes use of a message distribution system such PC COPS or equivalent, described in Chapter 8. This is not available at present. If a flood warning system is to be effective for Keswick Creek, it will need to be very carefully planned and the installation of PC COPS, or similar, for warning distribution is essential. The current manual system by phone call is only capable of warning approximately 12 people, assuming that they are available and respond to the phone calls. There is a wide range between the maximum and minimum times to respond, from 15 to 60 minutes, because management staff may not be on hand at the business, and may be required to drive to work from wherever they are, possibly contending with flooded road conditions. Experience suggests that 95 minutes is not an unreasonable estimate, by which time, under ideal conditions, a warning for flash flooding could be received and acted upon, however it could take 140 minutes or longer.

In general, where ALERT systems have been installed in catchments subject to quick response flash flooding, there will be situations where it is doubtful whether there is time for all steps to be completed. The comment by Gruntfest expresses this situation; there is only time to get part-way through the process, when the flood actually arrives, and the unfortunate duty flood hydrologist is left with the knowledge that a flood is occurring but without the ability to give the information to those in its path in time to protect themselves. Possible remedies for this situation are discussed in the next section.

There is no doubt that flash flooding can be extremely damaging and very difficult indeed to protect against. There is a tendency, following a severe flood event, for authorities to purchase an ALERT (or equivalent), "flood warning" system as a means of demonstrating a commitment to solving the problem. There is a temptation to adopt the technology and spend the money, without undertaking all of the other steps necessary to achieve mitigation of flood damage and minimisation of risk to human life. It is easier to say "We have bought an ALERT system, which will provide flood warnings for this community", than it is to go through the more difficult processes of community education, planning, mitigation and preparation. If the funds are available, ALERT systems are quick and easy to set up, but it is vital that it is not forgotten that installing ALERT is only one of a number of steps necessary for flood warning and that, without the other steps, it may be of little value. ALERT should not be a "scapegoat" solution which allows the community to avoid taking basic self-help action.

9.5 Searching for Solutions

The starting point in deciding what to do about a business and residential community located in a floodplain is to define the flood risk for a range of flood risk levels by carrying out hydrological studies, and preparing flood inundation maps. The technology for producing floodplain maps has improved enormously in recent years, and it is now possible to define, not only the areal extent of flooding, but also the velocity and depth of flood water at any point.

Accurate flood maps are of great value for:

- planners at state and local government level for zoning of flood prone areas for activities suited to flood risk. This may still be possible in some situations but, more often, development has already taken place. Zoning may still be a useful means of encouraging low flood risk activities as and when sites come up for redevelopment;

- advising occupants of the floodplain and future developers about the risk level for each location, to enable them to take decisions appropriate to the risk, knowing the potential depth of flooding which can occur for each risk level, and the possible velocity of flood water;

- BOM staff with responsibility for flood warning. The flood maps are the key to forecasting the extent of flooding, for relating forecast flows to the areas likely to be inundated;

- response agencies. The maps enable disaster response plans to be made, knowing;

    - which areas are at risk of flood;
    - which are safe;
    - location of vulnerable communities;
    - location of high risk property;
    - suitable evacuation routes;
    - safe locations for evacuation centres; and
    - possible road closure locations.

    During a flood event, the response agencies should be able to use the mapping, together with information from the BOM, to determine which parts of the floodplain this particular flood is threatening; and

- the general public and business managers, to understand flood risk as it affects them and their property.

The problem is to determine an appropriate solution for each floodplain, case-by-case, to determine what is required, and the most appropriate action to mitigate the risk. This is a continuous process, with changes taking place in the catchment affecting risk assessment. Both short and long-term assessment and planning measures are important, and the scale of mitigation needs to cover both catchment wide measures, such as the introduction of household rainwater tanks, the diversion of roof stormwater onto lawns, with measures for individual house and factory protection. Also, contingencies need to be made for failure of one or more mitigation measures; what can be done to overcome these and replace them with other measures?

In an environmentally conscious society many of the structural measures for flood mitigation are no longer in favour, since they often involve civil engineering construction at high cost, and, in any case, urban development may preclude such solution. Protection of individual buildings may be achieved by demolition or by transporting them away from flood prone locations, rather than trying to divert the flood waters. In most, if not all, cases, flood risk management for a flash flood catchment will be best achieved by a combination of measures, both structural and non-structural. The solution may combine some, or all, of the following options, and there may be others:

❑ Reduce the risk by relocating away from high flood risk areas. Wherever possible, remove the risk by either diverting the flood or, preferably, relocating the vulnerable property. It is probable that total flood prevention for all levels of risk cannot be achieved. There may well be structural mitigation works that will reduce flood risk for specific facilities or particular parts of the catchment such as widening or enlarging bridges and culverts. The effects of any such work need to be considered, not only for the facility which is being protected, but also for other parts of the floodplain to which the problem may be transferred. For instance, bridges and culverts are often the cause of backwater effects and upstream flooding, however, by removing these structures, flood storage is lost and the flood wave will pass down the catchment more quickly which could, in turn, increase the risk of flooding downstream. In situations where buildings are at high risk (AEP 1 in 5, for instance) the best option may be to offer to purchase the property for demolition. In the USA whole suburbs have been relocated to low risk areas. Subject to full financial analysis, this may be preferable to risk mitigation by other ways, or to reliance on flood warning to minimise flood damage. There are no firm guidelines as to the appropriate risk level for relocation. However, where dwellings or vulnerable buildings and structures with high flood loss exposure are within the AEP 1 in 20 flood risk area, consideration should be given to relocation or elevation. The capital cost of doing this will be high but if it is seen as a long term planning objective, arrangements can be programmed into local/state government finances for gradual buy-back. This has been done in Tulsa, Oklahoma, USA, albeit helped by a powerful federal government finance program (FEMA).

❑ In flood risk areas, say from AEP 1 in 20 to AEP 1 in 100, where structural works are not cost effective, planning measures could be introduced so that any new buildings or developments incorporate the risk of flooding in the design. This would result in elevation of building floor levels and locating services away from flood risk areas. For example, the Westpac banking facility on the banks of the River Torrens was designed with car parking areas on the lower levels. The computer facility was deliberately located on the first floor, and high risk facilities were kept above ground floor level. At the early planning and design stages, these measures cost relatively little, in marked contrast to retrofitting if flood risk mitigation was attempted after the building was complete. The RAA service depot on Richmond Road, Mile End is another good example of the benefits of considering flood risk at the planning stage. The cost of designing to minimise flood risk need not be excessive, if it is planned at an early stage. This form of self protection, by planning for flood risk minimisation, can provide cost benefits provided that accurate information on flood velocity and depths can be supplied. Local council planning approval procedures could assist in this, possibly by ensuring that flood risk information appears on the title deeds of each property in the floodplain. It is also important that tenants of buildings in the floodplain are aware of flood risk.

☐ For bigger than AEP 1 in 100 floods, perhaps flood warning is the only option available. However, if the flood mitigation and risk reduction measures are in place, the residual risk should be relatively low. It is probable that the capability of the BOM to detect severe storms and issue flash flood warnings will improve in the future, with technological improvements and faster communications, allowing longer lead time for warning.

9.6 Conclusions

Chapter 9 has discussed the general nature of flash flood risk, and changes that are taking place that could exacerbate the problem. The restricted time available for warning is a major problem, and an example is given of the time taken for each of the elements of a flood warning. Some examples of flood events have been mentioned. The need to combine long and short term risk mitigation measures, in attempting to solve flash flood risk problems has been discussed. There is a need for a coordinated approach to flood risk reduction, integrating a range of measures. The process of finding the best solution must involve all people and agencies with interests in the floodplain, including local and state government, response organisations, and particularly those who live and work in flood risk areas. The relative importance of Economic versus Financial costs needs to be determined, such as transfer payments when flood damage causes industrial production to be relocated interstate. It will be necessary for a lead agency or group to take the initiative to start the flood risk mitigation process. Resources for undertaking the program need to be determined and secured. In Chapter 10, a flood risk management and mitigation program is outlined, using Keswick Creek as the example, and integrating all elements of planning, forecasting, warning and response, in a time-frame which starts years ahead of, and continues to the day and hour of the next flood.

10. A FLASH FLOOD LOSS MITIGATION PROGRAM FOR KESWICK CREEK

Management of flash flood risk is the subject of Chapter 10, which takes the Keswick Creek floodplain as the example, and sets out a program integrating all of the elements to achieve risk minimisation. There is a portfolio of tools available for managing the risk. These include:

- ☐ rainfall measurement and analysis;
- ☐ hydrological studies;
- ☐ floodplain mapping;
- ☐ planning measures to minimise flood risk;
- ☐ flood forecasting processes;
- ☐ warning system design and implementation;
- ☐ flood mitigation by engineering works;
- ☐ flood risk reduction by individual business;
- ☐ Flood Action Plan preparation; and
- ☐ response to floods on the day.

The recently published *Floodplain Management in Australia - Best Practice Principles and Guidelines* (SCARM, 2000), provides guidance for flood risk management and is incorporated in the plan which follows. Chapter 9 provided an outline plan for combining all the elements. Chapter 10 puts them together

10.1 A Matrix Approach to Integrated Floodplain Management

The concept of a matrix planning approach to flash flood damage mitigation was introduced in Chapter 1, as an alternative to reliance on flood warning. This is given in detail on Figure 10.1. Flood risk management should not be a linear process, but should incorporate the interaction and interdependence of a range of actions and processes for efficient flood loss exposure reduction. The three red arrows on Figure 10.1 represent:

- ☐ Flood Warning and Response;
- ☐ Technical Hydrological Processes; and
- ☐ Planning/Mitigation.

These indicate three main ways in which flood losses can be minimised and are described in detail below. It is in the combination of the main processes that the solution lies. The circles increasing in density towards the flood, indicate the vital component of Time, starting years ahead of any flood, with planning and education processes, through a variety of preparatory steps down to the day and hour of the actual flood. By combining the benefits which can be achieved from each of the processes, it will be possible to minimise the risk and flood loss exposure. The overall objective is to build the matrix, and undertake all of the steps before the flood arrives. The objective should be to mitigate risk before the community has been devastated, rather than rely on recovery after it.

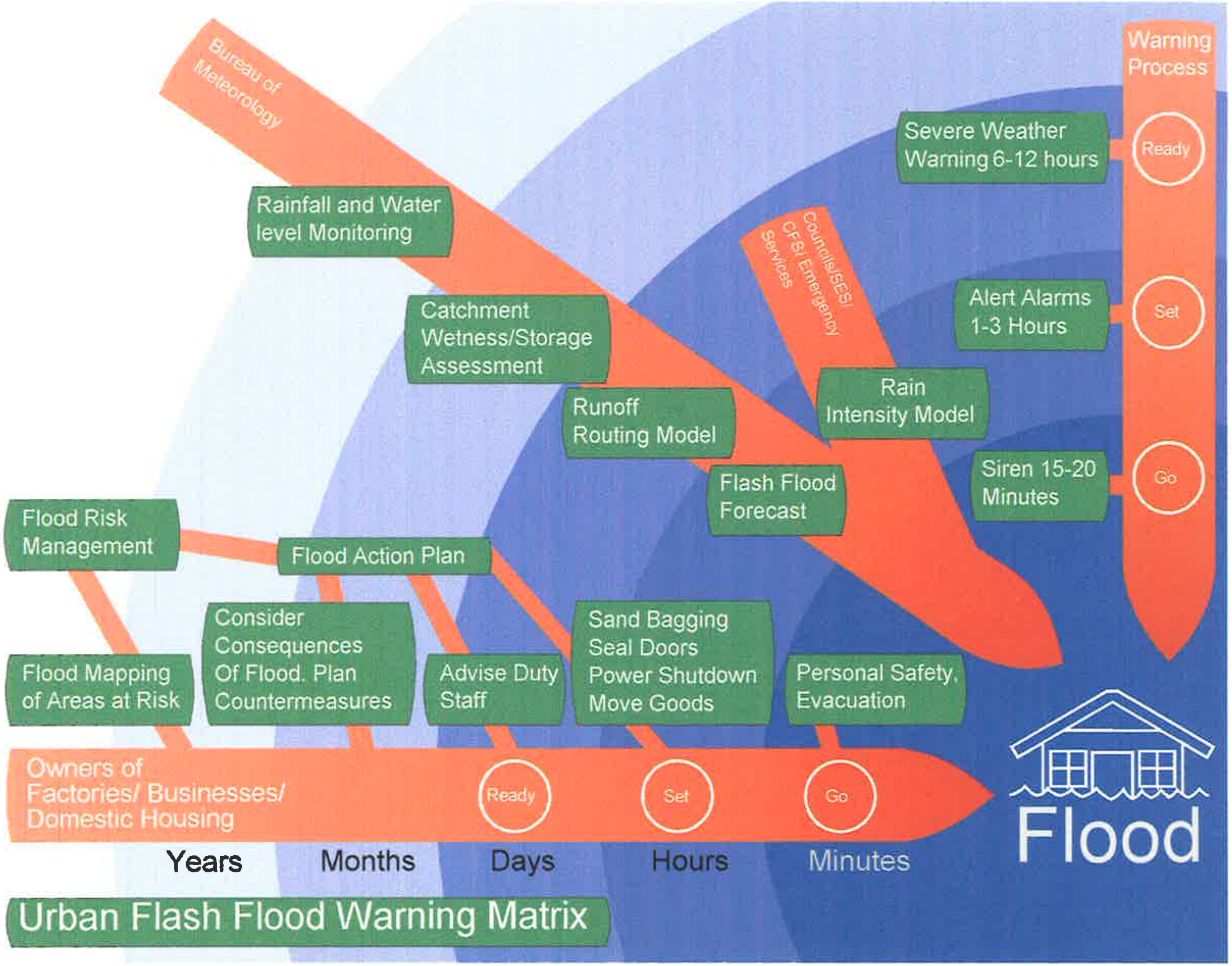


Figure 10.1 Urban Flash Flood Risk Management Matrix

10.1.1 The Horizontal Arrow

The processes shown here are based around flood risk awareness, with an emphasis on managing the risk. The impact of these processes should be strongest on those businesses and residences at the highest risk, and with the greatest flood damage exposure. Understanding the risk is the first step, based on information from flood maps. The way that risk is managed will vary from person to person and from business to business, but will access a range of possible flood risk management options. The aim is that, years before a flood, those within the flood risk zones will have considered the consequences of flood water through their business or house. This should lead to sensible planning decisions and to action which will ensure that in the event of a major flood, their business will survive, with flood damage kept to a minimum. Actions to be taken include:

☐ introduce basic flood mitigation planning;
☐ carry out risk minimisation work;
☐ develop and maintain Flood Action Plans; and
☐ introduce staff training and education.

