NATURAL HAZARDS *in* AUSTRALIA

Identifying Risk Analysis Requirements

Miriam H. Middelmann (Editor)

Australian Government

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Photos on front cover (left to right)

Crop damage from Cyclone Larry, Queensland, 2006
Photo courtesy: Bureau of Meteorology/J. Davidson.

Fire near Bruthen, Victoria, 2007
Photo courtesy: CFA Public Affairs/M. Anderson.

Flood in Lismore, New South Wales, 2005
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Tornado in Port Hedland, Western Australia, December 1975
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Flood damage in Brisbane, Queensland, 1893
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Debris flow on Bulli Pass, New South Wales, 1998
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Earthquake damage in Newcastle, New South Wales, 1989
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Lightning near Alstonville, New South Wales, 2003
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Foreword

Whether it's from bushfire, flood, severe storm, earthquakes, or even tsunami, Australia has suffered loss of life and extreme damage to infrastructure from natural hazards. And as our communities grow, so does the potential for greater losses in these areas.

My electorate of Paterson, New South Wales, has experienced firsthand the effects of natural hazards on a community. In 1989 the most damaging earthquake in Australia's history rocked the city of Newcastle, and more recently floods in the upper Hunter Valley caused major damage.

Following a Council of Australian Government (COAG) natural hazard review into reforming mitigation, relief and recovery arrangements, the Australian Government identified a new approach was needed for the management of natural disasters in Australia and tabled a number of recommendations.

The first two reform commitments relate to this report:

1) Develop and implement a five-year national programme of systematic and rigorous disaster risk assessments

2) Establish a nationally consistent system of data collection, research and analysis to ensure a sound knowledge base on natural disasters and disaster mitigation.

In response to the COAG review, Geoscience Australia and its partner, the Department of Transport and Regional Services, committed to provide risk assessment methods, models and data to be used as benchmarks for risk assessment projects.

The purpose of this Report is to provide a knowledge base of how to conduct a risk analysis for natural hazards in Australia. The Report considers the suite of natural hazards identified by COAG and addresses a range of issues including impacts, gaps, data requirements and risk analyses. The report highlights the gains in a long-term data collection system and how integral it is to the risk analysis process.

Geoscience Australia has been a leader in hazard risk research in Australia for over a decade, and this collaborative report is an example of how mitigation research can provide emergency response managers at ground level with the information they need to combat the conditions at hand.

Natural hazards are a constant threat that every Australian has to live with, and as such we have developed some of the best emergency management response techniques in the world.

To limit the impact on our communities, we as a nation must continue to further our understanding and research of natural hazards, and this report is a great platform from which to learn.

The Hon Bob Baldwin, MP
Parliamentary Secretary to the Minister for Industry, Tourism and Resources
5 October 2007

Foreword

Every year, many Australian communities are confronted with the devastation caused by natural disasters. These disasters often cause considerable disruption to the community and significant damage to property, infrastructure, industry and economy. Natural disasters pose a unique challenge that government, private enterprise and communities must work together to prepare for and manage.

Reliable information to identify the risk and degree of damage that can be caused by a natural hazard is very important. Risk analysis is an important step in a comprehensive risk management approach to minimise the potentially devastating impact of bushfires, floods, tropical cyclones and other natural hazards on communities.

Australia's Climate Change Policy (July 2007) identifies climate change as a serious challenge in the future and predicts impacts to include rising sea levels and a greater number of severe storms. A range of research suggests that the number and severity of natural hazards is set to rise across Australia, exposing a greater number of Australians to the risks they present, with potential flow on effects to the nation and the economy more generally.

The Australian Government plays an important role in mitigating the effects of natural disasters. This is done through:

- fostering strong relationships with communities, the private sector, state government and local authorities
- developing an understanding of common and individual goals before, during and after a natural disaster event
- developing a consistent national approach to the assessment of risks associated with different types of natural disasters
- improving mitigation measures to reduce the impact of natural disasters
- a more comprehensive approach to assisting communities to recover from an event
- identifying best practice initiatives to better manage events before, during and after they occur.

I have developed an appreciation of a range of issues relating to natural disasters through my current role as Secretary of the Australian Government Department of Transport and Regional Services (DOTARS) and in a previous role as Secretary of the Victorian Government Department of Natural Resources and Environment.

DOTARS oversees a number of future-oriented initiatives that aim to reduce the social and economic impact of natural disasters. While protection of the community and property is the responsibility of state and territory governments, DOTARS plays a vital role at the Australian Goverment level by providing policy advice and administering a number of funding programmes that enhance communities' ability to prepare for and recover from natural disasters.

This publication brings together current understanding of natural disasters across Australia. It provides a new, central source of information on the process involved in analysing risk, which is a vital step in reducing the loss and suffering caused by natural disasters in Australia.

Michael J Taylor

Michael Taylor
Secretary, Department of Transport and Regional Services
5 October 2007


Photo courtesy: NAA: A1200, L85800.

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Chapter 1 - Introduction

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Photo courtesy: NAA: A1200, L60753.


Photo courtesy: Emergency Management Australia.

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Photo courtesy: Geoscience Australia.

Photo courtesy: CFA Public Affairs.

Abbreviations

AAP	Australian Associated Press
ABC	Australian Broadcasting Corporation
ABCB	Australian Building Codes Board
ABS	Australian Bureau of Statistics
AEMC	Australian Emergency Management Committee
AEP	annual exceedence probability
AFAC	Australasian Fire Authorities Council
AGO	Australian Greenhouse Office
AGS	Australian Geomechanics Society
AHD	Australian Height Datum
AS	Australian Standard
ATWS	Australian Tsunami Warning System
AusAID	Australian Agency for International Development
BoM	Bureau of Meteorology
BTE	Bureau of Transport Economics
BTRE	Bureau of Transport and Regional Economics
CFA	Country Fire Authority
COAG	Council of Australian Governments
CRC	cooperative research centre
CRUE	Centre for European Flood Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAF	Development Assessment Forum
DEM	digital elevation model
DIPNR	Department of Infrastructure, Planning and Natural Resources, New South Wales
DNRE	Department of Natural Resources and Environment, Victoria
DNRM	Department of Natural Resources and Mines, Queensland
DOI	digital object identifier
DOTARS	Department of Transport and Regional Services
DSE	Department of Sustainability and Environment, Victoria
EMA	Emergency Management Australia
ENSO	El Niño–Southern Oscillation

FFDI	forest fire danger index
FMA	Floodplain Management Authorities
FSMAUGO	frequency, seriousness, manageability, awareness, urgency, growth and outrage
FWCC	Flood Warning Consultative Committee
GA	Geoscience Australia
GFDI	grassland fire danger index
GIS	geographic information system
HAT	highest astronomical tide
HB	handbook
ICA	Insurance Council of Australia
IPCC	Intergovernmental Panel on Climate Change
MEOW	maximum envelope of waters
MWL	mean water level
NAA	National Archives of Australia
NAFC	National Aerial Firefighting Centre
NDRRA	Natural Disaster Relief and Recovery Arrangements
NFRAG	National Flood Risk Advisory Group
NRAAG	National Risk Assessment Advisory Group
NSW SES	New South Wales State Emergency Service
NZS	New Zealand Standard
PMF	probable maximum flood
PMSEIC	Prime Minister's Science, Engineering and Innovation Council
PPRR	prevention, preparedness, response and recovery
SCARM	Standing Committee on Agriculture and Resource Management, Agriculture and Resource Management Council of Australia and New Zealand
SMAUG	seriousness, manageability, acceptance, urgency and growth
SMEC	Snowy Mountains Engineering Corporation
SMUG	seriousness, manageability, urgency and growth
SWL	still water level
WMO	World Meteorological Organization
WRC	Water and Rivers Commission, Western Australia

Photo courtesy: NAA: A6135, K28/3/74/22.

Executive Summary

No state or territory in Australia is immune to the impact of natural disasters. As well as having an enormous economic cost, natural disasters inflict a massive social cost on the community. Although disaster response, recovery and mitigation are reasonably developed in Australia, risk analysis, which provides the foundation for risk reduction, has received less attention.

As Australia's population and density of living continue to grow, so does the potential impact of a natural disaster on the Australian community. Increasing numbers of people, buildings and infrastructure assets are being exposed to natural hazards as the pressures for urban development extend into areas of higher risk.

This report provides an overview of the rapid onset natural hazards which impact on Australian communities, including tropical cyclone, flood, severe storm, bushfire, landslide, earthquake and tsunami events. Emphasis is placed on identifying risk analysis requirements for these hazards and the phenomena that they cause, with a particular focus on likelihood and consequence.

The gaps in information required to more rigorously analyse risk from natural hazards are identified, with emphasis placed on those which are research related. Also included is an overview of the roles played by government and non-government agencies, groups and individuals in the management of natural hazards.

Impact of Natural Disasters

Natural disasters have a significant economic, social, environmental and political impact on the community. While some of the impact of natural disasters can be mitigated, the risk cannot be completely eliminated.

Distribution

While some natural hazards have the potential to occur anywhere in Australia (e.g. severe storm), many occur only in reasonably well-defined regions (e.g. tropical cyclone) and are confined by topography (e.g. storm tide). Similarly, some natural hazards have the potential to occur at any time of year (e.g. tsunami), while others are often seasonal (e.g. thunderstorm).

The impact associated with hazards also varies and can range from frequent moderate impacts (e.g. bushfire) through to rare but potentially catastrophic impacts (e.g. earthquake). Some hazards may occur suddenly (e.g. rockfall), while in the case of others the threat may be identified in advance and a warning provided (e.g. flood).

The future distribution of some natural hazards may also be affected by climate change.

Role of communities

While Australia's growing economy and technological advances may assist in managing disasters, they also make communities more vulnerable to the potential impacts of hazards.

This occurs through the increase in numbers and concentration of people and other assets exposed to hazards, and the greater reliance on infrastructure such as power and water supplies.

A hazard develops into a disaster when it has a widespread or concentrated negative impact on people. Therefore, communities can play a key role in both creating and mitigating 'natural' disasters. The preparedness of a community for a natural hazard can reduce the impact of an event and allow for more rapid recovery. Therefore, a key to reducing the overall risk of natural disasters is for those who play a role in the management of natural disasters to work closely with the wider community.

Cost

The average annual cost of natural disasters in Australia is estimated at $1.14 billion (over the period from 1967 to 1999), although the actual cost incurred varies greatly from year to year (BTE 2001). Only natural disasters with an estimated total cost greater than or equal to $10 million were considered.

Tropical cyclones, floods, severe storms and bushfires have had by far the greatest impact historically in Australia. However, a single event, such as a moderate-sized earthquake in Sydney, could fundamentally change this picture of natural hazards.

Consequently, it is critical to quantify the potential impacts of a full range of small through to extreme events in order to fully understand the risks from natural hazards. It is also important to consider the potential impacts of climate change on future risk. The study of prehistoric impacts of natural hazards can also be useful in extending historical knowledge for application today.

An economic framework is often used to calculate the cost of natural disasters. However, the difficulty of measuring the actual impact of a natural disaster on the community continues to be a major challenge, because of the complexities in assessing loss.

Intangible losses, such as the destruction of personal memorabilia and the effects of post-disaster stress, are particularly difficult to measure. Though insured losses are the most easily captured, they represent only a small proportion of total loss. These complexities need to be kept in mind when measuring and communicating the concept of 'impact'.

Role of policy

Government policy determines the future development of Australia and the wellbeing of people living within Australia's borders. Therefore, policy plays a fundamental role in influencing the impact of natural disasters, particularly in areas such as land use planning, construction standards and emergency management. Creating closer links between policy, research and practice is central to reducing the impact of natural disasters.

Risk Analysis

A good understanding of the risk of natural disasters is vital to minimise their potential impact. The systematic process used to understand and assess the level of risk is called 'risk analysis', and provides essential inputs to planning emergency management response and prioritising resources for sound mitigation practice.

Scope and purpose

In the context of this report, the risk analysis process enables the likelihood and consequences of natural hazard events to be assessed. Risk is analysed by considering the combined effects of likelihood and consequence that produce disasters. Assessing likelihood involves assessing the frequency or probability of natural hazard events. Consequences are examined by collecting information on the elements likely to be exposed to the impact of the hazard phenomenon, such as buildings, infrastructure and people, and gathering information on their vulnerability to a particular hazard.

The purpose of the risk analysis is to describe the risk through an objective and consistent process, the results of which can be described either qualitatively or quantitatively. The level of quantification depends on the level of rigour and accuracy required for the application of the results. For example, whereas a qualitative ranking of hazard risks may be adequate for a general understanding of risk to the community, a much more rigorous and quantitative analysis would be required for input to the design of critical infrastructure.

Necessity for good data

A good understanding of hazard, exposure and vulnerability is fundamental in any rigorous analysis of the risk posed by natural hazards, as the assessment of risk is only as good as the data used.

Knowledge of the elements likely to be exposed to the impact of the hazard phenomena is vital in determining the potential impact or consequence of any hazard on a community or society. This includes information on the people, buildings and infrastructure potentially exposed to a hazard impact. Such data are fundamental to any analysis of risk, regardless of the hazard.

Although a basic analysis of risk may simply look at what elements are exposed to a hazard event, an understanding of the vulnerability of these elements is vital for a more rigorous analysis of risk. This may include information such as building type and construction, or a community's wealth, health and access to key facilities or services.

Data collection is a long-term investment which requires the ongoing support of all levels of government, the private sector and the community. Where the data are inadequate, the ability to analyse and effectively reduce the impact of natural hazards is severely limited.

Management of Natural Hazards

All levels of government, non-government groups and the community play a role in managing the impact of natural disasters.

Government agencies

The Australian Government plays an important role in:

- developing national strategic disaster management policy
- providing warnings and alerts to the community, for some meteorological and geological hazards
- undertaking nationally significant scientific research
- providing support in emergency management awareness, training and education
- providing states and territories with financial and/or operational support for natural disaster mitigation, response and recovery.

State and territory governments have primary responsibility for natural disaster management in their jurisdictions, including developing appropriate policies and strategies, warning systems, awareness and education, and response and recovery; and providing support and direction in natural disaster management for local governments and remote Indigenous communities.

A bushfire in the Blue Mountains, New South Wales, November 1968
Photo courtesy: Bureau of Meteorology.

Local governments generally lead the development of disaster risk assessments and emergency management plans, and the implementation of mitigation measures within their jurisdictions. However, the extent to which this is done varies from hazard to hazard and between states and territories. Local governments play a key role in increasing community awareness and preparedness for hazard impacts, issuing local warnings and managing impacts in their jurisdictions.

Non-government agencies

A large number of professional bodies, coordinating groups and industry bodies play an advocacy role in the management of natural hazards. There is a mix of informal and formal groups, with some functioning at a national level while others are state-based or locally based. The engineering profession plays a large role in mitigation, through Engineers Australia and Standards Australia.

Research into natural hazards and their impact is undertaken at many Australian universities. Numerous consulting companies are involved in developing risk assessment and disaster management plans on behalf of government and non-government agencies.

The media and the community

The media play a vital role in delivering warnings to the community and in raising the community's awareness of natural hazards in general.

Volunteers play an important role in managing the impacts of natural hazards, particularly through the state emergency services and rural fire services.

Members of the general community have a basic responsibility to be aware of the risk natural hazards pose to them, and to maintain their properties to minimise vulnerability. Ideally, individuals should know what to do during a natural hazard event; at a minimum, they should at least have adequate knowledge to understand the advice of the relevant authorities during an event.

Overview of Hazards

The following pages provide an overview of the hazards covered in the report: tropical cyclone, flood, severe storm, bushfire, landslide, earthquake and tsunami.

Tropical Cyclone

Tropical cyclones develop over the warm oceans to Australia's north, including the Coral Sea and Indian Ocean. Tropical cyclones can bring destructive winds, heavy rain and coastal inundation through storm tide to many parts of Australia's western, northern and eastern coastlines.

Tropical cyclones have caused over 2100 fatalities in Australia since 1839 (Blong 2005). The average annual cost of tropical cyclones is estimated at $266 million (BTE 2001), accounting for 25% of the cost of natural disasters in Australia.

Current likelihood analysis methods involve using statistical or physical models to simulate many thousands of years of tropical cyclone events. These models rely heavily on the short historical record (spanning approximately 100 years) of observed tropical cyclones. Data on specifics such as the size, inner structure and decay rate of tropical cyclones after landfall are significant for determining likelihood but are poorly captured in the existing observational record.

The level of exposure of buildings and infrastructure can vary dramatically because of local terrain and topography effects and surrounding structures. The vulnerability of individual structures can be assessed using either of two methods: an engineering approach, or an assessment based on previously observed levels of damage for the type of structure.

The influence of climate change on tropical cyclone impacts is an area for further work. Suggested climate change impacts on tropical cyclones include increases in intensity and more southward tracks, exposing a greater proportion of the Australian community to this hazard.

At a fundamental level, the understanding of tropical cyclone behaviour and occurrence is limited and requires further research. A greater awareness of the vulnerability of residential structures and key infrastructure components to wind, rainfall and storm tide will improve quantitative risk assessments. Improved models of severe wind and storm surge hazard will provide town planners and emergency managers with fundamental information on community exposure to tropical cyclones.

Damage to flats at Nightcliff from Cyclone Tracy in Darwin, Northern Territory, December 1974
Photo courtesy: Bureau of Meteorology/Noel Stair.

Flood

Floods in Australia are predominately caused by heavy rainfall, with La Niña years experiencing more floods on average than El Niño years. Rainfall can cause both riverine floods and flash floods.

Records for flood deaths extend back further than those for any other hazard, with over 2300 fatalities since 1790 (Blong 2005). Floods have been estimated to contribute 29% of the average annual natural hazard damage in Australia, costing around $314 million each year, which makes flooding the most expensive natural disaster in Australia (BTE 2001).

Flood modelling is used to determine the likelihood of flooding for a given area. It involves two stages: estimating flood potential or probable flood flows (i.e. hydrologic analysis), and evaluating the flow of water through an area of interest (i.e. hydraulic analysis). Some of the data necessary include good rainfall and stream gauge measurements, cross-sectional data that capture the channel and floodplain geometry, and information on human and environmental features that influence flow behaviour.

The accuracy of the digital elevation data is often the greatest constraint for flood consequence modelling. While many factors contribute to flood damage, knowledge of the depth of flooding in buildings (i.e. over-floor depth) is a minimum data requirement. Information on the velocity and duration of inundation is also required for a more rigorous analysis of flood risk.

The influence of climate change on flood impacts is an area for further work, with existing climate change projections suggesting that average rainfall is likely to increase in the north of Australia and decrease in the south, with the intensity of rainfall likely to increase in many parts of the country. The increase in extreme rainfall intensity is likely to result in an increase in the intensity of floods.

Much more research is required to understand and manage the risks from flash flooding, which is likely to be a significant problem for most heavily urbanised areas of Australia. There are also areas for which no assessment of riverine flood risk exists, or where a more rigorous analysis of the risk may be warranted. Further work in the areas of flood vulnerability, post-disaster assessment and ways of making buildings more resistant to flooding are also important to minimise flood impacts.

Aerial view of the flooding in Lismore, New South Wales, June 2005
Photo courtesy: NSW SES/Phil Campbell.

Severe Storm

Severe storms (excluding tropical cyclones) can range from isolated thunderstorms to intense low-pressure systems (or synoptic storms). Thunderstorms may affect only a few square kilometres, while synoptic storms can cause damage over thousands of square kilometres. Severe thunderstorms affect all parts of the country, while synoptic storms pose a large threat to the southern states.

Records for thunderstorm deaths extend back to 1824, with over 770 fatalities recorded in Australia since that time (Blong 2005). Severe storms have been estimated to cost Australia about $284 million each year (BTE 2001), representing 26% of the average annual cost of natural disasters in Australia.

Severe storms can cause a variety of phenomena, but the greatest impacts are generally a result of large hail, destructive winds (including tornadoes) and heavy rainfall. All of these hazards occur on local scales, meaning there are few direct meteorological observations available. The likelihood of these phenomena is commonly determined by modelling the likelihood of the atmospheric environments in which they occur.

Complete assessments of the consequences of severe storms are hampered by a lack of accurate damage models for phenomena unique to these events—for example, large hail. Consequences of other severe storm phenomena, including flooding and destructive winds, can be determined using damage models developed for those phenomena.

The influence of climate change on severe storms is an area for further work. Current research suggests climate change may cause a decrease in severe thunderstorm risk for southern Australia, but a marked increase in thunderstorm risk for the east coast. The tracks of severe synoptic storms are projected to move southward, with fewer but possibly more intense systems occurring along Australia's south coast.

Further work on understanding severe storm behaviour recurrence and impact will provide invaluable information on the appropriate standards of construction for buildings and infrastructure components required to minimise impacts. Quantitative vulnerability models for wind and hail damage for buildings (and other assets) will lead to better estimates of the overall impact from severe storms.

Isolated severe thunderstorm near Junee, New South Wales, November 2005
Photo courtesy: Will Barton Photography.

Bushfire

Bushfires in Australia originate from lightning and from accidental or deliberate ignition through human activity. Bushfires, including forest fires and grassland fires pose a threat in nearly all parts of the country, in different areas at different times of the year.

Since the first recorded death in 1850, there have been over 700 bushfire fatalities in Australia (Blong 2005). The estimated average annual cost of bushfires in Australia is $77 million (BTE 2001). Two iconic events, Ash Wednesday in 1983 and Black Tuesday in 1967, dominate house losses during the period considered; 1967 to 1999. While bushfires contribute only 7% of the cost of all major natural disasters in Australia, bushfires are the fourth most frequent disaster type.

Likelihood analysis for bushfire involves modelling the chance of arrival and the intensity of the bushfire. High-resolution digital elevation data, observations of fuel load and detailed information on weather conditions are required to adequately determine the level of hazard.

Aggregated probability models of house loss are commonly used to assess the impact of bushfires. The vulnerability of a building can be determined by analysing potential ignition points in combination with the likely ignition mechanisms, such as ember attack. Detailed cadastral information and high-resolution aerial photography are used to determine the exposure of structures to bushfire attack.

Current climate projections suggest that the risk of weather conducive to fire will increase across much of the country, which may result in increased bushfire impacts if fuel distribution and fuel types remain similar. Increased fire-weather risk could also reduce the opportunity for hazard reduction activities, further exacerbating the likely impact of bushfire.

Further research into bushfire behaviour is needed to quantify the impact of bushfire on the Australian community. Acquisition of the base datasets, such as topography and land use data, will also greatly advance the analysis of risk. Assessments of exposure and vulnerability to bushfires are also critical to a thorough assessment of the risk.

Aerial view of the devastation caused by the Ash Wednesday fires at Fairhaven, Aireys Inlet, Victoria, February 1983
Photo courtesy: Emergency Management Australia.

Landslide

Landslides in Australia are predominantly caused by an increase in pore water pressure from leaking infrastructure, or by intense or prolonged periods of rainfall. The three main types of landslide which occur in Australia are rockfall, debris flow and deep-seated landslide.

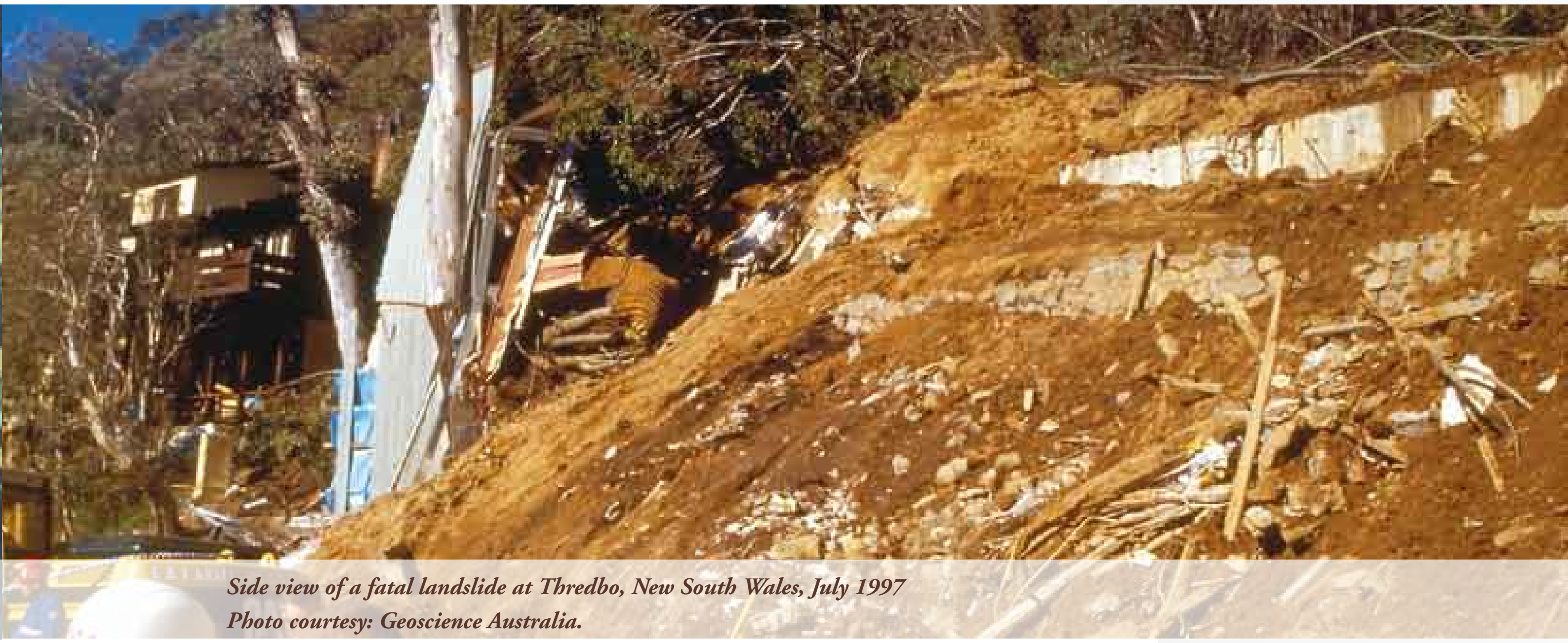
Since 1842 there have been approximately 84 known landslide events, collectively responsible for at least 107 fatalities (GA 2007). The economic cost of individual landslide events is typically much lower than the cost of other hazard events, with only one landslide event, the 1997 Thredbo landslide, achieving the damage threshold of $10 million used in calculating the impacts of severe events (BTE 2001).

Each type of landslide is governed by a different physical process and therefore needs to be analysed separately. Modelling likelihood involves determining the spatial and temporal probability of each landslide type. Some of the information necessary for effective modelling includes a good landslide inventory of historic events, an understanding of the source area and run-out path of landslide material, an understanding of the local site conditions, and data on the factors which trigger landslide.

Consequence analysis involves consideration up-slope, down-slope, laterally and in the run-out path of a landslide of the potential effects on elements such as buildings and people.

The influence of climate change on landslide impacts is an area for further work. Existing climate change projections suggest more frequent high-intensity rain, which may increase the frequency of some types of landslides.

Further research is also needed to understand and manage the risk from landslides to Australian communities. There are areas where landslide susceptibility mapping has not been conducted, and areas where a more rigorous analysis of the hazard and risk is required.



Side view of a fatal landslide at Thredbo, New South Wales, July 1997
Photo courtesy: Geoscience Australia.

Earthquake

Australia is in a relatively stable region which experiences few earthquakes large enough to cause damage in any given year. However, history clearly demonstrates that moderate-sized earthquakes have the potential to tragically affect Australian communities. Similarly, there is potential for much larger earthquakes to occur in urban areas, which could cause massive destruction and loss of life.

Earthquakes have been estimated to contribute 13% of the cost of natural disasters, at an annual average damage of $145 million (BTE 2001). However, the cost of earthquakes in Australia can be attributed almost entirely to the impact of a single earthquake—the Newcastle earthquake in 1989, which resulted in 13 fatalities (BTE 2001).

An understanding of earthquake risk requires an understanding of how frequent and how large earthquakes are likely to be in any particular region; how the ground shaking caused by the earthquake propagates; and how vulnerable communities and infrastructure are to the ground shaking. In practice this involves three key stages for assessing likelihood (i.e. earthquake source, ground motion and site response models) and two key stages for assessing consequence (i.e. exposure and vulnerability models).

By combining these models it is possible to quantify the risk, and to design structures to minimise the chance of catastrophic losses. To achieve this outcome requires high-quality seismic data; knowledge of the regional geological structures, including detailed near-surface geology; and comprehensive building and infrastructure inventories.

Because of the rarity of large earthquakes in Australia, there are several gaps in the fundamental data required for earthquake modelling. Further research is needed to identify active faults and their potential for releasing damaging earthquakes. Research is also needed to examine how soils in urban Australia will behave during earthquakes, as the manner in which near-surface soils respond to or amplify earthquake ground shaking has a dramatic effect on the resulting impact. Research into the performance of buildings and infrastructure exposed to earthquake shaking is also needed.

Damage following a devastating earthquake at Newcastle, New South Wales, December 1989
Photo courtesy: Emergency Management Australia.

Tsunami

Tsunamis occur rarely, but they are potentially very damaging. They are most often caused by earthquakes, but they can also be caused by landslides, volcanic eruptions or meteorite or comet impacts.

There is currently no estimate of the average cost to Australia from tsunami events. Anecdotal evidence from historic events suggests that the damage so far has been slight and restricted to marine and localised coastal areas. However, it is possible that Australia may be affected by large events in the future, which may cause much more widespread damage and fatalities.

Modelling the likelihood of a tsunami of a certain size reaching Australia involves two stages: modelling the likelihood of the source occurring in a location that could send a tsunami towards Australia, and modelling the propagation of the tsunami to the coast and any consequent inundation.

Modelling the source requires a good knowledge of the physical properties of possible sources (i.e. earthquake, landslide, volcano or meteorite/comet). Modelling the tsunami itself also requires a good knowledge of the bathymetry between the source and the coast. Once the tsunami reaches the coast, high-resolution digital elevation data of the potentially affected communities are also required.

To understand the consequence of a tsunami, information such as the height and velocity of the tsunami needs to be combined with knowledge of the structures and people within the area inundated, and how resistant the structures might be to the impact of the tsunami. The amount of warning time and the level of community awareness of the warning can also affect the consequences of a tsunami.

Since tsunamis happen so infrequently, it is not possible to use the historic record to accurately calculate the frequency of these events. To supplement the historic catalogue, evidence from prehistoric events and numerical modelling using high-resolution digital elevation data can be used. Accurately estimating the probability of events and the vulnerability of buildings and infrastructure are major areas for research.

Emergency treatment of survivors following a devastating tsunami in Aceh, Indonesia, December 2004
Photo courtesy: AusAID.

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An inundated farmhouse from flooding of the Hunter River near Hinton, New South Wales, June 2007
Photo courtesy: NSW SES/Phil Campbell.

Introduction

Australia experiences a range of meteorological and geological hazards. Some natural hazards occur only in certain climatic, geological or topographic regions, while others have a high potential of occurring anywhere on the Australian continent.

Natural disasters have helped to shape Australia's history. Notable examples include Cyclone *Mahina* (1899), Cyclone *Tracy* (1974), the Sydney hailstorm (1999) and the floods in New South Wales (1955) and southeast Queensland (1974). Other examples include the Newcastle earthquake (1989) and the Thredbo landslide (1997) in New South Wales, and bushfires such as Black Friday (1939), Ash Wednesday (1983) or the Canberra bushfires (2003).

Devastation to a building caused by Cyclone Larry at Innisfail, Queensland, March 2006
Photo courtesy: Geoscience Australia.

A flood in Ipswich, Queensland, January 1974
Photo courtesy: Hughes Collection/Ipswich Historical Society/A. Wright.

State Emergency Service volunteers involved in rescue efforts at a fatal landslide at Thredbo, New South Wales, July 1997
Photo courtesy: Geoscience Australia.

Remains of a house after the Ash Wednesday fires at Anglessa, Victoria, February 1983
Photo courtesy: Emergency Management Australia.

Smaller events which affect fewer people or are less severe, but occur more frequently, emphasise that the risk posed to the Australian community by natural hazards is real. Two recent smaller events declared natural disasters were Cyclone *Larry* (2006) and the storms and floods in the Hunter and central coast regions of New South Wales (2007).

The impact of natural hazards on both the natural and human environments has been recorded since European arrival through diary entries, newspaper articles and anecdotal accounts. Oral history, Aboriginal Dreaming stories and the geological record also provide some evidence of natural hazards and their impacts in Australia.

Australians have a long history of responding to disasters and can be proud of their successes in managing natural hazards through mitigation. However, recent natural disasters serve as a reminder that there is much more to be done to reduce the risk to communities and minimise losses.

As Australia's population and density of living continue to grow, so does the potential impact of a natural disaster upon the Australian community. Increasing numbers of people, buildings and infrastructure assets are being exposed to natural hazards as the pressures for urban development extend into areas of higher risk.

Australia's ability to deal with a catastrophic disaster which has the potential to exceed the combined resources of all jurisdictions was considered in the 2002 high-level report to the Council of Australian Governments (COAG) *Natural Disasters in Australia. Reforming Mitigation, Relief and Recovery Arrangements* (COAG 2004). The review concluded that although the probability of such an event occurring was low, the consequences of such an event would be extreme; and that the Australian community was not sufficiently prepared.

The need for a new approach to extend beyond existing measures to ensure 'a world-class national framework for natural disaster management' was identified (COAG 2004). As the report states (COAG 2004, p. 13):

> ***'Central to the new approach is a systematic and widespread national process of disaster risk assessment and, most importantly, a paradigm shift in focus towards cost effective, evidence-based disaster mitigation. This represents an historic move beyond disaster response and reaction, towards anticipation and mitigation.'***

The report includes 64 recommendations and 12 reform commitments aimed at improving existing practice to achieve 'safer, more sustainable communities, and reduced risk, damage and losses.'

This report, *Natural Hazards in Australia: Identifying Risk Analysis Requirements*, is a step towards meeting some of the objectives identified by COAG. In particular, this report relates to the first two reform commitments recommended by COAG (2004, p. 14):

> ***'1. develop and implement a five-year national programme of systematic and rigorous disaster risk assessments***
>
> ***2. establish a nationally consistent system of data collection, research and analysis to ensure a sound knowledge base on natural disasters and disaster mitigation.'***

This report also relates and contributes to the National Risk Assessment Framework (NRAAG 2007) which has been prepared by all levels of government. The framework identifies the need to produce consistent information on risk so that risks can be compared for different locations and for different natural hazards. The framework aims to produce an increasing evidence base for decision making in disaster mitigation.

Accurately modelling the likely impacts of natural hazards on communities provides decision makers with the tools to make more informed decisions aimed at reducing the impact of natural hazards. Minimising the impact of natural disasters must involve a long-term commitment from those in policy and programme areas at all three levels of government. It must also be done in close partnership with industry and with community involvement and support. It is a vital long-term investment in the welfare of the community, requiring significant foresight and planning.

Scope

The natural hazards selected for inclusion in this report were guided by the definition of a natural disaster stated in the report to COAG (2004, p. 4):

> ***'a serious disruption to a community or region caused by the impact of a naturally occurring rapid onset event that threatens or causes death, injury or damage to property or the environment and which requires significant and coordinated multi-agency and community response. Such serious disruption can be caused by any one, or a combination, of the following natural hazards: bushfire; earthquake; flood; storm; cyclone; storm surge; landslide; tsunami; meteorite strike; or tornado.'***

These disasters are also eligible for the Natural Disaster Relief and Recovery Arrangements (NDRRA) administered by the Australian Government through the Department of Transport and Regional Services (DOTARS).

Notable omissions from this definition include hazards such as heatwave, drought and frost. Heatwaves have killed more people in Australia than all other natural hazards combined, with the elderly particularly at risk. Severe drought regularly affects some parts of Australia, often with enormous impacts on agriculture and the economy. For example, the drought from 1991 to 1995 is estimated to have cost the Australian economy $5 billion and had a large social impact.

Frosts also regularly occur in Australia and have the potential to cause significant losses to agriculture. While heatwave, drought and frost are not considered in this report, they are increasingly being recognised as critical issues in Australia.

While the term 'natural hazard' is used throughout this report it is important to note that not all hazards that impact communities are initiated through natural means, and that the potential impact of a hazard is the same regardless of its origin. For example, arson is a common source of ignition for bushfires in Australia, and human activity can exacerbate the occurrence of landslides and floods.

Report Intent

This report provides an overview of the rapid onset natural hazards which impact on Australian communities. Emphasis is placed on identifying risk analysis requirements for tropical cyclone, flood, severe storm, bushfire, landslide, earthquake and tsunami events, with a particular focus on likelihood and consequence as identified in the risk management standard AS/NZS 4360:2004.

This report will be of value to those who have an interest in, or a responsibility for, the management of natural hazards and the reduction of their impacts. This may include policy makers, emergency managers, land use planners, researchers and members of the general community. The report is targeted at several levels and the reader should be guided by their experience, responsibility and level of interest.

The reader is encouraged to seek out more detailed information in areas of particular interest, using the reference list provided as a starting point. The reader is also encouraged to seek out the most up-to-date information, to consult those with expert knowledge in an area, and to challenge existing practice with the aim of improving it where appropriate.

Report Structure

The introductory chapter provides the context to the report and outlines the report's scope, intent and structure. Chapter 2 considers the impact of natural disasters in Australia, including their distribution and socioeconomic cost, and the role that policy plays in natural disasters. Chapter 3 provides a brief introduction to risk analysis.

Chapters 4 to 10 are hazard specific. It is acknowledged that many of the hazards do not occur in isolation from each other. Flooding, for example, can result from a tropical cyclone or severe storm. However, to avoid repetition, each phenomenon is outlined in the most appropriate chapter.

The tropical cyclone chapter (Chapter 4) incorporates severe wind, storm tide, heavy rainfall and east coast lows.

Flooding is the most costly natural disaster, and Chapter 5 focuses on flood from rainfall, including riverine flooding and flash flooding.

Severe storms, though very localised, are the most frequent and widespread natural hazard throughout Australia. The severe storm chapter (Chapter 6) focuses on thunderstorms and describes lightning and thunder, hail, wind gusts and tornadoes.

Bushfire also poses a significant threat to the Australian community; grassland fire and forest fire are described in Chapter 7.

Landslide, the first of the non-meteorological hazards examined, is covered in Chapter 8. However, landslides are often triggered by meteorological events such as heavy or prolonged rainfall. The chapter focuses on rockfall, debris flow and deep-seated landslide.

Earthquake is covered in Chapter 9. Although the level of earthquake hazard in Australia is relatively low, the reinsurance cost for earthquakes is higher than for any other natural hazard in Australia.

The final hazard included in this report is tsunami. The tsunami chapter (Chapter 10) incorporates meteorite strike, along with earthquake, volcano eruption and submarine landslide, because of their potential to trigger a tsunami.

Chapters 4 to 10 follow an identical structure. Each chapter:

- describes the hazard and its occurrence in the Australian setting
- provides an overview of what is known about the cost of the hazard
- summarises the potential influence of climate change (where relevant)
- outlines the factors required in the analysis of risk, with a focus on likelihood analysis and consequence analysis. This includes identifying the broad data and information that are required to undertake a risk analysis
- identifies some of the gaps in information and research, and data constraints relating to risk analysis
- provides an overview of the roles played by different agencies and groups in managing the risk posed by the natural hazard.

The first three sections of each hazard chapter and the overview of roles and responsibilities will be of interest to the general reader. The sections on risk analysis and information gaps will be of more interest to the specialist reader.

A glossary defines some of the non–hazard specific key terms used throughout the report. A reference list is also provided as a basis for further reading.

Chapter Two:

Impact of Natural Disasters

A burnt out fire truck on Warragamba Avenue following the fire storm in Duffy, Australian Capital Territory, January 2003
Photo courtesy: The Canberra Times/Richard Briggs.

Impact of Natural Disasters

Natural hazards have impacted on people since humans first walked on the earth. They have influenced, shaped and modified human behaviour, changing the way people live with and respond to the environment. In Australia alone, billions of dollars have been spent in trying to mitigate or prevent, prepare for, respond to and recover from natural disasters. Moreover, natural disasters have resulted in enormous intangible losses, causing grief through the loss of life and personal possessions.

A range of measures are used to illustrate the potential or actual impact of natural disasters. Examples include the probability or frequency of occurrence of a hazard, the number of people killed or injured, or the number of buildings damaged and the extent of that damage. An economic cost may be assigned, taking into account any of a number of measures. An economic cost, however, does not adequately portray the sense of enormous social loss that results from disaster.

Banana crops destroyed by Cyclone Larry near Innisfail, Queensland, March 2006
Photo courtesy: Geoscience Australia.

Destruction of the curator's residence in the Botanical Gardens by a flood in Brisbane, Queensland, February 1893
Photo courtesy: John Oxley Library/123308/Poul Poulsen.

Damage to railway tracks resulting from an earthquake in Meckering, Western Australia, October 1968
Photo courtesy: Geoscience Australia.

Road damage caused by a slow moving landslide at Pleasant Hills, North Tasmania
Photo courtesy: Geoscience Australia/captured in 1996.

This chapter provides an insight into aspects of natural disasters in Australia, including their distribution and the influence of communities. The socioeconomic impact of natural disasters in Australia is described, as well as the role of policy in influencing the impacts of natural disasters. The primary information sources used throughout the report are also highlighted.

Natural Hazard Phenomena and their Potential Effects

Natural hazards have the potential to cause a number of primary and secondary phenomena. The secondary phenomena produced by a natural hazard vary with event, as does their severity.

Tropical cyclones bring strong winds and heavy rains which cause secondary hazards such as flood, storm tide, landslide and water pollution. Flood inundates areas, which in turn may lead to landslide, erosion, water quality deterioration or turbidity, as well as sediment deposition. Severe storms range from isolated thunderstorms to intense low-pressure systems producing phenomena such as severe winds, heavy rain, lightning, flood, storm tide, hail and coastal erosion.

Secondary effects of bushfires include water pollution, erosion and reduced water catchment yield. A landslide may block a watercourse, leading to flooding and debris flows upstream. Earthquakes may also bring fire, flood, water pollution, landslide, tsunami and soil liquefaction, which can be as devastating as the primary hazard.

Each of these phenomena may produce physical, social and economic effects (Institution of Civil Engineers 1995). Physical effects on the built infrastructure may involve structural and non-structural damage and/or progressive infrastructure deterioration. They may also result in the release of hazardous materials such as chemicals which are usually stored in a safe environment. Social effects may include fatalities, injuries, homelessness or loss of income; or secondary effects such as psychological impact, disease or loss of social cohesion.

Economic effects may include business disruption; disruption to the supply of power, water and telecommunications; and the cost of response and relief operations. Secondary economic impacts, such as insurance losses and rising premiums, loss of investor confidence, and costs of providing welfare and medical assistance, may also result (Institution of Civil Engineers 1995).

However, a natural hazard is not inherently negative, as hazards produce a disaster only when they impact adversely on communities. Natural hazards can bring positive environmental and social benefits. Bushfires, for example, can stimulate growth and regenerate forest ecology, as the heat from fire is required for some seeds to germinate (Luke and McArthur 1977). Floodplains are picturesque places for recreational activity and floods can bring welcome relief for people and ecosystems suffering from prolonged drought.

Primary Information Sources used for Measuring Natural Disaster Impact

There are several sources of information which can be used to estimate the impact of natural disasters. The report *Economic Costs of Natural Disasters in Australia* (BTE 2001) is the main source referred to within this report for the estimated cost of disasters. Other primary information sources referred to include the Emergency Management Australia (EMA) Disasters Database (EMA 2007), the Insurance Council of Australia (ICA) Catastrophe List (ICA 2007), and Australian Government data on the Natural Disaster Relief and Recovery Arrangements (NDRRA) (DOTARS 2007a).

Red Cross volunteers helping with disaster relief, Victoria, 1986
Photo courtesy: Emergency Management Australia.

The socioeconomic cost estimates throughout this report are indicative only. Each source, and its limitations for the purpose of this report, is briefly described below. These summaries emphasise the difficulties of estimating the cost of natural disasters.

Economic Costs of Natural Disasters in Australia Report

The *Economic Costs of Natural Disasters in Australia* report (BTE 2001) was based on information from EMA Track (now the EMA Disasters Database) for the period from 1967 to 1999. In developing estimates of economic cost, insurance data from the ICA, as well as information from the media and published reports on disasters, were incorporated. Only natural disasters in Australia with an estimated total cost greater than or equal to $10 million (excluding costs associated with deaths and injuries) were considered. Both tangible and intangible costs were considered where the data were available. Estimates are usually given in 1998 dollar values. Details on the limitations in the completeness and accuracy of data used are provided in the report.

Emergency Management Australia's Disasters Database

The EMA Disasters Database is the main Australian Government database containing information on injuries, fatalities and costs of natural, technological and human-caused events. For inclusion in the database, disasters must have resulted in three or more deaths, 20 injuries or illnesses, and/or losses of $10 million or more.

Cost estimates are intended to include both insured and uninsured losses. Insured losses are sourced from the database maintained by the ICA. Uninsured losses are derived from a number of sources and relate to costs of repair and replacement to private property, public buildings, assets and records, and damaged infrastructure. Each cost estimate is stated in dollar values of the year in which the disaster occurred (EMA 2007).

Insurance Council of Australia's Catastrophe List

The Catastrophe List (or database) maintained by the ICA contains data on insured natural disasters since 1967. The database includes events which are likely to cost $10 million or more, or events declared a disaster by an appropriate government authority irrespective of the loss sustained. Insured losses are original costs incurred at the time of the event.

The ICA database records insured losses for an event by aggregating the losses from the following categories: residential (property, contents, vehicle); commercial (property, contents, vehicle, plant and equipment, interruption); rural (fencing, plant and equipment, crop); marine;

aviation; and engineering and construction The database is updated following each disaster event, though it can take up to 12 months for the full insured cost, particularly the commercial component, to be known.

Natural Disaster Relief and Recovery Arrangements Data

The NDRRA are administered by DOTARS on behalf of the Australian Government. Financial assistance is provided to eligible Australian states and territories following natural disasters.

Relief measures provided under the NDRRA include grants for relief of personal hardship and distress; concessional interest rate loans to primary producers, small businesses, voluntary non-profit bodies and individuals in need; restoration or replacement of essential public assets; and provision of counselling. In severe events, a community recovery package which includes a community recovery fund and clean-up grants for small businesses and primary producers may also be made available, subject to the approval of the Prime Minister (DOTARS 2007b).

Limitations of Data and Information Sources

The intended purposes of each data source must be considered when looking at the information they provide. Of the four mentioned above, only the NDRRA and ICA resources are confined to data obtained directly from the original source.

The data on NDRRA are limited to providing estimates on the Australian Government's NDRRA expenditure following natural disaster events. NDRRA data do not include expenditure from other government sources, such as state and territory and local government contributions. They also do not include other Australian Government expenditure such as the Australian Government Disaster Recovery Payments administered by Centrelink.

The database maintained by the ICA provides information on insured losses. It records a large proportion of costs associated with those disasters which are covered as part of all insurance policies, such as earthquake. It provides limited information for those hazards for which very few companies offer insurance. Consequently, losses for flood, tsunami, storm tide and landslide are greatly underestimated, as the provision of insurance for those hazards has been very limited.

Additionally, not everyone has insurance. Therefore, insured losses, particularly the contents component, represent only a proportion of the actual losses experienced by a community. The uptake of residential contents insurance is about 72%, although the rate varies considerably between owner-occupiers and renters. Building insurance is much more widespread, with an uptake in the Australian community for owner-occupied residential dwellings at 96% (Tooth and Barker 2007).

A level of underinsurance also exists. While the level has yet to be quantified, underinsurance is likely to be greatest during times of inflation or real estate boom, when the value of properties and contents increases rapidly. It is therefore believed that insured loss significantly understates actual losses.