During the last hours and minutes, when flooding is imminent, all that should remain to do is to ensure personal safety and put in place any final measures to protect equipment or materials.

For domestic housing, the objective would be to ensure that children and pets are kept safe, that family valuables and documents are saved, and that general damage to the house and household articles is minimised.

10.1.2 The Diagonal Arrow

This arrow covers the meteorology and forecasting components of flash flooding, and includes all technical hydrology and weather forecast components. It includes:

☐ routine monitoring procedures;
☐ severe storm forecasts;
☐ Quantitative Precipitation Forecasts;
☐ triggering of alarms, IFDchecks, running of runoff routing models; and
☐ flash flood forecasting.

Development of skills and techniques for improving flood watches and forecasts is envisaged, as a result of improvements in technology, and improved monitoring tools such as global atmospheric models, satellite imagery analysis, radar scanning and interpretation software. The interaction with local councils and emergency services is shown on the figure to stress the need for these agencies to be kept fully informed about the flood watch and forecast processes, and their involvement encouraged where appropriate.

10.1.3 The Vertical Arrow

This is the actual flood warning process. Once again, it begins with long-term planning, which would include development of warning messages that are generated automatically. Dissemination procedures are vital to effective warning, and the use of rapid computerised telecommunications for automatic distribution will be required. Figure 10.1 is intended to suggest that successful warnings must be properly planned and the processes set in place long before they are used for a flash flood.

Conventional flood warning systems for non-flash flooding tend to rely primarily on the vertical arrow, a linear warning process, on the basis that the other procedures can be completed within the time available, when the flood is on its way, but not yet arrived. For flash flooding this is not possible, hence the need to adopt the matrix approach.

The message which Figure 10.1 is intended to illustrate is that for successful flash flood risk mitigation warning the following issues are critical:

☐ effective minimisation of flood damage potential requires a coordinated approach, including planning, self protection, technical hydrology, communication and response; and

☐ the processes are time dependent, and planning should start at once.

In the following section, the processes described in the matrix are developed into a blueprint for Keswick Creek.

10.2 Keswick Creek Urban Flood Damage Mitigation Program (KURMIT)

A "blueprint" flood damage mitigation plan for Keswick Creek will focus on the risk of urban flash flooding in this catchment, and on ways of minimising the risk by an integrated approach. Subject to modification when new flood maps with better definition become available in mid-2001, the blueprint could, if it is adopted, become a basis for future management of urban flood risk.

Although the plan has been prepared specifically for Keswick Creek, the general approach to urban flash flooding should be a base upon which other urban areas subject to the risk of flash flooding could develop flood risk management procedures.

10.3 Appropriate Strategies for Keswick Creek Catchment

Keswick Creek floodplain mapping shows the areas which have the highest risk of flooding, but there is a natural division in flood risk between the upper and lower parts of the catchment, with the boundary at Goodwood Road.

10.3.1 Upper Catchment Strategy

The upper catchment, from the Mt Lofty Ranges to Goodwood Road, is mostly suburban housing, with some retail outlets and a few commercial/industrial businesses. It responds very quickly to heavy rainfall, estimated to be as little as 15 minutes from storm to flood peak at some locations. The threat of damage is most commonly due to shallow, fast-moving water. Floods would not generally last for long, and would subside within 30 minutes or so. With existing technology there is no time to warn people living in these areas, the storms cannot be pinpointed with sufficient accuracy and the subsequent flooding is so quick that there is no time for forecasting and warning. Structural mitigation works in the upper part of the catchment (Windsor Street, Unley), will give greater channel capacity and lower risk of flooding. Unfortunately, this will have the effect of transferring the flood risk further downstream. An alternative approach would be to provide more upstream storage on gardens, median strips and small wetlands, to hold the water in the catchment for longer, reducing the speed of concentration of flood water in the high risk areas of the floodplain.

There are several properties along Parklands Creek, including a large block of flats at Knox Court (King William Road, Unley),which are very vulnerable. A retention dam in the South Parklands would reduce the risk of flooding to these structures. Some critically flood-prone properties close to the creek near Goodwood Road should be purchased by government and demolished, since it is too difficult and costly to provide them with protection. Existing skills in meteorology and hydrology are not able to provide sufficient advance warning of a flood for this part of the catchment.

10.3.2 Lower Catchment Strategy

From Goodwood Road to the west, the situation is somewhat different. The Goodwood Road tunnel which passes under the Wayville Showgrounds, acts as a bottleneck, restricting the rate of flow in the channel to about 25 m^3/s. This compares with the alarm 1 in 100 flood which is nearly 35 m^3/s. Once the tunnel entrance becomes surcharged, water will back up, flow across Goodwood Road into the Showgrounds, and possibly down Leader Street. Subject to more detailed hydraulic calculations to be undertaken by consultants, it is probable that this backing-up process will delay the progress of the flood wave down the catchment to the west, providing vital additional response time. This will be valuable, because the flood loss exposure from Goodwood Road to the west is very large. At the present, there are restrictions in the channel downstream of the tunnel which limit the flow to about 18 m^3/s. It is probable that structural works are feasible to increase the channel capacity to 25 m^3/s, allowing the full flow from the Showgrounds to be retained within the channel. For greater flows, it is unlikely that any options for structural mitigation will be identified. Therefore, businesses and residences in the floodplain will be at risk of flooding and need to prepare themselves accordingly. There is a better chance of success for a flood warning system in this lower part of the catchment, with more time to monitor, forecast and issue warnings. Nevertheless, the additional time will aid the process only if proper pre-flood planning and preparation has been carried out. Development of a flood warning system could provide significant benefits for this part of the catchment.

10.4 KURMIT— Development of the Blueprint

The acronym KURMIT is proposed for a project to minimise flood risk in Keswick Creek floodplain based on the Urban Flash Flood Warning Matrix shown on Figure 10.1. The project would be established specifically for this floodplain with the purpose of minimising flood risk. A major challenge will be to overcome a state of paralysis among the agencies which should be directing a flood risk minimisation process. The objective is to establish a coordinated plan involving cooperative, mutually supporting activities. Successful implementation of the plan should result in major reductions to flood damage potential. The concept of the three arrows, described in the matrix, is developed into specific responsibilities and actions for each agency and occupier of the floodplain.

10.5 Application of the Matrix Process for Keswick Creek

Figure 10.2 shows the general allocation of tasks and responsibilities based on the matrix approach. The intention is to show that the process of protecting the activities within the floodplain requires the integration of a wide range of activities and agencies into one plan. Conversely, it is believed that the flood mitigation process cannot be achieved by a single agency working in isolation, and that effective mitigation cannot be achieved by a simple warning system activated on the day of the flood. Appropriate roles and responsibilities have been shown for each of the lead agencies, which are:

- ☐ local councils;
- ☐ Patawalonga Catchment Water Management Board;
- ☐ South Australian Government;
- ☐ emergency services (Police, SES, CFS); and
- ☐ Bureau of Meteorology.

Colour codes have been shown for clarity and maintained through the series of figures which follow. The reason for presenting the roles and activities in this way is to emphasise the need for involvement and cooperation at all levels if the risk of flood damage is to be kept to a minimum. Flood warning may be a critical part of any flood damage minimisation process, particularly in avoiding possible loss of life during a flood but, for flood warning to be effective, the other components shown in the Figure 10.1 must also be present and in good order. The following sections consider the roles and activities of each of the agencies involved in flood damage mitigation in the floodplain. The roles of each agency are generally in accordance with the *Floodplain Management in Australia - Best Practice Principles and Guidelines* (SCARM, 2000, pp. 24-28), mentioned in section 10.1. They are considered specifically for Keswick Creek, but the model which has been developed will be applicable to other urban flood situations, with modifications according to needs.

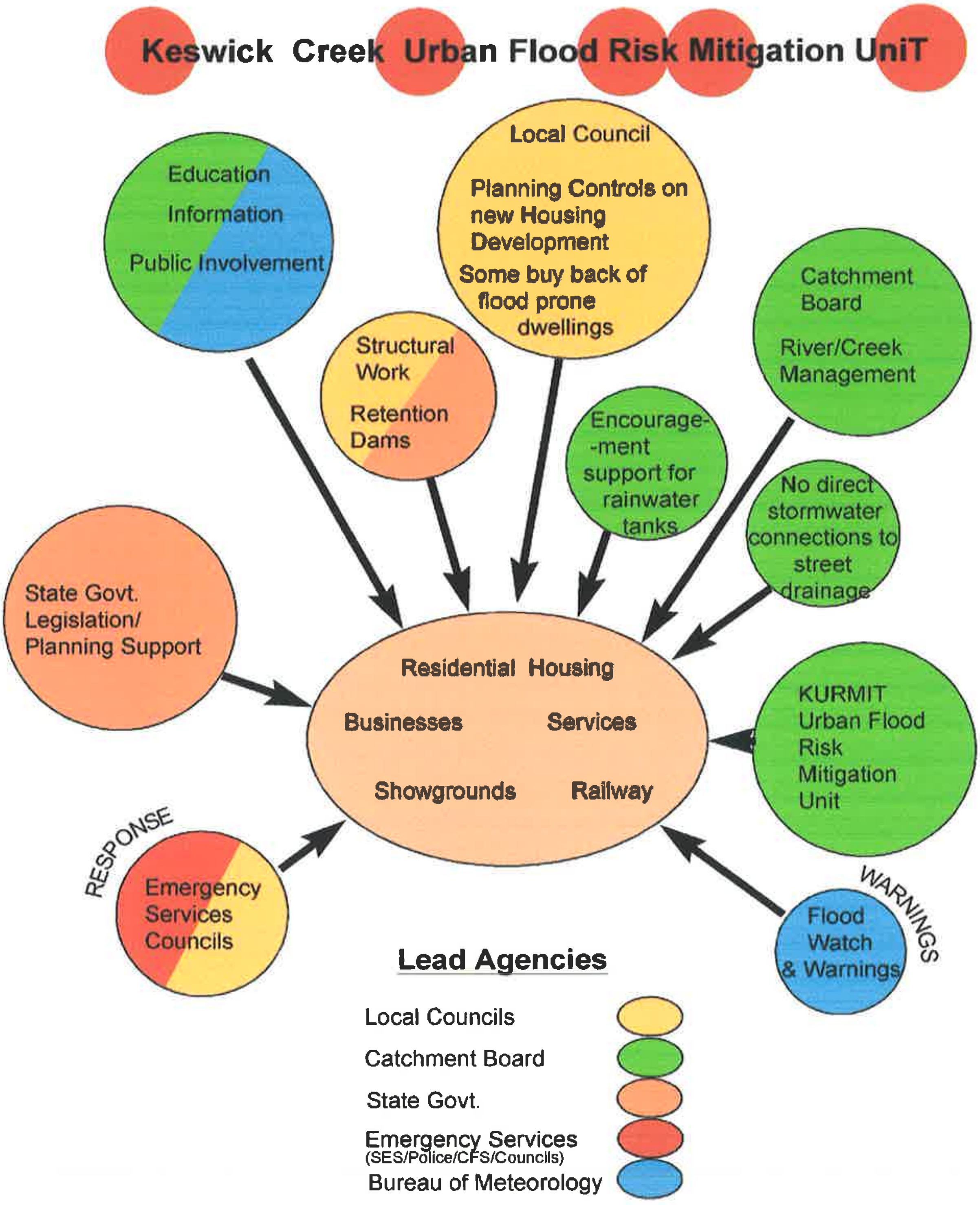


Figure 10.2 KURMIT flood risk management program, showing contributing agencies and their functions.

On the right hand side of Figure 10.2 is reference to the KURMIT Urban Flood Mitigation Unit. This consists of a two-person unit, with the key role of establishing the matrix approach and carrying out the planning and coordination of agency activities which will ensure that the flood damage mitigation process is effective, and continuous. The terms of reference for this unit are proposed in Section 10.6.3. Essential responsibilities of the agencies on Figure 10.2 are as follows.

10.5.1 State Government

The State Government (see Figure 10.3) needs to provide:

- ☐ a legislative framework to support floodplain management activities.;
- ☐ assistance in securing funding from Commonwealth Government;
- ☐ technical backup and support for planning processes; and
- ☐ engineering and management support for undertaking structural mitigation works, where appropriate.

Under current State Government legislation, the responsibility for protecting the community against flood damage is unclear. It is believed that the Water Resources Act (1997) does not make adequate provision for floodplain management.[1] Perhaps because of this lack of clarity, progress in development of effective risk management procedures has been limited to structural mitigation works and the undertaking of flood inundation mapping, partly funded under the Stormwater Management Subsidy Scheme. What is needed is legislation which adopts the principles in *Floodplain Management in Australia - Best Practice Principles and Guidelines*, which suggests the responsibilities and statutory powers required for flood damage minimisation (SCARM, 2000, p. 29).

Whether or not the legislative framework is provided, two specific actions could set in action the process of flood risk management. These are:

- ☐ that each land title which includes flood prone land, notes that flood risk exists and gives the estimated water level for, say, the AEP 1 in 100 flood; and

- ☐ for businesses within the floodplain, that each tenancy agreement, notes on the agreement that flood risk exists and, subject to the accuracy of the information available, provides expected water depths for the AEP 1 in 100 flood.

---

[1] There is a lack of floodplain management guidance in the Act, but this may be overcome to some extent. The State Water Plan, which was created under the Act, has provision for specific actions, which may include floodplain management planning. It remains to be seen whether the process will be effective under existing legislation.

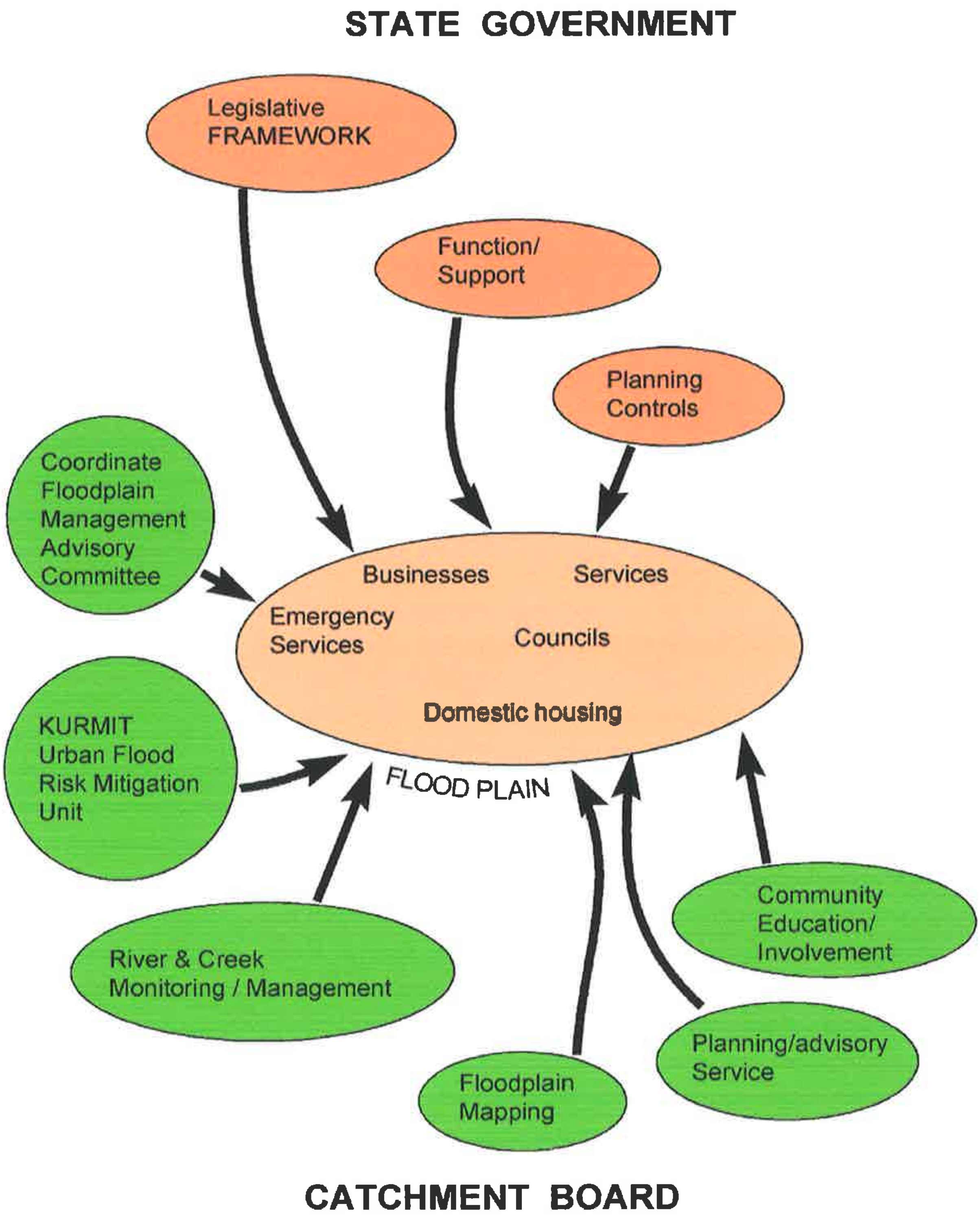


Figure 10.3 State Government and Catchment Board roles in flood risk minimisation.

It is acknowledged that in the absence of a major flood disaster and strong public support, there may not be the political will to introduce these measures. However, if these two steps were undertaken, the definition of flood risk would be apparent to any person or business taking up residence in a flood prone area. It is wrong that, under current procedures, a person or business, can purchase a property or enter into a binding lease without being made aware of a known risk that could cause that business to fail or a house to become badly damaged.

Within *Floodplain Management in Australia - Best Practice Principles and Guidelines*, there is provision for zoning of land within the floodplain to encourage appropriate development and activity, but this can only be achieved if there is a requirement within State Government legislation for the floodplain mapping to be formally adopted into each local council Development Plan (SCARM, 2000, pp. 19-21).

If the KURMIT project is to be successful in mitigating flood risk in the Keswick Creek floodplain, it will require a secure funding base. The State Government should have a key role in establishing KURMIT and deciding how the costs of running it will be apportioned.

10.5.2 The Catchment Board

The Catchment Boards have already undertaken considerable improvements to river catchments, mainly in water quality management. Since their jurisdiction covers the whole catchment, rather than local council boundaries, the Catchment Boards are ideally placed to coordinate activities in the floodplain. However, under their terms of reference the Boards are not required to undertake floodplain management or risk mitigation activities, although they may choose to adopt these issues. It may be that the Catchment Boards could adopt these issues in a new role or on a wider scale, subject to funding arrangements. The Patawalonga Catchment Water Management Board, which covers Keswick Creek, in its coordination role, is supporting measures to determine and minimise the potential for flood damages. It is proposed that a KURMIT unit should be set up, under the administrative umbrella of the Catchment Board, to manage the flood risk mitigation activities. Key activities proposed for the Catchment Board are shown on Figure 10.3.

Apart from providing a base for KURMIT, the remaining functions allocated to the Catchment Board, are in accordance with their existing role, and include:

- ☐ river and creek monitoring and management;
- ☐ planning and advisory service to local councils, businesses and residents;
- ☐ community education and involvement, in respect of flood risk;
- ☐ coordination of the floodplain mapping program; and
- ☐ coordinate and provide leadership to the Floodplain Management Advisory

Committee foreshadowed in *Floodplain Management in Australia - Best Practice Principles and Guidelines* (SCARM, 2000).

10.5.3 Keswick Creek Urban Flood Risk Mitigation Unit (KURMIT)

The Unit would consist of two people, fully resourced,[2] and based at the Patawalonga Catchment Water Management Board office. The project, at least in the initial stages, would focus on the Keswick Creek catchment. As the project progresses, and subject to resources, the intention would be to extend the program, first to Brownhill Creek, and subsequently to priority areas on the River Torrens catchment.

10.5.3.1 Terms of Reference

☐ Provide information and advice on flood risk for properties and businesses in the catchment;

☐ Work with local councils to strengthen planning and advisory services for new projects and for redevelopments in the floodplain to achieve efficient flood risk management;

☐ Assist and encourage State Government agencies in the introduction of Flood Risk Management Guidelines and legislative tools for control of development in the floodplain;

☐ Run/coordinate a Flood Audit Program to assist businesses to determine flood risk to their premises, goods and services, how it can best be minimised, and how to develop a Flood Action Plan;

☐ Run/coordinate a Flood Awareness Program for owners of private housing and for businesses;

☐ Work with the Bureau of Meteorology (BOM) to develop and improve severe storm prediction and monitoring, with the objective of providing a flood watch and warning service;

☐ Work with the BOM and the State Emergency Service to introduce and develop an efficient flood watch and flood warning distribution service; and

---

[2] If the unit is based at the Catchment Board, funds would need to be provided for staff salaries, office accommodation, phone, computer, and transport. This is not part of core Catchment Board activities, and would need to be funded separately, possibly through a levy or through State and Commonwealth funding programs. Contribution by businesses and the insurance industry is also possible.

- Work with the State Emergency Service to create a package of self-help measures for flood protection and flood proofing of buildings and services.

10.5.3.2 Staffing

KURMIT Team Leader

The team would be lead by a person qualified in planning and management, preferably with skills in communications, hydrology, hydraulics, floodplain management, flood damages and flood risk mitigation. Duties for this position would include coordination of the program within the Terms of Reference, setting goals and budget, undertake and support all activities, and provide guidance to the team. The success of the project will depend on the development of good liaison between the KURMIT team and:

- representatives from state and local government at all level;
- the general public;
- owners of businesses; and
- authorities in transport and service agencies.

KURMIT Support Person

The second person in the team would have skills in public relations, education, communication and graphics, and would provide support in all program activities. Communication and public relations work are very important components of this position.

10.5.4 Bureau of Meteorology (BOM)

The BOM, through its Hydrology Section and the Flood Warning Consultative Committee, has already played a major role in the development of flood awareness. However, at present, the BOM role in respect of Keswick Creek is limited to providing an advisory, rather than a warning, service for flash flooding. Tasks seen as appropriate to the BOM are shown on Figure 10.4. They include:

- adaptation of improved numerical models and remote sensing, leading to improved forecasts of severe weather and storms likely to cause flash flooding in the catchment;

- development of meso-scale severe weather forecasts, using numerical models, satellite imagery and radar, including the issuing of Severe Weather Warnings, with the objective of providing targeted warnings for individual catchments;

- development of "nowcasting" procedures for on-the-spot severe storm forecasts to improve the quality of warnings and early response to flood risk;

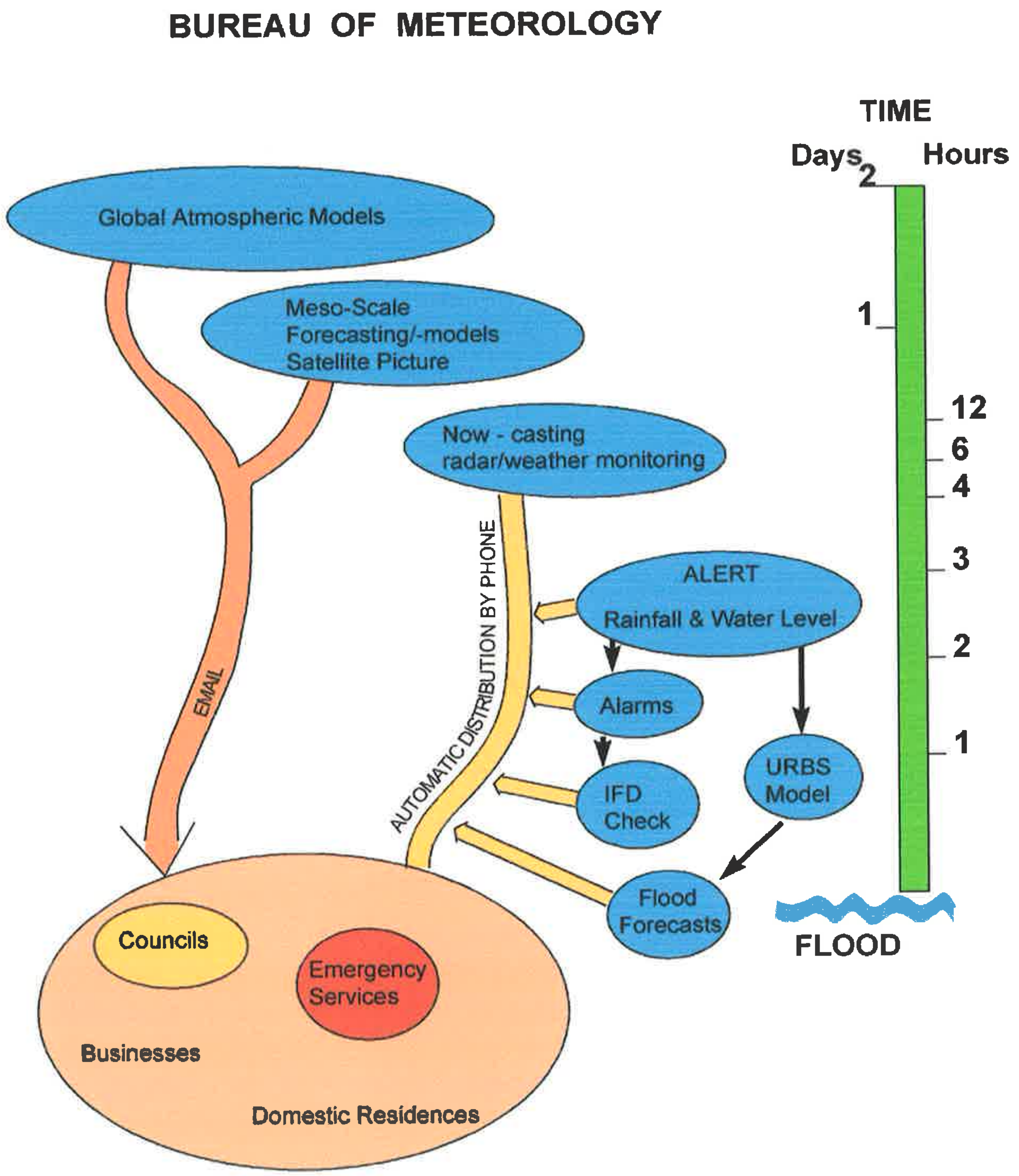


Figure 10.4 Bureau of Meteorology role in development of a flood watch and warning process.

- ☐ continued operation and optimising the performance of ALERT rainfall and water flow monitoring systems, including the integration with radar digital data, for improved analysis of rainfall distribution within the catchment;

- ☐ development and operation of the ALERT alarm system enhanced by IFDcheck, to provide value-added storm intensity alarms via mobile phone;

- ☐ development of runoff routing models for flood forecasting in real time; and

- ☐ cooperation with KURMIT staff and other agencies in the development of efficient communication systems for flood alarms and warnings.

The bar diagram on the right-hand side of Figure 10.4 represents the time component of each part of the flood watch, alarms and warning processes. The BOM role should logically include a flash flood warning service, since the BOM already operates a monitoring and forecasting service 24 hours a day, and has both Severe Weather and Hydrology Sections which are normally active in the forecasting and monitoring development of severe storms. It is possible that, in the future, the existing Severe Weather Warning service can be enhanced to the point that warnings can be issued for individual catchments.