All of the information sources have thresholds which must be reached before an event is included. The cut-off threshold is usually $10 million, or a number of deaths or injuries, per event. Therefore, natural hazards which occur regularly throughout Australia but rarely meet this threshold, such as landslide, are under-represented.

Distribution of Natural Disasters

The distribution of natural disasters in Australia varies both spatially (i.e. in space or location) and temporally (i.e. in time). The future distribution of some natural hazards may also be affected by climate change.

Spatial distribution of natural disasters is influenced by region and by topography. Hazards and disasters also vary in the size of the geographical area affected. Temporal distribution is influenced through factors such as frequency of occurrence, speed of onset and event duration, and seasonal weather conditions.

Spatial Distribution

While earthquakes and severe storms have the potential to occur anywhere in Australia, many of Australia's natural hazards occur only in reasonably well-defined regions. For example, tropical cyclones generally occur only in the northern, tropical regions of Australia. Similarly, riverine flooding is generally limited to low-lying areas adjacent to water courses.

Topography also plays an important role in the occurrence or impact of tsunami, storm tide, tropical cyclone, bushfire and landslide. The onshore impact of storm tide is limited to lower lying coastal areas. Similarly, the shape of the ocean floor and coastal topography play a large role in the behaviour and onshore impact of tsunami. Bushfire spreads faster when travelling up-slope. The wind speed from tropical cyclones or severe storms increases in areas of high relief. Landslides are common in hillside areas, although in some circumstances they occur on shallow slopes.

Generally speaking, the larger the area affected by a hazard event the greater the number of people or communities that are likely to experience loss or disruption. For example, the Black Friday bushfires in 1939 burned 1.6 million hectares across four states and the Australian Capital Territory and resulted in 84 fatalities (EMA 2007). Similarly, a tsunami might have successive impacts on an entire state's coastline as waves continued to travel away from the tsunami's source. Such a broad impact can make an event very difficult to effectively mitigate and respond to. However, these catastrophic but generally rare events must be considered in any comprehensive risk analysis.

The hazard impact may also be localised but cause loss of life and widespread disruption. For example, on average, lightning strikes kill between three and four people (Coates and others 1993) and result in over a hundred injuries (Courtney and Middelmann 2005) each year.

Significant damage to electrical appliances and communications equipment from lightning strikes is also common. For example, the *West Australian* of 25 January 1999 states that lightning strikes during an electrical storm in January 1999 resulted in more than 10,000 Perth residents reporting phone damage, with some having to wait up to 10 days to be reconnected. The cost to a major telecommunications company was estimated to exceed $1 million.

Lightning strikes are also a major ignition source for bushfires, with devastating impacts. During a single day in January 2003, lightning strikes started 87 fires in eastern Victoria (DSE 2007). The devastating Canberra bushfires of January 2003 were also started by lightning strikes.

Similarly, tornadoes occur in small localised areas but are intense and often have devastating effects. In 1918, three tornadoes occurred in the Melbourne suburb of Brighton. Though the tornadoes lasted only about two minutes, they destroyed or severely damaged buildings and caused two fatalities and many injuries (BoM 2007).

Temporal Distribution

The impact of natural disasters also has a temporal or time element. For example, the time of day or night at which a hazard occurs affects the scale and nature of a disaster, particularly in terms of mobile elements such as people and vehicles. A disaster which strikes in a residential area during the day is likely to have a lower death toll than a similar disaster that occurs during the night when people are at home sleeping.

Across a much larger time scale, increased population growth and urbanisation can influence the magnitude of a disaster. The temporal distribution of disasters in terms of their frequency of occurrence, speed of onset and event duration, and in terms of seasonal weather conditions, is described below.

Frequency of occurrence

Records of past events highlight the devastating impacts caused by natural disasters. They can also provide an insight into what may be expected in the future. Emergency managers often prioritise their mitigation and planning to focus on hazards which have regularly impacted on their community's history. Consequently, Australian communities are often better prepared in areas where particular events occur fairly frequently, such as floods in Lismore in New South Wales or bushfires in the Mount Lofty Ranges in South Australia.

However, many of the natural hazard events which affect Australia occur irregularly and have unexpected and devastating impacts on communities. One such event was the 1989 earthquake in Newcastle, New South Wales. In general terms, the lower the recurrence interval of hazards the less adequate the technologies and practices to control or mitigate them tend to be. An important part of risk analysis is to consider 'what if' scenarios in order to assess the risk for types of events which have not occurred, including those with the potential to be severely damaging.

Speed of onset and event duration

Some natural hazards, such as tropical cyclone, flood and tsunami, can often be detected hours or days before they impact upon a community. Other hazards, such as earthquake, can impact suddenly and without warning.

In catchments where the topography is relatively flat, such as in central Australia, floodwaters may be slow moving and shallow, but spread over thousands of square kilometres. A flood warning may be issued up to several months in advance, providing ample time for flood mitigation measures to be implemented downstream. However, in steep catchments, with often deeper water travelling at high velocities, warning time may be only a few hours, adding to the resulting impact.

The opportunity for emergency services to activate an emergency response plan and for residents to react to a warning is important, because it influences disaster losses. The Australian Tsunami Warning System provides approximately 90 minutes warning prior to a tsunami reaching the Australian coastline. Although short, this warning time provides emergency services with an opportunity to reduce the loss of life and damage caused by the event.

Lightning in Wollemi National Park, New South Wales, January 2007
Photo courtesy: Will Barton Photography.

A flood in Lismore, New South Wales, May 1963
Photo courtesy: NSW SES.

A grassland fire in the Bethungra Hills near Junee, New South Wales, January 2006
Photo courtesy: Will Barton Photography.

The length of time for which a natural hazard affects a specific place or region is also different for each hazard type. For example, in 1999 Sydney experienced Australia's most expensive insured natural disaster event. A supercell thunderstorm took 20 minutes to pass and produced the largest hailstones ever recorded in the Sydney region, while the entire storm lasted about five hours.

In contrast, a devastating earthquake may last for only tens of seconds. However, aftershocks may occur for days or weeks after the main event. Though landslides frequently occur suddenly, for example, as a rock fall, they may also be slower moving. Floods can inundate an area for weeks, though inundation of only a few days or hours is more typical. A grassland fire may run out of fuel within a few hours, while a forest fire may burn for many weeks.

Seasonal weather conditions

Earthquake and tsunami events have the potential to occur at anytime of the year. In contrast, bushfire, tropical cyclone and severe storm events are often seasonal. For example, the official tropical cyclone season in the Australian region runs from 1 November to 30 April (BoM 2007). This enables media advertising campaigns aimed at raising the community's awareness to target the lead-up of each tropical cyclone or bushfire season.

Bushfires tend to occur only where there are sufficient fuel loads and conditions for fire spread. These conditions are highly correlated to seasonal weather conditions, which affect the growth and drying out of vegetation. Climate variations across Australia mean that at any time of the year there is some part of the continent that is prone to bushfires, with the country's different weather patterns reflected in varied fire seasons. In southern Australia most fires occur during summer and autumn, while for northern Australia the fire season is winter and spring. The peak danger period for New South Wales and southern Queensland is spring and early summer (BoM 2007).

Potential Influence of Climate Change

Climate change will potentially affect the impact of some natural disasters, changing both their spatial and temporal distribution. The Fourth Assessment Report by the Intergovernmental Panel on Climate Change (Solomon and others 2007) indicates a likely increase in bushfires in southern and eastern Australia. The same report suggests an increase in the severity and frequency of storms and coastal flooding by 2050. The development of real estate in coastal areas affected by rising sea levels will exacerbate risk.

Crews work at repelling a fire as it burns over the Brindabellas and into the suburb of Gordon, Australian Capital Territory, January 2003 Photo courtesy: The Canberra Times.

For hazards such as tropical cyclone and storm tide, Australia is likely to suffer from less frequent but more extreme events in the future (Meehl and others 2007). This suggests that when an event does occur in a populated area the impact is likely to be severe. The potential influence of climate change for tropical cyclone, flood, severe storm, bushfire and landslide is described in more detail in the relevant hazard chapters.

Influence of Communities on Natural Hazards

A key distinction exists between what is termed a 'hazard' and what is referred to as a 'disaster'. For example, Twigg states (2001, p. 2):

> ***'We are concerned about natural hazards because they might lead to disasters. A disaster is the impact of a hazard on a community/ society—usually defined as an event that overwhelms that community/society's capacity to cope.'***

Humans therefore play a key role in creating 'natural' disasters. Blaikie and others state (1994, p. 3):

> ***'The crucial point about understanding why disasters occur is that it is not only natural events that cause them. They are also the product of the social, political, and economic environment (as distinct from the natural environment) because of the way it structures the lives of different groups of people.'***

A disaster may effect a largely urban environment, cause damage to an agricultural region, or both. Cyclone *Tracy* in 1974 caused devastation because it hit the city of Darwin. Had the tropical cyclone passed just 60 kilometres to the south, the impact would have been significantly less. More recently, Cyclone *Larry* in 2006 caused widespread devastation to agricultural crops and a number of towns in north Queensland.

The effects of urbanisation and increasing population growth and density, most notable in the big cities and coastal regions, have led to greater demand for and concentration of infrastructure and a higher potential exposure to natural hazards. Therefore, it is not surprising that in Australia the majority of deaths from natural hazards are concentrated in Australia's southeast, where a large proportion of the population is located (Blong 2005).

Combined with increasing wealth and materialism, the socioeconomic cost of a natural disaster today would typically be much greater than the cost of an event of the same magnitude and geographical extent that occurred at an earlier moment in history.

For example, since the massive development on the Hawkesbury–Nepean river floodplain in New South Wales, the catchment has fortunately not experienced a flood disaster. However, historical records reveal that large floods have occurred, the most severe of which was the devastating flood of 1867. Another example is the Glenorchy landslide of 1872, which caused the largest and most damaging debris flow recorded in Tasmania since European settlement (Mazengarb and others 2007). Were similar events to be repeated today, the impact on the now densely built or developing areas nearby would be severe.

Any mitigation measures implemented in the intervening periods may help to reduce the impact of some of the more frequently recurring events. Engineering and town planning professions have long been involved in flood mitigation, for example, through the construction of levees and land use planning controls. These methods, coupled with the implementation of effective warning systems, have resulted in a dramatic reduction in the loss of life from floods in Australia over the past 200 years.

Australia has also incorporated structural design standards for wind and earthquake into the building code (AS 4055:2006; AS/NZS 1170.2:2002; AS 1170.4:1993). The success of the wind-loading standard in mitigating wind damage was demonstrated in the impact of Cyclone *Larry* in March 2006, for example (Edwards and others 2007).

While the past can be used as an indicator of what may happen in the future, disasters will happen in areas where there is no memory or experience of them. This may be because the hazard has never arisen in the area before. This is particularly true for rarer, but potentially catastrophic, hazards such as earthquake and tsunami.

For example, three earthquakes with a Richter magnitude greater than 6 occurred in a single day in 1988 near Tennant Creek, Northern Territory. The region was previously thought to have had virtually no seismic activity (Bowman 1992). It is now classified as having a high hazard level, and provides an example of a hazard map which changed significantly after a large event. It illustrates how unreliable hazard maps can be if they are based on inadequate sampling of data.

Socioeconomic Cost of Natural Disasters

The cost of natural disasters in Australia and worldwide varies greatly from year to year (BTE 2001; ICA 2007; Walker 2005). Some years are punctuated by extreme, highly damaging disasters with large social and economic costs, while in other years fewer and/or less damaging events are experienced.

Insurance companies, governments, businesses and charities often absorb a large proportion of the cost following a disaster and are effective mechanisms for spreading the cost beyond those immediately affected. It can be concluded that the costs of natural disasters are eventually passed on to individual consumers and tax payers. Mechanisms need to be developed in order for these costs to be adequately factored into economic cost estimates for a better understanding of the cost of natural disasters to Australian communities.

A disaster will affect various parts of the community in different ways. For example, disasters have a greater financial impact on people of lower socioeconomic status (Blaikie and others 1994; Dwyer and others 2004). Although a household on a lower income may spend less in total terms than a wealthier household, they are likely to spend a higher proportion of their income on recovery (Institution of Civil Engineers 1995). Households on lower incomes are also less likely to have purchased insurance (Tooth and Barker 2007). Therefore, disasters may impose a greater social impact on those with lower incomes. Similarly, a small business is likely to feel the impact of a disaster much more than a multimillion dollar company.

While a single cost is typically assigned to a disaster, the composition of that cost should always be considered. Some questions for consideration may include: What direct costs are considered and how are there costs calculated? Have indirect tangible costs been considered and, if so, which ones? Has loss of life been considered and, if so, how?

Framework for Calculating Losses

A range of tangible and intangible measures are used to estimate disaster losses. Tangible measures are relatively easy to assign a loss to: for example, the loss of a car. Intangible measures, however, are much more complex and variable. The loss of cultural icons and personal memorabilia, for example, will affect people differently.

Tangible and intangible measures are generally described in terms of direct and indirect costs. Direct costs are the consequence of the initial disaster event and will be felt immediately, for example, through the loss of a life or destruction of a house. Examples of indirect losses are the costs of goods or services which, as a result of a disaster, are not produced or provided, and the inconvenience and stress imposed on people.

An economic framework is often employed to capture the measures used in calculating costs arising from natural disasters. A framework which portrays different types of losses arising from a natural disaster is shown in Figure 2.1, developed using Smith and others (1995) and SCARM (2000) as a reference tool.

An economic framework incorporates concepts such as the costs of a small business that has burnt down or the number of houses that have been destroyed. The framework attempts to capture those costs and any benefits which result from the flow-on effects of the disaster. Following the Canberra bushfires in 2003, for example, construction costs increased due to the high demand for builders and materials. In the example of a small business being destroyed, the framework would try to capture the cost of the salaries that the employees of the small business ceased to receive when the business was lost.

The measure most frequently used to calculate damage is direct tangible cost. This includes costs associated with replacing, rebuilding or repairing items which have been damaged or destroyed, and is often calculated through insurance costs. Clean up costs are also considered direct tangible costs.

Indirect tangible costs may include financial elements, such as accommodation costs and lost revenue, and the loss of opportunity through disruption of public services. Business continuity is also a significant component of indirect costs. For example, when the supply of agricultural

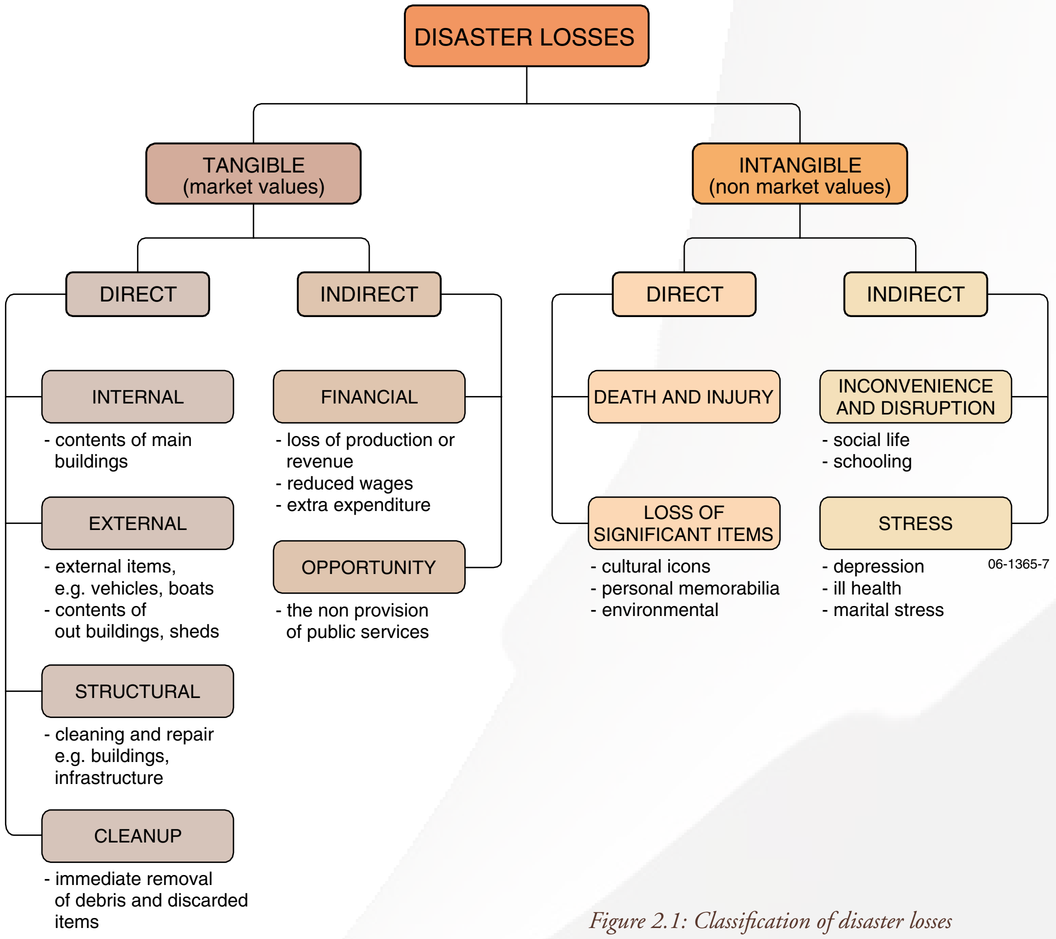


Figure 2.1: Classification of disaster losses

produce is affected by a disaster, the increased cost has implications reaching beyond the area immediately affected by the disaster. This was illustrated by the four-fold increase in the price of bananas across Australia that followed Cyclone *Larry* in 2006; prices returned to pre-disaster levels close to 12 months after the event (ABS 2007; ABS 2006a; ABS 2006b).

Tangible costs do not provide a complete picture of how extensive or devastating an event was, or the number of lives lost and the magnitude of social disruption caused. These losses are often described as intangible. Costs are sometimes assigned for intangible direct losses, such as loss of life and injury.

However, intangible indirect losses are very difficult to measure. The intangible impacts of a disaster, such as emotional trauma, may persist long after the event. The intangible impacts often remain even when recovery indicates that the tangible costs have ceased to be significant.

Economic Costs in Australia

The average annualised cost of natural disasters in Australia is estimated at $1.14 billion and includes an estimate of the costs of deaths and injuries (BTE 2001). All other references to economic cost in this report excludes the cost of deaths and injuries.

An annual estimation of economic cost in the period from 1967 to 1999 is shown in Figure 2.2. Floods, severe storms and tropical cyclones are estimated to have caused the greatest economic losses during those 33 years, as shown in Figure 2.3.

Figure 2.4 shows the average proportional annual cost of disasters for each state and territory, while Figure 2.5 shows the proportional cost of each type of disaster for each Australian state and territory, for the same period. Almost half of the total economic cost of disasters was incurred in New South Wales; severe storms made the greatest contribution to cost.

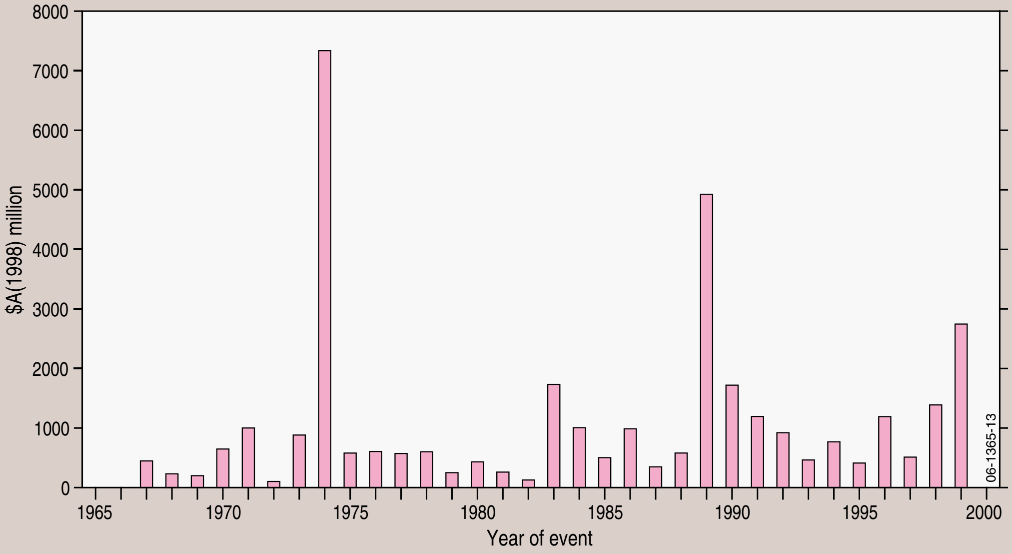


Figure 2.2: Annual total cost of natural disasters in Australia, 1967 to 1999
Source: BTE (2001), Figure 3.1.

During the same period, tropical cyclones dominated costs in the Northern Territory and Western Australia. Although Queensland suffered from the impact of many tropical cyclones during this period, tropical cyclones did not contribute a high proportion of cost to Queensland's total disaster expenditure. This can be attributed to the relatively high contributions of other meteorological hazards, including flood, bushfire and severe storm.

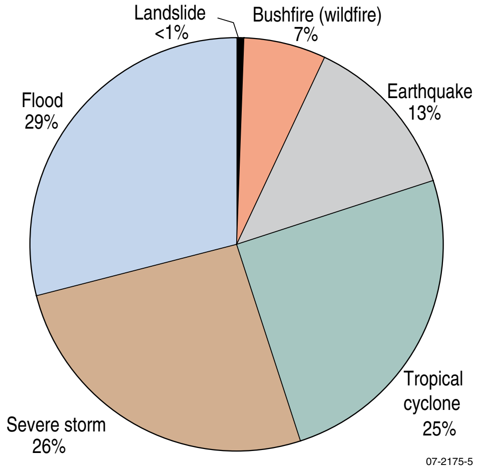


Figure 2.3: Average proportional annual cost of natural disasters, by type, 1967 to 1999
Source: Based on BTE (2001), Table 3.1.

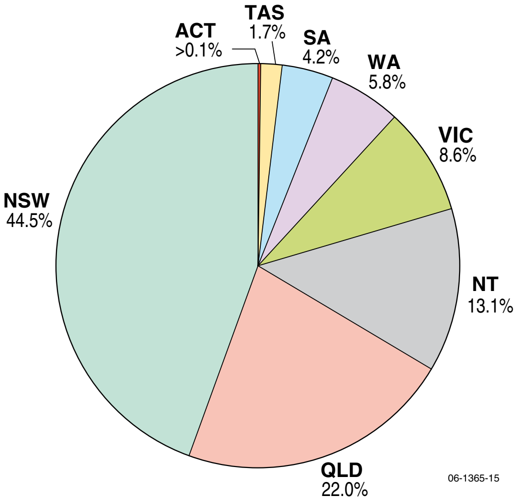


Figure 2.4: Average proportional annual cost of natural disasters by state/territory, 1967 to 1999
Source: Based on BTE (2001), Table 3.1.

Landslides occur regularly in Australia and, while the individual cost of each event is low, the cumulative costs to road and rail infrastructure and private property are high. The landslide in Thredbo, New South Wales, in 1997 was a notable exception, as a single event with very high costs. Historically, the impact of tsunami has been minimal, and that hazard is not included in the BTE (2001) data.

Single large events profoundly affect the total cost of natural disasters. This is particularly evident when comparing the number of events to the total cost. For example, Cyclone *Tracy* in 1974 dominates disaster costs in the Northern Territory. The Newcastle earthquake in 1989 has been the major contributor to the total cost of earthquakes in Australia, at 94%, and a significant contributor to disaster costs in New South Wales, at 29%. The Sydney hailstorm in 1999 contributed significantly to the cost of severe storms in New South Wales, causing damage estimated at $2.2 billion. The Ash Wednesday bushfires in 1983 were the major contributor to the total cost of bushfires during the 33-year period (BTE 2001).

It is expected that, given the disasters that have occurred since 1999, such as the Canberra bushfires in 2003 and Cyclone *Larry* in 2006, the proportions in Figure 2.4 would differ considerably if they took into account more recent data, particularly for the Australian Capital Territory and Queensland.

Insured Losses and Australian Government Payments

Another source of information on the cost of natural disasters is the expenditure of the Australian Government through NDRRA. Funding is administered to eligible states and

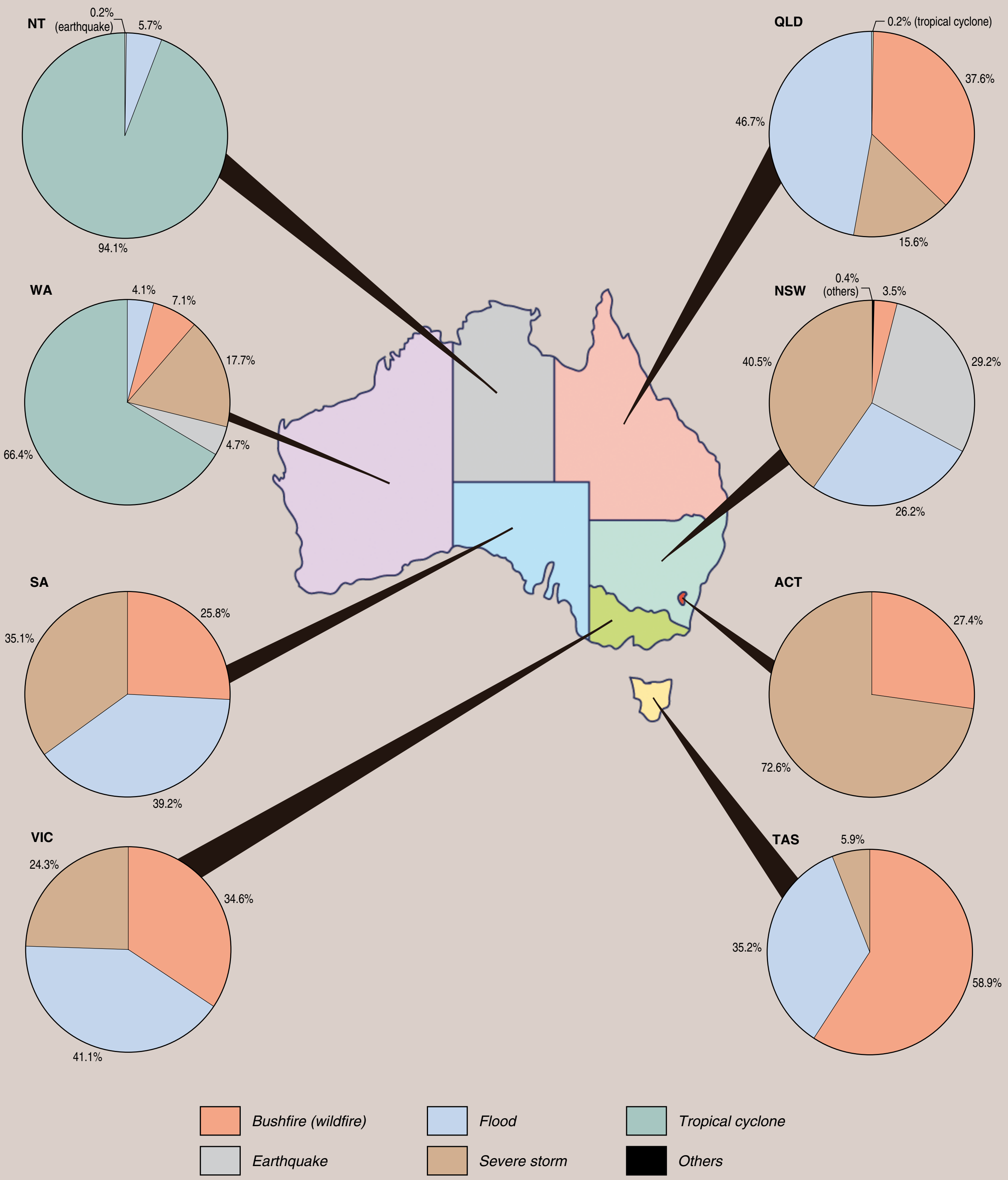


Figure 2.5: Average proportional annual cost of natural disasters in each state/territory, by type, 1967 to 1999
Source: Based on BTE (2001), Figure 3.12.

territories, following a natural disaster, by DOTARS.

In Figure 2.6, the expenditure of NDRRA is compared with insured losses from the ICA Database of Catastrophes for the financial years from July 1994 to June 2006.

It is evident from Figure 2.6 that insurance payouts significantly exceeded NDRRA expenditure. The most notable example occurred in 1999 following the Sydney hailstorm. Because of the type of impact, the event was readily costed through insurance claims. This highlights the role that insurance can play in reducing government expenditure, though NDRRA is only one aspect of government expenditure on natural disasters. Nevertheless, insured losses are still only a small proportion of estimated total costs, as shown in Figure 2.7 for the period from 1967 to 1999.

This emphasises that estimating losses solely from one source may be misleading. The expenditure resulting from the devastation caused by Cyclone *Larry* in 2006 is another example of the danger of using only one source to look at cost. An estimate of the total damage bill by a global reinsurance intermediary is $1.4 billion (Guy Carpenter 2007). Estimates of insured losses are $640 million (Guy Carpenter 2007) and $540 million (ICA 2007), while the EMA Disaster Database estimates total losses at $360 million (EMA 2007).

Building Damage

Meteorological hazards, including tropical cyclone, flood, severe storm and bushfire, accounted for 94% of total structural damage to buildings during the period from 1900 to 2003 (Blong 2005). More specifically, tropical cyclones contributed the greatest proportion of total building damage, at approximately 30%, as shown in Figure 2.8. Severe storms and floods contributed similar amounts to building damage. Severe storms included damage relating to wind gusts (excluding those associated with tropical cyclone), tornadoes and hailstones.

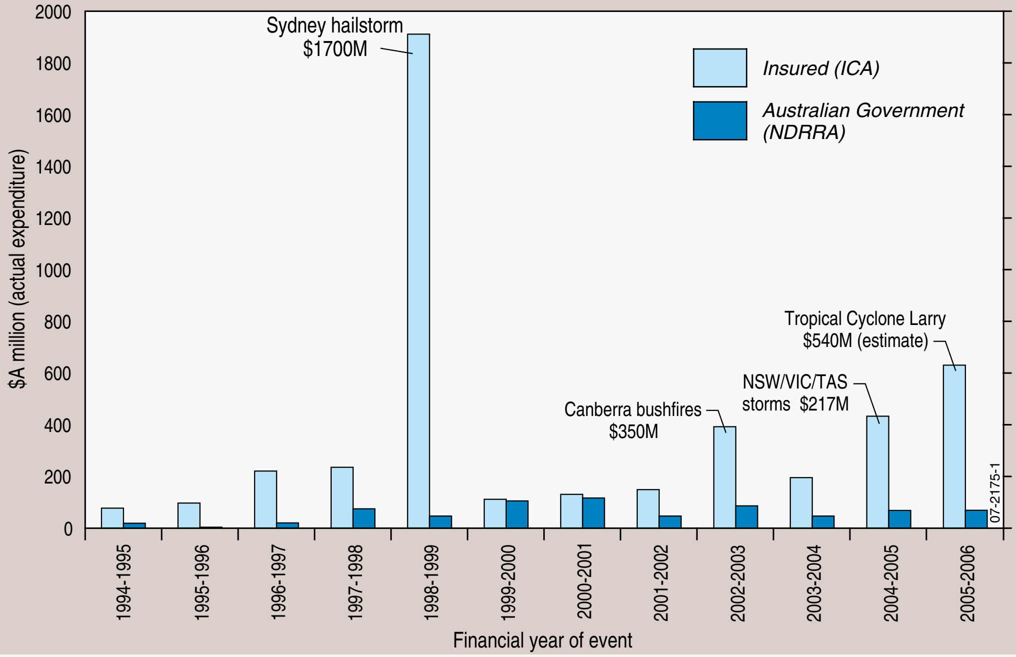


Figure 2.6: Actual expenditure following natural disasters in Australia
Note: NDRRA payments do not necessarily correspond with the year in which a disaster occurred, as the state governments occasionally delay seeking reimbursement.
Source: Insured cost has been calculated using the ICA Database of Catastrophes (ICA 2007). Australian Government expenditure has been calculated from the NDRRA payments (DOTARS 2007b).

Figure 2.7: Total and insured costs by natural disaster type, 1967 to 1999

Source: BTE (2001), Figure 3.13.

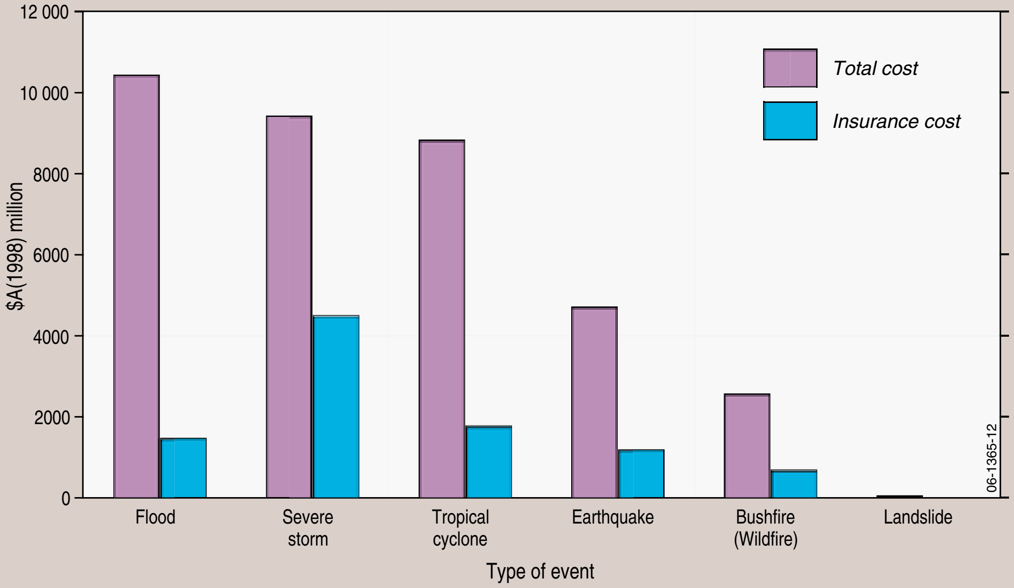


Figure 2.8: Proportion of total building damage caused by natural hazards, by type, 1900 to 2003

Source: Blong (2005), Figure 4.

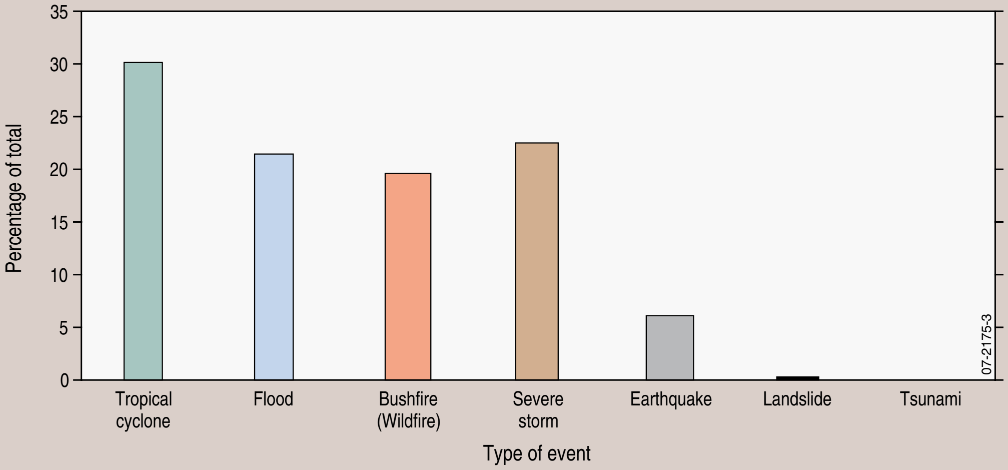
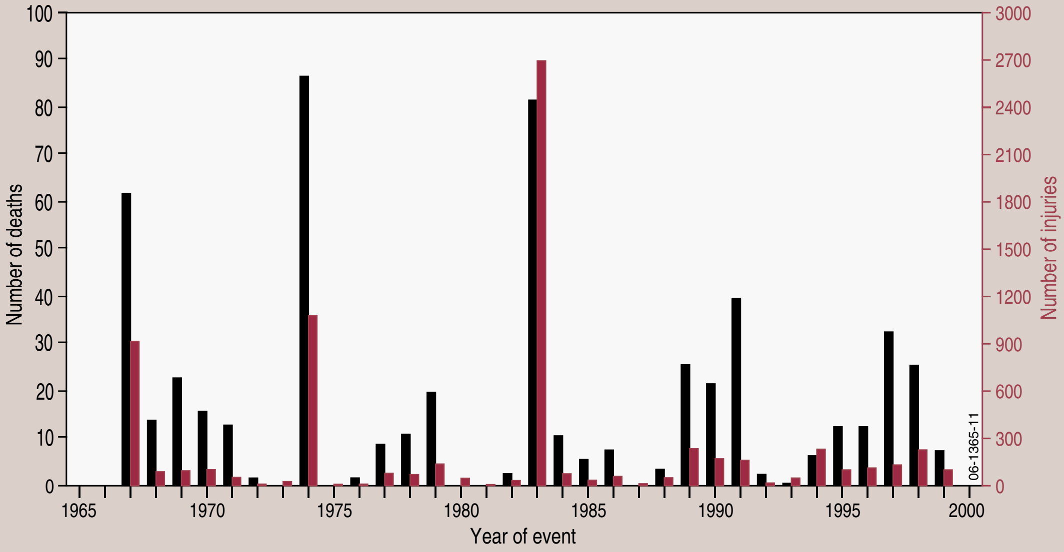


Figure 2.9: Number of natural disaster deaths and injuries, 1967 to 1999

Source: Based on BTE (2001), Figures 3.28 and 3.29.



Past experience has shown that a single event which causes extensive building damage can significantly bias the total cost. For example, of the 1200 events included in Blong's calculations (Blong 2005), half of the total damage can be attributed to only 20 events.

Intangible Losses

The numbers of deaths and injuries arising from natural disasters in Australia varies considerably from year to year, as shown in Figure 2.9. Over the period from 1967 to 1999, 565 fatalities and more than 7000 injuries were recorded (BTE 2001).

The Ash Wednesday bushfires (1983), Cyclone *Tracy* (1974) and the Tasmanian bushfires (1967) contributed the largest number of natural disaster–related deaths and injuries in the 33-year period (BTE 2001). The Ash Wednesday bushfires in Victoria and South Australia had very high intangible costs, with 250,000 people affected. This included 75 fatalities, 2700 injuries and 9000 people made homeless. Cyclone *Tracy* resulted in slightly fewer fatalities, with 71 lives lost. Fewer people were injured (650), and fewer people were affected overall (47,000), but many more were made homeless (41,000). The bushfires in Hobart in 1967 killed 62 people, injured 900 people, affected 35,000 people and made 7000 people homeless (EMA 2007).

Less damaging events result in intangible losses which are significant to those affected, but are often not recognised in the same way as events declared as natural disasters. In a survey of primary producers undertaken by Geoscience Australia after Cyclone *Larry*, it was found that papaya growers had experienced similar crop losses caused by less intense cyclones on a number of prior occasions. Cyclone *Larry*, however, caused widespread devastation to many crop types. This enabled the papaya growers to receive financial assistance for the first time, as part of the Australian Government's cyclone relief package.

Meteorological hazards, including bushfire, flood, tropical cyclone and severe storm, accounted for 95% of fatalities during the 33-year period, as

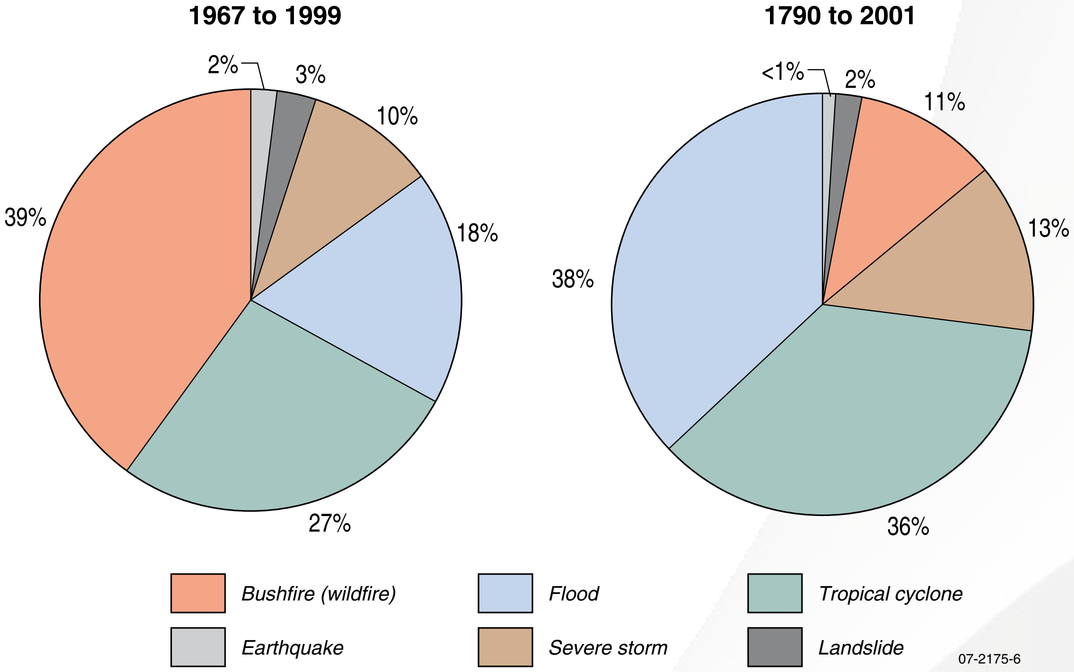


Figure 2.10: Proportion of fatalities caused by natural hazards, by type, 1969 to 1999 and 1790 to 2001
Note: The date of the first recorded death varies: bushfire -1850, flood - 1790, tropical cyclone - 1839, earthquake - 1902, severe storm - 1824 and landslide - 1842. Source: Based on BTE (2001), Table 3.2 and Blong (2005), Table 1.

shown in Figure 2.10, with bushfires contributing the most fatalities (BTE 2001). Figure 2.10 also shows that over a much longer period, from 1790 to 2001, flood-related fatalities surpassed the number of recorded deaths from bushfires and tropical cyclones (Blong 2005). The proportions of deaths arising from non-meteorological hazards remain very low in the second sample.

While the number of deaths and injuries is the primary measure of disaster impact in developing countries, an economic value is the primary measure used in Australia. The difference in measures used may be attributed to the decrease in fatality rates in Australia over the past two centuries, which allows economic costs to be considered as relatively significant. The decrease in the fatality rate due to natural disasters in Australia in the period from 1790 to 2001 is in the order of three magnitudes, as illustrated in Figure 2.11.

It is believed the decrease in natural disaster fatalities is testament to successful disaster mitigation strategies, particularly during the 1800s, which focused on reducing loss of life. These included improvements in warning systems, emergency services, land use planning, communication, education and the development of building codes, and a greater understanding of the characteristics and impacts of natural hazards.

Evidence for Prehistoric Natural Hazard Impacts

The historical record from which Australian experience in disaster management is principally derived is largely limited to the period following the arrival of the first European settlers in 1788. However, natural hazards often leave evidence of their occurrence in a region's landscape. For example, large tsunamis can deposit massive layers of sand that can be preserved for millions of years and provide a significantly longer record of tsunami occurrence than recorded history.

Information on tsunami characteristics such as wave height, run-up and velocity can be acquired by studying the sediments, stratigraphy, size and distribution of deposits (Atwater and others 2005). If several tsunami deposits occur in stratigraphic sequence, dating of the deposits

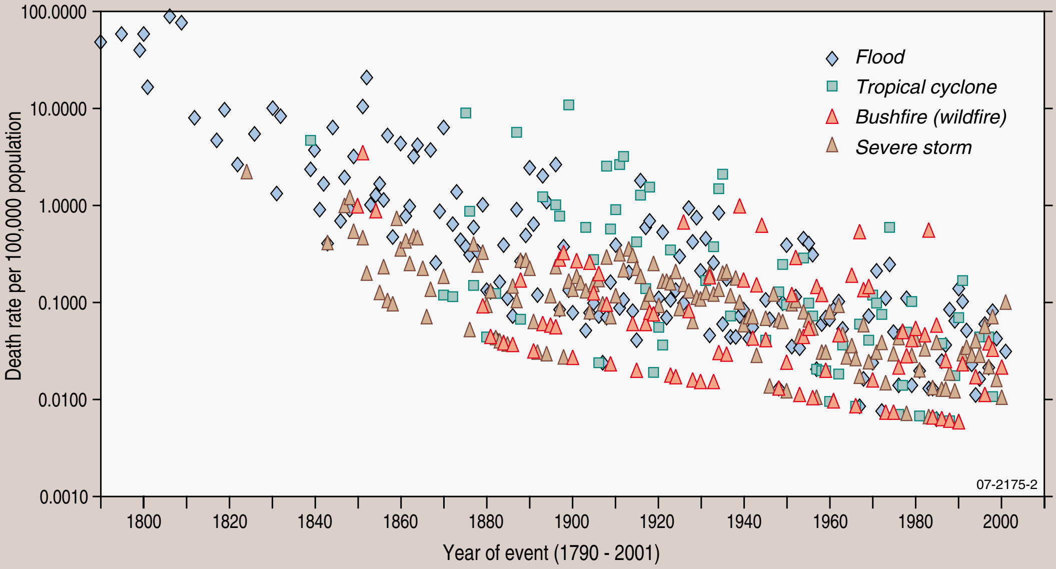


Figure 2.11: Fatalities caused by natural disasters per 100,000 population, 1790 to 2001
Source: Risk Frontiers cited in Blong (2005), Figure 2.

allows estimates of frequency (Cisternas and others 2005). Researchers have reported evidence thought to have been formed by large tsunamis along the Australian coastline (Bryant and Nott 2001; Switzer and others 2005); however, this work remains controversial (Felton and Crook 2003; Dominey-Howes 2007). These deposits suggest that past tsunamis were several orders of magnitude greater than any experienced in the historical period.

Evidence of prehistoric large earthquakes can also be found in the landscape, informing research on issues such as the spatial distribution of earthquake-prone regions, and the maximum likely magnitude and likelihood of recurrence of large events (Sandiford 2003; Clark and others in review–a; Clark and others in review–b). For example, the earthquake that occurred in Meckering, Western Australia, in 1968 produced a fault scarp 2 metres high and 37 kilometres long, which is still clearly visible. Two trenches excavated across the fault scarp revealed that a large earthquake had ruptured the same fault several hundred thousand years previously (GA 2007).

However, a preliminary analysis of data collected across Australia for traces of large prehistoric earthquakes suggests that large earthquakes are not restricted to the places where seismic activity is recorded today. The heights and lengths of many prehistoric fault scarps are much greater than those of the 1968 Meckering scarp, suggesting that earthquakes of much greater magnitude are possible almost anywhere across Australia (Clark 2007, written communication).

Various techniques have been used to investigate cyclonic variability over thousands of years. Some include analysis of lake sediments (Liu and Fearn 2000), dune ridges (Nott and Hayne 2001), pollen types in coastal sediment cores (Elsner and others 1999) or overwash deposits (Liu and others 2001).

Evidence for ancient flood events can be found through the examination of river sediments. Debris found high above normal river levels may also provide evidence for large flood events prior to the written record (McCarthy and others 2006).

The much longer history provided by the geological record provides evidence for much larger events than those in the historical record. This highlights the possibility of Australia experiencing far more devastating impacts than those experienced in human memory.

The Role of Policy in Natural Disasters

Government policy determines the future development of Australia and the wellbeing of people living within Australia's borders. Therefore, policy plays a fundamental role in influencing the impact of natural disasters, particularly in areas such as land use planning, construction standards and emergency management.