10.5.5 Local Councils

The responsibility for flood risk management and flash flood warning has devolved, more or less by default, to local councils, but the position is not defined in the legislation. Richard Smith, in "Flood damage to commercial and industrial businesses, Part 2. Possible legal ramifications consequent upon flood damage", foreshadows that the next severe flood, which causes damage to businesses, will be followed by litigation against councils for failure to provide planning advice and direction on flood risk (Smith, 2000, pp. 75-76). The State Government does not appear to have provided guidelines to assist councils in setting up suitable zones for development within the floodplain, and although structural mitigation works have been carried out, there has been little effective action to mitigate the residual flood risk in urban Adelaide. Where successes have come, they appear to be due to a fortunate combination of good advice from interested council staff, and willingness to listen on the part of the developer. For the KURMIT project, council roles, as shown on Figure 10.5 are:

- ☐ to support, participate in and provide funds for a comprehensive flood mapping program to define flood risk and flood loss exposure;

- ☐ where structural mitigation works are appropriate for flood risk reduction, to undertake construction, with financial support by the State Government;

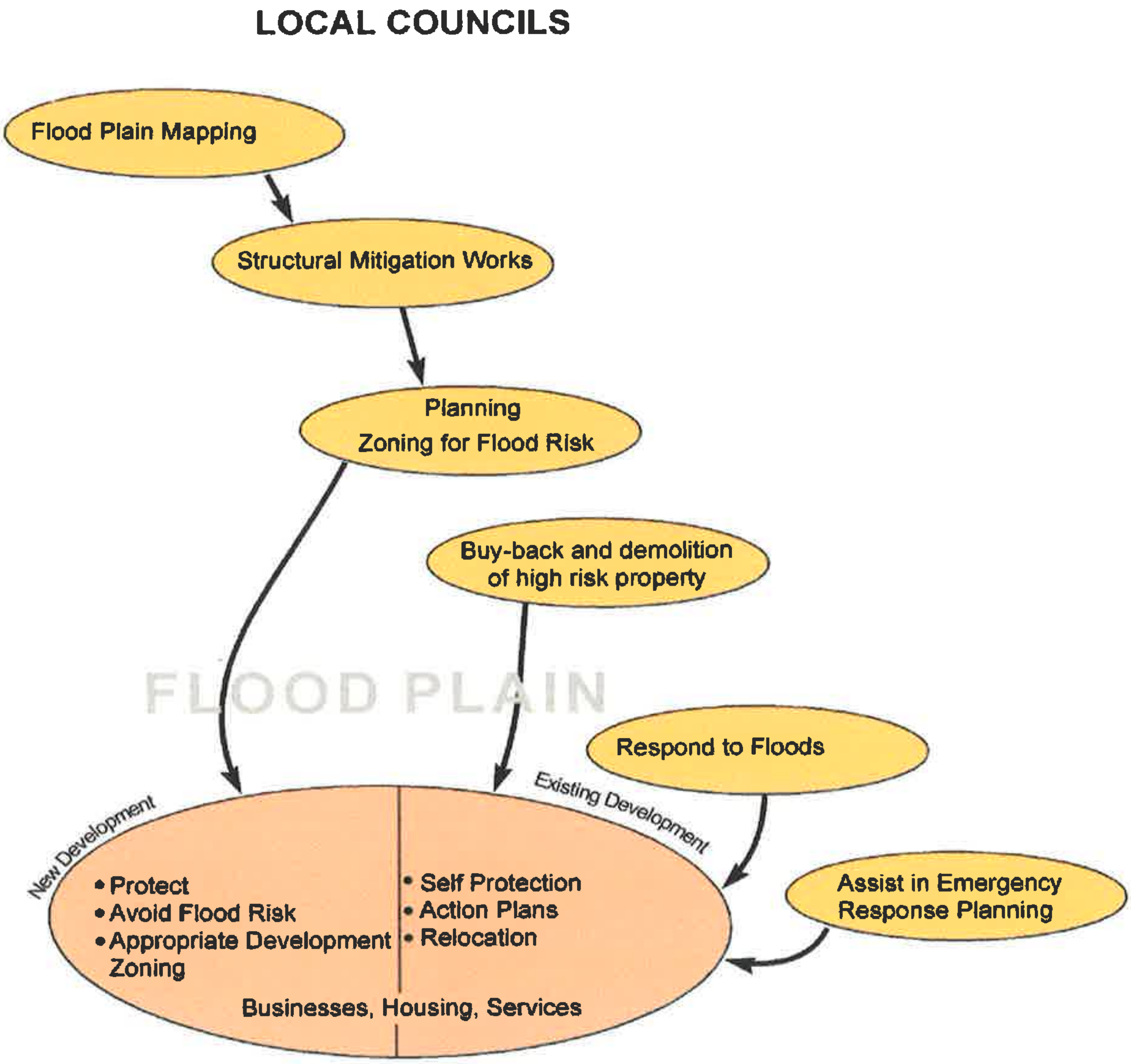


Figure 10.5 The role of local councils in planning and flood risk mitigation

☐ to develop zoning guidelines within the framework of the Development Plan, to encourage development appropriate to the flood risk at the specific location within the floodplain;[3]

☐ to support a program of phased buy-back of specific high risk properties, with assistance from the State and Commonwealth governments; and

☐ to continue to provide a flash flood response service to ensure that risk to life is minimised, and residents in need can be assisted.

---

[3] It is acknowledged that it is not practical to expect rapid transfer of flood sensitive properties out of the floodplain, and replacement with businesses or activities that are immune from flood damage, however, when property ownership changes and new developments take place there should be a gradual change which results in the risk of a flood disaster being reduced.

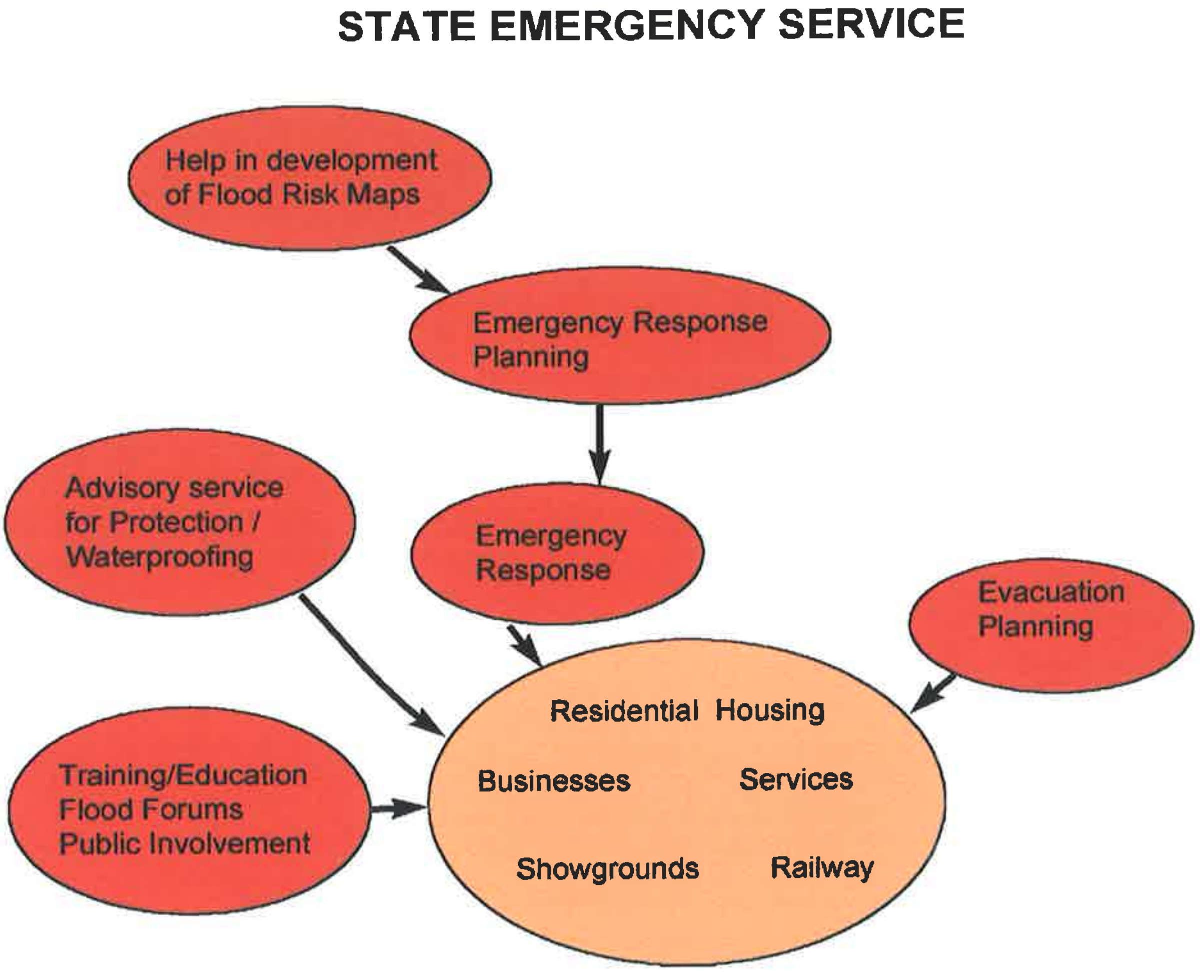


Figure 10.6 The role of the State Emergency Service in planning, training and response

10.5.6 State Emergency Service

The emergency services provide quick response to floods, arranging road closures, helping to protect individual residences, and organising evacuation when necessary. Although the Police has the lead role in disaster management, the State Emergency Service (SES) is most closely involved in the planning, training, education and response to flash floods. The SES also represents all the emergency services on the Flood Warning Consultative Committee, which coordinates the flood warning program for the State. For the SES, the general areas of responsibility, as indicated on Figure 10.6, are:

☐ participate in the development of flood inundation mapping, mainly by providing advice and feedback;

☐ planning of emergency response, using flood risk mapping for identification of areas of high and low risk, and possible safe transport corridors during floods;

☐ provide an advisory service for flood-proofing and protection of buildings and facilities;

☐ provide emergency response during flash flood events; and

☐ evacuation planning and implementation, training and education, flood awareness seminars, flood risk displays and other risk communication activities.

10.5.7 Owners of Businesses

It is believed that participation in the planning and risk management process by local business owners and managers is essential if effective flood damage mitigation is to be achieved. They bear the major risk of flood damage, and are most vulnerable to financial loss. This participation in the planning has not occurred previously in Keswick Creek floodplain, and the survey of flood prone businesses showed a lack of awareness of flood risk. Following the Newcastle earthquake, the Commonwealth Government introduced legislation to ensure that structural standards comply with earthquake loading. The same type of measures should be introduced for flood damage minimisation. It is not clear, under the present structure of local government, planning and flood risk management processes, how it would be possible to achieve large scale participation in a flood risk mitigation program.

169 flood prone businesses were surveyed. 21 of them comprised 76% of the total flood loss exposure. It is hoped that a direct approach to each of the 21 will result in a reasonable level of participation.

With this objective, the actions to minimise flood loss that owners of businesses should be prepared to take include (as shown in Figure 10.7):

☐ take notice of important information about flood risk and keep their awareness at a high level. This would be done through workshops, seminars and Flood Forum meetings organised by the KURMIT team. Good quality flood mapping to indicate the depth of water for respective flood alarms will be available in 2001. This should provide owners with an understanding of the level and, hence, the implications in terms of potential damage;

☐ allocate resources to undertake a flood risk minimisation process. This would also include nominating duty staff who will be required to manage the flood damage minimisation program;

☐ undertake a Flood Audit. Some businesses may not have the capability to undertake a flood loss exposure survey themselves. A Flood Audit service could be made available through the KURMIT program;

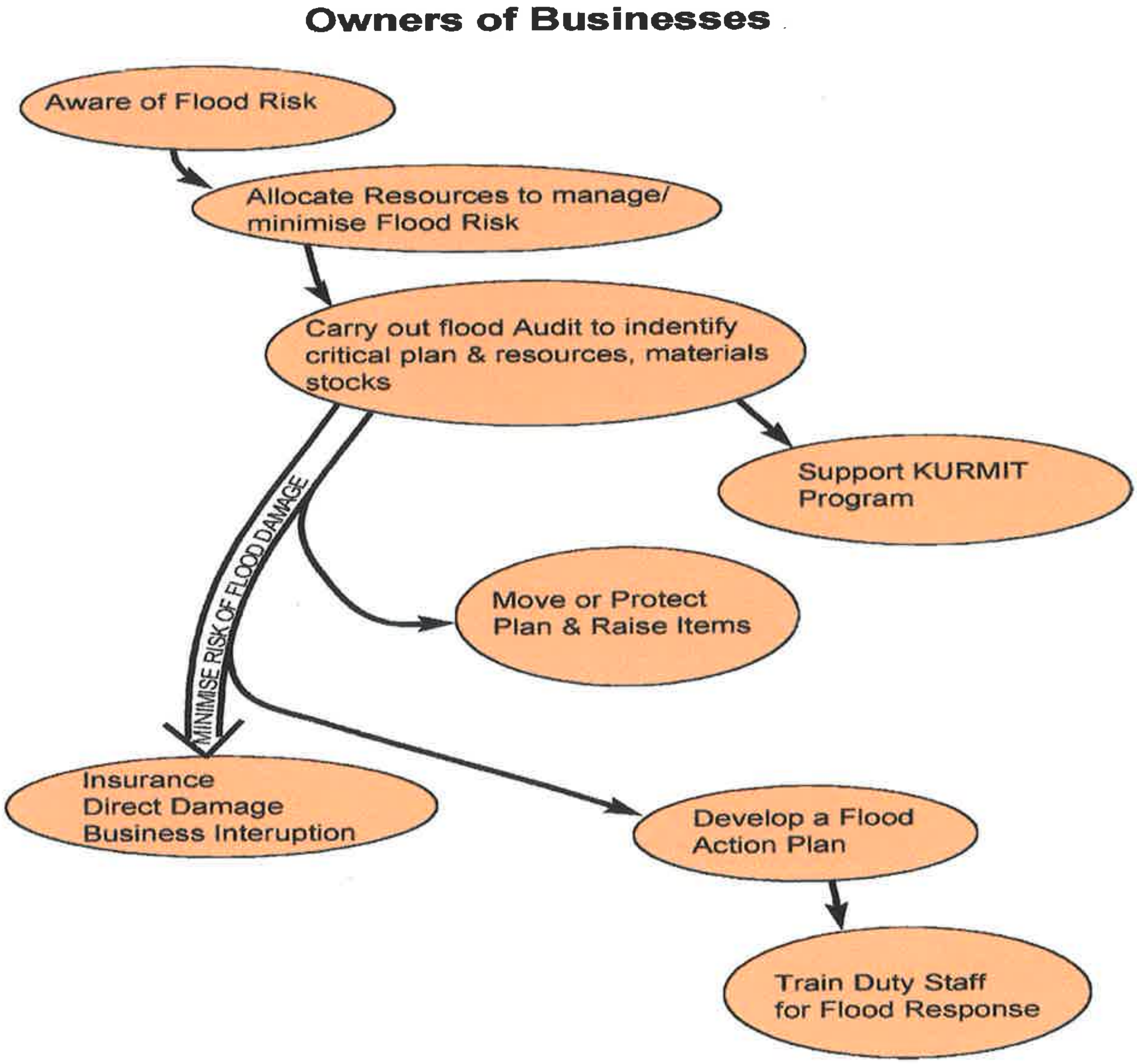


Figure 10.7 Owners of Businesses, actions to minimise flood loss exposure

- ☐ assess flood loss exposure and, where necessary, plan a risk reduction program;
- ☐ ensure that insurance cover is current, including flood risk to buildings, contents, plant, equipment, raw and finished goods, and business interruption costs;
- ☐ move and protect vulnerable, high value plant and equipment so that the risk of flood damage is kept to a minimum;
- ☐ develop a Flood Action Plan, so that in the event of a flood, staff will know what has to be done to minimise the risk of flood damage; and

- ☐ develop a training program for duty staff, repeated periodically to ensure that the plans are current and realistic, so that responsible staff are aware of what they will be required to do.