The Role of Government

The arrangements under the Australian Constitution (Commonwealth of Australia 1900) influence the management of natural hazards in Australia. That is, because emergency and disaster management is not addressed specifically in the Constitution, the states and territories have largely assumed responsibility for managing the impact of natural hazards (EMA 2000). The Australian Government guides and supports the states and territories in this role.

Local governments are often responsible for undertaking risk management and serving as the key point of contact for local emergency issues, because of their close ties to the community (EMA 2000). Further information on the roles and responsibilities of all levels of government is outlined in *Natural Disasters in Australia: Reforming Mitigation, Relief and Recovery Arrangements* (COAG 2004).

Disasters as Focusing Events

Natural disasters can influence changes in policy. Disasters have been described as 'focusing events' or 'turning points' in policy, and play an important part in setting agency agendas. The seriousness of the impact on a community and the extent to which that was recognised, rather than the size of the hazard, were found to be the key determining factors (Birkland 1997).

In Australia two examples stand out as focusing events in the management of natural disasters. The Brisbane floods in January 1974 led to the formation of the Natural Disasters Organisation (now EMA), and Cyclone *Tracy* in December 1974 cemented public resolve and political support for disaster planning (Walker 1999).

Political Will for Change

Political will and/or support is essential for change. Often, the optimal or preferred solution for managing natural hazards is not popular. For example, it is believed the reluctance by some governments to release flood maps stems partly from the fact that such a move would be unpopular with the real estate industry, developers and individual owners of flood-affected property, who fear that releasing such information would compromise the value of land (Yeo 2003). Similarly, Pelling states that (2003, p. 34):

> ***'inappropriate planning and legislation can exacerbate vulnerability. This is often an outcome of piecemeal approaches to development or inefficiencies in the administrative infrastructure.'***

Figure 2.12 shows an example from the Launceston region in Tasmania, where houses built in inappropriate locations were subsequently destroyed by landslides. In this instance, the planning system was unaware of the potential hazards and there was inadequate geotechnical investigation prior to development (Ezzy and Mazengarb 2007; Mazengarb 2007, written communication).

Information on natural hazards can often be seen as controversial or having the potential to cause panic if not adequately communicated. The development of appropriate policies and communication strategies to deal with sensitive situations is therefore essential. Equally important is instilling a culture of safety and local participation in the community. The recommendation by the Council of Australian Governments (COAG) (COAG 2004) to make all information on risk publicly available is one important step towards including the community in the solution to reducing risk.

Long-term, Apolitical Policy Development

Natural hazards are not confined by state or political boundaries. The actions of one local government can and do influence the potential impact of a natural hazard on neighbouring political areas. The construction of a dam or levee in one local government area, for example, may affect flood levels in other local government areas, depending on where they are located.

Policy relating to the management of natural hazards needs to be holistic (Twigg 2001), cross-jurisdictional and focused on achieving the best outcome for the whole Australian community. Arrangements, programs and policies within and between the different levels of government contribute to many effective natural disaster management relationships.

The cost of natural disasters can far outweigh the cost of preventative measures, in both economic and social terms. Investing in natural disaster risk reduction can be cost effective, as discussed by COAG (2004) and demonstrated for flood mitigation (BTRE 2002).

Figure 2.12: Orthophoto of Lawrence Vale, Tasmania, where over 40 houses were destroyed by landslide activity in the period from the 1950s to the 1970s
Source: Based on Ezzy and Mazengarb (2007), Figure 3.

Volunteers from the Wollongong State Emergency Services unit, New South Wales
Photo courtesy: NSW SES.

Reducing the risk of natural disasters requires the ability to correctly recognise emerging issues or problems. Two examples of emerging issues are demographic shifts to coastal regions in Australia, often known as the 'sea change phenomena', and the potential influence of climate change on meteorological hazards.

However, identifying and analysing risk are only parts of the process. The risk needs to be reduced to an acceptable level, by adopting risk evaluation and treatment strategies that ensure safer communities.

Incentives to Reduce Impact

The incentive for one level of government to minimise a natural hazard risk is reduced if another level of government pays for loss arising from the hazard (Environment Canada 2006). Therefore, policy should provide incentives for processes and practices to be implemented to help minimise risk.

Many mechanisms can be used by government and the insurance industry to help reduce risk. The provision of economic incentives and penalties such as grants, loans and taxes is one example (Institution of Civil Engineers 1995). The provision of resources, including professional expertise, is another.

Policy can be aimed at reducing risk on a large scale through land use planning and/or development controls. At an individual householder level, the reduction of insurance premiums on the provision that steps have been taken to minimise the household's risk might be an effective incentive.

A change in the NDRRA rules has had a big impact across Australian local governments. To be eligible for assistance, applicants are now required to demonstrate that mitigation measures have been adopted. Consequently, the majority of local government areas in Queensland and New South Wales have completed disaster risk management studies to demonstrate that they are actively attempting to mitigate their risks to be eligible for NDRRA (Granger 2007, written communication).

Link Between Research, Policy and Practitioners

Creating closer links between policy, research and practice is central to reducing the impact of natural disasters. Communication across these domains provides an appreciation, understanding and involvement across interrelated areas and is of high importance in reducing risk.

However, for science and research to effectively influence policy development, information must be clearly communicated to government in a timely and understandable manner. This is vital in ensuring scientific research reaches its full potential and assists policy makers to make informed and relevant decisions using the best information available. As the Centre for European Flood Research observes (CRUE 2007, p. 7):

> ***'If scientists really want to influence policy more, researchers need to become more visible, and clearer about the kind of changes they are aiming for, and are able to achieve.'***

Practitioners need to communicate effectively to those whose role is to develop policy. Similarly, any policy which is developed needs to be coherent in whole-of-government terms. It is also vital that those involved in policy development seek the expertise of those working 'on the ground'. Researchers need to liaise with practitioners to find out what their needs are, and work toward developing relevant methodologies and techniques which can be easily applied and communicated to effectively inform policy makers.

Successful linking of policy and research requires an open, continuous dialogue. Where this relationship is effective and natural hazard impacts are minimised, the benefit is felt by politicians, policy makers, researchers, practitioners and the community.

Conclusion

Natural disasters have a significant economic, social, environmental and political impact on the community. While some of the impacts of natural disasters can be mitigated, the risk cannot be completely eliminated. Therefore, decisions regarding what risks are acceptable need to be made by those involved in managing natural hazard impacts.

Tropical cyclones, floods, severe storms and bushfires and the phenomena that they produce have had by far the greatest impact historically in Australia. However, a single event, such as a moderate earthquake in Sydney, could change the historical picture of natural hazards.

It is for this reason that modelling potential impacts for a full range of small through to extreme events, and considering the potential impacts of climate change, is important. The study of prehistoric impacts of natural hazards can be useful in extending the knowledge provided by historical records.

The socioeconomic cost and natural disaster policy, as much as the spatial and temporal distribution of both hazards and communities, need to be considered when managing the impact of natural disasters. A hazard develops into a disaster when it has a widespread or concentrated negative impact on people.

While Australia's growing economy and technological advances may assist in managing disasters, they also make communities more vulnerable to the potential impact of hazards. This occurs through the increase and concentration of the population and the built environment, and a greater reliance on infrastructure such as power and water supplies.

The difficulty of measuring the actual impact of a natural disaster on the community continues to be a major challenge because of the complexities in assessing loss. Intangible losses, such as destruction of personal memorabilia and the effects of post-disaster stress, are particularly difficult to measure. Though insured losses are the most easily captured, they are only a small proportion of total losses.

These challenges need to be kept in mind when measuring and communicating 'impact'. A key to reducing the overall risk is for those who play a role in the management of natural hazards to work closely with the wider community, as well as with each other.

Chapter Three:

Risk Analysis

A flooded road in Canberra, Australian Capital Territory, June 1956
Photo courtesy: National Archives of Australia/NAA: A7973, INT482/23.

Risk Analysis

Risk analysis involves developing an understanding of risk, which is an important step in the risk management process, and provides the foundation upon which informed decisions on mitigation may be based. Analysing risk allows priority areas to be targeted for mitigation and can assist in the allocation of limited resources. Risk analysis may therefore play an important role in cost–benefit studies, which compare the costs of a particular action or project against its potential benefits.

This chapter provides an overview of risk analysis, with a particular focus on assessing the components of likelihood and consequence. Three factors which contribute to risk—hazard, exposure and vulnerability—are introduced.

Building damage following an earthquake in Newcastle, New South Wales, December 1989
Photo courtesy: Geoscience Australia.

State Emergency Service volunteers remove a tree from a roof following storm damage, New South Wales, January 1991
Photo courtesy: Emergency Management Australia.

A destroyed house following a bushfire on the Eyre Peninsula, South Australia, January 2005
Photo courtesy: Geoscience Australia.

State Emergency Service flood rescue boat used to transport fodder to stranded stock, northeast Victoria, October 1993
Photo courtesy: Emergency Management Australia.

Risk

Many definitions of 'risk' exist (Kelman 2003; Thywissen 2006). Risk is defined by the risk management standard AS/NZS 4360:2004 as (p. 4):

> ***'the chance of something happening that will have an impact on objectives. A risk is often specified in terms of an event or circumstance and the consequences that may flow from it. Risk is measured in terms of a combination of the consequences of an event and their likelihood.'***

'Likelihood' describes how often a hazard is likely to occur, and is commonly referred to as the probability or frequency of an event. 'Consequence' describes the effect or impact of a hazard on a community. Both likelihood and consequence may be expressed using either descriptive words (i.e. qualitative measures) or numerical values (i.e. quantitative measures) to communicate the magnitude of the potential impact (AS/NZS 4360:2004).

Risk in disaster management has been described by Crichton (1999) as the probability of a loss, which depends on three factors: hazard, exposure and vulnerability.

A 'hazard' refers to a single event or series of events which is characterised by a certain magnitude and likelihood of occurrence. 'Exposure' refers to the elements that are subject to the impact of a specific hazard, such as houses on a floodplain. 'Vulnerability' is the degree to which the exposed elements will suffer a loss from the impact of a hazard. These terms are described in further detail later in this chapter. The reader is also referred to the glossary for definitions of key terms.

Figure 3.1 portrays risk as a triangle. The area inside the triangle represents risk and the sides of the triangle represent the three independent factors that contribute to risk: hazard, exposure and vulnerability in equal proportions. Changing any one of the three components changes the amount of risk.

Figure 3.1: The risk triangle
Source: Crichton (1999), Figure 3.

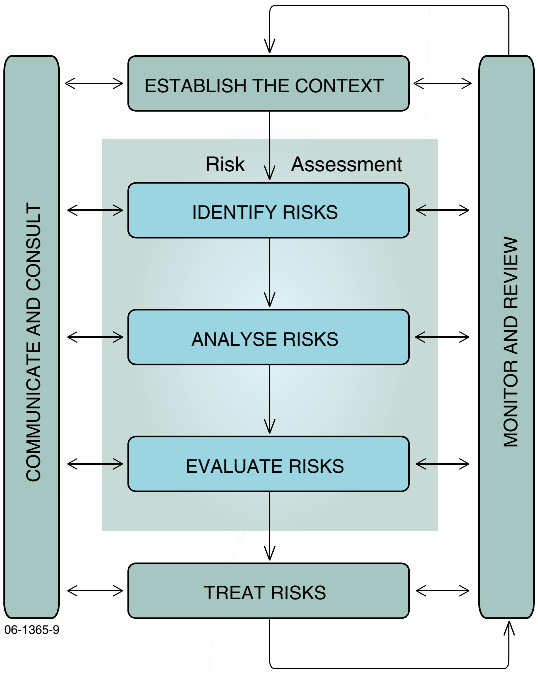


Figure 3.2: Risk management process
Source: AS/NZS 4360:2004, Figure 2.1.

Risk Management Process

The risk management standard AS/NZS 4360:2004 provides a framework for managing the risk posed by hazards. The broad steps involved in the risk management process as outlined in the standard are shown in Figure 3.2.

Damage caused by a bushfire on the Kings Tablelands, Blue Mountains, New South Wales, December 2006
Photo courtesy: Will Barton Photography.

The steps include: establish the context, identify risks, analyse risks, evaluate risks and treat risks. Throughout each step of the risk management process, it is essential to communicate and consult with stakeholders, and monitor and review the process. The steps in the shaded subsection—identify risks, analyse risks and evaluate risks—form the risk assessment process.

As AS/NZS 4360:2004 is generic, individual disciplines and persons have tailored individual sections to suit their areas of expertise and responsibility. For example, Emergency Management Australia (EMA) has developed a detailed risk management process for emergency management (EMA 2004), and the Australian Geomechanics Society (AGS 2007) has developed guidelines for landslide risk management.

The reader is referred to AS/NZS 4360:2004 and its companion guide HB 436:2004 for further information on the steps in the risk management process.

Risk Analysis

This report focuses on the third step in the risk management process, risk analysis, as defined by AS/NZS 4360:2004 (p. 4):

'the systematic process to understand the nature of and to deduce the level of risk. It provides the basis for risk evaluation and decisions about risk treatment.'

The type of risk analysis varies depending on the situation being considered. This is succinctly described in the standard AS/NZS 4360:2004 (p. 18):

'Risk analysis may be undertaken to varying degrees of detail depending upon the risk, the purpose of the analysis, and the information, data and resources available. Analysis may be qualitative, semi-qualitative or quantitative or a combination of these, depending on the circumstances.'

A risk analysis is usually conducted to identify adverse consequences, although it may also be used proactively to identify and prioritise potential opportunities (AS/NZS 4360:2004).

Risk Evaluation Criteria

The development of a set of risk evaluation criteria against which risk levels and the effectiveness of suggested treatment strategies can be measured is one component of establishing the context, the first step of the risk management process (AS/NZS 4360:2004). Developing risk criteria requires decisions to be made on specifically which risks are to be evaluated, and may be based on any number of types of criteria, such as humanitarian, social, environmental, operational and financial.

The risk analysis should be consistent with the risk evaluation criteria established up front. The evaluation criteria against which the level of risk is assessed will play a part in defining the methods used to analyse risk (HB 436:2004). Important evaluation criteria which should be considered are: the consequences that will be addressed (e.g. number of people killed or injured), how likelihood will be defined (e.g. qualitatively or quantitatively), and how it will be determined whether the risk level is such that further treatment activities are required (HB 436:2004).

Setting the evaluation criteria will also focus the risk analysis. For example, if the priority is to protect human life before considering economic loss, an economic analysis should take second place. Setting the evaluation criteria also assists in defining levels of risk acceptance.

Examples of possible risk criteria for managing the impact of natural hazards include establishing the tolerable number of fatalities and injuries, and the tolerable number of damaged or destroyed public infrastructure assets and facilities or private assets. 'Tolerable risk' is described in the handbook HB 436:2004 as (p. 65):

'The concept of tolerable risk derives from Sir Frank Layfield who in 1987 noted that 'although acceptable risk is often used in balancing risks and benefits it does not adequately convey the reluctance with which possibly substantial risks and benefits may be tolerated.' Thus individuals are prepared to 'tolerate' some risks under certain circumstances in return for specified benefits.'

Other examples include criteria related to impacts on cultural heritage and the natural environment, or the long-term impact on the local economy. An example of the development of specific criteria along these lines as part of a multi-hazard risk assessment is the report on risk management for Newcastle, New South Wales (Institute for International Development 2007).

Risk Factors

An understanding of three factors—hazard, exposure and vulnerability—which contribute to risk is vital in determining the potential impact or consequence of a hazard on a community or society. The hazard has been described by EMA as (1998, p. 59):

'a source of potential harm or a situation with a potential to cause loss. It may also be referred to as a potential or existing condition that may cause harm to people or damage to property or the environment.'

A hazard may affect different places independently or in combination. Some hazards are influenced by seasonal weather conditions. Hazards may also vary in duration, intensity and severity (some examples are provided in Chapter 2).

Exposure refers to 'the elements that are subject to the impact of a specific hazard' (Middelmann and others 2005, p. 1). The elements at risk are described by EMA as (2004, p. 48):

'the population, buildings and civil engineering works, economic activities, public services and infrastructure, etc. exposed to sources of risk.'

The elements at risk may be divided into tangible, intangible and institutional elements (Granger 2007). Examples of tangible elements include people, buildings and infrastructure related to power and water supply. Examples of intangible elements include heritage, personal memorabilia and community relationships. Both tangible and intangible elements are discussed further in Chapter 2.

Institutional elements include aspects such as the capacity to share information and the effectiveness of emergency management plans and coordination arrangements. However, institutional elements are rarely considered properly, because of sensitivities.

Any number and range of elements can be considered. The more elements at risk considered, the more comprehensive the risk analysis.

For a more rigorous assessment of risk, information on the vulnerability of the elements at risk to a particular hazard is required. As for risk, there are numerous definitions for vulnerability (e.g. Brooks 2003; Handmer and others 2007; Villagrán 2006). Two definitions are provided below:

'the degree of susceptibility and resilience of the community and environment to hazards' (*COAG 2004, p. 104*).

'The characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard. It involves a combination of factors that determine the degree to which someone's life and livelihood is put at risk by a discrete and identifiable event in nature or in society' (*Blaikie and others 1994, p. 9*).

Risk analysis, as defined in this report, focuses primarily on biophysical vulnerability which is experienced by the elements at risk as a result of an encounter with a hazard (Adger and others 2004). Biophysical vulnerability models aim to determine the impact of a hazard on the elements at risk, such as people, buildings, infrastructure and the economy.

Social vulnerability considers a person and/or society's inherent characteristics, such as social, economic and political background. Social vulnerability can be viewed independently of a hazard, as it refers to the characteristics of individuals which are shaped by the processes around them. For example, the loss of a house in a bushfire would not affect all individuals in the same way. This is because their situations are different, and their access to support networks such as family, friends and the community are different. The ability of individuals to recover financially from disaster also varies greatly.

Destruction caused by Tropical Cyclone Tracy in Darwin, Northern Territory, December 1974
Photo courtesy: Bureau of Meteorology.

A definition of vulnerability focused toward social vulnerability is (Twigg 2001a, p. 2):

> *'vulnerability is the human dimension of disasters. To understand what makes people vulnerable, we have to move away from the hazard itself to look at a much wider, and a much more diverse, set of influences: the whole range of economic, social, cultural, institutional, political and even psychological factors that shape people's lives and create the environment that they live in.'*

The difference between biophysical vulnerability and social vulnerability is described by Adger and others (2004, p. 30):

> *'In summary, biophysical vulnerability is a function of the frequency and severity (or probability of occurrence) of a given type of hazard, while social or inherent vulnerability is not. A hazard may cause no damage if it occurs in an unpopulated area or in a region where human systems are well adapted to cope with it.'*

There is a tendency for researchers to focus on only one aspect of vulnerability, depending on their expertise. Engineers tend to focus on building vulnerability models incorporating considerations such as structural type, building use, building codes and engineering assessment (Douglas 2007; Dale and others 2004). Economists develop models focusing on economic losses and the impact of government expenditure on recovery and mitigation options to reduce risk (Mullaly and Wittwer 2006). Social scientists focus on people, communities, access to services and organisational and institutional measures (Dwyer and others 2004; Twigg 2001b).

A comprehensive assessment of risk should consider all aspects; however, constraints in resources mean this is seldom done in practice.

A study conducted by Wittwer (2004) on modelling the economic impacts of a hypothetical earthquake in the Perth metropolitan region demonstrates the integration of building vulnerability models and economic models.

A notable example where biophysical vulnerability has been combined with social vulnerability is the 'hazards-of-place' model developed by Cutter and others (2000). Another is the development of combinations of geophysical parameters and census demographic data by Granger (2001).

The approach described by Granger (2001) breaks the elements and their vulnerability into five broad groups, relating to the setting, shelter, sustenance, security and society. The approach was applied in a case study for southeast Queensland (Granger and Leiba 2001; Granger and Hall 2001). The five broad groups are:

- the setting: basic regional data including information on the physical environment (e.g. climate and topography), access (e.g. external links by major roads and telecommunications infrastructure), administration arrangements (e.g. local government and suburb), and population and its distribution
- shelter: the vulnerability of buildings to various hazards and access to shelter
- sustenance: utility and service infrastructure, including the supply of power and telecommunications; infrastructure related to water and public health, such as water supply, sewerage and storm water; and logistic resources, such as surface transport, ports and airports, used for the distribution and transportation of items such as food, clothing and fuel
- security: a community's wealth and health, and level of protection provided, including the prevalence of access to key facilities such as hospitals, nursing homes and emergency services
- society: more intangible aspects of vulnerability which contribute to social cohesion, such as language, religion, education and involvement of groups within the community.

The elements potentially exposed to hazards remain the same, while the hazards and the vulnerability of the elements at risk vary. For example, buildings may be hazard dependent, while the vulnerability of people and economies tends to be independent of the hazard. The spatial and temporal distribution of disasters is described in Chapter 2.

The methods used to assess likelihood and consequences vary between the hazards. They also vary within a hazard type, depending on the purpose of the analysis and the information, data and resources available. The current process for assessing likelihood and consequence is described in the following chapters for tropical cyclone, flood, severe storm, bushfire, landslide, earthquake and tsunami and, where appropriate, for the secondary phenomena that they cause.

Beyond Likelihood and Consequence

This report highlights the current processes involved in analysing risk in terms of likelihood and consequence. However, the importance of extending beyond likelihood and consequence to evaluate and treat risk is acknowledged.

For example, the 'SMUG' approach (seriousness, manageability, urgency and growth) has been adopted by the New Zealand Civil Defence Emergency Management Groups to provide a more detailed risk analysis and evaluation process than that outlined in AS/NZS 4360:2004 (Cunningham 2006).

The SMUG approach is based on an earlier approach, 'SMAUG', developed by Kepner and Tregoe (1981) where 'A' is for 'acceptance'. A similar dimension called 'outrage' was proposed by Sandman (2007) to account for the political aspect of disasters, emergencies and risk.

Based on these approaches, an alternative, seven-factor risk analysis scheme, 'FSMAUGO' has been proposed by the Institute for International Development (2007). The first two factors, 'frequency' and 'seriousness', are equivalent to 'likelihood' and 'consequence' as outlined in AS/NZS 4360:2004. An additional factor has been added to account for the critical importance of community awareness of the risks posed before the impact. The factors proposed by the Institute for International Development (2007) include:

- frequency: how often a hazard is likely to occur
- seriousness: the relative impact in physical, social or economic terms
- manageability: the relative ability to reduce the risk through managing the hazard, the community or both, for example, through warnings and emergency management plans
- awareness: the level of awareness of the risks posed within the community and emergency management spheres before the hazard impact
- urgency: the measure of how critical it is to address the risk, such as how critical it is to implement a mitigation measure to address the problem
- growth: the potential or rate at which the risk will increase. This may be through an increase in elements exposed to the hazard via development and population growth, and/or an increase in the probability of an extreme event occurring, for example via the influence of climate
- outrage: the political dimension of risk. This becomes particularly evident after a disaster, as a community expresses its outrage at what it believes to have been an inadequate response or lack of preparedness on behalf of the authorities. As a result, time is spent addressing community outrage rather than community safety.

The process of risk analysis is just one step of the risk management process. Even the risk assessment stage is not the end point of the process, but should be used in making decisions about risk treatment. The evaluation criteria established at the start of the process need to be examined in the light of the risk assessment, and strategies need to be prioritised to achieve the desired target levels of risk reduction.

Risk reduction or treatment strategies are generally confined to three areas of activity (Granger in draft):

- Emergency management: this can be divided into proactive and reactive strategies and the recovery process. Proactive strategies are equivalent to the prevention and preparedness stages of PPRR (prevention, preparedness, response and recovery) often used by emergency managers, while reactive and recovery strategies are equivalent to the response and recovery stages of PPRR. Proactive strategies include areas such as warnings and community education. Reactive strategies focus on the activation of response agencies, such as the fire service and state emergency service, and evacuation from affected regions. Recovery includes post-event analysis aimed at identifying the strengths and weaknesses of the existing emergency management system
- Land use planning: this strategy is largely proactive and can have only limited impact on established development
- Construction standards: these are essentially proactive and include engineering codes, construction standards and maintenance levels.

Applying one or more strategies from these three groups will reduce the overall risk. However, some residual risk will remain. Once these treatment strategies are in place, insurance and government disaster relief programmes may also be considered as means of addressing the residual risk. In this case, the risk is transferred to a third party or to the population as a whole as a means of distributing the risk and thereby reducing the impact to those most affected by the hazard event.

Conclusion

Risk analysis is the third step in the risk management process. It is a systematic process used to understand and assess the level of risk. In the context of this report, the risk analysis process assesses the likelihood and consequence of a natural hazard event. Likelihood involves assessing frequency or probability and can be measured either qualitatively or quantitatively. The consequence is examined by considering the elements exposed to an event or series of events, and their vulnerability. A good understanding of hazard, exposure and vulnerability is therefore essential in any rigorous analysis of the risk posed by natural hazards.

Setting the evaluation criteria in the early stages of the risk management process will help to establish the focus of the risk analysis and define levels of risk acceptance. To minimise the consequences of natural disasters, a better understanding of the risk and potential impact is vital. Risk analysis provides essential inputs to planning the emergency management response and prioritising resources for sound mitigation decisions.

A flood in Nyngan, New South Wales, April 1990
Photo courtesy: Emergency Management Australia.

Chapter Four:

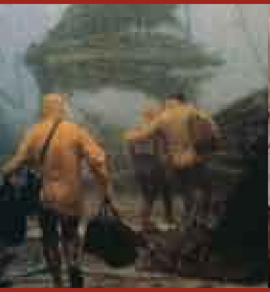
Tropical Cyclone

Trees stripped of leaves and toppled by Cyclone Ingrid on the Coburg Peninsula, Northern Territory, March 2005
Photo courtesy: Bureau of Meteorology/Bill Milne.

Tropical Cyclone

Tropical cyclones have long been considered the most devastating weather phenomena to affect Australia. Tropical cyclones are not the most frequent of events, but they can cause major impacts over significantly large areas. Tropical cyclones have affected Australians since the earliest days of settlement in tropical regions, and are entrenched in the cultures of Indigenous populations throughout the northern half of the continent.

Tropical cyclones can produce destructive winds, torrential rains, storm tides and phenomenal seas that inflict a heavy toll on communities in their paths. Weakening tropical cyclones can still cause major impacts and may adversely affect southern parts of the country as they interact with other weather systems. Some of the resulting rainfall can be beneficial to pastoral enterprises, water reservoirs and townships that rely on rainfall from decaying tropical systems.



Residents run for shelter from Cyclone Joy in Cairns, Queensland, December 1990
Photo courtesy: Bureau of Meteorology.

Aftermath of Cyclone Tracy in Darwin, Northern Territory, December 1974
Photo courtesy: National Archives of Australia/NAA: A6135, K30/1/75/17.

A building with its roof damaged in a cyclone in Mackay, Queensland, January 1918
Photo courtesy: John Oxley Library/5107.

Damage to flats at Nightcliff from Cyclone Tracy in Darwin, Northern Territory, December 1974
Photo courtesy: Bureau of Meteorology/Noel Stair.

From 1967 to 1999, the average annual cost of tropical cyclones was $266 million (BTE 2001). The greatest economic loss from a single tropical cyclone in Australian history was caused by Cyclone *Tracy*, which struck Darwin in December 1974. More than 2100 people have lost their lives in tropical cyclones, many in shipwrecks (Blong 2005).

The future impact of tropical cyclones will be strongly influenced by the effects of climate change on tropical cyclone behaviour, and this is explored in this chapter. Tropical cyclones may become more intense, and the areas exposed to tropical cyclones may increase in response to climate change (Meehl and others 2007).

This chapter presents information on the hazard posed by tropical cyclones, methods of analysing the hazard, and the data required to learn about the types and levels of risk that tropical cyclones pose. The roles and responsibility of government and industry bodies in reducing the impacts of tropical cyclones are highlighted. Importantly, the media also has a prominent role in reducing the impact of tropical cyclones. The chapter also identifies limitations in risk analysis and gaps in the information on tropical cyclones, and targets areas where more research may be warranted.

Hazard Identification

A 'tropical cyclone' is a low pressure system that develops in the tropics and is intense enough to produce sustained or average gale force winds (at least 63 kilometres per hour) around its perimeter. If the sustained winds reach hurricane force (at least 118 kilometres per hour) it is defined as a 'severe' tropical cyclone. Severe tropical cyclones are called hurricanes or typhoons in other parts of the world.

In general, tropical cyclones require favourable broad-scale winds and warm sea surface temperatures (greater than 26°C) to develop.

Research has shown that tropical cyclones in the Australian region tend to exhibit more erratic paths than cyclones in other parts of the world. A tropical cyclone can last for a few days or up to three weeks. Movement in any direction, including sharp turns and even loops, is possible (BoM 2007). Most tropical cyclones weaken when they move over land or over cooler waters, but they sometimes interact with mid-latitude weather systems to cause major impacts far from the tropics.

In the Australian region, tropical cyclones occur mostly between December and April. The official tropical cyclone season runs from 1 November to 30 April. In an average season, about 10 tropical cyclones develop over Australian waters, of which approximately six cross the coast, mostly over northwest Western Australia between Exmouth and Broome, and northeast Queensland between Port Douglas and Maryborough (as shown in Figure 4.1).

Tropical cyclones can cause a number of significant phenomena that can adversely (and sometimes favourably) impact on communities and the environment. The most well-known phenomena are destructive winds and heavy rainfall that may lead to flooding. Storm tide (i.e. coastal inundation by seawater) is a lesser-known phenomenon but can be the most dangerous hazard of a cyclone. Though rare in Australia, tornadoes have been reported during tropical cyclone events. The significant phenomena are described in more detail below.

Severe Wind

Tropical cyclones generate wind gusts in excess of 90 kilometres per hour around their core. In the most intense cyclones, gusts exceed 280 kilometres per hour. While the strongest winds are near the centre, damaging winds can extend several hundred kilometres from the centre. The cyclone centre or 'eye' can have quite calm winds and clear skies; however, this lull is temporary and is followed by destructive winds from the opposite direction.

The very destructive winds that can occur in cyclones may cause extensive property damage and turn airborne debris into potentially lethal missiles. These destructive winds can also produce phenomenal seas, which are dangerous for vessels at sea or moored in harbours, and have the potential to cause serious coastal erosion.

For a particular cyclone, the actual winds near the ground will be affected by local topography such as hills and valleys, vegetation (e.g. grasslands or forests), and shielding from neighbouring houses or buildings. While the generic effects of physical features may be simulated in wind tunnels or computer models, each location has its own subtle differences (e.g. extra trees or variable slope) that complicate the prediction of the wind impact.

The level of damage caused by severe winds depends on the strength and duration of the winds, and the environment affected by the winds. For example, the amount of pre-existing debris or the strength of the buildings affected may contribute to the damage levels.

Heavy Rainfall

Tropical cyclones can produce heavy rainfall over extensive areas. Rain can damage materials by making direct contact, for example when rain is driven into buildings by wind; by causing flooding; and by triggering landslides.

Direct water damage is generally the result of wind damage to walls, windows or roofs allowing water to penetrate buildings. With the improvement of building standards and consequent reduction in structural damage, water ingress is becoming a significant component of total damage in new structures. Flooding and landslides are covered in more detail in Chapters 5 and 8.

Rainfall can be associated with a cyclone as it directly impacts on the coast, further inland, or to the south after the cyclone has weakened. Often the most rainfall occurs after the system has weakened to below cyclone strength. Some of the biggest flooding events in Australia have been caused by decaying tropical cyclones. For example, the Brisbane floods in 1974 were caused by the decaying Cyclone *Wanda*.

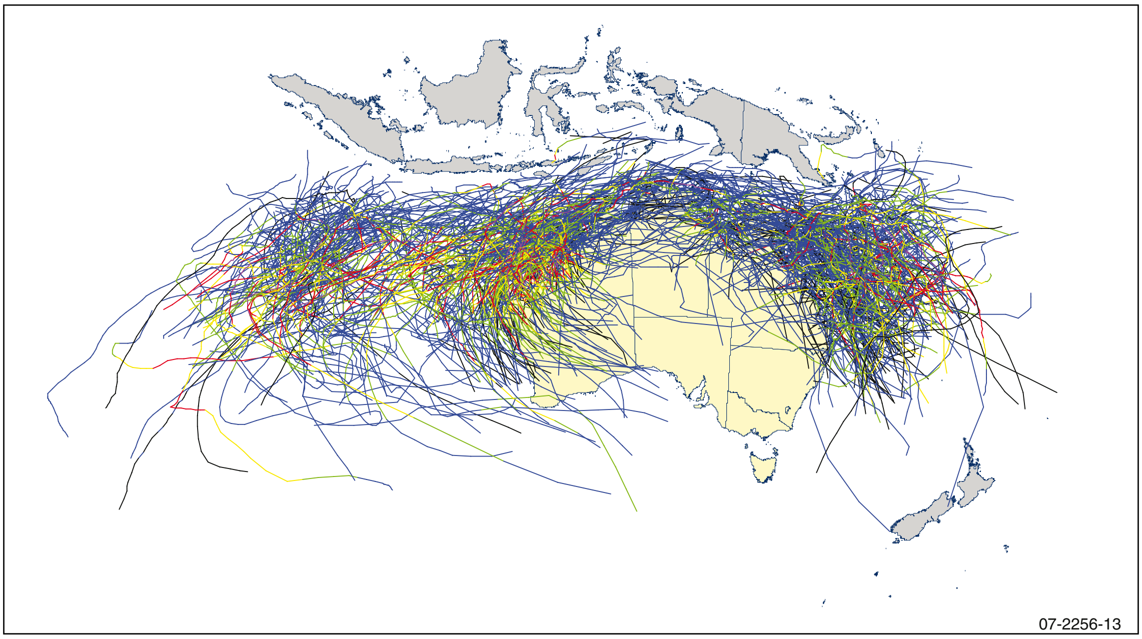


Figure 4.1: Historical tropical cyclone tracks in the Australian region
Note: Colours are indicative of cyclone intensity: blue – category 1 (weakest), green – category 2, yellow – category 3, red – category 4, purple – category 5 (strongest), and black - no intensity information available.
Source: BoM (2007).

Storm Tide

Potentially the most dangerous phenomenon associated with tropical cyclones that make landfall is storm tide. Storm tide is the combination of the normal astronomical tide (caused by the sun and the moon) and a storm surge that is generated by the cyclone, as shown in Figure 4.2.

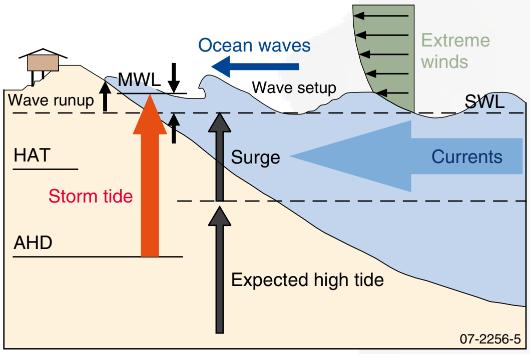


Figure 4.2: Components of a storm tide
Note: AHD - Australian Height Datum, HAT - highest astronomical tide, MWL - mean water level and SWL - still water level.
Source: Harper and others (2001), Figure 2.3.

Storm surge is like a raised dome of water, caused by a combination of the strong onshore winds driving the water ashore and lower atmospheric pressure in the core of the cyclone. On the west coast of Australia, the onshore winds occur to the north of the path of the tropical cyclone. On the east coast, the onshore winds occur to the south of the tropical cyclone's path.

The peak of the surge is usually about 20–50 kilometres from the crossing point of the cyclone centre (close to the region of maximum winds), but this depends on local bathymetry, coastal features and the angle of crossing (Harper and others 2001). The impact on the coast is exacerbated by the wave set-up and run-up on top of the storm tide.

The level of inundation caused by a storm surge depends directly on the height of the astronomical tide at the time of landfall. Quite often, a serious storm surge arriving at a low astronomical tide will result in a storm tide that does not exceed the highest astronomical tide, and hence has no significant impact on coastal communities. A low tide saved Townsville, Queensland, from a dangerous storm tide that accompanied Cyclone *Althea* in 1971.

Cost of Tropical Cyclones

For the period from 1967 to 1999, the total cost of tropical cyclone impacts was $8.8 billion (BTE 2001), at an average of $266 million per year. As shown in Figure 4.3, the year 1974 stands out as being by far the most costly for tropical cyclones, because of the devastation caused by Cyclone *Tracy* in Darwin.

The average annual cost in the years from 1979 to 1999 was considerably lower ($80 million) than the longer term average. The lack of costly events in the later part of the twentieth century was partly due to improved building standards and mitigation actions, particularly on the northwest coast of Western Australia. Since the 1970s there has also been a reduced occurrence of tropical cyclones crossing the coast, especially along the Queensland coast. This reduced activity is attributed, at least in part, to the increased frequency of El Niño events in this period.

Tropical cyclones account for over 35% of deaths from natural hazards in Australia. Since the first recorded death attributed to tropical cyclones, in 1839, over 2100 people have died as a result of cyclones (Blong 2005). Globally, more deaths have been caused by storm tides than by any other phenomenon related to tropical cyclones (WMO 1993). In Australia, the majority of deaths have been related to shipwrecks. Over 300 of the deaths attributed to Cyclone *Mahina* resulted from the sinking of the pearling fleet anchored in Bathurst Bay (EMA 2007).

Heavy rainfall from cyclones does bring benefits to the land. It is a valuable source of water for the vast inland river systems across Australia and pastoral enterprises, replenishes rural dams and recharges groundwater supplies.

Potential Influence of Climate Change

Tropical cyclones have received much attention in climate change discussions, largely because of their sensitivity to the state of the global climate and their high potential to cause widespread damage.

The sensitivity of tropical cyclones to the global climate results in significant variability in the number of tropical cyclones from year to year, linked to climate variability. The recent record seasons in the North Atlantic basin generated a flurry of research into the potential impacts of climate change on tropical cyclones (Emanuel and Nolan 2004). It is important to separate the impacts of climate variability (i.e. natural variations in tropical cyclone activity) from the impacts of climate change.

The most obvious and well-known form of climate variability to affect tropical cyclones is the El Niño–Southern Oscillation (ENSO), which has been the subject of significant investigation (Nicholls 1979; Solow and Nicholls 1990). An El Niño event tends to suppress tropical cyclone activity in the Australian region, especially over the Coral Sea, while a La Niña event tends to enhance activity in the region (as shown in Figure 4.4). Other longer-term cycles that may affect tropical cyclone activity exist, but their influence is difficult to determine given the relatively short historical record.

Recently, there has been concern that the relative frequency of intense tropical cyclones may be increasing (Emanuel 2005; Webster and others 2005; Hoyos and others 2006). These findings have generated significant controversy within the scientific community, because of concerns over the quality of the historical data on which these studies rely (Harper and Callaghan 2006; McBride and others 2006).

In the Atlantic Ocean, there is significant evidence pointing to an increase in the frequency of intense tropical cyclones (Holland and Webster 2007). However, there are no clear trends in the global number of tropical cyclones (Solomon and others 2007), largely because of questions over the reliability of the observational record used (Landsea 2007). The detection and attribution of any trends in tropical cyclone frequency and intensity requires significant research, so that

Figure 4.3: Annual cost and number of tropical cyclones in Australia, 1967 to 1999
Source: Based on BTE (2001), Figures 3.21 and 3.23.

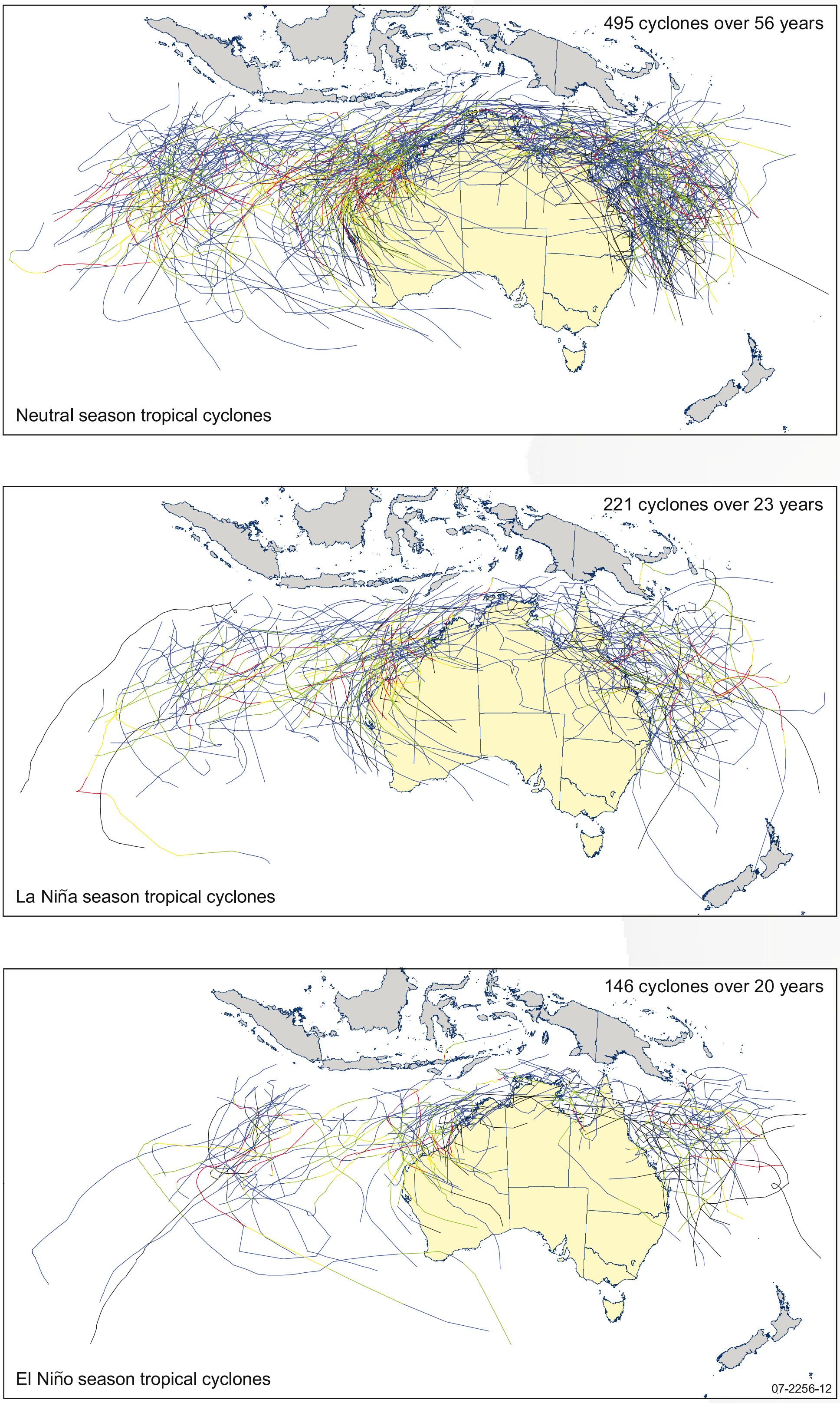


Figure 4.4: The influence of ENSO on tropical cyclones in the Australian region
Note: Colours are indicative of cyclone intensity: blue – category 1 (weakest), green – category 2, yellow – category 3, red – category 4, purple – category 5 (strongest), and black - no intensity information available.
Source: Geoscience Australia.

future changes in tropical cyclone activity can be accurately predicted.

The impact of climate change on tropical cyclones is hotly debated within the research community and continues to be the subject of much investigation. There are significant uncertainties in the projected changes in tropical cyclones, and in the natural modes of variability which modulate cyclone activity (McBride and others 2006). The Intergovernmental Panel on Climate Change Fourth Assessment Report summarised much of the recent research into tropical cyclone activity and concluded there is (Meehl and others 2007, p. 751):

'a likely increase of peak wind intensities and notably, where analysed, increased near-storm precipitation in tropical cyclones. Most recent published modelling studies investigating tropical storm frequency simulate a decrease in the overall number of storms, though there is less confidence in these projections and the projected decrease of relatively weak storms in most basins, with an increase in the numbers of the most intense tropical cyclones.'

Of studies that have been undertaken specifically for the Australian region, two found no likely significant change in total tropical cyclone numbers off the east coast of Australia (Walsh and others 2004, Leslie and others 2007), while a third found a significant decrease in tropical cyclone numbers for the Australian region (Abbs and others 2006). These climate simulations also indicated an increase in the intensity of tropical cyclones in the Australian region (Abbs and others 2006; Leslie and others 2007).

Storm tide is expected to be directly affected by climate change because of two aspects: the potentially increased intensity of tropical cyclone events, and long-term sea level rise. An increase in the intensity of landfalling tropical cyclones would result in a direct increase in the magnitude of the associated storm surge. Possible southward changes in the tracks of tropical cyclones may also increase the exposure of communities to tropical cyclone impacts.

Sea level rise is likely to be the major contributor to increased exposure to storm tide. For example, Hardy and others (2004) studied the changes in storm tide return periods along Queensland's east coast and concluded that the changes were dominated by the mean sea level rise scenario.

The wreck of the Korean Star after Cyclone Herbie at Cape Cuvier, Western Australia, May 1988
Photo courtesy: Bureau of Meteorology/Mark Kersemakers.

Changes in tropical cyclone intensity had less of an effect and changes in frequency had an insignificant effect.

Risk Analysis

As outlined above, there are several hazard components presented by tropical cyclones: wind, heavy rainfall and storm tide. Each has the capacity to cause an adverse impact to population, buildings or infrastructure. The severity of the impact will be related to the intensity of the cyclone event and the exposure and vulnerability of the community and infrastructure to each of the hazard components.

Tropical cyclone risk assessments have been performed in the United States for many years. Linked to these, several risk models have been developed (Neumann 1987; Powell and others 2005). The insurance industry has instigated a large amount of research into tropical cyclone risk, largely because of its own financial risk associated with these high-impact events.

Risk assessments for communities along the Queensland coast have been conducted, examining the risk from severe winds caused by tropical cyclones (Harper 2001; Harper and others 2001). The vulnerability of residential structures in Australia to impacts from tropical cyclones has been the subject of significant research, especially since the devastating impact of Cyclone *Tracy* in 1974. Several other assessments of tropical cyclone hazards and their impacts on residential property have also been conducted for Queensland (DNRM 2004).

The following sections describe the components of likelihood and consequence analyses for tropical cyclones, and outline the data requirements for each.

Likelihood Analysis

The likelihood of impact by a tropical cyclone at a given location can be determined by reviewing the number and intensity of landfalling cyclone events over a given time period.

The annual frequency of tropical cyclones is low, and the historical database in the Australian region is limited. There is less than 100 years worth of data in the database, and information for the earlier years of the period is less reliable and detailed (Trewin and Sharp 2007). This paucity of historical data limits its usefulness in a likelihood analysis (see Figure 4.5).

The likelihood of tropical cyclones can be determined using statistical models (Powell and others 2005) or physically-based models (Emanuel and others 2006). Statistical models depend heavily on having good quality records of tropical cyclone behaviour in the region of interest to generate realistic tropical cyclone events. Physical models require an understanding of the structure and influence of the broad-scale atmosphere on tropical cyclones.

These models are used to generate synthetic event sets which represent thousands to millions of years of tropical cyclone activity and are used to overcome the limits of the historical data. These synthetic event sets can eliminate the perceived gaps in landfall location data and provide a better picture of the likelihood of impact.

Assessing the severe wind hazard from tropical cyclones also requires knowledge of the area affected by damaging winds (i.e. the 'wind swath') associated with each tropical cyclone. There are many different empirical models of the tropical cyclone wind swath, and these are continually being reviewed as more data are gathered (Willoughby and others 2006). To accurately represent the swath from a tropical cyclone requires developing a thorough understanding of the structure and life cycle of cyclones in the region being studied, so that an appropriate model can be applied.

To determine the local wind hazard, a comprehensive understanding of the influence of topography and terrain on local wind speed (i.e. 'wind multipliers') is essential. The effect of terrain and topography can be determined using two-dimensional modelling of the winds, following the methodology outlined in the wind loading standard (Lin and Nadimpalli 2005). Alternatively, three-dimensional modelling tools can be used to capture effects such as funnelling (Ayotte and Taylor 1995).

Heavy rainfall associated with tropical cyclones that results in freshwater flooding is treated similarly to any flooding event. The process of assessing the likelihood of flooding is discussed in Chapter 5.

The magnitude of a storm tide event is sensitive to the combination of coastal topography, bathymetry, astronomical tide and wave set-up. Therefore, to determine the likely inundation associated with tropical cyclones requires a large number of scenarios to be developed for each location of interest. The surge associated with each scenario is computed using the best available data. The results can be stored as part of an atlas of surges, a useful resource for forecasters in the event of a landfalling cyclone. Results can also be aggregated to provide a 'maximum envelope of waters' (MEOW). This MEOW can be used in estimating exposure to the maximum likely storm surge.

In addition to the height of the storm tide, inundation patterns also require consideration. Hydrodynamic models that simulate the ebb and flow of surging water over coastal land (Nielsen and others 2005) can be used to determine inundated regions.

Data requirements

To assess the probability of impact by tropical cyclones in a particular area, there is a heavy reliance on historical data. Where possible, homogeneous records of tropical cyclones are preferred, providing a uniform assessment of events. For extreme events, newspaper records

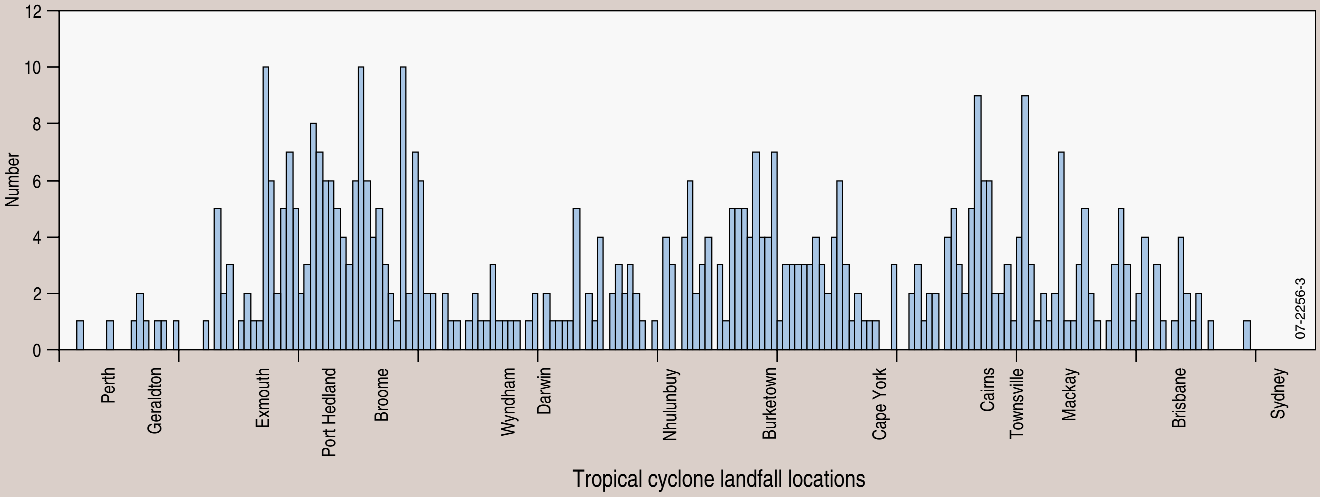


Figure 4.5: Number of tropical cyclones making landfall around the Australian coastline, July 1909 to June 2005

Note: Major coastal locations are indicated along the horizontal axis. The crossing points were determined by examining the tracks in the Bureau of Meteorology tropical cyclone 'best track' archive. Data before the 1950s would be biased to populated areas. Despite being almost a century long, the limited size of the database reveals perceived gaps that may be a reflection of lower impact probability rather than a 'safe haven'.

Source: Geoscience Australia.

extending beyond the timescale of the Bureau of Meteorology's database, which dates back to 1909, will help in the assessment.

High-resolution topographic and terrain multiplier datasets (showing the acceleration of winds due to topographic and terrain variations) are required to accurately determine the level of hazard at a local scale.

To accurately model the hazard of storm tide (and other forms of flooding) requires extremely detailed topographic and bathymetric data. Knowledge of floodplains and elevations of various key locations needs to be developed and maintained by the responsible authorities.

Consequence Analysis

An analysis of the consequences of a tropical cyclone includes an assessment of the elements exposed to the cyclone and the impact that the hazard components have on the elements. For example, population growth along the Queensland coast, especially in the marginal regions of the Sunshine Coast and the Gold Coast, is increasing the exposure of communities to tropical cyclones. The rapid increase in mining activities in the Pilbara region of Western Australia is increasing not only the population exposure, as more people are employed in the region, but the financial exposure of the mining and resources industries as well.

Power and telecommunications infrastructure assets are often highly exposed—above-ground power lines and telegraph poles are often brought down by high winds in tropical cyclones. Radio communications for emergency services may also be impacted by wind damage to transmission towers. Water supplies and sewerage systems can be affected through loss of power to pumping stations, or directly affected by exposure to storm tide or riverine flooding.

Transport infrastructure (predominantly rail and road) can be vulnerable to riverine flooding, storm tide and landslides. Landslides are a significant threat along the heavily populated sections of the Queensland coastline, because of the mountainous topography (see Chapter 8 for a general discussion of landslides).

The flow-on impacts of the failure of critical infrastructure elements to other facilities, such as hospitals, evacuation centres and emergency service centres, are also important. Inundation may cut evacuation routes or isolate important resources required in response and recovery operations. It is important to consider exposed locations, and understand which hazards may compromise resources or infrastructure at these locations, when developing risk management plans.

The exposure of buildings and infrastructure to severe winds can vary greatly across a town, because of the effects of terrain, topography and the buildings themselves. A detailed understanding of the variation of exposure to severe winds (and other hazards) is vital to planning considerations for key services, infrastructure and residential buildings.

In some local government areas, zoning for housing is based on the Australian wind loading standard (AS 4055:2006). In other areas, it is the responsibility of designers and builders to comply with the Building Codes of Australia provisions under the appropriate state or territory legislation.

Models of vulnerability relationships for residential buildings are under development, based on an understanding of the wind loads on building elements (Henderson and Harper 2003). These models include an understanding of how buildings resist and transmit wind loading forces, along with the contribution of wind-borne debris.

Vulnerability models also need to address age-related changes to building regulations and the extent of their uptake by the building industry.

Beach erosion after Cyclone Alby in Perth, Western Australia, April 1978
Photo courtesy: Emergency Management Australia.

The contributions of post-cyclone impact survey activity and the assessment of local wind speeds at individual infrastructure sites of interest are vital to developing vulnerability relationship models. The surveys identify the range and predominance of failure types, and provide validation data for the more rigorous engineering approach. As these tools mature they will provide a means of assessing the most cost-effective measures for reducing community risk. The survey activity following Cyclone *Larry* has provided valuable data for advancing the understanding of wind vulnerability (Edwards and others 2007).

For community members, the impacts of a tropical cyclone are directly related to their levels of knowledge and awareness. Negative consequences can be minimised by residents knowing how to prepare in advance of a cyclone, when to evacuate, where to shelter in a house and when it is safe to venture out after an event.

On the other hand, community complacency can increase the impact of an event. Complacency can set in when a community is affected by a weak tropical cyclone ('We've been through a cyclone and it wasn't so bad after all'), or does not experience a tropical cyclone for many years. It was recognised before the 2005–2006 cyclone season that a long time had passed since a severe tropical cyclone last impacted on a reasonably populated area of the Queensland coast. A large effort was made to remind people that a severe cyclone could arrive in the coming season (as Cyclone *Larry* did in March 2006).

Data requirements

Knowledge of the spatial distribution of buildings and infrastructure exposed to cyclonic winds, heavy rainfall, riverine flooding, storm tide and other hazards associated with tropical cyclones is imperative. The secondary consequences resulting from failure of critical infrastructure such as power, gas, communications and sewerage require detailed investigation to gain a complete understanding of the community vulnerability.

Vulnerability of buildings varies widely and depends on the material choice, architectural features, standards applicable at the time of construction and subsequent levels of maintenance. Specific data on these key parameters are required to better understand the risk posed by cyclonic wind. Insurance loss data are very valuable to the development and validation of vulnerability models.

Major industry and local commerce organisations need to have records of business contingency plans available. The potential impacts, particularly secondary effects like loss of income and employment, need to be ascertained by detailed financial analysis.

Information Gaps

A complete understanding of the risk of tropical cyclones is reliant on filling several gaps in existing information. First and foremost, understanding of tropical cyclone behaviour in the Australian region is incomplete. Economic vulnerability to tropical cyclones is another area that needs further investigation. This section outlines some of the information gaps and details how they may be resolved.

Tropical Cyclone Physics

It is important to gain a thorough understanding of the physics of tropical cyclones. This includes identifying and understanding any potential differences in the structure and behaviour of tropical cyclones in the Australian region from those in other regions around the world. A thorough understanding of tropical cyclone physics underpins several other information gaps relating to cyclone risk.

Impacts of climate change on tropical cyclones are fundamentally linked to how cyclones interact with the ocean, the upper atmosphere and the general circulation. The detection and attribution of trends in tropical cyclone activity on global and regional scales are critical in determining future changes in tropical cyclone activity.

A better understanding of the structure and behaviour of tropical cyclones will greatly improve the representation of tropical cyclones in hazard assessment models, for both severe winds and storm tide. This understanding will also help to improve intensity forecasts provided by the Bureau of Meteorology and used in developing community warnings.

The interaction of extreme winds with terrain and steep topography still requires significant research and assessment, and the processes involved are also important in determining the rate at which tropical cyclones weaken once they move over land. Cyclone *George* crossed the Western Australian coast near Port Hedland in March 2007 and caused significant damage more than 100 kilometres inland. This highlighted the importance of understanding the weakening of tropical cyclones as they move inland. Although intensity decay models have been developed in the United States (Kaplan and DeMaria 1995), these are region-specific empirical models. Differences in topography and terrain mean these models require more research before they can be applied to Australian tropical cyclones.

Probabilities at the Southern Margins

Both Perth and Brisbane lie near the margins of the regions of Australia regularly affected by tropical cyclones (see Figure 4.5). However there is a small chance of a severe tropical cyclone impacting directly on Brisbane, and Perth is vulnerable to tropical cyclones undergoing extra-tropical transition. Cyclone *Alby* in 1978 is an example of a tropical cyclone undergoing extra-tropical transition that caused significant impacts around Perth. Assessing the probability of a significant impact at these marginal but populous areas is difficult, because the historical dataset is limited.

Influence of Climate Change

The effect of climate change on tropical cyclone frequencies and intensities remains difficult to accurately assess. The detection and attribution of trends in tropical cyclone activity on global and regional scales are critical in determining future changes in tropical cyclone activity. A better understanding of the impacts of natural climate cycles (such as ENSO) on tropical cyclones, and how these may be affected under a future climate scenario, is critical.

Equally important is the need to objectively reanalyse the existing historical datasets for the very significant changes that have occurred over the past 50 years. Improvements in sensor technologies such as radars and satellites and the intensity estimation tools used by meteorologists have advanced the detection and analysis of tropical cyclones in more recent times.

Damage to papaya crops following Cyclone Larry near Innisfail, Queensland, March 2006
Photo courtesy: Geoscience Australia/Miriam Middelmann.

Vulnerability Research

The increase in exposure of major industries, such as mining and petroleum, to tropical cyclones forms an important component of assessing the impacts of tropical cyclones on the Australian community. Little is known of the costs incurred as a result of business interruption, closure of ports to shipping and other secondary consequences of tropical cyclones. Woodside Energy Ltd has invested significantly in understanding the exposure of its oil and gas infrastructure (both onshore and offshore) to tropical cyclones (Harper and Callaghan 2006). However, this work needs to be extended to all industries in northern Australia, including industries such as agriculture and tourism. The analysis also needs to include an understanding of the economic consequences of an impact.

The range of infrastructure assets present in typical communities is very broad and there are numerous gaps in the knowledge of their vulnerability. There is a need to advance the present work programme on building vulnerability and to engage industry in analysing and defining the vulnerability of key infrastructure elements. This process will enable targeted research to provide a more comprehensive range of vulnerability relationship models and to give a more complete assessment of wind risk.

Roles and Responsibilities

The risks posed by tropical cyclones affect a wide range of groups, including all levels of government, industry groups, businesses and the general community. Each of these groups has a role and responsibility in reducing the risk of tropical cyclones, as described in the following sections.

Australian Government

The Australian Government is responsible for the provision of forecast and warning services for tropical cyclones. The Australian Government also maintains records of past cyclone events and performs scientific study into tropical cyclones and their prediction.

The Australian Government liaises with state agencies in disaster situations, and acts as an overarching policy and educational resource for emergency services across the country. In major disasters, the Australian Government can step in to coordinate the supply of additional resources such as equipment, medical supplies and Defence personnel. Following a disaster, the Australian Government provides financial assistance to those suffering from the impact of the disaster.

The Australian Government also participates in initiatives with state and territory governments to strengthen links between the building industry and government agencies responsible for building regulation.

State and Territory Governments

State and territory governments are responsible for overarching planning laws and building regulations. This includes administration of the technical Building Codes of Australia, which ensure infrastructure in cyclone-prone areas is built with an acceptable level of resistance to tropical cyclone impact. State and territory governments are also responsible for the emergency services organisations.

Immediately before and during natural hazard events, state and territory governments may provide support to the community in the form of safe shelters, assistance to those in need and, in some states, direction to evacuate or take other preventative action. They also work closely with the community to develop plans of action before events occur to minimise impacts. This includes planning logistics under various scenarios, and developing structured chains of command, robust means of communication and evacuation plans.

States and territories also involve themselves in public education, often face-to-face in public forums and through brochures and media advertising. The focus of this public education is on action plans to reduce the risk of injury or material loss.

Local Government

Local councils are involved extensively in the prevention and preparation phases of tropical cyclone risk reduction. Issuing local by-laws and enforcing building regulations that aim to reduce tropical cyclone impact are important roles undertaken by local governments. Town planning is also vital in ensuring that future development does not increase the vulnerability of the community. This includes keeping housing and critical or vulnerable buildings or facilities in safer locations, for example away from storm tide zones, as well as ensuring that evacuation routes exist and are known.

Local authorities also coordinate community disaster response plans and facilitate the use of community assets as evacuation and recovery centres in the event of tropical cyclones. During the response and recovery phases they play a role in maintaining or repairing critical infrastructure for which they are responsible. The increasing privatisation of infrastructure has meant that some of these responsibilities now fall to the private operators.

Industry, Coordinating Groups, Professional Bodies and Research Institutions

There are a large number of professional bodies, coordinating groups and industry bodies that play an advocacy-type role in tropical cyclone risk assessment. Several groups also contribute to the assessment of impacts arising from various

Damage to the Minjilang community school caused by Cyclone Ingrid on Croker Island, Northern Territory, March 2005   *Photo courtesy: Bureau of Meteorology/Bill Milne.*

Damaged planes at Darwin Aero Club, following Cyclone Tracy, Darwin, Northern Territory, December 1974
Photo courtesy: National Archives of Australia/NAA: A6135, K13/3/75/23.

hazardous aspects of cyclones, such as wind, flood and storm tide.

The engineering profession, through Engineers Australia and Standards Australia, plays a large role in mitigation, being responsible for conceiving, developing and implementing many of the measures for hazard resistance in buildings. The insurance industry provides a stable financial basis for the community to resist tropical cyclone impacts and contributes greatly to recovery operations through the provision of cash that funds immediate repairs. Numerous consulting companies are involved in wind, flood and storm tide hazard and risk assessment on behalf of government and non-government agencies.

Various universities and CSIRO also conduct research into aspects of cyclone hazard and risk assessment. The Cyclone Testing Station attached to James Cook University in Townsville, Queensland, conducts research and testing and advises industry and governments on building practices which minimise loss and suffering as a result of severe wind events.

Property Developers

There is the potential that the spread of urban areas along coastal zones and into beachside settings is creating areas of increased storm tide impact risk. For example, the spiralling cost of hurricane impacts on the United States coast has been amplified by excessive developments on exposed coastal margins (Pielke and Landsea 1998). While property developers are subject to local government approval processes, the demands to cater for increasing coastal populations place strain on the approvals system. In response, Australian state governments have moved to tighten planning rules for vulnerable environments.

Courts and Legal Institutions

In most states, coroners have the power to conduct an inquest into any tropical cyclone event, but such inquests occur only after significant events, such as events in which fatalities have occurred. At a preventative level, courts are often required to ensure that landowners comply with legislative and regulatory requirements concerning provisions for minimising risk.

Coastal defences and other structural efforts to mitigate the impacts of tropical cyclones may detract from the environmental values or aesthetic amenity of an area, and the courts are often required to decide which aspect is more important under apparently contradictory pieces of legislation.

Media

The media are a critical component of the tropical cyclone warning process. Media outlets provide a means of distributing vital warning and mitigation messages to the community immediately before and during an event. They also provide a conduit for public education programmes, through community service announcements and on-air interviews.

It is the responsibility of the media operators to ensure they have robust, self-contained infrastructure and contingency arrangements in place so that they can safely operate during events and distribute important messages to the community. With a growing trend toward national networking based in major metropolitan centres, it is important to take into account the continued local media presence that may be required during tropical cyclone events.

General Community

Individuals have a basic responsibility to be aware of any tropical cyclone risk posed to them. They should also know how to respond effectively to tropical cyclone warnings, including knowing the location of evacuation routes. Individuals should understand that particularly extreme cyclones might occur, which may seriously damage even buildings that have been built to the appropriate standard for their location. Inundation may occur in areas where development has been approved by the local agency, and measures such as structural storm tide and flood mitigation works might not fully alleviate the primary or secondary impacts of a tropical cyclone.

Private properties need to be maintained. It is important for property owners to consider not only the security of themselves and their property, but also the potential impact on others in the community.

Often, structural failure is the result of weaknesses caused by decay and corrosion rather than imperfections in original design or construction. Loose objects or poorly maintained (but ‘expendable’) structures can cause significant damage downwind when propelled by cyclonic winds. Also, there is a need to consider the storage and protection of hazardous materials that may cause environmental contamination should inundation occur or containment infrastructure be compromised.

Conclusion

Tropical cyclones can be devastating events, bringing severe winds, heavy rainfall and coastal inundation. They contribute an average of 25% of the annual cost of natural disasters to the Australian economy, behind flood and severe storms ($266 million per year). Tropical cyclones have caused over 2100 deaths since 1839, many of which were a result of shipwrecks.

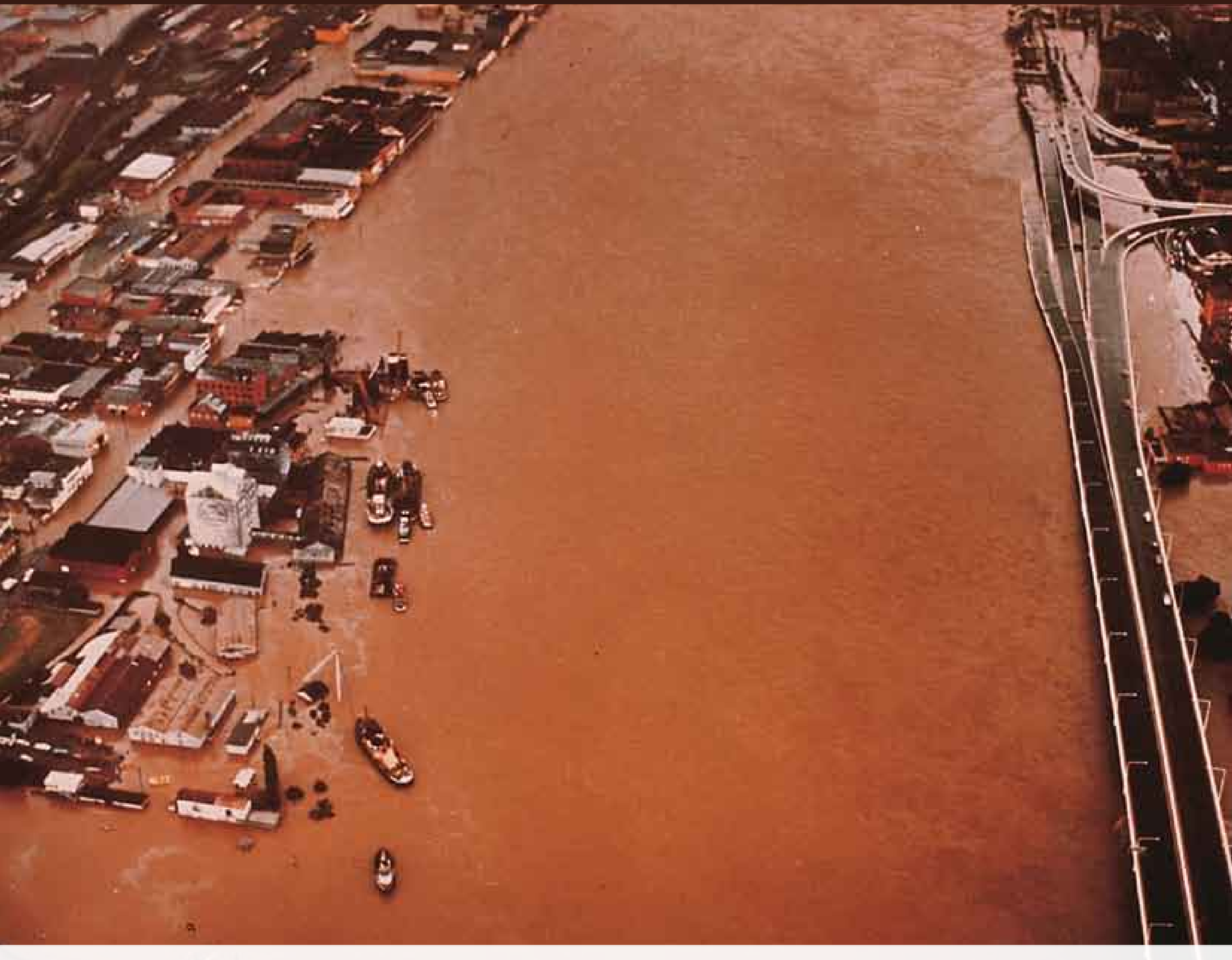
All levels of government, the media, non-government groups and communities contribute to the risk management process for tropical cyclones. State and territory governments retain responsibility for regulating the building standards which are an important component of managing tropical cyclone risk.

To develop an understanding of the risk posed by tropical cyclones, models of landfall frequency and the structure of tropical cyclones are required. Risk assessment models must also include information on the vulnerability of buildings, other infrastructure elements, agriculture and other industries. However, the historically low frequency of events means our understanding of the structure of tropical cyclones is incomplete. Data on the vulnerability of residential structures and other buildings is also limited by the low frequency of tropical cyclone impacts.

The understanding of the structure and behaviour of tropical cyclones and the influence of climate change on cyclones are key areas requiring further research. The vulnerability of built structures, as well as agriculture and industry, to severe wind, heavy rain and inundation also requires more study, to improve the assessments of risk from tropical cyclones.

Chapter Five:

Flood



Floodwaters on the South Brisbane freeway in Brisbane, Queensland, January 1974
Photo courtesy: Bureau of Meteorology.

Flood

Australia has long been called the land 'of droughts and flooding rains' (Mackellar 1911, p. 9). Historical records of floods date back to at least 1790, when the first flood fatality was recorded in Australia (Blong 2005). Since then, there have been over 2300 flood-related fatalities.

The estimated total cost of flooding during the period from 1967 to 1999 is $10.4 billion, equating to an average annual cost of $314 million (BTE 2001). A comparison with economic costs from other natural disasters confirms that flooding is the most costly natural disaster in Australia.

While vulnerability is increased through development in floodplains, the potential to gain significant benefits by effective management of flood risk is higher than for other hazards, as floods are restricted to definable areas and people directly influence flood risk.

Home contents thrown out following a flash flood in Melbourne, Victoria, January 2004
Photo courtesy: Geoscience Australia/Miriam Middelmann.

Flood damaged railway bridge over the Burdekin River, Queensland, January 1917
Photo courtesy: John Oxley Library/75246.

People receiving food after being made homeless by a flood, Charleville, Queensland, April 1990
Photo courtesy: Emergency Management Australia.

A devastating flood in Maitland, New South Wales, February 1955
Photo courtesy: NSW SES.

In Australia, floods are predominately caused by heavy rainfall, with La Niña years experiencing more floods on average than El Niño years. The process of analysing the flood risk from rainfall is described in this chapter. A number of gaps in the information are identified, including the uncertainties surrounding the potential influence of climate change on flood behaviour.

Flood risk analysis is an integral component of flood risk management. Though riverine flood hazard assessments have been undertaken for many years, the extension of this to consider the flood risk is less well developed. Many government and non-government agencies and groups play an important role in flood risk management, with state and territory governments having a major statutory responsibility in managing flood risk.

Hazard Identification

A 'flood' is described in *Floodplain Management in Australia. Best Practice Principles and Guidelines* as (SCARM 2000, p. 97):

> ***'Relatively high water levels caused by excessive rainfall, storm surge, dam break or a tsunami that overtop the natural or artificial banks of a stream, creek, river, estuary, lake or dam.'***

However, this definition does not convey the important concept that it is only when water is where it is not wanted that a flood is an issue.

Floods in Australia are predominately caused by heavy rainfall, though extreme tides, storm tide (covered in Chapter 4), tsunami (covered in Chapter 10), snow melt or dam break can also cause flooding. Rainfall can cause riverine and/or flash flooding. It can also exacerbate local drainage problems and cause groundwater to rise above the natural surface. This chapter focuses on flooding as a result of heavy rainfall.

There are a number of factors that influence whether or not a flood will occur. These include the volume, spatial distribution, intensity and duration of rainfall over the catchment; catchment conditions prior to the rainfall event; ground cover; topography; groundwater tables; the capacity of the watercourse or stream network to convey the run-off; and tidal influence. Development within the catchment and floodplain, and works which retard flows (e.g. dams and detention basins) or confine flows (e.g. levees) also influence whether or not a flood will occur.

Flooding from rainfall generally falls into the two broad categories, flash floods and riverine floods, that are described briefly below.

Flash Flood

Flash floods can occur almost anywhere, and result from a relatively short, intense burst of rainfall, for example during a thunderstorm. During these events the drainage system may be unable to cope with the downpour and flow frequently occurs outside defined water channels. Areas with low-capacity drainage systems, whether natural or artificial, are particularly vulnerable to flash flooding.

Although flash floods are generally localised, they pose a significant threat to human life, because of the high flow velocities, unpredictability and rapid onset of such events. Warning times for flash floods are short, with flash floods usually occurring within six hours of a rainfall event. Flash flooding is exacerbated in areas where there is a high proportion of impervious or near impervious surfaces which promote run-off. For example, highly developed urban areas have a high amount of impervious surfaces in the large areas taken up by roads and roofs. Areas where loss of vegetation has occurred, because of bushfire or activities such as overgrazing, also have a high amount of near-impervious surfaces.

Some recent flash flood events include the floods in the Hunter and central coast regions of New South Wales in June 2007, southeast

An abandoned car on a flooded road near Wyong, central coast region, New South Wales, June 2007
Photo courtesy: NSW SES.

Queensland and northeast New South Wales in June 2005, and in central west New South Wales in November 2005 (EMA 2007).

Riverine Flood

Riverine floods occur following heavy rainfall when watercourses do not have the capacity to convey the excess water. They occur in relatively low-lying areas adjacent to streams and rivers. In the flat inland regions of Australia, floods may spread thousands of square kilometres and last several weeks. In the mountain and coastal regions of Australia, flooding is often less extensive and of shorter duration, with higher flow velocities.

The spatial distribution of short-duration rapid-onset floods and long-duration slow-rise floods is shown in Figure 5.1. The Great Dividing Range in eastern Australia provides a natural separation of slower, wider rivers flowing west from faster, narrower coastal rivers flowing east.

In some cases natural blockages at river mouths may also cause flooding of estuaries and coastal lake systems or exacerbate riverine flooding in tidal sections of rivers. Examples of natural blockages include storm tide, high tide and sand berms which constrict river entrances.

Recent examples of riverine flood events include the floods in Gippsland, Victoria, in June–July 2007, the northwest Northern Territory in March 2007, and Katherine, Northern Territory, in April 2006; and on the New South Wales mid-north coast in March 2006 (EMA 2007). Details of severe riverine flood events across Australia are provided in SCARM (2000).

Cost of Floods

Floods frequently cause millions of dollars worth of damage, affecting both urban and rural environments and people's livelihoods. Both riverine and flash floods result in costly damage to residential, commercial and industrial properties. Damage to transport, power and telecommunications infrastructure also causes severe cost and disruption to the community. Riverine floods can cause huge cost to rural enterprises. For example, during the floods in Lismore, New South Wales, in 1974 the agricultural cost slightly exceeded the cost to buildings (BTE 2001). As well as having a huge economic cost, floods can also cause physical, psychological and emotional health costs, through death, injury, isolation and displacement.

Records for flood fatalities extend back further than the records for any of the other hazards considered in this report. From 1790 to 2001, there were 2292 recorded flood fatalities (Blong 2005), with flood fatalities commonly related to attempts to cross flooded creeks, bridges and roads. As noted in Chapter 2, the annual death toll from floods decreased substantially during that period, particularly during the 1800s, with improved warnings and flood awareness playing major roles. However, awareness of the risk posed by floods needs to be continually raised to further reduce the number of flood-related fatalities.

The more recent severe flood events leading to fatalities include floods on the east coast of New South Wales in 2007 (eight fatalities); in the Gympie–Maryborough area, Queensland, in 1999 (seven fatalities); in eastern New South Wales in 1989 (nine fatalities), and in Katherine, Northern Territory, in 1998 (three fatalities) (EMA 2007).

The total cost of flooding in the period from 1967 to 1999 has been estimated at $10.4 billion. This equates to an estimated average annual economic cost of flooding of $314 million (BTE 2001). At the time of writing, few companies provide flood insurance, contributing to difficulties in estimating the costs of floods, though the cost is likely to be underestimated rather than overestimated.

Loss caused by flooding varies widely from year to year. The annual economic cost of floods in Australia is shown in Figure 5.2 over the 33-year period to 1999. The figure also shows the number of flood events in Australia each year during the same time period. Events included in the database have a total cost of equal to, or over $10 million per event, with widespread flooding classed as a single event. This figure illustrates that loss due to flooding each year is dependent not only on the number of floods, but also on flood severity.

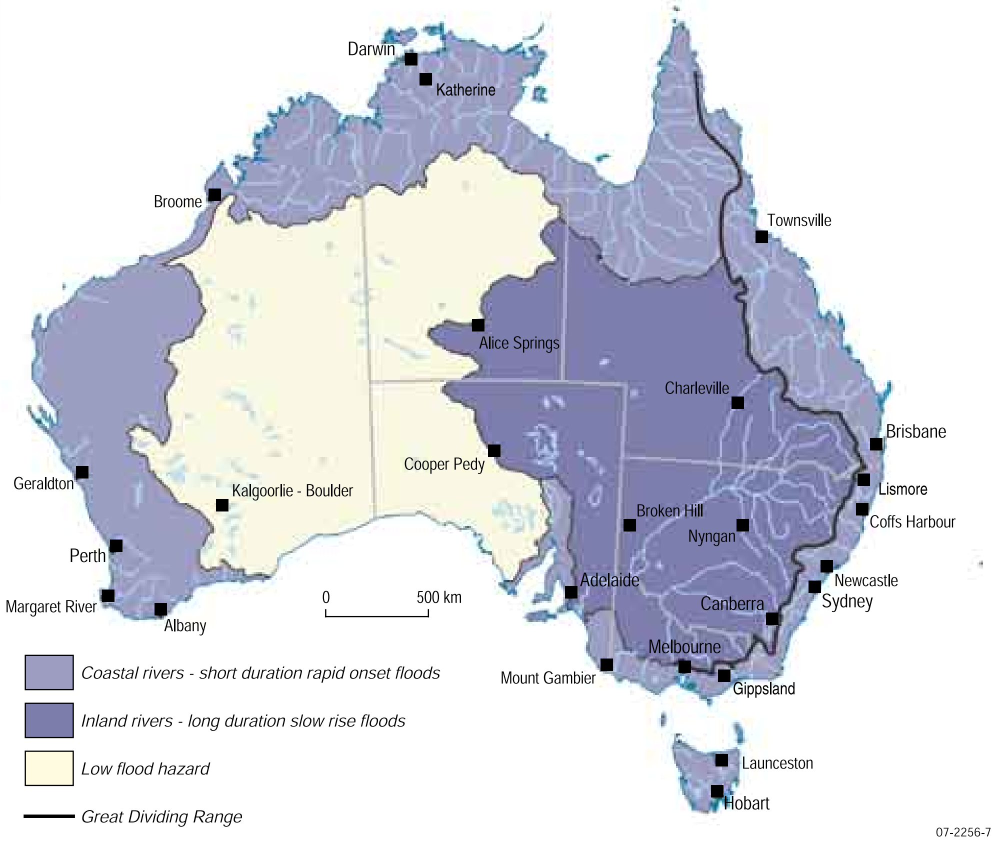


Figure 5.1: Flood potential in Australia
Source: Geoscience Australia.

Other factors, such as location and the nature of development, also play a role in determining loss.

Floods are not solely negative phenomena, as they are part of a natural cycle. Floods can have significant environmental and social benefits, particularly in areas which have suffered a long drought. Floods are important to the long-term viability of ecosystems, species and populations and the maintenance of ecosystem function. Floods encourage breeding, spawning, seed dispersal and germination, and increase the food source for aquatic birds (Handmer and others 2002). Floods may also increase agricultural productivity through the deposition of soils and nutrients and the provision of water for irrigation.

Potential Influence of Climate Change

The potential impact of climate change and variability on floods is being studied at various levels. Several organisations with responsibility for water resources have been active in trying to understand the impact of climate change.

Current projections suggest that average rainfall is likely to increase in the north of Australia and decrease in the south. The intensity of the extreme daily rainfall event is likely to increase in many parts of the country (McInnes and others 2003; Whetton and others 2002; Walsh and others 2001; Abbs 2004; Hennessy and others 2004). Rainfall intensity is a significant influence on the magnitude of flooding, as are antecedent conditions: for example, a dry catchment generates less run-off.

While most climate models do not provide information at the resolution required by hydrologists and planners, there are techniques which can downscale the results to localised regions. These techniques can identify regions where significant rainfall increases are likely to result in increased flooding (e.g. Abbs and others 2007).

The Intergovernmental Panel on Climate Change Fourth Assessment Report highlights the potential impacts of climate change on sea level rise (Meehl and others 2007). Any rise in sea level has the potential to have a significant impact on flood behaviour and levels where storm tide,

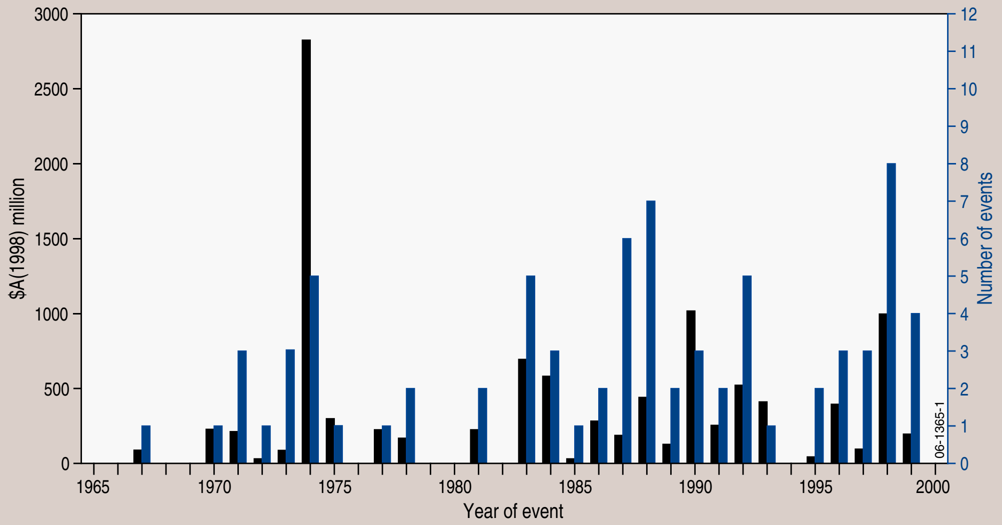


Figure 5.2: Annual cost and number of floods in Australia, 1967 to1999
Source: Based on BTE (2001), Figures 3.15 and 3.17.

high tides and/or constricted or closed outlets to the ocean influence flood behaviour.

Risk Analysis

Flood poses a risk only when it has the potential to impact on an element of tangible or intrinsic value, such as buildings, infrastructure or people. People directly influence flood risk. For example, the construction of new development in the floodplain, or changes in floodplain topography, may raise flood levels at another location. The increase in impervious areas also contributes to a greater volume of run-off and potentially larger peak flood flows. As further development occurs in floodplains, the number of elements exposed to flooding increases. However, effective mitigation strategies may help in reducing flood risk.

The development of the more hazardous parts of the floodplain can be a negative catalyst which transforms a 'hazard' into a 'disaster'. As the population in affected areas increases, so to does the potential scale of a disaster.

The most severe example of urban flooding in Australia occurred in Brisbane–Ipswich in 1974. Three floods prior to the 1974 floods (in 1841, 1844 and 1893) were, however, significantly greater in magnitude at the Brisbane City gauge. Had those floods occurred later in history, their economic impacts would have been far more damaging than those of the 1974 flood.

This highlights the importance of thoroughly analysing the risk in order to more effectively identify and implement appropriate mitigation strategies, and to plan and prepare for the response and recovery phases for when a flood does impact on communities.

Because flood damage is costly and the Australian population has settled very close to rivers, for the supply of water and transport, riverine flood hazard assessments have been undertaken regularly in Australia since the early 1950s. Therefore, the technology is well matured, and most areas affected by riverine flooding have undergone some assessment.

The extension of flood hazard assessment to a risk analysis that looks more objectively at likelihood and consequence is, however, much less widespread, and there are heavily populated urban areas for which no such analysis of flood risk has been made. This deficit is exacerbated by the fact that urban centres are more affected by flash flooding.

In many instances, assessments have led to structural and non-structural mitigation measures. Such measures are usually framed around a 'flood standard' expressed in terms of the annual exceedence probability (AEP). AEP is a statistical benchmark used for flood comparison, defined as the probability of a flood event of a given magnitude being equalled or exceeded in any one year (Pilgrim 2001).

Flood risk management, of which risk analysis is a component, is described in SCARM (2000) and other documents (e.g. DIPNR 2005). The approach is not prescriptive and requires

Flooding in Melbourne St., South Brisbane, Queensland, February 1893
Photo courtesy: John Oxley Library/66106.

Buildings destroyed by a flood in Ipswich, Queensland, February 1893
Photo courtesy: Hughes Collection/Ipswich Historical Society/A. Geertsma/B. Taylor.

Filling sandbags to form flood barriers at Lakes Entrance, Bullock Island, Gippsland, June-July 2007
Photo courtesy: CFA Public Affairs.

identifying and managing the full range of flood risks, in partnership with the stakeholders at risk of flooding and in consideration of local issues.

The 1% AEP flood or the largest known historical flood (plus an appropriate safety/error margin) is typically used for placing restrictions on new developments requiring planning or building permits. Likewise, it is typically used for determining the design standard for structural flood mitigation works. However, increasing recognition is being given to the use of a more robust risk assessment to justify the need for a higher or lower standard.

Increasingly, more extreme floods (e.g. 0.2% AEP) or the probable maximum flood (PMF) are used as the development controls for the building of critical facilities such as hospitals, emergency services, police facilities, power stations and water treatment plants (e.g. Queensland Government 2003).

The more extreme floods are also used to provide essential information on the scale and extent of the problem for emergency response planning. They can also be used to identify facilities that may need special consideration in an emergency response. Examples of such facilities include nursing homes, child care centres and high-security correctional centres.

A comprehensive risk analysis of the full range of flood risk, including damage by rarer floods and by the more common floods, enables a better balance in assessing overall risk. It also better takes account of the natural cycle of floods and the impact of structural measures already undertaken.

There are several key stages to analysing risk. The first two stages in the risk analysis process involve assessing the likelihood of flooding by developing an understanding of flood behaviour through modelling studies using floods of different frequencies. Outputs from such studies include maps showing the extent of flooding and, in some cases, other information such as the variations in water depth and flow velocity across the floodplain.

The third stage looks at the consequences of the full range of flood risks by assessing the exposure and/or vulnerability of the elements at risk of inundation, such as people, buildings and infrastructure. It also examines how risk can most effectively be managed to inform decision making.

All stages require making important decisions relating to the choice and scope of the modelling. The selection of models depends on variables such as catchment characteristics, the purpose of the modelling, budget, data available and time constraints. A model is only a representation of what may happen; therefore, the results will vary depending on the different models used and assumptions made. The issue of risk versus cost, including the concept of 'tolerable' risk (as described in Chapter 3), also needs to be considered when collecting data. The accuracy of the digital elevation data is often the greatest constraint for inundation consequence modelling.

The stages of likelihood and consequence analyses, and the broad data requirements involved in each, are described in more detail in the following sections.

Likelihood Analysis

Flood behaviour modelling is used to determine the likelihood of flooding for a given area, and is usually commissioned by flood management agencies from local or state government. The modelling is often undertaken by consultants because of the specialist technical nature of the work.

Modelling flood behaviour is technically a two-stage process. The first stage involves estimating the flood potential or probable flood flows. This may be done by combining flood frequency analysis (where sufficient flow data is available) and/or the use of artificial 'design' sets of rainfall data applicable to the area with a rainfall run-off model, to estimate design flood hydrographs for various frequencies and durations of events. This stage is commonly known as the 'hydrologic analysis'.

The Engineers Australia publication *Australian Rainfall and Runoff* (Pilgrim 2001) provides guidance on methods for estimating design floods, including estimates of applicable design rainfall. The hydrological component of the model needs to consider historical data. The model may be calibrated and verified, often in combination with hydraulic modelling, which is described below.

The second stage, called the 'hydraulic component', involves evaluating the hydraulic behaviour of flood flow through the area of interest. Hydraulic models are calibrated and verified against historical flood levels, flow data, rainfall data and even public recollections about what areas were affected, to ensure that modelled flood behaviour reflects reality.

Many hydrological and hydraulic models are available in the market, and often the selection is based on familiarity by the user, along with the broad characteristics or geometry of the particular floodplain. Some of these models have been reviewed by the Manly Hydraulics Laboratory (2006), and the more frequently used models have been identified by Middelmann and others (2005b).

The hydraulic models may be one dimensional or two dimensional (or combinations of these), and the flow analyses may be based on either steady states (i.e. inputs are not time dependent) or unsteady/dynamic states (i.e. inputs are time dependent). The impacts from structures such as levees and dams are required to be incorporated into the hydraulic modelling component. The Australian Flood Studies Database (GA 2007) provides a record of flood studies undertaken nationally since 1980.

Data requirements

It is essential that good records of both rainfall and stream gauge data are available for acceptable flood hazard modelling. In some cases, information on tides may also be required. Cross-sectional data of the channel and survey information that captures the floodplain geometry are essential, including data relating to the surface roughness of channels and floodplain areas. Details of environmental and human influences, including the storage capacity of various parts of the floodplain and features that influence flow behaviour, such

A railway station flooded at Maitland, New South Wales, February 1955
Photo courtesy: NSW SES.

as raised roads and levees, are also important. Ideally, these data are sourced from bathymetric and land surveys of the area concerned.

A model is only as good as the data it contains; therefore, the availability of high-quality and appropriate data is paramount. The number and distribution of rainfall and stream flow gauging stations, their history of operation, and the reliability of data can significantly affect the uncertainty around the estimates. Where possible, the model should be calibrated against several historic floods, using information such as historical flood levels and discharges and flood photography. As the floods of interest generally relate to rare events, the calibration data should focus on these in particular.

Consequence Analysis

At the most simplistic level, an assessment of consequence may be made for any elements, such as buildings or infrastructure, that essentially become 'wet' in a flood. As more data on both the hazard and the elements exposed become available, more sophisticated estimates can be made. This also requires the development and application of appropriate models, such as stage damage curves, to estimate vulnerability. Some of the broad types of models for flooding are briefly discussed in this section.

Floods cause damage not only directly, by inundation, erosion or 'washing away' of facilities, but also indirectly, off-site. The flooding or isolation by flood waters of critical facilities such as hospitals places pressure on the services provided by these facilities to communities in other areas. Flood damage to infrastructure can cause power outages and disrupt communication services for people living outside the inundated area. It may also have sewage and water supply implications and, therefore, health implications. Floods can cut off vital transport links, causing general disruption and isolation, particularly in remote communities.

Direct damage costs for residential buildings are typically estimated using engineering vulnerability models such as stage damage curves. Curves have been developed which estimate flood damage to building structure and/or to building contents, based on the depth (i.e. 'stage' height) of over-floor flooding. Though the structural and contents curves available worldwide are produced in different ways, they typically indicate a sudden increase in damage as soon as water goes over the floor.

From 1980 to 2004, the most commonly used stage damage curve in Australia was ANUFLOOD (Middelmann and others 2005b), though subsequent work using insured loss data suggests that ANUFLOOD significantly underestimates flood damages (Blong 2002).

Examples of specific damage studies that have been conducted with the use of geographic information system (GIS), survey and property data include two studies done for areas in Queensland: Gold Coast City (Betts 2002) and southeast Queensland (Middelmann and others 2001), and a study for Perth, Western Australia (Middelmann in draft).

Factors other than water depth influence damage. The flow velocity, the length of time for which an area is inundated, building materials, and the amount of sediment in the water also influence damage. Contents loss can be reduced where sufficient flood warning is given and contents are able to be moved to elevations above the flood level.

Research has been undertaken in Australia to assess how different building types are affected by various flood depths and velocities. Dale and others (2004) built on Black's (1975) research in the United States which described the combinations of water depth and velocity theoretically required to move a house subject to flooding off its foundations. Because the weight of the structure is a key factor in whether a house will move off its foundations in floodwaters, a house with brick veneer walls was found to be more resilient than a house with fibro walls. Roof type was also found to play a role, with buildings with tile roofs heavier and therefore more resilient than buildings with steel roofs (Dale and others 2004).

The economic cost resulting from flooding of commercial or industrial buildings can greatly exceed the cost from flooding of residential buildings (Booysen and others 1999). For example, damage to commercial and industrial buildings and contents was more than double residential damage in the 1974 Lismore flood (BTE 2001).

However, damage costs for commercial or industrial buildings can be more difficult to estimate, because the cost of damage greatly depends on the function and contents of the building. Therefore, estimates of damage on a site-by-site basis, through interviews of individual businesses, are more accurate than estimates using stage damage–type curves. Damage estimates based on floor area and the susceptibility of a building to flood damage were, however, developed for commercial properties by Smith (1994), for use in lieu of site-specific data.

Indirect damage costs, such as loss of production, revenue or wages, are more difficult to model than direct costs. Other indirect costs include clean-up and repair costs and the impact from loss of services. Residential clean-up time as a function of flood depth is shown in Figure 5.3, based on SMEC (1975). As with stage damage curves, the greatest increase in clean-up costs occurs as soon as the water goes over the floor.