10.6 Conclusions

A flood risk minimisation program has been described in Chapter 10. It is based around the Flash Flood Risk Minimisation Matrix shown in Figure 10.1, combining elements of:

- ☐ planning and self protection against flood damage;
- ☐ flood detection;
- ☐ forecasting;
- ☐ flood warning; and
- ☐ response.

All of these actions should be approached from the long-term perspective. Planning and preparation should begin years ahead, so that measures for mitigation are already in place in the days and hours leading up to a flash flood.

A comprehensive "blueprint" plan for Keswick Creek floodplain, involving all agencies with interests in flash flooding, together with owners and managers of businesses, and local residents, has been presented, showing the tasks to be undertaken by each. A management group, known as KURMIT, would coordinate the flood risk reduction program.

11. CONCLUSION

This thesis presents a research program into the problem of flash flooding of urban communities, and has concentrated on flood risk to business communities.

A flood study in the early 1980s identified large areas of suburban and business activity that are at risk of flood, and a potential damages bill after a major flood of around $76 million in current dollars. This is a major risk for South Australia, far greater than damage estimates for a major flood on the Gawler River which affects Greater Metropolitan Adelaide.

Keswick Creek, in the inner suburbs of Adelaide, has been identified as an area prone to flood with high financial risk due to potential flood damage, and so it has been used as a case study. Despite the identifying of the risk, there appears to have been little action to mitigate the risk or to advise those in the floodplain that the risk exists. There has also been development in the floodplain worth many millions of dollars, which has taken place without the developers being made aware of the risk of flood damage, consequently the new facilities are exposed to a significant amount of avoidable damage.

It was further determined that, even if a flash flood forecasting service was provided, there is, at present, no means of distributing flood information to those affected in time for them to respond, and no agency responsible for issuing flash flood warnings. A possible method of distribution has been proposed, using an adapted form of Police/Neighbourhood communications systems already in use in Western Australia and Victoria. The aim of the system is to distribute warnings quickly to a group of well prepared people.

11.1 Philosophy of Flash Flood Warning

At the start of the research program, the problem appeared to be flash flooding in an urban catchment, for which the solution was to provide a flood warning system based on flood detection using modern technology. As the investigations progressed, it became clear that there were differences between the behaviour of Brownhill Creek and its tributary Keswick Creek, and that flood forecasting for Keswick Creek was difficult due to the very rapid response to rainfall. Don Carroll, the creator of the URBS-CM flood forecasting model, stresses value of detailed knowledge of the catchment. He says in *URBS-CM. A Catchment Management and Flood Forecasting Rainfall Runoff Routing Model* that "Good hydrologic modelling comes from a detailed knowledge of the catchment", and "... define what you require from the model and know your model" (Carroll, 1999, p. 6). In getting to know the catchment with the purpose of developing a better model, it became apparent that, even with a much improved hydrologic model, there appeared to be very little knowledge or preparedness in the community for a flood. This led to a series of surveys to find out what damage would be caused during a flood and, at the same time, to begin the development of awareness of flood risk among those who would be affected. Don Carroll's exhortation to know the catchment was therefore extended to getting to know the occupation and use of the floodplain. The surveys quickly revealed a low level of comprehension of flood risk, and a very high level of exposure to flood damage to commercial, industrial and retail businesses. It became apparent that a sophisticated flood detection and warning system would only work if the business community takes steps to protect its vulnerable assets and reduce its exposure to flood damage. The surveys suggested that the benefits of a flood exposure reduction program were potentially very large.

The aims of this investigation were set out in Chapter 1. They are discussed in the following sections.

11. 2 Examine the Hazard of Flash Flooding As it Affects Brownhill Creek

A hydrological review of the catchment revealed that while Brownhill Creek is relatively slow to respond to a flood situation, Keswick Creek and its tributaries are in a highly urbanised environment and respond extremely quickly. Furthermore, despite an apparent lack of floods in the history of Adelaide, several minor floods occurred during the period of investigation, caused by storms of relatively low intensity. Kemp's recent "Keswick Creek Hydrology Review" (Kemp, 1997), confirmed that the risk of flash flooding is high. These issues are discussed in Chapter 3. In Chapter 4 it was concluded that accurate forecasts are possible using runoff routing models but the more accurate the forecast, the later in the storm and the shorter the time-span available for issuing warnings. Radar has potential for increasing the accuracy of the model, but may not be able to provide the forecast any earlier. An earlier flood forecast could be achieved by forecasting the rainfall that will produce it but techniques for forecasting rain are insufficiently accurate. Nevertheless, under the right circumstances, runoff routing models could be useful and may provide a valuable contribution to flood forecasting

11.3 Evaluate the Strengths and Weaknesses of ALERT Systems for Flash Flood Warning

ALERT systems for flash flood warning were introduced to Australia by the BOM in the mid-1980s. Approximately 50 catchments have been installed with the systems, including Keswick and Brownhill Creek catchments in South Australia. The systems work efficiently, transmitting rainfall and water level data instantaneously to a centre where the information can be assessed. It has been assumed that the systems are capable of solving flash flood warning problems, however, they are in fact only monitoring systems. For ALERT systems to be effective, they must be linked to a warning and response process. For Keswick Creek this has not been done, and in the process of working out how to do it, the need for a more comprehensive plan involving an overall process of flood risk management became apparent.

Chapter 5 reports on the use of ALERT data for runoff routing models and for development of efficient alarms to start the warning process. The weakness in ALERT systems as they are used at present is that when a flash flood is imminent, they are set up to contact a small number of people. The processes for using the alarm information to give flash flood warnings have not been developed. It is significant that although there are 50 ALERT systems in Australia, and many more in the USA and Japan, it was not possible to find any reports of ALERT systems actually being successful in warning communities about the onset of flash floods. The outstanding case of a flash flood was the 1997 Fort Collins storm, where nearly 100 lives were saved, not by an ALERT system, but by a long term planning and flood loss exposure reduction program. ALERT systems are valuable, they collect vital data on storms and floods, and they provide useful early warning but, in themselves, they do not provide a solution to flash flood risk. In Chapter 5 it was concluded that:

- ☐ a warning system based on optimised settings of alarms is feasible, but its performance is not guaranteed since it could fail to operate in an emergency;
- ☐ rainfall alarms in current use can be made more efficient to give earliest possible warning of a flash flood;
- ☐ analysis of rainfall intensity in real time to determine the severity of a storm, using the IFDcheck program, enables critically severe storms to be located quickly using ALERT automatic monitoring systems;
- ☐ linking the output of IFDcheck to the automatic alarm system will provide "value added" alarms, making it easier to decide whether a flood is imminent;
- ☐ alarm messages can be sent quickly to mobile phones, using the Short Message Service (SMS):
- ☐ a severe storm is likely to be critically intense over a wide range of durations, not just one. The Adelaide 1925 storm was the maximum on record for all storm durations from 48 minutes to 72 hours; and
- ☐ the use of runoff routing models in real time can provide accurate flood forecasts but requires forecast rainfall to be used (in addition to measured rainfall). Current technology/meteorology for Quantitative Precipitation Forecasts in Australia is rudimentary and cannot be depended upon.

11.4 Investigate the Possibilities and Limitations of Forecasting a Flash Flood

Successful forecasting of flash floods requires that the forecast, warning and response must be completed before the flood reaches the point where damage is caused. For flash floods, this could be less than an hour. If the forecast relies on measured rainfall from pluviometers in the catchment, then it will be too late. Therefore, what is needed is to forecast the rainfall before it occurs. Unfortunately, Quantitative Precipitation Forecasts are not available in Australia and, although techniques are being developed, they are not likely to provide accurate forecasts in the foreseeable future. Chapters 3 and 4 discuss these issues.

Keswick Creek has been provided with an ALERT automatic rainfall and water level monitoring system. This system uses current information technology and gives storm information continuously. However, investigations into the potential for providing a flash flood warning service determined that:

- ☐ the ALERT system can be used to forecast flooding on Keswick Creek, using a runoff routing model;
- ☐ by the time the forecast can be determined with confidence, the flood may be already affecting the flood prone businesses and houses;
- ☐ the structure of severe storms appears to be such that a single major storm can produce virtually simultaneous flooding for a series of different catchment times of concentration;
- ☐ the use of alarms based on rainfall is potentially useful, and a method for optimising the operation of alarms is described in Chapter 5;
- ☐ the alarm process can be integrated with rainfall frequency analysis, to determine the severity of a storm while it is happening, in effect a "value added" feature of rainfall alarms. This is a useful extension to the existing processes; and
- ☐ the use of weather and rainfall prediction is critical to effective flash flood warning but, at the present time, the meteorological tools for prediction rainfall are imprecise.

11.5 Determine the Vulnerability of Development in the Floodplain

The series of surveys carried out in Keswick and Brownhill Creeks covered all of the businesses in the floodplain identified in "South Eastern Suburbs of Adelaide - Stormwater Drainage Study" (WBCM, 1984). It was established in Chapter 7 that:

- ☐ the risk of a major flood on Keswick Creek is significant;
- ☐ when the flood occurs, the damage to commercial, industrial and retail businesses is likely to be large;
- ☐ the "Keswick Creek Hydrology Review" (Kemp, 1997), and the occurrence of minor floods during the research program, confirm the existence of the risk;

- ☐ if an AEP 1 in 100 flood occurred over Brownhill and Keswick Creeks, more than 99% of the damage suffered by commercial, industrial and retail businesses would be in Keswick Creek catchment;

- ☐ for a flood of this magnitude, the damages bill is estimated at $100 million, of which about half is avoidable, by relatively low cost self-protection measures;

- ☐ a further reduction in damages of approximately $15 million could be achieved by an effective flood warning service;

- ☐ 21 of the 169 businesses in the floodplain of Keswick Creek contribute 76% of the total flood loss exposure. Therefore, to target these few would have the potential to obtain maximum reduction at minimum cost;

- ☐ the estimated Annual Average Damages for Keswick Creek is $3.5 million; and

- ☐ by comparison, the flood loss exposure of the residential housing is relatively small. Nevertheless, even this at approximately $5.6 million for the AEP 1 in 100 flood is similar to the Gawler River floodplain, which in terms of priority in South Australia has rated far more attention, and is being considered for flood mitigation works valued around $7 million.

11.6 Find Ways of Reducing the Vulnerability

Subject to findings of a flood study, which commenced in June 2000, there are few opportunities for reducing the overall flood risk by structural measures, such as retention dams, larger channels, diversions or flood embankments. This is because urban development has covered the floodplain and confined the creek into a narrow concrete channel. However the surveys and cost estimates in Chapters 6 and 7 revealed that substantial reductions in flood loss exposure to businesses can be achieved:

- ☐ approximately half of the flood loss exposure can be avoided by self protection and damage mitigation, such as construction of walls around the property boundary, providing water-tight gates, and moving vulnerable facilities above ground level; and

- ☐ a further reduction in damages exposure of 15% may be achieved by the development of an efficient warning system involving the whole community and providing high speed transmission of warning messages, reaching a prepared community in time for it to respond effectively.

11.7 Look for Solutions to the Keswick Creek Problem with the Object of Wider Application in Australia and Overseas

Transmission of warning messages to the threatened community was identified as a weakness. Chapter 8 describes the existing warning distribution system, and its limitations for flash flood warning. An efficient information transmission system has identified, known as PC COPS, which sends warnings automatically by telephone to multiple destinations with minimum delay, and provides a means for the people warned to keep up to date with the progress of the flood. A similar system could be set up for flash flood warning, linking together the warning process of Chapter 4 and 5, with the response requirements described in Chapter 6.

Chapter 9 considers the need to look at each of the processes in flash flood warning, and to obtain a solution by integrating them both in the long and short term. Flash flooding problems should be seen as risk mitigation problems, requiring analysis of the risk, rather than warning problems like fire alarms. The warning processes take time, and there must be sufficient time for the warned community to respond.

Chapter 9 considered also, the general nature of flash flood risk, and changes that are taking place that could exacerbate the problem. The restricted time available for warning is a major problem and an example is given of the time taken for each of the elements of a flood warning. Some examples of flood events have been mentioned. The need to combine long and short term risk mitigation measures, in attempting to solve flash flood risk problems has been discussed. There is a need for a coordinated approach to flood risk reduction, integrating a range of measures. The process of finding the best solution must involve all people and agencies with interests in the floodplain, including local and state government, response organisations, and particularly those who live and work in flood risk areas. The relative importance of Economic versus Financial costs needs to be determined, such as transfer payments when flood damage causes industrial production to be relocated interstate. It will be necessary for a lead agency or group to take the initiative to start the flood risk mitigation process. Resources for undertaking the program need to be determined and secured.

A Flash Flood Risk Minimisation Matrix was used in Chapter 10 as the basis for a flood risk management and mitigation program which is outlined, using Keswick Creek as the example. The matrix approach was used to integrate all elements of planning, forecasting, warning and response, in a time-frame which starts years ahead of, and continues to the day and hour of the next flood. It combines the elements of:

☐ planning and self protection against flood damage;
☐ flood detection;
☐ forecasting;
☐ flood warning; and
☐ response.

All of these actions should be approached from the long-term perspective. Planning and preparing should begin years ahead, so that measures for mitigation are already in place in the days and hours leading up to a flash flood.