Prior experience of flooding at a location appears to reduce overall stress both during and after an event. Prior experience also appears to have an impact on physical health. A study of

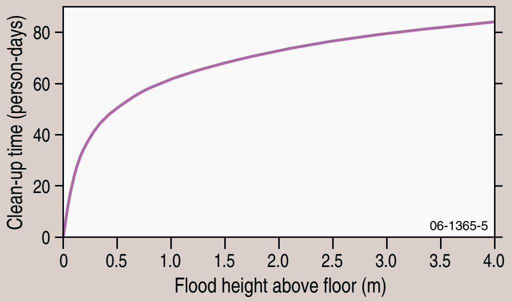


Figure 5.3: Residential clean-up time as a function of flood depth   Source: BTE (2001), Figure 4.6.

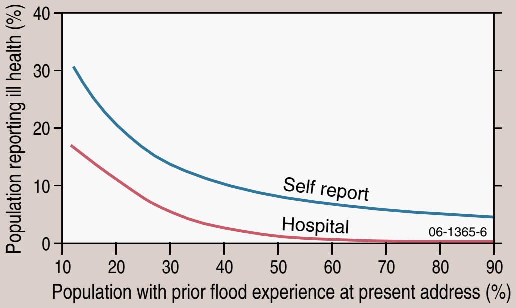


Figure 5.4: Health impact of floods as a function of prior flood experience   Source: Based on BTE (2001), Figure 4.7.

A rural road flooded in the Moree area, northwest New South Wales, December 2004
Photo courtesy: NSW SES.

populations in Queensland (Handmer and others 1986) found that those with prior experience of flooding at their current address were less likely to report ill health in the aftermath of severe flooding, as shown in Figure 5.4.

Data requirements

Determining consequence requires information on the flood hazard and the actual elements or facilities potentially subject to flooding. This may include the location and elevation of buildings and infrastructure such as power and telecommunications, and the location of people.

Defining the extent of the area of inundation and the variation in susceptibility to damage across the floodplain is essential in order to understand the potential consequences of flooding and how the particular components of exposure can be managed.

The most simplistic form of risk analysis looks at what elements are located within the flooded area. At a more detailed level, knowledge of the depth of over-floor flooding in relation to the elements at risk, such as buildings, is required, and information on building type can be useful. A digital elevation model (DEM) of suitable resolution may be used in conjunction with water surface elevation information to estimate water depths at specific points of interest.

A more rigorous risk analysis requires additional information on hazard parameters such as flow velocities and duration of inundation. It also requires more detailed information on the elements at risk, to assess their vulnerability.

The information required will vary depending on the damage model to be used, but may include information such as floor area, floor height, wall type, roof type and floor type. Data on commercial and industrial buildings may be collected through interview. Information on the location of critical facilities, such as ambulance stations and state emergency services, is also needed.

Unsteady or dynamic flood modelling, where inputs are time dependent, is essential in a more detailed risk analysis, to provide a good understanding of the variation in flood consequences. This approach will assist in estimating the time (after the onset of heavy rainfall or the commencement of flooding) before a particular element or group of elements at risk is flooded. Dynamic modelling should also estimate the length of time for which the elements at risk, such as roads and bridges, are inundated.

Identification of highly vulnerable groups of people, such as people with disabilities, is also important. Caravan parks sited on floodplains create a special risk category (Yeo 2003). In many cases, mobile caravans occupied by travelling people have been progressively replaced by semi-permanent ‘relocatable’ structures occupied by socioeconomically disadvantaged people.

Information Gaps

Although significant work has been undertaken over previous decades, there are still important information gaps relating to flood risk analysis. These include standards in modelling and reporting, risk from flash flooding, influence of climate change, vulnerability research, research into making buildings more flood-resistant and post-disaster assessment. Lack of data, such as high-resolution DEMs, rainfall records and streamflow records, though not specifically covered below, remains an issue in some areas.

Lack of Standards in Modelling and Reporting

Flood likelihood information is more comprehensive than the likelihood information available for many other hazards. However, there are large discrepancies in the information currently used. Flood investigations use a wide range of appropriate models: the selection of a model depends on the location, the flood type, the intent and budget of the study and the data available. There are no nationally accepted, consistent standards for models and approaches, or for the analysis and reporting of risk.

National guidance for reporting on risk analysis could be considered in light of the National Risk Assessment Framework (NRAAG 2007) and the need to compare risks between locations and hazards. This national guidance could also address general standards and methodologies and set some minimum standards or benchmarks for studies for particular purposes.

Models and approaches

Comparison of flood risks is difficult at a national level, because of the variation in models and approaches used, especially regarding hazard and building damage models. For example, Middelmann and others (2005b) found that less than 60% of the damage studies they assessed provided details such as which damage curve or model was used for the damage estimation, a critical factor in comparing loss estimates.

Substantial differences can be found in hazard determinations (Middelmann and others 2005a) and damage estimates (Blong 2002), depending on the model used. Selection of the most appropriate data for the purpose and location is therefore important.

Though factors other than depth of inundation play a role in determining the level of damage, they are rarely incorporated in a risk analysis. An analysis of published Australian flood risk studies to 2004 found that only 11% of damage assessments incorporated velocity and no studies incorporated duration of inundation (Middelmann and others 2005b). The substantial additional cost incurred to collect, implement and analyse this data, and the paucity of damage curves for combinations of velocity and water depth, may be the reasons for this. Work by Dale and others (2004) is a step towards remedying this situation.

Reporting of damage

The reporting of damage also varies significantly. Only 23% of damage assessments in the Australian Flood Studies Database gave both the number of properties with over-floor flooding and the number of properties with water at least on the property (Middelmann and others 2005b). Forty percent of damage assessments made no comment on the number of properties affected, but gave either an average annual damage or a total damage cost.

The latest published estimate of the number of residential properties in Australia susceptible to mainstream river flooding by the 1% AEP event is approximately 170,000 (Leigh and Gissing

Flooded central business district in Lismore, New South Wales, March 1974
Photo courtesy: NSW SES.

2006). Due to the differences in reporting in flood studies, no consistent risk measure could be used. Some areas have not had any form of risk analysis undertaken. Just in New South Wales, a state where much has been done to identify the flood risk, the study identified 26 towns and communities for which studies may be required. No estimates have been made of the numbers of properties affected at other levels of probability, because of the extremely limited data.

Understanding the potential impact from a full range of flood probabilities through to the PMF is important from an emergency management perspective. It is also important for identifying and implementing appropriate mitigation strategies.

Another hindrance when making a comparison nationally is that flood studies and risk assessments have been undertaken over a long period in history. Therefore, the impact of recent development is not reflected, nor have the most up-to-date flood levels available been used, highlighting the issues of data maintenance and currency. In some areas, though flood water levels may have been estimated, maps of the extent of inundation may not have been produced. The affects of factors such as water depth, velocity and duration are also often not considered.

In general, councils should review their flood management plans after a major flood event, or when there has been, or needs to be, a significant change in the management of the floodplain. This may involve updating the modelling, which provides an opportunity to collect additional data.

Risk from Flash Flooding

Currently, limited data is available on the risk posed by flash flooding, though the number of properties at risk from flash flooding is likely to far exceed the number at risk of riverine flooding.

The number of properties in the Melbourne area affected by flash flooding has been estimated by Melbourne Water (2006) to be more than 82,000. The same document estimated the average annual damages for flash flooding to be $215 million for Melbourne alone, compared to an estimated $30 million for riverine flooding. Clearly this is a significant problem for Melbourne, and one that is likely to be mirrored in most other heavily urbanised areas of Australia.

Much greater research is required to understand and manage the risks from flash flooding. The analysis of areas at risk from flash flooding can follow essentially the same process as for riverine flooding. However, the level of uncertainty surrounding the risk analysis is larger. Local impacts are difficult to predict, because of the complexity in assessing local overland flow path effects. Variable factors such as drains being temporarily blocked (sometimes by large objects such as cars) and flow paths being impeded, and other local occurrences including land use changes, create potential complexities that are hard to model other than by way of broad contingency allowances.

Influence of Climate Change

The development of new housing and infrastructure should factor in potential increases in flood risk arising from any increases in extreme rainfall and sea level rise as consequences of climate change. Various levels of government are analysing these changes to see how they can be factored into planning processes. Awareness of the changed flood risk enables local councils to implement new flood mitigation strategies, respond through land use planning, minimise future risk in emergencies and engage with and educate the community. An example of a preliminary study is that of the Gold Coast City Council (Rahman 2007).

Regional changes in peak rainfall intensity should also be determined directly, rather than through downscaling techniques. The impacts of changes in average rainfall on catchments are also important in determining the overall changes in flood risk.

Vulnerability Research

There are a number of gaps in the knowledge of structural vulnerability to flooding. Most existing structural vulnerability research considers loss caused by wetting of components to various heights (i.e. stage damage curves). Loss caused by partial structural damage (i.e. the failure of a component of the structure, such as a wall panel, door or window) is rarely considered. Complete structural failure, requiring a complete rebuild, is also rarely considered.

The work on residential structures tends to focus on particular housing types and materials. There is, therefore, an opportunity to broaden research to cover more residential structure types. Refinement of the curves currently in use, and examination of their sensitivity to changes in flood risk, are also important.

The majority of work to date has focused on residential premises, leaving gaps in vulnerability modelling of commercial and industrial premises.

There is a critical need to look at the potential secondary consequences of flooding from both a community risk perspective and an environmental risk perspective. Floods affecting sites that store hazardous materials, for example, pose unique and significant risks. Inundation of sewerage facilities poses significant health risks.

While there have been some attempts at modelling vulnerability connected to timeliness of

The Hunter River in flood at Morpeth, New South Wales, June 2007
Photo courtesy: NSW SES/Phil Campbell.

evacuation, such as in the Hawkesbury–Nepean catchment downstream of the Warragamba Dam in New South Wales (Opper 2004), this is another issue that needs more investigation.

Making Buildings More Resistant to Floods

Research into developing flood-resistant building materials to withstand flood loads or other actions is only beginning. Research could also be undertaken into the optimal location of electrics and telecommunications in flood-prone buildings. Many documents referenced by the Building Code of Australia have provisions relating to structural actions and the durability of components subject to site and soil conditions; however, this information is not specifically located in sections relating to flood inundation.

Flood damage to the Mitchell Highway near Nyngan, New South Wales, April 1990
Photo courtesy: Emergency Management Australia.

Post-disaster Assessment

Post-disaster assessments provide valuable information on losses, which may be used in areas such as model development and disaster management. The development and use of a consistent survey for the collection of post-disaster information nationally would enable more robust comparisons between events and locations. It would also assist in developing a more accurate assessment of the cost of floods in Australia. The data collected would also assist in demonstrating the effectiveness of mitigation strategies and provide vital information for the development of flood damage models.

Routine post-disaster assessments were recommended in the high level report to the Council of Australian Governments *Natural Disasters in Australia. Reforming Mitigation, Relief and Recovery Arrangements* (COAG 2004).

Roles and Responsibilities

Responsibility for the management of flood risk cuts across all levels of government, non-government agencies and groups, and the general community. State and territory governments play a particularly important role in managing flood risk, including a major statutory responsibility.

'Flood risk management' is essentially the way in which the likelihood and consequences of flooding are dealt with. Flood risk management is succinctly described in SCARM as (2000, p. 5):

'the analysis of the risk exposure of a flood-prone community; that is, a flood risk analysis, followed by the identification and implementation of appropriate measures to manage existing, future and residual flood risks to acceptable levels.' **[emphasis in the original]**

This section attempts to describe the various expectations of the different stakeholders in managing flood risk effectively.

Australian Government

The Australian Government's overarching goal in the management of flood risk is to ensure the economic and social health of Australia (SCARM 2000). The Australian Government provides financial assistance for flood studies, warning systems and mitigation measures, through its funding programmes aimed at reducing the risk of natural disasters. Following a disaster, the Australian Government also provides financial assistance to those suffering from the impact of the disaster. It also plays a role in raising broad community awareness of flood risk.

The Australian Government takes a lead role in the provision of flood warning services. It also plays a significant role in developing and managing rainfall data collection networks, and is the source of design rainfall information that is essential for flood estimation and warning. The government supports research into flood-related aspects of risk analysis, including post-disaster surveys, and invests in the development of new technology, such as remote sensing. The Australian Government also maintains the Australian Flood Studies Database.

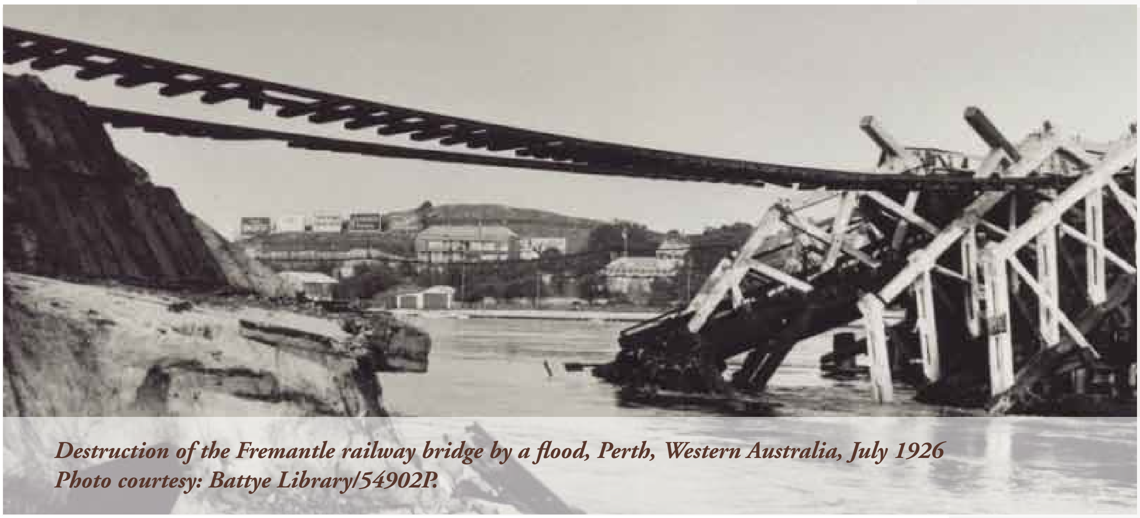
State and Territory Governments

State and territory government agencies play important roles in flood management in Australia. These roles encompass areas of technical, policy and financial support. The different types of agencies and their key roles are briefly described below; for further detail, the reader is referred to SCARM (2000).

Some state and territory variation exists in the roles played by the agencies, and some states and territories delegate greater responsibility to local agencies. A number of state and territory government agencies have developed their own flood management strategies, including guidance materials (DIPNR 2005; DNRE 1998; WRC 2004). They also play a key role in managing stream gauge networks essential for flood estimation.

Water resource agencies

Water resource agencies provide advice on flooding and floodplain behaviour, and maintain the expertise to deal with the technical aspects of flooding behaviour. They are often also involved in coordinating and funding research into specific aspects of flooding. Their primary function in relation to floods is to facilitate and guide local agencies in flood management, particularly in the development and implementation of flood management plans.



Destruction of the Fremantle railway bridge by a flood, Perth, Western Australia, July 1926
Photo courtesy: Battye Library/54902P.

Submerged houses by a flood in Ipswich, Queensland, January 1974
Photo courtesy: Hughes collection/Ipswich Historical Society/Philip Willey.

Water resource agencies provide guidance regarding flood modelling and help local agencies on definitional issues. They advise other state agencies, especially those involved in planning, transport and emergency services. They also advise and assist in relation to flood forecasting and warnings and the assessment of grants.

Land use planning agencies

The planning agency in each state and territory broadly administers the local planning system and the preparation of regional and special issue plans. It also oversees the development of local planning instruments which encompass planning requirements for flooding. The state planning agency liaises with the state water resource agency on appropriate floodplain development, and manages relevant documentation, including flood maps.

Road and rail transport agencies

Road and rail transport agencies have a responsibility to protect road and railway infrastructure against floods and to ensure that the infrastructure does not detrimentally increase flood levels and, thereby, flood hazard. They do this by liaising closely with the state water resource agency and local agencies.

Emergency management agencies

Emergency management agencies have the statutory responsibility to coordinate flood emergency operations, including warning the community. Associated with this is the expectation that they will help local agencies in the preparation of flood emergency response plans, though the actual responsibility varies across the states and territories. The development of these plans is considered critical to protect life and property, and requires input from various sources (including the relevant local government agency, state water resource agency and emergency services agencies).

Emergency management agencies are assisted in their response operations by flood forecasts from the Bureau of Meteorology. They also receive assistance and advice on flood behaviour from the state water resource agencies, to inform their flood response planning. Emergency management agencies also have a responsibility as combat agencies, for example in evacuation and rescue, and in some states and territories they have a responsibility in coordinating recovery operations.

Local Government

The expected role of local government in flood risk management varies across the country, as does legislation covering this aspect. The roles are invariably linked to storm water and flood management.

Generally, local government has the primary responsibility for managing the impact of flooding in their local area. Activities include undertaking flood risk assessments and implementing planning controls, and developing and implementing plans to mitigate flood risk. Local government also provides assistance to emergency services in times of flood, and make members of the community aware of the risks posed by flooding and ways to reduce the risk to themselves. Local government therefore materially contributes to the management of flood risk.

In most urban areas, councils or the territory government are responsible for local flood management, including risk assessment. In rural areas, the responsibility is sometimes shared with other groups such as state government agencies, catchment management authorities and river trusts. In the greater Melbourne area, councils are responsible for drainage and flooding issues for catchments up to 60 hectares in size, and Melbourne Water takes responsibility for all the larger catchments. Flood management outcomes are sometimes addressed through a floodplain management committee (SCARM 2000).

Industry, Coordinating Groups, Professional Bodies and Research Institutions

A number of professional bodies, coordinating groups and industry bodies play an advocacy role in flood risk management. There is a mix of informal and formal groups. Some function at a national level, such as the National Flood Risk Advisory Group (NFRAG 2006), Engineers Australia and the Insurance Council of Australia. Other groups are state-based or locally based, such as the state flood warning consultative committees (FWCC 1987), state flood policy committees and state emergency management committees.

The Floodplain Management Authorities is a key industry stakeholder representing about 80 organisations, primarily in New South Wales (FMA 2007). It provides opportunities for the discussion of issues in flood management and the sharing of experience across the industry. Numerous consulting companies are involved in flood hazard and risk assessment on behalf of government and non-government agencies. Research into different aspects of flood hazard and risk assessment is also conducted by various universities, cooperative research centres and CSIRO.

Elderly residents are evacuated from a nursing home near Wyong on the Central Coast, New South Wales, June 2007
Photo courtesy: NSW SES/Kim Palmer.

An aerial view of the flooded Richmond River High School in Lismore, New South Wales, June 2005
Photo courtesy: NSW SES/Phil Campbell.

Property Developers

Developers are required to prepare applications which address the provisions or conditions relating to development in a floodplain. Generally, the developer is required to undertake sufficiently detailed flood, economic and environmental studies to demonstrate that the proposal has no adverse flood or environmental effects and meets relevant performance standards.

Courts and Legal Institutions

The courts and other legal institutions, such as administrative appeals tribunals, play a significant role in settling disputes between developers, councils and other opposing parties regarding applications for development in a floodplain.

Media

The media play a vital role in delivering the message behind flood warnings to the community. In the event of an emergency, radio broadcasts are particularly effective in warning the community. The media are also very much involved in raising community awareness of flood hazard in general.

General Community

Individuals have a basic responsibility to be aware of any flood risk faced by themselves, their families and their communities. Ideally, individuals should know what to do during a flood event and understand how a flood height at a flood reference gauge will affect their individual property. At a minimum, members of the general community should at least have the knowledge to understand the advice of the relevant authorities during a flood event. Awareness raising requires input from agencies dealing with flood management and emergency response.

A specific knowledge of the location of evacuation routes and how to respond to flood warnings is vital for community safety. The community should also have a more general understanding that extreme floods occur, including in areas where development is being approved by the local agency. They should also understand that measures such as structural flood mitigation works can rarely, if ever, fully alleviate the flood risk.

Irrespective of the level of flood risk, vulnerability of a community is greatly reduced when individuals are able to obtain relevant information and are committed to meeting their responsibilities.

Conclusion

Floods have been estimated to contribute 29% of the average annual natural hazard damage in Australia, costing around $314 million each year. Records for flood fatalities extend back further than records for any other hazard, with over 2300 fatalities since 1790.

Because of the huge cost imposed on the community by floods, it is vital that the risk of flooding in Australia from a full range of flood events, including the potential impact of climate change, is determined. All levels of government, as well as non-government agencies and groups and local communities, play an important role in flood risk management, with state and territory governments having a major statutory responsibility, and local government generally having primary responsibility for managing the impacts of flooding in their local area.

The models used to assess risk are only as good as the data used in their development. The development of detailed, calibrated and verified flood modelling is therefore essential in order to accurately assess exposure. This requires good records of data such as rainfall, stream gauge and tidal information, flood photography and historic flood levels. High-resolution topographic and bathymetric data are also required, along with detailed information on environmental and human influences on flood flows and storages.

To assess consequence, information on the elements of risk and a high-resolution DEM are also required. While many factors contribute to vulnerability, knowledge of the depth of over-floor flooding is the minimum data requirement. Information on velocity and duration of inundation is required for a more rigorous analysis of flood risk.

Further work in areas such as flash flood risk, vulnerability model development, post-disaster assessment and climate change is also important. Guidance in modelling, damage reporting, and research into making buildings more resistant to floods are also areas for further work.

Flooding at Rosebrook, Victoria, March 1946
Photo courtesy: Glenelg Hopkins Catchment Management Authority.

Chapter Six:

Severe Storm

Lightning strikes through a roll cloud near Alstonville, New South Wales, January 2003
Photo courtesy: NSW Storms/Dave Ellem.

Severe Storm

Severe storms can range from isolated thunderstorms that affect only a few square kilometres to intense low-pressure systems that affect thousands of square kilometres. They can be associated with tropical cyclones, a type of low-pressure system originating over the tropical oceans (covered in Chapter 4), and can be a substantial contributor to flooding (covered in Chapter 5).

From 1967 to 1999, severe storms have been estimated to cost Australia about $284 million each year (BTE 2001), representing just over one quarter of the average annual cost of natural disasters in Australia. Storm damage is a significant issue for the insurance industry: paid insurance claims for severe storm damage are greater than those for tropical cyclones, earthquakes, floods or bushfires. Thunderstorms have killed over 770 people since 1824 (Blong 2005), and large-scale storms often cause deaths through flooding or shipwreck.

Damage caused by hail and wind, Brisbane, Queensland, January 1985
Photo courtesy: Emergency Management Australia.

Cars left stranded during a flash flood in Melbourne, Victoria, January 2004
Photo courtesy: Glenn Gibson.

A car lies crushed by a tree brought down by a storm in Fairfield, New South Wales, October 2003
Photo courtesy: NSW SES.

Storm damage to a building at Tara, Queensland, March 2007
Photo courtesy: Emergency Management Queensland.

This chapter deals in detail with aspects of severe storms not covered in earlier chapters, including the risk analysis process for tornadoes, hail and lightning risks. The impact of climate change on these phenomena remains a significant gap in understanding the risk associated with severe storms, and several other gaps are identified. The roles and responsibilities in minimising the impacts of severe storms are shared between governments and community members, with the media also playing an important role.

Hazard Identification

Severe storms are atmospheric disturbances usually characterised by strong and hazardous winds, frequently combined with heavy rain, snow, sleet, hail, ice and/or lightning and thunder. This definition includes unusual meteorological disturbances, such as tornadoes or waterspouts, caused by severe thunderstorms. Severe storms are defined in two broad categories: large-scale storms and thunderstorms.

On the largest scale, severe storms are associated with the intense low-pressure systems depicted on weather maps. These low-pressure systems are also called synoptic storms or extratropical cyclones. These systems, and the associated cold fronts, can bring hazardous winds and heavy rain that may extend over large areas, causing both local flash flooding and riverine flooding. Such weather systems may also cause coastal erosion, as a result of the combined effects of large waves and increases in the sea level because of storm tide.

Often, the main wind damage from these low-pressure systems occurs in coastal areas and along mountain ranges. A notable example is the severe storm that tragically affected the Sydney–Hobart yacht race in December 1998.

There are several types of synoptic storms that can be categorised as severe storms: mid-latitude lows and cold fronts, east coast lows and decaying tropical cyclones.

Mid-latitude lows and cold fronts form in the westerly wind band over the Southern Ocean. These affect Tasmania and the southern parts of Western Australia, South Australia, Victoria and New South Wales. They occur mainly between winter and early summer and commonly produce sustained gale force winds (exceeding 63 kilometres per hour) and gusts exceeding 90 kilometres per hour, reaching speeds as high as 150 kilometres per hour in exposed areas.

East coast lows form along the east coast from southeast Queensland to Tasmania. These systems are often quite small, usually only a few hundred kilometres across, and can be quite short lived (Holland and others 1987). East coast lows are most common during autumn and winter and can generate storm force winds (wind gusts exceeding 150 kilometres per hour), flooding and damaging seas.

Decaying tropical cyclones are discussed in Chapter 4. One example is the decaying Cyclone *Wanda*, which contributed to the 1974 floods in southeast Queensland.

Synoptic storms can exacerbate other hazards, such as bushfires. The strong winds associated with synoptic storms can heighten the likelihood of bushfires becoming destructive events. During winter months, deep low-pressure systems can result in snowfalls to very low elevations, which can cause serious stock and crop losses and significant disruption to communities that are not equipped to cope with heavy snowfalls.

The term 'thunderstorm' is a general term for relatively small-scale convective processes that develop when warm, humid air near the ground receives an initial upward push from converging surface winds and rises rapidly in an unstable atmosphere (as shown in Figure 6.1). Cumulonimbus clouds may rapidly develop, potentially reaching heights of up to 20 kilometres, with associated lightning, thunder, hazardous wind gusts, heavy rain and hail.

Thunderstorms are typically short lived (up to a few hours) and can be of limited size (up to 10 kilometres in diameter). They generally move in the direction of winds in the lower atmosphere, but not necessarily in the direction of the surface winds.

The most common region for thunderstorms in Australia is the tropical north, where the supply of warm, moist air is greatest (Figure 6.2). Southeast Queensland and eastern New South Wales also experience a significant number of thunderstorms, while southern Tasmania experiences an average of only five thunderstorms annually.

Thunderstorms may at times be arranged in lines several hundreds of kilometres in length (i.e. 'squall lines'), or in clusters. Thunderstorms may be embedded in synoptic storm systems or generated along cold fronts. The strong cold fronts that affect southern coastal areas during winter and spring may also spawn severe localised winds, including tornadoes that may be strong enough to unroof houses.

A 'severe' thunderstorm is a thunderstorm that produces one or more of the following phenomena (BoM 2007a):

- a tornado
- hail of diameter 2 centimetres or greater
- wind gusts of 90 kilometres per hour or greater
- very heavy rain leading to flash flooding.

Only about 10% of thunderstorms are severe, but these account for approximately 90% of the damage produced by all thunderstorms (BoM 2007a). All thunderstorms can produce lightning which can cause death, injury and damage.

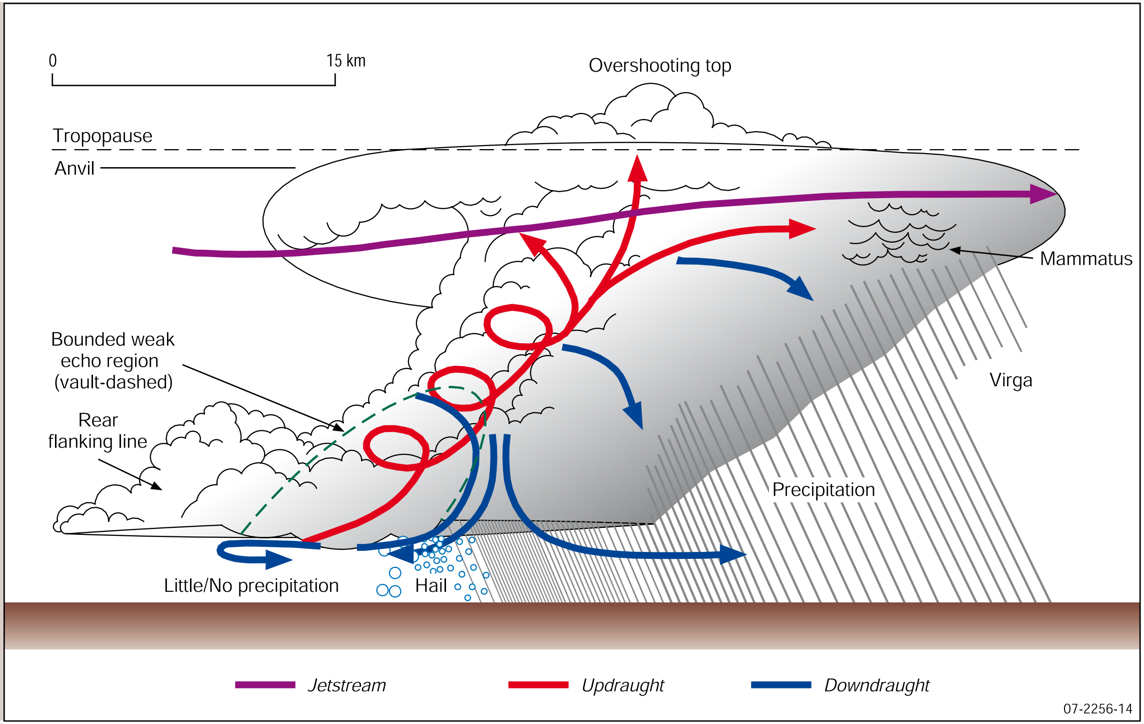


Figure 6.1: The development of severe thunderstorms
Source: Based on Rauber and others (2005), Figure 17.18.

Severe thunderstorms can occur at any time of the year, although they occur very rarely during the dry winter months in the north. Most thunderstorms strike between September and March, when the supply of solar energy is greatest. Severe thunderstorms linked to cold fronts also occur from autumn to spring in southwest Western Australia, southeast South Australia, Victoria and Tasmania. Severe thunderstorms are most common in New South Wales, Queensland and parts of Western Australia, and least common in Tasmania.

Useful introductory studies of the nature of severe storms and their occurrence in Australia are given in Colls and Whitaker (2001), Crowder (1995), and Sturman and Tapper (2006), as well as on the Bureau of Meteorology website (BoM 2007a). Reports of noteworthy storms are included in BoM (2004) and Whitaker (2006).

The meteorological phenomena associated with large-scale low-pressure systems (storm tides) and severe storms (lightning and thunder, hail, tornadoes, water spouts, damaging winds and flash floods) are described in more detail below.

Storm Tide

Strong winds pushing on the ocean surface and the reduced atmospheric pressure within a low-pressure system can cause the water to pile up higher than the normal sea level. The movement of the storm ashore can cause a storm tide, resulting from the combination of the surge, wave run-up, the astronomical tide and any freshwater flooding. Storm surges accompany a tropical cyclone as it comes ashore (as discussed in Chapter 4). They may also be formed by intense low-pressure systems, in non-tropical areas; or sustained winds blowing along the coastline, with the coast to the left, in the mid-latitudes, such as on the coast of South Australia. The worst impacts occur when the storm surge arrives on top of a high tide. Large waves generated by powerful winds can add to the impact of a storm tide.

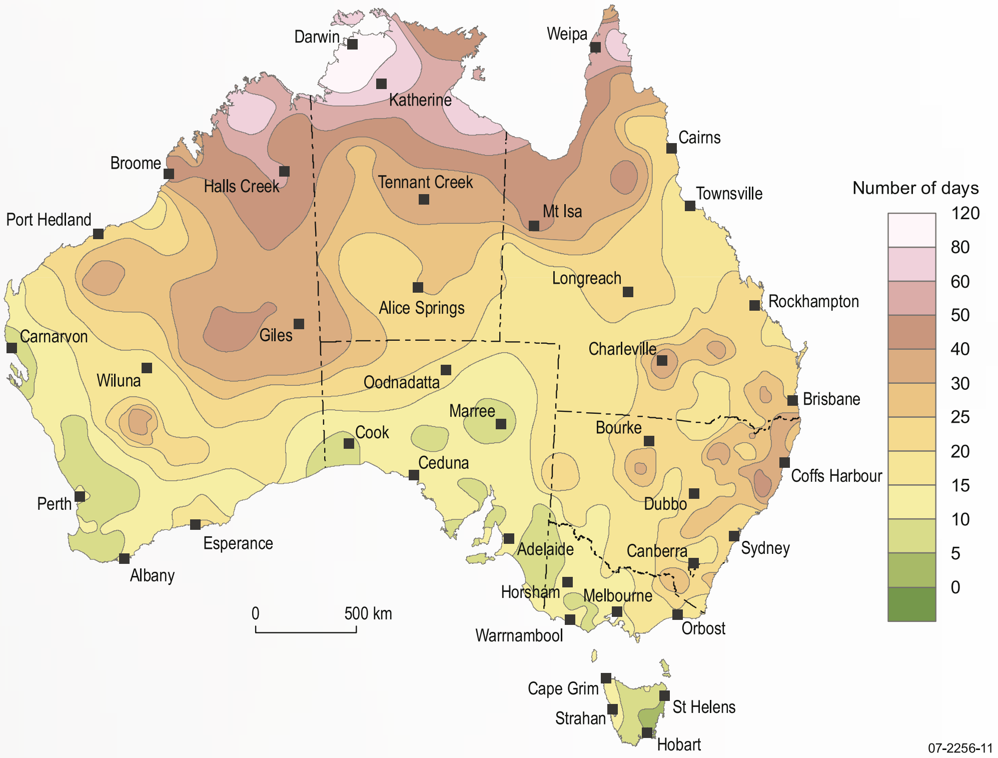


Figure 6.2: Average annual thunder-day map of Australia, derived from Bureau of Meteorology climatological records from 1990 to 1999
Source: Kuleshov and others (2002), Figure 2.

Devastation caused by the Bucca tornado north of Bundaberg, Queensland, November 1992
Photo courtesy: Emergency Management Australia.

Lightning and Thunder

Lightning and thunder are the defining characteristics of thunderstorms. Lightning can occur between the cloud and the ground, within the cloud, or from the cloud into the surrounding air. It is possible for lightning to strike the ground tens of kilometres from the thunderstorm, making it extremely dangerous.

Hail

Hailstones form in thunderstorms with a strong updraught when frozen rain droplets suspended in the updraught grow rapidly through accretion (Iribarne and Cho 1980). Hailstones larger than cricket balls have been recorded in Australia: for example, in Sydney in April 1999.

The potential for damage from large hail is clear. However, storms where there have been copious amounts of small hail have also caused property damage, because blocking of roof gutters and drains has led to inundation into roof spaces or the collapse of flat roofs. Examples include the hailstorms that struck Brisbane in May 2005 and Canberra in February 2007.

Tornado

Tornadoes are rapidly rotating columns of air that descend from the base of a thunderstorm, forming the recognisable funnel-shaped cloud. Tornadoes can range in size from a few metres to more than a kilometre. The winds associated with weak tornadoes can reach 125 kilometres per hour, but winds are estimated to exceed 400 kilometres per hour in the largest tornadoes.

While most common in North America, tornadoes are a global phenomenon that have been observed across Australia. Approximately 360 tornadoes were recorded in New South Wales from 1795 to June 2003 (BoM 2007b), but the incidence is certainly far greater given that many tornadoes occur in uninhabited areas and go unreported.

Tornadoes are usually thought of as being associated with severe thunderstorms in spring and summer. ‘Cool-season’ tornadoes occur in winter in the southern part of the continent, often associated with the passage of cold fronts and synoptic storms. They are generally different from those that occur in the warmer months; they are relatively weak, usually only rating F0 (estimated wind speeds of 62–117 kilometres per hour) or F1 (118–178 kilometres per hour) on the Fujita tornado scale (Fujita 1971), which is based on the extent and severity of damage. Some, such as the tornado in Collie, Western Australia, in April 1960, reach the F2 category (179–250 kilometres per hour).

The most intense tornado officially reported in Australia—the only example in the F4 category (334–419 kilometres per hour winds)—occurred at Bucca, Queensland, on 29 November 1992. Another intense tornado occurred in Brighton, a suburb of Melbourne, on 2 February 1918. In the few minutes that the tornado lasted, two people were killed and many others were injured. From the damage, wind speeds were estimated as being up to 320 kilometres per hour (BoM 2007a).

Water Spout

Water spouts are similar to tornadoes, but generally smaller and weaker, and are not necessarily associated with a thunderstorm (Crowder 1995). Water spouts moving over adjacent land have the potential to be dangerous and have caused both property damage and loss of life in Australia.

Damaging Wind

Intense low-pressure systems are able to generate damaging winds over a large area. The intensity of the winds may be enhanced on the exposed sides of mountain ridges, or downwind of mountains, because of atmospheric waves and turbulent eddies. These winds can also generate large waves on beaches, with persistent intense synoptic storms causing significant beach erosion.

Downdraughts from thunderstorms can generate short-lived wind squalls (i.e. 'downbursts') that can be much stronger and from a different direction to the winds experienced before or after the thunderstorm. Downbursts are a particular hazard to aviation.

Severe thunderstorms can, by definition, produce wind gusts of at least 90 kilometres per hour, but peak winds may exceed 160 kilometres per hour in the most damaging thunderstorms. The strongest measured wind gust during a thunderstorm is 196 kilometres per hour, recorded at Double Island Point, Queensland, on 16 December 2006.

Flash Flood

Strong low-pressure systems often have extensive rain bands associated with them. Such rain bands may lead to flash flooding, especially in

A crushed caravan following a storm in Coffs Harbour, New South Wales, October 2004
Photo courtesy: AAP Image/Bruce Thomas.

areas of steep terrain. The intense updraughts of thunderstorms can suspend huge amounts of rain before releasing a deluge; such rainfall can reach intensities of more than 200 millimetres per hour. Flash floods often result when the storm moves slowly, but the drainage and run-off characteristics of the ground determine the impact.

Cost of Severe Storm

Severe storms can occur anywhere in Australia, and they occur more frequently than any other major natural hazard. Synoptic storms can cause heavy economic losses as shown in Figure 6.3. They can impact large areas, particularly through associated flooding. However, a severe thunderstorm was responsible for the most costly storm event in Australia—the Sydney hailstorm of April 1999, with a total insured loss of approximately $1.7 billion (ICA 2007). Annually, severe storms cost approximately $284 million, exceeded only by the cost of floods (BTE 2001). The total cost of severe storms from 1967 to 1999 is estimated at $9.4 billion (BTE 2001).

Severe thunderstorms have resulted in over 770 deaths in Australia since 1824 (Blong 2005). Of those, 650 were attributed to being struck by lightning (Coates and others 1993). Other causes of death included being struck by a falling tree limb or drowning as a result of the capsizing of small boats. Contrary to the popular belief that tornadoes do not occur in Australia, tornadoes have caused 41 deaths (BoM/EMA 2004).

The number of deaths caused by synoptic storms is unknown. Many of the deaths associated with these large-scale storms are a result of shipwrecks (EMA 2007), but deaths may also have been attributed to flooding or severe thunderstorms embedded in a larger storm.

Potential Influence of Climate Change

Neither global climate models nor regional, high-resolution models are able to accurately capture thunderstorm characteristics. Therefore, it is difficult to infer the impact of climate change on thunderstorms using a modelling approach. One possible methodology is to use the large-scale environment parameters of climate models to infer the impact of climate change on thunderstorm numbers and severity. Results

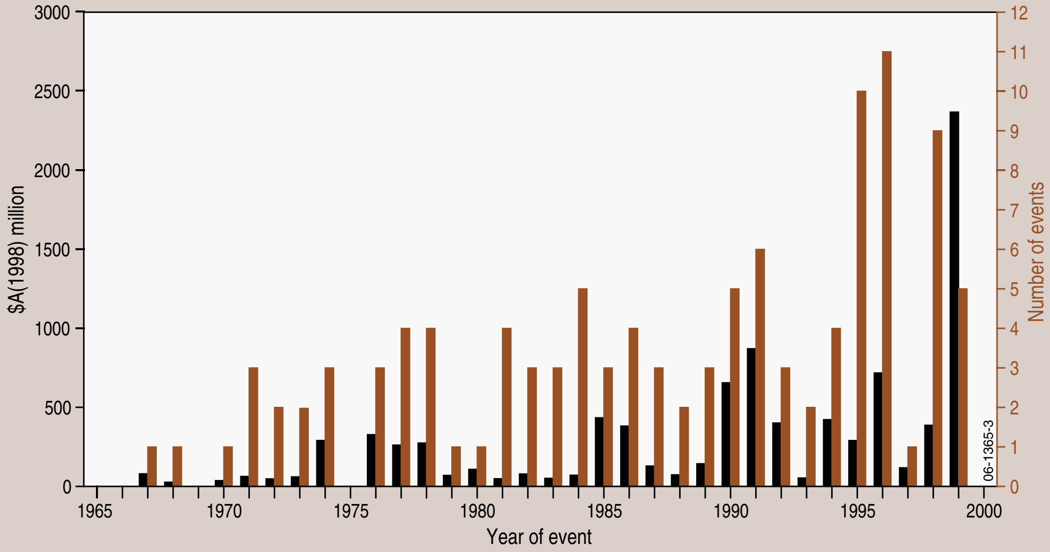


Figure 6.3: Annual cost and number of severe storms in Australia, 1967 to 1999
Source: Based on BTE (2001), Figures 3.18 and 3.20.

using this methodology indicate a decrease in the probability of conditions conducive to thunderstorm development over southern parts of Australia (Kounkou and others 2007).

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report reported that trends had been observed in the intensity and frequency of synoptic storms, with increases observed in both cases (Trenberth and others 2007). Under future climate scenarios, the most consistent outcome is a southward shift in the tracks of these storms (Meehl and others 2007). There is little consensus on the likely frequency or intensity of synoptic storms in the future.

Cold fronts that traverse southern Australia are generally associated with synoptic storms located between 45 degrees south and 60 degrees south. This band of high storm activity is often referred to as the 'storm track'. Several recent studies show a poleward movement of the mid-latitude storm tracks with fewer but possibly more intense systems occurring along Australia's south coast (Yin 2005).

The potential impact of climate change on storm tides has been investigated along Victoria's eastern coastline (McInnes and others 2005; McInnes and others 2006). The studies found that, under the worst case scenario of wind speed change for 2070, the one-in-100-year storm tide event increased in height by about 0.18 metres on average, while sea level rise added a further 0.07–0.49 metres to the total sea level. In all regions of Australia's coastline, it is sea level rise rather than changes in the intensity of storms that will have the greatest impact on extreme sea level events in the future (as discussed in Chapter 4).

Risk Analysis

For synoptic storms, the impact of the individual meteorological elements, including winds, rain, lightning, large waves and embedded thunderstorms, will vary considerably within the storm. Thunderstorms are a more discrete event and their occurrence, along with their destructive features such as hail and lightning, can be considered more random. The analysis below considers the methods of modelling the likelihood of severe storms and the separate meteorological elements associated with severe storms. Models of vulnerability that are used to determine the consequences of the various hazards are described.

Likelihood Analysis

Because of the range of storm types—both synoptic storms and thunderstorms—and the range of phenomena these events can cause, there are no models which determine the combined likelihood of all these events.

One approach is to analyse the underlying meteorological conditions for the likely occurrence of severe storms or the destructive phenomena they bring (e.g. Kounkou and others 2007). For some hazards, such as hail, stochastic models of frequency are applied in risk modelling (Leigh and McAneney 2005).

The difficulty of developing a likelihood analysis for severe thunderstorms is highlighted in a comprehensive study of natural hazards for southeast Queensland (Harper and others 2001, p. 6.13):

> ***'Whilst it can be anticipated that at least one damaging thunderstorm could have an impact somewhere in any given year, and that their impact could be both lethal and destructive, their impacts will tend to be localised and somewhat random in their distribution.'***

A more realistic approach for both synoptic storms and severe thunderstorms is to study the risks from individual phenomena associated with severe storms. The processes specific to analysing the risk from each hazard are outlined below.

The collapsed part of the road along the Old Pacific Highway following a severe storm near Somersby in the central coast region, New South Wales, June 2007 *Photo courtesy: AAP Image/Dean Lewins.*

Wind gusts and tornadoes

Wind loading standards for Australia are based on analysis of extreme, three-second duration wind gusts recorded at observation stations (AS/NZS 1170.2:2002). The localised nature of tornadoes and other strong winds associated with severe thunderstorms may mean these events are not well represented in the observations, even with many years of record.

Substantial improvements to the assessment of risk can be made by improving the hazard assessment of severe winds. By using high-resolution terrain and topographic data, the regional hazard (e.g. from AS/NZS 1170.2:2002) can be modified to determine the site-specific hazard (Cechet and others 2007). In some cases, the regional hazard can also be modified to account for the distance from the coast (Lin and Nadimpalli 2005). Peak wind gusts for locations can be stochastically modelled using extreme value distributions, based on historical observations (Sanabria and Cechet 2007).

Probabilistic models of thunderstorm downburst occurrence can be used to determine the likelihood of damaging winds affecting structures such as power transmission lines (Oliver and others 2000; Harper and Hawes 2004). A detailed study of thunderstorm characteristics that was undertaken for the insurance industry in southeast Queensland identified the significant climatology elements in that area (Harper and Callaghan 1998).

No systematic assessment of the likelihood of tornadoes over all parts of Australia has been carried out. Lists of tornado events have been compiled in disaster databases held by agencies such as the Bureau of Meteorology, Emergency Management Australia and the Insurance Council of Australia, as well as the computer tool PerilAUS, a searchable database prepared by Risk Frontiers.

Analysis of historical records can provide valuable information on the regional likelihood of damaging wind events. For example, Foley and Hanstrum (1990) analysed press reports of severe local wind storms, combining tornadoes and damaging downbursts, during the cooler months in the southwest of Western Australia. An alternative method to assess the frequency of severe local wind storms is to identify the atmospheric environmental features in which they occurred (Hanstrum and others 1998).

Lightning

Lightning strikes have the capability to destroy life and property almost instantaneously. As lightning is the defining characteristic of thunderstorms, the likelihood of lightning strike is closely related to the likelihood of thunderstorms. Because of the slightly different characteristics between thunderstorms in the tropics and the mid-latitudes, thunderstorms across northern Australia tend to generate more lightning.

Hail

Primarily, models of hail occurrence are closely related to models of thunderstorm occurrence. Models of loss caused by hail are generally based on stochastic models of hailstorm frequency (Leigh and McAneney 2005). The main limitation of this approach is the lack of observations of hail size distribution over much of the country.

Flash flood

The likelihood of flash floods is closely linked to the likelihood of thunderstorms and synoptic storms. Flash flood is covered in greater detail in Chapter 5.

Storm tide

Storm tides can occur in coastal areas where winds associated with intense weather systems can blow over large bodies of water. Storm tide is covered in greater detail in Chapter 4.

Data requirements

The core data elements required are the meteorological observations of wind speed, including gusts, and rainfall rate; and visual observations of hail, thunderstorms and tornadoes. Hail size measurement and hail size distribution data are largely restricted to Bureau of Meteorology observation sites. Other types of meteorological data, such as radar echoes and lightning detection, may be useful as indirect data sources.

For large-scale storms the wind and rainfall patterns are reasonably well sampled by the observing network. However, due to the small scale of severe thunderstorms, and their generally very small impact areas, vital information on extreme wind gusts and hail size will require on-the-spot observations from those in the affected area, or indirect evidence from damage assessments.

Consequence Analysis

Severe storms can have several adverse impacts on a community and related infrastructure. These can include disruption of power supply, as a result of lightning strike or downed power lines, or flooding of property. Crop damage caused by severe winds, hail or heavy rainfall can result in significant economic impacts. Injury or death to humans and animals from both direct and indirect causes, such as lightning strike and flooding, are all too common consequences of severe storms. In this section, only residential building vulnerability is examined, though it is acknowledged that other assets are vulnerable to damage from severe storms.

Wind and hail vulnerability models for key infrastructure components are essential to the assessment of damage. Building vulnerability to wind is significantly influenced by the regulations in force at the time of construction. While tropical regions of Australia have seen marked changes in regulations that have led to significant reductions of wind vulnerability in recent decades, the regulatory changes in non-cyclonic

Hailstones compared with a 7 centimetre diameter cricket ball, Sydney, New South Wales, April 1999
Photo courtesy: Bureau of Meteorology.

regions have been more gradual and the changes to vulnerability have been correspondingly gradual.

For hail hazard, changes in roof materials, from the slate used during the Victorian period to less vulnerable modern metal sheeting have been driven by construction preferences rather than changes in building regulations. The age of a building is a useful indicator of what regulations are likely to have influenced its construction, as well as other vulnerability factors such as the likely deterioration of materials and the nature of roof construction. The lack of published vulnerability relationships is even more acute for hail than for wind (discussed in Chapter 4), although several consultants and researchers have developed models for commercial use.

Available residential wind models typically have been derived from empirical insurance data from a handful of tropical cyclone events, and relate the overall population damage loss to an incident peak gust wind speed. Vulnerability models for the types of exposed structures and shorter duration extreme winds associated with severe storm events outside tropical regions are essentially non-existent. However, some private risk consultants have developed non-cyclonic wind vulnerability relationships based on insurance loss data (Harper 2007).

Limited quantification of post-event damage has been undertaken, more recently for tornado-related winds (Edwards and others 2004), but this work has been limited by the reliability of assessed local wind speed data. Notwithstanding these limitations, a small number of relationship models for severe storm events have been derived heuristically through a series of wind vulnerability expert workshops (TimberED Services 2006). These models are presently being used by Geoscience Australia to obtain an emerging picture of non-cyclonic wind risk.

The currently employed wind vulnerability relationships are also limited in that they do not provide information on the variation in damage outcomes within a population. This variation influences the assessment of other impact measures, such as casualties and temporary accommodation requirements. Furthermore, the approach of utilising loss data and assessed causative wind speed provides some limited information on existing building stock vulnerability but not on the effectiveness of mitigation options.

To address these limitations, vulnerability relationships are being developed that are based on an understanding of the wind loads on building elements and of how buildings resist and transmit these forces. The outputs of this engineering modelling approach, applied in the first instance to North Queensland structures (Henderson and Harper 2003), are fragility curves that define the range of damage for a given gust wind speed. The engineering approach also provides a measure of the uncertainty of the vulnerability model predictions.

Data requirements

The vulnerability of buildings varies and depends on the material choice and architectural features, and the standard in place at the time of construction. Specific data on these key parameters are required to better understand the risks posed by severe wind and hail.

Insurance loss data are very valuable to the development and validation of wind vulnerability models. For hail damage, insurance data are the primary source of loss data, along with reliable information on the size of hail that caused the damage.

Other key data requirements concern the relationships between the meteorological phenomena and the losses incurred.

Information Gaps

Complete assessments of the risk posed by severe storms are hampered by several gaps in information. These include an understanding of thunderstorm behaviour, the influence climate change will have on severe storms, and the vulnerability of infrastructure and communities to the impacts of these events. The following section provides more details on some of these areas.

Behaviour of Severe Storms

Increasing the knowledge of the formation and behaviour of severe storms will greatly enhance the understanding of the risks they present. Increased observation of storms will provide more information on the storm formation regions and tracks, as well as the severe meteorological phenomena of damaging hail, wind gusts, heavy rainfall and tornadoes associated with severe thunderstorms.

Better knowledge of the near-surface boundary layer wind structure of severe thunderstorms is especially important, as current design standards do not completely cover this phenomenon. Much denser instrumentation than is presently available from the Bureau of Meteorology observation network is required to capture the climatology of these systems.

Detailed knowledge of the spatial distribution of hail frequency, size and damage is required to fully assess the risk to buildings and vehicles. A database of hail size distributions collected by observation in the aftermath of hailstorms would increase the information crucial to hail risk assessments for cities and regions beyond Sydney and Brisbane (Leigh and McAneney 2005).

Increased meteorological observations of thunderstorms will allow more detailed warning information to be disseminated to the public and emergency managers. For example, the increased use of Doppler radar information will improve the ability of forecasters to observe the signatures of downbursts, tornadoes and the presence and size of hail. The ability to accurately detect these signatures is a major step in increasing the lead time of warnings for these phenomena which will provide communities with more opportunity to take preventative action.

A tornado below a thunderstorm cloud in Port Hedland, Western Australia, December 1975
Photo courtesy: Bureau of Meteorology/Peter Mudra.

A severe thunderstorm approaching the beach suburbs of Adelaide, South Australia, December 1986
Photo courtesy: Emergency Management Australia.

Influence of Climate Change

It remains difficult to determine the influence of climate change on severe thunderstorms, largely due to the coarse resolution of existing climate models. Improvements in the resolution of climate models and the parameterisation of deep convection associated with thunderstorms will aid in improving estimates of changes in thunderstorm behaviour. There is also evidence that thunderstorm activity is modulated by El Niño–Southern Oscillation (ENSO). The interrelationship between thunderstorm activity and ENSO should also be fully explored.

One component of the influence of climate change on severe storms, a southward movement in the mean synoptic storm path, was reported by Yin (2005). Expected changes in the intensity of these synoptic storms are less clear. Changes in the frequency of east coast lows, decaying tropical cyclones and other synoptic storms also require investigation. Secondary impacts, such as changes to peak rainfall rates, may change under a future climate, and the magnitude of these changes also requires quantification.

Vulnerability Research

The range of infrastructure elements present in a typical community is very broad, and there are several gaps in the information on their vulnerability. The vulnerability of critical infrastructure components—such as power, telecommunications, water, sewerage, gas and transport—to the impact of severe storms remains unclear. Collaboration with private operators of these infrastructure components would greatly benefit future risk assessments.

There is a need to advance the present work programme on building vulnerability and to engage industry in a gap analysis of vulnerability definition. This process will enable targeted research to provide a more comprehensive range of vulnerability relationships and to give a more complete assessment of wind and hail risk.

An essential part of this vulnerability research is ongoing storm impact survey activity and the assessment of local wind speeds at the sites of individual infrastructure components. This activity provides loss data for the refinement of empirical models that are presently being used to assess wind risk to communities. It also identifies the range and predominance of failure types, and provides validation data for the more rigorous engineering approach. Post-disaster assessments also contribute a significant amount of information to the meteorological knowledge base. As these tools mature they will provide a means of assessing the most cost-effective measures for reducing community risk.

Roles and Responsibilities

The roles and responsibilities for minimising risk associated with severe storms cover all parts of the community, from government through to individuals. For many of the groups, the role in risk reduction remains static. However, the increased privatisation of utilities such as power, water and telecommunication services is one area where the responsibilities for risk management are changing.

Australian Government

The Australian Government has similar roles and responsibilities for reducing the risk posed by severe storms as it has for tropical cyclone and flood risk. The Australian Government provides severe weather warnings to minimise damage and injury to members of the public, as well as to industries such as agriculture, fishing, aviation and surface transport. Severe weather warning services are provided through radio, television and email, to authorities such as the police and emergency services, and to public access systems which include recorded telephone services, automated facsimile messages and the internet. The Australian Government also assists state agencies in disaster situations and acts as an overarching policy and educational resource for emergency services across the country.

After major events, Australian Government agencies work with state and territory agencies to conduct post-disaster impact assessments as part of research into improving knowledge of storm behaviour and impacts. The Australian Government also maintains a database of severe storms and the impacts of those storms.

State and Territory Governments

State and territory governments are responsible for the overarching planning laws and building regulations (administered through the Australian Building Codes Board) that ensure that infrastructure and housing are built to an acceptable level of resistance to severe storm impact.

State and territory governments, through the relevant emergency services agencies, work closely with the community to develop plans of action to minimise impacts. This includes logistical planning under various scenarios, developing structured chains of command, robust means of communication and evacuation plans. They also involve themselves in public education activities, such as presentations in open public forums, publication of brochures and media advertising. The focus of this public education is on action plans to reduce the risk of injury or material loss. The defensive action statements in Bureau of Meteorology warnings are provided by state emergency agencies.

Some variation exists between the states and territories, with some delegating greater responsibility to local agencies.

State Emergency Service volunteers assist with roof damage following a storm, New South Wales, January 1991
Photo courtesy: Emergency Management Australia.

A gustnado, a type of tornado on the leading edge of a wind squall, just ahead of a ragged shelf cloud, Melbourne, Victoria, December 1995 Photo courtesy: Bureau of Meteorology/Andrew Treloar.

Local Government

Local governments are responsible for town-planning decisions which are critical in ensuring that future development does not increase the vulnerability of the community. The planning responsibilities include keeping housing and critical or vulnerable buildings or facilities in safe locations.

Local governments, in collaboration with state government and Australian Government agencies, often lead the development of regional emergency management and disaster response plans. They also conduct community awareness and preparedness programmes aimed at reducing the impacts of severe storms. In the response and recovery phases, local government agencies are responsible for repairing and maintaining key infrastructure components.

Industry, Coordinating Groups, Professional Bodies and Research Institutions

Standards Australia has responsibility for developing relevant design standards, such as lightning risk and protection (AS 1768:2007), the Australian/New Zealand wind loading code (ASNZS 1170.2:2002) and the standard on wind loading of residential housing (AS 4055:2006).

The insurance industry has become increasingly active in risk assessment, including vulnerability modelling for residential buildings and vehicles. The overall increase in weather-related damage claims, and the IPCC's indication that there will be a continuing increase in climate extremes (Solomon and others 2007), has caused some insurance companies to take a strategic view of their future operations (Lloyd's 2007).

Lightning and wind damage can cause major interruptions to electrical power transmission. The power industry has an interest in risk assessment and mitigation activities, and has been active in public awareness campaigns, particularly in New South Wales and Queensland. Some power companies have already undertaken extensive risk assessments of their networks and become proactive in monitoring thunderstorms and taking measures to respond to disruptions.

Telecommunications may also be disrupted by severe storms. Issues for telecommunications companies are sustainable supply of communications infrastructure, and awareness of the risk related to telephone use during thunderstorms.

Property Developers

There are planning issues relating to property development in areas prone to flash flooding or coastal areas subject to erosion resulting from the action of large waves. The risks of high wind and large hail should be considered in building design.

Courts and Legal Institutions

The courts play a role in settling litigation among parties seeking compensation for damage caused by natural hazards.

Media

The media play a vital role in delivering Bureau of Meteorology forecasts and warnings. During severe thunderstorms, radio is quite often the most effective medium for distributing warnings. Media outlets can also play an educational role, distributing information on mitigation actions the general public can take in advance of severe storms, such as tidying properties at the start of the thunderstorm season.

General Community

A network of approximately 3000 volunteer storm spotters, who provide valuable reports of severe weather to weather forecasters, is coordinated by the Bureau of Meteorology.

Individuals have a basic responsibility to be aware of any storm risk posed to them. Property owners are responsible for the continued maintenance of houses to reduce the potential damage suffered in severe storms. Individuals should also know how to respond effectively to severe weather warnings.

Conclusion

Severe storms represent approximately 26% of the average annual cost of natural disasters in Australia, costing around $284 million each year. They have been responsible for some of Australia's costliest natural disasters and caused over 770 deaths. The responsibility for reducing the impact of severe storms is shared across all levels of government, while state and territory governments often lead the response to severe storms through their emergency services agencies.

Risk assessments for severe storms require a wide range of hazard models, because of the number of damaging phenomena these events can produce. As for tropical cyclones, the risk models must also comprise information on the vulnerability of buildings and other infrastructure to the hazards associated with severe storms.

The phenomena which cause the greatest impact, such as large hail, extreme winds (including tornadoes) and heavy rainfall that induces flooding are highly localised. The records of many of these events are based on their impacts rather than direct measurement by weather instruments. This limits our ability to conduct accurate likelihood analyses for these events, which in turn affects the risk analysis.

Advances in technology such as satellites and radar are improving observations and will contribute to improved assessments of the level of hazard. The improved observations will also permit a better assessment of the influence that climate change may have on severe storms. Further research into the likelihood of destructive phenomena such as hail will greatly benefit future analysis of risk. The vulnerability of buildings and other infrastructure, such as power supplies and telecommunications, also requires significant research to improve analysis of severe storm risk.

A State Emergency Service volunteer next to a large tree that has fallen on to a house during storms in the central coast region, New South Wales, June 2007 Photo courtesy: NSW SES.

Chapter Seven:

Bushfire

A bushfire rages as fire crews work close by, near Merimbula, New South Wales, January 2006
Photo courtesy: Bureau of Meteorology/Stephen Kemp.

Bushfire

Bushfires are an intrinsic part of Australia's environment. The natural ecosystems have adapted to bushfire, while the diversity of the landscape has been shaped by fire. Bushfires have been responsible for some of the most unforgettable natural disasters in Australia, such as the Ash Wednesday fires in Victoria and South Australia on 16 February 1983. Fire has also been harnessed to clear land for agricultural purposes and, importantly, to reduce risk to property from intense, uncontrolled bushfires.

Across Australia, major bushfires are estimated to have cost $2.5 billion in the period from 1967 to 1999, corresponding to average annual cost of $77 million (BTE 2001). There have been over 700 deaths caused by bushfire since the first recorded death in 1850 (Blong 2005).

A fire crew on the Great Alpine Road near Bruthen, Victoria, January 2007
Photo courtesy: CFA Public Affairs/Martin Anderson.

The charred remains after a bushfire, showing signs of regeneration in the Royal National Park, New South Wales, January 1994
Photo courtesy: Emergency Management Australia.

A bushfire near Wentworth Falls in the Blue Mountains, New South Wales, January 1994
Photo courtesy: Bureau of Meteorology/John Nairn.

Devastation resulting from the Black Tuesday bushfires in a small town in Tasmania, February 1967
Photo courtesy: National Archives of Australia/NAA: A1200, L60751.

The impacts of bushfires differ from those of tropical cyclones, earthquakes and severe storms because an individual has a greater ability to mitigate the negative impacts of fire. Fires generally have some scope to be detected and extinguished early, and their subsequent impacts can be greatly reduced by risk reduction strategies. Bushfire is the only hazard considered in this report for which the potential of the hazard itself can be reduced—by reducing human ignitions and through early suppression.

In this chapter, the bushfire hazard and the processes of analysing the risk associated with bushfire, including the gaps in the available information, are described. Several national groups coordinate firefighting activities, such as aerial firefighting, across the country. The roles and responsibilities played by government agencies and the community in bushfire risk management in Australia are also important in minimising bushfire impacts.

Hazard Identification

In Australian usage, 'bushfire' is a general term used to describe a fire in vegetation. Fires lit purposefully for fuel reduction or land management purposes are often more accurately referred to as 'prescribed fires' (AFAC 2007). While bushfire activity in Australia is prevalent in most landscapes that carry fuel (e.g. grasslands, forests, scrub and heath lands), the two predominant bushfire types in Australia are grassland fires and forest fires. Common to both are sources of ignition and factors such as weather conditions that affect the intensity of a bushfire.

Bushfires are ignited either naturally by lightning, or by human activity. Across the Australian continent, lightning is the predominant ignition source of fires, being responsible for just over 50% of all ignitions. In the southern states, where most asset loss occurs, natural causes account for approximately 30% of ignitions. Human causes of bushfire include accidental ignition through carelessness, and deliberate ignition, predominantly through arson or land clearing.

Most areas of Australia experience bushfires. For most of southern Australia, including southern New South Wales, the danger period is summer and autumn (see Figure 7.1). For northern New South Wales and southern Queensland, the peak period of fire activity is usually in spring and early summer. Northern Australia experiences most of its fires in the drier months between May and September.

The level of bushfire hazard is influenced by several factors. Primarily, the weather conditions at the location of the fire dictate the behaviour of the fire. The McArthur grassland and forest fire danger indices (GFDI and FFDI respectively) are used to determine the spread rate and difficulty in fighting fires (McArthur 1958). Both indices require weather parameters of wind speed, relative humidity and temperature. Additionally, estimates of the grass curing percentage (for GFDI), drought index (for FFDI) and fuel load are required.

High winds can contribute to the impact of a fire by increasing the spread rate of the fire, as well as by carrying burning embers further downwind (causing 'spotting'). Significant and rapid changes in the wind direction associated with cold fronts can result in rapid increases in the size of the fire front, as was the case with bushfires on Ash Wednesday. Local wind effects caused by topography also make it difficult to predict how a fire may progress.

Relative humidity is an indication of the amount of water vapour in the atmosphere. Very low relative humidity levels can rapidly reduce the moisture content of fine fuels (e.g. leaves, grasses and twigs), which are responsible for propagating the main fire front. Sustained high temperatures can increase the curing level of fuels, further adding to the level of hazard.

The dryness of available fuels is measured by two means—the grass curing index and the drought factor (Noble and others 1980; Griffiths 1999). The drought factor is used for estimating the dryness of forests. The dryness of fuels is directly affected by rainfall amounts preceding a bushfire and the atmospheric conditions, such as relative humidity, at the time of the fire.

Fuel load is the other main contributor to bushfire hazard. A region with less available fine fuel will result in a lower intensity fire compared to a region with a higher fine-fuel load, assuming all other factors are equal. As the type and arrangement of available fuel affects the intensity and spread of a fire, specific fuel management practices, such as prescribed burning or mechanical slashing, can have a significant impact on bushfire intensity.

Grassland Fire

Grassland fires affect pastoral districts and the savannahs of northern Australia. These fires account for the majority of area burnt by bushfires—in the 2002–2003 bushfire season some 38 million hectares were affected by bushfire across northern and central Australia (Ellis and others 2004). However, these fires result in comparatively little economic impact, due to the low exposure of life and property in central and northern Australia.

Forest Fire

Forest, scrub and heath land fires affect the more densely vegetated regions of southeast Australia (e.g. the Blue Mountains in New South Wales) and the southern part of Western Australia.

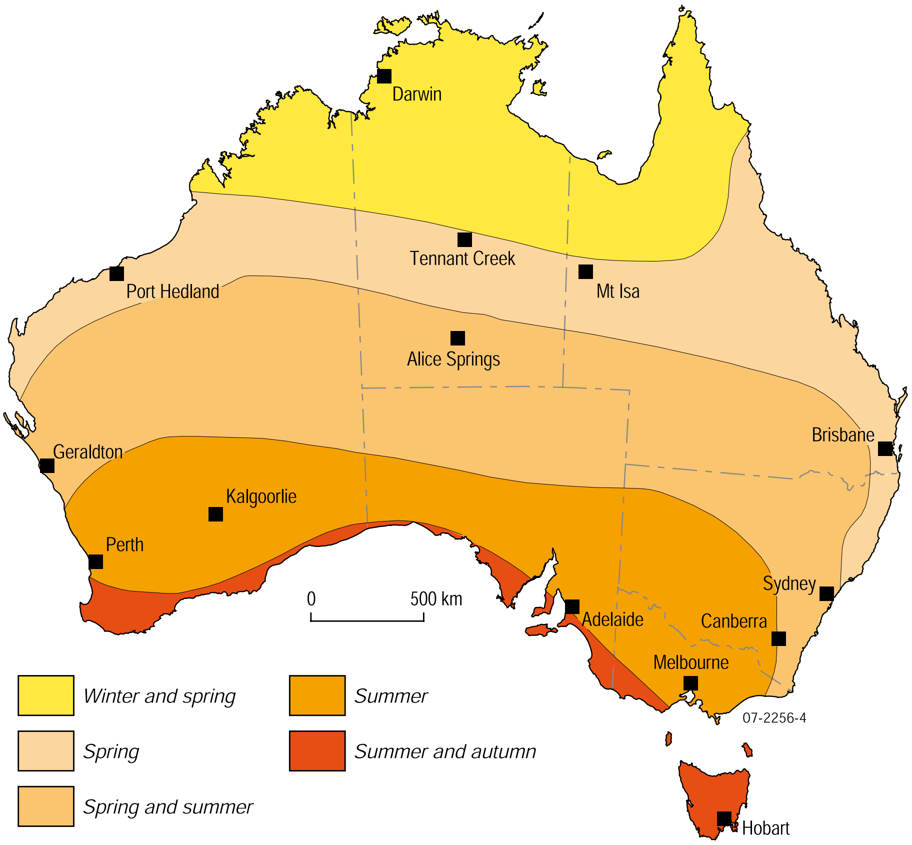


Figure 7.1: Fire seasons across Australia
Source: Bureau of Meteorology, cited in Lindesay (2003), Figure 4.2.

The greatest loss of life and economic impact occurs in the southern states in the urban fringes of cities, where homes and other property are commonly in close proximity to forest, scrub or heath lands. There are, however, cases where bushfires have caused losses deep in suburban areas—for example, the Canberra bushfires of January 2003.

Cost of Bushfires

The cost of a bushfire is often related to the assets lost or insurance claim value of the event, but real costs include the social and environmental costs as well as the economic losses. The costs of two fires of similar size can vary significantly depending upon the exposure of assets and the population density and socioeconomic profiles of the areas in the paths of the fires.

For the period from 1967 to 1999, the total economic cost of major bushfires has been estimated at $2.5 billion, contributing about 7% to the annual cost of natural disasters and an average annual cost of $77 million (BTE 2001). These values do not (explicitly) include the costs of damage to timber plantations, which would add to the overall costs.

The costs of bushfires vary significantly from year to year, as highlighted in Figure 7.2. The two years with the highest losses correspond to two iconic events—the Ash Wednesday fires in South Australia and Victoria in 1983, and the Black Tuesday fires in Tasmania in 1967. The impact of these events is also reflected in the breakdown of house losses by geographic area, as shown in Figure 7.3.

From 1850 to 2001, 696 lives have been lost in bushfires across Australia (Blong 2005). However, there has been a decline in the number of lives lost in bushfires over the past 20 years (Ellis and others 2004).

The cost of controlling fires may be a major component of the total economic costs, if

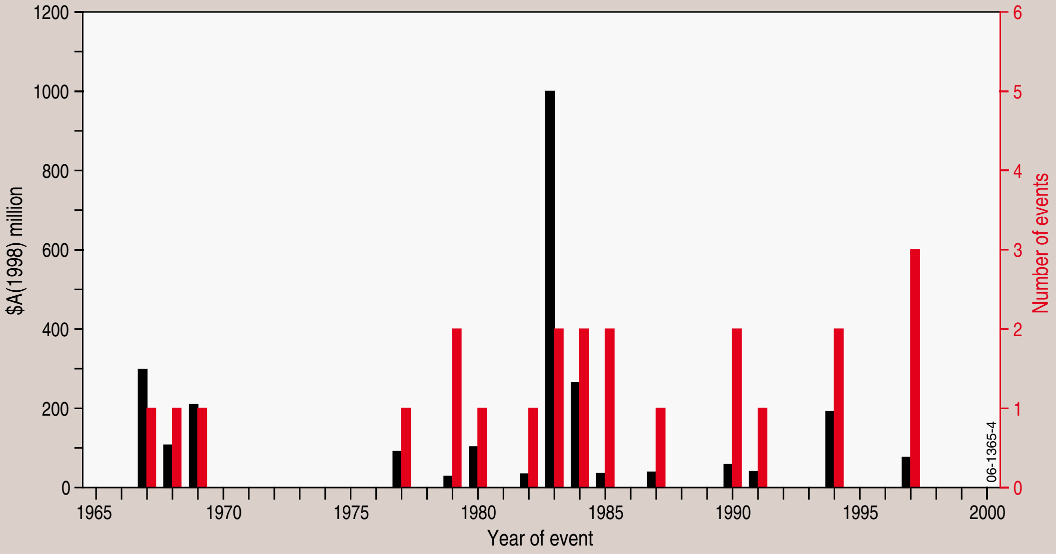


Figure 7.2: Annual cost and number of bushfires in Australia, 1967 to 1999
Source: Based on BTE (2001), Figures 3.25 and 3.27.

firefighting efforts are successful in protecting assets. Some of these costs are very difficult to estimate. Many loss estimates, particularly for historical fires, cover only the direct physical costs of rebuilding and replacing infrastructure.

There are a wide range of environmental impacts associated with bushfire. These include loss of habitat, changes to biodiversity levels, erosion, effects on water quality and carbon emissions. In many cases, bushfire may also bring environmental benefits, such as regeneration of bushland, particularly in low-intensity fires.

Potential Influence of Climate Change

Over the past 50 years, Australia has become warmer, with reduced rainfall in the south and east. It is likely this has increased the frequency of dangerous weather conditions. Given that southern and eastern Australia is projected to become hotter and drier over the coming decades as a result of climate change (Christensen and others 2007), further increases in weather conditions conducive to fire are expected (Hennessy and others 2005).

It is likely that higher fire weather risk in spring, summer and autumn will increase the period in which extensive fire suppression efforts are required. This will also move periods suitable for prescribed burning (i.e. hazard reduction) toward winter, and reduce the opportunity for hazard reduction activities (Hennessy and others 2005).

The occurrence of higher temperatures and reduced rainfall could result in drier forests and lower fuel loadings in grasslands. In turn,

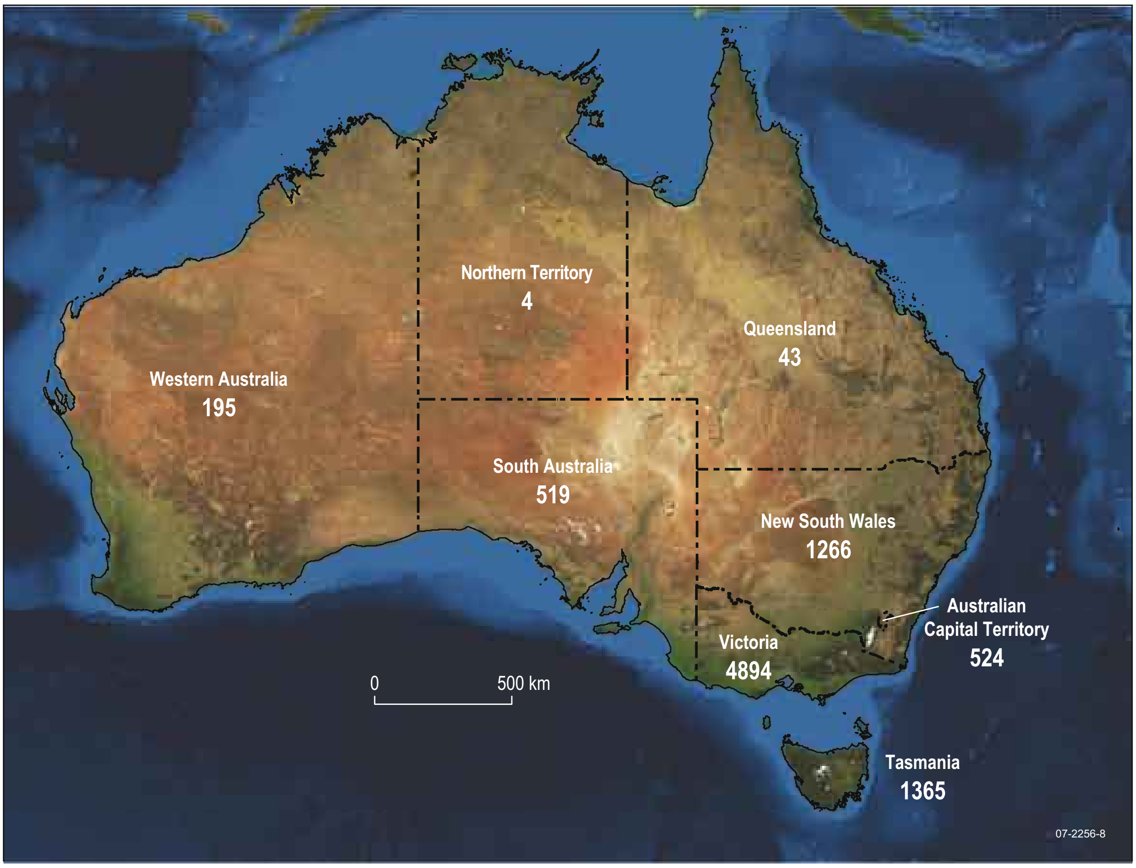


Figure 7.3: House loss from bushfires in Australia by state and territory, 1939 to 2006
Source: Based on Leonard and others (2006).

this could lead to an increase in the proportion of forest bushfires relative to grassland fires. Conversely, increased rainfall in northwest Australia could result in heavier grassland fuel loadings and more grassland fires (AGO 2005).

Risk Analysis

The likelihood of bushfire hazard can be summarised in terms of the probability of a fire arriving at a point in the landscape and the intensity of the fire at that point. Consequences of bushfire are highly dependent on the exposure of assets, the landscape immediately surrounding assets, and the nature of each asset—for example, whether it is an occupied structure or a commercial forest plantation. The community's behaviour before, during and after bushfire attack also influences the overall vulnerability of a community.

The lack of a risk assessment framework has been the primary limitation to quantitative risk assessments. Geographic information systems (GIS) have resulted in more accurate inventories of assets exposed to bushfire. Estimates of asset vulnerability have only recently been undertaken by programmes within the Bushfire Cooperative Research Centre (CRC) (Blanchi and others 2006; Leonard and Blanchi 2005).

Likelihood Analysis

Likelihood analysis is based on the combination of arrival probability and the intensity of the fire when it arrives. Arrival of a bushfire at a certain point in the landscape is dependent on several factors. Local weather conditions at the time of the fire are important—since the FFDI was introduced, significant house losses have occurred only in cases where the FFDI was observed to be in the extreme range (FFDI >50). The slope and aspect of nearby topography also impacts the intensity of a bushfire. Therefore, to accurately determine the likelihood of arrival requires complex and fine-scale geospatial modelling tools.

Houses destroyed by the Black Tuesday bushfires in Hobart, Tasmania, February 1967
Photo courtesy: National Archives of Australia/NAA: A1200, L60753.

A bushfire at Moondarra, Victoria, January 2006
Photo courtesy: CFA Public Affairs.

Fire spread models such as the *Phoenix* fire model (Clark and Tolhurst undated) can be used to quantify the intensity, size and speed of fires under different weather conditions. Other fire spread models incorporate feedback mechanisms between the fire and the atmosphere, to determine the spread and intensity of bushfires (e.g. Clark and others 2004).

The climatological likelihood of dangerous weather conditions can be determined at regional scales, such as in the work of Hennessy and others (2005). This type of likelihood analysis can be used to inform planning decisions and urban design to minimise exposure to bushfire attack.

Bushfire is one hazard that human action can actively reduce either before or during an event. Through prescribed burns and other fuel reduction activities, the range of weather conditions in which a fire brigade can effectively suppress a fire is increased, reducing the likelihood of arrival at a specific point in the landscape. Further to this, human activity and behaviour are responsible for nearly 50% of bushfire ignitions. Curbing activities that cause ignition—such as burning for land clearing, and arson—can also reduce the likelihood of a bushfire occurring.

Data requirements

The accuracy of fire spread models greatly improves when they utilise high-resolution data on topography, vegetation and meteorology to predict fire spread patterns for a given scenario. Vegetation and fuel load data are seasonally variable and difficult to determine through spatial means. A combination of aerial photography, predictive models and ground-based validation are the current best practice methods for collecting such information.

Weather conditions such as temperature, humidity and number of days since rain are well-defined inputs, while predictions of localised future weather patterns are highly sensitive inputs for fire spread models. Local-scale influences of topography on wind are challenging to predict, but are important considerations in defining the likelihood of a fire event (Tolhurst and others 2006).

For analysis of possible future events, knowledge of fire-conducive weather frequency is important, preferably at the finest spatial scale possible.

Consequence Analysis

This section focuses primarily on the vulnerability of residential housing. However, it is acknowledged that other assets, including infrastructure (e.g. power utilities), industrial, cultural, environmental and agricultural assets, are also exposed and vulnerable to damage or destruction by bushfire.

The exposure of a structure to bushfire attack can be determined in several ways. The Australian standard for construction in bushfire-prone areas contains methodologies for assessing the exposure to bushfire attack (AS 3959:1999). Exposure databases can also provide necessary information, such as the proximity of assets to bushland and the construction types of the exposed assets.

Aggregated probability models are often used to determine the impact of bushfire on residential housing (Blanchi and others 2006). The vulnerability of buildings to bushfires varies due to characteristics such as construction material, architectural design, tidiness and proximity to surrounding flammable objects. The Bushfire CRC is conducting research into aspects of vulnerability such as ember attack and ignition, building design, and materials used for windows, facades, water storage tanks and fencing (Bushfire CRC 2007).

Over 90% of all house loss occurs in the absence of direct flame or radiation exposure from the fire front itself. This is directly related to the large influence that human activity (or inactivity) immediately following passage of the fire front has on house loss risk (Blanchi and others 2006). Property owners can greatly reduce the probability of house loss by staying and defending their house from bushfire attack mechanisms such as ember attack and spotting. Often, when a house is lost, it is because of a small construction detail which represents a weak link in the building design or materials (Leonard and Blanchi 2005).

Studies of past bushfires involving significant loss of houses also provide valuable information on the probability of house loss.

Vulnerability models with broader scope are under development and promise to provide a basis for better overall planning and building provisions.

Data requirements

Broad scale spatial data sets are essential for effective vulnerability analysis at the urban level. A complete exposure database incorporating information on the vulnerability of structures is essential to quantitative risk assessments. High-detail cadastral maps showing property boundaries and building footprints overlayed with high-resolution aerial photography are necessary to determine the spatial relationships between buildings, vegetation and other combustible elements.

At the individual house level, detailed analyses of building design and condition are needed, with close attention given to potential entry points that various fire mechanisms may exploit.

Information Gaps

To develop a comprehensive understanding of bushfire risk, there are areas of knowledge

Devastation following a bushfire at Seabreeze Avenue in Ferny Creek, Dandenong Ranges, Victoria, January 1997
Photo courtesy: Emergency Management Australia.


A firefighter fighting a blaze from the Great Alpine Road, near Bruthen, Victoria, January 2007
Photo courtesy: CFA Public Affairs/Martin Anderson.

where more information is required. Understanding the dynamics of fire behaviour will allow improvements in determining the likelihood of bushfire exposure. Historical fires may provide a wealth of information on the performance of bushfire risk management strategies. The following section outlines some of the information gaps and ways in which they may be resolved.

Fire Dynamics

Developing more robust theory and models in order to better understand and predict fire behaviour and the ecological impacts of fires, across the range of scales and intensities, is necessary for a number of reasons. One is that fire regimes and ecosystems are very diverse; another is that there are limits to experimentation with high-intensity fires.

Ecological Impacts

The impact of bushfires on natural ecosystems has been identified as an area requiring improved understanding (Ellis and others 2004). Research in this area is underway, but necessarily requires long-term monitoring of ecosystems and their responses to fires.

Indigenous Australians' Use of Fire

There is potential for all Australians to benefit substantially from learning from Indigenous Australians' traditional ways of understanding and using fire. Research into operationally feasible ways of integrating customary and modern practices and technologies will greatly support bushfire mitigation and management.

Bushfire History

Much of Australia's fire history has not been formally documented, yet history provides a critical insight into the nature and intensity of fires that resulted in loss of life and assets, or had the potential to do so. Recently, individual states have developed methods of recording the spread and extent of fire. Using a nationally consistent methodology and database format would provide an effective basis for verifying and calibrating risk models to underpin future policy decisions.

Vulnerability Research

The range of assets at risk from bushfire extends well beyond residential buildings—for example, timber plantations and agricultural, cultural and environmental assets are all at risk from destruction from bushfire. Some of these assets, such as power utilities, may be particularly vulnerable to smoke plumes. Exposure data and vulnerability relationships for all assets and people would be a long-term data requirement for any truly comprehensive risk analysis.

Roles and Responsibilities

As with other hazards, the management of bushfire risk is shared across all levels of government, as well as non-government agencies and groups and the general community. This section outlines the roles and responsibilities of the various stakeholders in the management of bushfire risk across Australia.

Australian Government

The Australian Government plays a significant role in the management of bushfire risk in Australia. The Australian Government runs the Bushfire Mitigation Programme aimed at identifying and addressing bushfire risk priorities across the country.

The Australian Government also provides weather forecasts and warnings to state fire agencies and the public. This enables fire agencies to prepare for the outbreak of fire on days of extreme fire danger, and to develop strategies for controlling existing fires.

The Australian Government provides national bushfire monitoring services, such as the *Sentinel* mapping system. This delivers information about hotspots to emergency service managers across Australia. The mapping system allows users to identify fire locations which present a risk to communities and property.

The Australian Government interacts with state agencies in emergency bushfire situations, and acts in a coordinating role between state agencies. In major disasters, the Australian Government provides additional resources such as equipment, medical supplies and Defence personnel, as well as post-disaster relief funds to assist with recovery.

State and Territory Governments

State and territory fire agencies generally comprise an urban fire agency; a rural fire service covering private property and certain crown lands; and one or more land management agencies covering categories of public lands. State legislation provides for a fire agency to restrict or prohibit the lighting of fires. State agencies with responsibility for issuing total fire bans consult with other agencies, including the Bureau of Meteorology.

State and territory governments have a role in promoting better building design in bushfire-prone areas. State and territory agencies assist in administering the Building Code of Australia, which ensures that buildings in vulnerable areas are built to an acceptable level of bushfire resistance (AS 3959:1999). State fire agencies also

A destroyed house in the aftermath of the Ash Wednesday bushfires in Macedon, Victoria, February 1983
Photo courtesy: Emergency Management Australia.

A captain on a radio in front of a burning house, Victoria
Photo courtesy: CFA Public Affairs.

provide recommendations for town planning to reduce the exposure to bushfire attack.

State and territory fire agencies also interact with other organisations, including local government agencies, across a range of issues, including risk communication and education programmes. Prevention and preparedness strategies to establish community resilience are jointly established by state and territory fire agencies and local government.

State and territory fire agencies assume responsibility for mitigating bushfire hazard by identifying and reducing fuel load (through hazard reduction actions) both in the lead-up to and during the fire season.

State Emergency Services respond to a wide range of bushfire-related incidents, and have important roles in emergency operations. State police and road agencies also are involved, responding to such issues as traffic control, victim identification and asset protection.

Local Government

Local councils are involved extensively at the prevention and preparation phases of bushfire risk reduction. The issuing of local bylaws and enforcement of building regulations that aim to reduce bushfire risk are important roles for local government. Local government agencies also coordinate community disaster response plans and facilitate the use of community assets, such as voluntary evacuation centres, in the event of bushfires.

Local government agencies also have a role in developing planning policies that either restrict the spread of residential developments into areas of high bushfire hazard, or prescribe conditions for developments that ensure the provision of buffer zones and design of buildings with high fire safety attributes. These agencies also share in the responsibility for managing fuel loads.

Industry, Coordinating Groups, Professional Bodies and Research Institutions

The Bushfire CRC brings together researchers from universities, CSIRO and other government organisations, and private industry, to undertake long-term programmes of collaborative research. These programmes aim to achieve real outcomes of national significance in areas such as protecting people and property; preventing, suppressing and managing bushfires; and ensuring community self-sufficiency for fire safety (Bushfire CRC 2007).

The Australasian Fire Authorities Council is a national peak body which provides advice on a range of policies and standards. The Council enables state fire agencies to adopt common practices, resulting in more effective use of interstate resources when required.

The National Aerial Firefighting Centre (NAFC) coordinates a fleet of firefighting aircraft for use by state and territory fire agencies (NAFC 2007). NAFC also assists in developing national protocols for aerial firefighting activities, which assist in minimising the impacts of bushfires.

Property Developers

There are growing concerns that the spread of urban areas into bushland settings around major cities is creating areas of high bushfire risk. Property developments in these areas need to optimise the desired natural values while minimising fuel loads in the vicinity of buildings. Building design can be adapted to use materials and designs that reduce the risk of embers igniting buildings after the fire front, and provide greater protection to radiant heat.

If requirements for building design, subdivision design and location are considered early in the development process, additional bushfire mitigation costs can be minimised. In most states, development control provisions are in place to provide minimum standards for these requirements.

Forestry plantations are often privately owned, and there is a need to maintain buffer zones for asset protection around plantations. In some states, regulations exist to provide these minimum requirements.

Courts and Legal Institutions

Courts are often required to enforce compliance with legislative and local government requirements concerning provisions for minimising bushfire risk. In these situations, courts can be required to decide which piece of legislation should prevail when measures appear to be contradictory: for example, when environmental or heritage protection measures conflict with fuel reduction measures or building codes and regulations.

The decisions of courts in response to litigation associated with bushfire events may result in changes to the legal responsibilities of other groups, primarily state and territory fire agencies and property owners.

Media

An important role for the media during bushfire events is the transmission of timely warnings and information regarding bushfires. The possibility that power and telecommunications will be disrupted by bushfires makes radio a particularly

A grassland fire in the Bethungra Hills near Junee, New South Wales, January 2006
Photo courtesy: Will Barton Photography.

Building ruins following a bushfire at Leura in the Blue Mountains, New South Wales, December 1957
Photo courtesy: National Archives of Australia/NAA: A1200, L29036.

effective delivery mechanism, because people in affected areas can receive information through vehicle or battery-powered radios.

The Australian Broadcasting Corporation has arrangements with state and territory fire and emergency services agencies to transmit urgent safety messages and information during times of bushfire and other emergencies. It is essential that the media report responsibly during these events, and avoid encouraging hysteria through overemphasising the risk or magnitude of an event.

The media also have a role in raising awareness during and ahead of each bushfire season. Involvement includes broadcasting community service announcements encouraging landowners to plan ahead and prepare for the coming fire season, and providing information on fire-related community meetings.

General Community

Volunteers make up the vast majority of rural fire service members, collectively contributing over 20 million hours annually (Ellis and others 2004). The contribution of these volunteers to minimising the impact of bushfires is invaluable. In addition to actively fighting bushfires, rural fire service volunteers undertake fuel reduction activities and are involved in community education projects to increase awareness of the bushfire hazard.

Residents of bushfire-prone areas need to prepare themselves and their properties ahead of each fire season, in order to increase the likelihood that they and their assets will survive in the event of a bushfire. Activities range from reducing fuel loads around the property (as required by legislation in some states and territories) and performing maintenance on buildings and firefighting equipment, through to planning what actions to take if fire occurs.

Several deaths in recent major bushfires reflected the danger of fleeing a bushfire too late. Occupants are urged to either stay and defend their properties if capable, or to evacuate early before escape routes become affected by fire or smoke. A clear understanding of the nature of bushfire and the specific risks of each situation is paramount to the protection of life and property.

Conclusion

Bushfires contribute about 7% of the total cost of all major national disasters in Australia at an average annual cost of $77 million. The records of bushfires in Australia extend back to 1850, with over 700 fatalities recorded since that time.

While large areas of the continent are affected by fire, the greatest losses of property and life occur on the fringes of cities and towns, particularly in southeast Australia. The effects of climate change are likely to result in increased numbers of days of extreme fire danger in southeast Australia, which will increase the likelihood of destructive bushfires.

A quantitative analysis of bushfire risk is not generally feasible because of the difficulty in spatially defining many of the parameters that affect bushfire likelihood. Probability models of building vulnerability are used in conjunction with exposure catalogues and fire-spread models to provide risk assessments at a regional level.

Improvements in the acquisition of relevant and timely datasets, such as topography and fuel load data, will increase the potential for rigorous, quantitative risk analyses relevant to specific seasonal or even daily weather conditions. Risk assessments will also benefit from ongoing research into the vulnerability of residential housing and other built structures. Across all of Australia, environmental and cultural values must also be considered in assessing the risk from bushfires.

Risk analysis is an important step in justifying and targeting localised actions to minimise bushfire impacts. These actions, which are most often implemented by state or territory fire agencies, are the point where the risk is actually modified. Actions such as fuel reduction by property owners and, importantly, rural fire service volunteers also contribute to minimising the impact of bushfires.

The fires in Canberra, Australian Capital Territory, January 2003
Photo courtesy: AAP Image/Alan Porritt.

A resident battling a blaze from a fire in Farrer, Australian Capital Territory, January 2003
Photo courtesy: The Canberra Times/Andrew Campbell.

Chapter Eight:

Landslide

Site adjacent to a fatal limestone sea-cliff collapse at Cowaramup Bay, near Gracetown, southwest Western Australia, September 1996
Photo courtesy: Geoscience Australia/Brian Gaull.

Landslide

Landslides regularly occur in localised areas across Australia, and pose a serious threat to people and property. They occur over a wide range of velocities and are often at their most damaging when they happen suddenly and without warning.

The economic cost of individual landslide events is typically much lower than the cost of flood or earthquake events. Since 1842 there have been approximately 84 known landslide events, collectively responsible for the deaths of at least 107 people and injury to at least 141 people, as recorded in the Australian Landslide Database (GA 2007). Although many landslides have natural causes, well over half of the landslides that have caused death and injury can be attributed either directly or indirectly to human activity.

Cracks in the retaining wall and road from landslide activity near the head of the Lawrence Vale landslides in Launceston, Tasmania
Photo courtesy: Geoscience Australia/captured in 1996.

Vehicles caught in the run-out of a debris flow on the Bulli Pass near Wollongong, New South Wales, August 1998
Photo courtesy: NSW SES.

State Emergency Service volunteers involved in rescue efforts at a fatal landslide at Thredbo, New South Wales, July 1997
Photo courtesy: NSW SES.

Damage to a road caused by a landslide at Macquarie Pass south of Wollongong, New South Wales, February 1997
Photo courtesy: Geoscience Australia/Marion Leiba.

This chapter highlights the types of landslides which occur in Australia, and the factors which cause them. Information is provided on the risk analysis process and the data required for modelling. The basic theory of landslide processes is well understood. However, landslide risk assessments are complex and there are significant information gaps in undertaking landslide risk analyses which are outlined. The potential influences of climate change and the impact of climatic cycles on landslide processes remains a significant gap in information. The majority of landslide practitioners in Australia are in the private sector, and local governments have principal responsibility for managing landslide risk.

Hazard Identification

Landslides are a form of erosion known as 'mass wasting', which is an important natural phenomenon in the formation of slopes and in the evolution of landscapes. The term 'landslide', which encompasses a range of processes, is the term favoured by geotechnical professionals. Other terms such as 'landslip' are entrenched in legal terminology, and the general public and media may use terms such as 'slumps' or 'mudslides'.

In simple terms, landslides occur when the downward force of gravity acting on slope materials exceeds the cohesive force that holds the soil particles together, or the frictional force which holds the material to the slope (i.e. 'shear strength'). The failure of slope materials can be related to a number of contributing factors and trigger factors.

The contributing or 'site setting' factors which influence whether a landslide will occur include: steepness of the slope; shape of the hillside; engineering properties of different materials in the subsurface profile; depth to the water table (or the pore water pressures on the landslide failure surface); the potential for subsurface water concentration; and vegetation cover.

Often a number of factors will contribute to a landslide occurring. However, frequently the dominant factor which triggers the movement of slope material will be an increase in pore water pressure from rainfall or leaking infrastructure. Other triggers include earthquakes, vibrations caused by human activities, and undercutting of slopes by fluvial erosion or artificial excavation. Additional information is available in a range of texts, including Turner and Schuster (1996) and Fell (1992). The relationships between these factors are important in understanding the causes of landslides.

All factors can be influenced either positively or negatively by human activity. Although in some areas landslides may be limited to failures in uncontrolled and unretained fill or road cuttings and excavations, they still pose a risk to people and property. Consequently, it is unusual to find a populated area in Australia that is not susceptible to some form of landslide process. It is believed that all local government areas have land stability challenges of one form or another (Leventhal and Kotze in press).