The concept of a flood risk management program, to be known as the Keswick Creek Urban Flood Mitigation Unit, with the acronym KURMIT, is explained. It is believed that this program, which incorporates all of the elements described above, is a useful basis for establishing an efficient and effective program for urban flood risk mitigation. The KURMIT concept, if adopted successfully for Keswick Creek, could be used for other flash flood catchments in the city, and may well be appropriate for interstate and overseas use.

11.8 Further Investigations Into Flash Flood Risk Management

Although this research program has concentrated on flood risk to businesses, there is a significant risk to private housing. The KURMIT project has the capability to extend the warning process to owners of suburban dwellings in the lower parts of the catchment. There are areas in the upper catchment that will flood too quickly for a warning process to be effective. For these dwellings, a program of voluntary purchase and demolition by the government is a feasible way of reducing the risk.

Flash flood risk management is difficult. For the Keswick Creek situation, with only 21 businesses representing the major portion of flood loss exposure, it should be possible to set up an effective risk reduction program. The problem of extending the risk reduction program to private dwellings is believed to be much more difficult, involving a much larger number of individuals. Although the financial loss suffered by owners of houses may be small in comparison with business losses, the trauma and public anger that may be aroused by a flood disaster is a major problem for public authorities responsible for the safety of communities. The solution lies in community involvement and education. Some progress has been achieved in flash flood-prone communities in Colorado, USA.

The lack of evidence of successful use of ALERT systems for flash flood warning is a concern. With the large number of systems in place, it would be expected that there should be information available. It is suggested that:

☐ a review of performance of ALERT systems in Australia should be carried out; and

☐ the performance of flash flood warning systems worldwide should be investigated, with particular emphasis on the distribution of warnings and the response by the threatened communities.

These programs would contribute significantly to understanding how the deductions that have been made during this study could be applied more widely, and may establish the need to continue this research program.

BIBLIOGRAPHY

American Meteorological Society, 1993, "Policy Statement Prediction and Mitigation of Flash Floods", *Bulletin of the American Meteorological Society,* 74 (No. 8, August 1993) pp. 1586-1587.

Black, R.D., 1975, *Floodproofing Rural Residences,* US Department of Commerce, Economic Development Administration, Washington, DC.

Boyd, M.J., 1985, "Effect of Catchment Sub-Division on Runoff Routing Models", *Civil Engineering Transactions,* Institution of Engineers, Australian, Barton ACT, pp. 403-410.

Braga, B.P.F., and Massambani, O. (Editors), 1997, *Weather Radar Technology for Water Resources Management,* UNESCO Press, Uruguay.

Bruist, H., 1999, "Flash Flood Warning Services - What the Bureau can do for you", *Disaster Prevention for the 21st Century,* Emergency Management, Canberra, Australia, pp. 33-38.

Bureau of Meteorology, 1996, *Bureau of Meteorology Policy on the Provision of the Flash Flood Warning Service,* Melbourne, Victoria.

Bureau of Meteorology, 1995, *Weather Services Handbook,* Bureau of Meteorology, Melbourne, Victoria.

Carroll, D.G., 1999, *URBS-CM. A Catchment Management and Flood Forecasting Rainfall Runoff Routing Model,* Gutteridge Haskins & Davey, Brisbane.

Chow, V.T., 1959, *Open-Channel Hydraulics,* McGraw-Hill Book Company, New York.

Cluckie, I.D. and Collier, C.D. (Editors), 1998, *Hydrological Applications of Weather Radar.* Ellis Horwood Ltd., London

Dance, B., 1998, *PC COPS: A Crime Prevention and Emergency Management,* Prepared for Inspector Brian Fahy, State Duty Officer, South Australian Police by A/Sergeant Brian Dance, pcCops Project Manager, Crime Prevention Bureau, Cannington, Western Australia.

Daniell, T.M., Kemp, D., Dickins, J., 1998, "The Olary Flood, February 1997. Implications for South Australia", 1998 Conference on Dams; The Challenge - Managing Dams in a Competitive Business Environment (ANCOLD, NZSOLD), Nangking, China.

Dickins, J., 1997, "Nowcasting with AIFS - A South Australian Perspective", Nowcasting Workshop, Bureau of Meteorology, Melbourne, Victoria, Australia.

Grimm, M., 1998, "Floodplain Management", *Civil Engineering,* March 1998, pp. 62-64.

Gruntfest, E., "Notes on the COMET course at Fort Collins", University of Colorado, Colorado Springs, 15 May 1998.

Gruntfest, E., (Editor), 1997, "Introduction and Overview", *Twenty Years Later. What we have learned from the Big Thompson Flood,* Special Publication Number 33, The Natural Hazards Research and Application Information Center, Institute of Behavioural Science, University of Colorado, Boulder, Fort Collins, Colorado.

Gunnarson, H., 1997, "The Bureau of Reclamation and Dam Safety", *Twenty Years Later. What we have learned from the Big Thompson Flood,* Special Publication Number 33. The Natural Hazards Research and Application Information Center, Institute of Behavioural Science, University of Colorado, Boulder, Fort Collins, Colorado.

Hassell & Partners, (1998), "Stormwater Management and the Development Plan", Local Water Plans Seminar at Asia Water Seminar, Adelaide, 17 July 1998.

Hausmann, P., Gaschen, S., Menzinger, I. and Schaad, W., 1998, *Floods - An Insurable risk? A Market Survey,* Swiss Reinsurance Company, Zurich, Switzerland.

Henderson, F.M., 1966, *Open Channel Flow*, The MacMillan Company, New York.

Henri, C., 1991, "The Insurance Industry Response to Flood", in Britton N.R. and Oliver J. (Editors), *Natural and Technological Hazards: Implications for the Insurance Industry*, Sterling Offices (Australia) Ltd., Sydney.

Hilmes, M., 1997, "Special Report on July 1997 Fort Collins Flood", City of Fort Collins, Colorado.

Horton, R.E., 1933, "The Role of Infiltration in the Hydrological Cycle", *Transaction American Geophysical Union,* 14, pp. 446-460.

Hydro-Tasmania, 2001, *Brownhill and Keswick Creek Flood Inundation Study,* Consultants Study Report in preparation for the Patawalonga Catchment Water Management Board, Adelaide.

Institution of Engineers, Australia; Pilgrim, D.H. (Editor), 1987, *Australian Rainfall and Runoff*, Institution of Engineers, Australia, Barton ACT.

ISMES Consulting Group, 1992, "Sydney-Newcastle-Wollongong, Flash Flood Warning System", New South Wales Flood Warning Consultative Committee, Edgecliff, New South Wales.

Jarrett, R.D. and Browning, T.W., 1998, "Effects of rainstorms on water and sediment runoff following the 1996 wildfire, Buffalo Creek", Colorado. Draft in preparation.

Kemp, D.J., 2000. "The Development of a Rainfall-Runoff-Routing (RRR) Model", PhD thesis in preparation, University of Adelaide, South Australia..

Kemp, D., 1998, "Brownhill Creek Hydrology Review", Transport SA, Adelaide, South Australia.

Kemp, D., 1997, "Keswick Creek Hydrology Review", Transport SA, Adelaide, South Australia.

Kemp, D.J. and Daniell, T.M., 1996, "A Proposal for a Rainfall - Runoff - Routing (RRR) Model", IE Australia's 23rd Hydrology and Stormwater Symposium, Hobart, Tasmania, pp. 15-20.

Krzysztofowicz, R., 1992, "Performance Tradeoff Characteristic of a Flood Warning System", *Water Resources Bulletin*, 28 (No. 1) pp. 193-200.

Lange, Dames and Campbell (SA) Pty Ltd. and Snowy Mountains Engineering Corporation Ltd, 1995, "River Torrens Flood Hydrology Study", SA Government, Engineering & Water Supply Department, Adelaide, South Australia.

Laurenson, E.M., Mein, D.R.G. and McMahon, A.P.T., 1975, "Flood Estimation by Runoff Routing", Water Engineering Workshop No. 2, Department of Civil Engineering, Monash University, Victoria..

Laurenson, E.M. and Mein, R.G., 1990, *RORB - Version 4 Runoff Routing Program User Manual*, Monash University, Melbourne.

Linsley, R.K.J., Kohler, M.A. and Paulhus, J.L.H., 1972, *Hydrology for Engineers*, McGraw-Hill Book Company, Auckland.

Livingston, A.H., 1993, "The Failure of Briseis Dam", Hydrology and Water Resources Symposium, The Institution of Engineers, Australia, Newcastle, New South Wales, pp. 425-431.

Marles, D.M., 1980, *A Pictorial History of West Torrens,* Lutheran Publishing House, Adelaide, South Australia.

McPherson, N., 1999, "Flood Warning Alert - A Practical Solution", Inaugural Victorian Flood Management Conference, North East Catchment Authority, Wangaratta, Victoria.

Moore, R.J., 1995, "Rainfall and Flow Forecasting using Weather Radar", British Hydrological Society National Meeting on Hydrological Uses of Weather Radar, Institution of Civil Engineers, London.

Munich Reinsurance Company, 1997, *Flooding and Insurance*, Munich Reinsurance Company, Munich, Germany.

New South Wales Government, 1987, *Floodplain Development Manual,* Sydney, New South Wales.

New South Wales Government, 1999, *Draft Floodplain Management Manual,* Land & Water Conservation, Newcastle, New South Wales.

National Weather Service, 1977, *Automated Local Flood Warning Systems Handbook, Weather Service Hydrology Handbook No.2*, US Department of Commerce, Silver Spring

Peddie, A.J. and Ball, J.E., 1993, "Real Time Flood Forecasting for the Upper Parramatta River", Hydrology and Water Resources Symposium: Towards the 21st Century, Institution of Engineers, Australia, Barton, ACT, pp. 405-410.

Penning-Rowsell, E.C., 1977, *The Benefits of Flood Alleviation - A Manual of Assessment Techniques,* Gower Publishing Company Limited, Aldershot, Hampshire, England.

SCARM, 2000, *Floodplain Management in Australia - Best Practice Principles and Guidelines* CSIRO Publishing, Collingwood, Victoria.

Schwab, G.O.F., Richard K., Edminster, Talcott W., Barnes, K.K., 1955, *Soil and Water Conservation Engineering*, John Wiley & Sons Inc., New York.

Smith, D.I., 1999, "Proposal for the Addition of Flood to the Building Code of Australia" Prepared by Emergency Management Australia on behalf of the National Emergency Management Committee.

Smith, D.I., 1998, *Water in Australia,* Oxford University Press, Melbourne, Australia.

Smith, D.I., 1993, "Greenhouse Climatic Change and Flood Damages: The Implications", *Climatic Change,* vol. 25, nos 3-4, pp. 319-333.

Smith, D.I., 1991, "Extreme Floods and Dam Failure Inundation: Implications for Loss Assessment" in Britton N.R. and Oliver J. (Editors), *Natural and Technological Hazards: Implication for the Insurance Industry,* Sterling Offices (Australia) Ltd, Sydney, pp. 149-165.

Smith, D.I. and Handmer, J.W., 1986, "Flooding in Australia: the background to flood warnings", in Smith D.I. and Handmer J.W. (Editors), *Flood Warning in Australia,* Centre for Environmental Studies, Canberra, pp. 3-13.

Smith, D.I. and Greenaway, M.A., 1984, "Commercial and Industrial Flood Damage - A Case Study for the Taminda Estate - Tamworth, NSW", Centre for Resource and Environmental Studies, Australian National University, Canberra, ACT.

Smith, R., 2000, "Flood damage to commercial and industrial businesses, Part 2. Possible legal ramifications consequent upon flood damage", *Water and The Law,* Hydrological Society of South Australia Inc., National Environmental Law Association, Environmental Engineers Society (South Australian Chapter), Adelaide, South Australia, pp. 73-76.

Stewart, K., 1988, "Effecting Timely Responses to Urban Flash Floods", Proceedings of the 3rd Water Resources Operations Management Workshop, Fort Collins, Colorado.

Shire Council of Strathbogie, 1997, "Euroa Flood Plan, Operation Procedures for Flood Warning System", Euroa, Victoria.

Summer, S.G., 1997, "Comparison of Deficiencies Associated with the Big Thompson Flash Flood Events and Recent Flood Events in the Eastern United States", *Twenty Years Later. What we have learned from the Big Thompson Flood,* Special Publication Number 33, The Natural Hazards Research and Application Information Center, Institute of Behavioural Science, University of Colorado, Fort Collins, Colorado.

Sun, X., Keenan, T.D. and Mein, R.G., 1999, "Formulation and optimisation of the probability matching method for radar reflectivity and rain rate in the Darwin region", *Australian Meteorological Magazine,* 48, (4 December 1991), pp. 233-240.

Tonkin, B.C.A., 1995, "Sturt River Flood Hydrology Study", South Australian Water Corporation, Adelaide, South Australia.

US Army, 1982, *HEC2 Water Surface Profiles, Users Manual,* US Army Corps of Engineers, Davis, California.

Walker, G. R., 1999, "Analysis of insurability for flood", *Disaster Prevention for the 21st Century,* Emergency Management, Australia; Canberra, Australia,

WBCM Consultants, 1984, "South Eastern Suburbs of Adelaide - Stormwater Drainage Study" Volume I, Main Report, Adelaide, South Australia.

WBCM Consultants, 1983, "South Eastern Suburbs of Adelaide, Stormwater Drainage Study" Progress Report, Adelaide, South Australia.

Webb, McKeown & Associates Pty Ltd, 1997, "Coffs Creek Flood of 23 November 1996, Data Collection, Councils response and Flood Study", *Clear Water, A Technical Response,* Stormwater Industry Association Conference, Coffs Harbour, New South Wales, Australia, 26-29 April 1997.

Weaver, J.F., 1998, "Some Unusual Aspects of the Fort Collins, Colorado Flash Flood of 28 July 1997", 8th Conference on Mountain Meteorology, Flagstaff, Arizona, USA.

Wilson, D.R., Krohn, S.N. and Misson, C.J., 1994, "A Flexible Real-Time Forecasting Model", Water Down Under '94, XXV Congress of the International Association of Hydrogeologists, with the International Hydrology and Water Resources Symposium in Adelaide, South Australia. Published Institution of Engineers, Australia, Barton, ACT, pp. 81-85.

WP Software, 1992, *RAFTS_XP, Runoff Analysis and Flow Training Simulation, Incorporating the EXPERT User Environment. Operators Manual,* WP Software.