Fell (1992) provides a regional overview of land instability in Australia, which describes the location and extent of landslides and the conditions and mechanisms which are conducive to slope failure. Most landslides in Australia occur in Tertiary basalt, Tertiary and Cretaceous sediments and older inter-bedded sedimentary and coal measure formations (Fell 1992). Maps which show the distribution of such materials for New South Wales, Victoria, southern Queensland and Tasmania, along with a comprehensive bibliography, are also provided in Fell (1992). Further information is provided by Johnson and others (1995), Michael-Leiba (1999), Michael-Leiba and others (1997), Blong and Coates (1987) and AGS (2007).

The distribution of reported landslide events in the Australian landscape is shown in Figure 8.1, which reflects the results of specific landslide mapping programmes based in Tasmania, southwest Victoria, Wollongong and Newcastle–Lake Macquarie in New South Wales, and Brisbane and Cairns in Queensland. The remainder of the landslides depicted were reported by the media or by 'landslide spotters'.

The types of landslides that occur in various geomorphic settings in Australia are explained below.

Rockfall

Typical settings where rockfalls may occur include cliffs in coastal zones, mountain sides, gorges, road cuttings or quarry faces. The coastal cliff lines of New South Wales (Kotze 2007) and the dolerite mountains of Tasmania are prominent examples. Rockfalls are characterised by an extremely rapid rate of movement and have been responsible for many of the landslide-related deaths in Australia. Depending on local conditions, the run-out distances of rockfalls can be considerable. Although the source areas of these features are generally too steep to build upon, popular beaches and structures such as walking tracks, roads and houses may be located in the run-out area.

The largest rockfall in Australian history is believed to be a 30 million tonne rockfall which collapsed above the shoreline of the Lake Burragorang Reservoir (Warragamba Dam) in New South Wales in 1965; the rockfall was

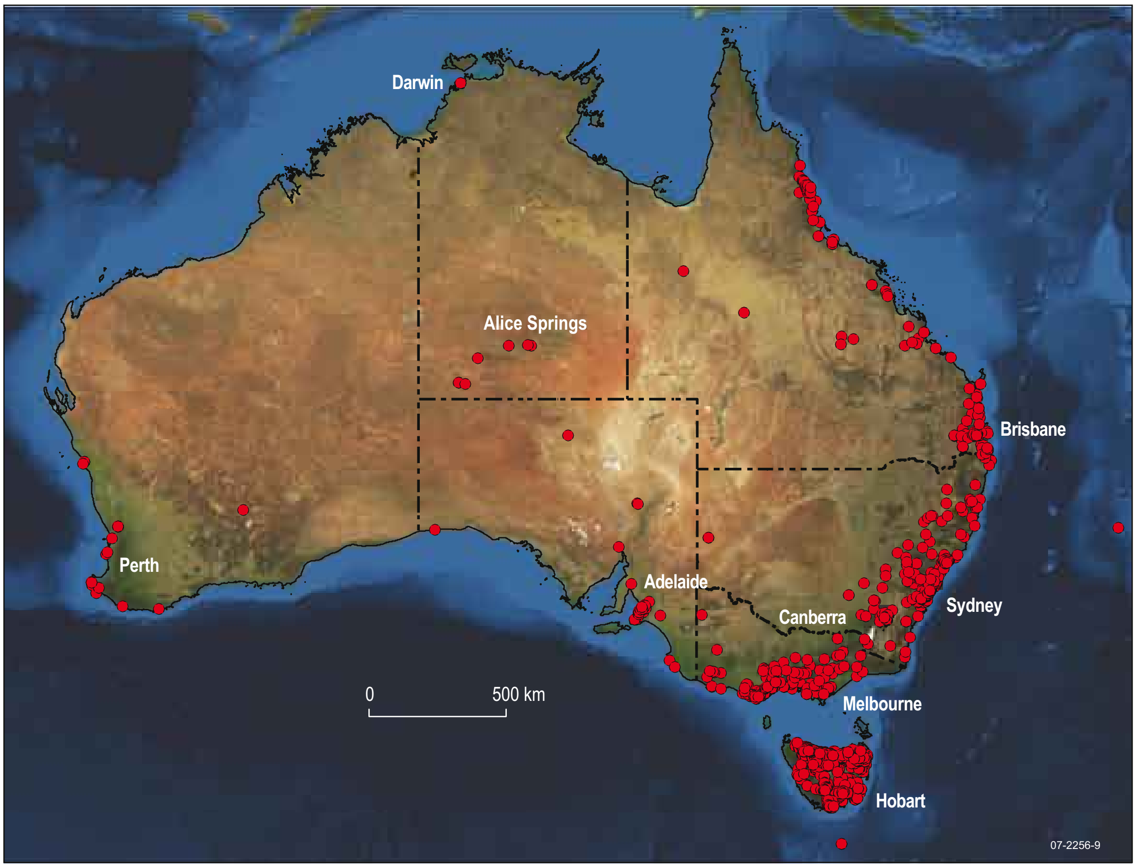


Figure 8.1: Recorded landslide events in Australia
Source: This map was compiled by Geoscience Australia in August 2007 from data available in the Australian Landslide Database (incorporating records from Geoscience Australia, Mineral Resources Tasmania and the University of Wollongong). Data for southwest Victoria were supplied by Corangamite Catchment Management Authority in association with the University of Ballarat and A.S. Miner Geotechnical.

attributed to underground coal mining (Pells and others 1987). Other examples include the rockfall at Gracetown, Western Australia, in 1996, where 30 tonnes of rock and sand fell from a limestone sea cliff onto people sheltering under an overhang, injuring three and killing nine; a 100 metre rockslide at Mulligans Bluff on the Gwydir Highway, New South Wales, in 2002; and regular rockfalls along Lawrence Hargrave Drive in Wollongong, New South Wales, including notable falls in 1988 and 2003.

Deep-seated Landslide

Deep-seated landslides typically occur in steep terrain. However, they can be observed on slopes with angles as low as a few degrees, because the geological materials involved typically have low shear strength or are subject to high pore pressure. Areas include the Tertiary basalt soils and the Tertiary sediments of eastern Australia (Fell 1992; McGregor and others 2007).

Across Australia, there are many examples of houses and subdivisions built on existing landslide sites or on slopes that are susceptible to failure. While most of these landslide sites may be dormant, some can be reactivated with changes in pore water pressures and/or disturbance through human activities such as property development.

An example of a deep-seated landslide in Tasmania is the Taroona Landslide in Hobart, a very to extremely slow-moving landslide on which two schools and nearly one hundred houses are located (Moon and McDowell 2002; Latinovic and others 2001). Monitoring over a seven-year period indicated that movement occurred at the site every year, although only a few structures were affected by the movement.

Debris Flow

Debris flows can originate on slopes in the range of approximately 16 to 40 degrees, where loose rock and soil materials are subjected to high-intensity rainfalls. Where water content is high, debris flows can travel at rapid velocities with considerable destructive potential. Houses and other structures may be situated on or near the source area or run-out path of such features.

The landslide at Thredbo, New South Wales, in 1997 became a debris flow which destroyed two buildings and claimed 18 lives. It was the worst landslide disaster in Australian history, and the ground failure was attributed to a leaking water main.

Debris flows triggered by intense rainfall include: the debris flow at Humphrey Rivulet, Tasmania, in 1972 (Mazengarb and others 2007); the slides which blocked the Captain Cook Highway behind Ellis Beach, north of Cairns, Queensland, in 1951 (Michael-Leiba and others 1999); and the 60,000 tonne debris flow at Montrose in the Dandenong Ranges of Victoria in 1891 (Moon and others 1992).

Shallow Landslide

Shallow landslides occur in areas with a shallow layer of weak material and are often triggered by brief episodes of intense rainfall. They tend to occur on the edge of embankments and on steep natural slopes of 30 degrees or more. The infrastructure most commonly affected is roads and railway lines, although shallow landslides occasionally damage houses and other private property.

Numerous shallow landslides occur during the wet season. For example, they are often associated with tropical cyclones in the Cairns region and along the Cairns–Kuranda railway (Michael-Leiba and others 1999).

Cost of Landslides

The financial and social consequences posed by landslides are extremely underestimated in Australia. Landslides regularly damage buildings, roads, railways, vehicles, pipelines and communication lines, and have adverse social effects that include death, injury, stress

Damage to a road caused by a slow moving landslide at Pleasant Hills, northwest of Launceston, Tasmania
Photo courtesy: Geoscience Australia/Marion Leiba/captured in 1996.

and displacement. Not only is stress detrimental from the psychological and social point of view, it also can have detrimental physical effects that may even lead to fatalities.

The total direct cost of landslides in Australia for the period from 1967 to 1999 is estimated at $40 million. This can be solely attributed to the 1997 Thredbo landslide as only landslides costing $10 million or over were included in the BTE (2001) estimate. However, for the period from 1900 to 1999 the total socioeconomic cost of landslides was estimated at $500 million in 1998 dollars (EMA 1999).

Most damage is the result of many small landslide events, and it is believed they have a significant cumulative cost. Few insurance policies in Australia cover landslides, and it is understood that the majority of landslide costs are absorbed directly by individual property owners as well as by infrastructure authorities.

Costs associated with disaster assistance and road maintenance, relocation and repair are among the greatest public costs resulting from landslides. For example, the Australian Landslide Database indicates that the construction cost of diverting the Lawrence Hargrave Drive coastal route around a cliff face subject to rockfalls was $49 million in 2006 dollars, and it is estimated that from 1989 to 1996 the cost of repairs to railway infrastructure in Wollongong amounted to $175 million. Reconstruction of the Alpine Way after the Thredbo landslide cost $24 million (BTE 2001).

Adding to the complexities of estimating landslide costs are the different types of landslide processes. The costs of extremely slow-moving landslides which cause cracks or irregularities in the fabric of buildings and in the surface of roads, footpaths or pipelines are typically absorbed into general maintenance and repair costs. Other hazards, such as tropical cyclone or flood, may trigger landslides, presenting a challenge in isolating and determining the damage that is a specific consequence of the landslide.

Environmental cost is difficult to quantify in financial terms. Landslide-derived sediment may cause prolonged turbidity in stream channels that, in turn, may adversely impact on water reservoirs or fish habitats. A significant increase in the incidence of landslides on Macquarie Island, Tasmania, is believed to be the consequence of the removal of vegetation by a rapidly expanding population of rabbits. Costs of controlling the rabbit numbers and preventing further landslides are estimated to be $24.6 million (ABC 2007; Parks and Wildlife Service 2007).

Further information on the economic and social impact of landslides in Australia is provided by Blong and Eyles (1989), Schuster (1996), and Michael-Leiba (1999).

Potential Influence of Climate Change

In geological time, climate change has been extensive and has had a profound influence on sea level, rainfall patterns, and temperature-related hillside processes such as chemical and mechanical weathering. Climatic phenomena, such as the complex interactions of the Interdecadal Pacific Oscillation Index, the El Niño–Southern Oscillation (ENSO) and the deep-ocean conveyor cycle, have impacted on the short-term and long-term rates of mass wasting in Australia, which span from decades to thousands of years and longer. Further information on these interactions is available in Kiem and others (2006).

Rainfall patterns are significant to landslide occurrence. Conceptually, it is almost a certainty that predicted climate change will impact on the rate and severity of landslide hazard to some degree. More frequent high-intensity rain in some areas could be expected to increase the likelihood of landslides and erosion, particularly in the urbanised catchments on Australia's east coast (CSIRO 2002).

Potential impacts of climate change include increases in sea level and temperature and a drier climate.

A rise in global sea level in the order of 0.09–0.88 metres by 2100 (Solomon and others 2007) will have an influence on Australia's coastal environments, accelerating the erosion of sandy dunes along soft coasts and cliffs along hard coasts.

A drier climate will lead to a drawdown of the water table, and may reduce the likelihood of deep-seated landslides, debris flows and intermittent slip-stick movement. For instance, a marked drop in annual rainfall from 1975 to 1976 was reflected in a drop in landslide activity in Tasmania (Ezzy and Mazengarb 2007). However, in areas with shallow slopes of reactive clay soils, a lowering of the water table may cause 'fissuring' (i.e. cracking) on slopes. This may increase the susceptibility of the slopes to water infiltration during rainfall, which can lead to slope failure.

An increase in temperature is likely to bring more frequent and intense storms. Storms accompanied by heavy rainfall may trigger landslides and short-duration erosion. Stream flow from increased run-off may also accelerate erosion rates and undercut slopes. An example of the relationships between intense storms and increased stream flow and shallow slides and debris flows is provided by Reinfields and Nanson (2001).

Guidelines for responding to the effects of climate change in coastal and ocean engineering are outlined in Engineers Australia (2004).

Risk Analysis

Landslide risk analysis involves determining the likelihood of a particular landslide event and understanding the possible consequences of that event. The data required to model or map actual and potential landslides vary with the scale and purpose of the assessment. Modelling of landslide susceptibility, hazard and risk requires the existence of a landslide inventory, which is the fundamental source of historic information on landslide occurrence and is used to validate or 'ground truth' any models which are built.

A variety of skills are required to perform a landslide risk analysis, and the number of personnel involved might range from a single individual for a house site analysis to a team for a regional analysis.

The practice of landslide risk analysis is a requirement for a range of activities, including infrastructure development, mining, monitoring and maintenance (e.g. for hydroelectric dams and roads), and as a condition for development approval imposed by local government. It is important to note that the mining sector is an area where an advanced understanding of soil and rock behaviour is critical to ensuring safe working conditions. This specialised area is outside the scope of this chapter, though is an area where the principles of risk management are routinely applied.

Prior to the 1997 Thredbo disaster, the general public regarded the issue of landslide risk to be primarily related to loss of property (Leventhal and Kotze in press). The Thredbo landslide changed public and political perception of the hazard, and led to the formulation of guidelines for practitioners by the Australian Geomechanics Society (AGS). The suite of guidelines outlines good practice in landslide susceptibility, hazard and risk zoning for land use planning (AGS 2007a; AGS 2007b), landslide risk management (AGS 2007c; AGS 2007d) and slope management and maintenance (AGS 2007e).

Despite the guidance offered by the AGS, there remain variations in the approach to landslide risk analysis within Australia. Some practitioners find it difficult to achieve the desired standard, for reasons such as complexity and cost. A landslide risk assessment is a complex and difficult process (van Westen and others 2005) and methods are still evolving. Assessments are increasingly becoming multidisciplinary and technology driven.

Further information on risk analysis and assessment is provided by Cruden and Fell (1997), Hungr and others (2005), Miner and Dalhaus (2006), Flentje and others (2005), Flentje and others (2007), and Lee and Jones (2004); and in the reference lists of the AGS guidelines and van Westen and others (2005). Further information on the role of the AGS guidelines is provided in Leventhal and Kotze (in press), Leventhal (2007) and Leventhal and others (2007).

Likelihood Analysis

Since the adoption of a risk-based approach to landslide assessment in recent years, the estimation of landslide likelihood has proven to be particularly challenging. Estimations of likelihood are evolving from the use of relative terms such as 'possible' and 'unlikely' to semi-quantitative and quantitative approaches (e.g. Moon and Wilson 2004, and Moon and others 2005). Estimating potential movement of an existing landslide is difficult, but predicting a first-time slide is even harder. This is partly because records of past events are invariably incomplete and provide little guidance on infrequent events (Moon and others 2005).

There are at least three distinctly different landslide processes that need to be considered (i.e. rockfall, debris flow and deep-seated landslides), as well as the range of triggering and contributing factors, which may be poorly understood regionally and/or locally. Each type of landslide varies in frequency, speed and style of movement, duration and run-out distance, and has unique properties and characteristics for risk analysis and management. Additionally, for each different type of landslide process the risk analysis needs to take into consideration potential effects up-slope, down-slope, laterally and in the run-out zone.

The estimation of likelihood is a two-stage procedure for each landslide type. The first stage generates a landslide susceptibility map, and incorporation of the second stage generates a landslide hazard map. Each type of landslide needs to be analysed separately in these stages, as each is governed by a different physical process.

The first stage of analysing likelihood is to determine the susceptibility of landslides, which is a measure of the 'spatial probability' of failure. This stage considers any historic landslide occurrence and analyses the underlying site setting factors which contribute to landslides. For all three landslide processes, susceptibility analysis involves the identification of potential source areas, as well as the separate prediction of potential landslide run-out areas. Both procedures can be done in several ways using various modelling and mapping techniques. These are outlined in AGS (2007a; 2007b) and Flentje and others (2007).

The second stage is to determine 'temporal probability'. There are several approaches, as outlined in van Westen and others (2005). The temporal probability can be obtained by correlating the data on landslide occurrence with data on the triggering factors, provided data records are sufficient, or through dynamic (i.e. time dependant) modelling (van Westen and others 2005).

For example, long-term record keeping of landslide events can allow the relationship of landslide occurrence to triggering events such as rainfall to be determined (Michael-Leiba and others 2002; Walker 2007), although this relationship may not always be clear (MacGregor and others 2007). Rainfall analysis may require consideration of duration (e.g. antecedent values over weeks and months) and intensity (e.g. over a 24-hour period or shorter event), depending upon the style of landslide. The likelihood of failure can then be derived for any point on the ground by analysing the number of landslides per year, and their susceptibility, combined with the predicted recurrence interval of the rainfall conditions which trigger the landslides.

Additionally, based on observed relationships in nature whereby smaller events tend to occur more often than larger events, the analysis of magnitude–frequency relationships may further refine the likelihood modelling of event size.

Data requirements

The information required will vary depending on the type, scale and purpose of investigation. Likelihood analysis requires data to estimate the spatial and temporal probability of landslides (i.e. the landslide hazard map).

The historic information on landslide events is fundamental, as it provides an insight into the frequency of the phenomena, the types of landslides involved, the volumes of materials involved, and the damage caused (van Westen and others 2005). The data should span as lengthy a time as possible and include landslide

View from the headscarp of a fatal landslide at Thredbo, New South Wales, July 1997
Photo courtesy: Geoscience Australia.

Homes perched precariously after a major landslide on Currumbin Hill, southeast Queensland, July 2005
Photo courtesy: Emergency Management Queensland.

inventories, aerial photographs, remote-sensing data and terrestrial photography.

Historic data on landslide occurrence, in addition to the site setting factors, are important in determining landslide susceptibility. This generally requires data on topography, geology, geomorphology, soil type, soil depth, geotechnical characterisation of slope materials, vegetation, hydrology and hydrogeology. Such data, where available, are typically represented spatially as data 'layers' and analysed in a geographic information system (GIS). For example, a digital elevation model is important for modelling the run-out distance for landslides of a given type and volume.

Incorporation of data on trigger factors is required to develop a landslide hazard map. This includes the data required to determine landslide susceptibility; rainfall data sets (both raw and derivative interpretations); data on seismic hazard; and other trigger information, which may include the location and type of underground pipes.

High-resolution data are essential for undertaking likelihood analyses in localised regions. In some cases, the absence of spatial information may be replaced with the requirement for the practitioner to have sufficient understanding of the slope-forming processes operating in a particular area and the effects that individual components contribute to slope instability. Competent and skilled practitioners must be involved in the interpretation.

Consequence Analysis

The consequence of a landslide changes with temporal and thematic variations in vulnerability. For example, thematic variations include the material type of a building or the age distribution of a population. The estimation of the degree of damage should be based on vulnerability/fragility curves derived from historical damage inventories, where records are sufficient. Curves can also be derived from structural modelling or though empirical relations (van Westen and others 2005).

The exposure of mobile elements such as people and vehicles will vary considerably between day and night, and seasonally, depending on where people work and reside. The vulnerability of elements which are at risk may also vary considerably depending on the type of landslide and its rate of movement (Cruden and Varnes 1996). Typically, the faster a landslide moves, the greater the amount of damage to people and property, because speed reduces the opportunity for remedial action or escape. However, even buildings situated on extremely slow landslides may be completely destroyed over a number of years.

For landslides with potentially long run-out lengths, the destructive potential will be strongly influenced by topography, slope angle and obstacles such as forests, as well as the shape, dimensions and mass of the boulders.

Data requirements

Data on historic damages for different landslide types and volumes and information on the vulnerability of the elements at risk are required. Generic exposure databases may be utilised, although these are better suited to hazards which impact regionally per event (e.g. flood or earthquake) rather than for landslides which generally impact isolated elements (van Westen and others 2005).

Information Gaps

Worldwide, much is known about landslide processes and the potential consequences of the range of landslide phenomena. However, for most of Australia there is no ready source of landslide information relating to the local setting and Australia does not have a good understanding of how its population centres relate to landslide risk.

There is no coordinated means of data collection in Australia. Where such information exists, landslide mapping and geotechnical reporting is highly variable in standard and quality, and there is generally apprehension about sharing any information which may relate to potential issues of legal liability. There is also space to better consolidate and integrate geotechnical engineering expertise with research from domains of geology, geomorphology, hydrology, meteorology, GIS, and computation.

The primary constraints to addressing landslide research gaps are skill shortages and resource limitations. There are currently no universities within Australia that teach the holistic range of skills required to undertake landslide risk analyses. Very few engineering departments teach or research engineering geology or geology for engineers. Furthermore, it is estimated that 30,000 engineers will retire by the end of the next decade (Engineers Australia 2005). Skill shortages are particularly apparent in the civil sector, partly because of competition for skills from the lucrative mining sector.

Further information on gaps in landslide knowledge and processes is provided in van Westen and others (2005) and Leventhal and Kotze (in press).

Landslide Inventories

The AGS (2007a; 2007b) considers that landslide information should be entered into inventories to underpin all successive risk analyses, research and land use decisions. The ongoing collection and analysis of landslide data and related data is a vital exercise, although the provision of funding for ongoing maintenance of these databases presents a challenge.

A landslide inventory represents a fundamental base of knowledge for land use planning that strongly helps local authorities in their decision making. With few exceptions throughout Australia, the activity of recording landslides is currently undertaken in a haphazard way, and records are not detailed enough to be used confidently in probability assessments. Data are collected and recorded in different formats and cannot be compared or aggregated easily with other sources. The Landslide Database Interoperability Project being coordinated by Geoscience Australia is a first step toward addressing this information gap (Osuchowski 2006).

Additionally, throughout Australia geotechnical investigations are occurring as routine activities performed by councils within their development approval processes. The councils retain a great deal of detailed information on the landslides in their municipalities, although the data are difficult to retrieve once they have been lodged with a regulator. There is seldom incorporation of, or reference to, these geotechnical reports in landslide databases and landslide information is rarely synthesised across multiple jurisdictions. If this information was made easily accessible to those who undertake risk analysis, it could significantly improve the availability of the basic knowledge required to assess landslide frequency and occurrence. Additionally, successive investigations in one vicinity would be able to build on previous research.

Landslide Susceptibilty Mapping

The distribution of landslides in the Australian landscape is not well known. There has never been a national landslide susceptibility or hazard (likelihood) mapping programme, and only limited nationwide studies of landslides have been conducted.

It is difficult to assess landslide susceptibility on a national scale, because landslides are dependent on the interaction of localised conditions, and methods to overcome the data limitations are still being developed. Landslide mapping, when conducted, generally occurs only on a site-specific scale and is performed by geotechnical consultants for purposes of zoning, building infrastructure or applying for development approvals.

The regional susceptibility mapping of areas prone to landslides is not commonly undertaken in Australia. Without regional mapping, it is difficult for those with regulatory responsibilities to be aware of any landslide risks within their jurisdictions and target areas for detailed mapping. Examples are provided in Ezzy and Mazengarb (2007), Miner and Dalhaus (2006), and in a Victorian Government report regarding the Alpine Resorts Planning Scheme (DSE 2007a).

First-pass landslide susceptibility maps are needed, particularly across areas with known histories of landslide occurrence. The limitations of the mapping and the levels of accuracy need to be made explicit on such maps.

The availability of relevant datasets, such as geomorphology at scales of 1:25,000 or better, is highly variable throughout the country, even when considering the major urban areas. High-resolution data are essential for undertaking susceptibility, hazard and risk analyses in localised regions.

Fundamental research directed at better understanding landslide processes in the Australian setting is currently very limited. There are also significant geomorphic research gaps which include measuring the age of Australia's landscape and developing landscape evolution models which can contribute significantly to better appreciation of slope-forming processes and their associated process rates.

Landslide Hazard Mapping

The primary constraint to hazard mapping is a lack of good inventory maps and validated inventory databases, in addition to resource constraints.

There is a need for systematic and standardised landslide hazard assessments throughout the country, in order to assist stakeholders, such as regulators, to be aware of landslide hazards and to make informed land use decisions. Emergency management agencies would also benefit from acquiring a more technical understanding of landslide hazard areas to inform the development of emergency action plans.

Determining temporal probability is often not possible, because of the absence of historical landslide records which can be related to the historical records of triggering events, the scarcity of input data, or the insufficient length of historical records of triggering events (van

Westen and others 2005). Determining the cumulative effects of human influence is difficult, particularly in urbanised areas susceptible to landslides.

Ongoing analysis of the influence of triggering factors, such as rainfall events, on representative and problematic landslides in Australia is needed. Monitoring programmes, including the use of near real-time technologies, can provide information on the relationships of landslide movements to triggers. This is important if public safety warning systems are to be developed as part of risk management and disaster plans.

At the local and regional levels, there is a need for research programmes that determine the relationships of contributing factors to landslide occurrence, magnitude–frequency rules and run-out limits for representative areas across Australia. As a strategic exercise, in the absence of national mapping strategies, this would provide context for site-specific investigations and other regional mapping exercises. Coupled with this aspect is the ongoing development of methods for implementation in applications such as landslide zoning.

Influence of Climate Change

The influence of climate change on landslides in Australia is not being specifically addressed by any agency. The effects of climate change on the frequency and intensity of rainfall triggers, as well as the impacts of rising sea level, need research.

Further research is also needed on the differences between a changing climate and 'climate change', climate mechanisms which deliver high-risk periods, and ways in which human activities complicate the interactions of climate cycles.

This includes better understanding the relationships between fossil landslides and the climate at the time of failure. This would allow a picture of prehistoric landslides and their causes to be developed, analogous to the process of identifying and dating fault scarps formed during

The aftermath of a debris flow damaging a resort on Magnetic Island, January 1998
Photo courtesy: Geoscience Australia/Marion Leiba.

State Emergency Service volunteers involved in rescue efforts at a fatal landslide at Thredbo, New South Wales, July 1997
Photo courtesy: Geoscience Australia.

large prehistoric earthquakes. This is important, as decadal cycles influence the activity of deep-seated failures and raise issues with likelihood prediction.

Roles and Responsibilities

The majority of landslide practitioners in Australia are in the private sector; considerably smaller numbers are in universities or state government agencies. The roles and responsibilities of those involved in managing parts of landslide risk are described below.

Australian Government

The Australian Government's overarching goal in the management of landslide risk is to ensure the development of safer communities. The Australian Government offers some financial assistance for landslide studies and landslide mitigation measures, through its funding programmes aimed at reducing the risk of natural disasters. It maintains the Australian Landslide Database and provides overarching emergency management and land use planning guidelines.

The Australian Government plays a role in raising awareness of landslide hazard though education and training programmes (EMA 2001a; EMA 2001b), and contributes to innovative research to assist the mining industry through the development of models which assess the geotechnical stability of artificial slopes.

The Australian Government also underpins and coordinates a number of intergovernmental organisations and groups, particularly those directed to planning and building codes, such as the Development Assessment Forum.

State and Territory Governments

Legislation varies across states and territories in Australia; some have stronger legislative requirements than others. Current Australian legislative controls are outlined in ABCB (2006), Leventhal and Kotze (in press) and Tefler (1988).

State and territory governments differ in their approaches to managing landside hazards. Some have accepted the AGS (2007) predecessor *Landslide Risk Management Concepts and Guidelines* (AGS 2000) as an industry reference paper within legislation. All play an important role in strengthening partnerships with local governments, and in encouraging and supporting them to undertake disaster risk assessments and mitigation measures.

All state and territory governments, with the exception of the Tasmanian Government, delegate responsibility to their local governments. Mineral Resources Tasmania is the only state government agency that undertakes regional mapping of landslides, maintains a state-wide landslide database, and provides landslide information to the public. Mapping is generally undertaken by the private sector in other jurisdictions.

Planning agencies in each state and territory develop coastal policies and landslide or erosion policies (EMA 2001a; DAF 2007). However, it is believed that some erosion policies do not specifically relate to landslide hazard, which can result in confusion among land owners and members of the general public. One example is the Erosion Management Overlay in Victoria (Golder Associates 2004; DSE 2007b).

Road and rail transport agencies have a responsibility to protect road and rail infrastructure against landslides and to ensure construction does not increase landslide hazard. They do this by liaising strongly with geotechnical consultants.

Local Government

The majority of mitigation and development controls for slope management are achieved at the local government level (Leventhal and Kotze in press). Most landslide work is also undertaken at this level, with the private sector providing advice and support.

Local governments have principal responsibility for systematically taking proper account of risk assessments in land use planning to reduce landslide risk. Local government agencies are responsible for reducing landslide losses using the best information available (COAG 2004).

Zoning and planning schemes across local government are variable across jurisdictions within each state and territory. Some local governments designate 'landslide hazard zones' which control development within their jurisdictions, while others have not recognised or planned for landslide-related risk (Leventhal and Kotze in press).

While guidance is provided by the Development Assessment Forum (DAF 2007), systematic policy implementation to address landslide hazard is rare across local governments.

Local governments also have a regulatory responsibility, and regulatory approaches vary widely. There are no requirements for building constructions with the capability to withstand a landslide; regulatory control is currently directed toward preventing exposure to landslides (Leventhal and Kotze in press). A number of parties are involved in the landslide risk management process, although pragmatically the regulator sets the tolerable risk levels. Regulators need to appreciate the complexities of landslide risk analysis in order to ascertain the rigour of any geotechnical landslide reports upon which they base their decisions. The regulator is best placed to act in the interests of the community with respect to landslide hazard, particularly for matters relating to transfer of risk upon sale of properties.

Industry, Coordinating Groups, Professional Bodies and Research Institutions

There are a number of professional bodies and industry bodies that play an advocacy and leadership role in landslide risk management. Most function at a national scale: for example, Engineers Australia and the Australian Building Codes Board. The National Engineering Registration Board recognised the challenges some regulators face and developed a 'specific area of practice' within the National Professional Engineering Register for landslide risk management.

Professional societies help to integrate the engineering and geotechnical science into decision making. They serve as conduits of information from researchers to practitioners. They are the source of codes and handbooks

A fatal landslide at Paluma Road, north of Townsville, Queensland, March 1997
Photo courtesy: Geoscience Australia/Marion Leiba.

which provide best practice guidance, and some also offer professional training. For example, the Australian Building Codes Board identified that construction in areas prone to potential landslide hazard was an issue that requires consistent uniform guidance across the nation, and published a non-mandatory guideline (ABCB 2006) to provide advice on this matter.

Numerous geotechnical and engineering consulting companies are involved in landslide hazard and risk assessment on behalf of government and non-government agencies. Many conduct landslide research, develop landslide mapping and monitoring techniques and maintain their own landslide inventories. Engineering geologists, geotechnical engineers and building professionals provide geotechnical advice to government, business, industry and private property owners. They make a significant contribution to the development of methods, for example in undertaking landslide risk assessments for property developers and addressing legal liability in slope stability assessments.

The University of Wollongong undertakes research encompassing landslide risk management, the development of GIS-based mapping techniques (Flentje and others 2007) and continuous real-time monitoring. The monitoring stations are facilitating quantitative landslide frequency assessments and providing real-time warning capabilities. The university works cooperatively with the Wollongong City Council, the local office of the New South Wales Roads and Traffic Authority and RailCorp. It is known that other universities undertake landslide research programmes although it is believed that this occurs on an ad hoc basis.

Property Developers

Developers are required to prepare development applications which address councils' provisions relating to development in areas susceptible to landslides. The developer is required to provide a geotechnical assessment of the site which demonstrates that the development proposal takes into account appropriate mitigation techniques, and to seek advice from qualified engineering geologists and geotechnical engineers on site slope instability as part of that assessment. A qualified geotechnical professional may assess the reliability of these reports in landslide-prone areas.

AGS (2000; 2007a-e) provides a means for owners, occupiers, regulators and insurers to be aware of the risks involved in construction of all manner of developments, from residential developments to infrastructure critical to community safety, and to manage such risks (Leventhal and Walker 2005).

General Community

Members of the general community have a responsibility to be aware of how their activities might impact upon their own property and that of their neighbours. Valuable information for the general public is contained within the GeoGuides (AGS 2007e).

While it is possible for marginal land to be developed within tolerable levels of risk, meeting any imposed maintenance requirements is the responsibility of the home owner. The risk level one owner or occupier is prepared to accept may not be accepted by another, and there may be transfer of risk issues and issues of nondisclosure during the sale of affected property. The regulation of this is legally and pragmatically challenging and legal intervention commonly results in local governments shouldering this liability.

Individuals who intend to purchase or occupy homes on, or in proximity to, sloping land or a cliff should contact their local council for guidance on slope instability or development issues. Individuals should seek professional advice if they are concerned about slope stability in their area, and should seek any landslide mapping information that may be detailed enough for site specific analysis from the council.

Conclusions

Landslides in Australia are predominantly triggered by an increase in pore water pressure from intense short-period or prolonged rainfall. Human activity can impact both positively and negatively on the occurrence of landslides. The regular occurrence of landslides across Australia makes it difficult to estimate their cumulative impact in socioeconomic terms, as costs are distributed, misreported or not documented.

Modelling the likelihood of landslides requires each physical process to be approached differently and analysed separately, in any level of risk analysis. The information and approach necessary for effective modelling depends on the scale of investigation and requires data primarily on historic landslide occurrences as well as on site setting and trigger factors. To model consequence requires knowledge of the type of landslide and the elements at risk, and an understanding of how vulnerability varies with each element at risk.

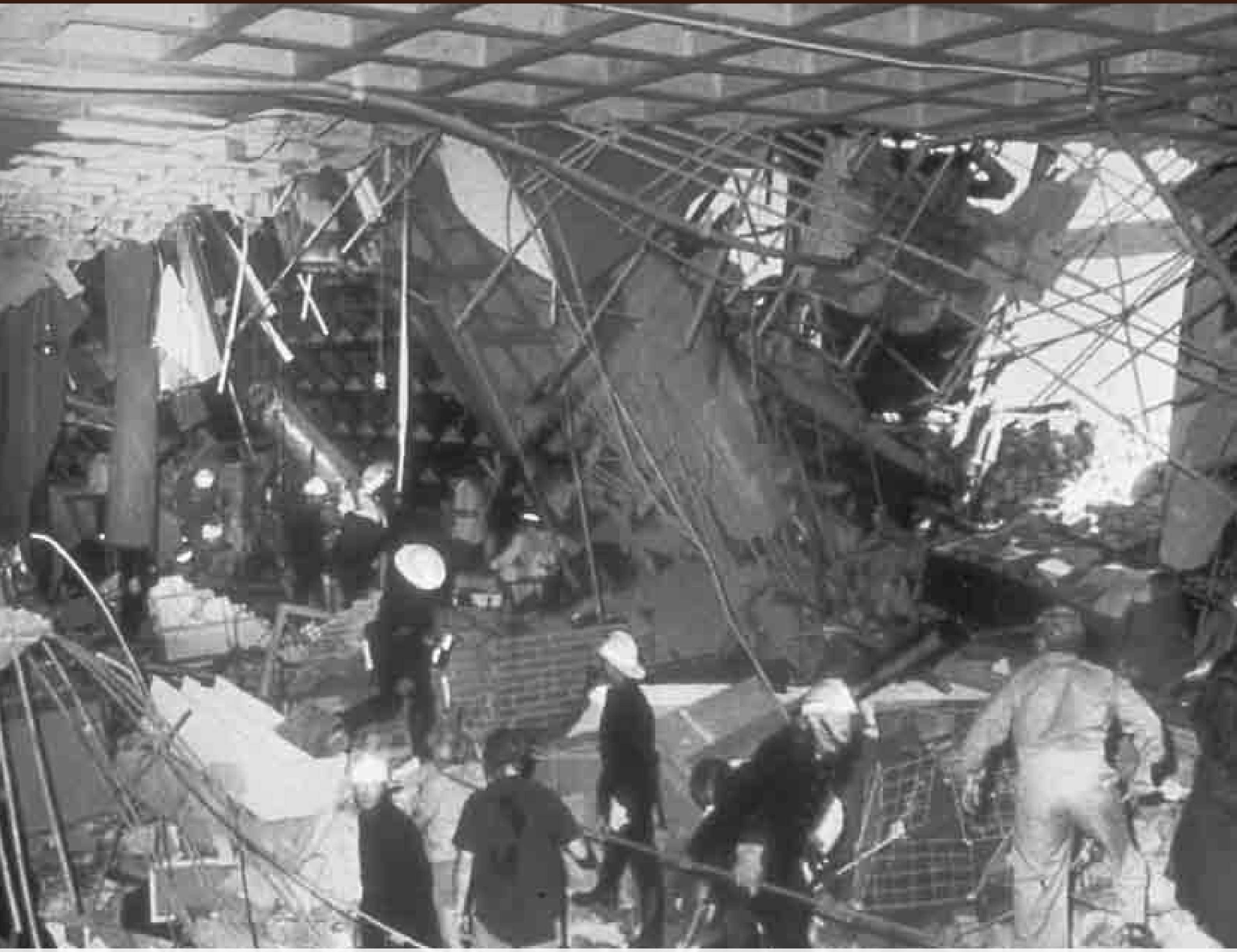
The adoption of best practice guidelines and methods is an important step in minimising and managing landslide impacts. Further work in the areas of landslide inventories, including reliable maintenance of landslide databases and model development, is important. There is also a need to contribute to management of landslide risk at the technical level through support for nationwide landslide susceptibility mapping at the scale of regional or local government areas.

The management of landslide risk is important for all levels of government, non-government agencies and groups and the community. However, local governments have a major statutory responsibility for managing landslide risk and private industry plays a fundamental role in this process. Skills shortages and resource limitations are primary constraints in furthering landslide research.

Residential development along a 22 metre high coastal cliff-top subject to ongoing erosion at North Bondi, New South Wales
Photo courtesy: Greg Kotze/captured in 2005.

Chapter Nine:

Earthquake



Damage sustained by the Workers Club following an earthquake in Newcastle, New South Wales, December 1989
Photo courtesy: Emergency Management Australia.

Earthquake

Earthquakes pose a risk that is fundamentally different to those of more frequently occurring natural hazards such as tropical cyclones and floods. Australia is a tectonically stable region and has few earthquakes of any consequence in any given year. The relative rarity of large earthquakes ensures that earthquakes are not prominent in the public consciousness. However, the earthquakes in Newcastle, New South Wales, in 1989, in Meckering, Western Australia, in 1968, and in Adelaide in 1954 clearly demonstrated that moderate-sized earthquakes have the potential to tragically affect Australian communities.

Damage to a building from an earthquake in Meckering, Western Australia, October 1968
Photo courtesy: Emergency Management Australia.

A fault scarp caused by a prehistoric earthquake at Lake Edgar, Tasmania, circa 15,000 BC
Photo courtesy: Geoscience Australia.

A car damaged by falling rubble from an earthquake in Newcastle, New South Wales, December 1989
Photo courtesy: Emergency Management Australia.

A warped pipeline from an earthquake near Tennant Creek, Northern Territory, January 1988
Photo courtesy: Emergency Management Australia.

While the severity of earthquakes in Australia is not as great as at tectonic plate boundaries, the typically higher vulnerability of infrastructure can lead to severe consequences. The Newcastle experience showed how vulnerable Australian cities are to earthquakes, resulting in death, injury and substantial economic loss. The average annual cost of earthquakes in Australia is $144.5 million taken over the period from 1967 to 1999 (BTE 2001); most of this can be attributed to one key event, the Newcastle earthquake which resulted in 13 fatalities. The historical records of earthquakes demonstrate that large earthquakes do occur in Australia and there is no doubt that a large earthquake has the potential to cause massive destruction and loss of life in Australian communities.

There are still significant gaps in the understanding of earthquakes in Australia. Both government and non-government agencies have a role to play in filling these gaps, through the acquisition of fundamental data and through research into hazard and risk. Improving our understanding of earthquake hazard and the risk posed to communities and infrastructure will lead to better strategies for mitigation and emergency response. This chapter describes the process of earthquake risk analysis, and points to some of the issues that still need to be addressed.

Hazard Identification

The earth's outer shell is about 100–200 kilometres thick and is broken into nine major and several smaller plates. These plates are constantly moving away from, towards or past each other; because the continents are part of these plates, they also move. Earthquakes occur when the stresses caused by the plate movements result in the rocks fracturing along fault planes. The energy released when the rocks fracture generates seismic waves, and these cause ground shaking when they reach the surface of the earth.

Most earthquakes occur along plate edges (i.e. 'inter-plate'), where the plates meet and are forced against each other. Some 95% of earthquakes are inter-plate, with 80% of all recorded earthquakes occurring around the edge of the Pacific plate, which includes Canada, Japan, New Zealand, Papua New Guinea, South America and the United States.

Australia is situated within the Indian-Australian plate and is not on the edge of a plate, so its earthquakes are 'intra-plate' and are fundamentally different to the more common inter-plate earthquakes. The Indian-Australian plate is being pushed north and squeezed between the Antarctic, Eurasian, Philippine and Pacific plates. The stress from this squeezing builds up as compression within the Australian continent and is released during an earthquake.

Earthquake sizes are often compared using the Richter magnitude scale. This scale is based on the maximum amplitudes of the seismic waves generated by the earthquake. The magnitude of an earthquake is an estimate of the energy released by it. For every unit increase in magnitude on the Richter scale, there is roughly a thirty-fold increase in the energy released by an earthquake. For instance, a magnitude 2 earthquake releases 30 times more energy than a magnitude 1 earthquake. The difference in the energy released between earthquakes of magnitudes 3 and 1 is 900 times (30 x 30).

In populated areas, the effects seen during an earthquake depend on many factors, such as the distance of the observer from the epicentre. Even small earthquakes will be felt if very close, but generally the effects will be as shown in Table 9.1.

In Australia the principal hazard component of earthquakes is the associated ground shaking. This shaking can damage or destroy structures, which in turn can cause injuries or deaths. However, there are numerous other hazards associated with earthquakes, such as liquefaction and fault ruptures. Liquefaction occurs when shaking causes water to be expelled from the subsurface sediments and soil, leading to ground failure and loss or weakening of building foundations. Fault ruptures occur when the earthquake is shallow and the fault reaches the surface and displaces it horizontally and vertically.

Although earthquakes are nowhere near as common in Australia as on plate boundaries, Australia has a long history of earthquakes. The first recorded event occurred near Sydney Cove on 22 June 1788, just five months after European settlement began. Many of the first settlers mentioned the event in their diaries. Their descriptions help us understand the source and magnitude of the earthquake.

One diarist, Blackburn, wrote (Cobley 1987, p. 167):

> ***'The shock did not last more than two seconds. It came from the (southwest) like the wave of the sea, accompanied by a noise like a distant cannon. The trees shook their tops as if a gale of wind was blowing.'***

Another noted that (Bradley 1802, p. 115):

> ***'This shock was distinctly felt on board the ships in the cove and by several people on shore, who supposed it to be the shock of an earthquake.'***

Adelaide has the highest earthquake hazard of any Australian capital city (AS 1170.4-1993), having had more medium-sized earthquakes in the past 50 years than any other. South Australia is slowly being compressed at an estimated rate of 0.1 millimetres each year (Leonard in review); the stress builds up in the rocks over many years, until they break and cause an earthquake. Earthquakes cannot be predicted, but measuring these changes, in the context of Adelaide's earthquake history, helps researchers to estimate the likelihood of earthquakes in the region around Adelaide.

MAGNITUDE	EFFECTS
< 3.4	Recorded only by seismographs
3.5–4.2	Felt by some people who are indoors
4.3–4.8	Felt by many people, windows rattle
4.9–5.4	Felt by everyone, dishes break and doors swing
5.5–6.1	Causes slight building damage, plaster cracks and bricks fall
6.2–6.9	Causes much building damage, houses move on their foundations
7.0–7.3	Causes serious damage, bridges twist, walls fracture and many masonry buildings collapse
7.4–7.9	Causes great damage, most buildings collapse
> 8.0	Causes total damage, waves are seen on the ground surface and objects are thrown in the air

Table 9.1: Earthquake magnitudes and typical associated effects
Note: Events between magnitudes of roughly 2.0 and 3.4 may be felt within a few kilometres of the epicentre.

Australia's largest recorded earthquake occurred in 1941 at Meeberrie, Western Australia. Its magnitude is estimated to be 7.2 but, fortunately, it occurred in a remote area. The magnitude 6.8 earthquake that occurred at Meckering in 1968 caused extensive damage to buildings and was felt over most of the southern part of the state. Earthquakes of magnitude 4 or more are fairly common in Western Australia, with one occurring approximately every five years in the Meckering region. For four years, Burakin, 150 kilometres east of Perth, has been Australia's most active earthquake region. A magnitude 5.0 earthquake in September 2001 was followed by 18,000 much smaller earthquakes over the next six months.

Cost of Earthquakes

Earthquakes pose a particularly challenging risk to Australian communities in that they are relatively rare events but have the potential to cause catastrophic losses. This can be seen from an analysis of historic earthquake losses in Australia (as shown in Figure 9.1). The average annual cost of earthquakes in Australia is $144.5 million (BTE 2001); over the period from 1967 to 1999, there is only one decade with losses due to earthquakes in excess of $250 million. However, the losses in the decade from 1980 to 1989 are almost entirely from a single, catastrophic event, the earthquake in Newcastle in 1989 which resulted in 13 deaths and injured 130, and had an overall cost of around $4.5 billion.

Risk Analysis

The general approach to estimating earthquake risk is to model numerous earthquakes and to estimate the consequences associated with each event as well as the probability of such an event occurring. This process requires five key models:

- an earthquake source model that describes the likelihood of an earthquake of a given magnitude occurring in a given location
- a ground motion model that defines the ground shaking experienced at a given distance from a simulated earthquake of a specific magnitude
- a site response model which estimates the level of local ground amplification
- an exposure model that describes the number of structures exposed to earthquake-induced ground shaking
- a vulnerability model that characterises the nature, magnitude and economic cost of the damage that structures will experience when exposed to ground shaking.

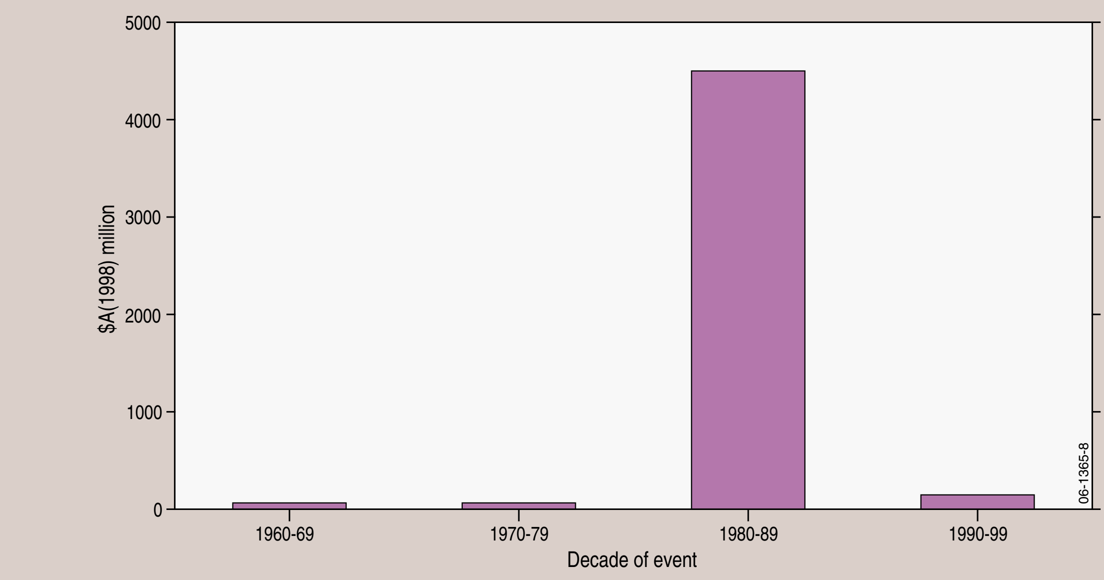


Figure 9.1: Total cost of earthquakes in Australia by decade, 1967 to 1999
Source: BTE (2001), Figure 3.24.