Wright, C.J., forthcoming, March 2001. "Keswick Creek - Flood Risk Management - Final Report", Patawalonga Catchment Water Management Board, Adelaide, South Australia.

Wright, C.J., 2000b, "Flood damage to commercial and industrial businesses, Part 3. Looking for remedies - before the flood", *Water and The Law,* Hydrological Society of South Australia Inc., National Environmental Law Association, Environmental Engineers Society (South Australian Chapter), Adelaide, South Australia, pp. 77-79.

Wright, C.J., 2000a, "Flood damage to commercial and industrial businesses, Part 1. Introduction to urban flood risk on Keswick Creek, Adelaide", *Water and The Law,* Hydrological Society of South Australia Inc., National Environmental Law Association, Environmental Engineers Society (South Australian Chapter), Adelaide, South Australia, pp. 69-71.

Wright, C.J., 1999, "Keswick Creek - Flood Risk Management - Pilot Study Report", Patawalonga Catchment Water Management, Board, Adelaide, South Australia.

Wright, C.J., 1998, "Rainfall Alarms for Flash Flood Warning. ALERT Transmission" AUG-SAAS Newsletter, Summer 1998, p. 2.

Wright, C.J., 1994, "Advances in Flash Flood Warning in South Australia", Water Down Under '94, XXV Congress of the International Association of Hydrogeologists, with the International Hydrology and Water Resources Symposium in Adelaide South Australia.. Published Institution of Engineers, Australia, Barton, ACT, pp. 499-503.

APPENDIX A

Flood Risk and the Insurance Industry

FLOOD INSURANCE

A. 1 Role of Flood Insurance

Insurance is a means of spreading risk over time and across the insured community. In Australia, buildings and facilities are normally covered for fire damage, however the same is not necessarily true for flood. The survey of businesses indicated that most were not insured, or did not know whether they were insured for flood damage. Insurance policies for private housing do not normally include cover for flood damage. However, it is probable that most owners of houses assume that they are covered for flood damage. Each new flood disaster, as soon as the victims realise that their damages are not necessarily insured, gives rise to a new wave of anger. Two examples are the Barossa flood of March 1983 and the Wollongong floods of 1998, but is a common occurrence.

The role of insurance in flood risk mitigation has given rise to considerable acrimony and debate, which is renewed each time another urban community is struck by flooding. The basic problem is that, while large businesses are usually insured against loss caused by flooding, the same is not true for small commercial and retail businesses or for private dwellings. The exclusion of flood cover for private housing has, it is believed, always been the case in Australia. In New Zealand and in the USA, by contrast, flood insurance is available for domestic housing.

The definition of a flood, for which insurance cover is normally *excluded*, is given by Henri in a conference address entitled "The Insurance Industry Response to Flood" (Henri, 1991, p. 168) as follows:

> "Being the inundation of normally dry land by water escaping or released from the normal confines of any natural 'watercourse' or lake whether or not altered or modified, or any reservoir, canal or dam."

On the other hand, stormwater that enters a dwelling as a result of overflowing roof drainage, *is covered* by insurance. Walker, in a paper entitled "Analysis of insurability for flood." (Walker 1999, p. 305), states that insurance cover is also standard for:

> "flooding due to direct run-off of rainwater before reaching a watercourse."

In the confusion of a real flood, it can be difficult to distinguish between the causes. These terms therefore give rise to hot debate after the event. A further complication for situations where there was more than one source of flooding, is the question of "proximate cause", or "which was the first cause of the flood damage".

The insurance industry is very much aware of the problem. In the same paper referenced above, Walker notes that;

> "The implementation of this approach has resulted in almost every significant flood becoming a public relations disaster for the insurance industry, as those denied their insurance claims have publicly vented their feelings of unfair treatment."

The current situation is unsatisfactory, with considerable room for argument over every insurance claim that is made after a flood.

A.2 Insurance for Private Housing

The fundamental problem with insurance cover for private housing is that the risk of flooding is not equal for all houses because floods are site-specific. In Adelaide, most houses are located in areas where flood risk is low and there is little probability of flood damage, but there are certain areas where the risk is high. There is, therefore, considerable variability in flood risk according to location. This is in contrast to fire risk which does not vary significantly within urban areas. Flood cover can sometimes be included in the policy on specific request because, these days, there are insurance companies that offer it but in most cases it is neither a standard feature nor offered as an optional extra. Since the risk of flooding varies from one location to another, blanket flood insurance cover would, it is argued, give unfair advantage to those who choose to live in high risk areas and discriminate against those who choose sites for their houses in lower risk areas. Alternatively, if flood insurance is offered on an individual policy basis, this would require that the risk would need to be assessed individually. The cost of assessing flood risk for specific locations is high, because there is no standard Geographical Information System (GIS) data base that can be accessed to provide flood risk information, and many areas still do not have adequate flood risk mapping anyway.

A.3 Flood Insurance for Businesses

The larger businesses in the Keswick Creek floodplain, which were included in the survey, all claimed that they had full insurance cover for flood damage, and that the cover included Business Interruption (loss of profit and additional costs due to delays in getting back into business after a flood). The situation is more confusing in the case of small businesses and retail outlets. The survey by Megaw and Hogg indicated that, although most business claimed that they were insured; for the most part they did not have any idea what cover they had, and few knew what cover, if any, and limits would apply for business interruption.

A.4 Influence of the Re-insurance industry

In a review of the literature on flooding and insurance, it became clear that although the insurance companies appeared to be doing little in respect of flood damage evaluation and assessment, the re-insurance industry has taken a close interest, and has set up significant research units specifically for disaster analysis, with emphasis on floods. Two publications, *Floods - An Insurable risk? A Market Survey* (Hausmann, Gaschen et al. 1998), and *Flooding and Insurance* (Munich Reinsurance Company, 1997), relate specifically to flood damage and provide excellent descriptions and photographs of floods and flood damage for a host of countries around the world.

The reason for this research activity among reinsurers appears to be that the insurance companies who offer flood cover, distribute their loss exposure by reinsurance. The reinsurers then end up paying much of the cost of major flood disasters and, therefore, have an interest in knowing the risks of such disasters. In discussions with George Walker and Chris Henri (authors referenced previously), it became clear that the way in which the industry operates is to balance premiums against claims for run-of-the-mill risks and to ensure that for major disasters, they have transferred the risk to reinsurers. The real business that the insurance companies depend on is investment of funds collected in premiums. Therefore, there is little incentive to provide flood cover, and perhaps less still to take a close interest in flood risk and disaster minimisation.

A.5 Insurers as Damage Mitigators

At least in theory, the insurance companies could have a major role to play in disaster management. If they were to offer incentives to large businesses, in terms of reduced premiums, in return for flood risk mitigation programs, one would expect that there would be a direct reduction in flood loss exposure. However, the reason that the insurance industry exists is to carry the risk to which individuals are exposed, for a negotiated fee. If the risk is removed, there is no need for insurance, therefore at least on first principles, insurance is not about risk reduction.

Alternatively, it would be expected that some insurers, particularly those who provide flood cover for businesses (and not private housing), would need to know the level of loss exposure and take a direct interest in the assessment of flood risk. However, the assumption that the need for determining flood risk is important to insurance companies and that they should be prepared to pay for it, is not borne out by experience. In the case of Keswick Creek, where funds were required for undertaking the Pilot Flood Risk Study, and for the Floodplain Mapping Study, no financial support was forthcoming from either the Insurance Council of Australia (which represents the insurance industry), nor any of the insurance companies doing business in South Australia. This was the case, despite a number of direct approaches to individual insurance companies.

A.6 Involvement of the Insurance Industry in Flood Risk Minimisation

As part of this research program, direct approaches were made to the Insurance Council (South Australian branch), Commercial Union, Zurich Insurance Company and letters were written to the insurers of some of the larger flood prone businesses in Mile End. The objectives were to:

- ☐ foster, if possible, an interest by the insurers in the flood problem;
- ☐ through involvement of the insurers, get a flood damage mitigation program under way; and
- ☐ obtain financial support from the insurers for floodplain mapping, which would provide them with accurate flood risk information, and a ready means of assessing premiums in the these areas.

The initiative was not successful. For the most part, the insurers were prepared to listen but even Zurich Insurance Company, which holds the insurance portfolio for a very large flood prone business in the floodplain, was not prepared to do anything at all. Despite this attitude, the Bureau of Meteorology, Hydrology Section receives regular calls from the insurance industry, asking for information on flood risk. The information is provided without charge. Insurance companies have, from time to time, offered to buy the flood maps, at cost. The fact that the cost of the maps bears no relation to the cost of the professional fees and study costs required to provide the maps is not taken into account.

A.7 Insurance Claim Issues After a Flood

This hiatus over flood risk and insurance inevitably leads to unsatisfactory consequences after a major flood. The Wollongong floods were followed by the usual uproar, when people discovered that their insurance policy did not cover flood damage. Such was the political heat that the insurance industry was forced to interpret fairly liberally, the phrase "flooding due to direct run-off of rainwater before reaching a watercourse". Even though much of the damage was caused by water bursting out of the creeks, the insurers chose to pay most of the claims. It is understood that, in an attempt to recoup their losses, the insurers were contemplating a class action against the local council for allowing residents to construct housing in flood prone areas. The insurance situation after the recent floods at Catherine and Coffs Harbour was much the same. There is a distressing similarity in these events in respect to insurance, but nothing much seems to be happening to achieve a more satisfactory outcome. Chris Henri (personal communication), indicated that the insurance industry is contemplating changing the definition of flood cover to include "local flash flooding". However this, surely, will create as many problems as it solves, since the same argument over the causes of flooding will simply shift slightly, and someone will have to decide in each case whether the cause of damage was mainstream flooding (not covered), or other causes.

A.8 Flood Insurance in the USA and New Zealand

In the USA, flood insurance is provided by the Federal Emergency Management Agency (FEMA), therefore, for those who choose to take up the policy, all flood damage is covered by insurance. (In New Zealand a similar system exists.) However, until recently, the percentage of flood prone properties was quite small, around 10% in 1998, according to Mary Fran Myers.[1] This has led to a different set of problems:

☐ that because people know that any losses that they suffer will be covered by insurance, there is little incentive for self protection and risk mitigation; and

☐ the low rate of take-up of flood insurance.

---

[1] Mary Fran Myers, Director, Natural Hazards Research and Applications Information Center, University of Colorado, Boulder, personal communication.

Steps are being taken to overcome the low rate of participation by requiring that the banks can only provide finance for the purchase or construction of private housing if the owner takes out a flood insurance policy and, secondly, that flood insurance will only be provided if there is a flood mitigation program in place. (This would normally be developed and managed by the local council). According to Myers, now that these measures have been implemented, the participation rate is rising.

A.9 Possible Future Directions for the Insurance Industry in Australia

The current flood insurance situation in Australia is totally unsatisfactory. Each time there is a flood, there is a completely predictable sequence of events:

- ☐ beginning with uproar in the days after the flood when people discover that their insurance policy does not cover flooding;
- ☐ political pressure on the insurance companies to pay up, even though policies may clearly exclude this risk; and
- ☐ negotiation between owners, insurers and politicians leading to some sort of compromise.

Nowhere in the process is there any incentive or initiative to minimise flood risk, to do things smarter. A better approach would be to:

- ☐ arrange with insurers to offer flood insurance cover at a cost that people could reasonably pay, even if this meant spreading the cost over the whole housing portfolio, which disadvantages to some extent, those who are not at risk;
- ☐ instigate a program of flood risk evaluation for all flood prone land, which includes setting up of a Hazards data base on a GIS. The data could be accessed by insurance companies and the risk for individual properties quickly and efficiently assessed, leading to flood risk premiums appropriate to the risk; and
- ☐ arrange a public awareness campaign giving information on flood risk (flood maps), and the need to carry flood insurance.

These steps will at least enable anyone who wishes to obtain flood insurance to do so. And should ensure that after the flood there will not be too many cries of "Why am I not insured?" It will also provide an opportunity for insurance companies to fine-tune their premium assessment, using an efficient GIS system to access flood (and perhaps other) risk information.

If flood insurance is provided only by the industry, and not by Government, it will be difficult to incorporate flood risk mitigation. Those living in high risk areas will be paying more, but there is a need to establish a link between lower insurance premiums, paid by individuals, and a flood risk mitigation program which would be financed and carried out by local and state government agencies.