Police rescue squad looking in the rubble for survivors following an earthquake in Newcastle, New South Wales, December 1989
Photo courtesy: Emergency Management Australia.

Likelihood Analysis

A likelihood analysis for earthquakes is aimed at determining the chance of an earthquake occurring at a specific location. Because of the relative rarity of earthquakes in Australia, it is not yet possible to identify the specific faults on which earthquakes will occur in future. Therefore, an earthquake likelihood analysis is generally conducted through the use of source models which divide Australia into regions that are considered to have a consistent rate of earthquake occurrence. The aim is to identify broad regions that are more or less likely to have earthquakes. These regions are typically derived from an interpretation of the historical earthquake records within Australia, combined with an understanding of regional geology.

An earthquake likelihood analysis can be extended to produce an earthquake hazard map that can be used to underpin building codes. An earthquake hazard map for Australia is shown in Figure 9.2. The development of an earthquake hazard map requires not only an understanding of the occurrence of earthquakes, but also a ground motion model that describes how the intensity of ground shaking decays as distance from an earthquake increases. For example, in the regions of Australia which are geologically old such as Western Australia, the rocks are hard, so there is relatively little absorption of energy and earthquakes are felt over unusually long distances. These models are very region dependent, and to date very little is known about what the appropriate ground motion model for Australian conditions should be.

Local soils and shallow geological sediments (collectively known as 'regolith') affect the ground motion, and models must be modified to account for these effects. The shaking by a seismic wave that moves from hard rock into regolith is amplified because of several factors which significantly increase the risk of damage from an earthquake. These include the increased amplitude required to transmit a given amount of energy and the resonance effects within surface layers. It is possible to develop detailed models that account for the effect of regolith; however, this requires detailed geological and geotechnical data, such as shear-wave velocity and regolith thickness, which are generally available only for urban centres.

Data requirements

Determining the likelihood of earthquakes relies on the availability of a consistent, high-quality record of the magnitude and location of earthquakes in Australia. Until the late 1970s, Richter's formula was generally used to calculate the local magnitude at all Australian observatories. In the late 1980s and early 1990s most observatories developed their own local magnitude scales, with several observatories changing their approach more than once.

The use of different magnitude scales has resulted in magnitudes for same-sized earthquakes recorded prior to 1990 and since 1990 differing up to 0.5 magnitude units, though this is also partly the result of seismograph instrumentation changing from traditional pen recorders to digital recorders. This is equivalent to a factor of 10 in energy release. Producing a comprehensive earthquake catalogue with consistent magnitude, both between regions and in time, is a key requirement, and requires high-quality seismic data to develop regional earth models.

The development of ground motion models depends upon high-quality recordings of the ground shaking from earthquakes. Ideally, recordings from large earthquakes are used directly to produce models to predict the ground shaking from future earthquakes. However, due to the rarity of large earthquakes in Australia, there are virtually no high-quality recordings of ground motion for large earthquakes at distances closer than hundreds of kilometres. An alternate approach is to use the ground shaking recorded from small earthquakes to help predict the shaking that would be associated with large earthquakes, but this is complicated by differences in the vibration frequencies from small and large earthquakes.

The final dataset required to understand the hazard associated with earthquakes is detailed information on the regolith. In particular, it

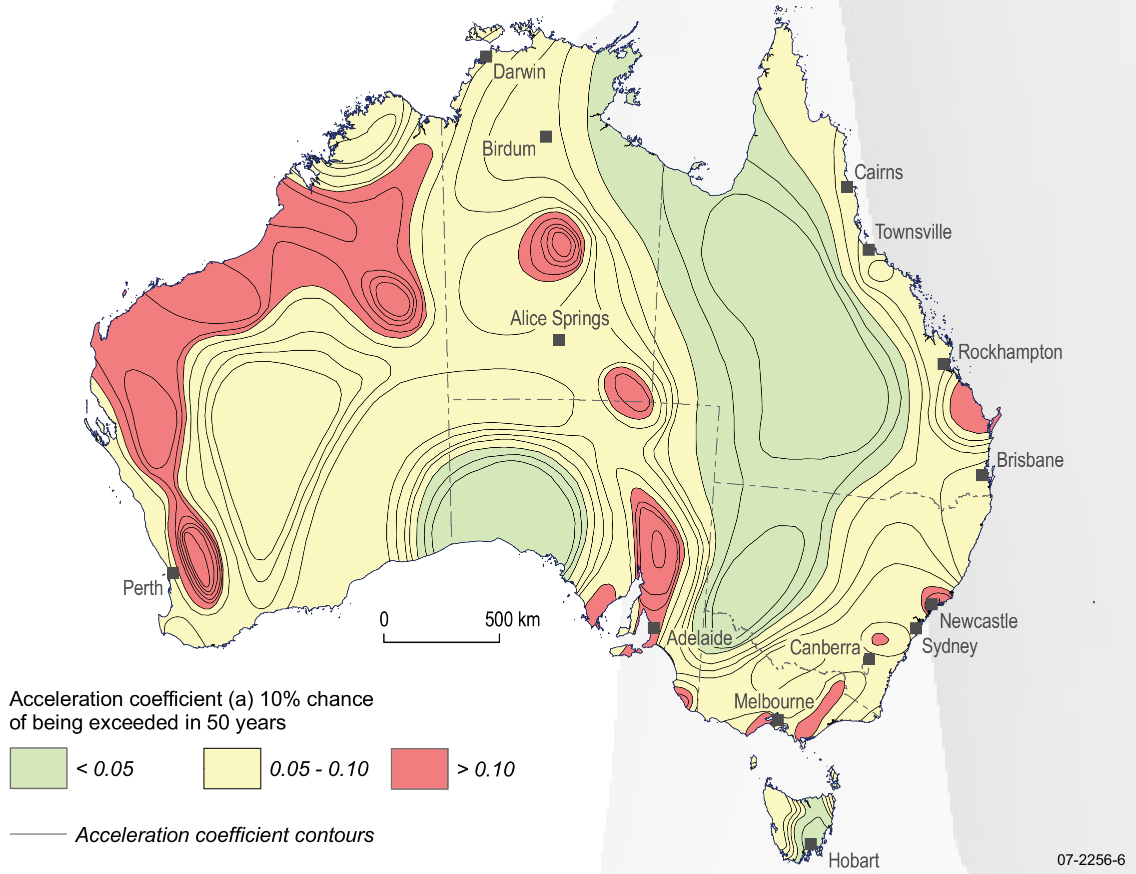


Figure 9.2: Earthquake hazard map of Australia
Source: Geoscience Australia.

is necessary to have data on the thickness and shear-wave velocity of the regolith in order to accurately understand its effect on earthquake hazard. These data can be collected by a variety of methods, ranging from geotechnical studies, including seismic cone penetrometer tests, through to passive monitoring techniques that use seismic noise (generated by cars, pedestrians, ocean waves etc.) to determine the regolith's properties. However, it is critical to recognise that regolith can be very spatially variable. Therefore, the required data need to be captured at a high spatial resolution in order to accurately model the hazard.

Consequence Analysis

Consequence analysis is focused on examining the elements that are subjected to a specific hazard, and their associated vulnerability.

It is important to recognise that it is inappropriate to determine the consequences of earthquakes, unlike hazards such as riverine flood, from a hazard map. The extent of a flood is largely constrained by the geometry of the river channel and floodplain being considered. Therefore, a flood hazard map is generally representative of a single flood event, and it is realistic to determine the consequences of such an event from a hazard map. In contrast, earthquakes can occur anywhere, meaning an earthquake hazard map is not representative of any single earthquake. An earthquake risk map is normally produced by modelling the damage caused by a large number (e.g. thousands) of synthetic earthquakes, and weighting them according to their magnitude and source zone.

Earthquakes are like many other hazards in that they have great potential to disrupt communities. Seismic events do this directly through damage to buildings and, less directly, through the damage they cause to the infrastructure that communities rely upon. Damage to building contents causes further impact on residents and a disruption to business activity, through the loss of stock and damage to the means of production. The direct damage to structures is typically estimated through the use of engineering models that relate the likely degree of structural damage to the severity of ground shaking (Robinson and others 2005).

For discrete residential buildings, these vulnerability models are typically associated with the wall and roof type. Residential house walls usually brace the building for lateral loads. Some wall types, such as unreinforced double brick, have been associated with greater losses from earthquake damage than other types, such as framed wall systems (Edwards and others 2004). Analysis of insurance claim data derived from the Newcastle earthquake in 1989 revealed that the repair costs for unreinforced masonry buildings were double those for timber-framed constructions exposed to the same intensity of ground shaking. Heavier, tiled roof construction also influences damage outcomes by accentuating inertia loads, while much lighter sheet metal–clad roofing reduces the demands on the bracing walls.

For commercial and industrial buildings the vulnerability model is generally related to the structural system and the nature of infill walls. Australian reinforced concrete frame systems, while massive, inherently possess a degree of ductility that has been shown to be generally adequate for the Australian seismic hazard. However, in some instances stiff infill walls have not been separated from the structural elements, leading to a compromised resistance.

Building vulnerability research is by no means mature in Australia, and an improved understanding of susceptibility of buildings to earthquake hazard is challenged by a lack of well-documented historical data. Consequently, damage model research is now more focused on developing an understanding of the engineering system than on using actual loss data to produce empirical models. Furthermore, engineering models validated against the available data can be used to identify mitigation options for more vulnerable structures, and to quantify their effectiveness.

One of the main indirect effects from earthquakes is their potential to disrupt essential utility services, such as electricity, water and gas supply, along with transportation systems. This has been illustrated in recent damaging Australian earthquakes. An earthquake in Tennant Creek, Northern Territory, in 1988 severely damaged the main gas pipeline from Tennant Creek to Darwin, although there was no disruption to supply in that case. The Newcastle earthquake caused significant damage to high-voltage circuit breakers at the Kilmore electrical substation, thereby disrupting supply. There are considerable lead times for the replacement of some vulnerable asset types, such as high-voltage transformers.

The widespread impact of damage to critical infrastructure assets has highlighted the need to better understand their vulnerability. The disruption of major highway corridors was the subject of work by Dale and others (2005) in which an approach from the HAZUS-MH tool (National Institute of Building Sciences 2003) was used to model the damage caused by representative earthquakes. Similar models that separately examine the individual components of more complex assets are under development and are aimed at predicting the damage to other critical infrastructure assets, such as large storage tanks, thermal power stations, electrical substations and telephone exchanges. This work will lead to a more complete picture of the vulnerability of Australian communities to earthquake hazard.

Data requirements

A consequence analysis has the same data requirements as the likelihood analysis described above. In particular, it is essential that realistic models of earthquake likelihood and associated ground shaking are used in order to accurately model the consequences of earthquakes. If a site-specific study is going to be conducted (e.g. for critical facilities or infrastructure), it is also important to have accurate, detailed geotechnical information at the site of interest.

In addition to the information on the earthquake hazard, current earthquake damage models for buildings typically require information such as each structure's construction type (i.e. wall and

A collapsed house following an earthquake in Meckering, Western Australia, October 1968
Photo courtesy: Emergency Management Australia.

Damage sustained to the Workers Club following an earthquake in Newcastle, New South Wales, December 1989
Photo courtesy: Emergency Management Australia.

roof material), number of storeys, floor area and replacement value. Structural information is also required for critical infrastructure in order to model the impact of earthquakes.

Information Gaps

A fundamental problem in Australia is the limited availability of the basic physics and engineering models that underpin any earthquake risk analysis. The development of these models has been particularly difficult in Australia because of the rarity of large earthquakes and the associated lack of data. The following section describes the gaps in earthquake source and ground motion models and vulnerability research, as well as the research required to address these gaps.

Earthquake Source Models

Earthquake source models are generally produced from an interpretation of the historical record of earthquakes in Australia. However, there is no clear consensus as to how the limited historical record should be interpreted. There are at least three published source models available (Leonard in review; Gaull and others 1990; Brown and Gibson 2004). The underlying assumption for most of these models is that the history of earthquakes in the past century is an accurate indicator of the likely occurrence of earthquakes in the future.

The zonation for the Brown and Gibson (2004) model is based on regional geology. Although geological deformation and faulting was considered in quantification of the zones, the activity estimates rely heavily on the short period of historical earthquake activity. However, this fundamental assumption has not been rigorously tested. Furthermore, there is some indication that seismicity in a given region, and on individual faults, is highly episodic (Crone and others 1997; Crone and others 2003; Leonard in review).

The rarity of earthquakes in Australia means it would take thousands of years to record enough events to confidently understand the distribution of future earthquakes. However, a careful study of the Australian landscape can provide evidence of prehistoric earthquakes that can be used to improve earthquake source models. This neotectonic evidence can be used to extend our understanding of the history of earthquakes in Australia back tens of thousands of years (Clark 2006).

In addition to identifying prehistoric earthquakes in the landscape, it is possible to use precise measurements of the deformation in the Australian crust, combined with numerical modelling, to try to identify regions that are more likely to experience earthquakes in the future. This work requires repeated observations of landmarks to detect sub-millimetre movements over the course of many years. Given time, this work will provide a more realistic understanding of the deformation of the Australian crust that can be used to improve our earthquake source models.

Ground Motion Models

The first ground motion model developed for Australia using only Australian data was the Gaull and others (1990) model. This model is based entirely on seismic intensity data, which are obtained from personal perceptions of shaking and damage. Because engineering damage models typically need more information than seismic intensity, earthquake hazard and risk assessments in Australia generally adopt ground motion models from other stable continental regions, such as eastern North America (e.g. Dhu and Jones 2002).

However, there has been very little analysis undertaken to show whether these models are applicable to Australian conditions. For example, an analysis of data recorded during the earthquake sequence at Burakin, Western Australia, in 2001 and 2002 (Allen and others 2006) suggests that, at small distances from the earthquake, higher ground motions are observed compared with eastern North America. This results in ground shaking in southwest Western Australia that decreases at a lower rate with distance compared to ground shaking in eastern North America for an earthquake of the same magnitude. However, this may also be due to the influence of surface waves from these shallow events.

As the quality of seismic data recorded in Australia continues to improve, there is a continuing need to use these data to develop Australia-specific ground motion models. The current lack of data will result in large uncertainties in these models; however, this will improve over time as modelling techniques are refined and the amount of data increases.

As mentioned previously, there is also a need to develop models that describe the effect of regolith on earthquake ground shaking. The development of these models is fundamentally limited by the availability of detailed geotechnical data. These data are particularly crucial in urban areas where consequence analyses are usually conducted. In many urban areas significant amounts of data are held by local councils, industry and the state government, but no urban area has a single comprehensive database of this information. Another potential source of such data is the datasets acquired for the development of infrastructure such as bridges and tunnels. These projects often require geotechnical studies as part of the construction process.

Vulnerability Research

Building vulnerability research in Australia is challenged by a lack of well-documented historical data. Sufficient structural damage and loss data do not exist to permit the development of empirical models. There are further difficulties in assessing the local hazard that caused damage, due to a lack of strong motion records. This is unlikely to change in the near future. Therefore, damage model research is now more focused on developing an understanding of the engineering system.

The use of engineering models can provide the opportunity to identify and assess the effectiveness of mitigation options where vulnerabilities exist. Additional research needs to be done to better predict physical damage and to include economic cost. Furthermore, the detailed analysis in some of this work needs to be generalised so that reliable assessments of damage and cost can be made for large populations of building structures.

The vulnerability of critical infrastructure to earthquake is less well understood than that of building structures. Critical infrastructure can comprise extremely complicated systems with many components that are all vital to successful operation (e.g. the complex systems comprising a coal-fired thermal power station). The components within a system each have their own seismic vulnerability, and knowing each of these is essential to an understanding of the overall vulnerability and prognosis for restoration of the asset.

Roles and Responsibilities

Management of earthquake risk cuts across all levels of government, non-government agencies and groups, and the general community. The analysis of earthquake hazard and risk requires collaboration between these sectors as each has their own responsibility and role.

Australian Government

The Australian Government's overarching goal in the management of earthquake risk is to ensure the sustainability and prosperity of Australia's communities. It provides financial assistance to help achieve this through its funding programmes aimed at reducing the risk of natural disasters. The Australian Government also operates a national seismograph network which monitors earthquakes in the region and maintains the Australian Earthquake Database. It also provides earthquake information and undertakes research into reducing risk through improved understanding of the earthquake hazard and risk in Australia. However, numerous other collaborators also have crucial roles in this process.

State and Territory Governments

State and territory governments play an important role in earthquake risk management in Australia. Historically, the state and territory governments have been involved in the preparation of emergency management plans for earthquakes, the mitigation of earthquake risk, and responses to earthquakes that have affected Australian communities. In addition to these roles, some of the fundamental data required for risk analysis can only be acquired in collaboration with state and territory agencies.

Local Government

Local government agencies are involved in planning and mitigation, as well as emergency response at the local level. An accurate understanding of earthquake risk requires some components that are very site specific, such as an understanding of the local regolith and a comprehensive building inventory.

Industry, Coordinating Groups, Professional Bodies and Research Institutions

A few professional bodies, coordinating groups and industry bodies have an advocacy and/or coordinating role in earthquake risk mitigation. For example, the Australian Earthquake Engineering Society, a technical society of Engineers Australia, promotes the practices of engineering seismology and earthquake engineering. Similarly, the Australian National Committee on Large Dams Incorporated has supported research into earthquake hazard and arranged for earthquake data collected by its members to be made available for research purposes.

The University of Queensland undertakes some research into earthquake hazard assessment as part of a wider programme of investigating the physics of earthquakes through the use of computer simulations. The Australian National University has a major seismic research programme in observational and theoretical seismology, with a focus on understanding the earth's structure and processes, but undertakes minimal research into earthquake hazard.

Several universities in Australia (University of Adelaide, Curtin University, University of Melbourne and University of Western Australia) undertake neotectonic geological investigations, and several universities in Australia (University of Adelaide, University of Melbourne, Monash University, University of Newcastle and Swinburne University of Technology) undertake research into the structural vulnerability of buildings to earthquakes. No university in Australia has a major programme of earthquake hazard research.

The Seismology Research Centre within Environmental Systems and Services, Melbourne, monitors seismic activity in eastern Australia with its own networks, and undertakes hazard studies both within Australia and overseas.

Conclusion

The earthquake hazard risk is low in Australia compared to more seismically active regions of the world, but there is potential for a disastrous and costly event. Historically the average annual economic loss caused by earthquakes has been low at $144.5 million per year or about 13% of the cost of natural disasters; however, events such as the Newcastle earthquake which resulted in 13 deaths and a total loss of about $4.5 billion, demonstrate the potential for very significant overall cost to the community.

An understanding of earthquake risk in Australia requires an understanding of the fundamental characteristics of earthquakes in Australia, how their associated ground shaking propagates, the effects of local site conditions, the vulnerability of buildings, and the exposure of buildings and people to the ground shaking.

To develop new and improved models in these areas requires high-quality earthquake and ground motion data, along with comprehensive building and infrastructure performance data and inventories. By combining these models it is possible to understand the risk, and to minimise the chance of catastrophic losses by improving the design of structures through appropriate building codes.

Gaps in the knowledge and information that is required to achieve these outcomes, particularly in the areas of earthquake source models, ground motion models and vulnerability research, need to be addressed, and the three levels of government, as well as industry and academia, all have important roles to play.

A fault scarp caused by an earthquake in Meckering, Western Australia, October 1968
Photo courtesy: Geoscience Australia.

Chapter Ten:

Tsunami

A destroyed campsite following a tsunami at Steep Point, Western Australia, July 2006
Photo courtesy: Paul Dickson.

Tsunami

Tsunami is a Japanese word based on two elements: tsu (津) meaning 'harbour' and nami (波 or 浪) meaning 'wave'. It was coined several hundred years ago by fishermen who came back from sea to discover the harbour had been devastated by waves, even though there had been no wind and no unusual wave action in the open ocean. Tsunamis are generated by sudden movement of the sea floor, through undersea earthquakes, landslides, volcanoes or meteorite impacts rather than by the wind. Tsunamis only have a small amplitude in the open ocean but they grow substantially in size as the wave approaches the coast and gets into shallower water.

While the overall risk from tsunamis is lower in Australia than it is in many parts of the world, tsunamis have affected the Australian population in the past and will again (PMSEIC 2005). Historically, tsunamis have been rare events and have caused only minimal damage in Australia. However, there is potential for a large tsunami to cause significant damage to coastal communities in the future.

Devastation following a tsunami at Aceh, Indonesia, December 2004
Photo courtesy: AusAID.

A profile showing an example of a tsunami sediment sheet, in stratigraphic sequence from Maullin, Chile
Photo courtesy: Geoscience Australia/Amy Prendergast/captured in 2005.

Construction work following a tsunami in Aceh, Indonesia, December 2004
Photo courtesy: AusAID.

Damage following a tsunami in Aceh, Indonesia, December 2004
Photo courtesy: Emergency Management Australia.

This chapter identifies and briefly describes the most likely sources of tsunami that have happened in the past or could in the future. The Australian Government in partnership with state and territory governments are currently the main players in assessing tsunami risk to Australia, and the current method for assessing risk from tsunamis is described. Since the Indian Ocean tsunami of December 2004 highlighted the potential catastrophic impacts of tsunami, significant work on managing the tsunami risk to Australia has been undertaken. However, many information gaps still hinder our knowledge of the risk posed by these rare, but potentially very damaging, natural disasters.

Hazard Identification

Tsunamis are waves generated by sudden movement of the sea floor, usually caused by undersea earthquakes, but sometimes caused by landslides, volcanic eruptions or meteorite impacts. A tsunami is very different from a typical wind-generated wave. Wind-generated waves cause movement of water only near the sea surface, and have wavelengths measured in metres. In contrast, tsunamis involve water movement to the sea floor, and can have wavelengths of 100 kilometres or more.

In the deep ocean, tsunamis rarely have a wave height (peak-to-trough) greater than a couple of metres. However, as they approach shallow water they slow down and increase dramatically in height. This effect makes them potentially very destructive to coastal buildings and infrastructure. Waves during the Indian Ocean tsunami of December 2004 had heights of less than 2 metres in the open ocean but ran up to heights of 10 metres above sea level along many coasts, even those thousands of kilometres from the earthquake (Narayan and others 2005). The maximum height reached by the wave as it inundates an area (i.e. the 'run-up height') is often larger than the wave height off the coast.

The following section describes in more detail the potential trigger sources of tsunamis. The majority of tsunamis are caused by large earthquakes under the sea floor. Submarine landslides also cause tsunamis when sediments on steep slopes (such as those around volcanic islands or along the edges of continental shelves) become unstable and fail (see Chapter 8 for a general discussion of landslides). Less common are tsunamis initiated by the explosion or collapse of a volcano. Meteorites and comets may cause tsunamis if they fall in the ocean. Although such impacts are rare, some argue that tsunamis generated by this mechanism may have reached Australian shores in prehistoric times (Bryant 2001).

Earthquake

The most frequent sources of large tsunamis are earthquakes that occur in subduction zones, where two of the rigid plates comprising the earth's surface converge and one slides beneath the other (Figure 10.1). As the plates 'rub' past each other, friction along their contact pulls the upper plate downward, causing stress to increase on the inter-plate contact. This stress builds up continuously along the 8000 kilometre system of subduction zones that surround Australia to the north and east, as the Australian plate moves northward at a rate of approximately 7 centimetres per year. An earthquake occurs when the stress exceeds the frictional strength and the upper plate 'pops' back upward, vertically displacing a large mass of water. Vertical movement of the sea floor in this manner causes the overlying water to move upwards and spread outwards from the earthquake centre as a tsunami (PMSEIC 2005).

Subduction zones have the potential to produce the largest earthquakes in the world. Of the 12 largest earthquakes that have occurred since 1900, all but one occurred in subduction zones and produced large tsunamis. While there is still insufficient information to perform a detailed assessment for most of the subduction zones facing Australia, some general conclusions can be drawn from the information available.

Historically, the tsunamis which have created the largest run-ups in Australia have come from earthquakes off the south coast of Indonesia and have inundated parts of the Western Australian coast. Earthquakes above magnitude 7.5 have created several tsunamis over the past few decades, particularly those from eastern Indonesia, such as the Java tsunami in 2006.

To the east of Australia, earthquakes from the subduction zones stretching from Papua New Guinea to New Zealand have not yet generated tsunamis large enough to create substantial inundation along the east coast.

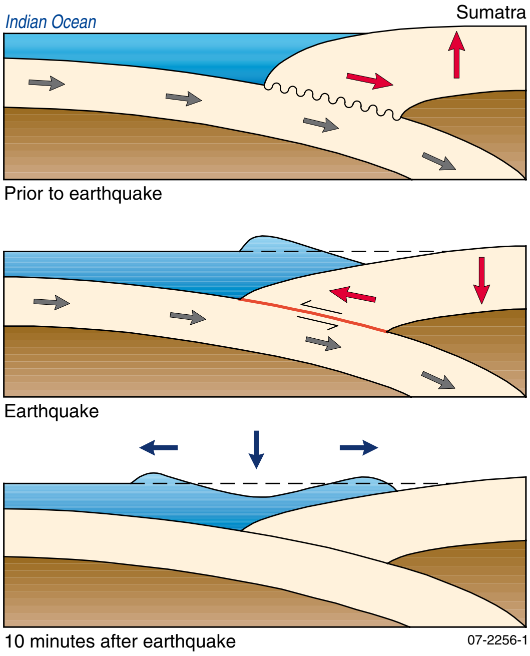


Figure 10.1 Simplified diagram showing how an earthquake along a subduction zone generates a tsunami Source: Geoscience Australia (2005).

Large earthquakes have been known to occur in the eastern Pacific, off South America. The largest recent earthquake, the magnitude 9.5 Chile earthquake in 1960, was far away, and most of the tsunami did not head in Australia's direction. Although this event did not create any major inundation on the Australian coast, it did create currents strong enough to tear boats from their moorings in several harbours along the east coast (Lynam and others 1988).

Volcano

There are at least five active source regions which have volcanoes capable of generating a tsunami that could affect Australia: eastern Indonesia (including Krakatau), Papua New Guinea (New Britain–New Ireland), the Kermadec Islands region, the Tonga–Samoa volcanic arc and the South Fiji basin (Rynn and Davidson 1999).

However, the Krakatau eruption of 26–27 August 1883 is the only documented eruption to have affected Australia (Gregson and Van Reeken 1998). It caused 36,000 deaths in Indonesia and generated a tsunami in the Indian Ocean that was more extensive than the 2004 Indian Ocean tsunami. Within four hours of the final eruption, a tsunami which ran up to 1.8 metres above sea level reached several locations along the coast of Western Australia (Hunt 1929). The recurrence time for major eruptions at Krakatau is thought to be 21,000 years (Beauregard 2001).

Landslide

Less is known about the effect and frequency of submarine landslides that cause tsunamis. The tsunami that hit Sissano, Papua New Guinea, in 1998, causing the loss of 2000 lives, was probably caused by an earthquake-triggered submarine landslide (Tappin and others 2001).

A recent targeted survey along the New South Wales continental slope identified several potential sources of similar failures (Glenn and others in review). Multiple landslide scars were located along the continental slope, several of them adjacent to population and critical infrastructure locations.

It is also thought that an ocean-wide tsunami can be produced by massive collapse of a part of a volcano (Ward and Day 2001). Although an argument could be made that such a collapse is possible of a volcano in the Heard and McDonald Island region, there is no information on the likelihood of such an event occurring, nor on whether such events occur in a manner that actually generates a tsunami.

Anecdotal evidence exists of freak waves having swamped the coast on clear, calm days at several Australian locations. One example is the event known as 'Black Sunday', which occurred on 6 February 1938 at Bondi Beach, New South Wales (PMSEIC 2005). This event was characterised by three successive waves that piled water on the beach and returned as backwash, sweeping swimmers out to sea. Five people were drowned. The waves were not restricted to Bondi Beach; they were reported on adjacent beaches and as far north as Newcastle. These freak wave events may represent tsunamis generated by small, localised submarine landslides.

Meteorite or Comet

Meteorites or comets in near-earth orbits are ultimately the source of the most spectacular and life-threatening impacts. Evidence indicates that several major extinction events marking the transitions between geologic eras, such as between the Cretaceous and Tertiary periods 65 million years ago, may be at least partially due to the massive impacts of comets or meteorites of about 10 kilometres in diameter (PMSEIC 2005). Such objects would certainly be capable of causing massive tsunamis, with wave heights far exceeding any tsunami in recorded history, if they landed offshore.

There is considerable uncertainty about the likelihood of intermediate-sized objects, with diameters in the range from 100 metres to 1 kilometre, generating tsunamis. Objects smaller than 100 metres almost certainly do not generate damaging tsunamis (PMSEIC 2005).

Cost of Tsunamis

The average annual cost of tsunamis to the Australian community has not been calculated. Anecdotal evidence suggests that the cost so far has been small, with only minor damage to ports and beach-side campsites and the loss of some small boats. For example, a range of marine impacts (such as boats being torn from their moorings) were reported along the New South Wales coast as a result of the 1960 Chile event.

More recently, the 2006 Java tsunami inundated Steep Point (on the western margin of the Shark Bay world heritage area in Western Australia), where it caused widespread erosion of roads and sand dunes and transported a vehicle 10 metres inland. It also caused extensive vegetation damage and destroyed several campsites (Prendergast and Brown 2006). If a similar tsunami were to hit a major populated centre, significant losses could be expected.

There have been no confirmed deaths from tsunamis in Australia (although the deaths arising from the Black Sunday event may be attributable to a tsunami). However, in the past few hundred years Australia has not experienced a large tsunami that directs its energy towards the more densely populated parts of the coast. Should such an event occur, it could cause loss of life as well as significant amounts of damage.

Risk Analysis

The general approach to estimating tsunami risk is similar to that for earthquakes (as discussed in Chapter 9). There are five key, sequential stages in assessing the risk. The first two stages relate to

A four-wheel drive transported 10 metres inland following a tsunami at Steep Point, Western Australia, July 2006
Photo courtesy: Paul Dickson.

assessing the likelihood of a tsunami occurring; the rest relate to estimating the consequences from a particular tsunami. The stages involve developing:

- a source model that describes the likelihood of a source (earthquake, landslide, volcano or meteorite) producing a tsunami of a given size at a given location
- a tsunami deep-water propagation model to simulate the wave from the source to the shallow water off the coast of interest (analogous to a ground motion model for earthquakes)—the results of this stage can be used to produce a tsunami hazard map for the region
- an inundation model to determine the run-up (i.e. maximum height above sea level reached by the wave) and inundation distance (i.e. maximum distance from the coast reached by the wave) at a given locality on the coast
- a vulnerability model that characterises the nature and magnitude of the damage that a structure will experience from a wave of a given height and velocity
- an exposure database for the area of interest.

An analysis of the tsunami risk for the area concerned is conducted by combining the inundation, vulnerability and exposure data. If the source is very close to the location of interest, the propagation stage can be omitted.

The majority of the tsunami hazard and risk assessment modelling for the Australian community is done by the Australian Government in partnership with the relevant state government agencies.

Likelihood Analysis

Determining the probability and location of large events is quite difficult for tsunamis, because the events are so infrequent that few have occurred in Australia's historical record. Current methods use a combination of geophysical, geological and historical research to try to quantify the probability of the occurrence of a large source capable of producing a tsunami that could impact Australia. Once a likely source of tsunami has been identified, the size of the tsunami it can produce at various levels of probability is estimated. This usually depends on the physical properties of the source: for example, the geometry of a subduction zone and the rate at which stress is building up along it.

Once the physical properties and probability of the earthquake or other source have been estimated, the resulting tsunami is numerically modelled, up to, and often onto, the shore. The model results can be used to calculate the probability of a tsunami exceeding a given height along a given section of coast. The impact of the tsunami is controlled by the depth of the water (i.e. the bathymetry) between the source of the earthquake and the coast, the topography of the coast and the physical structures on the coast.

Data requirements

Several different types of data are required for a tsunami hazard assessment: historic catalogues of tsunamis, geophysical and geological data about the source, bathymetric data and topographic data about the coast.

Historic catalogues provide empirical estimates of the frequency of tsunami sources as well as the impacts tsunamis have had.

Since the historic catalogue for tsunamis is too short to completely constrain the likelihood, geophysical and geological data of the source area are needed as well. These data can be used to estimate the likelihood, based on some assumptions about the physical processes that cause the tsunami source to happen.

Finally, moderate-resolution bathymetry data for the deep-water tsunami propagation are needed for the areas between the source and the coast. High-resolution bathymetric and topographic data are needed close to specific communities and/or infrastructure.

Consequence Analysis

For exposure modelling, the area inundated by a hypothetical tsunami is calculated as described above and combined with a database containing information on the structures within the area inundated. The structural vulnerability of the infrastructure within the area being inundated must also be estimated.

As with other aspects of tsunami risk assessment, the models for estimating the structural vulnerability of buildings to tsunami are still under development. The hydrodynamic loads acting on a structure during a tsunami can be very complex. One modelling method is based on assessing the damage from past events in order to better estimate the effect of future events on similar structures. However, structures affected by previous tsunamis are typically dissimilar to Australian buildings, and most surveys tend to be biased towards damaged structures rather than structures representative of the population as a whole (Dale and Flay 2006). Alternatively, an engineering modelling approach can be taken. This involves generalising the loads on a structure, then using knowledge of the strengths of components and connections, as well as their variability, to assess damage outcomes (if any) for the resultant loads.

Little research has been done to look at human vulnerability, such as estimating casualty rates. Factors likely to affect human vulnerability include the vulnerability of structures, population density, and the time of day of the event, as well as simply the height and velocity of the tsunami.

Data requirements

Wave height and velocity estimates of the incoming tsunami, based on high-resolution topography and bathymetry, are essential data for modelling consequence. Any limitations in the resolution and accuracy of the data will introduce errors to the inundation maps, in addition to the range of approximations made within the models themselves.

An accurate and up-to-date exposure database of the area is also required. This may include information about residential and commercial buildings, as well as critical infrastructure. The database should include information on the structure type, number of floors, typical number of inhabitants and building materials, and other information depending on the purpose of the vulnerability modelling and the requirements of the vulnerability model.

Information Gaps

It took the catastrophic events of the Indian Ocean tsunami to alert the Australian public to the potential for a tsunami tragedy closer to home. At the strategic level, policy decision makers, planners and emergency managers need to assess the likelihood of a major tsunami impacting Australia and consider what can be done to reduce the loss of life. The current lack of knowledge about the tsunami hazard means that some crucial questions cannot be answered.

Acquiring the knowledge needed requires a significant, focused and coordinated scientific effort. As with most research, the range of science required is not yet known. However, there are some priority areas where the coordination, development and application of science can improve the understanding of the behaviour of tsunamis and make a vital contribution to the safety of communities in Australia and the region.

The following sections describe some of the more important information gaps that need to be filled for both likelihood and consequence analysis, based on a report published by the Prime Minister's Science, Engineering and Innovation Council (PMSEIC 2005). The first few examples concentrate on determining the likelihood of a tsunami being generated and reaching the coast with a large enough amplitude to cause damage. The rest concern trying to work out the impact on a community once a tsunami arrives.

Subduction Zone Dynamics

Substantial scientific questions remain about the fundamental physical properties of subduction zones. This makes it difficult to estimate the likelihood of an earthquake occurring along one of the subduction zones, the maximum magnitude that can be expected for each zone and, particularly, the dynamics of a possible rupture.

Non-seismic Tsunami Sources

In general, even less is known about non-subduction zone sources of tsunami. Substantial questions remain regarding whether other sources (landslides, volcanoes and meteorites) are likely to produce tsunamis, and how they may affect Australia's overall level of tsunami risk. For example, to ascertain the potential locations, the prevalence and return frequency of future near-shore submarine landslides, a high-resolution bathymetry dataset is needed for high-priority areas. This would be coupled with focused analysis of the nature of the marine sediments in order to estimate the frequency of the landslides.

Historic and Prehistoric Events

Research on historic and prehistoric tsunamis is one method for constraining the uncertainties in analysing the likelihood and impact of tsunamis. Such research can give information on the return frequency of tsunamis in the past, as well as their sizes and the areas they affected.

Numerical Modelling

While the basic physics of tsunami propagation is fairly well known, there are still questions in this area. It is not yet clear how important a detailed knowledge of bathymetry, topography, erosion and basal friction is to predicting a tsunami. These questions are particularly important to the inundation component of tsunami risk modelling.

Vulnerability Research

Because no substantial tsunami has impacted on an Australian community, there are no data available on how vulnerable Australia's structures are to a tsunami. The level of damage from a tsunami of a given height and velocity is therefore not clear. Equally, the best way to improve the resistance of structures to tsunami is also not known. It is not possible to exactly estimate the economic impact of a major tsunami nor to confidently estimate the average annual loss tsunamis might cause over the next few centuries.

Modelling the impact of a tsunami involves more than simply calculating the economic loss. It also involves trying to work out the expected casualties and how fast a community will recover from the impact of tsunami. Major gaps in knowledge also exist in this area.

One factor affecting recovery time from any natural hazard event is the impact on infrastructure (such as roads and power lines). Damage to these infrastructure could affect an area much larger than that directly affected by a tsunami, as is the case with other hazards.

In addition to the effect on human communities, tsunamis can produce long-term environmental effects (such as the contamination of ground water with salt). It is unclear how much environmental damage a tsunami can do, and how long it may take to rectify the damage.

Post-disaster Assessment

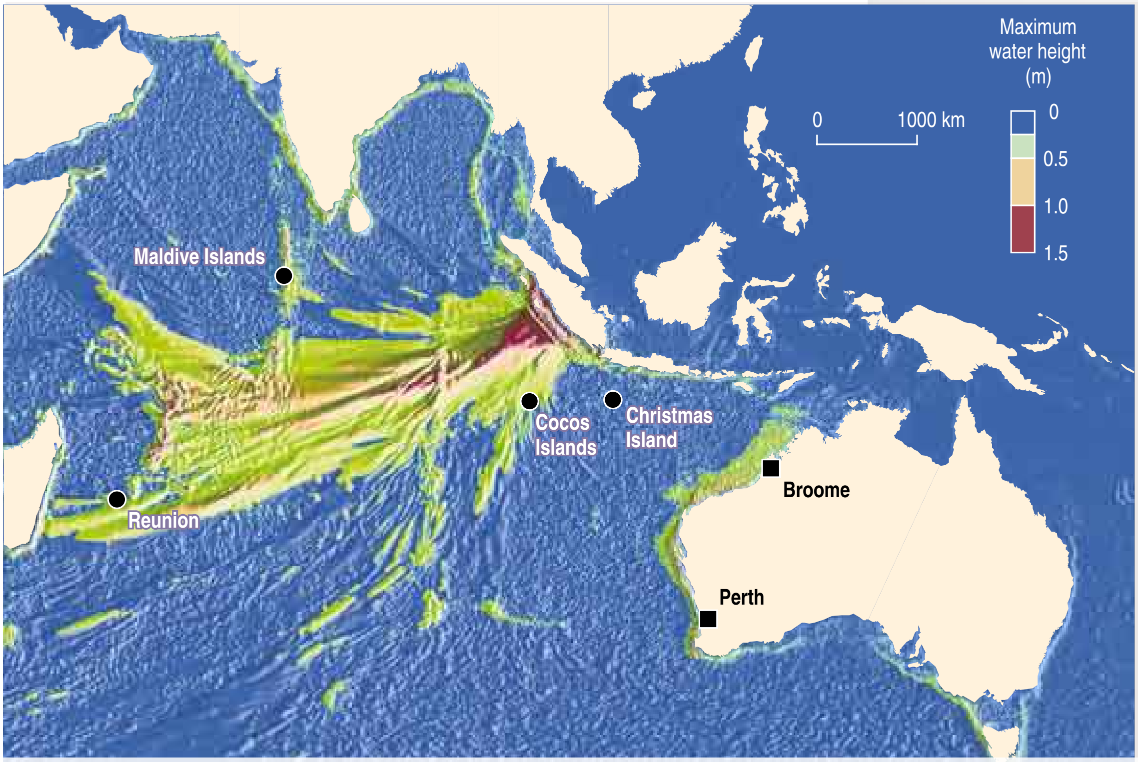
In order to improve future forecasts and hazard assessments it is important to update the historical records whenever a tsunami event occurs. This requires quantitative measurements of the extent of inundation and run-up as well as any damage that the tsunami may have caused. Such data can be used to validate and calibrate models, helping to produce better tsunami risk assessments and warnings in the future.

Roles and Responsibilities

The different levels of government in Australia, and the general community, have different roles and responsibilities in managing tsunami risk. The Australian Government, state government and the Northern Territory, and academic institutions in particular play important roles, as described below.

Australian Government

The Australian Government is the main organisation in Australia involved with assessing tsunami hazard and risk. As with earthquake, the Australian Government is involved in tsunami hazard assessments at a national scale.



The modelled extent of the 1833 tsunami from Sumatra, showing the maximum open-ocean amplitude in the Indian Ocean Courtesy: Geoscience Australia.

Devastation in the suburbs caused by a tsunami in Aceh, Indonesia, December 2004
Photo courtesy: AusAID/Gregson Edwards.

The Australian Government is also involved in research designed to improve future vulnerability and exposure assessments of communities, through tsunami risk modelling.

The Australian Tsunami Warning System (ATWS) is run jointly by several Australian Government agencies. The role of the ATWS is to detect and warn of approaching tsunamis generated by major earthquakes along any of the plate boundaries surrounding Australia or other, more distance sources. The Australian Government is responsible for seismic monitoring, sea level monitoring, numerical modelling and forecasting, and for issuing warnings to state and territory emergency agencies. The Australian Government also has some responsibility for public awareness activities and the coordination of national assistance to state and territory responses in the event of a tsunami disaster.

State and Territory Governments

State and territory government emergency agencies have a responsibility to prepare and plan for the impact of a tsunami on the communities within their jurisdiction, and to warn communities of the impending tsunami (and evacuate communities, if necessary) once they have been alerted by the ATWS. State and territory agencies would also be involved in providing emergency assistance and relief in the event of a major tsunami.

Local Government

Local governments should include tsunami as part of their natural disaster emergency risk management plans for the coastal communities in their jurisdiction.

Industry, Coordinating Groups, Professional Bodies and Research Institutions

Several universities are involved in researching tsunamis and/or assessing the hazard they present to Australia and the region. Examples include the University of Queensland, Macquarie University, the Australian National University, the University of Western Australia, James Cook University and the University of Wollongong. Various private companies in Australia and overseas are also contracted to provide tsunami hazard and risk advice to insurance companies or to government.

General Community

The general public should be aware of the possibility of a tsunami and should take preventative actions when a warning is given or unusual sea conditions become apparent. An example of an unusual sea condition could be a sudden change in sea level not associated with normal tidal changes.

The media also have a role in issuing warnings to the community if required, and generally raising the community's awareness of tsunamis and emergency procedures.

Conclusions

The recent history of tsunamis in the Australian region has raised the profile of this hazard which historically has caused little damage in Australia. Though the amount of work being conducted in this area has grown dramatically, scientists are still at the early stage of assessing this particular hazard for Australia.

Tsunami risk is assessed by estimating the likelihood of a tsunami source generating an event, modelling that event to a community, and working out the likely damage based on the vulnerability of that community to tsunamis. However, many questions remain regarding both the nature of tsunamis and the potential risk to Australia. The Australian Government, in collaboration with the state and territory governments and academia, is actively working on these questions.

As tsunamis are such rare events, basic scientific research coupled with sophisticated computer modelling are essential to improve the estimates of the risk to Australia from tsunamis. The computer modelling requires high-quality, high-resolution data in the coastal areas, including better estimates of the coastal bathymetry, topography, demographics and infrastructure, as well as better geophysical data on tsunami sources. Bringing together these data, and conducting more research into past tsunami events, are likely to remain the main focuses of tsunami risk research in Australia for many years to come.

The Australian Tsunami Warning System at Geoscience Australia, Canberra, Australian Capital Territory
Photo courtesy: Geoscience Australia.

Photo courtesy: Bureau of Meteorology.

Glossary

The following non–hazard specific definitions are used in this report. The definitions from the risk management standard AS/NZS 4360:2004 have been used, except where other sources provide a more comprehensive definition, or a definition is not provided in the standard.

Consequence refers to the outcome or impact of an event and may be expressed qualitatively or quantitatively. There can be more than one consequence from one event (AS/NZS 4360:2004). In this context, consequences are generally described as the effects on persons, society, the environment and the economy.

Elements at risk refers to the population, buildings and civil engineering works, economic activities, public services and infrastructure, etc. exposed to sources of risk (EMA 2004).

Event refers to the occurrence of a particular set of circumstances. The event can be certain or uncertain. The event can be a single occurrence or a series of occurrences (AS/NZS 4360:2004).

Exposure refers to the elements at risk which are subject to the impact of a hazard event (Middelmann and others 2005).

Frequency is a measure of likelihood expressed as the number of occurrences of an event in a given time (EMA 1998).

Hazard is a source of potential harm or a situation with a potential to cause loss. It may also be referred to as a potential or existing condition that may cause harm to people or damage to property or the environment (EMA 1998).

Likelihood is used as a general description of probability or frequency. It can be expressed qualitatively or quantitatively (AS/NZS 4360:2004).

Loss refers to any negative consequence or adverse effect, financial or otherwise (AS/NZS 4360:2004).

Mitigation refers to the measures taken in advance of, or after, a disaster aimed at decreasing or eliminating its impact on society and the environment (COAG 2004).

Natural disaster refers to a serious disruption to a community or region caused by the impact of a naturally occurring rapid onset event that threatens or causes death, injury or damage to property or the environment and which requires significant and coordinated multi-agency and community response. Such serious disruption can be caused by any one, or a combination, of the following natural hazards: bushfire; earthquake; flood; storm; cyclone; storm surge; landslide; tsunami; meteorite strike; or tornado (COAG 2004).

Risk refers to the chance of something happening that will have an impact on objectives. A risk is often specified in terms of an event or circumstance and the consequences that may flow from it. Risk is measured in terms of a combination of the consequences of an event and their likelihood (AS/NZS 4360:2004).

Risk analysis refers to the systematic process to understand the nature of and to deduce the level of risk. It provides the basis for risk evaluation and decisions about risk treatment (AS/NZS 4360:2004).

Risk assessment refers to the overall process of risk identification, risk analysis and risk evaluation (AS/NZS 4360:2004).

Risk evaluation refers to the process of comparing the level of risk against risk criteria. Risk evaluation assists in decisions about risk treatment (AS/NZS 4360:2004).

Risk management process refers to the systematic application of management policies, procedures and practices to the tasks of communicating, establishing the context, identifying, analysing, evaluation, treating, monitoring and reviewing risk (AS/NZS 4360:2004).

Risk reduction refers to the actions taken to lessen the likelihood, negative consequences, or both, associated with a risk (AS/NZS 4360:2004).

Risk treatment refers to the process of selection and implementation of measures to modify risk. The term ‘risk treatment’ is sometimes used for the measures themselves. Risk treatment measures can include avoiding, modifying, sharing or retaining risk (AS/NZS 4360:2004).

Vulnerability is the degree of susceptibility and resilience of the community and environment to hazards (COAG 2004).

Photo courtesy: Will Barton Photography.

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