APPENDIX B

Analysis of Pluviograph Data for Rainfall Stations in Victoria, South Australia and Australian Capital Cities

Catchment	Area km ^{2}	Tc Hrs	Rain Stn	Data Rec. Years	Alarm Rainfall mm	Alarm Performance (5 worst storms)			Worst Storm	Chances of 'x' mm of rain falling after the alarm has triggered				
						Time hrs	Best hours	Worst hours		50% mm	20% mm	10% mm	1% mm	0.1% mm
Broken to Benalla	1461	12	l.Nillahcootie	25	34.5	6	3.7	9.6	6.7	9	22	31	62	93
					32	5	3.6	9.8	6.6	10	24	34	69	103
					28	4	3.3	9.8	6.3	10	24	35	69	104
					25	3	3.2	9.9	6.1	11	26	37	74	111
					21	2	3.6	9.8	6.8	10	23	32	65	97
					15.7	1	3.5	10	8.4	9	20	28	57	85
Seven Cks. to Euroa	100	5	Euroa	31	24	4	1.3	3.6	1.3	7	16	23	46	69
					22	3	1.2	3.7	1.6	7	16	23	46	69
					19	2	1	3.6	1.2	7	17	25	49	74
					17.5	1.5	1	3.5	1	8	20	28	56	84
					16	1	0.9	3.5	0.9	9	22	31	63	94
					12	0.5	0.6	4	0.8	10	23	32	65	94
Hovells Ck	230	6	Little River	18	22.5	4	0.5	3.5	1.8	9	20	29	57	86
					19.5	3	0.4	3.8	1.6	10	24	35	69	104
					16	2	0.4	5.8	1.5	9	21	30	60	91
					14	1.5	0.3	5.7	1.5	9	21	31	61	92
					12.5	1	0.3	5.9	1.4	10	22	32	64	96
					9	0.5	0.3	2.7	1.4	9	21	30	61	91
Hovells Ck	230	6	Geelong North	22	13	4	1	3.5	1.7	7	15	22	44	66
					12	3	0.9	3.5	1.7	7	15	22	43	65
					10	2	0.8	3.3	1.6	7	17	24	48	73
					8.5	1.5	0.7	3.1	1.6	8	18	26	52	78
					7	1	0.5	3	1.8	7	17	24	48	73
					5	0.5	0.4	3.8	1.8	7	17	24	48	72
Traralgon Ck to	189	6	Calignee North	34	18	4	1	3.2	1.8	6	14	20	40	61
					15.5	3	0.9	3.1	1.7	8	19	27	53	80
					13.2	2	0.5	2.9	1.7	6	15	21	42	63
					12	1.5	0.5	3	1.6	6	15	21	42	63
					10	1	0.4	3	1.7	7	16	23	45	68
					7.2	0.5	0.5	3.4	1.8	7	17	25	49	74

NOTES: + indicates that the alarm was tripped before the start of the critical rainfall burst.
Rainfall (Crit. dur), indicated that for the critical duration or "burst", which is taken as the Time of Concentration, Tc, the range of rainfalls in the 5 worst storms, eg. 189 to 114 mm

Figure B1 Analysis of Pluviograph data for rainfall stations in Victoria (Sheet 1)

Catchment	Area km^2	Tc Hrs	Rain Stn	Data Rec. Years	Alarm Rainfall mm	Alarm Performance (5 worst storms) Time hrs	Best hours	Worst hours	Worst Storm	Chances of 'x' mm of rain falling after the alarm has triggered 50% mm	20% mm	10% mm	1% mm	0.1% mm
Ovens River to Bright	495	8	Bright	24	29	4	2.8	7	2.8	10	22	32	63	95
					24	3	2.7	6.8	2.7	12	27	39	78	117
					19.5	2	0.6	7.3	2.8	11	26	37	73	110
					17	1.5	0.6	7.2	2.8	11	26	38	76	114
					14	1	0.6	6.5	2.8	10	24	35	70	104
					10.5	0.5	0.5	7.5	2.8	10	23	33	66	100
Werribee River to Bacchus Marsh	240	6	Parwan	20	23	4	-1.5	3.3	-1.5	13	31	44	89	133
					20	3	-1.4	3.3	-1.4	13	31	44	89	133
					17.5	2	-1.4	3.4	-1.4	13	29	42	83	125
					16	1.5	-1.4	3.7	-1.4	12	27	39	78	116
					13	1	-1.5	3.6	-1.5	12	28	40	80	119
					9.5	0.5	0.3	3.6	0.8	13	29	42	83	125
Werribee River to Bacchus Marsh	240	6	Blackwood	20	18.5	4	1.1	5.4	1.1	8	18	25	50	76
					16.5	3	0.9	5.3	0.9	7	17	24	48	71
					15	2	0.7	5.2	0.7	6	13	18	37	55
					12.5	1.5	1	5.2	1	6	15	21	42	62
					10.7	1	1.8	5.1	1.8	7	16	23	47	70
					7.1	0.5	0.4	5.2	1.8	8	18	26	52	78
Ballarat	60	3.5	Ballarat	44	18	2.5	0.5	2.4	0.7	7	17	24	48	72
					17	2	0.5	2	0.7	8	18	25	50	76
					15.5	1.5	0.5	2.6	0.6	8	18	26	52	79
					14	1.2	0.5	2.6	0.6	8	19	27	54	81
					12.5	0.9	0.5	2.6	0.6	8	19	27	54	82
					10.5	0.6	0.5	2.5	0.6	9	21	29	59	88

NOTES: + indicates that the alarm was tripped before the start of the critical rainfall burst.
Rainfall (Crit. dur), indicated that for the critical duration or "burst", which is taken as the Time of Concentration, Tc, the range of rainfalls in the 5 worst storms, eg. 189 to 114 mm

Figure B2 Analysis of Pluviograph data for rainfall stations in Victoria (Sheet 2)

Location	Assumed Tc hr	Rain Stn	Data Rec. yr	Alarm Rainfall mm	Alarm Performance (5 worst storms)			Worst Storm	Chances of 'x' mm of rain falling after the alarm has triggered				
					Time hr	Best hr	Worst hr		50% mm	20% mm	10% mm	1% mm	0.1% mm
Brisbane	6	Reg Office	84	48	3	+	4.7	+	20	47	68	136	203
				42	2	+	4.7	+	20	47	68	135	203
Rainfall range(crit. dur) mm		181 - 127		39	1.5	+	4.8	+	20	46	65	130	195
				33.7	1	1	5	3.6	19	43	62	124	186
				31	0.8	0.9	4.8	3.7	18	43	61	122	183
				27.7	0.6	0.9	4.8	3.6	19	43	61	123	184
				22.8	0.4	0.8	4.8	4.8	17	44	58	116	174
Sydney	6	Reg Office	84	43	3	0.2	3.1	3.1	24	55	78	157	235
				36.5	2	+	3	3	24	57	81	162	244
Rainfall range(crit. dur) mm		197 - 133		33.4	1.5	0.9	3	3	24	56	80	161	241
				28.4	1	0.8	3	3	25	57	82	163	245
				26	0.8	0.8	3	3	25	57	82	163	245
				23.2	0.6	0.8	3	3	24	56	81	161	242
				18.7	0.4	0.9	3	3	22	51	73	147	220
Hobart	6	Reg Office	87	18.3	3	+	4.7	+	10	24	34	68	102
				14.8	2	0.5	4.6	1.1	10	23	33	65	98
Rainfall range(crit. dur) mm		87 - 49		13	1.5	0.5	4.5	0.9	10	23	33	66	98
				10.4	1	0.5	4.6	0.9	9	20	29	57	86
				9.4	0.8	0.9	6.6	1	8	18	26	51	77
				8.1	0.6	1	4.7	1.3	7	17	24	48	72
				0.5	4.7	0.5	4.7	2.9	7	16	23	46	69
Melbourne	6	Reg Office	26	23	3	0.7	4.4	4.1	8	18	26	52	78
				20.8	2	0.7	4.7	4.1	8	19	27	55	82
Rainfall range(crit. dur) mm		62 - 43		17	1.5	0.6	4.7	4	9	21	29	59	88
				15	1	0.5	4.7	4	8	20	28	56	85
				14	0.8	0.5	4.7	4	9	20	29	58	86
				12.5	0.6	0.4	4.1	4	9	21	30	59	89
				11	0.4	0.2	5.7	3.9	9	20	29	58	87

NOTES: + indicates that the alarm was tripped before the start of the critical rainfall burst.
Rainfall (Crit. dur), indicated that for the critical duration or "burst", which is taken as the Time of Concentration, Tc, the range of rainfalls in the 5 worst storms, eg. 189 to 114 mm

Figure B3 Analysis of Pluviograph data for rainfall stations in State Capitals (Sheet 1)

Location	Assumed Tc hr	Rain Stn	Data Rec. yr	Alarm Rainfall mm	Alarm Performance (5 worst storms)			Worst Storm	Chances of 'x' mm of rain falling after the alarm has triggered				
					Time hr	Best hr	Worst hr		50% mm	20% mm	10% mm	1% mm	0.1% mm
Canberra	6	Reg Office	38	21.4	3	0.8	3.4	1.8	9	21	29	59	88
				17.5	2	+	3.5	1.5	10	22	32	64	96
				16.3	1.5	+	3.4	1.5	9	21	30	61	91
Rainfall range(crit. dur) m		62 - 38		14.5	1	+	3.6	1.5	9	21	31	61	92
				13	0.8	0.5	4.5	1.4	9	22	31	62	93
				11.5	0.6	+	3.6	1.5	10	23	32	65	97
				10	0.4	+	4.5	1.5	9	21	30	59	89
Darwin	6	Reg Office	45	66.8	3	1.6	5	3.1	19	43	62	123	185
				60	2	1.4	5.1	3	20	46	66	132	198
Rainfall range(crit. dur) m		189 - 114		57	1.5	1.4	5.1	3	20	46	65	130	196
				50.3	1	1.1	5.6	2.9	19	43	62	123	185
				45.9	0.8	0.1	5.6	2.7	19	44	63	127	190
				41	0.6	1	5.2	2.6	19	44	62	125	187
				33.8	0.4	0.7	5	3.4	19	44	63	129	189

NOTES: + indicates that the alarm was tripped before the start of the critical rainfall burst.
Rainfall (Crit. dur), indicated that for the critical duration or "burst", which is taken as the Time of Concentration, Tc, the range of rainfalls in the 5 worst storms, eg. 189 to 114 mm

Figure B4 Analysis of Pluviograph data for rainfall stations in State Capitals (Sheet 2)

Catchment	Area km^2	Tc Hrs	Rain Stn	Data Rec. Years	Alarm Rainfall mm	Alarm Performance (5 worst storms)			Worst Storm	Chances of 'x' mm of rain falling after the alarm has triggered				
						Time hrs	Best hours	Worst hours		50% mm	20% mm	10% mm	1% mm	0.1% mm
Keswick	31.9	4	West	82	17.5	3	0.5	1.4	1.4	6	15	21	43	64
Creek			Terrace		14.5	2	0.4	1.6	0.3	7	17	24	49	73
Rainfall Range(crit.dur)mm			138 - 49		13.5	1.5	0.4	1.6	1.3	7	17	24	49	73
					11.7	1	0.4	1.6	1.3	7	17	25	50	75
					10.5	0.8	0.4	1.6	1.4	8	18	26	52	79
					9.4	0.6	0.3	1.6	1.4	7	17	24	49	73
					7.8	0.4	0.4	1.5	1.4	8	18	25	51	76
Keswick	31.9	4	Kent	16	16	3	1.7	3.5	1.7	5	12	18	35	53
Creek			Town		14.5	2	1.5	3.5	1.5	5	11	16	32	48
Rainfall Range(crit.dur)mm			32 - 28		13	1.5	1.3	3.5	1.3	4	10	14	29	43
					10.2	1	0.9	3.5	0.9	4	10	14	28	43
					9.4	0.8	0.9	3.5	0.9	5	10	15	30	45
					8.7	0.6	2.8	3.6	2.8	4	9	13	26	39
					7.4	0.4	2.8	3.5	2.8	4	10	14	29	43
Keswick	31.9	4	Waite	17	17.5	3	0.9	3.7	0.9	6	13	18	37	55
Creek			Institute		14.3	2	0.7	3.7	0.7	6	14	19	39	58
Rainfall Range(crit.dur)mm			54 - 30		12.7	1.5	0.7	3.7	0.7	6	14	20	41	61
					11.5	1	0.6	3.7	0.6	8	18	26	52	79
					9.3	0.8	0.5	3.6	0.5	8	20	28	56	84
					8	0.6	0.4	3.6	0.4	9	20	28	57	85
					7	0.4	0.4	3.6	0.4	10	22	32	64	96

NOTES: + indicates that the alarm was tripped before the start of the critical rainfall burst.
Rainfall (Crit. dur), indicated that for the critical duration or "burst", which is taken as the Time of Concentration, Tc, the range of rainfalls in the 5 worst storms, eg. 189 to 114 mm

Figure B5 Analysis of Pluviograph data for rainfall stations in Brownhill Creek Catchment, South Australia (Sheet 1)

Catchment	Area km^2	Tc Hrs	Rain Stn	Data Rec. Years	Alarm Rainfall mm	Alarm Performance (5 worst storms)			Worst Storm	Chances of 'x' mm of rain falling after the alarm has triggered				
						Time hrs	Best hours	Worst hours		50% mm	20% mm	10% mm	1% mm	0.1% mm
Keswick	31.9	4	Mt Crawford	27	19	3	0.2	2.9	1	6	14	19	39	58
Creek					16	2	0.8	3.2	0.9	6	13	19	38	56
Rainfall Range(crit.dur)mm			41 - 33		15	1.5	0.8	3.1	0.8	6	13	19	39	58
					12.2	1	0.7	3.8	0.7	6	13	19	38	56
					11	0.8	0.3	3.3	0.6	5	12	17	33	50
					9.5	0.6	0.3	2.1	0.6	6	14	20	39	59
					7.7	0.4	0.4	2	0.5	7	16	23	47	70
Keswick	31.9	4	Blackwood	13	17.8	3	1.4	2.9	2	7	17	24	48	71
Creek			(missing data)		15.3	2	1	3.2	1.8	6	15	21	42	63
					13	1.5	0.4	2.4	1.7	8	19	27	54	81
Rainfall Range(crit.dur)mm			55 - 26		11	1	0.3	2.4	1.8	9	21	30	59	89
					10	0.8	0.3	2.5	1.8	9	21	30	59	89
					8.8	0.6	1.6	3.7	1.7	7	16	22	45	67
					7	0.4	0.4	3	1.7					
Keswick	31.9	4	Adelaide	25	14	3	1.4	3.7	2.3	7	15	22	44	66
Creek			Airport		12	2	1.1	3.6	2.4	6	15	21	43	64
Rainfall Range(crit.dur)mm			45 - 30		11	1.5	1	3.6	2.4	5	12	17	35	52
					9.6	1	0.8	3.6	2.4	5	12	18	35	53
					9	0.8	0.8	3.6	2.4	5	11	16	31	47
					8	0.6	0.7	3.6	2.3	4	10	15	29	44
					6.5	0.4	0.6	3.5	2.3	5	11	16	32	49

NOTES: + indicates that the alarm was tripped before the start of the critical rainfall burst.
Rainfall (Crit. dur), indicated that for the critical duration or "burst", which is taken as the Time of Concentration, Tc, the range of rainfalls in the 5 worst storms, eg. 189 to 114 mm

Figure B6 Analysis of Pluviograph data for rainfall stations in Brownhill Creek Catchment, South Australia (Sheet 2)

APPENDIX C

Photographs of Recent Floods at Mile End, Goodwood and Unley.

Figure C.1 Keswick Creek in Flood at Mile End, January 25 2001

Figure C.2 Flooding at Australia Post Depot in Mile End, January 2001

Figure C.3 Floodwater at National Foods Office, 25 January 2001

Figure C.4 Floodwater at the the gates of Le Cornu warehouse, 25 January 2001

Figure C.5 Keswick Creek overflowing at Mile End, 25 January 2001

Figure C.6 Flooding from Glen Osmond Creek on Unley Road, August 2000.

Figure C.7 Keswick Creek at the entrance to the Showgrounds Tunnel, flood of August 1999.
Note: Peak flood level reached the level of the roadway.